1. O BASIC SCIENCE

1.1.1 INTRODUCTION TO CYTOLOGY

Cytology; this is a branch of biology that studies the structure and function of cells. It involves the study of cells using a microscope.

Cell theory

Cell theory is concerned with the study of cells. Modern theory of cellular organisation states that;

- All living organisms are made of up of cells
- All cells are obtained from other cells
- Cells contain the hereditary material of an organism which is inherited from the parents by daughter cells.
- All metabolic processes take place within the cell.

A cell is therefore the basic (fundamental) unit of life.

Theoretical work summary of cells

a) Cells are classified as;

- Unicellular organisms consist of one cell, and include protozoa, bacteria, blue green algae and certain other algae.
- A cellular or non-cellular organisms or tissues not composed of cells:
- Plant coenocyte, cell substance with many nuclei surrounded by one cell wall - found in certain fungi, e.g. Mucor, and certain algae, e.g. Vaucheria.
- Animal syncytium, cell substance with many nuclei surrounded by one cell membrane - found in certain tissues, e.g. striated skeletal and heart muscle.
- Multicellular organisms are made up of many cells
- Prokaryotic cells, these cells lack true nucleus, DNA is enclosed within nuclear envelope. They include bacteria and blue green algae.
- Eukaryotic cells, these cells have true nucleus, have membrane bound organelles such as mitochondria and chloroplasts within the plasma of the cell e.g. plant cell and animal cell.

b) **Cell Structure**

Protoplasm is the name given to the living cell's contents:

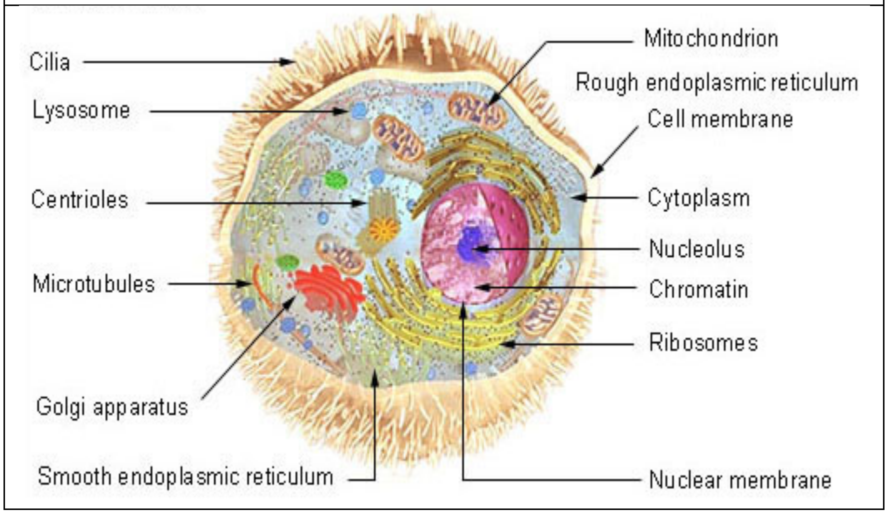
- plasma or cell membrane
- cytoplasm
- nucleus

Cell wall: non-living, rigid material surrounding the cell protoplasm of bacteria and plants. (No cell walls in animal cells.)

Biological membranes are of three kinds:

- Cell membrane: plasma membrane, or the cell surrounding membrane.
- Nuclear membrane surrounding the cell nucleus.
- Organelle membranes surrounding or forming cell organelles with specific functions.
- Organelle: specialised parts of living cells. Examples are the nucleus, mitochondria, ribosomes, Golgi bodies and chloroplasts.

General cell structure



Cells are made up of organic and inorganic materials. Organic materials consist of; carbohydrates, proteins, lipids and vitamins. While inorganic materials are water and mineral salts. All cells depend on their surrounding environment for obtaining nutrients as well as depositing their wastes.

Cells produce daughter cells of their own kind during cell division. Also division of cells results into tissues, organs and systems.

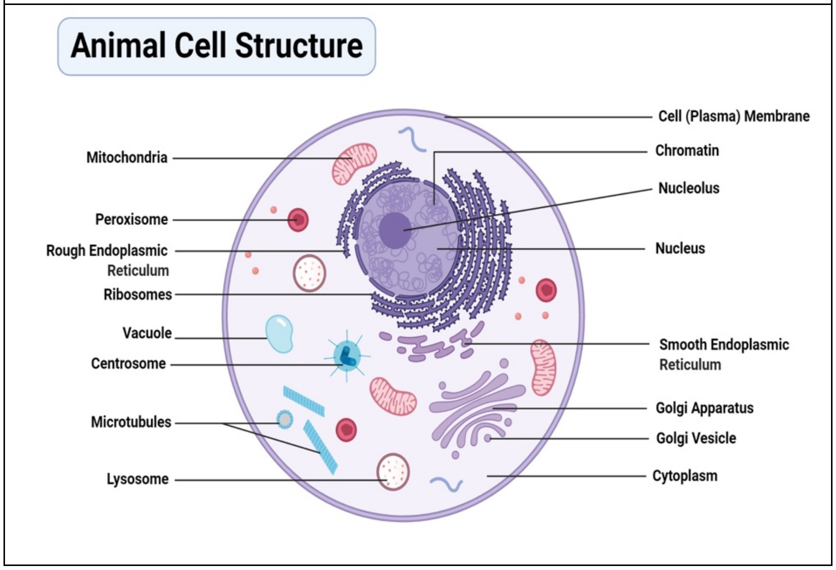
The cells that constitute an animal are called Animal cells and those that constitute plants are known as plant cells.

The differences between the cells of simple organisms (prokaryotes) and all other organisms (eukaryotes) are summarized in the table below.

FEATURE	PROKARYOTES	EUKARYOTES
Cell size	Up to 3μm diameter	Up to 40 μm diameter
Nucleus	No true nucleus	True nucleus with chromosomes, nucleolus, centriole in higher animals only
Cell wall	Made of amino acids and polysaccharides (no cell wall in viruses)	Cellulose only in green plants, fungal cellulose in fungi
Organelles	Few, without a membrane	♦ Many, with a double or single membrane ♦ No chroloplast in animals

1.1.2 AN ANIMAL CELL

An animal cell is a eukaryotic cell that lacks a cell wall, and it is enclosed by the plasma membrane. The cell organelles are enclosed by the plasma membrane including the cell nucleus. Unlike the animal cell lacking the cell wall, plant cells have a cell wall.



Since animal cells lack a rigid cell wall it allows them to develop a great diversity of cell types, tissues, and organs. The nerves and muscles are made up of specialized cells that plant cells cannot evolve to form, hence giving these nerve and muscle cells have the ability to move.

Animal cells are smaller than the plant cells and they are generally irregular in shape taking various forms of shapes, due to lack of the cell wall. Some cells are round, oval, flattened or rod-shaped, spherical, concave, rectangular. This is due to the lack of a cell wall. Note: most of the cells are microscopic hence they can only be seen under a microscope in order to study their anatomy.

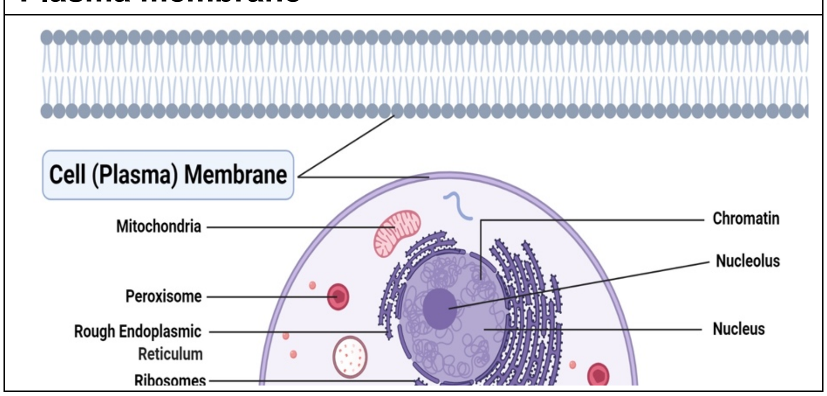
But animal cells share other cellular organelles with plant cells as both have evolved from eukaryotic cells.

Animal cell organelles

Plasma membrane

Structure of Plasma membrane (Cell membrane)

Plasma membrane



- Thin semi-permeable membrane, it contains a percentage of lipids making a semi-permeable barrier between the cell and its physical environment.
- It has some protein components
- It is very consistent around the cell

All living cells have a plasma membrane.

Functions of Plasma membrane (Cell membrane)

- To enclose and protect the cell content

- To also regulate the molecules that pass into and out of the cell, through the plasma membrane. Therefore it controls homeostasis.
- The proteins are actively involved in transporting materials across the membrane
- The proteins and lipids allow cell communication, and carbohydrates (sugars and sugar chains), which decorate both the proteins and lipids and help cells recognize each other.

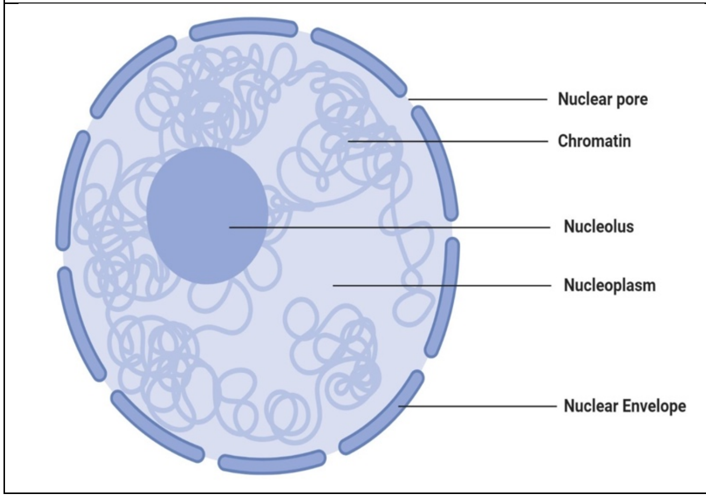
Nucleus; this is a spherical structured organelle found majorly at the center of a cell surrounded by a double-layered nuclear membrane separating it from the cytoplasm.

It is held together to the cytoplasm with the help of the filaments and microtubules.

It holds other cells organelles including the nucleolus, nucleosomes, and chromatins.

A cell has one nucleus which divides producing multinucleated cells e.g. the skeletal muscle cell fibers.

Nucleus



Some cells lose their nuclei after maturation e.g. the red blood cells.

Structure of Nucleus

- The double-layered membrane is a continuous channel of membranous from the endoplasmic reticulum network.
- The membrane has pores which allow entry of large molecule
- Nucleoli (Singular; nucleolus) are tiny/small bodies found in the nucleus.
- The nucleus and its component organelles are suspended in the nucleoplasm house of the chromosomal DNA and genetic materials)

Functions of Nucleus

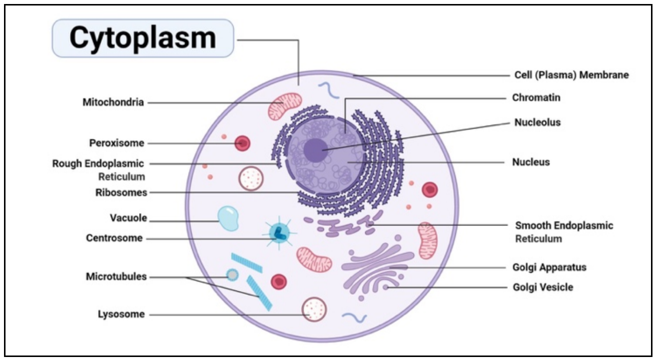
- The primary role of the nucleus is to control and regulate cell activities of growth and maintain cell metabolisms.
- It also carries the genes that have hereditary information of the cell.
- The chromosomal DNA and genetic materials, which are made up of genetic coded ultimately make up their proteins' amino acid sequences for use by the cell.
- Therefore, the nucleus is the information center.

- It is the site for Transcription (formation of mRNA from DNA) and the mRNA is transported to the nuclear envelope.

Cytoplasm

Cytoplasm is a gel-like material that contains all the cell organelles, enclosed within the cell membrane.

These organelles include; mitochondria, ribosomes, endoplasmic reticulum, golgi apparatus, lysosomes intermediate filaments, microfilaments microtubules, and vesicles.

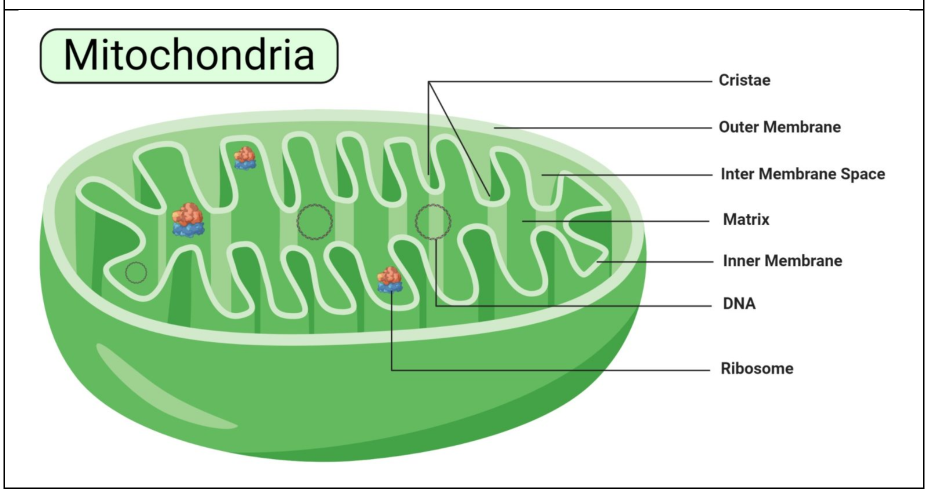


Mitochondria; these are membrane-bound organelles located in the cytoplasm of all eukaryotic cells.

The number of mitochondria found in each cell varies widely depending on the function of the cell it performs.

For example, erythrocytes do not have mitochondria while the liver and muscle cells have

Mitochondria



Structure of Mitochondria

They are rod-shaped or oval or spherically shaped, with a size of 0.5 to 10 µm.

Mitochondria have two special membranes – outer and inner membrane.

They have a mitochondrial gel-matrix in the central mass.

The membranes bend into folds known as cristae which increases surface area for ATP production.

Functions of Mitochondria

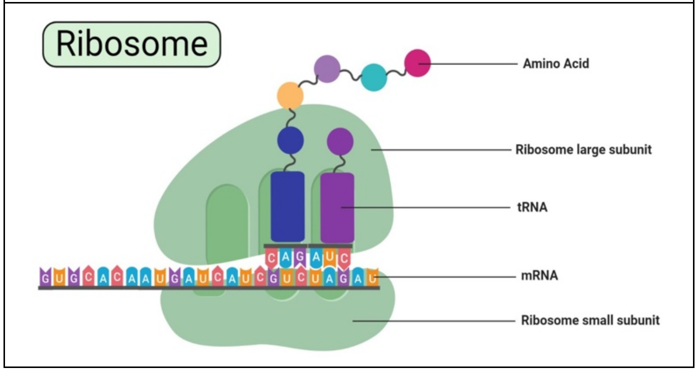
- Their primary function is to generate energy for the cell i.e. they are the power generators, producing energy in form of Adenosine Tri-phosphate (ATP), by converting nutrients and oxygen into energy enabling the cell to perform its function and to also release excess energy from the cell.
- Mitochondria also store calcium which assists in cell signaling activity, generating cellular and mechanical heat and mediating cellular growth and death.
- The outer membrane is permeable, allowing the transport of small molecules and a special channel to transport large molecules.

- The inner mitochondrial membrane is less permeable thus allowing very small molecules into the mitochondrial gel-matrix in the central mass. The gel matrix is composed of the mitochondria DNA and enzymes for the Tricarboxylic Acid (TCA) cycle or the Kreb's Cycle e.g. decarboxylase, cytochrome oxidase enzymes.
- Mitochondria can carry out ptotein synthesis due to the presence of circular DNA and ribosomes.
- They can carry out self-replication due to presence of circular DNA.

Ribosomes; they are small organelles majorly made up of 60% RNA cytoplasmic- granules and 40% proteins.

- All living cells contain ribosomes, which may be freely circulating in the cytoplasm and some are bound to the endoplasmic reticulum.
- It is the site for protein synthesis.

Ribosomes



Structure of Ribosomes

Ribosomes are made up of ribosomal proteins and ribosomal RNA (rRNA). In a eukaryotic cell, ribosomes constitute half ribosomal RNA and half ribosomal proteins.

Each ribosome is made up of two subunits i. e large subunit and small subunit with their own distinct shapes. These subunits are designated as the 40s and 60s in the animal cell.

Functions of Ribosomes

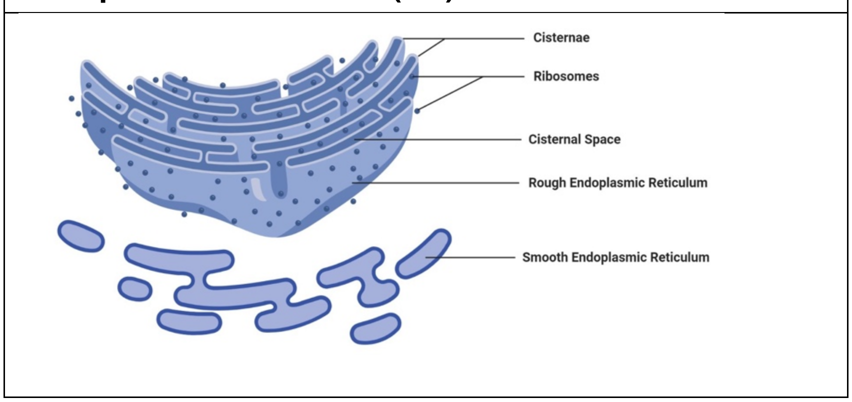
The ribosomal subunits are the site for genetic coding into proteins. On the ribosomes, the mRNA helps determine the coding for Transfer RNA (tRNA) which also determines the protein amino acid sequences. This leads to the formation of the rRNA which are involved in the catalyzation of peptidyl transferase creating the peptide bond found between the amino acid sequences that develop the proteins.

Endoplasmic Reticulum (ER)

Structure of Endoplasmic Reticulum (ER)

ER is a continuous folded membranous organelle found in the cytoplasm made up of a thin network of flattened interconnected compartments (sacs) that connects from the cytoplasm to the cell nucleus.

Endoplasmic Reticulum (ER)



Within its membranes, there are membranous spaces called the cristae spaces and the membrane foldings are called cristae.

There are two types of ER based on their structure and the function they perform including Rough Endoplasmic reticulum and the Smooth endoplasmic reticulum.

Functions of Endoplasmic Reticulum (ER)

- Manufacturing, processing and transporting proteins for cell utilization both in and out of the cell. This is because it is directly connected to the nuclear membrane providing a passage between the nucleus and the cytoplasm.
- The ER has more than half the membranous cell content, hence it has a large surface area where chemical reactions take place. They also contain the enzymes for almost all the cell lipid synthesis hence they are the site for lipid synthesis.

The variation in physical and functional characteristics differentiate the ER into two types i.e. Rough endoplasmic reticulum and Smooth endoplasmic reticulum.

Types of Endoplasmic Reticulum

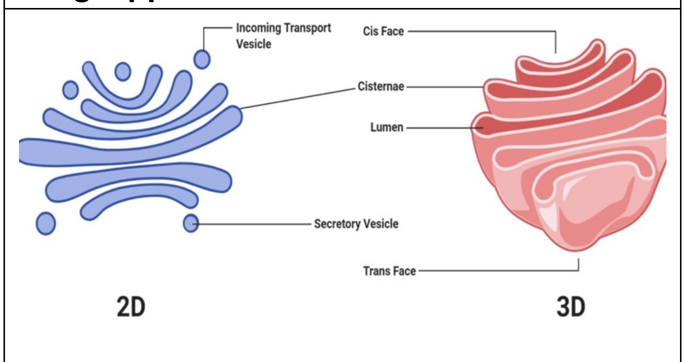
Rough Endoplasmic Reticulum (Rough ER) – Rough ER is called "rough" because there surface is covered with ribosomes, giving it a rough appearance. The function of the ribosomes on rough ER is to synthesis proteins and they have a signaling sequence, directing them to the endoplasmic reticulum for processing. Rough ER transports the proteins and lipids through the cell into the cristae. They are then sent into the Golgi bodies or inserted into the cell membrane.

Smooth Endoplasmic Reticulum (Smooth ER) – Smooth ER is not associated with ribosomes and their unction is different from that of the rough endoplasmic reticulum, despite lying adjacent to the rough endoplasmic reticulum. Its function is to synthesis lipids (cholesterol and phospholipids) that are utilized for producing new cellular membranes. They are also involved in the synthesis of steroid hormones from cholesterol for certain cell types. It also contributes to the detoxification of the liver after the intake of drugs and toxic chemicals.

There is also a specialized type of smooth ER known as the sarcoplasmic reticulum. Its function is to regulate the concentration of Calcium ions in the muscle cell cytoplasm.

Golgi apparatus (Golgi bodies); these are membrane-bound cell organelles found in the cytoplasm of a eukaryotic cell, next to the endoplasmic reticulum and near the nucleus.

Golgi apparatus



Structure of Golgi apparatus (Golgi bodies)

Golgi bodies are supported together by cytoplasmic microtubules and held by a protein matrix

It is made up of flattened stacked pouches known as cisternae.

These cisternae maybe 4- 10 in number for animal cell Golgi bodies though some organisms like single-celled organisms have about 60 cisternae.

They have three primary compartments known as cis (Cisternae Nearest the Endoplasmic Reticulum), medial (central layers of cisternae) and the trans (cisternae farthest from the endoplasmic reticulum).
Animal cells have very few (1-2) Golgi bodies while plants have a few hundred.

Functions of Golgi apparatus (Golgi bodies)

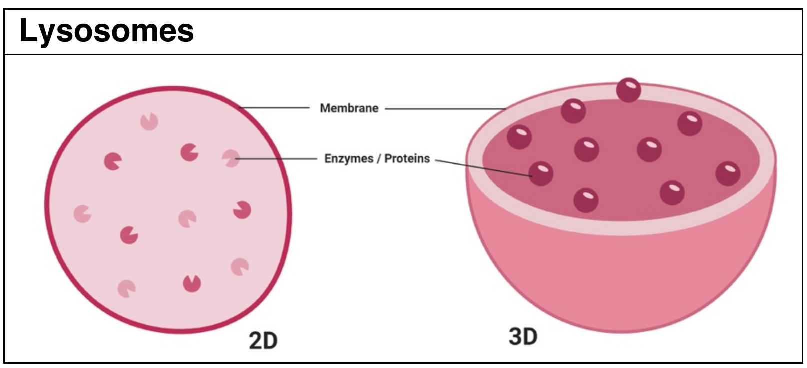
- Their primary function is to transport, modify and pack proteins and lipids into the Golgi vesicles to deliver them to their target sites. Animal cells contain one or more Golgi bodies while plants have a few hundred.
- The vesicle clusters fuse with the cis Golgi network, delivering the proteins and lipids into the cis face cisternae and as they move from the cis face to the trans face, they get modified to functional units. These functional units get delivered to intracellular and extracellular components of the cell.
- It adds carbohydrates to proteins to produce glycoproteins that are later releases out of the cell e.g. mucus.
- Sorting of the modified proteins and lipids occurs in the trans-Golgi network and packed into the trans vesicles, which then delivers them to the lysosomes or sometimes to the cell membrane for exocytosis.
- It replenishes the cell membrane when vesicles burst to releasesecretions to the exterior.
- It produces polysaccharides for making plant cells and cuticle for insects.

Lysosomes

It is also known as cell vesicles; Lysosomes were discovered by Christian Rene de Duve, a Belgian cytologist in the 1950s.

Structure of Lysosomes

They are round or spherical dark sub cellular organelle found in almost all eukaryotic cells



Lysosomes are very acidic organelles containing the digestive enzymes and therefore each of the lysosomes is surrounded by a membrane to protect it from the outer environment.

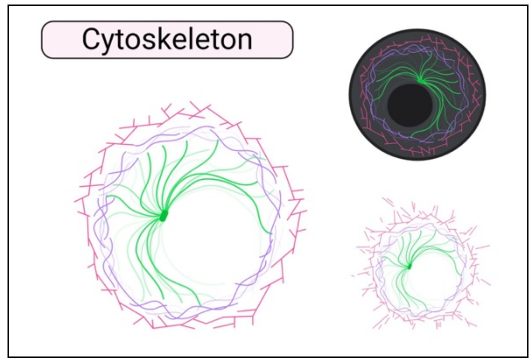
Functions of Lysosomes

1. This is the site for digestion of cell nutrients, excretion, and cell renewal.
2. Lysosomes break down macromolecules components from the outside of the cell into simpler elements that are transported into the cytoplasm via a proton pump to build new cell materials.
   These macromolecule components include old cells and parts, cell waste products, microorganisms, and cell debris.

3. The digestive enzymes found in the lysosomes are called hydrolytic enzymes or acid hydrolases, breaking down large molecules into smaller molecules that can be utilized by the cell.
4. These enzymes also break down large molecules e. g proteins, carbohydrates, lipids, into small molecules e.g. amino acids and simple sugars, fatty acids, respectively.
5. Proteolytic enzymes destroy foreign materials such as bacteria through phagocytosis.

Note: The enzymes are active only on the inside of the acidic lysosome and their acidity protects the cell from degrading itself when there is lysosomal leakage because the cell pH is neutral to slightly alkaline.

Cytoskeleton



Structure of Cytoskeleton; this is a fibrous network that's formed from and by different proteins of long chains of amino acids.

These proteins are found in the cell cytoplasm of the eukaryotic cells.

They are also made up of 3 types of tiny filaments: Actin filaments (Microfilaments), Microtubules, Intermediate filaments.

Functions of Cytoskeleton

- The cytoskeleton functions to create a network organizing the cell components and to also maintain the cell shape.
- It also provides a uniform movement of the cell and its organelles, by the filament system network found in the cell's cytoplasm.
- It also organizes some of the cell components maintaining the cell shape
- It plays a major role in the movement of the cell and some cell organelles in the cytoplasm.

The tiny filaments include:

Actin filaments; also known as microfilaments; it's a meshwork of fibers running parallel to each other and they play a primary role in giving the cell its shape; they change consistently, helping the cell to move and to also mediate certain cell activities such as adherence ability to substrates and cleavage mechanisms during mitotic cell division

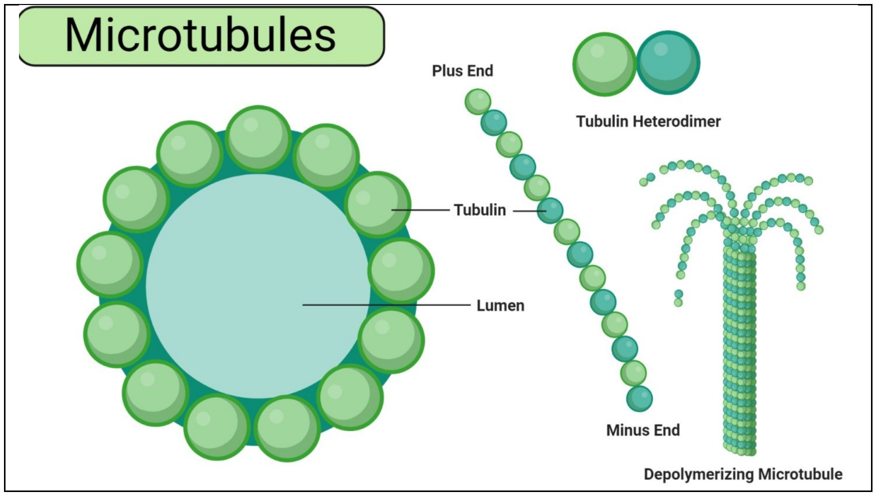
Microtubules- these are long filaments that assist in mitosis moving daughter chromosomes to new forming daughter cells.

Intermediate filaments– they are more stable filaments in comparison to the actin and microtubules. They form the true skeleton of the cell, and the hold the nucleus in its rightful position within the cell.

It also allows the cell's elasticity factor enabling it to endure physical tension.

Microtubules

Structure of Microtubules



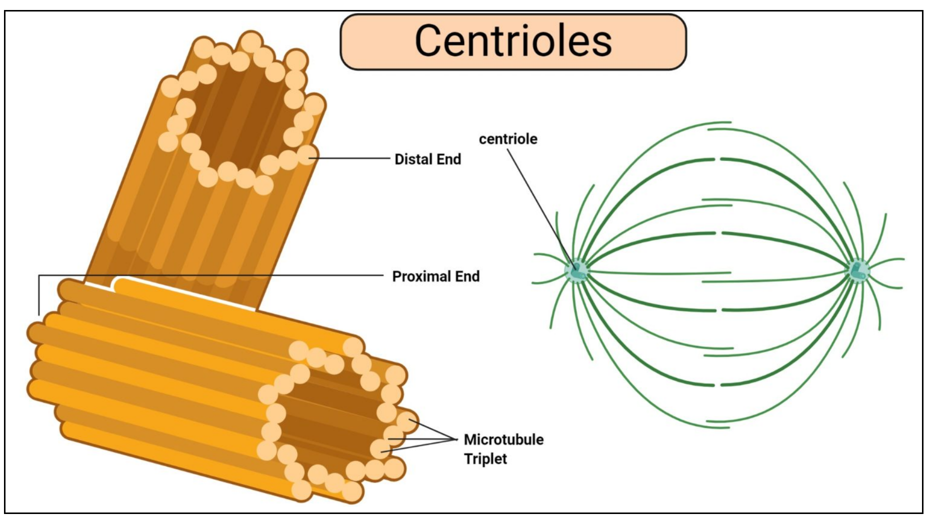
These are long, straight, hollow cylinders filaments that are constructed from 13-15 sub-filaments (protofilament) strand of a special globular protein called tubulin, found only in eukaryotic cells.

They are found throughout the cytoplasm of the animal cell.

Functions of Microtubules

- Transportation of some organelles like the mitochondria and the vesicles i.e. transporting vesicles from the neuron cell body to the axon tips, and back to the cell body
- Structural support, they give characteristic support to the Golgi bodies, holding them within the gel-matrix of the cytoplasm.
- They provide the rigid and organized component of the cytoskeleton of the cell, enabling a cell to take up a particular shape.
- They are the main elements that make up the locomotive projections of a cell (cilia and flagella)
- They also play a role in forming the spindle fibers of the chromosome of the cell during mitotic cell division.

Centrioles



This is distinctly found in the animal cell, which has the ability to replicate or make copies by itself. It is made up of 9 microtubule bundles and their primary function is to assist in organizing the cell division process.

Structure of Centrioles

It is a small structure that is made up of 9 sets of microtubules, placed in groups of three hence they are triplet microtubules.

As triplets, they remain very strong together hence they have been observed to be in structures like cilia and flagella.

The triplet microtubules are held together by proteins, giving the centriole its shape.

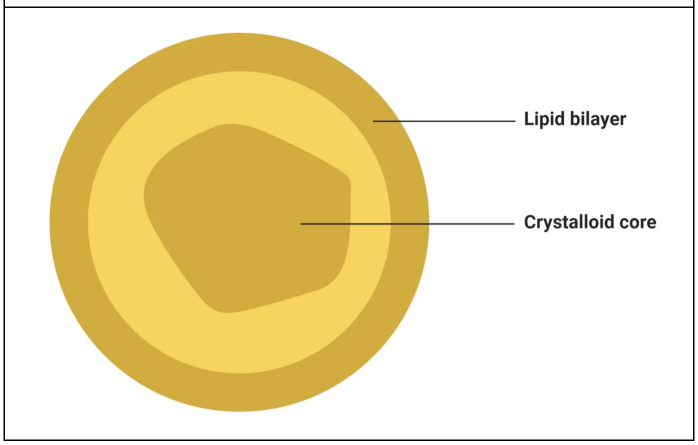
They are found in the centrosome, creating and holding microtubules within the cell.

The triplet microtubules are surrounded by a pericentriolar matrix containing molecules that build up the microtubules.

Functions of Centrioles

- The centriole microtubules allow the transportation of substances that are linked together with a glycoprotein to any cell location. The glycoprotein linkage acts as a signaling unit to move specific proteins.
- The centrioles anchor the microtubules that extend from it and contain the factors needed to create more tubules.
- Mitosis is achieved by replication of each centriole which makes duplicates of each centriole (4 centrioles). The newly formed centrioles divide into two centrosomes, each centriole at an angle to the second centriole. The microtubules between the centrosomes, push the pairs of centrioles apart, to the opposite ends of the cell. When the centrioles are in place, the microtubules extend to the cell cytoplasm, to seek for the chromosome. The microtubules then bind to the chromosome at the centromere. The microtubules are then unassembled from the centriole moving the chromosomes apart.

Peroxisomes



Peroxisomes; these are tiny bodies found in the cytoplasm.

Structure of Peroxisomes

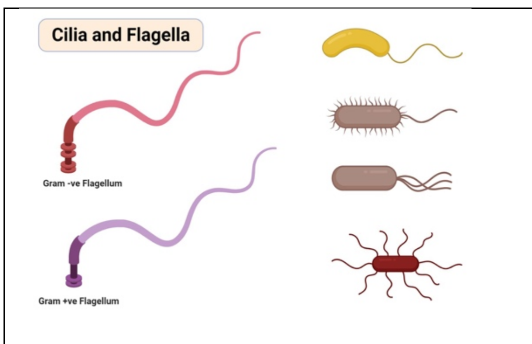
They are spherically shaped, bound by a membrane and they are the most common micro-bodies in the cell cytoplasm.

Functions of Peroxisomes

Peroxisomes functions include:

- Lipid metabolism
- Chemical detoxification by moving hydrogen atoms from various oxygen molecules to produce hydrogen peroxide, hence neutralizing body poison such as alcohol. Its mechanism in Reactive Oxygen species is highly essential.

Structure of Cilia and flagella



Cilia and flagella
These are locomotive projections found on the surface of the cell

They are made of strands of filaments, these filaments have partial and complete microtubules that extend the projections. Partial microtubules don't extend to the tip of the cilium and the complete microtubules extend to the tip of the cilium.

The microtubules also have motor proteins known as dynein making a link between the partial microtubules to the complete microtubules.

The whole collection is combined together as extensions on the plasma membrane of the cell.

Functions of Cilia and flagella

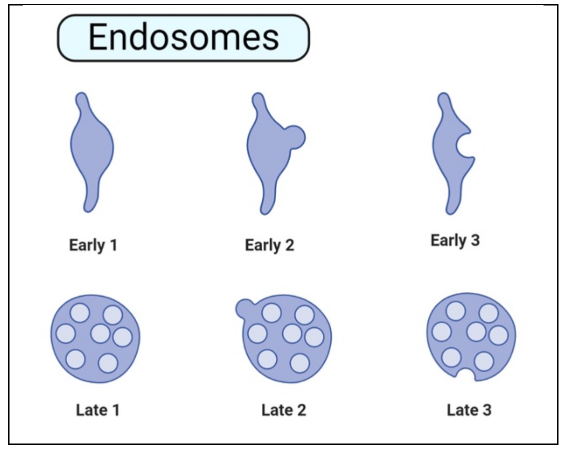
Sperm cells have flagella allowing it to swim to the ova for fertilization. For single cells, such as sperm, this enables them to swim.

Cilia in the animal cell helps move fluids away from and past immobile cells.

Cilia help move surface particles especially on the epithelial lining of the nostrils, and moving mucus over the surface of the cell.

Endosomes

These are vesicles bound by membranes and formed by a mechanism of endocytosis. They are found in the cell cytoplasm.



Structure of Endosome

They are membranous organelles that are bound to the cell membrane.

Functions of Endosome

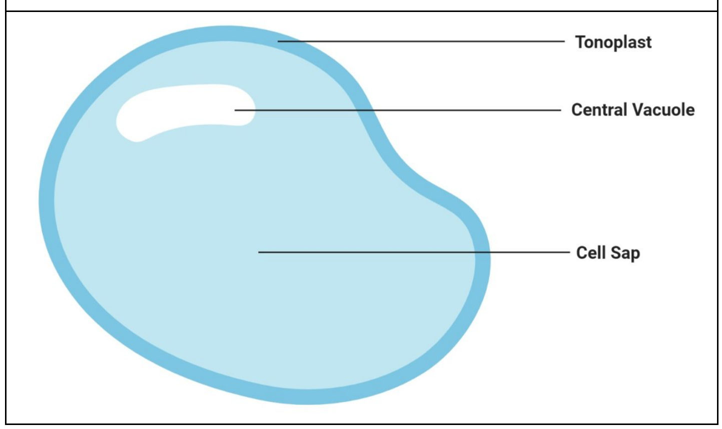
Its main function involves folding in of the plasma membrane. The folding allows diffusing in of molecules through the extracellular fluids.

Their primary role is to remove waste materials from the cell by endocytic processes such as exocytosis and phagocytosis

Vacuoles

These are fluid-filled cell organelles enclosed by a membrane.

Vacuoles



Structure of a vacuole

They are membrane-bound sacs found within the cell cytoplasm.

The vacuole sac has a single membrane surrounding it known as a tonoplast and this membrane resembles the plasma membrane.

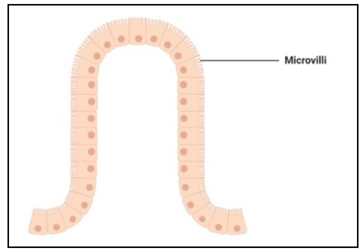
Functions of Vacuoles

- The primary function of vacuole is to store food, water, carbohydrates in the form of sugars and waste materials.
- Tonoplast is a regulator controlling the inflow and outflow of salts across a protein pump
- acts as the guard for what kinds of matter are allowed passage to and from vacuoles
- They also remove toxic substances and waste materials from the cell as a protection strategy.
- They also remove poorly folded proteins from the cell.
- Vacuoles also can be able to change their functionality to provide necessary roles that suit the cell, by being able to change shape and size.

Microvilli; these are surface protrusions found in the intestinal lining, on egg cell surfaces, and on white blood cells.

Microvilli

Structure of Microvilli



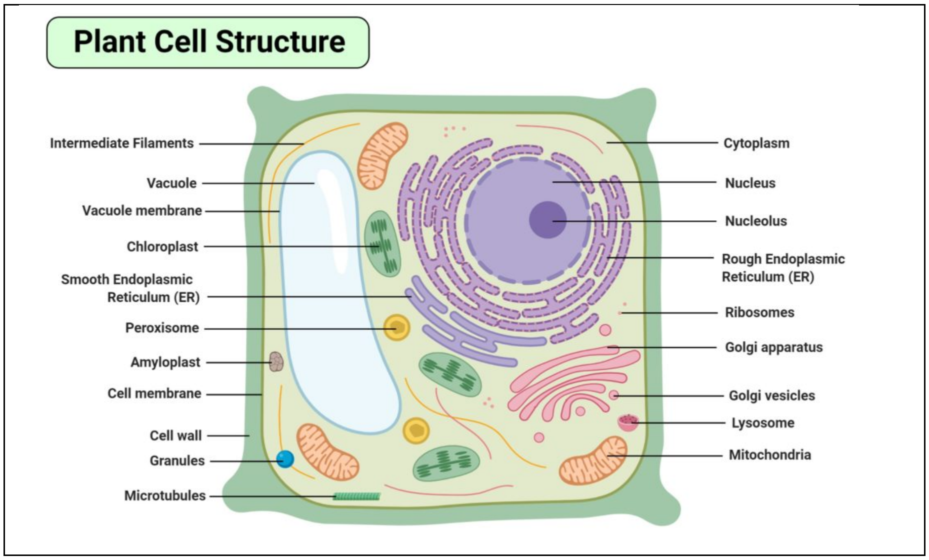
These are surface protrusions formed from accessory proteins of the actin filaments. The accessory proteins bundle together to form microvilli on the surface of the cell membrane

Functions of Microvilli

- In the small intestines, they increase the surface area for the absorption of digested food and water. Some microvilli may be found in the ear for detection of sound and they transmit the sound waves to the brain through an electric signal.
- They also help to anchor the sperm to the egg for easy fertilization.
- In white blood cells, they also act as anchors allowing the white blood cells freely moving in the circulatory system to attach to possible pathogens.

1.1.3 PLANT CELL

Plant cells are eukaryotic cells that are found in green plants, photosynthetic eukaryotes of the kingdom Plantae which means they have a membrane-bound nucleus. They have a variety of membrane-bound cell organelles that perform various specific functions to maintain the normal functioning of the plant cell.



Structure of plant cell

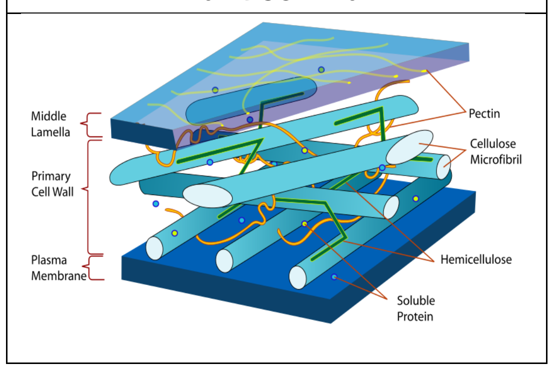
Generally, plant cells are a lot bigger than animal cells.

The typical characteristics that define the plant cell include cellulose, hemicellulose and pectin, plastids which play a major role in photosynthesis and storage of starch, large vacuoles responsible for regulating the cell turgor pressure. They also have a very unique cell division process whereby there is the formation of a phragmoplast (a complex made up of microtubules, microfilaments, and the endoplasmic reticulum) all assembling during cytokinesis, to separate the daughter cells.

<u>These organelles most of them are similar to the animal organelles performing the same functions as those of the animal cell</u>. Organelles have a wide range of responsibilities that include everything from producing hormones and enzymes to providing energy for a plant cell.

Plants cells have DNA that helps in making new cells, hence enhancing the growth of the plant. The DNA is enclosed within the nucleus, an enveloped membrane structure at the center of the cell. The plant cell also has several cell organelle structures performing a variety of functions to maintain cellular metabolisms, growth, and development.

Plant cell wall



Plant cell organelles

A typical plant cell organelles include; cell wall, cell membrane, cytoskeleton, plasmodesmata, chloroplast, vacuole, endoplasmic reticulum, Golgi bodies, mitochondria, ribosomes, peroxisomes, nucleus and nucleolus.

Plant cell wall; it is the rigid outer cover of the plant cell with a major role of protecting the plant cell, giving it, its shape.

Structure of plant cell wall

It is a specialized matrix that covers the surface of the plant cell. Every plant cell has a <u>cell wall layer which is a major distinguishing factor between a plant cell and an animal cell.</u>

The cell wall is made up of two layers, a middle lamella, and a primary cell wall and sometimes a secondary cell wall.

The middle lamella acts as the strengthening layer between the primary walls of the neighboring cells.

The primary wall is made up of cellulose underlying the cells that are dividing and maturing. The primary wall is a lot thinner and less rigid as compared to those of the cells that have reached complete maturation. The thinness allows the cell wall to expand.

After full cell growth, some plants get rid of the primary wall but most, they thicken the primary wall or it makes another layer with rigidity but a different arrangement, known as the secondary wall.

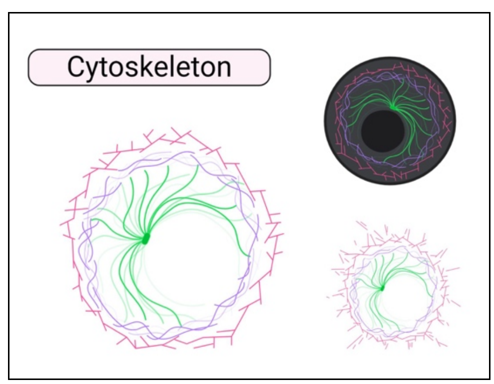
The secondary wall offers permanent stiff mechanical support to the plant cell especially the support found in wood. In contrast to the permanent stiffness and load-bearing capacity of thick secondary walls.

The function of the plant cell wall

The primary role of the cell wall is defined to be a mechanical and structural function that is highly effective in serving the plant cell. These functions include:

- Providing the cell with mechanical protection and shielding the cell from the chemically harsh environment, provided by the secondary wall layer.
- It is semi permeable hence it allows in and out, the circulation of materials such as water, molecular nutrients, and minerals.
- It also forms provides a rigid building block to stabilize the plant to produce some of its structures, for example, the stem and leaves of the plants.
- It also provides a site for storage of some elements such as the regulatory molecules that detect pathogens in the plant, hindering the development of diseased tissue.
- The thin primary walls serve as structural and supportive functional layers when the cell vacuoles are filled with water, exerting turgor pressure on the cell wall, thus maintaining the plants' stiffness and preventing plants from losing water and withering.

The basic building block made of cellulose fibers, of both the primary and secondary walls, despite having different compositions and structures. Cellulose is a polysaccharide matrix that offers tensile strength to the cells. This strength is entrenched within the highly concentrated matrix of water and glycoproteins.



Definition of the plant cytoskeleton

This is a network of microtubules and filaments that plays a primary role in maintaining the plant cell shape and giving the cell cytoplasm support and maintaining its structural organization. These filaments and tubules normally extend all over the cell, through the cell cytoplasm. Besides giving support and maintaining the cell and the cell cytoplasm, it is also involved in the transportation of cellular molecules, cell division, and cell signaling activities.

Structure of the plant cytoskeleton

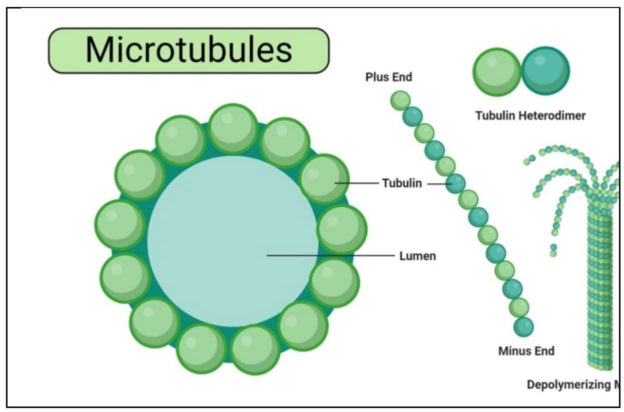
The cytoskeleton has an essential definition of the structure of eukaryotic cells, describing the support system of these cells, the maintenance factors and transport involvements within the cell. These functions are defined by the structure of the cytoskeleton which is made up of three filaments i.e. actin filament (microfilaments), microtubules and intermediate filaments.

Microfilaments, also known as actin filaments, are a meshwork of fibers running parallel to each other. They are made up of the thin strands of actin proteins hence the name actin filaments. They are the thinnest filaments of the cytoskeleton with a thickness of 7 nanometers.

Microtubules are hollow tubes made up of tubulins, with a diameter of 23nm. They are the largest filament compared to the other two filaments.

Functions of the plant cytoskeleton

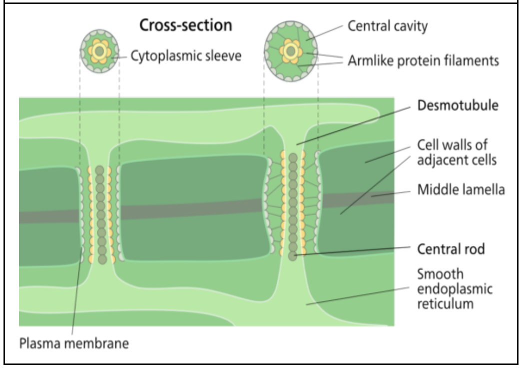
- Microfilaments; they play a primary role is a division of the cell cytoplasm by a mechanism known as cytokinesis, forming two daughter cells.
  They also participate in cytoplasmic streaming, a process of cytosol flow all over the cell, transporting nutrients and cell organelles.
- **Intermediate Filaments;** the intermediate filaments' role in the plant cells is not clearly understood but has a role to play in maintaining the cell shape, structural support and retain tension within the cell.
- **Microtubules**; unlike the role of the microtubule in cell division in the animal cell, the plant cell uses the microtubules to transport materials within the cell and they are also used in forming the plant cell, cell wall.



Other functions of the cytoskeleton in plants include:

- Giving the plant cell shape, maintaining the cell shape and transportation of some cell organelles throughout the cell, molecules, and nutrients across the cell cytoplasm.
- It also plays a role in mitotic cell division.
- In summary, the cytoskeleton is the frame of building the cell; hence it maintains the cell structure, provides cell structural support and defines the cell structure.

Plant cell membrane



Plant cell membrane (plasma membrane)

Structure of the plant cell

This is a bi-lipid membrane that is made up of protein subunits and carbohydrates, with a characteristic semi permeability factor.

It surrounds the cell cytoplasm, thus enclosing its content.

Functions of the plant cell (plasma) membrane

- In-plant cells the cell membrane separated the cytoplasm from the cell wall.
- It has a selective permeability hence it regulates the contents that move in and out of the cell.
- It also protects the cell from external damage and provides support and stability to the cell.
- It has embedded proteins which are conjugated with lipids and carbohydrates, along the membrane, used to transport cellular molecules.

Plasmodesmata

Definition of Plasmodesmata of the plant cell

These are microscopic channels that assist in communicating and transporting materials across plant cells. They **connect the cellular plant spaces** allowing intracellular movement of cellular nutrients, water, minerals, and other molecules. They also allow signaling of cellular molecules. There are two types of plasmodesmata

Primary plasmodesmata, formed during cell division.

Secondary plasmodesmata, formed between mature plant cells.

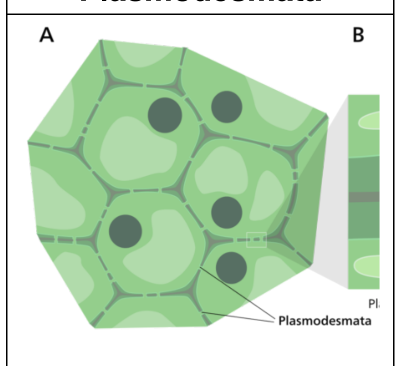
Primary plasmodesmata are formed when part of the endoplasmic reticulum is caught in the middle lamella as the new cell wall is processed during cell division.

As they form, they create a connection between each adjacent, and at the connection site, they form thin spaces known as pits on the walls.

Structure of plasmodesmata of plant cells

Plasmodesmata have a diameter of 50–60 nm in diameter. They have three layers i.e. plasma membrane, cytoplasmic sleeve, and the desmotubules. these layers can thicken the cell wall up to about 90nm.

Plasmodesmata



Plasma membrane – it is a continuous extension on the plasmalemma that is made up of phospholipids layered structure.

Cytoplasmic sleeves – are fluid-filled spaces enclosed by the plasmalemma forming an endless pouch of the cytosol.

Desmotubules – this is a flat tube originating from the endoplasmic reticulum, running between two adjacent cells.

Functions of the plasmodesmata

- Transportation of transcription proteins, short units of RNA, mRNA, viral genomes and viral particles from one cell to another. Such as the movement of MP-30 proteins of the Tobacco mosaic virus, which binds to the viral genome moving it from infected cell to non-infected cell, through the plasmodesmata.MP-30 is thought to bind to the virus's own genome and shuttle it from infected cells to uninfected cells through plasmodesmata.

- They are used to regulate the sieve tube cells with the help of the companion cells.
- They are also used by the phloem cells to facilitate the transportation of nutrients.

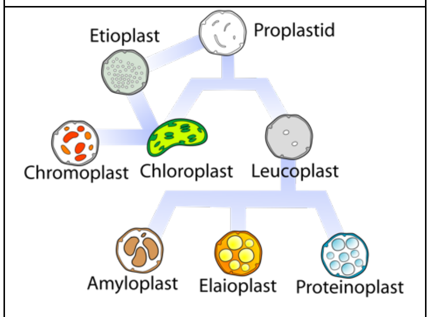
Cytoplasm of the plant cell

This is a gel-like matrix lying just below the cell membrane, housing most of the cell organelles.

- It is made up of water, enzymes, salts, organelles, and various organic molecules.
- It is not classified as one of the cell's organelles because it doesn't possess major roles except being a physical medium for holding and housing most of the complex cell's interior organelles and being a medium for transporting and processing cell molecules for maintaining cell life.

This is because some of these organelles have their own membranes that protect them, for example, the mitochondria and the Golgi bodies have at least 2 layers offering several functions to the organelles.

Plastids of plant cells



Note; The nucleus is not classified as part of the cytoplasm because of its double-layered centrally placed features and it has its own organelles and sub-organelles enclosed within it.

- The cytoplasm of the plant houses several organelles including Plastids, Mitochondria, Central vacuoles, Endoplasmic reticulum, Golgi bodies, Storage granules, lysosomes.

Plastids of plant cells

Plastids are specialized organelles found specifically in plant and algal cells. They have a double-layered membrane.

- They have characteristic pigments that aid their mechanisms majorly in food processing and storage. These pigments also determine the color of the plant.
- Generally, plastids are used to manufacture and store food for plants double-membrane organelle which is found in the cells of plants and algae.
- Plastids have the ability to differentiate in between there forms and they can multiply rapidly by binary fission, depending on the cell, forming over 1000 plastid copies. In mature cells, plastids reduce in number to about 100 per mature cell.
- Plastids are derivates of proplastids (undifferentiated plastids), found in the meristematic tissues of the plant.

General functions of plastids

- They are actively involved in manufacturing food for the plant by photosynthesis due to the presence of chlorophyll pigment in the chloroplast.
- They also store food in the form of starch.

- They have the ability to synthesize fatty acids and terpenes that produces energy for the cell's mechanisms.
- Palmitic acid, a component synthesized by chloroplasts is used in manufacturing the plant cuticle and waxy materials.

Types of Plastids

Plastids are classified based on their functions and the presence of the characteristic pigments. They include:

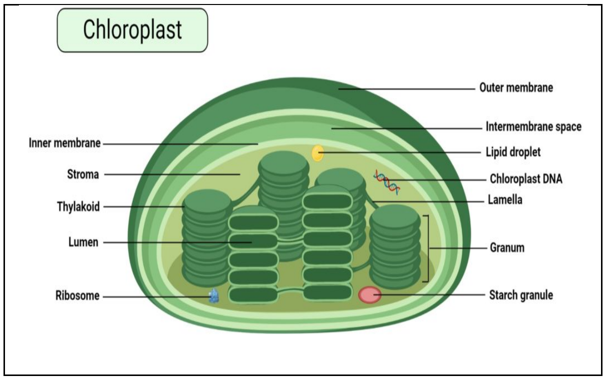
Chromoplasts – colored plastids used to synthesize and store plant pigments

Gerontoplasts – they dismantle photosynthetic apparatus during aging of plants

Leucoplasts – they are colorless plastids used to manufacture terpene substance that protects the plants. They can differentiate, forming specialized plastids performing a variety of functions. i. e amyloplast, elaioplasts, proteinoplast and tannosomes.

Chloroplasts – green plastids used in photosynthesis

Structure of the plant cell chloroplast



These are organelles found in plant cells and algal cells.

They are oval-shaped.

They are made up of two surface membranes, i.e. outer and inner membrane and an inner layer known as the thylakoid layer has two membranes.

The outer membrane forms the external lining of the chloroplast while the inner membrane is below the outer layer.

The membranes are separated by thin membranous space and within the membrane, there is also a space known as the stroma. The stroma houses the chloroplast.

The third layer known as the thylakoid layer is extensively folded making the appearance of a flattened disk known as **thylakoids which have large numbers of chlorophyll and carotenoids** and the electron transport chain, defined as the light-harvesting complex, used during photosynthesis.

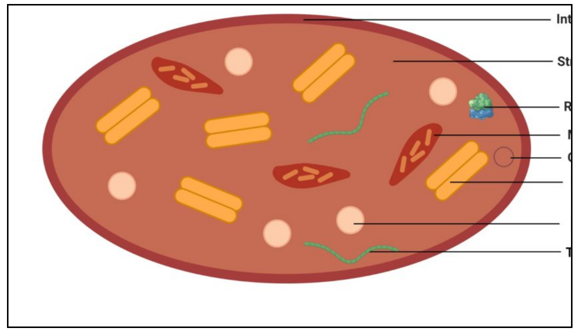
Thylakoids are piled on top of each other in stacks known as grana.

Functions of the plant cell chloroplast

- The chloroplast is the site of food synthesis for plant cells, by a mechanism known as photosynthesis.
- Chloroplasts contain chlorophyll, a green pigment that absorbs light energy from the sun for photosynthesis.
- The photosynthesis process converts water, carbon dioxide, and light energy into nutrients for utilization by the plants.
- Thylakoids contain chlorophyll pigments and carotenoids for trapping light energy for use in photosynthesis.
- The chlorophyll pigment gives plants their green color.

Chromoplastid

Definition



- Chromoplasts define all the plant pigments stored and synthesized in plants. They are found in a variety of plants of all kinds of ages.
- They are normally formed from the chloroplasts is the name given to an area for all the pigments to be kept and synthesized in the plant.
- They have carotenoid pigments that allow the differentiation in color seen in flowers and fruits. Its color attracts pollination mechanisms by pollinators.

Structure of plant chromoplast

The more specialized plant chromoplast feature has been observed classifying it further into 5 types:

1. Globular chromoplasts which appear as globules
2. Crystalline chromoplast which appears crystalized
3. Fibrillar chromoplast which appears like fibers
4. Tubular chromoplast which looks like tubes

Membranous chromoplast; these chromoplasts live amongst each other though some plants have specific types such as mangoes have the globular chromoplast while carrots have crystallized chromoplast, tomatoes have both crystalline and membranous chromoplast because they accumulate carotenoids.

Functions of plant chromoplast

- They give distinctive colors to plant parts such as flowers, fruits, roots, and leaves. Differentiation of chloroplast to chromoplast makes the fruits of plant ripen.
- They synthesize and store plant pigments such as yellow pigments for xanthophylls, orange for carotenes. This gives the plant and its parts the color.
- They attract pollinators by the colors they produce, which helps in the reproduction of the plant seed.
- Chromoplats found in roots enable the accumulation of water-insoluble elements especially in tubers such as carrots and potatoes.
- They contribute to color change during plant aging, for flowers, fruits, and leaves.

Leucoplast plastids

These are the non-pigmented plastids. Since they lack the chloroplast pigments, they are found in non-photosynthetic parts of the plants like the roots and seeds.

They are smaller than the chloroplasts, which varying morphologies others appearing ameboid shaped.

They are interconnected with a network of stromules in roots, flower petals.

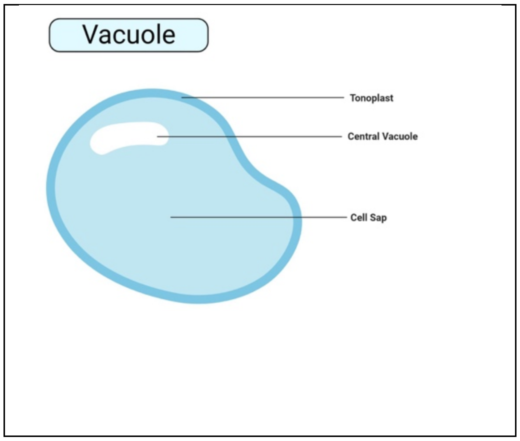
They can be <u>specialized to store starch, lipids, and proteins in large quantities</u> hence named as amyloplasts, elaioplast, and proteinoplast, depending on what they store respectively.

The main function of the leucoplast includes:
- Storage of starch, lipids, and proteins.
- They are also used to convert amino acids and fatty acids.

Plant vacuoles definition

Plant cells have large vacuoles as compared to animal cells.

The central vacuoles are found in the cytoplasmic layer of cells of a variety of different organisms, but larger in the plant cells.



Structure of plant cell vacuoles

These are large, vesicles filled with fluid, within the cytoplasm of a cell.

It is made up of 30% fluid of the cell volume but can fill up to 90% of the cell's intracellular space.

Functions of the central vacuole
- The central vacuoles are used to adjust the size of the cell and to maintains the turgor pressure of the plant cells, preventing wilting and withering of plants especially the leaves.
  When the cytoplasmic volume is constant, the vacuoles account majorly for the size of the plant cell.
- Plant cells thrive in high water levels (Hypotonic solutions), taking up water by osmosis from the environment, thus maintaining turgidity especially in herbaceous plants.
- A plant cell can have more than one type of vacuole. Some specialized vacuoles especially those structurally related to lysosomes contain degradative enzymes used to break down macromolecules.
- Vacuoles are also responsible for the storage of cellular nutrients including sugars, organic salts, inorganic salts, proteins, cellular pigments, lipids. these elements are stored until when the cell requires them for cellular metabolisms. For example, vacuoles store proteins for seeds and opium metabolites.
- They provide mechanical support to the cell in general.

Plant cell mitochondria

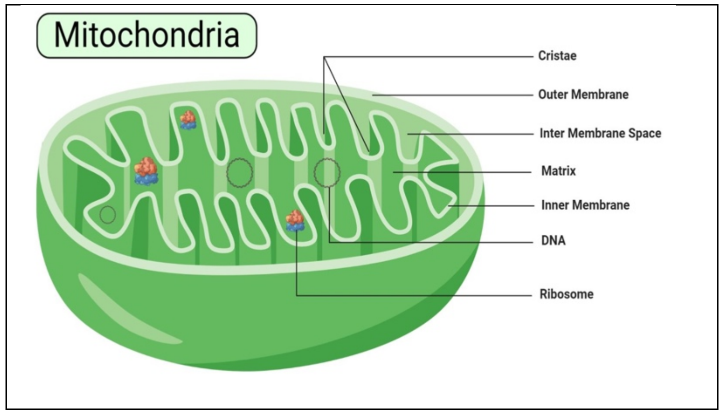
Mitochondria are also known as chondriosomes, are the power generating organelles of a cell, hence they are commonly known as the powerhouse of the cell.

The mitochondria convert stored nutrients by the help of oxygen to produce energy in form of (ATP)Adenosine TriPhosphate, hence they are the site for non-photosynthetic energy transduction.

There are hundreds of mitochondria within a single plant cell.

Mitochondria are found in high numbers within the phloem pigment of the plant cell, and the neighboring cells have high metabolism rates. This is to supply energies that support various needing mechanisms, like the transportation of food through the sieve tubes.

As they perform their mechanisms, mitochondria continuously move and change their shapes, depending on its interactions with light trapped for photosynthesis, level of cytosolic sugars and the endoplasmic reticulum mediated interactions.



The animal and plant mitochondria are very similar except for a few notable differences e.g. mitochondria in plants have reduced nicotinamide adenine dinucleotide (NADH) dehydrogenase used for oxidation of exogenous NADH which animal cell lack.
Mitochondria from many plant sources are relatively insensitive to cyanide inhibition, a feature not found in animal mitochondria. On the other hand, the b -oxidation pathway of fatty acids is located in animal mitochondria, whereas in plants, the enzymes of fatty acid oxidation occur in the glyoxysomes.

Structure of plant mitochondria

Plant cell mitochondria have high pleomorphism (*the occurrence of more than one distinct form of a natural object, such as a crystalline substance, a virus, the cells in a tumour, or an organism at different stages of the life cycle.*
Pleomorphism is the ability of some microorganisms to alter their morphology, biological functions or reproductive modes in response to environmental conditions.)
Mitochondria in green plants are **discrete, spherical-oval shaped organelles** of diameter ranging from 0.2to1.5µm
The mitochondria have a double-layered system i. e a smooth outer membrane and an inner complex membrane that encloses the organelle matrix.
The two layers are lipid bilayers complexed with a hydrophobic fatty acid chain. These lipids are a class of phospholipids that are highly dynamic with a strong attraction to the fatty acid regions.
They have a mitochondrial gel-matrix in the central mass.
The mitochondria also possess all the enzymes for the Tricarboxylic cycle (TCA) including citrate synthetase, Pyruvate oxidase, Isocitrate Dehydrogenase, Malate Dehydrogenase, Malic Enzyme.

Functions of mitochondria in plants

- The mitochondria are the powerhouse of the cell, hence their major function is generating energy for use by the cell.
- They have a high rate of metabolism because they supply energy for the unknown mechanism by which foods, mainly sucrose, are transported in the sieve tubes.
- Within the mitochondria, the potential energy in food that is manufactured by photosynthesis is what is used for the metabolisms of the cells. For example, energy used for the formation of new cell content, enzyme production and moving of sugar molecules are produced by the mitochondria.

- This is the site for the Tricarboxylic cycle (TCA), also known as the Krebs cycle. The TCA cycle uses the cell's nutrients, converting them into by-products that the mitochondria use for producing energy in cristae.

Plant cell endoplasmic reticulum (ER) definition

The ER is a continuous network of folded membranous sacs housed in the cell cytosol. It is a complex organelle taking up a sizable part of the cell's cytosol

It is made up of two regions known as the rough endoplasmic reticulum (they have ribosomes attached to their surface membrane) and the smooth endoplasmic reticulum (they lack ribosomal attachment).

The endoplasmic reticulum

The endoplasmic reticulum known for its high dynamics functions in eukaryotic cells, play major roles in synthesizing, processing, transporting and storing proteins, lipids, and chemical elements. These elements are used by the plant cell and other organelles such as the vacuoles and the apoplast (Plasma membrane).

The inner space of the ER is known as the lumen.

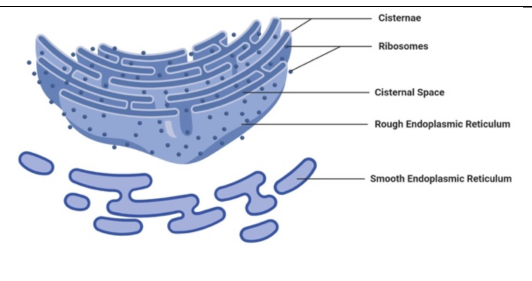
It is attached to the nuclear envelope, providing a link between the nucleus and the cell cytosol, and also giving a link between the cell to the plasmodesmata tubes, which connect to the plant cells.

Rough ER almost always appears as stacks of double membranes that are heavily dotted with ribosomes. Based on the consistent appearance of rough ER, it most likely consists of parallel sheets of membrane, rather than the tubular sheets that characterize smooth ER.

These flattened, interconnected sacs are called cisternae, or cisternal cells. The cisternal cells of rough ER are also referred to as luminal cells. Rough ER and the Golgi complex are both composed of cisternal cells.

Functions of the endoplasmic reticulum

endoplasmic reticulum



The Rough endoplasmic reticulum is covered by ribosomes around its surface membrane, making a rough bumpy appearance.

- The primary role of the Rough ER in synthesizing proteins, which are transported from the cell to the Golgi bodies, which carry them to other parts of the plant to help in its growth. These proteins are an assembly of amino acid sequences that combine to form antibodies, hormones, digestive enzymes. The assembling is accomplished by the ribosomes attached to the rough ER.
- The smooth ER is smooth due to a lack of attached surface ribosomes.
  Its role is synthesizing, secreting and storing lipids, metabolizing carbohydrates and manufacturing of new membranes. This is enhanced by the presence of several enzymes bound to its surface.

- Excess lipids manufactured by the cell are stored in the smooth Endoplasmic reticulum in the form of triglycerides. And when the cell needs more energy, the triglycerides are broken down to produce the energy required by the plants.
- Minimally, the smooth endoplasmic reticulum has also been linked to the formation of the cellulose on the cell wall.
- Endoplasmic reticulum has been linked to regulating the excess calcium by converting it to calcium oxalate crystals by specialized cells in the endoplasmic reticulum known as crystal idioblast
- The ER also act as plant sensors. Plants have the ability to make rapid movements in response to certain external stimuli e. g light intensity, temperature, and atmospheric pressure.

Plant cell ribosome

Definition; this is the organelle responsible for protein synthesis of the cell.

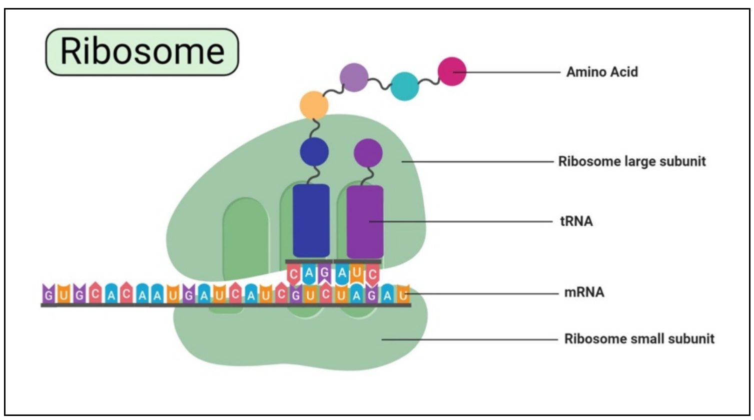
- It is found in the cell cytoplasm in large numbers and a few of them called functional ribosomes can be found in the nucleus, mitochondria, and the cell chloroplast.
- It is made up of ribosomal DNA (rDNA) and cell proteins
- The process of protein synthesis by the ribosomes is known as **translation**, by using the messenger RNA, which delivers the nucleotides to the ribosomes.
- The ribosomes then guide and translate the message in the form of nucleotides, contained by the mRNA.

Structure of ribosomes of the plant cell

The ribosomes' structure is the same in all cells but smaller in prokaryotic cells.

Ribosomes found in the mitochondria and chloroplasts are as small as the prokaryotic ribosomes.

The cytoplasm is the primary site for protein synthesis (translation).



Functions of ribosomes in plant cells

- Containing a subunit of RNA, ribosomes major functions is to synthesize proteins for the cellular functions such as cell repair mechanism.
- Ribosomes act as catalysts in producing strong binding for portion extension using peptidyl transfer and peptidyl hydrolysis.
- Ribosomes found in the cell cytoplasm are responsible for the conversion of genetic codes to amino acid sequences and building protein polymers from amino acid monomers.
- They are also used in protein assembling and folding.

Storage granules of plant cell

These are aggregates found within the cytoplasmic membrane and the plant cell plastids.

They are inert organelles found in plants whose primary function is to store starch.

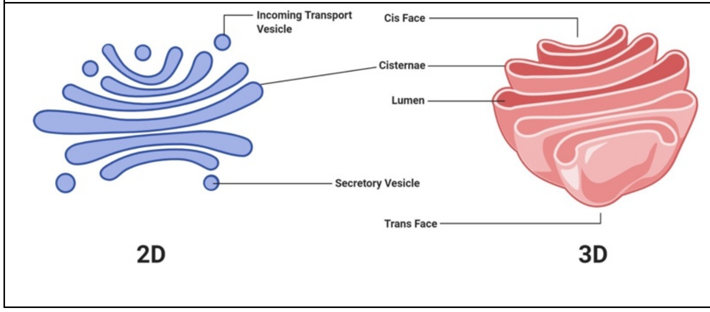
Functions of storage granules in plant cell

- They are used as food reservoirs
- They store carbohydrates for the cell in the form of glycogen or carbohydrate polymers
- They naturally store starch granules for the plant cell
- They also fuel metabolisms in the cell that involved chemical reactions thus producing energy for the production of new cellular materials.

Plant cell Golgi bodies

These are complex membrane-bound cell organelles found in the cytoplasm of a eukaryotic cell, which is also known as the Golgi complex or Golgi apparatus. They lie just next to the endoplasmic reticulum and near the nucleus.

Golgi bodies



Structure of the Golgi bodies in a plant cell

They are made up of flattened stacked pouches known as cisternae.

Plant cells have a few hundreds of the Golgi bodies moving along the cell's cytoskeleton, over the endoplasmic reticulum as compared to the very few found in animal cells.

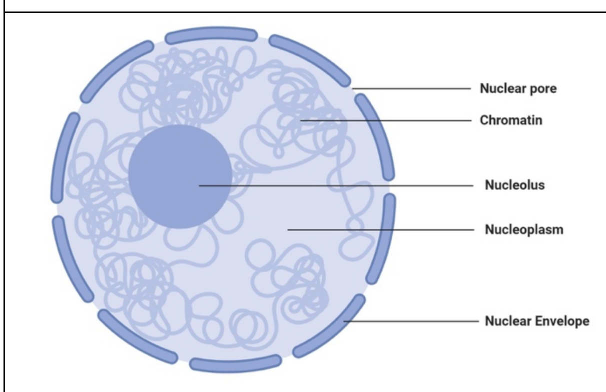
Functions of the Golgi bodies in a plant cell

- The Golgi bodies are found in the middle of the cells' secretory pathway, as a membranous complex that primarily functions to process, distribute and store proteins for use by the plant during stress responses and others in leguminous plants such as cereals and grains.
- When the vesicles have transported the proteins and lipid molecules, the Golgi bodies are responsible for assembling the product and transporting it to the final destination. This is enhanced by the presence of enzymes in the plants' Golgi bodies, which attach to the sugar to the proteins, packing them and transporting them to the cell wall.

The plant nucleus

The nucleus is the information center of a cell. It is a specialized complex organelle whose primary function is to store the cell's genetic information.

Plant nucleus



Structure of the nucleus of the plant cell

The nucleus is spherically shaped, centrally placed in the cell. It occupies about 10% of the cell volume content.

It as a double-layered membrane known as the nuclear envelope which separates the contents in the nucleus from those in the cell cytoplasm.

The nuclear materials included chromatins, DNA which forms the cell chromosomes during cell division, the nucleolus which is responsible for synthesizing the cell ribosomes.

Functions of the nucleus of the plant cell

- The Primary role of the cell nucleus is, it functions as the cell's control center. It is also responsible for coordinating the cell's activities including cell metabolism, cell growth, synthesis of proteins and lipids and generally the cell reproduction by cell division mechanisms.
- The nucleus contains the cells' genetic information known as Deoxyribonucleic Acid (DNA), on the Chromosomes (special thread-like strands of nucleic acids and protein found in the nucleus, carrying genetic information)
- The nucleus is also linked to the site for protein synthesis, i.e. the endoplasmic reticulum by a network of microfilaments and microtubules.
- Storage DNA; DNA strands have a negative charge which is neutralized by the histones' positive charge. Unused DNA is folded and stored for future use.

Nucleolus

It is a sub-organelle in the cell nucleus, which lacks a membrane.

Its primary function is to synthesize the cell ribosomes, the organelles used to produce cellular proteins.

The cell has about 4 nucleoli.

The nucleolus is formed when chromosomes are brought together, just before cell division is initiated.

The nucleolus disappears from during cell division.

Plant cell peroxisomes

Definition; these are highly dynamic tiny structures that have a single membrane containing enzymes responsible for the production of hydrogen peroxide. They play major roles in primary and secondary metabolisms, responding to abiotic and biotic stress in regulating photorespiration and cell development.

Structure of the peroxisomes

Peroxisomes are small with a diameter of 0.1-1 μm diameter.

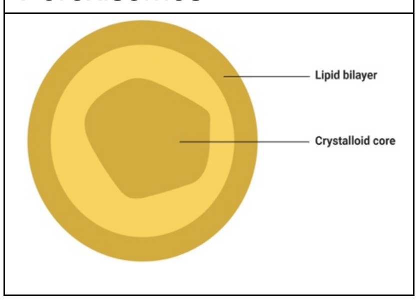
It is made up of compartments having a granulated matrix.

They also have a single membrane layer.

They are found in the cytoplasm of a cell.

The compartments assist in various metabolic processes of the cell to help sustain the cellular activities within the cell.

Peroxisomes



Functions of the peroxisomes

- Production and degradation of hydrogen peroxide
- oxidation and metabolism of fatty acids
- Metabolizing carbon elements
- Photorespiration and absorption of Nitrogen for specific functions of the plant.
- Providing defense mechanisms against pathogens

Lysosomes of plants

The presence of lysosomes in plants has been long debated over with little evidence on their structural presence. In plants, it is believed that lysosomes partially differentiate into vacuoles and partially into the Golgi bodies which perform the functions stipulated for lysosomes in plants. Unlike in animals where lysosomes distinctively posses hydrolytic enzymes and digestive enzymes, for breaking down toxic materials and removing them from the cell and digestion of proteins respectively, in plants these enzymes combined are found in the vacuoles and the Golgi bodies.

Structural and functional differences between animal cell and plant cell

Characteristic	Animal cell	Plant cell
Definition	Animal cells are also the basic functional unit of life for animals constituting all cell organelles that perform a variety of functions to support the animals' metabolisms.	Plant cells are basic functional units of plants constituting all cell organelles performing a variety of functions that support the plants' metabolisms.
Size and shape	Animal cells are generally smaller than plant cells with their cells ranging from 10-30um in length. Animal cells shape and sizes vary greatly from irregular shapes to round shapes, most defined by the function they perform.	Plant cells are larger than animal cells with the cell size ranging from 10um-100um in length. Plant cells similar in shape with most cells being rectangular or cube-shaped.
Cell wall	They lack the cell wall but possess a plasma (cell) membrane, which performs the function of support and protection of the cell from external damage. It also plays a major role in selective permeability allowing in and outflow of nutrient molecules, water, and other cell elements.	They have both a cell wall that is made up of cell membrane and cellulose. The cell wall is, a rigid membrane matrix found on the surface of all plant cells whose primary role is to protect the cell and its content.
Plasma membrane	They have a plasma membrane that is a thin flexible membrane, which acts as a protective covering for the animal cell. It also has selective permeability.	The presence of the plasma membrane made up of cellulose, just below the cell wall which allows selective permeability of cell contents into and out of the cell cytoplasm.
Cytoplasm	It houses all the cell organelles.	It houses most of the cell organelles
Ribosomes	They are present and they are used for protein synthesis and genetic coding of the protein, amino acid sequences.	They are present and they are used for protein synthesis and cellular repair mechanisms.
Lysosomes	Animal cells have lysosomes that contain digestive enzymes to break down cellular macromolecules.	Plant cells rarely contain lysosomes as the plant vacuole and the Golgi bodies handle molecule degradation of waste cellular products.
Vacuoles	Animal cells may have many small vacuoles, a lot smaller than the plant	Plant cells have a large central vacuole that can occupy up to 90%

	cell.	of the cell’s volume.
Nucleus	Present and it lies at the center of the cell	Present and it lies on the side of the cell
Nucleolus	Present in the nucleus	Present in the nucleus
Centrioles	They are present with their major function involving the assistance of the cell division process.	They are absent in plant cells
Peroxisomes	They are present in the cytoplasm. They perform the oxidation mechanisms for specific biomolecules and they assist in the synthesis of plasmalogen lipids.	They are present in the cell cytoplasm functioning as cell oxidizers for cellular molecules, synthesis of lipids and recycling carbon from phosphoglycolate during photorespiration.
Microfilaments and microtubules	They are present functioning to give support to the cell cytoskeleton, transport materials across the cytoplasm into and out of the nucleus. They are also involved d in cytokinesis.	They are present, to give cytoskeletal support, transportation of molecules across the cytoplasm and the nucleus and they play a major role in cytokinesis.
Cytoskeletons	Present and its major functions include creating a network that organizes the cell components and maintains the cell shape.	They have a cytoskeleton that maintains the plant cell shape, supports the cell cytoplasm and maintains the cell’s structural organization.
Cytosol	Present and its where all the cell organelles are suspended	Present, its where most of the cell organelles are suspended.
Microvilli	They are present in the intestinal lining to increase the surface area for the absorption of food.	Absent in plant cells.
Cilia and filaments	Present; they allow movement of cells or part of the cell, for example, swimming of the sperm to the ova.	Absent in plants
Plastids	Absent	Present; they give pigmentation color to the plants and also facilitate trapping of light energy used for photosynthesis.
Plasmodesmata	Absent	Present; they facilitate the communication and transport of materials across plant cells.
Golgi bodies	They have larger and fewer Golgi bodies with their major function being to process and package protein and lipid macromolecules as they are being	They have smaller but more Golgi bodies with their major role being modification, processing, sorting and packaging proteins for cellular

	synthesized.	secretion.
Synthesis of cellular nutrients	They cannot synthesize amino acids, vitamins, and coenzymes.	The can synthesize amino acids, vitamins, and vitamins.
cytokinesis	It takes place by constriction	It takes place in the cell plates
Osmosis in a hypotonic solution	They take in water molecules by osmosis and easily burst when placed in hypotonic solution because of the lack of a cell wall	They absorb water molecules by osmosis but they do not burst in a hypotonic solution due to the presence of a cell wall.

*Structural and functional similarities between an **animal cell** and a **plant cell***

Characteristic	Animal cell	Plant cell
Granules	Present	Present
Endoplasmic Reticulum	They are present in two types: rough endoplasmic and smooth endoplasmic reticulum	They are present in two types: rough endoplasmic and smooth endoplasmic reticulum

Looking at the Structure of Cells in the Microscope

A typical animal cell is 10–20 μm in diameter, which is about one-fifth the size of the smallest particle visible to the naked eye. It was not until good light microscopes became available in the early part of the nineteenth century that all plant and animal tissues were discovered to be aggregates of individual cells. This discovery, proposed as the cell doctrine by Schleiden and Schwann in 1838, marks the formal birth of cell biology.

Animal cells are not only tiny, they are also colorless and translucent. Consequently, the discovery of their main internal features depended on the development in the latter part of the nineteenth century, of a variety of stains that provided sufficient contrast to make those features visible. Similarly, the introduction of the far more powerful electron microscope in the early 1940s required the development of new techniques for preserving and staining cells before the full complexities of their internal fine structure could begin to emerge. To this day, microscopy depends as much on techniques for preparing the specimen as on the performance of the microscope itself. In the discussions that follow, we therefore consider both instruments and specimen preparation, beginning with the light microscope.

Different Components of the Cell Can Be Selectively Stained

There is little in the contents of most cells (which are 70% water by weight) to impede the passage of light rays. Thus, most cells in their natural state, even if fixed and sectioned, are almost invisible in an ordinary light microscope. One way to make them visible is to stain them with dyes.

In the early nineteenth century, the demand for dyes to stain textiles led to a fertile period for organic chemistry. Some of the dyes were found to stain biological tissues and, unexpectedly, often showed a preference for particular parts of the cell—the nucleus or mitochondria, for example, making these internal structures clearly visible. Today a rich variety of organic dyes is available, with such colorful names as *Malachite green, Sudan black,* and *Coomassie blue,* each of which has some specific affinity for particular subcellular components. The dye *hematoxylin,* for example, has an affinity for negatively charged molecules and therefore reveals the distribution of DNA, RNA, and acidic proteins in a cell.

1.1.4 CELL DIVISION

This is the process of division of the cytoplasm into new daughter cells. The length of the cell cycle depends on the type of the cell and the external factors such as temperature, food and oxygen supply.

Cell cycle

The cell cycle is the period from the formation of the cell to its division into daughter cells. It has three main stages.

- Interphase
- Nuclear division
- Cytokinesis (cell division)

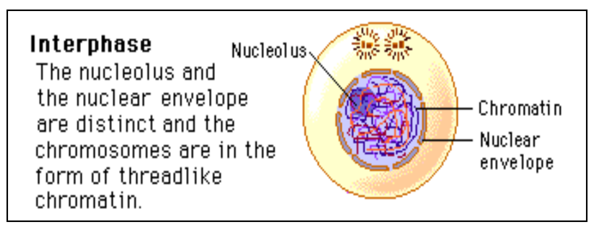
There are two types of cell division are; mitosis and meiosis.

Mitosis

This is the process by which a cell nucleus divides to produce two daughter nuclei containing identical set of chromosomes to the parent cell. It is usually followed immediately by division of the whole cell to from two daughter cells. This type of cell division results into an increase in cell numbers.

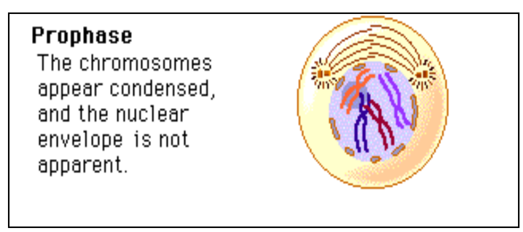
- In eukaryotes, mitosis occurs in five stages.
- Interphase
- Prophase
- Metaphase
- Anaphase
- Telophase

Interphase



This is the process of general cellular synthesis and DNA replication. The chromosomes are visible are in form of much coiled threads called chromatin. Each chromosome then will carry two chromatids which are enclosed in a nuclear membrane with visible nucleolus.

Prophase



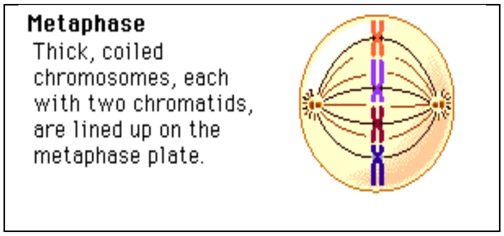
This stage has two phases i.e. early prophase and late prophase.

Early prophase; this is the longest phase of nuclear division. Chromatids shorten and thicken by spiralisation and condensation of DNA replication.
Nucleolus shrinks and spindle fibres start to form.

Late prophase; nuclear membrane breaks down to form small vesicles allowing microtubules of spindle to interact with chromosomes.

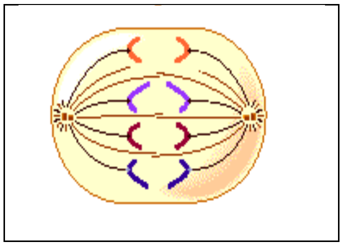
Chromosomes become shorter and fatter each seen to consist of a pair of chromatids each joined at centromere.

Metaphase



Chromosomes migrate and arrange themselves at the equator of the spindle (central position of the nucleus).
Chromosomes attach to the spindle by their centromeres.

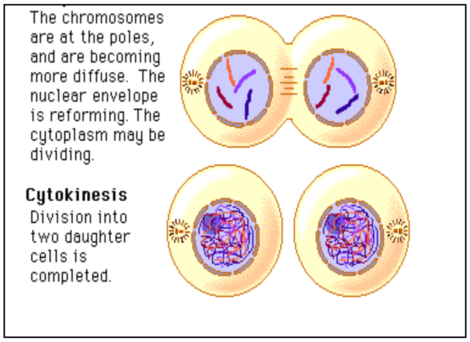
Anaphase



Centromeres split into two and the spindle fibres pull the daughter centromere to the opposite poles. Separated chromatids now called chromosomes are pulled towards the opposite poles.

Telophase

Chromosomes reach the poles of the cell, uncoil and become invisible.
Spindle fibres disintregrate, centrioles replicate, chromosomes and nucleolus re-appear.
The cell constricts in the middle and divides into two daughter cells.



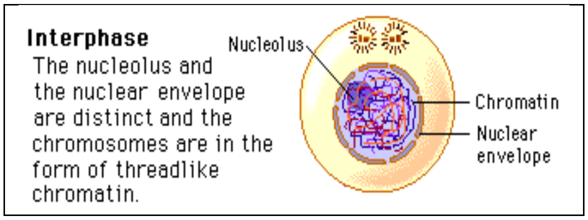
Cytokinesis, the division of the cytoplasm to form two new cells, overlaps with the final stages of mitosis. It may start in either anaphase or telophase, depending on the cell, and finishes shortly after telophase.

Significance of mitosis

- Maintains genetic stability since it produces two nuclei each with the same number of chromosomes as the parent cell.
- It brings about growth of new cells
- It brings about repair of worn out and cells and tissues.
- It is basis for asexual reproduction
- It ensures cell regeneration

Meiosis

This is a type of cell division in which cell nucleus divides to produce four nuclei each containing half the number of chromosomes as the parent cell. It occurs in diploid cells and consists of nucleus of chromosomes. It occurs in two phases, meiosis I and meiosis II.
In meiosis I there are five main stages namely; Interphase, prophase I, metaphase I, anaphase I and telophase I. Meiosis as a special cell division reduces the cell from diploid to haploid.



Interphase; this is the process of general cellular synthesis and DNA replication. The chromosomes are visible are in form of much coiled threads called chromatin. Each chromosome then will carry two chromatids which are enclosed in a nuclear membrane with visible nucleolus.
Interphase in meiosis I is as for mitosis.

Prophase I

The homologous chromosomes pair and exchange DNA to form recombinant chromosomes. Prophase I is divided into five phases:

Leptotene: chromosomes appear as long and thin threads, spindle fibres start to form, chromosomes start to condense.

Zygotene: there is pairing up of homolohushomologous chromosomes(same size, shape and contraction) become closely associated (synapsis) to form pairs of chromosomes (bivalents) consisting of four chromatids (tetrads).

The process in which homologous chromosomes associate with each other i.e. come to lie sides by side is called synapsis.

Pachytene: crossing over between pairs of homologous chromosomes to form chiasmata (sing. chiasma). Thick threads spear representing full synapsis.

The non- sister chromatids exchange genetic materials, a procees known as crossing over.

Diplotene: homologous chromosomes start to separate but remain attached by chiasmata. Each pair of homolohus chromatids appear as a four bundle four chromatids. There is disintegration of nucleus. Chiasmata form between non-sister chromatids.

Diakinesis: homologous chromosomes continue to separate, and chiasmata move to the ends of the chromosomes. Nuclear membrane also breaks down.

Metaphase I

Homologous pairs of chromosomes (bivalents) arranged as a double row along the metaphase plate (equator of spindle). The arrangement of the paired chromosomes with respect to the poles of the spindle apparatus is random along the metaphase plate. (This is a source of genetic variation through random assortment, as the paternal and maternal chromosomes in a homologous pair are similar but not identical. The number of possible arrangements is 2^n, where n is the number of chromosomes in a haploid set. Human beings have 23 different chromosomes, so the number of possible combinations is 2^{23}, which is over 8 million.

Anaphase I

The homologous chromosomes in each bivalent are separated and move to the opposite poles of the cell but chromatids do not separate.

Telophase I

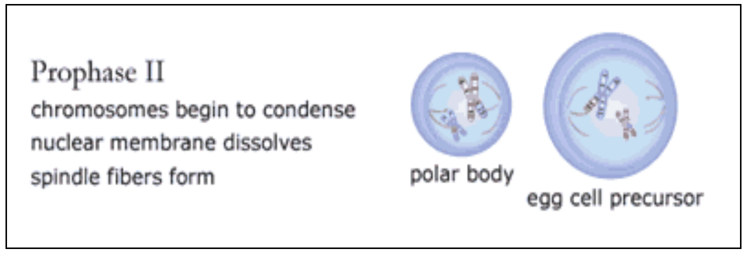
The chromosomes reach the poles, become diffuse and the nuclear membrane reforms. Spindle fibres disappear, chromosomes elongate and become visible again. The cell membrane invaginates (constricts).

In case of plant cells, cell wall develops into the middle and the cell develops into two.

Cytokinesis; The final cellular division to form two new cells, followed by Meiosis II. Meiosis I is a reduction division: the original diploid cell had two copies of each chromosome; the newly formed haploid cells have one copy of each chromosome.

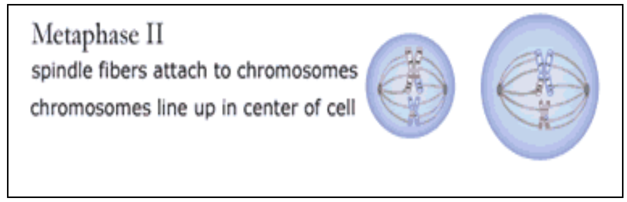
Meiosis II; this is similar to mitosis.

Prophase II is characterised by chromosomes showing the haploid number.



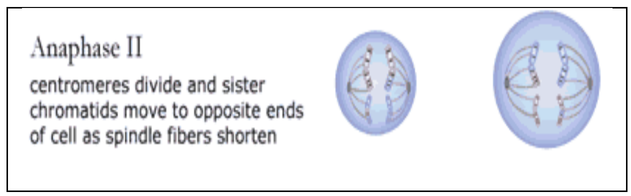
Metaphase II

Chromosome**s** arrange themselves at the equator spindle. Chromatids partly dissociate from each other instead of being closely held together.



Anaphase II

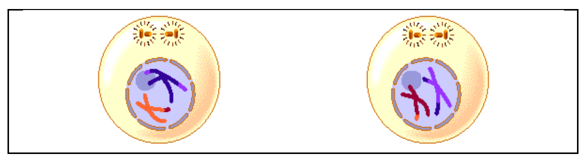
Chromosomes split and chromatids are pulled towards opposite poles by spindle fibres.



Telophase II

Chromatids arrive at the opposite poles, nuclear membrane and nucleolus reform.

The cell membrane constricts and four daughter cells are formed each with haploid number of chromosomes.



Importance of meiosis in sexually reproducing individuals

- Halving of chromosomes ensures that when the gametes with haploid number of chromosomes fuse to form a zygote, the normal diploid condition is restored.
- Meiosis leads to variation because;
- Chiasmata and crossing over can separate chromosomes thereby mixing genes creating new gene combinations causing genetic variation.
- When the haploid cells fuse at fertilisation, there is combination of parental genes.
- It forms basis of sexual reproduction by forming gametes.

Assignment

Compare and contrast mitosis and meiosis.

1.2. 0 GENETICS

1.2. 1 INTRODUCTION TO GENETICS

Genetics was derived from the Greek word "*gen*" meaning to become or to grow into something (William Bateson, 1906). The branch of biology that studies heredity and variation among living organisms.

It is concerned with the study of how resemblances and differences among living organisms are brought about.

Common terms related to genetics

Gene; this is a unit of inheritance that determines the characteristics of an organism e.g. colour and height.

Allele; this is one of the alternative forms of the same genes responsible for determining contrasting traits/ characteristics.

It is one alternative form of a given gene pair e.g. tall and dwarf for height of a pea plant. More than two alleles can exist for any specific gene but only one of them will be found in any individual.

Allelic pair; it is a combination of two alleles.

Gene locus; this is a position occupied by a gene on a chromosome.

Chromosomes; these are minutes thread-like structures in the cell nucleus that carry genes.

Homozygous condition; this is a diploid condition in which the alleles on a given locus are identical.

An individual which possesses two identical alleles of a given gene is said to be **homozygous/ homozygote**. For example; DD is homozygous dominant and dd is homozygous recessive.

Pure lines; these are homozygous for the gene of interest. Pure line is a population that breeds true for a [particular trait.

Heterozygous condition; it is a diploid condition in which alleles at a given locus are not identical i.e. dominant and recessive alleles occurring together.

An individual that possesses two different alleles at allelic pair is said to be **heterozygote/ heterozygous**. For example Dd is heterozygote.

Haploid and diploid; these are terms referring to the number of chromosomes in a cell.

Ploidy is a term referring to the number of sets of chromosomes.

Diploid cells have two (di) sets of chromosomes. Humans except for gamete cells, most animals and many plants are diploid. Diploid is abbreviated as 2n.

Haploid organisms/cells have only one set of chromosomes. Haploid is abbreviated as n.

Organisms with more than two sets of chromosomes are termed as polyploid.

Organisms that carry the same genes are termed as homologous chromosomes. The alleles on the homozygous chromosomes may differ as in the case of heterozygotes. Organisms normally receive one set of homologous chromosomes from each parent.

Genotype; this is the genetic constitution of an organism with respect to the alleles under consideration.

Phenotype; this refers to the external characteristics of an individual resulting from the interaction of genes it contains.

It is the physical appearance of a particular trait of an organism.
Dominant allele; this is an allele that influences the appearance of phenotype of an organism even in the presence of an alternative allele.
Recessive allele; this is an allele that influences the appearance of phenotype only in the presence of an identical allele.
Sometimes, a trait will have a dominant gene that masks a recessive gene. For example, assume a dominant gene (G) represents a green colour in pea plants, and a recessive gene (g) represents yellow colour. Pea plants with genes GG will be green in colour. Plants with genes gg will be yellow and Gg is green due to the dominant gene G
The GG and gg are known as genotypes, they represent the specific gene for that trait. The colours yellow and green are known as phenotypes, they represent physical appearance of respective genotypes. When mating two parents whose genotypes are known, offspring phenotypes, genotypes and ratios can easily be determined. These are two methods for determination of phenotypic and genotypic ratios i.e. punnet square and fork-line.

PUNNET SQUARE

When using the punnet square, each possible gene combination for a male gamete is located in columns and the possible female gamtes are located in rows.

female gametes ♀	Male gametes (♂)	
	G	G
G	G g	G g
	G g	G g

If G denotes green seeds and g denotes yellow seeds, all offsprings (G g) are green seeds

Symbolic representation of the cross between tall and short pea plants

Parental generation	DD		dd
Parental gametes	D		d
F_1 genotype		Dd	

The following punnet square shows the F_2 generation created by selfing (crossing) the F_1 plants.

		D	d
Union of gametes	D	DD (tall)	Dd (tall)
Random union of gametes	d	Dd (tall	dd (short)

Assuming; D represents allele for tall and d represents allele for short

Then, the genotypic and phenotypic ratios of the generation are expressed as follows;

F_2 genotypic ratio	1DD: 2Dd: 1dd /(3D_: 1dd)

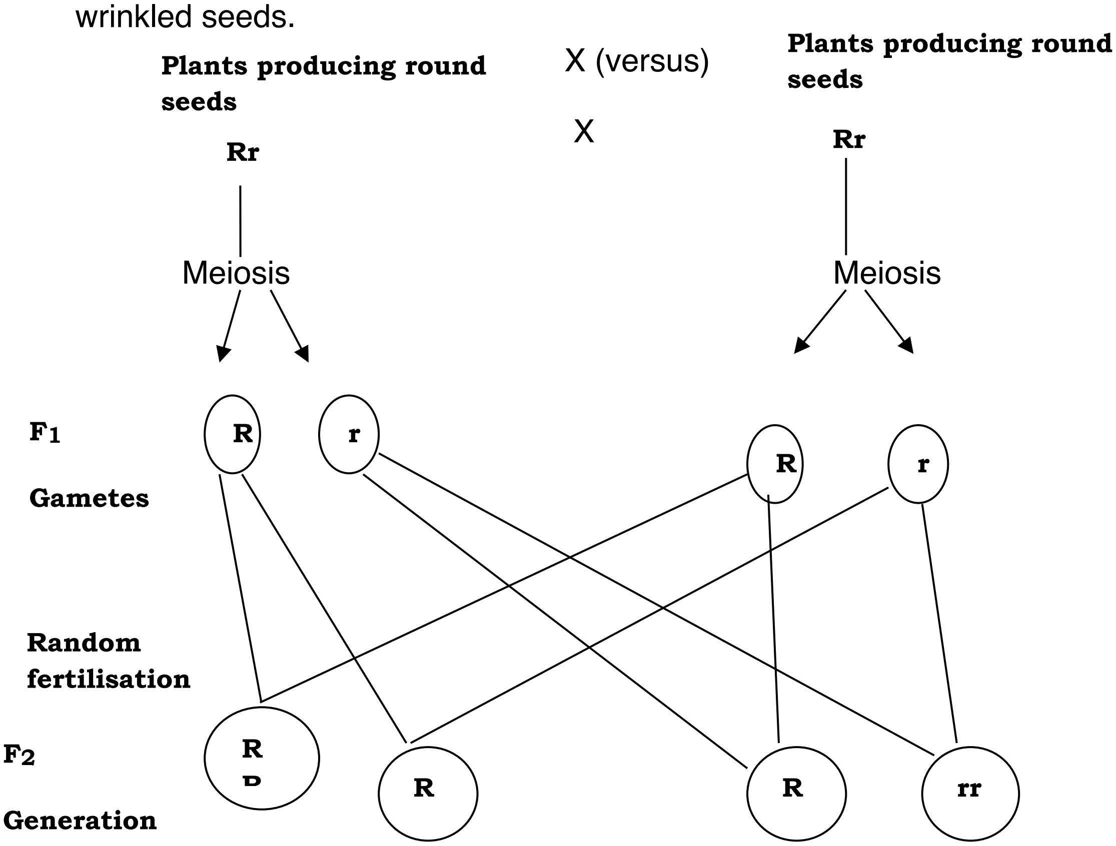
F_2 phenotype	3 tall: 1 short

FORK-LINE METHOD

Fork-line method can be used by sketching/ estimating the occurrence of each gene or set of genes/allele to be found in the gametes and then multiply/cross them together.

For example; state the phenotypic ration of filial one (F_1) generation intercross for hetereozygous peaplants use Rr to show heterozygous dominant.

Let R denote allele for plant producing round seeds and r denote allele for plant producing wrinkled seeds.



Genotypic ratio 1RR: 2Rr: 1rr

Phenotypic ratio 3 plants producing round seeds: 1 plant producing wrinkled seeds.

Filial one (F_1) generation refers to the offsprings of the organisms after their genes have interacted.

Exercise

Green seed coat colour is dominant and the yellow seed coat is seen only when the yellow pea plant is homozygous recessive. Using punnet square, determine the phenotypic and genotypic ratios of cross between green pea plant and homozygous yellow pea plant.

CHROMOSOMES

Each chromosome is seen to comprise a pair of chromatids joined at the centromere. Chromosomes appear in pairs, in man there are 22 pairs of autosomes (non sex chromosomes). In females, there other pair comprises x chromosomes while in males the other pair comprises X and Y chromosomes as sex chromosomes. The total number of chromosomes in man is 46 (23 pairs). Members of the some species have a diploid number of chromosomes in somatic cells.

For example;

Organism	Chromosomes number	Pair
Tomatoes	24	12
Man	46	23
Cotton	52	26
Cattle	60	30
Sorghum	20	10
Mosquitoes	6	3

In some organisms, different sexes have different numbers of chromosomes e.g. a male locust has 23 while the female has 24 in bees, the workers and queen have 32 while drones have 16 (haploid).

Cross over occurs in prophase I of meiosis and involves chiasmatas formation. During cross over, alleles of parental linkage groups separate and new association of alleles are found in gamete cells, a process known as gene recombination. Offsprings formed from these gametes showing new combinations are called recombinants.

Cross over is the major source of observable genetic variation within a given population.

1. 2. 2 MONOHYBRID INHERITANCE

Monohybrid inheritance refers to inheritance of a single character/trait from one individual parent.

Monohybrid cross over to a cross between parents that differ by a single allelic pair. For example, **AA X aa.**

Monohybrid is the offspring is the offspring of two parents that are homozygous for alternate alleles of a gene.

Mendel's experiment

Mendel was an Australian monk and teacher. He was one of the first scientists to work with genes and heredity. As a farther of genetics (1822- 1884), Mendel set foundation for many advance in biotechnology through the study of peas. He based himself on characteristics that are not linked and hence could be separated by meiosis.

One of His experiments on peas was as follows;

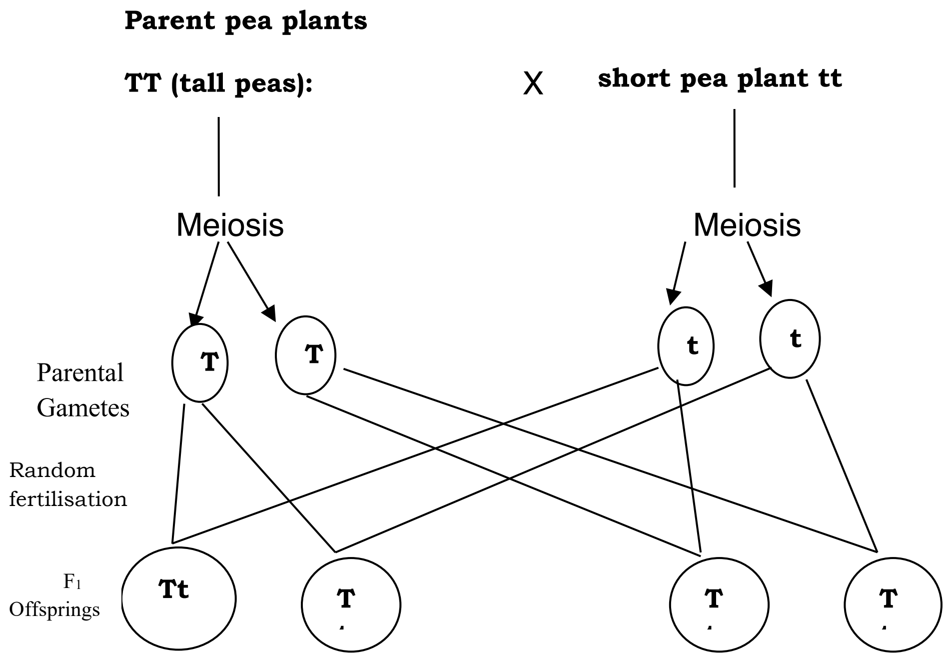
Parent pea plants: **Tall pea plant X short pea plant**

The resulting seeds were collected, counted and planted again. These tall pea plants were fertilised amongst themselves (selfed), allowed to grow. Seeds obtained were carefully collected, counted and planted again. The resulting plants of these seeds were in proportions of 3tall: 1 short (F_2 offspring).

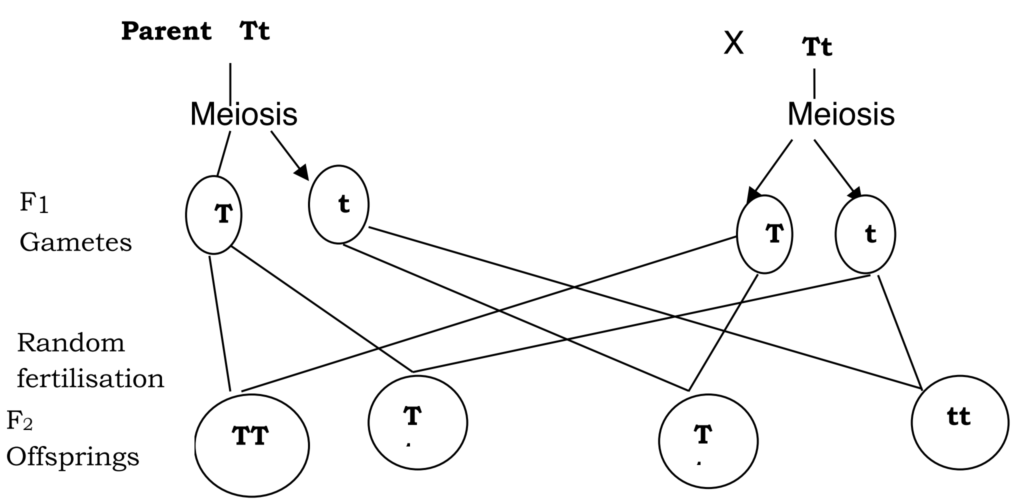
From this experiment, we notice the following;

There are no medium plants in either F_1 or F_2. This means that the genes for tallness or shortness are separate and don't mix. They can be transmitted from one generation, can be separated in one generation and be brought together in another generation.
There were no short plants in F_1 yet they appeared in F_2. Therefore, tall plants of F_1 must be having genes for shortness in hidden form.
It is probable/likely that the presence of one gene may stop the other from showing its effects i.e. the gene for tallness is dominant over that for shortness.

Let TT represent homozygous dominant alleles
tt represent homozygous recessive genes for shortness



On selfing F_1 Offsprings;



Genotypic ratio 1TT: 2Tt: 1tt
Phenotypic ratio 3 tall: 1 short pea plar

The above cross is called monohybrid cross.

Results of Mendel's experiment on peas to confirm the ratio 3:1.

Two characters investigated	Number in F_2	Ratio
Smooth seeds x wrinkled seeds	5474 + 1850	2.96:1
Yellow seed coat X Green seed coat	6022 +2001	3.01:1
Grey seed coat X White seed coat	705 + 224	3.15:1
Tall X short	787 + 277	2.84:1
Inflated pods X constricted pods	882 + 299	2.95:1
Green pods X Yellow pods	428 + 152	2.82:1
Axial flowers X Terminal flowers	782 + 274	2.85:1

Mendel's first law (law of segregation)

It states that the characteristics of an organism are determined by internal factors which occur in pairs and only one pair of such factors can be present in a single gamete.

This law was illustrated by mendel's experiments but mendel even knew meiosis which explains the law.

Back cross

This is the cross of an F_1 hybrid to homozygous parent for pea plant height, the cross would be Dd X DD or Dd X dd, most often though a back cross is a cross to fully recessive parent.

Parental cross	DD X dd
	↓
F_1 genotype	Dd

If G denotes green seeds and g denotes yellow seeds, all offsprings (G g) are green seeds

Instead of selfing F_1 offspring, mendel crossed F_1 offspring to a pure line homozygous dwarf plant to confirm the first law of segregation.

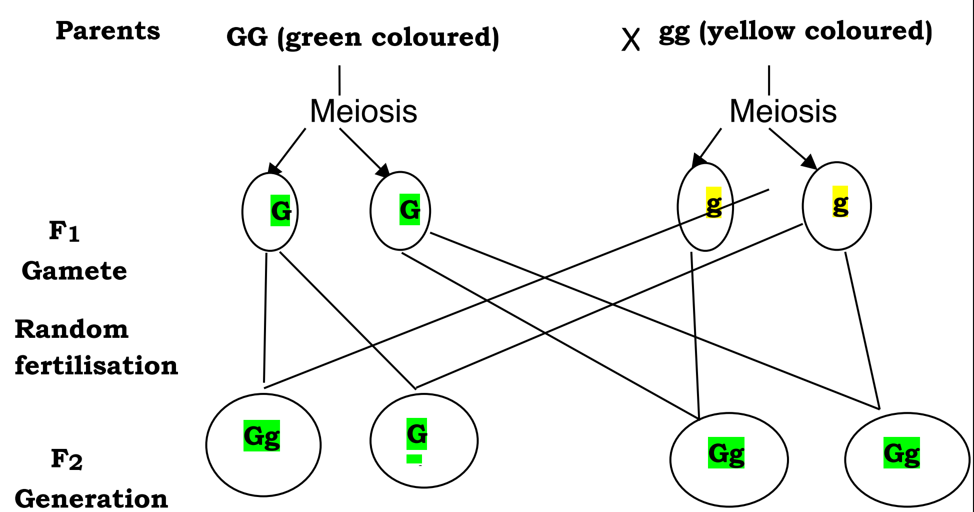
Back cross DD X dd

		Male gametes
female gametes		d
	D	Dd
	d	dd

Back cross one (BC_1) phenotypes 1Tall: 1dwarf
BC_1 genotype 1DD: 1dd

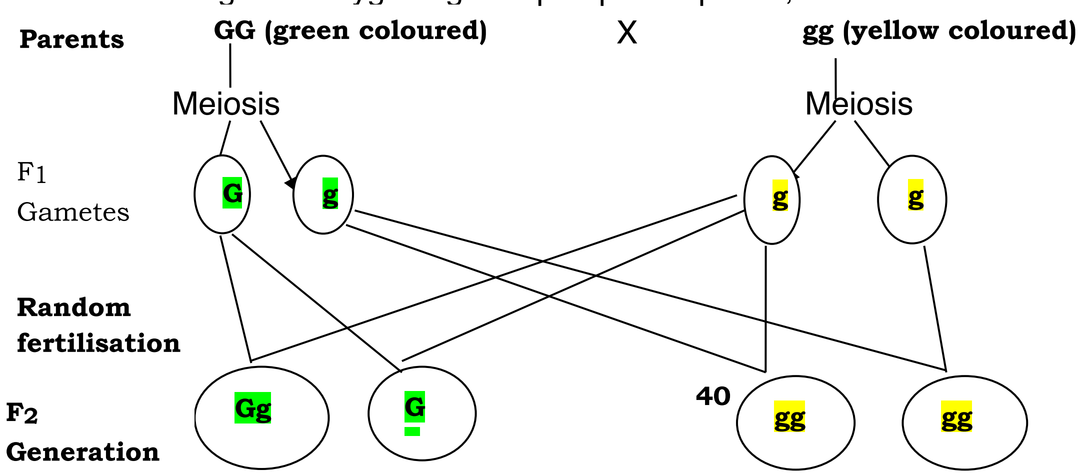
Testcross
Test cross is the cross of any individual to a homozygous recessive parent. It is used to determine if the individual is homozygous dominant or heterozygous.
It is a cross between an organism whose genotype for a certain trait is unknown and an organism that is homozygous recessive for that trait, so the unknown genotype can be determined from that of the offspring within one breeding generation. For example;
Pea plant with pods given is dominant to that with yellow pods. The genotype of green coloured type may be homozygous (GG) or heterozygous (Gg).

In order to determine which is the correct genotype, the plant is test crossed with a double recessive (gg) yellow colour pea plant. If the cross offspring are all green, the unknown genotype is homozygous dominant. A ratio of 1green: 1yellow indicates that the unknown genotype is heterozygous.
Considering homozygous green pod parent plants;



Phenotypic ratio all green coloured pod plant

Considering heterozygous green pod parent plants;



Phenotypic ratio

2 green coloured pod plants: 2 yellow coloured pod plants i.e. 1 green: 1yellow

Exercise 2

a) What are recombinants?

b) In maize, the genes for yellow midrib (y) and long internodes (n) are recessive to green (Y) and short internodes(N) and are on the same chromosome. A yellow maize with long internode (yynn) was crossed with maize heterozygous for yellow midrib and long internode (YyNn). The offsprings were;

Number of offspring	Genotype
256	YyNn
272	yynn
38	Yynn
34	yyNn

Calculate recombination frequency?

1.2.1 DIHYBRID INHERITANCE

DIHYBRID INHERITANCE (MENDEL'S LAW OF INDEPENDENT ASSORTMENT)

Dihybrid inheritance refers to the inheritance of two characteristics simultaneously. This is based on mendel's second law of inheritance (law of independent assortment).

This law states that; each pair of contrasted characters may be combined with either of another pair. This law can also be written (basing on present knowledge of genetics) as;

Each number of an allelic pair may combine randomly with either member of another pair.

Dihybrid cross; this is a cross between two parents that differ by two pairs of alleles for example, AABB X aabb.

Dihybrid is an individual heterozygous for two pairs of alleles (AaBb).

In one of his experiments, Mendel crossed a pure breeding pea plant having round ad yellow seeds with pea plant having wrinkled and green seeds.

Let **R** represent allele for round seed
r represent allele for wrinkled seed
G represent allele for yellow seed
g represent allele for green seed

Parents
Phenotype round yellow seed X Wrinkled green seed
Genotype RRGG gg

Meiosis Meiosis

Parental Gametes RG r

Fertilisation
fusion

F1 generation
Genotype RrGg
Phenotype round yellow seed

Meiosis

F$_1$ Gametes RG Rg rG rg

OR

Parental genotype	R RGG	X	r rgg
Parental gametes	RG		rg
F$_1$ Genotypes		RrGg	
F$_1$ Gametes		RGRgrGrg	

As the pea plants are self pollinated, the male and female gametes are the same types. The offsprings of F$_1$cross are represented in a punnet square below.

	Male			
Female	RG	Rg	rG	rg
RG	RRG G	RRGg	RrGG	RrGG
Rg	RRGg	RRgg	RrGg	Rrgg
rG	RrGG	RrGg	rrGG	rrGg
rg	RrGg	Rrgg	rrGg	rrgg

In the list below "_____" represents either dominant or recessive allele

Genotype	Phenotype	Total offspring
R_G _	Round yellow	9
R_g_	Round green	3
rrG_	Wrinkled yellow	3
rrgg	Wrinkled green	1

Phenotypic ratio; 9 Round yellow: 3Round green: 3Wrinkled yellow: 1 Wrinkled green.

Back cross confirmation of Mendel's second law.

Let us use the example of yellow round seeded F_1

Parental genotype	RrGg X r rgg
	↓
Parental gametes	RGRgrGrg

The unknown genotype should be homozygous double recessive.
Using punnet square for the back cross

Female gamtes					
Male gametes		RG	Rg	rG	rg
	rg	RrGg	Rrgg	Gg rr	rrgg

In the above illustration, the results show that the unknown was heterozygous since the phenotypic ratio is 1:1:1:1 i.e.

1Round yellow: 1Round green: 1Wrinkled yellow: 1 Wrinkled green

Exercise 3

In tomatoes, the allele for red fruit R is dominant to that for yellow fruit r. the allele for tall plant T is dominant to that for short plant t. The two genes concerned are on different chromosomes.

Use suitable genetic diagram to show the proportion of F_2 generation after selfing F_1 generation.

If the possible genotypes of the gametes of the plant chosen as male parent were RT, Rt, rT and rt. What was the genotype of the unknown plant?

Hybrid

A hybrid, also known as cross breed, is the result of mixing genes, through sexual reproduction, in production of two animals or plants of different breeds, varieties, species or genera.

Hybrid generally refers to any offspring resulting from the breeding/mating of two genetically distinct individuals, which usually will result into a high degree of heterozygosity, though hybrid and heterozygous are not strictly synonymous.

Genetic hybrid carries two different alleles of the same gene;

Structural hybrid results from the fusion of gametes that have differing structure in at least one chromosome, as a result of structural abnormalities;

Hybrids are often sterile because the set of chromosomes from one species cannot pair during meiosis with the set of chromosomes from the other species. Hybrid varieties are those which are developed through crossing two plants of the same species.

It is distinguishable from genetic modification because it is accomplished without manipulating the DNA through physically cutting a gene from one plant and then inserting it into another. It is also different from genetic engineering in that hybridization crosses plants of the same or similar species and genetic engineering removes a gene or genes from one species, such as a bacteria or virus, and inserts it into a totally different species, such as corn or soy.

Inbreeding depression is the reduced biological fitness in a given population as a result of inbreeding, or breeding of related individuals. Population biological fitness refers to an organism's ability to survive and perpetuate its genetic material.

Genetic drift (also known as allelic drift or the Sewall Wright effect[after biologist Sewall Wright) *is the change in the frequency of a gene variant* (allele) *in a population due to random sampling of organisms*.

Genetic drift refers to a drop or rise in gene frequency in a population.
The alleles in the offspring are a sample of those in the parents, and chance has a role in determining whether a given individual survives and reproduces.
A population's allele frequency is *the fraction of the copies of one gene that share a particular form.*
Genetic drift may cause gene variants to disappear completely and thereby reduce genetic variation.

When there are few copies of an allele, the effect of genetic drift is larger, and when there are many copies the effect is smaller.
Question; Discuss causes of genetic drift
Causes of a fall in gene frequency

- Mutation
- Infertility in a population
- Natural selection
- Isolation of some members
- Death of members of reproducing age
- Presence of lethal genes.

Causes of rise in gene frequency

- Inbreeding
- Mutation through gene duplication
- Immigration
- Fertility of the population

INHERITANCE RELATED TO SEX
Sex linkage
Sex linkage refers to the carrying of genes on the sex chromosomes. The X chromosome carries many of such genes that determine body characteristics. The Y chromosome has very few features linked to it. The Y chromosome will only arise in the heterogametic (XY) sex, i.e. males in mammals and females in birds. Features linked to X chromosomes may arise in either sex.

To represent sex linked crosses, the same principles which were laid I genetic crosses in monohybrid and dihybrid inheritance should be followed. However, the letter representing each allele should be attached to sex chromosome it is linked to.

Sex linked traits

These are traits that are carried on the sex chromosomes. Many diseases tend to be sex linked traits and many of such traits are recessive. For example, sickle cell in human beings is more visible in males (XY) than in females (XX).

Two well known sex linked genes in humans are those causing haemophilia and red-green colour blindness. For this condition to happen in females requires a double recessive state. When the recessive allele occurs in males, it expresses itself because the Y chromosomes cannot carry corresponding dominant alleles.

Inheritance of red green colour-blindness;

Let B represent the allele for normal clour and b represent the allele for colour blindness.

As this gene is carried on X chromosome, in Humamns the male is heterogametic sex (XY) and female is homogametic sex (XX).

Parents; **Phenotype normal sighted** ♀ X **Colour blind** ♂

Genotype X^BX^B X^bY

Meiosis Meiosis

Parental Gametes X^B X^b Y

	♂	
♀	X	Y
X	$X^B X^b$	X^B Y

50% normal sighted carrier ♀ ($X^B X^b$)

50% normal sighted carrier ♂ (X^B Y)

Example 2

If a white female hen (XY) is crossed with a homozygous barred rooster (XX), what is the phenotype of each genotype assuming allele for barred rooster B is dominant?

Solution;

The gene for barred rooster is carried on X chromosome, in birds, male is homogametic (XX) and female is heterogametic (XY).

Let B be barred rooster

Let b be white

Using punnet square

	♂	
♀ X	X	X
	X^B Y X^b	X^B X^b
Y	X^B Y	X^B Y
	Male	Female
Genotype	X^B X^b	X^B Y
Phenotype	Barred	barred

If the male heterozygous and the female is barred, what would their offsprings look like?

	♂	
♀ X	X	X
	X^B X^B	X^B X^b
Y	X^B Y	X^b Y

	Male	Female
Genotype	X^B X^B , X^B X^b	X^B Y, X^b Y
Phenotype	2Barred	1barred, 1white

Sex limited traits

These are traits that are expressed in only one sex. Such traits may be controlled by sex linked or autosomal loci and usually controlled by sex hormones e.g. breast/udder development in females. These traits are present in both sexes of sexually reproducing species but expressed in only one sex. For example, sex limited traits for fighting in male and female elephants. The sex limited genes instruct a male elephant to grow big and fight, at the same time instructs female elephant to grow small and avoid fight.

Sex influenced

These are traits which are different for each gender, they are not directly controlled by sex hormones. For example balding is different among men and women. A woman to be bald needs to be having two balding genes(homozygous recessive, one gene inherited from each parent) while if a male has one recessive allele, he will show that trait.

ALLELIC INTERACTION

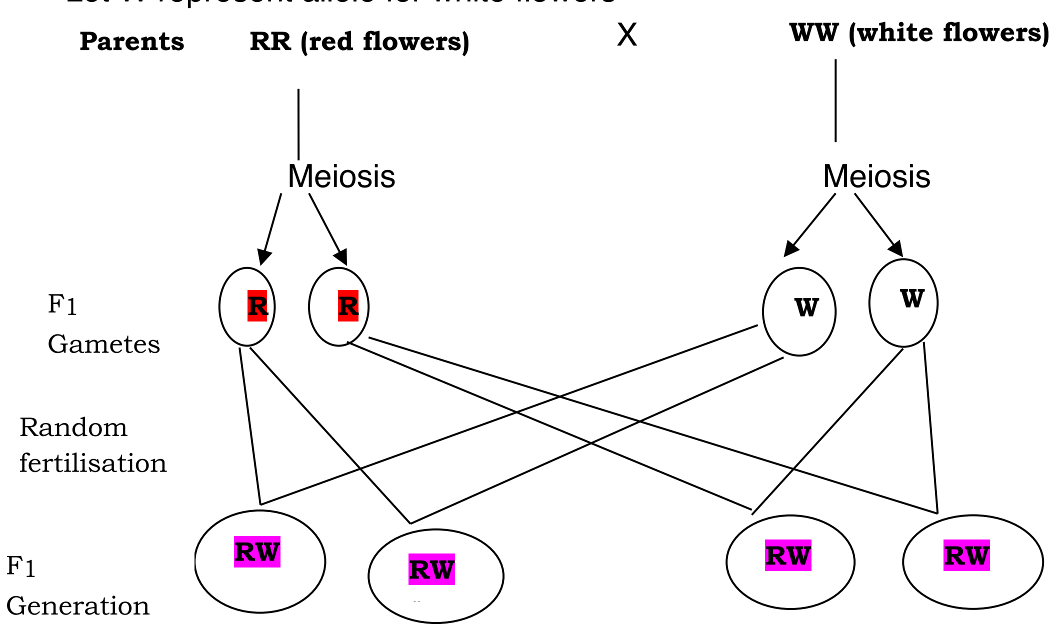
This involves interaction between alleles of a single gene. It may result into incomplete dominance/ over dominance. The term dominance is used to explain expression of a phenotypic trait in presence of an alternative allele.

Codominance is a situation where two homozygous alleles show incomplete dominance. i.e. they do not show complete dominance or recessiveness due to failure of any one allele to be dominant in heterozygous condition. The offsprings are therefore a blend between two parental characteristics.

For example when two plants with red and white flowers were crossed, the offsprings were having pink flowers.

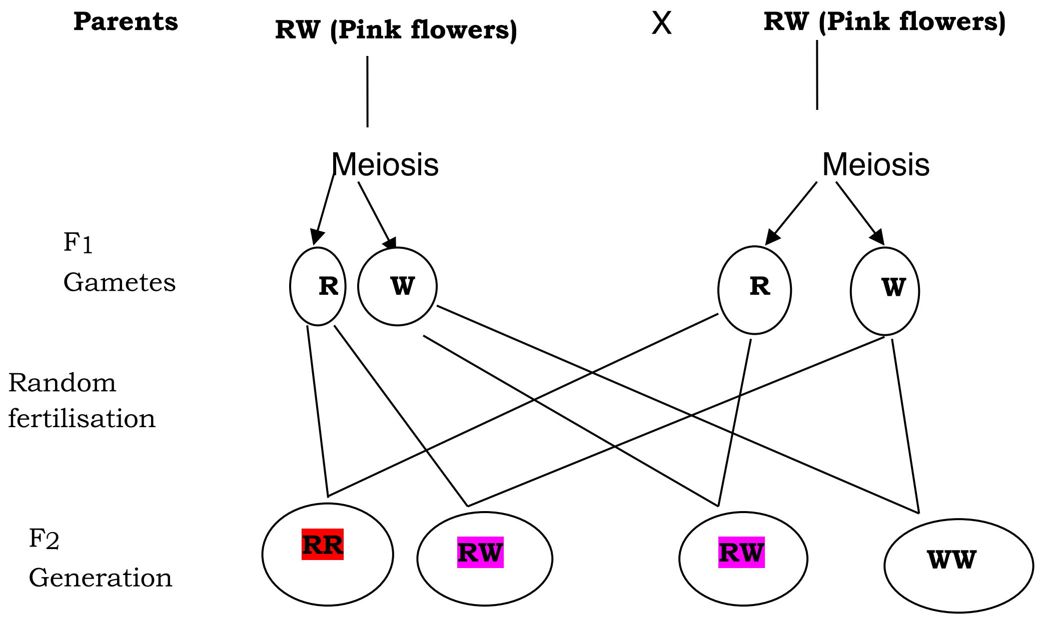
Let R represent allele for red flowers

Let W represent allele for white flowers



Phenotypic ratio all pink flower plants

When F1 offsprings were interbred/ selfed;

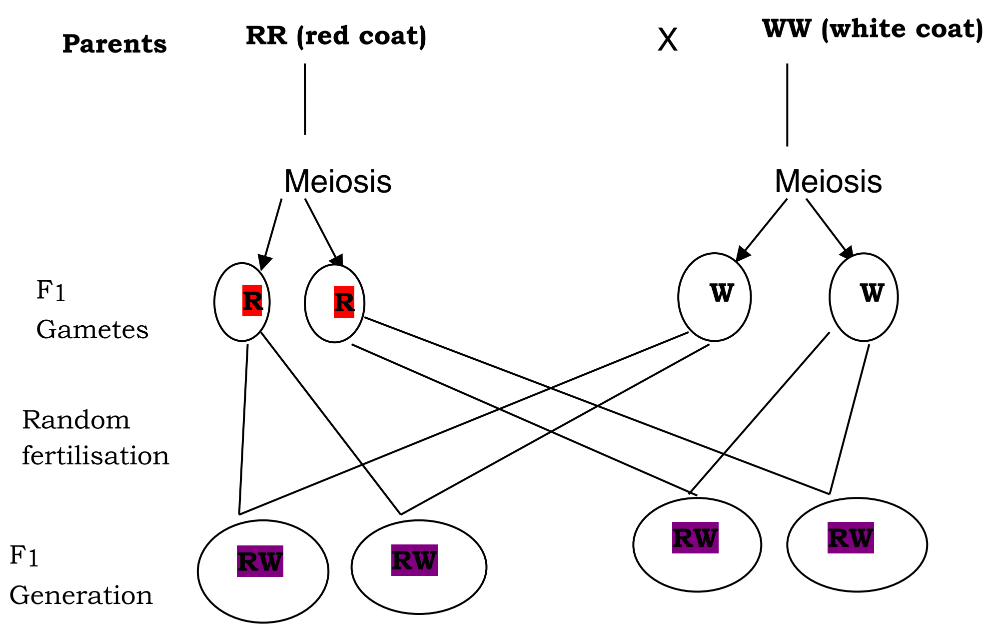


F2 Phenotypic ratio 1Red flower: 2pink flower : 1white flower plants

Example 2; a cross between red coat cattle with white coat cattle to produce a roan.

Let R represent allele for red coat

Let W represent allele for white coat



Phenotypic ratio all have roan coat.

Partial dominance

This is a form allelic interaction where both alleles express themselves in a phenotype but one more so than the other.

It is an intermediate between complete dominance and incomplete dominance. For example alleles that show normal heamoglobin and abnormal haemoglobin have forms 68-70% for normal Hb and 30- 40% for abnormal Hb.

1.2.3 GENE INTERACTION

Gene interaction

This occurs when a group of genes from different loci act together

It refers to interaction between alleles of more than one gene.

Forms of gene interactions include; simple interation, epistasis and polygenes.

Simple interaction

This occurs when two or more genes act together to determine a particular trait. For example interaction between genes that determine comb shape in poultry.

Epistasis; this refers to interaction between alleles of a single gene controlling a certain phenotype.

It is a form of interaction where alleles of one gene can suppress the action of the other.

It's a combination of genes that are both recessive

Poly genes

This is a form of interaction where a group of genes control expression of a single trait. For example genes controlling comb shape in chicken.

Lethal genes, these are genes that lead to the death of the bearer.

Application of genetics

1. It has been applied in crop improvement, to improve growth rate, disease resistance, taste, and fibre length in fibre crops.
2. It has been applied in animal improvement to improve on traits such as animal growth rate, animal yield, and quality such as butter- fat content in milk.
3. It has been applied in bio-technology in production of genetically modified organisms through genetic engineering.
4. It has been applied in genetic counseling to determine true parents of offsprings

1.3.0 VARIATION

Variation refers to differences between individuals of the same species.

Types of variation

Variation is divided into two types namely; continous and discontinuoius variation.

Continuous variation

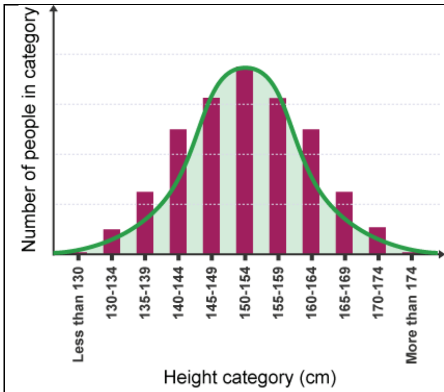
This where characteristics of individuals show gradation from one extreme to another.

For example

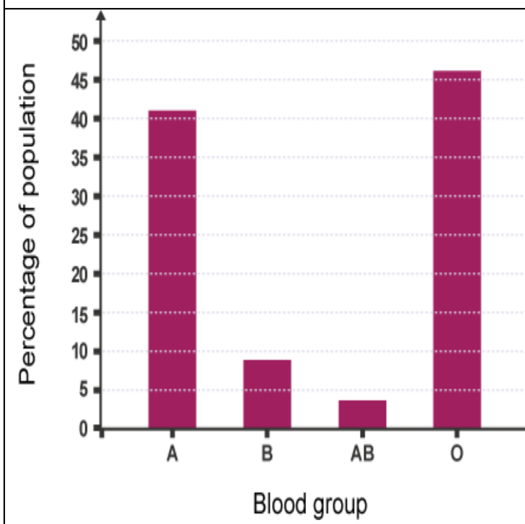
i) Weight
ii) Height
iii) Skin colour
iv) Fertility and hair length.

There is no clear cut between the characteristics of individual organisms.

This type of curved graph is the result of a variable being normally distributed. It is called 'bell shaped' and shows normal distribution.



The graph below showsindividuals in population with different blood groups (A, B, AB or O). There are no values in between (intermediate values), so this shows discontinuous



Discontinuous variation

In this type of variation, characteristics of individual organisms within a given population have limited number of forms and do not show gradation.

These forms are distinct and there is a clear difference between characteristics of individuals.

- Such characteristics are qualitative in nature. For example; sex(male or female), blood group, albinism and eye colour.

Causes of variation

Variation is caused by either changes in an environment of an organism or genetic factors.

Environmental causes

1. Habitat; for example plants growing in soils with different nitrogen concentrations attain different height.
2. Light intensity; it influences skin/ coat colour
3. Nutrition level; it influencse diferemnces in weight of organisms.
4. Trauma; it causes differences in the phenotypes of different organisms.

Genetic causes of variation

These may arise from sexual reproduction or mutation.

a) Variation due to sexual reproduction

1. Mixing of two parental genotypes when fertilization takes place
2. Random distribution of chromosomes during metaphase I of meiosis

3. The crossing over of homologous chromosomes during prophase I of meiosis.

b) Variation due to mutation

This results from change in amount or structure of DNA or chromosomes of an organism. It causes a change in genotype which can be inherited from one generation to another. Only mutations which occur in formation of genes can be inherited.

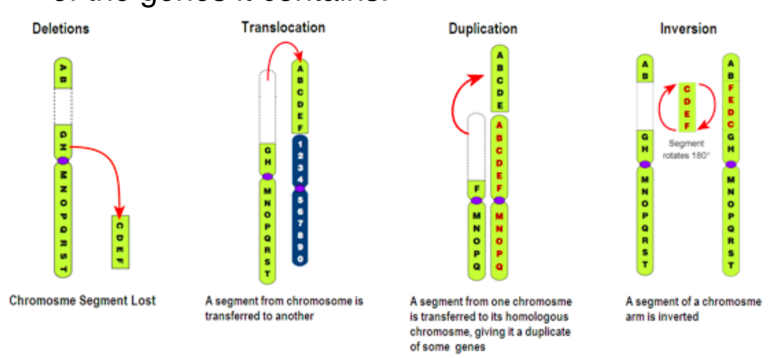
Examples of inheritable mutations/ genetic mutations

Gene mutation; this occurs due to change in DNA at a single locus on a chromosome.

Chromosomal mutation; this occurs due to change in chromosomes which usually occurs during meiosis, for example polyploidy (a condition where an organism acquires one or more complete set of chromosomes. This can tresult into triploidy, tetraploidy and hexaploidy.

Forms of chromosomal mutation

1. Deletion; this is where a portion of chromosomes is lost together with the genes it contains.
2. Inversion; this is where a portion of chromosome is deleted and then attached to the chromosome in an inverted way.
3. Translocation; this is where a portion of chromosome is deleted and rejoins at a different point of the same chromosome.
4. Duplication; this occurs when a part of chromosome is doubled resulting into repetition of the genes it contains.



1.4.0 SELECTION

SELECTION

This is the process by which organisms which appear physioilogically, and behaviourally better adapted to the envitromnmetont survive and reproduce while those not so well adapted either fail to reproduce or die.

Types of selection

- Natural selection
- artificial selection

Natural selection

This refers to a process in nature in which organisms possessing certain traits that make them better adapted to an environment tend to survive , increase in numbers or frequency and therefore able to transmit and carry on their essential genotypic traits to the subsequent/ succeeding generation.

Artificial selection

Selective breeding (also called artificial selection) is the process by which humans use animal breeding and plant breeding to selectively develop particular phenotypic traits (characteristics) by choosing which typically animal or plant males and females will sexually reproduce and have offspring together.

Domesticated animals are known as breeds, normally bred by a professional breeder, while domesticated plants are known as varieties, cultigens, cultivars, or breeds.

Two purebred animals of different breeds produce a crossbreed, and crossbred plants are called hybrids.

Flowers, vegetables and fruit-trees may be bred by amateurs and commercial or non-commercial professionals:

Major crops are usually the proven products of the professionals.

In animal breeding, techniques such as inbreeding, linebreeding, and outcrossing are utilized. In plant breeding, similar methods are used.

Charles Darwin discussed how selective breeding had been successful in producing change over time in his 1859 book, *On the Origin of Species*.

Darwin used artificial selection as a springboard to introduce and support the theory of natural selection.

Selective breeding can be unintentional, e.g., resulting from the process of human cultivation; and it may also produce unintended desirable or undesirable results. For example, in some grains, an increase in seed size may have resulted from certain ploughing practices rather than from the intentional selection of larger seeds. Most likely, there has been interdependence between natural and artificial factors that have resulted in plant domestication.

Bakewell was also the first to breed cattle to be used primarily for beef. Previously, cattle were first and foremost kept for pulling ploughs as oxen but he crossed long-horned heifers and a Westmoreland bull to eventually create the Dishley Longhorn. As more and more farmers followed his lead, farm animals increased dramatically in size and quality. In 1700, the average weight of a bull sold for slaughter was 370 pounds (168 kg). By 1786, that weight had more than doubled to 840 pounds (381 kg). However, after his death, the Dishley Longhorn was replaced with short-horn versions.

Animals with homogeneous appearance, behavior, and other characteristics are known as particular breeds or pure breeds, and they are bred through culling animals with particular traits and selecting for further breeding those with other traits.

Purebred animals have a single, recognizable breed, and purebreds with recorded lineage are called pedigreed.

Crossbreeds are a mix of two purebreds, whereas mixed breeds are a mix of several breeds, often unknown.

Animal breeding begins with breeding stock, a group of animals used for the purpose of planned breeding.
When individuals are looking to breed animals, they look for certain valuable traits in purebred stock for a certain purpose, or may intend to use some type of crossbreeding to produce a new type of stock with different, and, it is presumed, superior abilities in a given area of endeavor. For example, to breed chickens, a breeder typically intends to receive eggs, meat, and new, young birds for further reproduction. Thus, the breeder has to study different breeds and types of chickens and analyze what can be expected from a certain set of characteristics before he or she starts breeding them. Therefore, when purchasing initial breeding stock, the breeder seeks a group of birds that will most closely fit the purpose intended.

Note; further reading, refer to crop improvement and animal selection

1.5.0 GENETIC ENGINEERING

Genetic engineering refers to the manipulation of genes composed of the DNA to create heritable changes in biological organisms and products that are beneficial to people, animals, soil living organisms or the environment.

- ✓ It's a technique of choosing desired genes from organisms and moving it between organisms in a fast, accurate and efficient manner.
- ✓ It's the selective and deliberate alteration of genes by man to get suitable products.

Genetic engineering gives rise to genetically modified organisms (GMOs)**;**

Common terms used in genetic engineering

1. **Embryo rescue**; the removal and culture of an immature embryo to produce a plant, often following a wide cross
2. **Cultivar**; a product of plant breeding that is released for access to producers
3. **Gene cloning**; isolating a gene and making many copies of it by inserting the DNA sequence into a vector, then into a cell and allowing the cell to reproduce and make many copies of the gene
4. **Vector;** an agent that is used to carry the gene of interest into another cell. They can be viruses, yeasts or plasmids
5. **Genetic erosion**; the loss of genetic diversity caused by either natural or manmade processes
6. **Gene marker**; a genetic factor that can be identified and thus acts to determine the presence of genes or traits linked with in but not easily identified
7. **Genetically modified organisms** (GMOs); organisms whose genetic makeup have been changed by any method including genetic engineering, cloning, mutagenesis etc. The organisms containing genes that have been artificially inserted into them other than acquisition through a natural process
8. **Cloning**; asexually producing multiple copies of genetically identical cells or organisms descended from a common ancestor
9. **Germ plasm**; the sum total of all hereditary material in a single (interbreeding) species

10. **Landrace**; a population of plants, typically genetically heterogeneous, commonly developed in traditional agriculture from many years of farmer directed selection and which is specifically adapted to local conditions

Reasons for genetic engineering in agriculture production

➢ In plants

1. To develop crops that are resistant to biodegradable weed killers (increase herbicide tolerance in some crops)
2. To create crops that are resistant to insect by inserting a gene in crops that destroys pests
3. To improve nutritional value of crop plants and ensure good health due to healthy eating
4. To develop crops with high commercial value such as sweetness, juiciness, colour, appearance, etc (improves quality of food)
5. To develop crops that are high yielding and improve profitability of farming
6. To develop crop that grow faster and reach maturity
7. To eliminate allergies in some crop products
8. To reduce the use of pesticides hence control of environmental pollution
9. To reduce the time taken in breeding process
10. To make plants more adaptable to different soil conditions
11. To increase the ability of some plants to remove toxins from soil
12. To reducethe post-harvest losses in crops

➢ In animals

1. To develop animal that are resistant to most disease and pests
2. To develop animals that are resistant to most extreme climatic conditions.
3. To develop animals that are better converters of feeds into usable products.
4. To eliminate genetic disorders amongst animals
5. To reproduce animals asexually through cloning

Problems associated with genetic engineering

1. It is costly to purchase equipment and reagents for use
2. Due to poor management ofGMO genes can find their way into the wild species of plants such as weeds resulting into genetic contamination making them difficult to control and may affect the environment
3. Sterility may be enhanced in many plants and animals due to massive gene manipulation
4. Pest resurgence with time, pests may become resistant to toxins in plants leading to pest resurgence.
5. The effects of changes in a single species may extend well beyond to the ecosystem resulting into damage and destruction
6. Impossibility of follow-up once GMOs have been introduced into the environment and some problem arise, it is impossible to eliminate them and may turn out to be dangerous
7. It may encourage farmers to overuse GMOs with time, making weeds resistant to the herbicides.
8. Genetically modified seeds are sterile and this increases the cost of buying seeds for planting
9. Genetic erosion may occur as indigenous genes are replaced by new genes

10. Introduction of genes by transformation disturbs the natural genetic balance or order
11. Genetically modified organisms (GMOs) may have negative effects on pollinators
12. The modified genes can turn invasive and aggressive to other indigenous species
13. Modification of genetic material may lead to extinction or loss of some species

Steps followed in genetic engineering

1 Isolation of the genes of interest
2 Insertion of the genes into a transfer vector
3 Transfer of the vector to the organism to be modified.
4 Transformation of the cells of the organisms
5 Separation of the genetically modified organisms from those that have not been successfully modified.

Reasons for low adoption of genetic engineering technology in Uganda (Challenges)

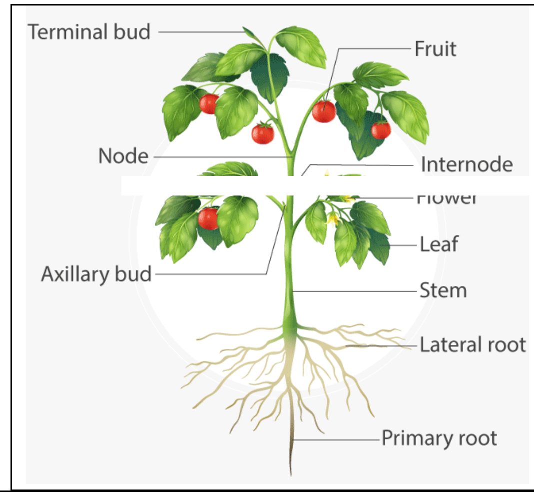
1. The equipment and reagents for use in genetic engineering like DNA markers are expensive to afford by most farmers
2. The population is generally ignorant (lack scientific knowledge and consensus) and not willing to adopt genetic engineering technology
3. Inadequate personnel and skills to develop and monitor the genetically engineered organisms.
4. Negative public perception of GMOs .the technology since it is considered strange and inappropriate.
5. Inadequate laws or legal framework to enable the technology be implemented
6. The technology is very sophisticated and expensive because it requires expensive inputs to be practiced

Application of biotechnology

1 Production of penicillin by bacteria
2 Use of fungus in wine production
3 Use of fungus in fermentation to produce alcohols
4 Use of microbes in decomposition to form manures
5 Use of rhizobia in nitrogen fixation
6 Use of bacteria in making yoghurt
7 Use of microbes in sewage degradation
8 Production of enzymes by some microbes
9 Production of hormones like insulin by some organisms
10 Modification of fruit ripening and tuber shelf life
11 Production of vaccines for livestock
12 Modification of plant nutrient content
13 Repair of tissues and organs in plants and animals

1.6.0 PLANT MORPHOLOGY AND PHYSIOLOGY
1.6.1 PLANT MORPHOLOGY

1.6.1.1 MORPHOLOGY OF FLOWERING PLANTS



Plant morphology refers to the study of the form and structure of plant especially the external structures.

A typical flowering plant consists of two main parts;

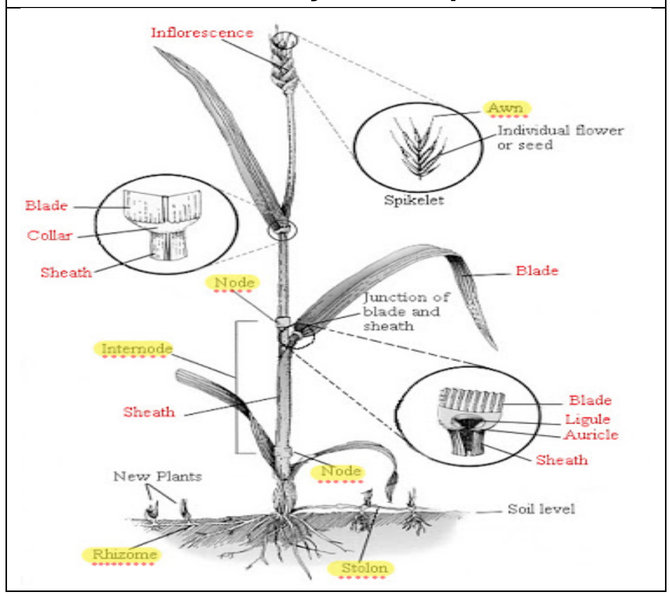
- Vegetative parts which include leaves, stems and roots.
- Reproductive parts which include flowers.

All these parts are organised into two systems i.e. the shoot system and root system.

The shoot system

A shoot is the aerial part of a vascular plant. It develops from plumule and consists of stem, leaves, buds, nodes and flowers.

Monocotolydenous plant



The stem

Stem is the part of the plant that usually grows vertically upwards and supports leaves, flowers, buds and reproductive structures. Stems of certain plant species are modified as bulbs, corms, rhizomes, tubers, runners and stolons.

Types of stems

- Aerial stems
- Underground stems.

a) **Aerial stems** are further categorized as erect stems and weak stems.

b) **Erect stems**; these are stems that can keep themselves in upright position. Erect stems are classified as woody stems and herbaceous stems.

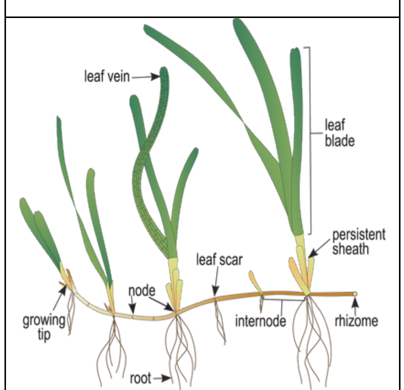
c) **Weak stems**; these are stems that cannot support themselves upright and therefore creep on the surface of ground or climb around the support.

Weak stems are divided into three types;

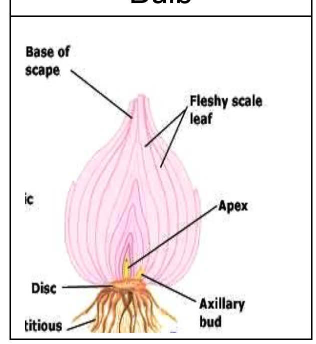
Twinning stems e.g. morning glory

- Creeping stems e.g. offsets and runners in desmodium species.
- Climbing stems e.g. passion fruit
- Stem tendrils.
- Stem tubers e.g. Irish potatoes

Rhizome



Bulb



- Bulbs e.g. onions

d) **Underground stems**; these are modified stems which remain permanently underground. They are often swollen and serve as storage organs. Examples include;

- Rhizomes e.g. couch grass

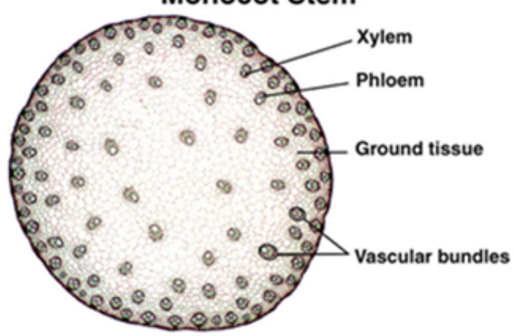
Functions of stems

1. Stems conduct water and mineral salts from roots to the leaves
2. They translocate manufactured food from leaves to different parts of the plant.
3. They bear leaves and keep them them in a postion suitable for receiving sunlight.
4. Some stems are involved in vegetative propagation e.g. sugar cane.
5. Some stems act as storage organs e.g. stem tubers and sugarcanes.

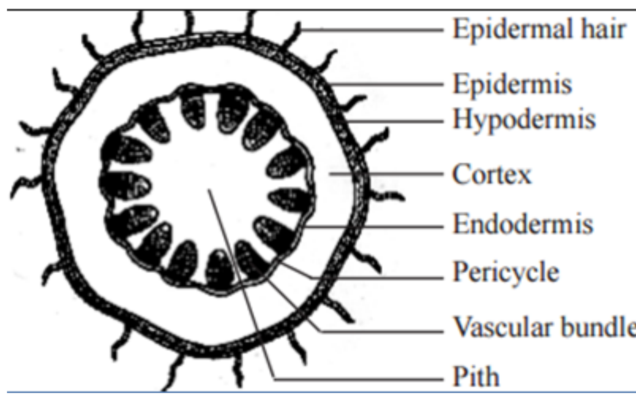
Stem tuber

Internal structure of a stem

Monocot Stem



Dicot stem

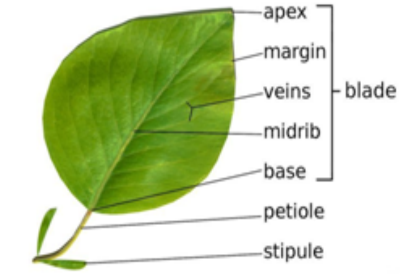


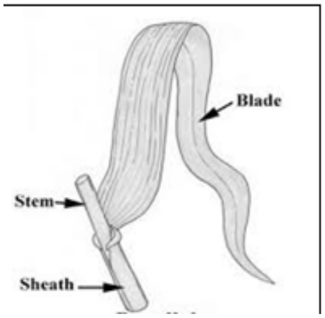
The leaf

A leaf is a flat lamina usually green and made of thin walls supported by veins.

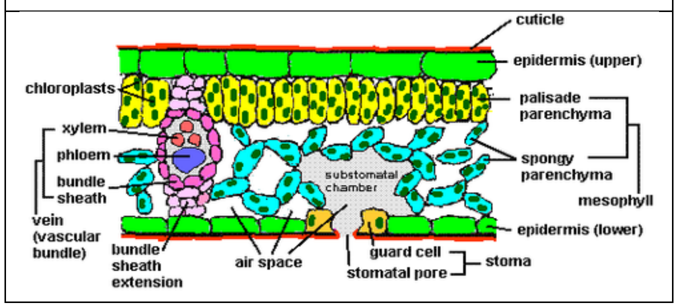
<u>Main parts of the leaf</u>

External features of the dicot leaf





Internal structure of a leaf



Functions of leaves

- **Manufacturing food,** leaf is called the kitchen of the plant. Leaves prepare food for the plant using carbon dioxide and water in presence of chlorophyll and sun light.
- **Gas exchange,** leaves facilitate gas exchange via stomata. During day they take in carbon dioxide and give out oxygen during photosynthesis. During night, they take in oxygen and give out carbon dioxide during respiration.
- **Transpiration,** the loss of water through stomata helps in cooling plants and absorption of water and minerals.

The root system

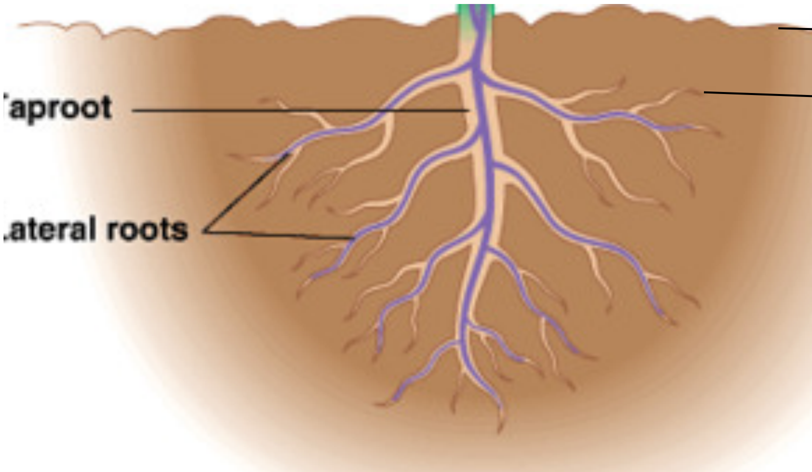
A root is the descending portion pf the axis of the plant. Roots are mainly of two types namely;

- Tap root
- Fibrous root

Tap root system

This is a characteristic of a dicotyledonous plants, tap root has the main root from which secondary roots branch sideways and small roots called tertiary roots that branch form secondary roots.

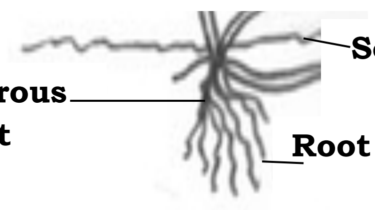
Figure showing the tap root system



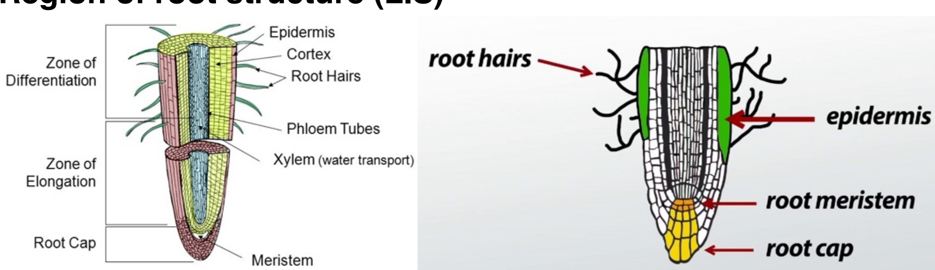
Fibrous root

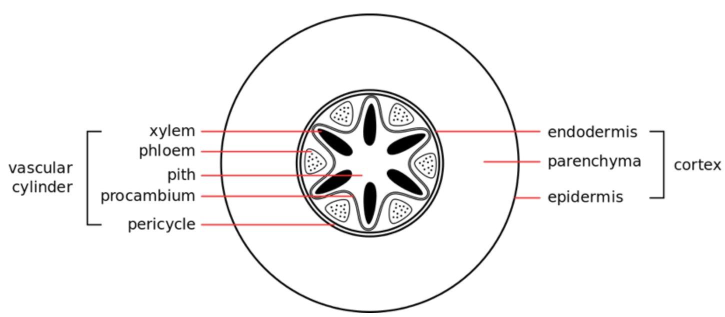
Fibrous root system is a characteristic of monocotyledonous plants e.g. maize and grass. The main root dies after germination and is replaced by many small roots of approximately equal length and thickness.

Figure showing the fibrous root system

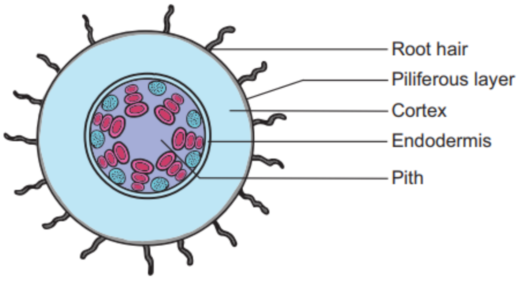


Region of root structure (L.S)

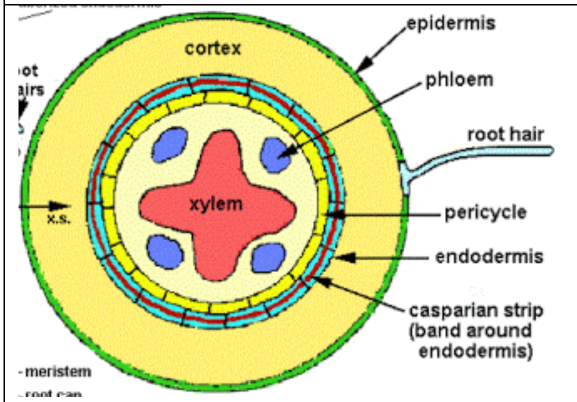




Cross section of a typical transverse section of a monocotyledonous root



Cross section of a typical transverse section of a dicotyledonous root



Functions of plant roots

- Plant root offers anchorage to the plant so as to keep it firm in the soil.
- Plant roots absorb water and mineral salts from the soil and conduct them to the stem and other parts of the plant.
- Some roots store water, starch and sugars for future use by the plant.
- Some plant roots have been modified for support, climbing, clasping and breathing.

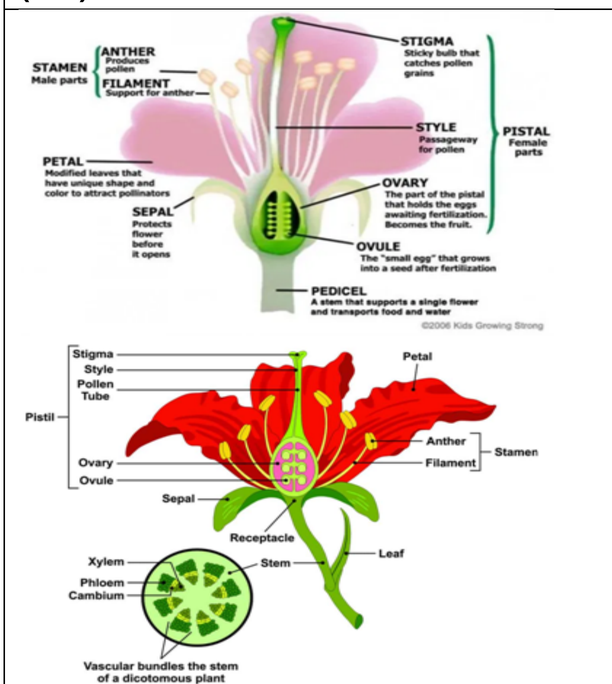
Flower

A flower is a reproductive structure of plant. Components of a flower include;

Functions of parts of a flower

- Pistil, it is the female reproductive part of the flower
- Stigma, it is a sticky pollen- receptive part of pistil.
- Style, it is the stalk of the pistil down which the pollen tube grows.
- Ovary, contains the ovules which later become fruits.
- Ovule, it develops into seeds when pollen grains fertilise the ovules.

Figure showing longitudinal section (L.S) of a flower



Functions of flowers

- Flowers are reproductive parts of the plants.
- They attract pollinators which leads to cross pollination hence increasing variation in crop plants.

Fruits

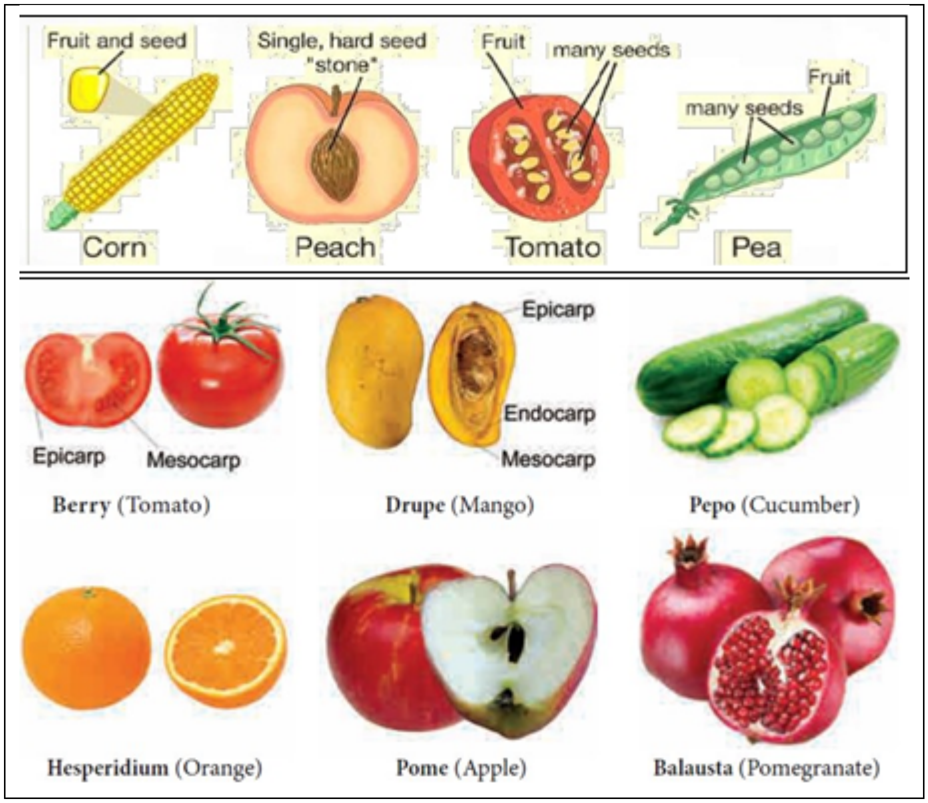
A fruit is defined as a ripened ovary that contains angiosperm seeds.

The function of a fruit

A fruit holds and protect the seeds.

A fruit stores the food reserves

- Each kernel of corn on a cob is an individual fruit.
- In peaches, the fruits are soft and fleshy and contain a single stony seed.
- Legumes like beans and peas produce a fruit called a pod that contains many seeds



1.6.2.0 PLANT PHYSIOLOGY

Plant physiology deals with the processes that occur during the growth and development of the plant. Plant physiology consists of;

- Chemical composition of the plant seed
- Physiology of plant growth and development
- Transpiration and regulation of water loss
- Water uptake by the plant
- Mineral requirements and uptake by plants
- Nitrogen metabolism
- Plant growth regulators
- Photosynthesis

1.6.2.1 PHYSIOLOGY OF PLANT GROWTH AND DEVELOPMENT

Physiology of plant growth and development

In flowering plants, plant growth begins with germination, seedling emergence and development.

Seed germination

Seed germination is the resumption of metabolic activities and growth of the seed tissues to form a new plant.

Germination refers to the emergence of normal seedlings from the seeds under ideal conditions of optimum temperature, moisture, oxygen, nutrients and sometimes light. The key indicator of seed germinations is the emergence of radical and plumule.

Chemical composition of the seed.

Important components of seeds include the water and stored food materials.

Dry seeds contain 85-90% food reserves which are needed for the development of the embryos.

Small seeds like lettuce and millet contain food reserves which can support embryo growth for several days. Bigger seeds like beans contain food reserves which can last for at least two weeks.

Food reserves are found in the cotyledon for dicots, in the endosperm for *gramineae* family (grass family) and in the perisperm for the *malvaceae* family e.g. cotton. Stored food reserves include; proteins, lipids, mineral salts, nucleic acids and carbohydrate derivatives. The quantity of these seed components vary from seed to seed.

Table showing chemical composition of some dry seeds

seed species	Starch (%)	Sugar (%)	Protein (%)	Lipids (%)
Maize (*zeamays)*	50-70	1-4	10.0	5.0
Garden peas (*pisum sativum)*	30-40	4-6	20.0	2.0
Ground nuts (*Arachis hypogea)*	8-21	4-12	20-30	2.0
Sunflower	0	2.0	2.5	40-50
Castor oil	0	0	13.3	64

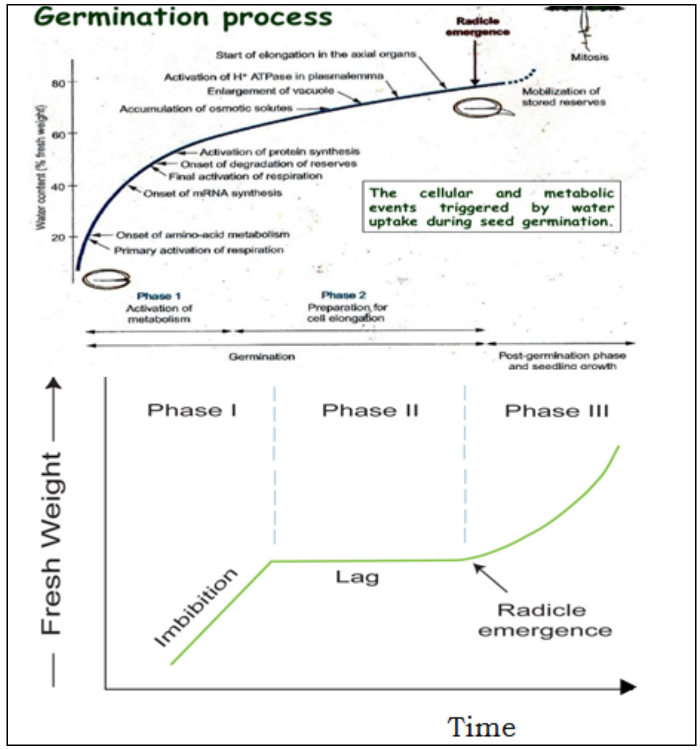
Phases of seed germination

Germination starts when metabolic activities increase by conversion of stored food into soluble and utilizable food. The initial energy for germination is provided by ATP which is present in almost all living cells.

Germination of seeds involves the following phases;

(i) Rehydration phase
(ii) Imbibition phase
(iii) Activation phase
(iv) Utilisation phase

- **Rehydration phase;** this is the first process that occurs during germination. It involves imbibition and osmosis. Imbibition in plant cells refers to the absorption of water by protoplasmic and cell wall contents).



Imbibition is due to colloidal properties of seeds. The cytoplasm has dissolved substances that make the seed osmotically active.

As the protoplasm becomes hydrolysed, it resumes physiological activity.

Pre-exixiting enzymes become activated follower by synthesis of more enzymes.

- **Activation phase;** this pahse follows rehydrationphase,when stored hormones and enzymes are catalysed, they stimulate physiological development leading to growth of the embryo. Maturation of the growing regions is directed towards the synthesis of the new cell components and structures.

  Growth is usually more visible in radical before plumule. Cell division, elongation and increase in dry weight begin very suddenly in the radical and plumule.

- **Utilisation phase;** the first stage in utilisation of nutrient reserves is their hydrolysis to soluble products that are translocated to the growing regions.

  Storage tissues of parent origin, endosperms and perisperm die when food reserves are exhausted.

  Part of the soluble products is used in respiration and synthesis in storage tissues with a greater part transported to the growing parts.

  The dry weight of the storage parts decreases and that of the growing parts increases.

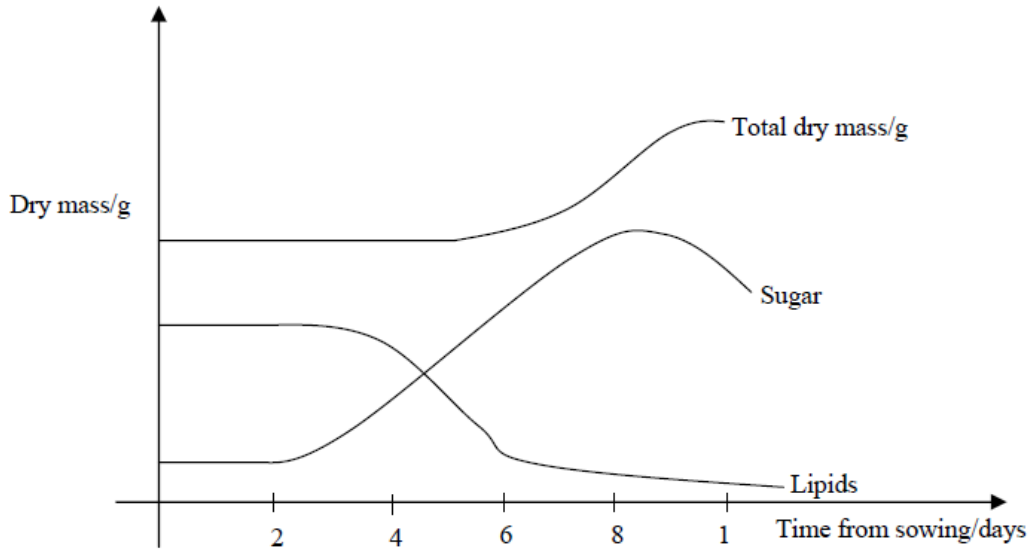
  As the food reserves get exhausted, storage cells die and collapse.

Respiration in a germinating seed

Respiration is high in storage tissues and the embryo due to high metabolic activity in both regions.

Respiratory substrates differ in each region and they also change during germination.

When castor oil seed were analysed for lipids and sugar content during germination in darkness, the following results were obtained.



The respiratory quotient (RQ) of the seedling was measured at day 5 and the embryo was found to have an RQ of 1.0, while the remaining cotyledons had an RQ of about 0.4 and 0.5. Changes in lipids and sugar content in castor oil seeds during germination in the dark can be explained as follows.

By day 4, the mass of lipids is starting to decrease and the mass of sugar begins to increase. Lipids are therefore converted to sugar and translocated to the embryo. No sugars can be formed by photosynthesis as the plant is in the dark.

At day 5, the RQ of the embryo is 1 indicating that the embryo is respiring using sugars obtained from lipids. At the same time, the cotyledons are gaining energy from conversion of sugars and fatty acids.

Conversion of lipids to sugars takes place with an increase in dry mass so that dry mass of the seedlings is up in the 6-7 days. Beyond this point lipid deposits run low so that rate of sugars exceeds their production net mass of sugars in the seedling as the sugars are used up in respiration.

At day 11, the RQ of the whole seedling will be slightly less than 1.

The main one is the oxidation of sugar in respiration with RQ of one but there would still be some contribution from conversion of lipids to sugars, RQ of 0.4-0.5.

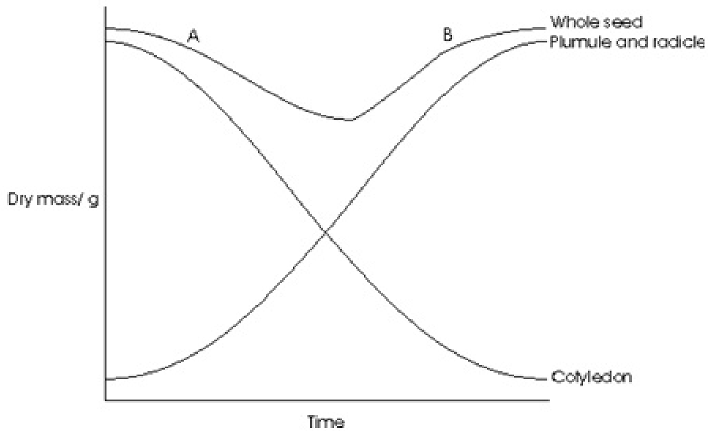
The respiratory quotient (RQ) is the amount of carbon dioxide produced divided by amount of oxygen used in a given period of time. The main importance of RQ is to indicate the substrate being used in respiration. Complete oxidation of carbohydrates gives an RQ of 1.0, fats 0.7, proteins of 0.9. An RQ of less than 1.0 may mean that fats as well as are being respired whereas an RQ exceeding 1.0 is indicative of anaerobic respiration.

$$RQ = \frac{\text{Oxygen used}}{\text{Carbondioxide produced}}$$

E.g. oxidation of glucose: $C_6H_{12}O6 + 6O_2\ (g) \rightarrow 6CO_2(g) + 6H_2O(l)$

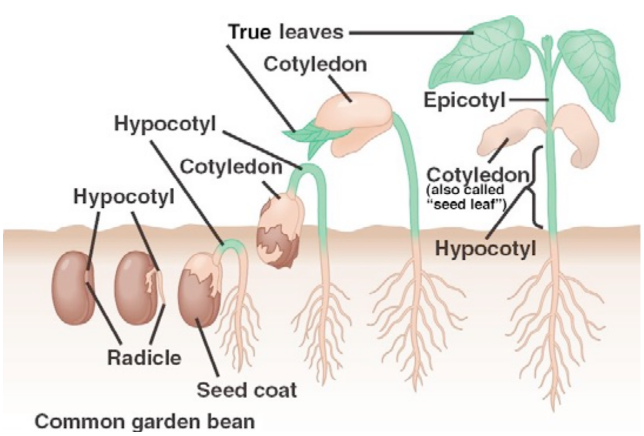
The soluble products of digestion are then translocated to the growing regions of the embryo. The sugars, fatty acids and glycerol are used to provide respiratory substrate.

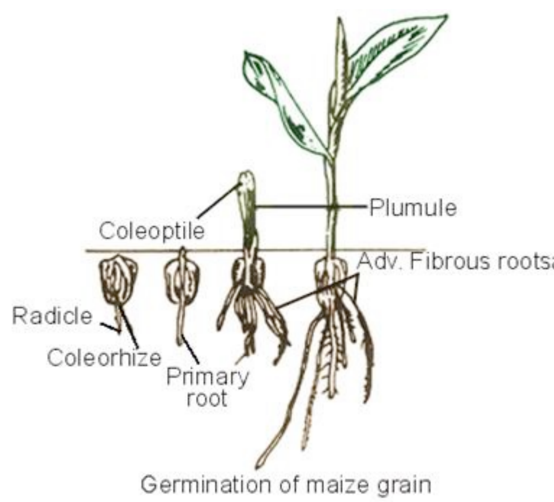
They may also be used for synthesis of materials e.g. glucose is used in cellulose synthesis.
Fatty acids can also be converted into sugars. Amino acids are used in protein synthesis e.g. enzymes and compounds of the protoplasm.
During respiration, sugars and fatty acids are oxidised to produce carbon dioxide and water.



At the start of germination, enzymes are activated which convert starch to glucose and proteins to amino acids.
These are translocated to the embryo for use in growth. The endosperm dry mass decreases while the embryo dry mass increases. There is an overall loss in dry mass during the first week. This is due to aerobic respiration which consumes sugars in both the embryo and endosperm. After the first week, foliage leaves emerge and start to photosynthesise. This increases dry mass and more than compensates for the dry mass losses in respiration so that a net increase in dry mass is obtained.

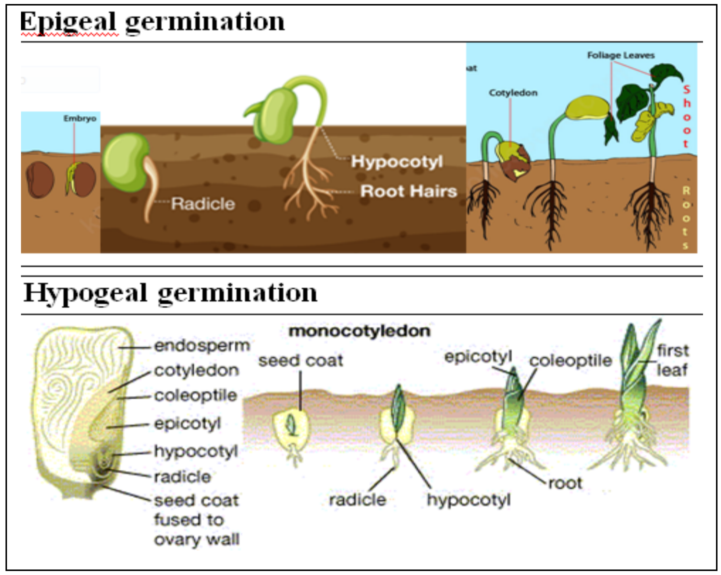
Types of seed germination





a) Epigeal germination

In this type of germination, cotyledons come out of the ground due to rapid elongation of hypocotyls .it is common in dicotyledonous seeds for instance family of beans and sunflower.



b) Hypogeal germination

This is a type of germination where cotyledons remain in the ground and become part of the food reserves for the young growing embryo. It is common cereals (gramineae family)/monocotyledonous seeds.

Conditions that affect seed germination

(i) Water; most dry seeds contain 13% water. Most of the water is bound to colloids and is inaccessible for hydrolytic reactions. Therefore, adequate water supply is necessary for germination hydrolysis. Germination begins with uptake of water which involves imbibition and osmosis. Water imbibition depends on; c

- Chemical composition of the seed
- Permeability of the seed coat
- Availability of water

(ii) **Suitable temperature;** seeds germinate within a given range of temperature. The optimal temperature for seed germination is between 5°c and 37°c. This varies with plant species and ecological habitat.

Optimal temperature for germination is the temperature at which the highest percentage of germination occurs in a shortest possible time. Hydrate seeds can survive temperature range of 12°c and 18°c e.g. in seed banks.

(iii) Air composition; normal air composition is necessary for germination to take place. Oxygen is required in germination for respiration to produce energy. Low oxygen concentration lowers seed germination. For example when seeds are soaked for a long time they fail to germinate. Also carbon dioxide concentration of about 40°c to 45°c helps in preserving seeds for a long time.

(iv) Light intensity; light intensity and duration affect seed germination in different ways by either inhibiting or promoting seed germination. Light absorbed by phytochrome undergoes photo transformation.

(v) Soil structure; good soil structure which allows good water retention with adequate depth promotes seed germination.

Pr 665ɲm $\longrightarrow$ **red light (day light)**

Pr 725ɲm $\longrightarrow$ **far red light (night/ darkness)**

Red light	Far red light

(i) Inhibits stem elongation (ii) Stimulates leaf expansion (iii) Stimulates growth of lateral roots	(iv) Stimulates stem elongation (v) Inhibits leaf expansion (vi) Inhibits lateral root growth

(vi) Presence of micro organisms; these have a great effect on germination and seedling mortality which results from microorganisms attack especially in cold soil. Hence seed treatment with antibiotics improves germination efficiency.

Some micro organisms promote germination by eating seed coat making it permeable to water and air entry.

Measurement of Growth

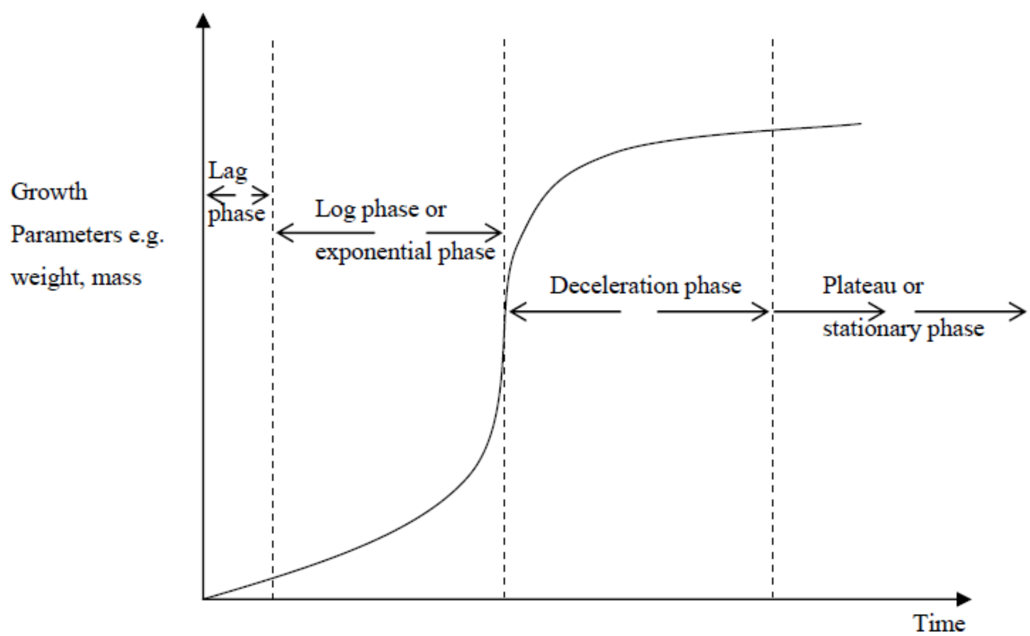
Growth can be estimated by measuring some parameters of an organism for example fresh weight, dry weight, volume of girth, surface area, etc.

Fresh Weight: This is the weight of an organism taken in its natural condition. It is influenced by variation of fluid in the body and is therefore inaccurate.

Dry Weight: This is the weight after all moisture of an organism has been given off. It is obtained by heating in an oven to over 110ºC until all water is lost.

Growth Curves: If an organism's measurement such as height, weight etc are plotted against time, a growth curve is obtained. This shows the overall growth pattern and the extent of growth.

A Sygmoid graph showing growth of the four characteristic growth phases



There are four distinct phases to the normal S-shaped (Sigmoid) growth curve i.e. lag phase, log/exponential phase, decelerating phase (linear growth phase), plateau/stationary phase.

Lag Phase: In the lag phase, there is little or no cell replication, organism is adapting to available resources.

Logarithm/Exponential Phase: In the logarithm/exponential phase, n o apparent limit on growth. Supply of nutrients is adequate. Waste products have not yet accumulated and more cells are produced than those which die.

Seed viability

This refers to the ability of a seed to germinate when planted. The viability/ germinability of the seeds is tested before seeds are planted to establish their percentage germinability.

Methods of testing seed viability
There are mainly 3 methods;

- The germination test method
- The lackon of technique
- Using potassium Permanganate solution.

1. Germination test method

Materials required:

- Seed sample
- Cotton wool /filter paper
- Water
- Petri dish /plate

Procedure

- Obtain seeds from a seed lot randomly
- Count the number of seeds in the sample.
- Select a suitable medium e.g. cotton wool, news paper or filter papers.
- Place the seeds in the cotton wool.
- Water the seeds and cover them.
- Provide all the conditions necessary for germination.
- Continue watering the seeds.
- After 4- 6 days, count the seeds that have germinated.
- Express the number of germinated seeds as a percentage of total seeds planted.
- Viability/ germination percentage = $\frac{\text{number of germinated seeds X 100}}{\text{Total seeds in the sample}}$

Conclusion

If the germination percentage is above 80% then the seeds are viable and good for planting.
If the germination percentage is less than 70 – 80% then the seeds are unsuitable for planting.

Example

Given that 45 seeds were tested and 36 of them germinated. Calculate the germination percentage and Comment on the suitability of the seeds for planting.
Solution

Germination percentage = $\frac{\text{number of germinated seeds X 100}}{\text{Total seeds in the sample}}$

$= \frac{36}{45} \times 100\%$

$= 4 \times 20$

Germination percentage = <u>80%</u>

Conclusion; the seeds are able to germinate so they are suitable for planting.

2. The lackon technique / Tetrazolium salt test

Materials

- Seed sample
- Petri dish
- Tetrazolium salt solution

Procedure

- Obtain seeds from a seed lot randomly
- Count the number of seeds in the sample.
- Immerse/ soak seeds in the Tetrazolium salt solution over night
- Provide all necessary conditions for germination
- Remove the seeds from the salt solution, cut the seeds open to expose the embryo.
- Count the number of seeds that have pink/ reddish embryo
- Express number of seeds that have pink/ reddish embryo as a percentage of the total seeds soaked in salt solution.
- Germination percentage = $\frac{\text{Number of seeds that have pink/ reddish embryo X 100}}{\text{Number of the total seeds soaked in salt solution}}$

Observation

When the viable seeds respire they produce carbon dioxide that turns Tetrazolium salt solution pink or reddish.

Conclusion

If the germination percentage is above 80% then the seeds are viable and recommended for planting.

If the germination percentage is less than 70 – 80% then the seeds are unsuitable for planting. Then the seeds should not be planted.

3. Use of potassium permanganate

Materials used

- Seed sample
- Potassium permanganate solution
- Beaker
- Heat source

Procedure

- Obtain seeds randomly from a given seed lot
- Put a counted number of seeds in a beaker containing potassium permangate solution.
- Heat the seeds in the beaker for some time to break the testa so that they can release the liquid in them.

Observation

- Potassium permanganate solution is usually purple in colour, if it changes to colourless/gets decolourised, the seeds are viable and recommended for planting. But if the purple colour persists then seeds are non viable and not recommended for planting.

NB; In this method, calculation of the germination percentage is impossible because it is difficult to identify the seeds that release the liquid and those that have not.

Some plants do not have viable seeds to be planted. Seeds of some plants have low germinability.

Seed selection

This is the process of choosing seeds to be used in planting from a given seed lot.
It is the sorting of good quality seeds for planting from a given seed lot. The selected seeds should have desirable qualities i.e.

i) They should be uniform in shape, colour and size
ii) They should be from a variety which is resistant to pests and diseases
iii) Should be free from physical damages.
iv) Should be wholesome i.e. not broken or not having any physical defect
v) Should be from variety which is early maturing
vi) Should be from variety which is high yielding
vii) Should be from variety that is used to local environment conditions such as temperature, moisture
viii) Should have long shelf life i.e. longevity
ix) Seeds should be viable i.e. ability to germinate.
x) Should be fully mature so that they don't rot when planted.
xi) Should be of desirable genetic make up
xii) Seeds should be selected from an easy to cook variety e.g. garden peas

Seed dormancy

Seed dormancy refers to the condition/ period when the variable seeds do not germinate when planted even when provided with favorable conditions for germination.

Causes of seed dormancy

(i) Hard seed coats, this prevents the entry of water and oxygen into the seeds. It also prevents the emergency of the plumule and radical.
(ii) Immature seed embryos; in some plants the embryo is not fully developed when the seeds are shed by the mother plant. Such seeds with immature embryo which cannot germinate when planted.
(iii) Presence of seed coat hairs which prevents the absorption of oxygen by the seeds e.g. barley and mango seeds.
(iv) Presence of germination inhibitors that prevents the germination of sees e.g. Absicic acid.
(v) Prolonged seed storage leading to death of the embryo.
(vi) Shortage of growth stimulating hormones e.g. gibberellins and cytokinins
(vii) Light intensity and temperature; some seeds are negatively photo blastic and their germination is inhibited by presence of light while others e.g. onions, tobacco seeds do not germinate unless there is enough light and they are said to be positively photo blastic.

Methods of breaking seed dormancy

(i) Soaking the seeds in growth stimulating substances such as gibberellins/ gibberellic acid, indole acetic acid, Naphthalene acetic induce production of hydrolytic enzymes.
(ii) Pre- chilling i.e. seeds are exposed to very low temperatures for a short period of time before planting in normal conditions.
(iii) Soaking seeds in cold water overnight to soften the testa before planting in normal conditions.

(iv) Mechanical scarification e.g. breaking of the seed coat by pricking seeds with sterilised pins to break the testa and rubbing seed testa with sand paper so that water and oxygen can go through the seeds.
(v) Heat treatment; the seeds are soaked in hot water at about 80^{o}c for 3 – 5 minutes before taken for planting.
(vi) Allowing seeds of certain plant species a short dry period to allow after harvest ripening period to enable full embryo growth.
(vii) Chemical treatment; here the seeds are soaked in chemical reagents e.g. sulhpuric acid, potassium nitrate. They are then washed in water before planting.
(viii) Microbial attack by soil fungi and bacteria which cause it to decay,
(ix) Passage through the guts/alimentary canal of birds and mammals which eat the fruits in which the seeds are found.

Advantages of seed dormancy

(i) It enables the seeds to withstand unfavourable/ adverse conditions before germination e.g. extreme temperatures.
(ii) Allow sufficient time for dispersal of seeds to enable them colonize new areas.
(iii) Prevents death of the entire population in bad times since some would not have germinated
(iv) Prevents pre- harvest germination especially of cereal crops
(v) Facilitates proper storage of grain crop produce.

1.6.2.2 PLANT GROWTH REGULATORS

Plant growth substances are organic compounds that in low concentrations affect the physiological processes of plants.

The natural occurring growth promoting substances are also called growth hormones while those not naturally occurring are not usually called hormones but growth regulators.

Plant growth substances include;

i) Auxins
ii) Gibberellins
iii) Cytokinins
iv) Abscisic acid
v) Ethylene (ethene)

Gibberellins

Gibberellins are compounds which in very low concentrations promote elongation (growth) of certain dwarf plant varieties e.g. peas and maize.

These stimulate rapid growth in many varieties of certain plants e.g meristems of apical buds and roots, young leaves and developing seeds.

Gibberellins have multiple effects for instance;

i) Gibberellins are used in the breaking of seed dormancy of certain seeds. Germination is triggered by soaking the seeds in water. After imbibition of water, the embryo secretes gibberellins which diffuse to the aleuxion (aleurone layer) which stimulates synthesis of several hormones, including α-amylase. These catalyse the breakdown of food reserves in the endosperm and the products of digestion diffuse to the embryo.

ii) They promote cell division and cell elongation
iii) They promote parthenocarpy in some plants because they initiate formation of IAA (Indole Acetic Acid.)
iv) They promote growth of side branches from lateral buds.
v) They induce production of enzymes e.g. enzyme amylase in barley.
vi) They increase size of many young fruits e.g. grapes hence increase yield per hectare.
vii) They promote flowering in many plants e.g. in carrots.
viii) They inhibit growth of adventitious roots.

Gibberellins differ from auxins because;

- High concentrations of gibberellins can be tolerated without being toxic.
- Their primary function is to cause elongation in the main stem e.g. in sugarcane.
- They do not affect tropic movements

Auxins

These are growth substances whose greatest effect is cell elongation, phototropism and to a less extent geotropism.

TROPISMS

Plants don't show locomotion but movement of individual organs is possible.

I) Tropism is the growth response of a plant to unidirectional stimuli e.g. light.

Phototropism – growth response towards light – roots are negative and shoots are positive

Geotropism – growth response towards gravity- roots are positive and shoots are negative

Hydrotropism – growth response towards water – roots are positive and shoots (negative response)

Chemotropism – growth response towards chemicals

Thigmotropism – growth response towards touch – tendrils twin around support

II) Taxis – This is the movement of the whole organism in response to unidirectional stimuli.

Phototaxis – growth response towards unidirectional light- Euglena move towards moderate light

Thermotaxis – growth response towards unidirectional temperature – green algae move towards warm places

Chemotaxis – growth response towards unidirectional chemicals – Antheroroids (sperms) in ferns, mosses liverworts move towards chemicals secreted by the archegonium.

III) Nastic – This is the response of part of the plant to diffuse stimuli e.g. closing of leaves when touched in mimosa pudica

The most common thoroughly studied auxin is IAA (indole acetic acid)

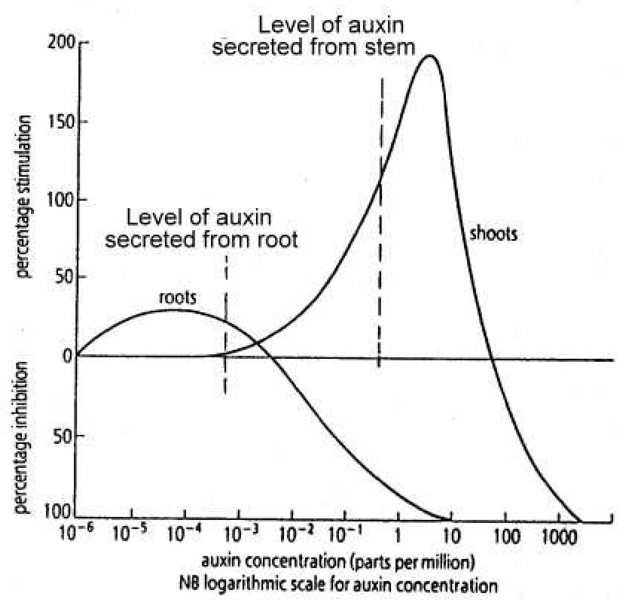
Other effects of auxins

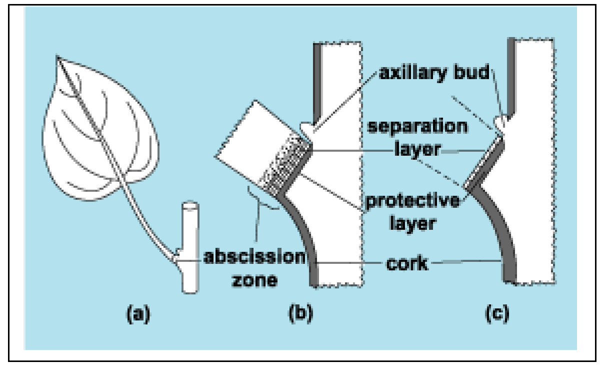
i) **Promote apical dominance –** Auxins inhibit the formation of side branches from lateral buds.

Apical dominance is a phenomenon where the apex suppresses growth of the lower parts of the plant. When the apex is removed, lateral growth takes place. This is the theory behind pruning. Cutting the main tips removes the source of auxins thus encouraging sprouting of the side branches. If IAA is applied to the cut main stem tip, no branching occurs. IAA stimulates the growth of adventitious roots which are lateral roots from the main stem.

ii) Auxins promote pathenocarpy which is the development of fruits and seeds without the act of fertilisation.
   Pathenocarpy can be induced by producing unpollinated flowers with IAA, napthaline, autic acid
iii) Auxins are also involved in secondary growth division of cambium tissue and development of fruits. Thus auxin sprays improves fruit size.
iv) They inhibit growth of lateral buds, Auxins are produced in shoot apical meristems and young leaves, and they are then transported down the stem.
   Removal of the apical bud from the same plant enables lateral branches to grow.
   Applying a gelatine capsule containing auxin to the stump prevents the lateral branches from growing.
   Auxins transported down the shoot from apical bud directly inhibit auxiliary buds from growing.
v) They promote root growth, cell elongation over a wide range of concentrations. The enlargement is proportional to the amount of IAA present. IAA (indole acetic acid) and naphylacatic (NAA) are commonly applied in agriculture to promote rooting in cuttings in producing clonal planting materials e.g. coffee.
vi) Inhibition of abscission of leaves and fruits, auxins prevent production of abscission layer at the abscission zone of leaf stalk.
vii) Auxins shorten internodes of some plants making them dwarf for easy harvesting.
viii) Synthetic auxins are commercially used in weed management. Weed killers such as 2,4-D (2,4-dichlorophenoxy acetic acid), 2,4-T (2,4-trichlorophenoxy acetic acid) and MCPA (methyl chlorophenoxy acetic acid) in low concetrations have similar effects to the natural auxins but in high concentrations, they induce distorted growth of some plant parts inhibiting normal plant growth. Such auxins have ability to penetrate the cuticle of waxy epidermis of the plant.

Effect on growth by application of different concentrations of auxins to the roots and shoots of seedlings





How auxins bring about cell enlargement

Increased concentration leads to secretion into the cell walls. Low PH activates an enzyme that breaks polysaccharides, bends the cell wall making it more permeable to water.

Summary of effects of auxins

(i) Promote adventitious and lateral roots; IAA application causes abundant lateral root growth.
(ii) Promote secondary growth
(iii) Promote cell division
(iv) Promote cambium growth
(v) Promote apical dominance
(vi) Promote pathonocarpy;
(vii) Promote fruit development
(viii) Delay abscission; auxins are applied to prevent premature fruit and leaf fall e.g. in pineapples and avocado giving maximum time for ripening.
(ix) Cell enlargement – growth in length
(x) Bud development- beheaded young shoots and auxin agar block- no lateral buds. Suppress the development of lateral buds.
(xi) Cambium promote the building up of vascular bundles

Cytokinins - stimulate cytokinesis

These promote cell division in presence of auxins. They delay the normal process of aging in leaves. They are produced in roots. They regulate cell division in shoots and roots. They modify apical dominance, promote lateral bud growth.

Abscisic Acid (Growth hormone)

It slows growth and so works antagonistically to auxins gibberellins and cytoxinin. Its main effect is <u>causing fall of fruits, seeds and leaves and this is called abscission</u>.

Diagrams of the abscission zone of a leaf
(a) A leaf with the abscission zone indicated at the base of the petiole.
(b) The abscission zone layers shortly before abscission.
(c) The layers after abscission.
Auxin applied experimentally to the distal (organ) side of an abscission zone retards abscission,
while auxin applied to the proximal (stem) side accelerates abscission.
As the fruits ripen, the level of auxins which inhibits abscission reduces while that of abscisic acid increases. This leads to the formation of abscission layer and the leaf or fruit falls. Abscission also prevents seeds from germinating and brings about dormancy of buds, leaf senescence, promotes desiccation tolerance, promotes stomata closure.

Commercial Applications

It may be used to stimulate fruit fall/abscission at the end of the season, promoting picking over a long time span.

Ethylene

It is produced in high concentration during senescence, leaf abscission, ripening.
Production is stimulated by wounding, stress. It triggers a sudden increase in respiration rate which leads to the ripening of fruits.
It also causes leaf fall and releases buds and seeds of certain plants from dormancy.

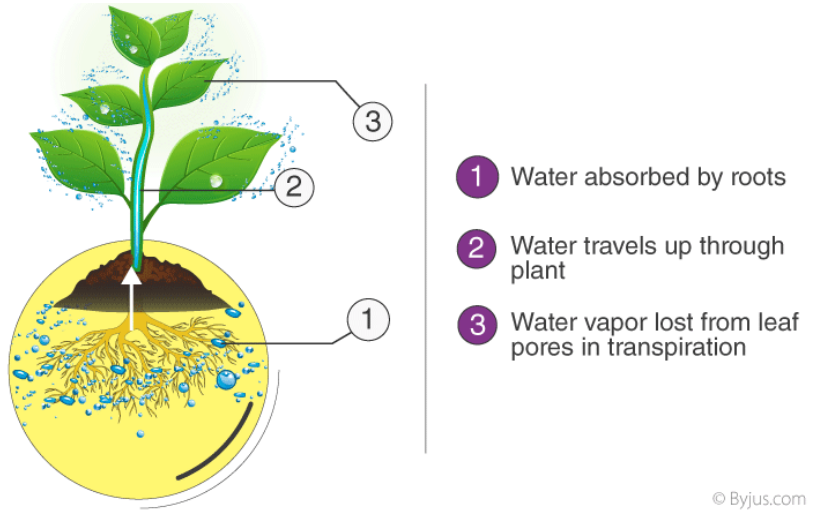
Commercial Applications

- Ethylene induces flowering in pineapples and stimulates ripening of tomatoes and citric fruits.
- Fruits can be prevented from decay by storage in an atmosphere lacking oxygen.

1.6.2.3 TRANSPIRATION

Transpiration

Transpiration is the process of water movement through a plant and its evaporation from aerial parts, such as leaves, stems and flowers.
It is the process of excess water loss from the aerial parts of the plant especially leaves in form of vapour.
Water is necessary for plants but only a small amount of water taken up by the roots is used for growth and metabolism. The remaining 97–99.5% is lost by transpiration and guttation.

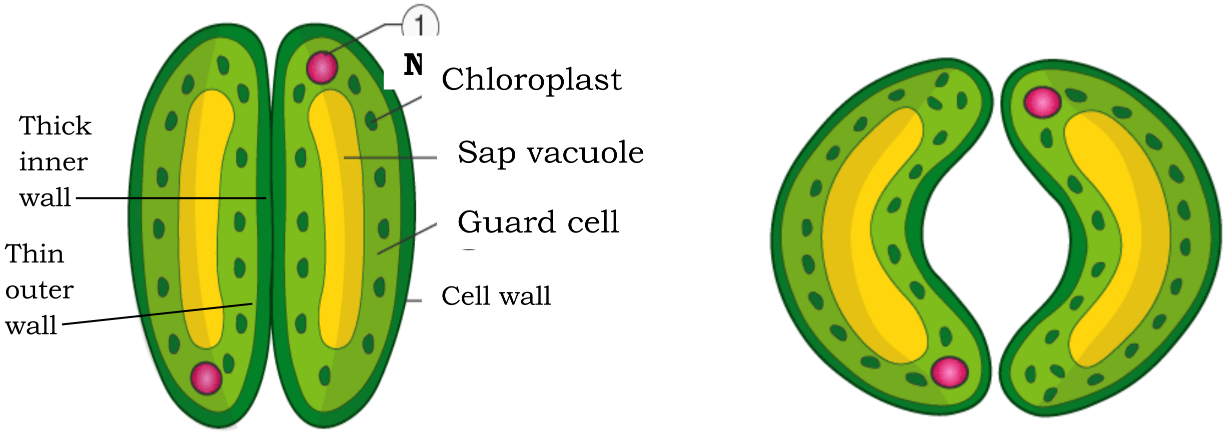


Types of Transpiration

There are three different types of transpiration in plants:

- **Stomatal Transpiration**; it is the evaporation of water from the stomata of the plants. Most of the water from the plants is transpired through stomata. The water near the surface of the leaves changes into vapour and evaporates when the stomata are open.

Opening and Closing of Stomata



(a) Stoma Closed (b) Stoma Open

Stomata consist of a pair of guard cells with an aperture in between. It remains open during the daytime and is closed at night. The reason for the opening and closing of this structure is the turgidity of guard cells.

The interior wall of the guard cells present towards the aperture is dense and flexible. The stomata open when the turgidity of the guard cells increases. The exterior walls bulge out, and the interior walls form a crescent shape.

The orientation of the microfibrils in the guard cells also plays an important role in the opening of the stomata.

The radial orientation of the microfibrils makes it easier for the stomata to open. The stomata close when the turgidity of the guard cells decreases due to the water loss and the interior walls form a crescent shape retrieve their original shape.

In dicots, the lower side of leaves have more stomata while in monocots, both the sides have an equal number of stomata.

- **Lenticular** Transpiration; lenticels are minute openings in the bark of branches and twigs. Evaporation of water from the lenticels of the plants is known as lenticular transpiration.
  Lenticels are not present in all the plants. A minimal amount of water is lost through lenticels.
- **Cuticular Transpiration;** it is the evaporation of water from the cuticle of the plants. The cuticle is a waxy covering on the surface of the leaves of the plants. About 5-10% of the water from the leaves is lost through cuticular transpiration. During dry conditions when the stomata are closed, more water is transpired through the cuticles.

Illustration of guttation

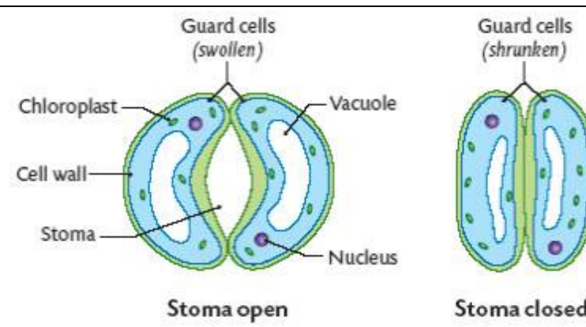
Guttation is the process of secretion of water droplets from the pores of some vascular plants like grass. Guttation is often confused with dew droplets that condense from the atmosphere on to the plants surface. The liquid of guttation comprises a variety of inorganic and organic compounds which mainly include potassium and sugars. A white crust remains on the leaf surface.

The mechanism of stomatal opening and closing

There are several theories that explain the opening and opening of stomata e.g.;

a) **Changes in turgor pressure**, this theory stipulates that opening and closing of stomata depends on the changes in the turgidity of guard cells. When water is drawn into the guard cells by osmosis, the guard cells expand and their turgidity increases. The thick and inelastic inner wall makes the guard cell to bend, this results into inner walls of the two guard cells to draw apart from each other and the stoma pore opens.

stomatal opening and closing



When water is lost from the guard cells, they become flaccid due to decrease in turgor pressure and the stomata close.

The guard cells lose their turgidity and the inner thick walls straighten and the stomata close.

$$\textbf{Starch} \underset{\textbf{Acidic pH}}{\overset{\textbf{Alkaline pH}}{\rightleftharpoons}} \textbf{glucose/sugars}$$

b) **PH changes**, this theory is based on pH. The enzymatic conversion of starch to sugar proceeds when little acid is present i.e. at high pH. While conversion of sugar to starch is favoured by low pH when acid concentration is high.

During night, accumulation of carbon dioxide in intercellular spaces of the leaf raises the concentration of carbonic acid. The resulting drop in pH favours conversion of sugar to starch in the guard cells raising water potential leading to closure of stomata.
The resumption of photosynthesis in the morning lowers carbon dioxide and the level of carbonic acid falls, **pH rises**, **starch is converted to sugar**, water potential decreases and **stomata open**.

c) **Potassium- chloride influx**, this theory stipulates that stomata opening may be achieved due to active transport of ions into guard cells thereby building the necessary solute concentration that draws in water by osmosis. It has been found out that the concentration of ions is much higher in the guard cells of open stomata than closed stomata.

During Day Light	During Night/Dark
Accumulation of K^+ ions by the guard cells ↓ Increased solute concentration ↓ Endosmosis of water ↓ Increased turgidity ↓ Stomata open	Lose of K^+ ions by the guard cells ↓ Decreased solute concentration ↓ Exosmosis of water ↓ Decreased turgidity ↓ Stomata close

d) **Hormonal regulation**, this theory is based on the observation that abscisic acid (ABA) accumulates in the leaves of water stressed (water deficit) plants. ABA application to intact leaves stimulates stomatal closure.

Significance of Transpiration in Plants

The significance of transpiration is explained below:

1. Transpiration helps in the conduction of water and minerals to different parts of the plants.
2. Due to the continuous elimination of water from the plant body, there is a balance of water maintained within the plant. Excess water weakens plant stems and reduces plant resistance to diseases.
3. It maintains osmosis and keeps the cells rigid and moist.
4. A suction force is created by transpiration that helps in the upward movement of water in the plants.
5. It maintains the turgidity of the cells and helps in cell division.
6. Allows the cooling effect of a tree is due to the evaporation of water from its leaves.
7. Optimum transpiration helps in the proper growth of the plants.

However, transpiration has a few setbacks:

1. Plenty of unnecessary water is absorbed by the plants during the process.
2. It causes wilting of plants in case of excessive transpiration
3. It may eventually cause death of the plant, when the plant loses water excessively due to excessive transpiration

Factors affecting stomatal movement

1. PH, high pH increases turgidity in leaves increasing stomatal opening.
2. Water deficit
3. ABA application
4. Light intensity
5. Carbon dioxide concentration
6. Solute influx into the vacuoles of the guard cells

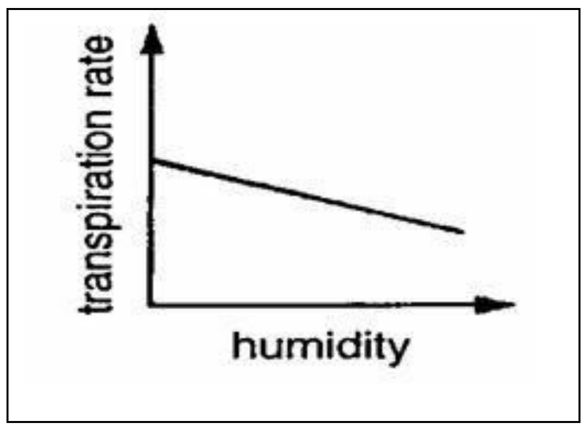
Factors affecting transpiration in plants

These factors are both external (environmental) and internal.

a) **Environmental /external factors** that affect the rate of transpiration

- **Light intensity;** light greatly influences the opening and closing of stomata. Increase in light intensity increases the rate of water evaporation from plant surface thereby increasing the rate of water loss form plants.
  Increase in light stimulates production of malic acid due to conversion of starch to sugar hence stomata open due to increase in turgor pressure.
- **Temperature,** increase in temperature increases latent heat of vapourisation thus encouraging evaporation of water from plant leaf cells.
  A high temperature lowers the relative humidity and opens the stomata even in darkness. As a result, the rate of transpiration increases.
- **Relative humidity**, this refers to the degree to which the atmosphere is saturated with water vapour. Low relative humidity increases the rate of transpiration due to greater saturation deficit experienced around the leaf.
  High humidity in the external atmosphere of the leaf increases water vapour thus reduces saturation deficit which lowers transpiration rate.

Effect of Relative humidity ontranspiration



- **Air movement** (Wind speed), If the air is still, the transpiration rate is low. This is because the water vapour accumulates around the transpiring organs and reduces the diffusion pressure deficit of the air.
  If the air is moving, the water concentrated around the leaves is removed/ dispersed and the transpiration rate increases.
- **Soil water Availability**, the transpiration rate is directly proportional to the absorption of water by the roots from the soil. A decrease in water absorption causes the closure of stomata and wilting, thereby reducing the rate of transpiration.
- **Atmospheric pressure,** water vapour and the atmospheric pressure decreases with increasing altitude. The lower the atmospheric pressure the greater the rate of evaporation of water. This implies that plants growing on a mountain have a higher rate of transpiration than those growing in low-land areas.

b) **Internal factors/plant cellular factors**

The cellular factors affecting the rate of transpiration are:

- **The water status of the plant**,
- **the leaf structure**, e.g. plants that are native to dry habitats exhibit a number of structural modifications in leaves such as needle like structure, thick cuticle, sunken stomata which reduces the rate of water loss.
- **Leaf surface area**. Plants with broad leaves with large surface area have higher magnitude of water loss than plants with narrow and small leave
- **Total number and distribution of stomata** in a leaf, transpiration rate is greater on the upper surface of the leaf with more stomata than lower leaf surface especially in dicot leaves.
- **Surface Area of the Leaves**, leaf having more surface area will show more transpiration rate than the leaf with a lesser surface area.
- **Ascent of Saps**, when water evaporates through the leaves, a pull is created through the xylem, and water moves back to the leaves. This is known as the transpiration pull.
  The ascent of sap that is driven by transpiration depends on the following properties of water:
- Cohesion; this is the mutual attraction between molecules of water.
- Adhesion; the attraction of water molecules towards polar surfaces.
- Surface tension; the molecules of water are more attracted to each other in the liquid phase than in the gas phase.
- **Root-shoot ratio**, transpiration has been found to increase with increase in root : shoot ratio due to large amount of water provided to the shoo by the increases root system.
- **The orientation of leaf**, the leaves of some plants are arranged in such a way that they shade each other (overlap). This restricts water loss.

	Transpiration	Evaporation
(i)	It is a physiological process and occurs in plants.	It is a physical process and occurs on any free surface.
(ii)	The water moves through the epidermis with its cuticle or through the stomata.	Any liquid can evaporate. The living epidermis and stomata are not involved.
(iii)	Living cells are involved.	It can occur from both living and non-living surfaces.
(iv)	Various forces such as vapour pressure, osmotic pressure, etc. are involved.	Not much forces are involved.
(v)	Formation of vapours continues for some time even after the saturation of outside air.	Evaporation stops when the air is fully saturated.

1.6.2.4 ABSORPTION OF WATER AND MINERALS PLANTS

Absorption of water and mineral in plants

During the plants' life cycle, large amount of water is continuously absorbed from the soil and translocated through the plant.

Water and mineral salts first enter through the cell wall and cell membrane of the root hair cell by osmosis. Root hair cells are outgrowths at the tips of plants' roots. They function solely to take up water and mineral salts. The vacuoles have salts, which speed up water absorption from soil water.

Soil factors affecting amount of water absorption in plants

- **Temperature**; low temperature inhibits water absorption. At low temperature, water is more viscous, less mobile, the protoplasm is less permeable to water and root growth is inhibited hence reduced water absorption.
- **Osmotic potential of solution (solute concentration)**; if osmotic potential of solution is greater than that of the plant cell sap, water will move out plant cell instead of being absorbed except in halophytes.
  High osmotic potential of plant cell sap results into water absorption from the soil solution.
- **Soil aeration**; some plants such as tobacco do not tolerate poor drainage which causes wilting. Wilting is caused by decline in water absorption due to poor aeration while water loss through transpiration continues.
- **Carbon dioxide concentration**; accumulation of carbon dioxide in the soil increases viscosity in protoplasm decreasing plant root permeability to water hence causing decrease in water absorption.
- **Availability of water**; as the soil water in the immediate surrounding area of the root system is depleted, the absorption of water by the plant becomes more difficult.

Absorption of water

Under natural conditions, all water absorption by rooted plants is through root system. Most absorption takes place in root hair zone and to a lesser extent through root epidermal cells. An increase in solute concentration of the root hair cell or a decrease in its turgor pressure will increase the water uptake. Since root systems of different plants vary in branching pattern and extent of soil penetration, their water absorption capacity also differs.

Water absorption through the root

Water is taken up into the root hairs and epidermal cells or near root hair zone. It moves from these cells through the cortex tissue, the endodermis, the pericycle and finally into the xylem. The xylem tissue of the root connects directly with that of the stem.

Large amount of water is drawn into the root hairs by osmosis or by following the common pathways along cortical cells.

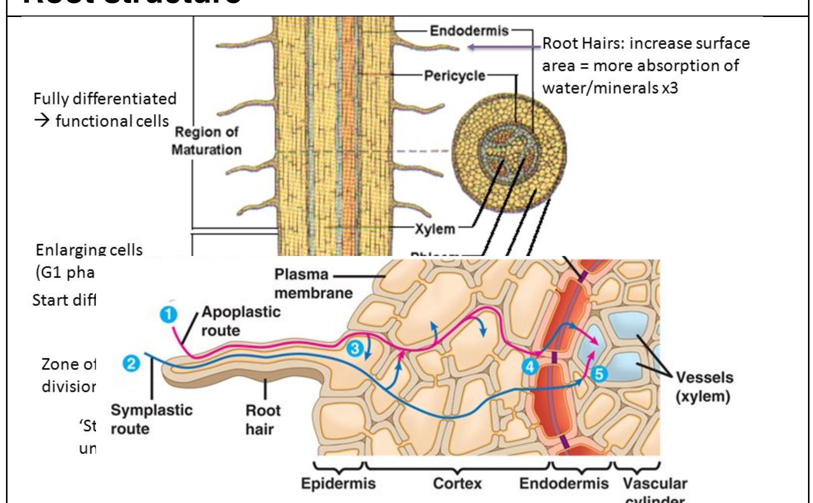
Water movement along endodermal cells through cell walls is impeded by the presence of casparian strip, a band of suberin in the inner surface of the transverse and radial walls of the endodermal cells.

Note; the root hair zone is the area where most water absorption takes place.

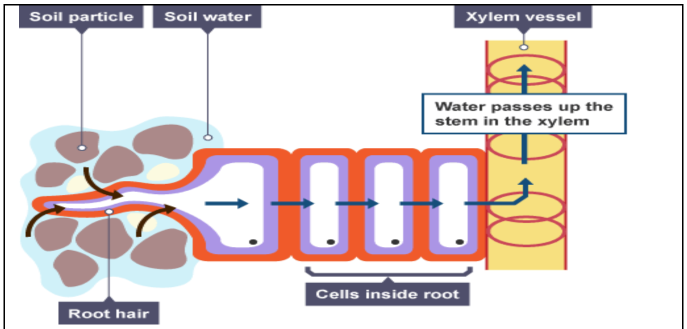
Water absorption by root pressure

- Root pressure is caused by active transport of mineral nutrient ions into the root xylem. In absence of transpiration to transport the ions into the root xylem, they accumulate in the root xylem and lower the water potential.
- Water then diffuses from the soil into the root xylem due to osmosis. Root pressure is caused by accumulation of water in the xylem pushing on along the rigid cells.

Root structure



- Root pressure provides a force which pushes water up the stem, but it is not enough to account for the water to leaves at the top of the tall trees. The maximum root pressure measured in some plants can raise water only to about 20 meters and the tallest trees are over 100 meters tall.



Transpiration pull

This is exerted due to the lower water potential that develops in the cells of the leaves as a result of transpiration. This force pulls water or exerts a suction force/pressure on the water on the narrow xylem vessels and tracheids which pulls water in a single continuous stream.

Pathways responsible for water movement from the root hairs to vascular tissues.

Water flows by osmosis form the root hairs to the endodermal cells using three pathways, namely;

- Apoplast pathway
- Symplast pathway
- Vascular pathway

Apoplast pathway, this involves movement of water along the cell walls within the adjacent cells through the small intercellular spaces between them.

Symplast pathway, water can move through the cytoplasm of one cell to another through the plasmodesmata strands which link cytoplasm of one cell to that of the next.

Vacuolar pathway, water can pass from one vacuole to another by osmosis through cell wall, cell membranes and cytoplasm of adjacent cell.

Note; movement of water through cell walls by Apoplast pathway is prevented by the suberin of the casparin strip in the endodermis. Casparin strip acts as a barrier because it is hydrophobic i.e. does not like water, therefore water enters vascular tissues via the lining protoplast of endodermal cells.

Qn Explain the role of casparian strip in transport of materials in plants

The casparian strip facilitates the pushing of water upwards through the xylem vessels by root pressure up to the leaves due to its active pumping of the salts. In addition, this active pumping of the salts into the xylem vessels prevents leakage of salts (ions) out of the xylem vessels so as to maintain a low water potential in this vessel.

Mineral uptake in plants

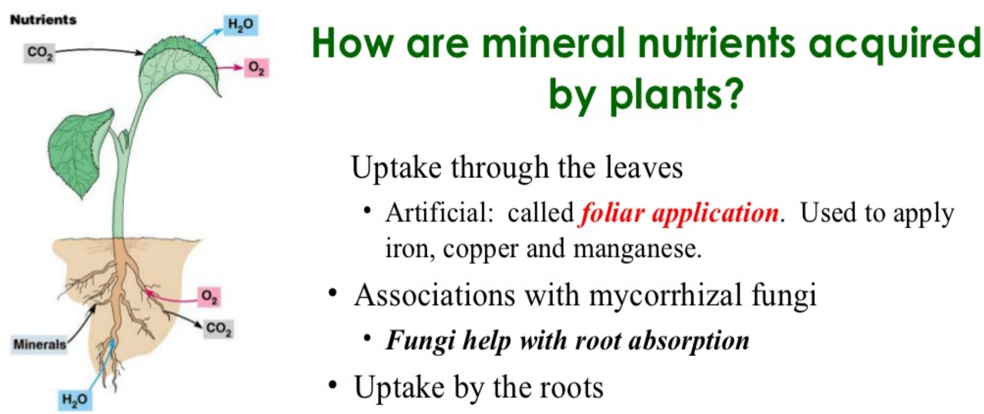
Plants usually absorb minerals in ionic form. The ions that are available to plants for absorption are in solution form (dissolved in water) e.g. NO^{-}_{3}, K+, PO^{-}_{4}. Mineral ions cross plasma membranes by chemiosmotic mechanism. Mineral ions find difficult in crossing plasma membrane. Ion concentration varies according to;

- Soil fertility
- Soil pH
- Presence of other ions in the soil

Mineral uptake is the process in which minerals enter the cellular material, typically following the same pathway as water.

The most normal entrance portal for mineral is through plant roots

Question; how are root hairs adapted for water and mineral absorption?



Minerals may be absorbed either actively or passively

1**. Active absorption of minerals**

Most minerals are absorbed from the soil solution having the less mineral concentration into the root hairs with the higher mineral concentration, selectively by using active transport which uses a lot of energy.

The active transport of ions from the outer space of the cell to the inner space generally occurs against concentration gradient hence requires metabolic energy obtained from cells either directly or indirectly.

The rate of active absorption of minerals into the root hairs depends on the rate of root respiration. Factors such as oxygen supply and temperature will affect the rate of ion uptake. The addition of respiratory poison has shown to inhibit uptake of mineral ions.

2. Passive absorption

- If the concentration of a mineral in a soil solution is greater than its concentration in the root hair cell, the mineral may enter the root hair cell by diffusion.
- Mass flow or diffusion occurs once the minerals are absorbed by the root hairs so that they move along cell walls (apoplast pathway). In mass flow, the mineral ions are carried along in solution by water being pulled upwards in the plant in the transpiration stream, due to the transpiration pull i.e. the mineral ions dissolve in water and move within the water columns being pulled upwards.
- The mineral ions can also move from one cell of the root to another against the concentration gradient by using energy inform of ATP.
- The mineral ions can also move through the Symplast pathway i.e. from one cell cytoplasm to another.

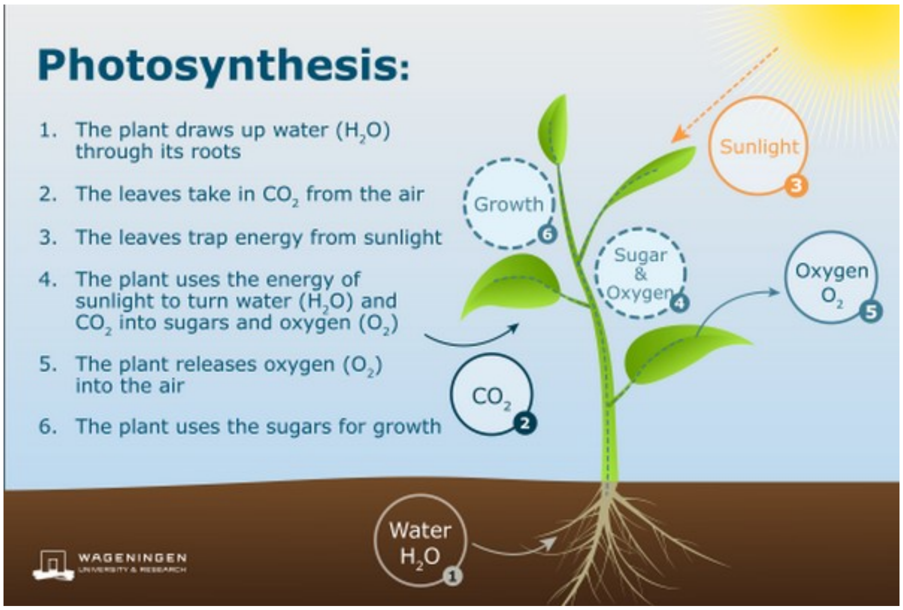
- When the minerals reach the endodermis of the root, the Casparian strip prevents their further movement along the cell walls (apoplast pathway). Instead the mineral ions enter the cytoplasm of the cell (Symplast pathway) where they are mainly pumped by active transport into the xylem tissues and also by diffusion to the xylem.
- Once in the xylem, the minerals are carried up the plant by means of mass flow of the transpiration stream. From the xylem tissues, minerals reach the places where they are utilized called sinks by diffusion and active transport i.e. the minerals move laterally (sideways) through pits in the xylem tissue to the sinks by diffusion and active transport.

1.6.2. 5 PHOTOSYNTHESIS

This is the process by which green plants/cell containing chlorophyll make complex organic substances from simple inorganic molecules of carbon dioxide and water in presence of light energy trapped by chlorophyll and producing oxygen and water as by-products.

Photosynthesis is the process by which green plants and certain other organisms transform light energy into chemical energy. During photosynthesis in green plants, light energy is captured and used to convert water, carbon dioxide, and minerals into oxygen and energy-rich organic compounds

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



During photosynthesis, carbon dioxide is reduced to carbohydrates and water is oxidized to O_2 gas and hydrogen ions. Thus the process involves both reduction and oxidation known as redox reaction.

I.e. oxidation of water would be:

$$2H_2O \xrightarrow{\text{light energy}} O_2 + 4H^+ + 4e^-$$

Oxygen evolved is lost to the atmosphere as a by- product of photosynthesis while the hydrogen ions are used in the reduction of CO_2 to carbohydrates.

$$CO_2 + 4H^+ + 4e^- \longrightarrow (CHO)\ n + H_2O$$

This implies that the summarized equation of photosynthesis is obtained by combining the 2 equations i.e. the oxidation of water and the reduction of CO_2

$$6CO_2 + 7H_2O \xrightarrow[\textbf{Chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + H_2O + O_2$$

From the above equation the following conclusions are made;

- The carbon in the carbohydrate is obtained from the CO_2.
- oxygen atoms of the CO_2 are used in formation of the carbohydrate and water released as a by-product of photosynthesis (metabolic water)

- Oxygen developed as a by-product of photosynthesis comes from the oxidation of water by the process of photolysis.
- The hydrogen atoms in the carbohydrate and metabolic water are obtained from the water as a raw material of the process.

The above conclusions are approved using the Isotope labeling technique i.e. carbon-14 in the CO_2, oxygen -18 in CO_2 and oxygen – 16 in water. When the above isotopes are used, subsequent testing with a mass spectrometer found that the carbohydrate contained, carbon -14 and oxygen – 18 but the oxygen evolved as a by- product contained oxygen – 16 which was contained in the water molecules.

Importance of photosynthesis

- It provides a source of complex organic molecules for heterotrophic organisms. It makes both carbon and energy available to organisms. All organisms directly or indirectly depend on photosynthesis.
- It releases oxygen into the atmosphere that is used by aerobic organisms for respiration.
- It is the means by which the sun's energy is captured by plants for use by all organisms
- It avails man with fossil fuels
- The process of photosynthesis is a CO_2 sink .i.e. The process reduces on the amount of carbon dioxide in the atmosphere thus controlling global warming
- Photosynthesis together with respiration create a cycling of carbon dioxide ($C0_2$) and oxygen in the atmosphere

Conditions necessary for photosynthesis

***1.* Carbon Dioxide**

Terrestrial plants obtain carbon dioxide;

a. from the atmosphere (where it's about 0.03%) via the stomata
b. By absorbing carbonates from the soil through the roots. Aquatic plants absorb dissolved bicarbonates through their general surface to carbon dioxide.

2. Water

Water provides the H^+ ions and electrons for the reduction of carbon dioxide in oxygenic photosynthesis of all organisms.

$$2H_2O \xrightarrow{\text{light energy}} O_2 + 4H^+ + 4e^-$$

3. Light

The three properties of light that are of importance to organisms are **(i) spectral quality**/colour **(ii) intensity/**brightness **(iii) duration/**time.

Light is electromagnetic energy propagated in discrete particles called **photons or quanta.**

***4.* Photosynthetic Pigments**

The photosynthetic pigments which are of two categories:

(1) Chlorophyll

(2) Carotenoids take part in absorption of light energy for the purpose of photosynthesis.

Chlorophyll belongs to a class of organic compounds called porphyrins and bears a close resemblance to the chemical structure of haem and the cytochromes.
Chlorophyll b and carotenoids are called **accessory photosynthetic** pigments because they hand over the energy absorbed by them to chlorophyll a.

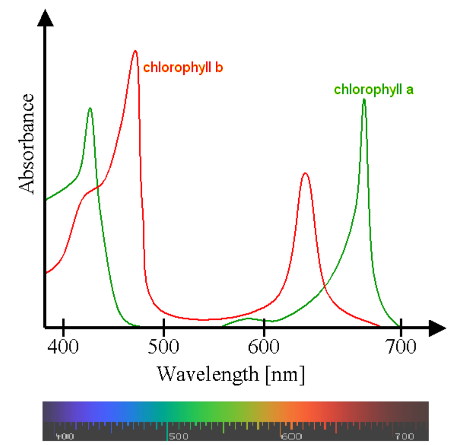
Carotenoids serve two key roles in plants and algae:
(1) Absorb light energy and pass it over to chlorophyll a for use in photosynthesis,
(2) Protect chlorophyll from being destroyed by excess light/photo damage and from oxidation by oxygen produced by photosynthesis.
3) They provide bright and attractive colours to the leaves/bracts for attraction of insects for pollination and to fruits to attract agents of dispersal.

Absorption and action spectra

Absorption spectrum **is the graph showing the relative amount of light absorbed at different wave lengths by photosynthetic pigments**/*chlorophyll.*

The absorption of radiation by a substance can be quantified with an instrument called a **spectrophotometer**

A graph showing the relative amount of light absorbed at different wave lengths by photosynthetic pigments

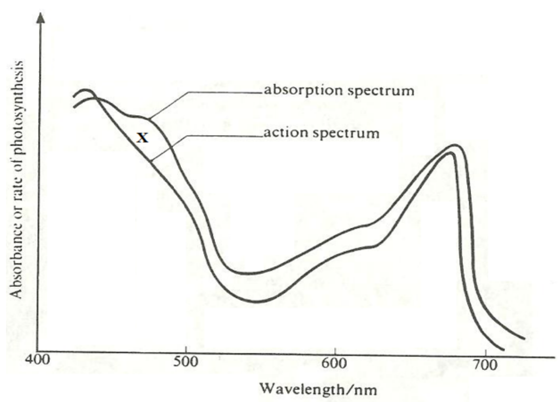


Action spectrum of photosynthesis

This is the graph showing the amount of photosynthesis occurring at each wave length. It is measured in terms of O_2 produced at each wave length. It is obtained by subjecting light of these same wave length in turn for a unit of time on to aquatic pond weed the gas evolved is collected and its volume measured (rate of O_2 production is a measure of the photosynthesis rate.

Conclusions

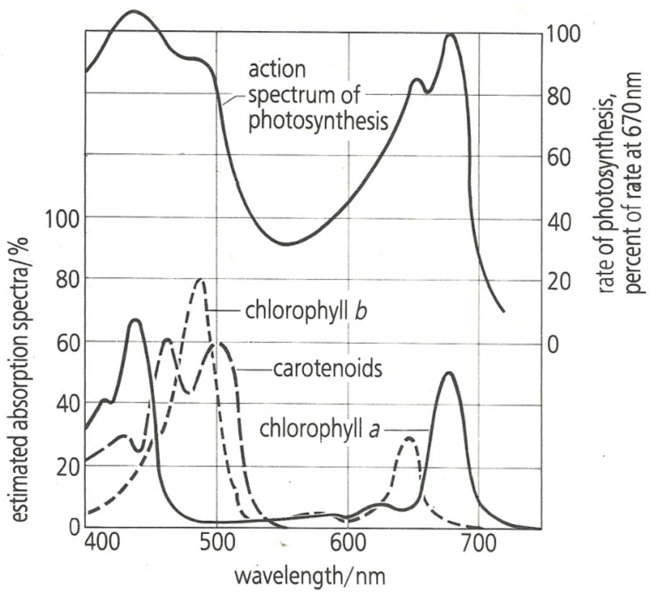
- Red and blue light is the most effective wave length for photosynthesis



Conclusions from graph on the right

1. carotenoids absorb the largest amounts in the violet blue region of light
2. chlorophyll b absorbs more blue light than red light
3. Chlorophyll a absorbs both blue and red light in large amounts.
4. There is very low light absorption of green light by chlorophyll and none for the carotenoids.

- The more the absorption of light the higher the rate of photosynthesis;
- The action spectrum shows a dose correlation with the absorption spectrum of chlorophyll a and b



Other observations

- Chlorophyll a absorption in red light is about twice that of chlorophyll b and the absorption peak is at a slightly longer wavelength (lower energy)
- Absorption of chlorophyll a in the blue is lower and shifted to a slightly shorter wavelength (higher energy).

ADAPTATIONS OF LEAVES FOR PHOTOSYNTHESIS

Adaptations for obtaining sunlight

1. ***Phototropism*** causes shoots to grow towards the light in order to allow maximum illumination.

2. ***Etiolation*** causes rapid elongation of shaded shoots to enable leaves capture light as soon as possible.

3. The **mosaic leaf arrangement** minimizes leaf overlap and reduces leaves shading each other.

4. leaf surface area, some leaves are broad to have a Leaf large surface area for capturing maximum sunlight.

5. Thickness of leaves, leaves are thin to allow easy diffusion of CO_2 and maximum light penetration.

6. The **transparence of leaf cuticle** and epidermis allow light penetration into the photosynthetic mesophyll beneath.

7. The palisade mesophyll cells are densely packed with chloroplasts and arranged with their long axes perpendicular to the surface to form a continuous layer which traps most of the incoming light.

8. ***Cyclosis*** (movement of chloroplasts within the mesophyll cells) allows them to arrange themselves into the best positions for efficient absorption of light.

9. Chlorophyll content, the chloroplasts hold chlorophyll in an ordered / structured way on the sides of the grana to present maximum chlorophyll to the light and also bring it close to other pigments / substances necessary for functioning.

10. The age of photosynthetic tissue, young leaves have increased capacity for trapping light, expanding capacity for absorbing water and synthesizing products than old leaves.

11. In leaves of shade plants, the cells of palisade and spongy mesophylls are densely packed with chloroplasts to increase on light trapping hence photosynthetic efficiency.

12**. Numerous stomata are present in the epidermis of leaves to enable entry (CO_2) and exit of gases (O_2).**

13. **The extent of opening and closing of stomata**, the guard cells bordering stomata pores can be opened and closed to regulate the uptake of carbon dioxide and the loss of water.

Spongy mesophyll possesses much airspace to enable faster and uninterrupted diffusion of gases between the atmosphere and the palisade mesophyll which wouldn't happen if the gases were to diffuse through the cells themselves, a process which would be much slower.

External factors

1. **Carbon Dioxide concentration,** there is a general increase in the rateb of photosynthesis with increase in carbon dioxide. In the atmosphere there is about 0.03% that provides steady supply of carbon dioxide to plants via the stomata

   By absorbing carbonates from the soil through the roots, aquatic plants absorb dissolved bicarbonates through their general surface to carbon dioxide.

2. Water availability;

Water provides the H^+ ions and electrons for the reduction of carbon dioxide in oxygenic photosynthesis of all organisms.

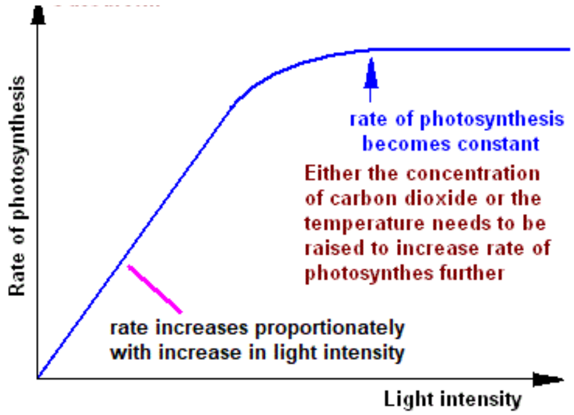
Water stress decreases the gross rate of photosynthesis.

3. Light

The three properties of light that are of importance to organisms are **(i) spectral quality**/colour **(ii) intensity/**brightness **(iii) duration/**time.

Light is electromagnetic energy propagated in discrete particles called **photons or quanta.**

The rate of photosynthesis increases with an increase in light intensity. This is up to a cetain point where some other factors become limiting e.g. carbon dioxide and temperature.



4. **Temperature range,** the rate of photosynthesis is restricted to certain range which can be tolerated by protein compounds. The biochemical reactions/ dark reactions that are part of photosynthesis are controlled by enzymes and are strictly temperature dependent.

Stages of Photosynthesis

Photosynthesis is an oxidation-reduction process, in which water is oxidized to release oxygen and carbon dioxide is reduced to form carbohydrates. Photosynthesis occurs in two phases

(1) Photochemical reactions (also called light dependent phase or **Hill reaction**)

(2) Biochemical reactions (also called **dark** or light independent phases)

Photosynthesis basically divided into 2 stages

i) Light dependant stage
ii) Light independent stage or dark reaction

Light dependent stage

It takes place in the thylakoid membranes of chloroplasts.

The main functions are:

(1) *Photophosphorylation* i.e. formation of Adenosine triphosphate (ATP) by the addition of an inorganic phosphate to Adenosine diphosphate (ADP) using light energy.

(2) Formation of $NADPH^+$ which is the reduced form of *Nicotinamide adenine dinucleotide phosphate*.

The light dependent stage involves 3 major events

1. Photolysis of water ; splitting of water
2. Formation of $NADPH^+$; reducing agent.
3. Photophosphorylation; addition of phosphorous.

This is a stage of photosynthesis that requires light energy which is absorbed by the photosynthetic pigments (chlorophyll) found in the thylakoids of the chloroplast.

These pigments are located in special reaction centres called photosystems. These systems convert the absorbed light energy (photons) into chemical energy (in form of ATP)

1. Photolysis of water; is the splitting of water using sunlight energy absorbed by chlorophyll.

Water used as a raw material for photosynthesis is chemically oxidized (split) by using light energy (protons) absorbed by chlorophyll molecules into an oxygen molecule, hydrogen ions and 4 electrons

$$2H_2O \xrightarrow{\text{light energy}} O_2 + 4H^+ + 4e-$$

The oxygen produced by photolysis of water is evolved to the atmosphere as a by -product of photosynthesis. The protons of the hydrogen ions are used in the dark stage of photosynthesis to reduce CO_2 to carbohydrates.

2. Formation of $NADPH_2$ i.e. reduced NADP

Also known as Nicotinamide adenine dinucleotide phosphate Hydrogen. This event involves reduction of oxidized NADP in the presence of two hydrogen ions and electrons obtained from the photolysis of water. Reduced NADP is one of the products of the light stage. its purpose is to carry hydrogen from the light to the dark stage for the reduction CO_2 to carbohydrates in the presence of NADP- reductase;

$$NADP + 2H^+ + 2e^- \xrightarrow{\text{NADP-reductase}} NADPH_2$$

3. Photophosphorylation

The synthesis of high energy chemical compound, ATP from Adenine Diphosphate (ADP) and a free inorganic phosphate by using energy emitted by photo-excited electrons/using the sun light energy absorbed by photosynthetic pigments in the presence of the ATPase enzyme.

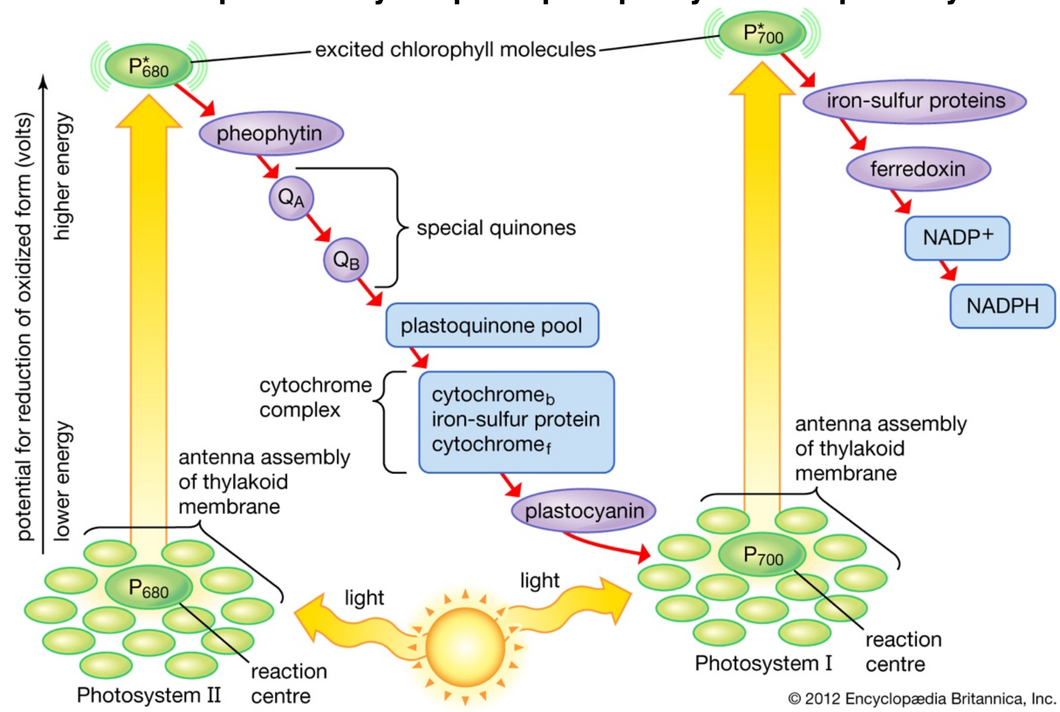
The energy used the in the formation of ATP molecules is lost by excited electrons as they are carried from higher to lower energy levels. Through this process, solar energy that excites electrons is converted into chemical energy.

$$ADP + P_i \xrightarrow[\text{Light energy}]{\text{ATPase enzyme}} \text{ATP (high energy chemical compound)}$$

N.B: phosphorylation:-involves addition of a free inorganic phosphate to Adenine Diphosphate (ADP) forming a high energy compound ATP.

$$ADP + P_i \longrightarrow ATP$$

Electron transport and cyclic photophosphorylation in photosynthesis



Mechanism of photophosphorylation

Light energy in form the photons is absorbed by the photosynthetic pigments in the reaction centres called photosystems .In each photosystem, there are several chlorophyll molecules and accessory pigments i.e. carotenes and xanthrophyll which all harvest light energy and pass it onto chlorophyll a in the reaction centres each pigment absorbs light of different wave length

There are 2 types of photosystems

i) Photosystem 1 (PSI)

With chlorophyll a molecule called P-700 which absorbs light of wave length 700 nm which functions as reaction centre. In P700 photochemical reaction takes place. The pigment system I is located on both the non-appressed part of grana thylakoids and stromal thylakoids.

ii) Photosystem II (PSII)

With chlorophyll a absorbing light of wave length 680nm (p 680) light energy absorbed excites electrons which are raised to higher energy levels and then get accepted by electron carriers (coenzymes). The lost electrons are replaced by the ones from photolysis of water or from photosystem II. This system is located in the appressed part of grana thylakoids only.

There are 2 types of photophosphorylation

1. Non cyclic photophosphorylation

This is the formation of ATP from ADP + P_i using energy emitted by photo-excited electrons as they flow unidirectionally through electron carriers from PSII/p680 to PSI/p700.

The light stage reactions are triggered by light energy exciting photosystems **I** and **II** inside the **thylakoid membranes** at the same time, **not** one after the other.

Chlorophyll molecules of PSII and PSI are excited by light of wavelength 680 nm and 700 nm respectively; causing the loss of electrons to a chain of electron carriers in a series of reduction-oxidation reaction.

Cyclic photophosphorylation

It is the formation of ATP from ADP + P*i* using energy emitted by photo-excited electrons of P-700 as they flow along photosynthetic electron carriers and back to photosystems I (P-700).

In this phosphosphorylation, light energy absorbed by PSI boosts electrons to a higher energy level that excited electrons are accepted by a ferrodoxin (electron acceptor). From ferrodoxin, electrons are recycled back in PSI directly via a series of electrons carries which are at different energy levels.

The energy lost by the electrons as they are returned to PSI is captured and released in the synthesis of ATPs from ADP and an in organic phosphate

By so doing, light energy is converted to chemical energy. The only product of cyclic photophosphorylation is ATP and involves only PSI

Cyclic and non-cyclic photophorylation compared

Similarities

In both:

(1) There is flow of electrons through several electron carriers
(2) There are photosystems which accept and lose electrons.
(3) ATP is formed.
(4) pigment system I is involved
(5) Electron movement is located in the thylakoid membranes
(6) Protons are moved outwards of the thylakoids.
(7) Protons (H^+) are actively pumped from stroma into thylakoid space.
(8) There is photo-excitation of electrons in the pigment systems.

Differences

Non-cyclic photophorylation	**Cyclic photophorylation**
• Electrons flow unidirectionally (non-cyclically)	• Electrons flow cyclically
• First electron donor is (source of electrons) water	• First electron donor is pigment system I (PSI)
• Last electron acceptor is NADP	• Last electron acceptor is pigment system I (PSI)
• The products are ATP, NADPH and Oxygen	• The product is ATP only
• Involves both pigment systems I and II	• Involves only pigment system I
• Photolysis of water occurs	• No photolysis of water

Light independent or dark stage

It's called **dark reaction** because does not require light, although can take place in light also.

The main pathways for the dark reaction

(I) Calvin-Benson cycle / C_3 pathway
(**2)** Hatch-Slack pathway / C_4 pathway

Dark reaction occurs in a cycle of reactions called the Calvin cycle named after Melvin Calvin and it occurs in the stroma of chloroplasts of C_3 -plants. The major purpose of the dark reaction is to reduce the CO_2 absorbed from the atmosphere and water to the carbohydrates.

This requires ATP and reduced NADP from the light stage of photosynthesis. ATP provides energy for the endogenic with action reaction of the dark stage and reduced NADP provides hydrogen atoms required to reduce CO_2 to carbohydrates.

Main events/ stages of the light independent or dark stage

1. **Carboxylation stage**

During this stage carbondioxide fixation occurs in the stroma of the chloroplast of the mesophyll cells.

CO_2 which has diffused into the stroma of the chloroplast reacts with 5 carbon compound, ribulose Bisphosphate under the catalysis of ribulose Bisphosphate carboxylase enzyme/RUBISCO to produce an unstable 6 carbon compound.

The 6carbon compound splits up into two molecules of 3 carbon compound, the first stable product of phosynthesis called phosphoglyceric acid (PGA) or glycerate -3- phosphate /phosphoglycerate .

Some of the Phosphoglycerate is used for the synthesis of amino acids and fatty acids needed for the synthesis of proteins and lipids respectively.

The fixing of CO_2 by RUBP is called carboxylation of RUBP or carbon dioxide fixation i.e.

$$CO_2 + RUBP\ (5C) \xrightarrow[\text{Carboxylase}]{\text{RUBP}} \text{unstable 6C organic compound}$$

2. Reduction stage

The remaining and the biggest portion of phospglycerate is reduced by hydrogen donated by reduced NADP, using energy from hydrolysis of ATP to form phosphoglyceraldehyde (PGAL) /glyceraldehydes-3-phosphate/ 3-phosphoglyceraldehyde.

Water molecules are released as PGA is reduced to the Aldehyde PGAL

$$PGA/G.P \xrightarrow[NADPH_2 \quad NADP^+]{ATP \quad ADP} PGAL \quad + H_2O$$

Part of PGAL is used for the synthesis of glycerol.

The triose phosphate is the end product of photosynthesis.

3. Isomerisation and condensation

The remaining and biggest portion of PGAL passes via a series of reactions and is used to form Monosaccharide sugars mainly hexose sugars which condense into sucrose and starch. I.E Two of the 3-phosphoglyceraldehyde molecules undergo isomerisation and several reactions to form fructose-1-phosphate and glucose-1-phosphate, both of which may condense to form sucrose or starch.

4. Regeneration of ribulose Bisphosphate (RUBP)

Another portion of PGAL is used for regeneration of RUBP via several enzyme catalyzed reactions, using energy from hydrolysis of ATP into ADP.

In regeneration of RUBP; 5 PGAL are used to regenerate 3 RUBPs .this process require ATPs and re arrangement of the carbon atom in the sugar phosphate to generate 5 carbon compounds from 3 carbon compounds

$$5\ \text{PGAL} \xrightarrow{\text{rearrangement of carbon chain}} 3\text{RUP} \xrightarrow{3\text{ATP} \rightarrow 3\text{ADP} + 3\text{P}_i} 3\text{RUBP}$$

5. **Product synthesis stage**;

Product of photosynthesis (Triose Phosphate) is assimilated through different pathways some of which are:-

- It is **converted into sucrose**; a form in which it's translocated either in storage organs or growing points.
- It is **fed into the glycolytic pathway** (respiration) to produce energy required for endogenic reactions. T.P/GPAL enters the Glyccolytic pathway where it is converted into acetyl CO.A which enters the Kreb's cycle.
- **Synthesis of lipids**:-lipids are formed from glycerol which is formed directly from T.P/PGAL and fatty acids which are obtained from phosphoglycerate/PGA/G.P.

PGA/G.P enters the glycolytic pathway to form Acetyl co-enzyme A which is then used to synthesis fatty acids, which finally react with glycerol through condensation reaction forming lipids.

- **Synthesis of proteins**: - The Triose Phosphate is fed into Kreb's cycle after converting it to Acetyl co.A. Proteins are formed from amino acids which are also formed from phosphoglycerate/glycerate-3-phosphate.

SUMMARY OF THE CALVIN CYCLE

Light independent mechanisms of photosynthesis in C_4 -plants.

C_4 Plants are the ones whose first formed stable compound of carbondioxide fixation is a 4carbon compound known as oxalo acetate.

Plants that produce the 3 carbon compound as the first stable product of photosynthesis of carbondioxide fixation are called the **C_3 plants**.

C_4 plants include; maize, sugar cane, millet, sorghum, and many tropical grasses. These are plants which are mainly monocots that produce a 4 carbon compound called oxalo acetic acid (OAA) as the first stable product of carbondioxide fixation.

They undergo two pathways of photosynthetic reactions which includes the Hatch-slack pathway and the Calvin cycle.

Hatch-slack pathway

A type of photosynthesis in which CO_2 is first, fixed by phosphoenol pyruvate catalyzed by PEP carboxylase (PEP) into Oxaloacetate (OAA) inside mesophyll cells, stored as organic acid (mainly malate) which is later decarboxylated, refixed and CO_2 is assimilated in the Calvin-cycle inside bundle sheath cells.

Hatch-slack pathway Involves transportation of hydrogen and carbondioxide from the mesophyll cells into the bundle sheath cells.
During this pathway Carbondioxide is fixed by a 3 carbon compound called phosphoenol pyruvate (PEP) in the cytoplasm of the mesophyll cells under the catalysis of phosphoenol pyruvate carboxylase enzyme to form a stable 4 carbon organic compound called oxalo-acetate (OAA).

$$\text{PEP} \xrightarrow{\text{PEP carboxylase}} \text{Oxalo-acetate (4C)}$$

Oxalo-acetate (OAA) is reduced by hydrogen from Nicotinamide adenine dinucleotide phosphate Hydrogen /reduced NADP to form a 4 carbon compound called Malate. Fixation of CO_2 by PEP to form Malate occurs in the mesophyll cells.

$$\text{OAA (4C)} \xrightarrow[\text{NADPH}_2 \;\to\; \text{NADP+}]{} \text{Malate (4C)}$$

The malate produced in the mesophyll cells diffuses through the plasmodemata and then diffuses into the chloroplast of the bundle sheath cells.
Within the chloroplasts of the bundle sheath cells, malate is dehydrogenated to give large amount H^+ ions and decarboxylated to form CO_2 and pyruvate. The C_4 path way pumps CO_2 and H^+ ions into the bundle sheath cells where they are used by the normal Calvin's cycle.

$$CO_2 \dashrightarrow \text{Calvin cycle}$$

$$\text{Malate (4C)} \xrightarrow[\text{NADP+} \;\to\; \text{NADP H}_2]{CO_2} \text{pyruvate (3C)}$$

The H^+ ions produced are used to reduce NADP to form reduce NADP/NADPH whose synthesis is limited to a bundle sheath cells.

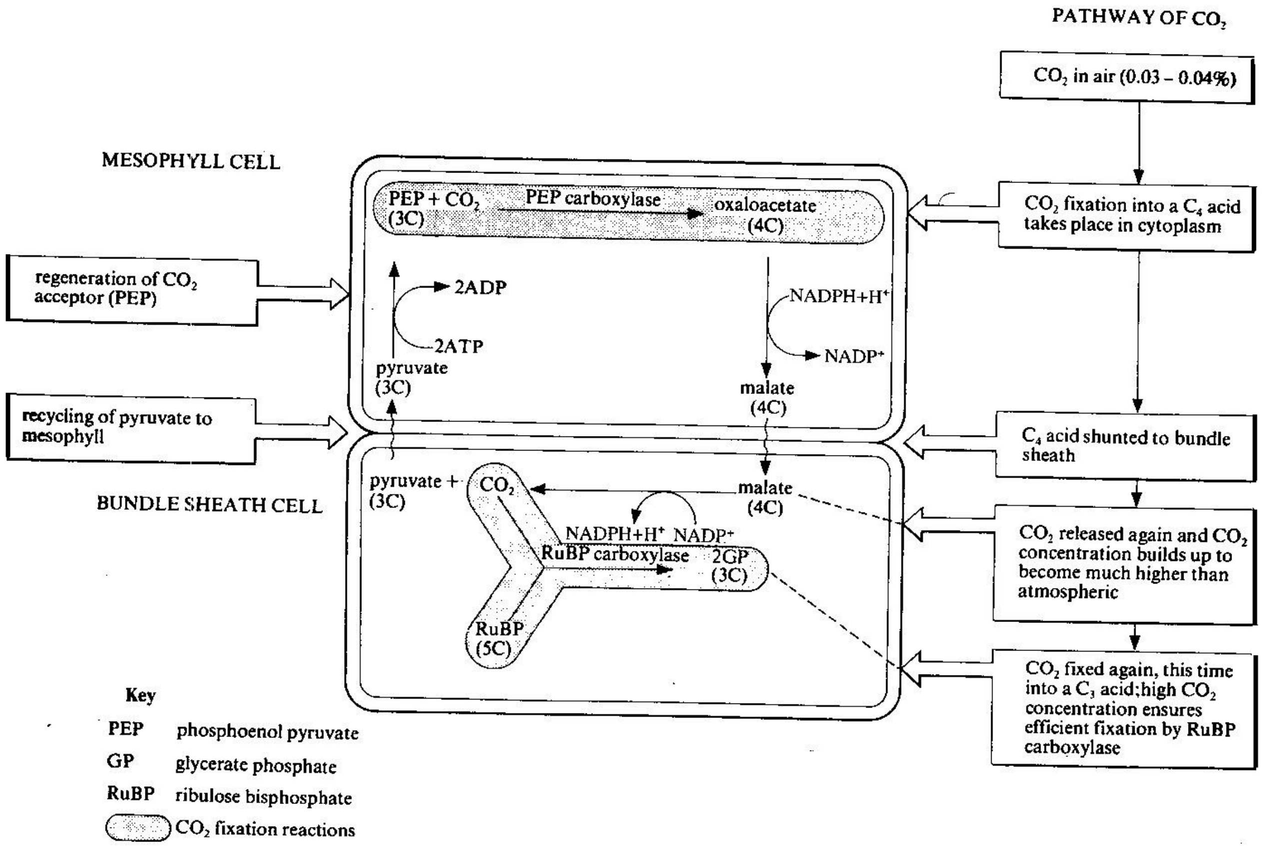
The formed CO_2 in the bundles Sheath cells is fixed by RUBP under the catalysis of RUBP carboxylase to form organic food substances via a series of reactions.

Regeneration of PEP

The pyruvate diffuses back into the mesophyll cells where it is phosphorylated using 2 molecules of ATP to regenerate the carbondioxide acceptor, PEP.

$$\text{Pyruvate (3C)} \xrightarrow[\text{ATP} \;\to\; \text{ADP +P}_i]{} \text{PEP (3C)}$$

Illustration of hatch slack-pathway



Note. 1;

1. Carbondioxide fixation in the mesophyll cells does not occur inside their chloroplasts because they *lack RUBP carboxylase enzyme.*
2. *PEP* carboxylase has a much higher affinity for CO_2 than RUBP carboxylase and therefore a higher level of carbondioxide is fixed into the carbohydrate metabolism leading into formation of a larger amount of food, energy than in C_3 plants.
3. Because of the high concentration of CO_2 fixed by PEP under the catalysis of PEP carboxylase initially, RUBP carboxylase only catalyses fixation of CO_2 rather than oxygen. The high CO_2 concentration in the chloroplast of the bundle sheath cells out completes O_2 for RUBP carboxylase active site. Hence prevents photorespiration in C_4 plants ensuring efficient CO_2 fixation by RUBP carboxylase.
4. Its high affinity for CO_2 also makes it unable to fix oxygen instead of CO_2.

Note.2

- Most C_4 plants register a high photosynthetic yield in tropics and subtropics regions with high temperatures and high light intensity due to their ability to fix a high concentration of CO_2.
- C_4 plants yield more food materials than C_3 plants because they don't photorespire.

C_4 plants have a characteristic leaf Anatomy which is described as kranz anatomy which is the arrangement 2 distinct rings of leaf cells around the vascular bundles each with a different type or form of chloroplasts, where by the inner ring of cells are called the bundle sheath surrounded the outer ring referred to as the mesophyll cells.

Chloroplasts in the C4 plants show some Dimorphism i.e. they exist in two forms. Those of the bundle sheath cells have rudimentary grana where as the grana are prominent in the mesophyll cells.

C_3 cycle: is the series of reactions in plants to form glycerate-3-phosphate (which has 3 carbons) as first organic substance during photosynthesis.

C_3-Plants are plants that fix CO_2 directly in glycerate-3-phosphate/ G.P which is a 3 carbon organic compound as the first stable product during photosynthesis.

OR C_3-Plants are plants whose first stable compound of carbon dioxide fixation is a 3 carbon organic compound called PGA/G.P/Phosphoglycerate.

Comparison of c_3 and c_4 plants

Similarities

Both:

1) contain RUBISCO enzyme
2) depend on light for their reactions
3) show CO_2 fixation
4) have RuBP
5) form several same organic products e.g. PG, PGA, sucrose
6) have the calvin cycle

Differences	**C_3 PLANTS**	**C_4 PLANTS**
structural	Lack Kranz anatomy	Exhibit Kranz anatomy
	All chloroplasts have identical structure(have one type of chloroplast)	Chloroplasts are dimorphic (have two types of chloroplasts) e.g. those of palisade cells have grana yet are lacking bundle sheath cells.
Physiological	• CO_2 acceptor is a 5-Carbon RuBP • CO_2 fixation occurs once • Photorespiration occurs • Less photosynthetically efficient • G.P is the first organic product • Enzymes are more efficient at lower temperatures(20-25^{0}C) • Use only RUBISCO enzyme for CO_2 fixation • Compensation point is attained	• CO_2 acceptor is a 3-Carbon PEP • CO_2 fixation occurs twice • No photorespiration • More photosynthetically efficient • OAA is the first organic product • Enzymes are more efficient at high temperatures(30-35^{0}C) • PEP carboxylase and RUBP carboxylase enzyme are used • Compensation point is attained at lower CO_2 concentration

	at higher CO_2 concentration	
	Oxygen is an inhibitor of photosynthesis	Oxygen is not an inhibitor of photosynthetic process
	Grows at a low rate	Grows at a high rate

Note

C_3 plants can survive best in an environment of **C_4 plants**

i) -Low temperature -Regions of high temperatures

ii) -In low light intensity -in high light intensity

iii) -Low oxygen levels -In high CO_2 levels

iv) -In high CO2 levels - RUBP carboxylase has a higher affinity for CO_2

<u>Crassulacean acid metabolism</u>

CAM plants are plants that fix CO_2 into organic Compounds i.e. citrate and malate in the absence of light .In the presence of light , the organic acids malate decompose to release CO_2 (decarboxylation) which is used in the synthesis of sugars via the C_3 path way.

Crassulacean acid metabolism photosybtnesis is a type of photosynthesis in which CO_2 is taken in at night via open stomata, fixed by phosphoenol pyruvate (PEP) carboxylase into **OAA**, stored as organic acid (mainly malate) which is **later** decarboxylated during daytime, refixed and CO_2 is assimilated in the Calvin-cycle when stomata are closed. CO_2 enters the leaf and fixed at night through the PEP system. The enzymatic conversion /breakdown of the mallic acids formed during day provide a supply of CO_2 for C_3 pathway/Calvin cycle.

Examples of CAM plants

Cacti, agaves (sisal), opuntia, *Kalanchoe* (*Bryophyllum*), Vanilla (family: Orchidaceae)*, pineapples (Family*: ***Bromeliaceae),*** Mesembryanthemum crystallinum (Common ice plant), and *Euphorbia milii* **a.k.a** Crown of Thorns plant – a spiny climber with showy red bracts, commonly grown in school gardens

Significance of CAM photosynthesis

For terrestrial CAM plants, there is increased water use efficiency (WUE) in which nocturnal stomatal opening greatly reduces stomatal loss of water as it would in day light.

Factors affecting the rate of photosynthesis

Internal factors

- Structure of the leaf and chlorophyll content
- Influence of enzymes
- Accumulation with in chloroplasts of products of photosynthesis
- Hormones
- Leaf size
- Number of stomata
- Vascular bundles
- Air spaces

External factors

- Quantity and quality of light incident on leaves
- Suitable temperature
- Concentration of carbon dioxide in the surrounding atmosphere
- Concentration of oxygen in the surrounding atmosphere
- Availability of water
- Inorganic ions; absence of ions like mg, N and Fe , chlorophyll can't be synthesized
- Salinity; One of the major effects of salinity is osmotic stress, and hence there are intimate relationships to drought stress or 'water stress'. This results in stomata closure in an effort to avoid desiccation, which reduces photosynthesis because uptake of CO_2 reduces.

The principle of limiting factors

It states that:

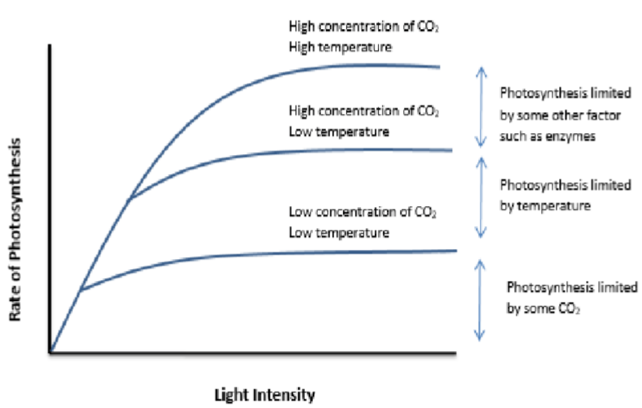
When a chemical process depends on more than one essential conditions being favourable, its rate is limited by that factor nearest its minimum value/in its short supply.i.e.

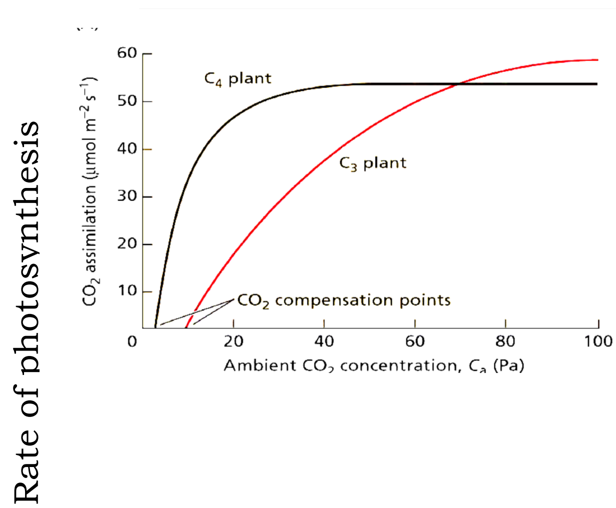
A limiting factor is this factor which directly affects the process if it's quantity is changed.

Example photosynthesis can't proceed in the dark because the absence of light limits the process. The absence of light will alter the rate of photosynthesis

When one factor is favourable e.g. when light is increased the rate of photosynthesis increases until it levels of because another factor other than light intensity limits the rate of photosynthesis. But when the limiting factor such as CO_2 is increased, the rate of photosynthesis further increases until yet another factor like temperature tends towards its minimum and limits the rate of photosynthesis resulting its leveling off.

A limiting factor is any essential factor whose deficiency slows down the rate of a reaction.





Effect of carbondioxide

1.4.O CHEMICALS OF LIFE

1.4.1 MEANING OF CHEMICALS OF LIFE

Chemicals of life are substances which constitute or make the protoplasm of cells of the living organisms. They are also referred to as bio-chemicals.

The study of chemicals of life and chemical reactions in which they take place is known as bio-chemistry. Chemicals of life are grouped into two categories e.g.

Organic compounds for example;

1. Proteins
2. Carbohydrates
3. Lipids
4. Vitamins

Inorganic compounds for example;

1. Water
2. Mineral salts
3. Bases
4. Acids

1.4.2 ORGANIC CHEMICALS OF LIFE

Organic compounds

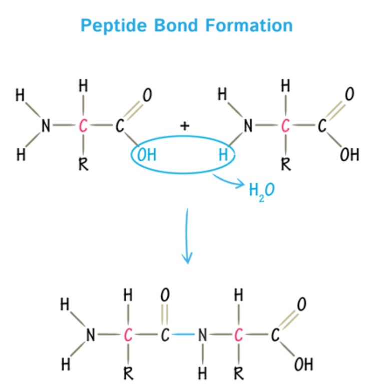
Organic compounds are compounds that contain carbon-hydrogen bonds. Due to carbon's ability to form chains, millions of organic compounds formed are known.

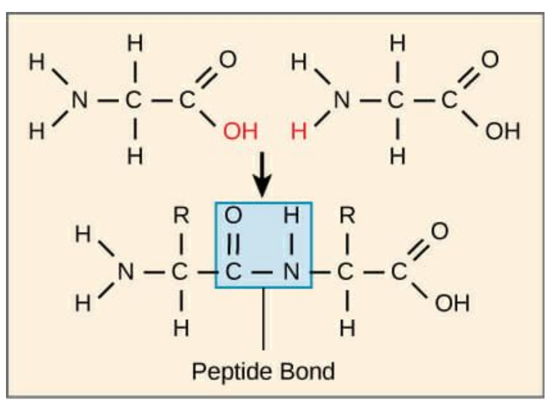
Organic chemicals of life are;

Proteins

These are organic compounds made up of carbon, hydrogen, oxygen, nitrogen, sulphur and sometimes phosphorus.

Proteins are complex molecules, they are long chains of amino acids. The amino acids are linked together to form a dipeptide joined by a peptide bond through a process known as condensation.





Protein molecules have a high molecular weight e.g. beta lacto globulin found in milk.

General properties of proteins

- Proteins are colloidal in nature; they <u>form colloids</u> in suspensions i.e. proteins exist in two phase system in which particles of one phase are suspended in a second phase.
- They are <u>large size molecules</u>, proteins have molecular mass/weight e.g. Haemoglobins have a molecular weight of 64500g.
- They are <u>amphoteric,</u> proteins have acidic and basic properties.

- Denaturation, all proteins are affected by a variety of stimuli e.g. protein structure is destroyed by heat, chemical reagents and solar radiation (ultra violet rays).
- Hydrolysis of proteins, a complete hydrolysis of all proteins yields a mixture of amino acids and usually some ammonia.
- Specificity of proteins, proteins such as enzymes like amylase and pepsin are specific in the action they act.
- Proteins dissolve in concentrated acids in excess.

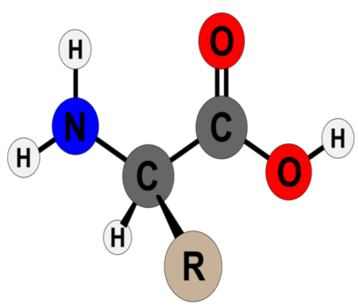
Amino acids

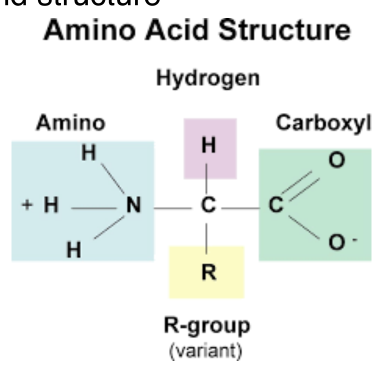
Amino acids are basic structural molecules that make up proteins.

Amino acids are organic compounds composed of nitrogen, carbon, hydrogen and oxygen, along with a variable side chain group.

Animal body needs 20 different amino acids to grow and function properly.

Amino acid general formula and structure





Amino acids have four different parts i.e. hydrogen group, amine group, carboxyl group and R-group.

The presence of amine group (basic) and carboxyl group (acidic) in all amino acids accounts for the name and gives them amphoteric nature.

Amino acids are buffers, if pH falls below the required point (isoelectric point) of amino acids, hydrogen group is taken up by the hydroxyl group and the solution becomes less acidic. When pH rises above the required point of amino acid, hydrogen ions are released from the amine group hence the solution becomes less alkaline. This keeps a given solution nearly neutral.

Amino acids are classified into two groups. Though all 20 of these are important for animal health, only nine amino acids are classified as essential, others are non essential amino acids.

Essential amino acids

Essential amino acids are amino acids which are required by the body in large quantities. They are not synthesised by the body but are rather supplied to the body in the diet.

Essential amino acids are also called first class proteins, they include all plant proteins and some animal proteins. Foods lacking one or more of the essential amino acids in proteins are referred to as secondary proteins.

Non essential amino acids

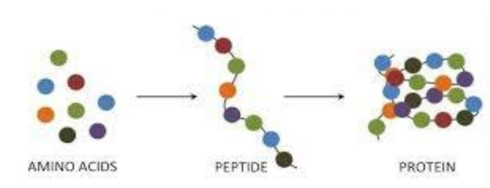
These are amino acids which the body can synthesise and are required in small quantities. Their absence in the does not cause stunted /retarded growth.

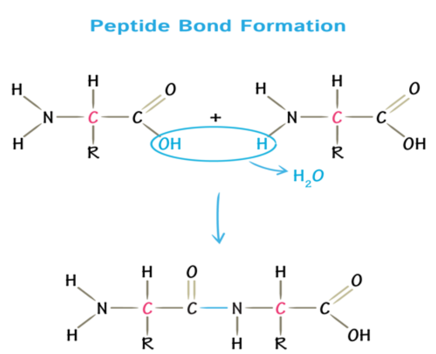
S. no	Essential amino acids	S. no	Nonessential amino acids
01	Arginine	01	Alanine
02	Histidine	02	Asparagine
03	Isoleucine	03	Aspartate
04	Leucine	04	Cysteine
05	Lysine	05	Glutamate
06	Methionine	06	Glutamine
07	Phenylalanine	07	Glycine
08	Threonine	08	Proline
09	Tryptophan	09	Serine
10	Valine	10	Tyrosine

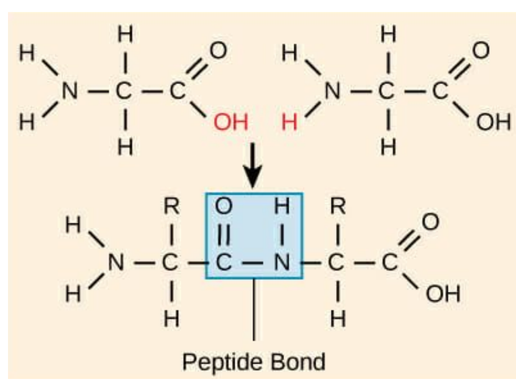
Building up proteins

Amino acids are joined together in condesnsation reaction to form a dipeptide. Individual amino acids are joined together by a peptide bond.

Different amino acids join to form polypeptides.







The water molecule formed is a result of loss of hydroxide group from carboxylic group of one amino acid and hydrogen atom from amine group of a different amino acid.

Protein structure

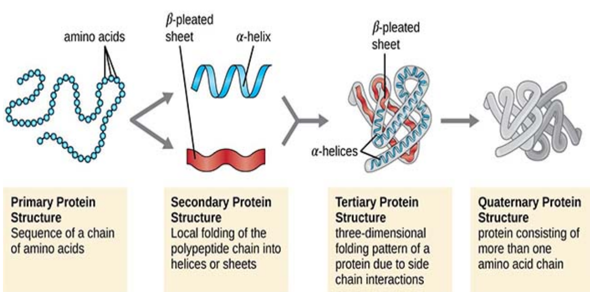
The structure of protein is described at different levels for example;

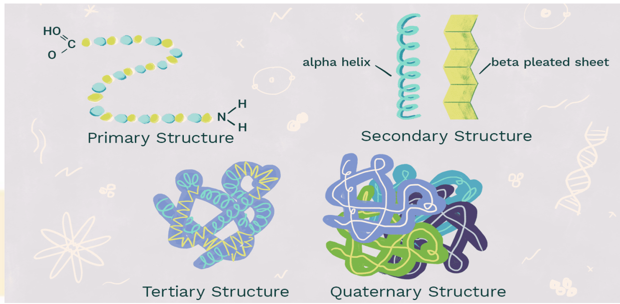
Primary protein structure; this is a specific amino acid sequence in the polypeptide chain.

Secondary protein structure; this is an irregular arrangement of polypeptide chains forming sheet or helix. It is maintained by hydrogen bonds at regular intervals. For example collagen, silk and keratin. Collagen is a fibrous protein found in muscles and tendons. Inter molecular hydrogen bonds produce a regular coiling in form of alpha helix.

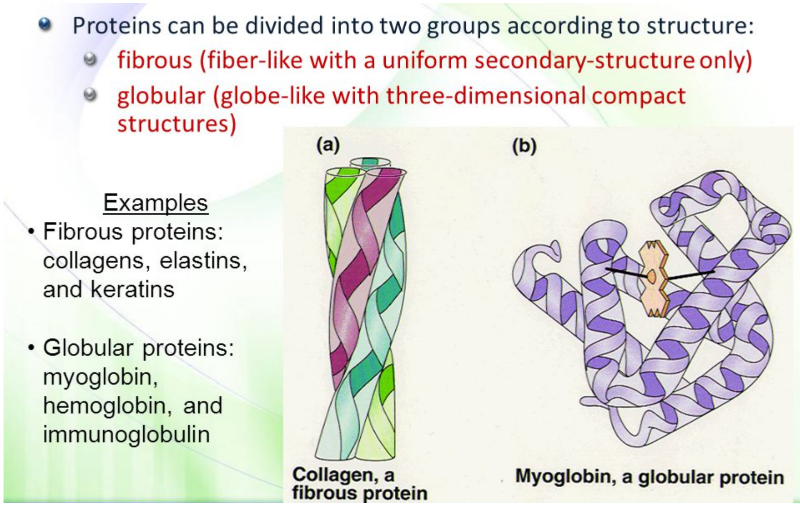
Tertiary protein structure; this is a structure that is formed from further coiling and coiling of polypeptide chains. The folding of polypeptide chains are maintained by sulphur bonds (S-S) and covalent bonds formed by hydrogen intercalations.

Quaternary protein structure; this is formed from arrangement of polypeptide chains in protein that have more than one polypeptide per molecule e.g. in heamoglobin. The polypeptide chains are joined together to form complex structure.





Types of proteins



Fibrous proteins consist of long, parallel polypeptide chains crossing over at the main points along the length.

They are soluble in water e.g. keratin that makes up finger nails and feathers.

Globular proteins are made from polypeptide chains that are tightly folded to form special shapes. They are relatively soluble and form colloidal suspension, they are found in blood plasma and cell protoplasm e.g. antibodies, hormones and enzymes

Examples	- Keratin (in hair) - Collagen (in skin and bone).	- Haemoglobin - Insulin - Enzymes
Solubility in water	Insoluble	Soluble
Roles	Structural: - Collagen in bone and cartilage - Keratin in fingernails and hair.	Metabolic - Enzymes in all organisms, - Plasma proteins, antibodies in mammals.

Importance of proteins in the animal's body

1. Support; some proteins are structural which give support to the skin and tendons.
2. Body defense (protection); some proteins play a vital role in fighting against disease causing agents and prevent them from destroying body cells for example antibodies.

3. Metabolism; some proteins are digestive enzymes that speed up the chemical reactions in the body cells e.g. amylase, pepsin and trypsin.
4. Transport; carrier proteins in blood plasma and plasma membrane allow substances to enter and exit the cells for example; haemoglobin is a complex protein that transports oxygen in blood of animals.
5. Regulation/homeostasis; hormones are regulatory proteins in the body e.g. insulin regulates testosterone, amount of glucose content in the blood and growth hormone thyroxin determines height of individual organisms.
6. Locomotion; contractile proteins e.g. myosin and actin allow passage of body tissues to allow animal body tissues to move and contract thus enabling locomotion.

Importance of proteins in plants

1. Proteins are the most complex and abundant of the macro molecules. Within cells, many proteins function as enzymes in the catalysis of metabolic reactions, while others serve as transport molecules, storage proteins, electron carriers, and structural components of the cell.
2. They are especially important in seeds, where they make up as much as 40 percent of the seed's weight and serve to store amino acids for the developing embryo.

Nuleic acids

Nucleic acids are polymers of nucleotides. The nucleotides are joined by phospholipids ester linkage formed between one nucleotide and hydroxyl group at carbon 3 (c3) of the sugar of another nucleotide.

Structure of a nucleotide

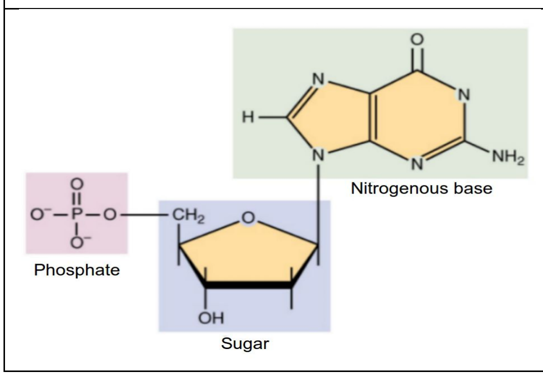
A nucleotide is a building block (monomer) of nucleic acid

The commonest nucleic acid is DNA (deoxyribonucleic acid)

DNA is the genetic material in all living organisms apart from some viruses which use RNA (ribonucleic acid) as a genetic material.

DNA and RNA are called nucleic acids, this is because they were first detected in the nucleus.

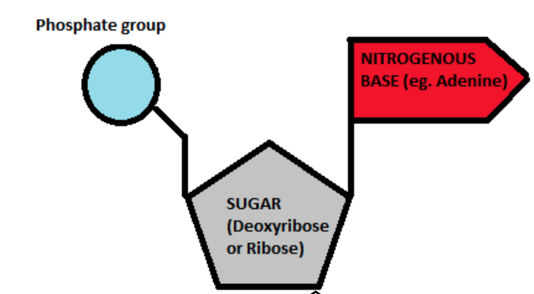
Nucleotide



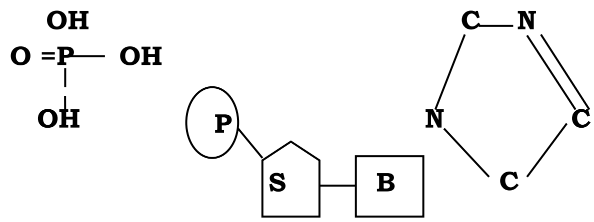
DNA consists of many genes and genes specify the sequence of amino acids in the proteins. In the eukaryotic cells, DNA is found in the nucleus and found with nucleus protein called histone which forms parts of chromosomes.

RNA is the helper that makes the genetic information to the site of protein synthesis. Nucleic acids have monomers as basic units that form polymers.

Illustration of a nucleotide model

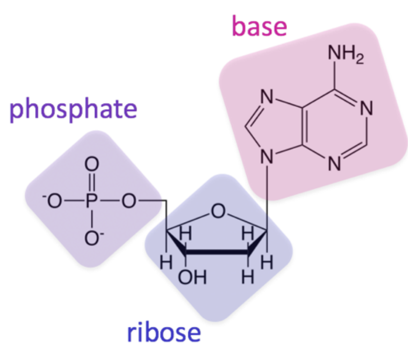


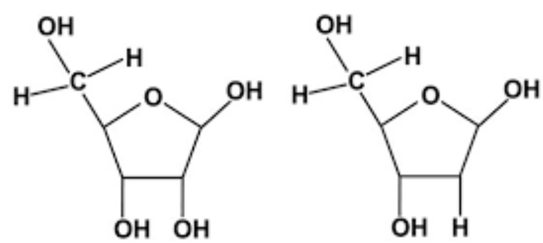
A nucleotide is made up of phosphate group, pentose sugar and organic nitrogen containing base shown below respectively.



P Phosphoric acid S Pentose sugar B Organic nitrogen containing base

DNA nucleotide Pentose sugars





Ribose Deoxyribose

Organic nitrogen containing bases are of two types; purine and pyrimidine.

Pyrimidines are single ring compounds with nitrogen in position one of a six member ring.

Examples of pyrimidines;

Cytosine (C)

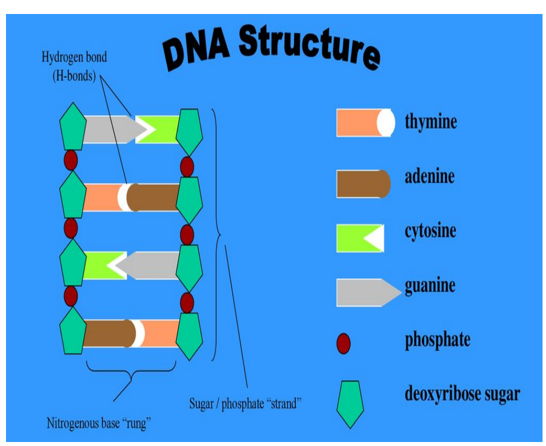
Thymine (T)

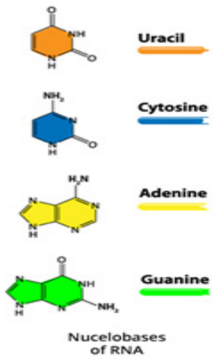
Purines are double ring compounds.

Adenine (A)

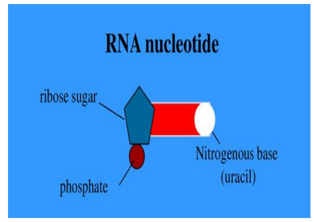
Guanine (G)

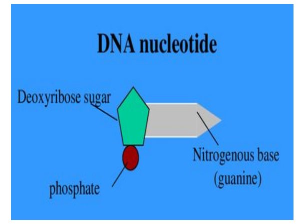
During pairing of DNA molecule, Adenine pairs with Thymine (A - T), and Guanine pairs with Cytosine (C - G).





Note; RNA has bases adenine, guanine, cytosine and uracil. It is a single ring structure with bases G,U, A, C.





Differences between DNA and RNA

DNA	RNA
Double stranded	Single stranded
Pentose sugar is deoxyribose	Pentose sugar is ribose
DNA mainly confined in nucleus	RNA mainly confined in cytoplasm
Pyrimidines are thymine and cytosine	Pyrimidines are uracil and cytosine
It is the genetic material in all living organisms	It is the genetic material in some viruses
It is very stable chemically	It is less stable chemically
DNA stores protein encoding information	RNA carries protein encoding information

CARBOHYDRATES

Carbohydrates are compounds made up of hydrogen and carbon int the ratio of hydrogen to water 2:1 as it is in water.

True carbohydrates are all saccharides, that to say, sugars with various combinations.

They have general formula with $(CH_2O)n$, that is why they are called carbohydrates.

Functions of carbohydrates in animal's body

1. They form important storage compounds e.g. glycogen.
2. They form principle respiratory substrates e.g. hexose sugar like glucose.

Functions of carbohydrates in plants

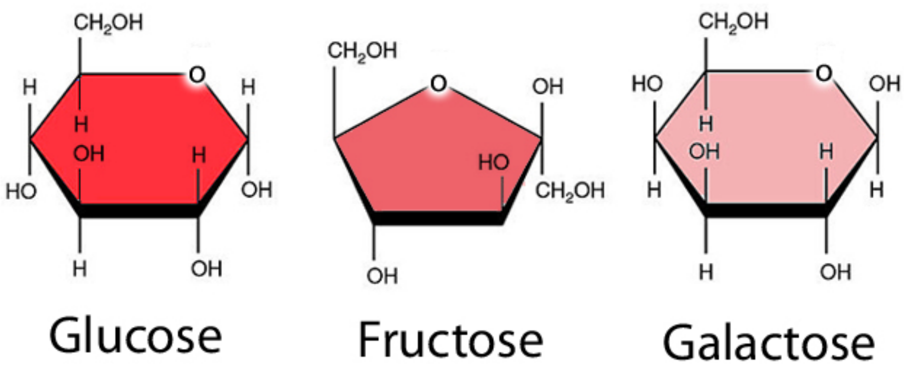
1. Carbohydrates form basic structural compounds e.g. sucrose in cell wall of plant cells, pectin and lignin in woody plant species.
2. They form important storage compounds e.g. starch.

Carbohydrates are polymers formed from monosaccharides.

Monosaccharides

Monosaccharides are compounds which are the simplest forms of sugars. They are the building blocks of carbohydrates.

Examples of monosaccharides



Properties of monosaccharides

1. They are soluble in water
2. They are crystalline
3. They are all sweet
4. They are subdivided to number of carbon atoms in a monosaccharide molecule

The simplest number is 3, hence called triose sugars e.g. glyceraldehydes; 5-carbon sugar, pentose sugar e.g. ribose and ribulose; 6-carbon sugar, hexose sugar e.g. galactose, glucose and fructose. The common monosaccharides in cells have three to seven carbon atoms.

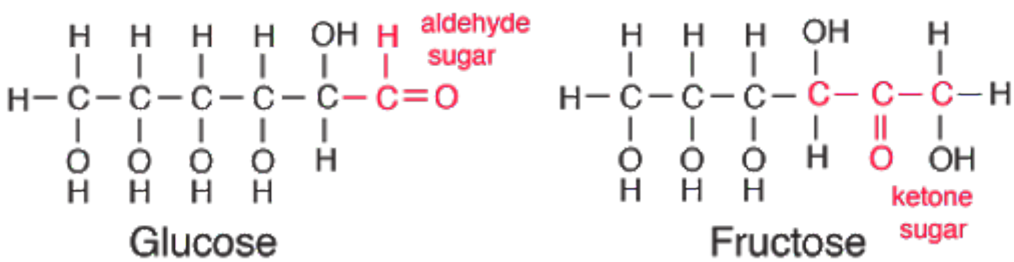
Reactive groups found in monosaccharides are; aldehyde and ketone groups.

Examples of sugars with ketone groups;

Ribulose and fructose

Examples of sugars with aldehyde groups;

Glucose and most other simple sugars



Test for simple sugars

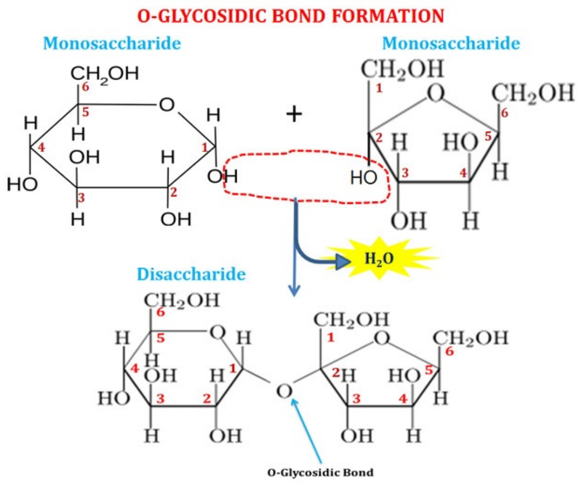
All monosaccharides are simple sugars, when heated with standard test reagent (Benedict's or Fehling's solution), they give either some or all of these colours; green, yellow, orange and brown.

In absence of the reducing sugars, these standard test reagents retain their basic colour (blue). The colour changes are due to reduction of copper (II) ions to copper (I) ions which give re precipitate of Cu(I) oxide.

Disaccharides

These are sugars formed as a result of combination of two monosaccharides. They have a general formula $C_{12}H_{22}O_{11}$ and not $C_{12}H_{22}O_{22}$ because their formation involves loss of water molecules. i.e. one disaccharide formation involves loss of water molecule.

$C_6H_{12}O_6 + C_6H_{12}O_6 \longrightarrow C_{12}H_{22}O_{11} + H_2O$



Such a reaction that involves loss of water molecule is known as **condensation reaction.** The backward reaction that involves addition of water to break down the disaccharide is known as **hydrolysis.** Hydrolysis is done by enzymes in living organisms and by hydrochloric acid in laboratory. The monosaccharides are held together by covalent bonds known as glycosidic bonds.

Properties of disaccharides

1. Some disaccharides like maltose can reduce the Benedict's reagents like monosaccharides to give a basic colour of their test (green, yellow, orange) but others like sucrose are non reducing sugars.
2. They have sweet taste.
3. They are all soluble in water and readily converted to monosaccharides when hydrolysed.

Examples of disaccharides

Disaccharide	Monosaccharide	Source
Sucrose	Glucose + fructose	Sugar cane
Lactose	Glucose + galactose	Milk
Maltose	Glucose + glucose	Germinating seeds

Functions of disaccharides

1. They are food reserves in living organisms e.g. sucrose.
2. Disaccharides are a major form of transport of organic salts in the phloem of plants.

Chemical test for disaccharides

Both lactose and maltose are reducing sugars, so their chemical test is similar to that of monosaccharides.

Sucrose is non reducing sugar, it is first hydrolysed to its constituent sugars in order to give positive test with Benedict's solution of Fehling's solution.

Sucrose is first heated/ boiled in HCl for about two (2) minutes, followed by sodium hydroxide (NaOH) solution to neutralize the acid and then Benedict's solution added, and then boil to get test results.

Polysaccharides

These are polymers of many polysaccharides. They are formed from condensation of a variety of many monosaccharides to form chains of variable length.

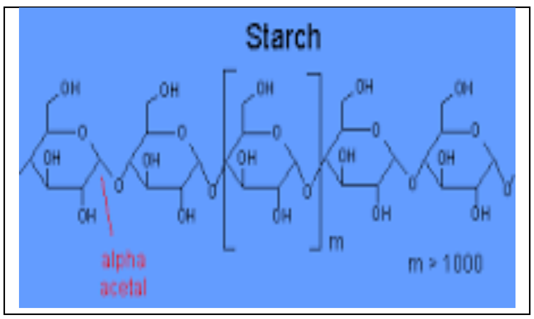
Polysaccharides are branched, un branched or coiled for example starch. Some others are coiled or straight e.g. cellulose.

Properties of polysaccharides

1. They are either soluble or insoluble in water or form colloidal suspension.
2. They form coloured products with iodine.
3. They are uncrystallisable.
4. They are chemically inert.
5. They are insoluble in water hence form good storage compounds in the body and cannot easily diffuse out of cells.

Examples of polysaccharides include;

- Starch
- Cellulose
- Glycogen
- Chitin



Starch is a storage disaccharide in plants and stored in form of large molecules called starch grains.

Starch grains exist in seeds, tubers such as potato and cassava, and in chloroplast.

Addition of iodine to solution containing starch results into a solution changing to dark blue colour. This indicates that starch is present, if the brown colour of iodine persists it implies that starch is absent.

Cellulose is the most common organic molecule which is the structural material in plant cells. It has straight chains of beta (β) group.

Glycogen

This is the storage form of glucose in the animal body. It is found in the liver and muscle cells. It is stored in the cytoplasm of animal cells.

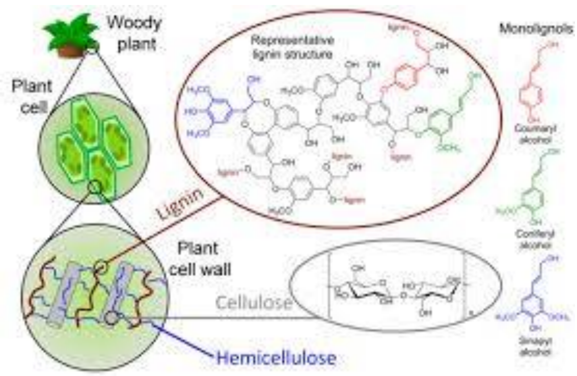
Chemical test for glycogen

Test procedure; Addition of iodine solution to a substance containing glycogen.

Observation; brown colour changes to red or violet.

Lignin

Lignins are plant polymers made from phenyl propanoid building units. They contain most of the wood methoxyl content.



Lignins are resistant to acid hydrolysis, readily oxidized, soluble in hot alkaline and bisulfite, and readily condensed with phenols or thiols.
Lignin is a three-dimensional polymer built up of phenyl propane units that is laid down within the cell wall after tracheid elongation has ceased.
The incorporation of lignin into the cellulose microfibril structures within the cell wall greatly enhances the mechanical strength properties of wood, over pure cellulose.

LIPIDS

Lipids are macromolecules made of fatty acid monomers.

Lipids generally refer to natural fats and oils. They also include other substances like hormones, steroids, phospholipids and waxes.

Properties of lipids

1. Lipids are less dense than water, therefore can float on water.
2. They are non polar and they are relatively insoluble in water but soluble in organic solvents.
3. They can be hydrolysed by dilute acids like sulphuric acid or enzymes like lipase to fatty acids and glycerol.
4. They have high proportion of hydro-carbon group in molecule.

They are basically made up of C, H, and O; just as carbohydrates but unlike in carbohydrates where the ration is 2:1, for lipids they have more hydrogen atoms than oxygen.

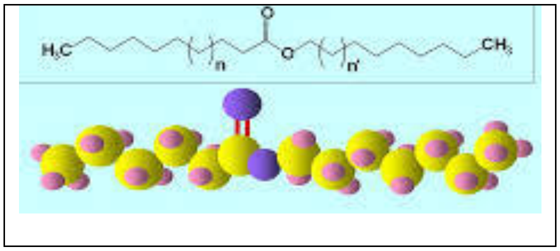
Natural fats and oils

A fat is differentiated from oil by its physical state at room temperature (20 - 25^{o}c).

Oils are liquids while fats are solids at room temperature, however they are chemically similar.

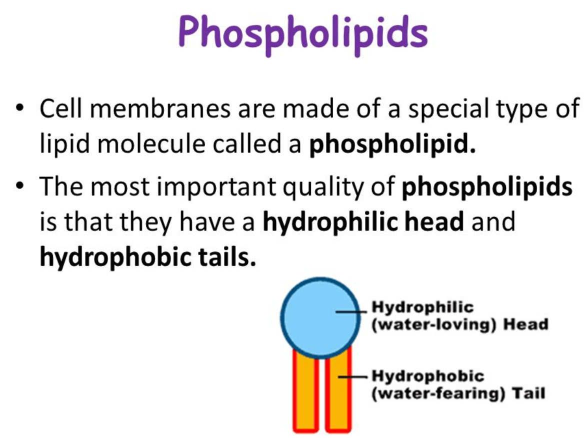
Wax

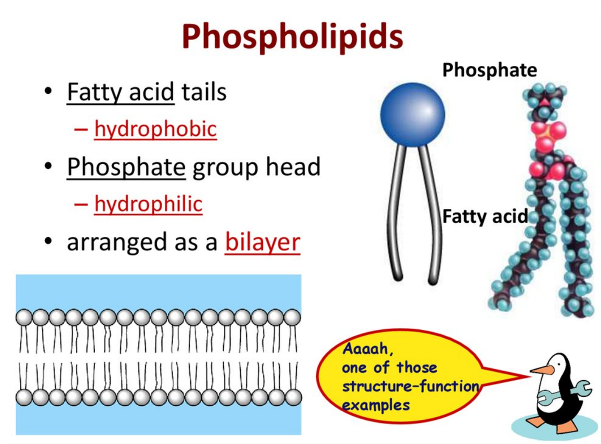
Wax is an ester with a long chain of alcohol and another chain of fatty acids.
Closely resembles a long hydrocarbon chain.
Wax base is similar to plastic base, hence its hydrophobic tendency.
Wax is difficult to hydrolyse unlike fats and oils.

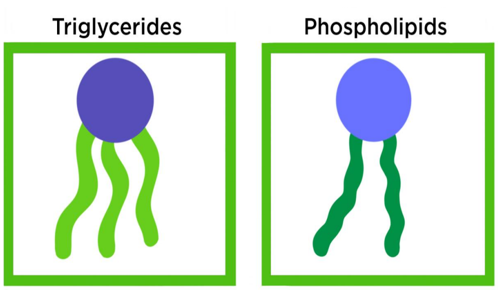


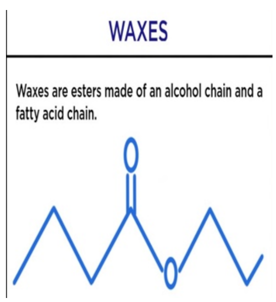
Steroids
Apart from being insoluble in water, all steroids have similar structures.
They are synthesised from cholesterol.
Other lipids include; phospholipids

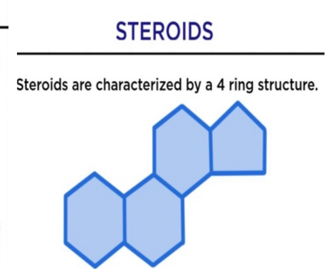
Phospholipids;
Phospholipids are found in cell membranes in the phospholipid layer, one of the fatty acids is replaced by nitrogen containing molecule connected to glycerol by a phosphate group.



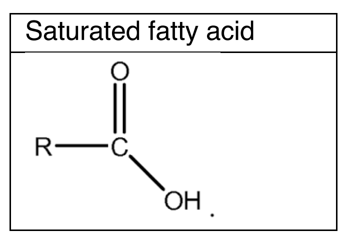


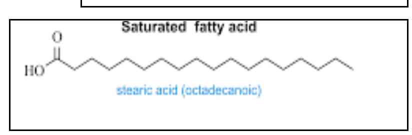




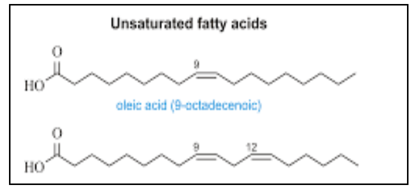


Fatty acids and glycerol
Both fatty acids and glycerol have general formula $C_nH_2O_n$





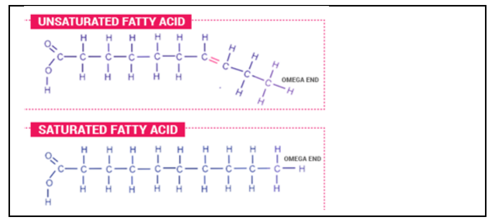
Their formula can be summarized as $(CH_2)_n$ COOH, where n is any number between 4 and 24.



Fatty acids are called saturated if the (CH_2) group is joined by a single bond.

If the (CH_2) group is joined by double bonds in the carbon chain, then it is referred to as unsaturated.

Saturated fatty acids do not contain double bonds C-C (only single bonds), whereas unsaturated fatty acids contain one or more double bonds C=C. The chain length of most common fatty acids is of 16-18 number of carbon. The triglyceride is considered as the common and simple type of fat, having three fatty acids and glyceride. By the chemical structure of fatty acid chain, the division is done.

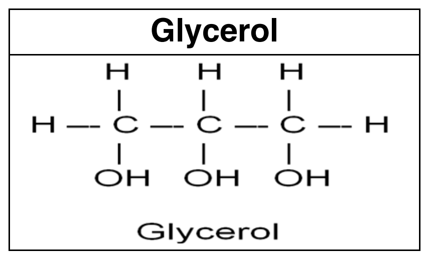


Fatty acids are the carboxylic acids with the side chain of hydrocarbon and also the simplest form of lipids. These lipids are considered as the concentrated chief fuel reserve of the body.

To remain healthy both saturated as well as unsaturated fats are necessary, but it is suggested by the dietary, that the unsaturated fats should be consumed in high proportion as compared to saturated fats, as unsaturated fatty acids are said to maintain the cholesterol level in the body.

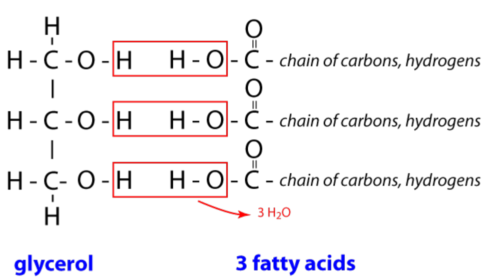
Glycerol

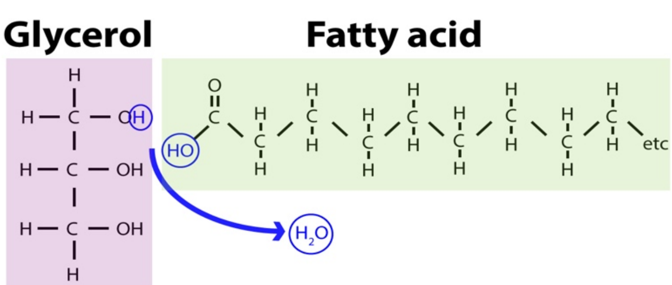
Glycerol is also referred to as propane 1, 2,3 trial,. This is an alcohol with the formula $C_3H_8O_3$.



During formation of fats and oils, three fatty acids either similar or different combine with glycerol molecule during condensation reaction.

Fat synthesis





Importance of lipids

1. Fats and oils are used as sources of energy.
2. Lipids offer additional protective layer on cuticle of epidermis of some plants.
3. Lipids form cuticle on the epidermis of skin and feathers of insects and birds respectively.
4. Fats are used in ninsulation of the body against heat loss especially where hair and feathers have negligible significance.
5. Phospholipids are essential in the building up of cell membranes in animals.
6. Wax forms water proof layer of terrestrial organisms.
7. Lipids are important for shock absorption especially in delicate mammalian organs like kidney.

Chemical test for lipids

Translucent mark test

A lipid is rubbed on a piece of white paper and looked through light.

Observation; permanent translucent mark formed confirms presence of lipids.

Vitamins

Vitamins are organic substances of low molecular weight required in small amounts but very essential for normal metabolism and health of plants and animals.

Examples of vitamins

1. Vitamin A
2. Vitamin B
3. Vitamin C
4. Vitamin D
5. Vitamin E
6. Vitamin K

Source of vitamins

Type and source	Function	Deficiency
Vitamin A Egg yolk, milk, liver, cheese, butter and fish	Helps in healing wounds Maintains normal functioning of skin and mucus membrane lining nerves and respiratory tract. Forms part of light sensitive pigment in the retina eye for seeing in dim light.	Night blindness Poor vision in dimmlight Dry conea Dry scaly patches on the skin
Vitamin C Citrus fruits, Fresh green, vegetables, liver	Formation and maintenance of collagen protein that supports body structures e.g. muscles. Proper formation and development of bones. For wound healing on the body. Enhances absorption of ions from food of vegetable origin.	Scurvy Dry skin and hair Muscle and joint pain Loosening of teeth Swollen and bleeding gums
Vitamin D Sunshine, liver, fish, butter, cheese, fortified milk.	For normal bone formation Retention of calcium and phosphorus in the body. Protects bones and teeth against effect of low calcium intake.	Rickects in children Soft bones in adults Deformed rib cage and skull Soft and painful bones Bow legs
Vitamin E Vegetable oil, liver, wheat, leafy green vegetable.	Forming normal red blood cells Promotes the oxidation of fats and vitamin A Promotes fertility in vertebrates	Sterility in rats
Vitamin K Eggs, soya, fish, liver oil.	for normal blood clotting aids formation of prothrombine to produce fibrous cloth.	Moderates disorders in blood clotting.
Qn. State the sources, functions and deficiency symptoms of vitamin B complex.		

1.4.3 INORGANIC CHEMICALS OF LIFE

Inorganic chemicals of life

Mineral salts

Total mineral matter of a plant is determined by burning a sample of feed until all the moisture evaporates and organic matter decomposes and is lost to atmosphere as smoke. Ash residues left represent mineral matter.

Minerals are categorized as macro and micro minerals.

Macro minerals are minerals required by the body in large quantities.

Micro minerals are minerals required in small quantities by the body.

Both micro and macro minerals are essential. When micro minerals are taken in large quantities, they become toxic to the animal's body.

Classification of minerals

Major/macro mineral	Micro/trace mineral
Calcium (Ca)	Chromium (Cr)
Chlorine (Cl)	Cobalt (Co)
Magnesium (Mg)	Copper (Cu)
Phosphorus (P)	Flourine (F)
Possium (K)	Iron (Fe)
Sodium (Na)	Manganese (Mn)
Sulphur (S)	Molybdenum (Mo)
	Selenium (Se)
	Silcon (Si)
	Zinc (Zn)

Note; when Copper, molybdenum, selenium, fluorine and manganese are provided in large quantities, they become toxic to the body.

Functions of minerals salts in the animal's body

1. Mineral salts are constituents of skeleton e.g. calcium and phosphorus.
2. They maintain acid-base balance in the body fluids such as blood.
3. They are components of enzyme activators and catalysts.
4. They maintain osmotic pressure and ion exchange in the body system.
5. They aid in muscle contraction.

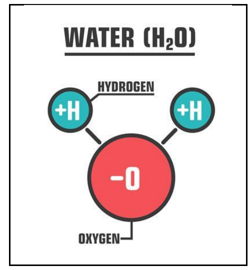
Guiding question

a) State the source of the following mineral nutrients; Ca, P, K and Mg.
b) Give the functions and deficiency symptoms of the above minerals.

Mineral element	Source	Function /importance	Deficiency
Calcium	Milk, hard water and vegetables	Formation of middle lamella in plants. Strengthening of bones in animals.	Poor bone formation Rickets
Chlorine	Table salt	Maintaining osmotic balance involved in chloride shift during CO_2 transport in blood.	
Magnesium	Table salt, mineral lick	For bone and tooth structure formation. Cofactor for many enzymes.	Chlorosis in plants
Phosphorus	vegetables, Mineral lick and rock salt.	Synthesis nuleic acids and ATP A constituent of bones and enamel of teeth.	Stunted plant root growth Weak bones in animals
Possium	Milk	Cofactor for enzymes involved in	Yellow and brown

		respiration and photosynthesis. Maintains electrical potential across cell membranes.	leaf margins. Premature death of leaf apex.
Sodium	Table salt	Maintains electrical potential across cell membranes.	Muscular cramps in man
Sulphur	Fish, oil legumes.	Synthesis of proteins e.g. keratin.	Chlorosis

Water



Water is the largest inorganic component of the body (protoplasm). It is also one of the most components in the plants and animal life. The total volume or weight of water varies from one animal to another according to the size and other factors like diet.

Water turnover

Water turnover refers to the rate at which the body gains or loses water. It varies from species to species, for example, non ruminants have a higher water turnover due to nature of their gastro-intestinal tract than ruminants.

Species	Water turnover (ml/kg/day)
Camel	38 – 76
Sheep	62 – 127
Goat	76 – 196
Zebu	63 – 178
Buffalo	108 - 203
Source: Macfarlane et al (1963)	

Factors affecting water turnover of animals

- Nature of feed; feeding animals on concentrates increases water intake since concentrates have moisture content while pasture reduces water intake.
- Environmental temperature; during hot weather, there is more water loss from animal's body in form of sweat hence more water is taken than during cold days.
- Humidity of the area in the animal's environment; high humidity reduces water loss from animal's body and also reduces water intake.
- Salinity of water; salt content in the feed influences high amount of water intake. i.e. increase in salt content increases water intake.

- Body size of an animal; large animals require more water for body metabolism than small animals. also large animals have a large surface area for water loss.
- Physiological state of an animal; lactating animals require more water than non- lactating animals since water forms a big composition of milk.
- Animal species; most temperate animal species have high water turnover compared to tropical species e.g. exotic cattle have high water requirement and give more milk than local breeds.
- Work doen by the animal; worker animals such as oxen take more water than other types of animals since they lose more water in form of swear.
- Ability to conserve water; animals such as camels, goats, and humped cattle have got higher capacity to conserve water and have a low rate of water loss.

Water requirement for different classes of animals

Class/type of animal	Amount of water (litres/litre)
Beef cattle	20-70
Dairy cattle	40-110
Horses	40-45
Pigs/ swine	10-20
Small ruminants	10-50
Chicken	0.6-02
Turkey	04-06

Properties that make water necessary for life I the animal body

1. Water has a high boiling point of 100°c.
2. It is a universal solvent that dissolves many substances that are transported in the body.
3. Liquid water has got specific heat capacity. It has high latent heat of vapourisation. I.e. it has ability to absorb a lot of energy before it can change from liquid to vapour state.
4. Water has a high surface tension, this allows water to move through plant tissues and to be raised through soil pore spaces.

Problems of inadequate water supply in animal's body

1. Reduced feed intake leading to low animal production.
2. Loss of weight due to dehydration.
3. Death can occur in severe conditions of water shortage due to increased blood concentration.
4. Failure of urinal-digestive system due to the accumulation of urine in the body.
5. Limited absorption of digested food.

Question; Give the importance of water in animal's body and plants.

In animals

1. Water is important in cooling of the body through evaporation in form of sweating.
2. It neutralizes the body fluid pH e.g. blood pH.

3. It acts as lubricant in the body of living organisms with endo-skeleton like mammals for example synovial fluid lubricates bones of the joints.
4. It helps in transport of material across surface along the epithelium of the alimentary canal.
5. It contains dissolved oxygen and stabilises temperature that favour aquatic life hence being supportive to aquatic organisms.
6. Water supports organisms with hydrostatic like skeleton like earth worms supported by a highly pressure fluid.

In plants

1. Water is important in germination of seeds where by seeds absorbs water, swells and breaks the testa to open for further development.
2. It is important in transportation of dissolved solutes from soil to plant tissues.
3. If facilitates cooling in plants through transpiration.
4. It supports plants in upright position through maintaining plant cells turgid.

1.4.4 ENZYMES

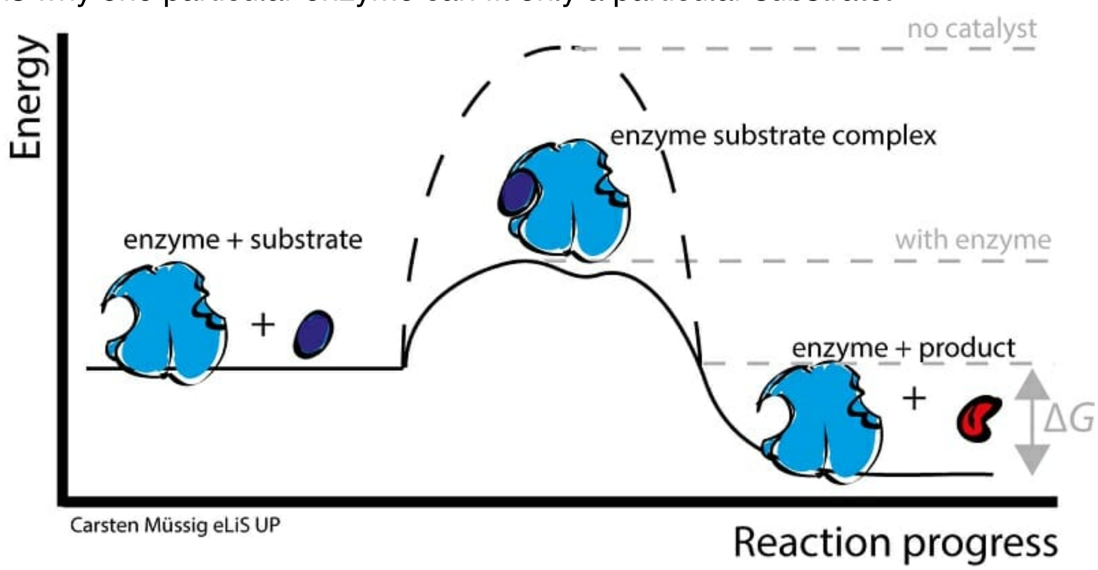
Enzymes are biological catalysts which speed up chemical reactions in the body and remain unchanged chemically at the end of the reaction.

Enzymes work by lowering the activation energy.

Activation energy is the energy required to break chemical bonds in food substrate and start a reaction.

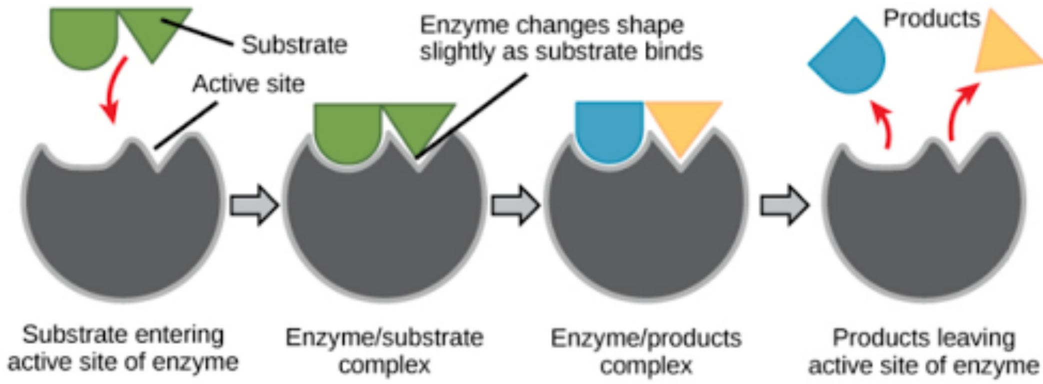
Enzymes are biologically active, highly specific and protein catalysts that reduce energy requirements for speeding up chemical reactions.

Enzymes have the shape (active site) that differentiates one type of enzyme from another that is why one particular enzyme can fit only a particular substrate.



A substrate is a substance which is chemically changed by an enzyme. The active site of an enzyme closely matches the molecular configuration which fits the active site of an enzyme.

Enzymes remain unchanged chemically at the end of the reaction; after it has done work it is again available for more work.



Assignment

Describe the lock and key hypothesis in relation to enzyme catalysed reactions

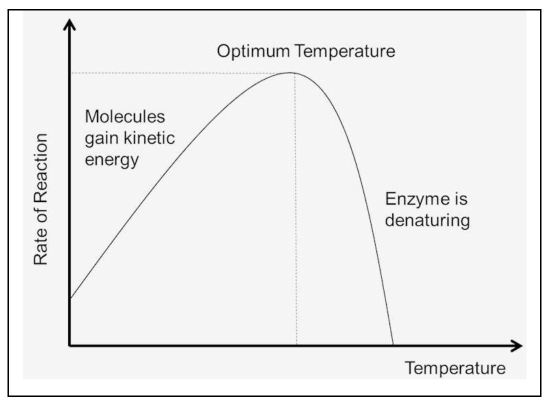
Properties of enzymes

1. Enzymes are protein in nature
2. They are specific in action
3. They are denatured by temperature and chemical reagents.
4. They are pH dependent.
5. They are biological catalysts of chemical reactions.

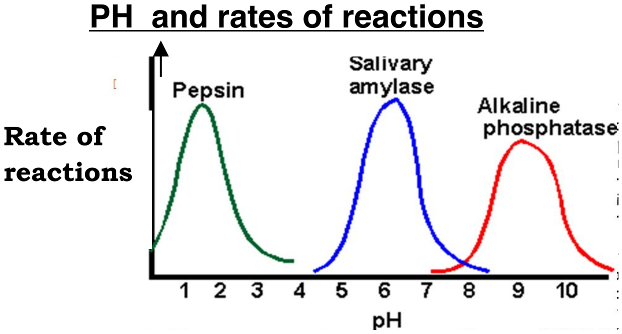
Factors affecting enzyme activity

Temperature; enzymes operate efficiently within certain temperature range. Low temperature makes enzymes inactive while high temperature range breaks the enzymes' bonds hence changing their configuration/shape and denaturing them.

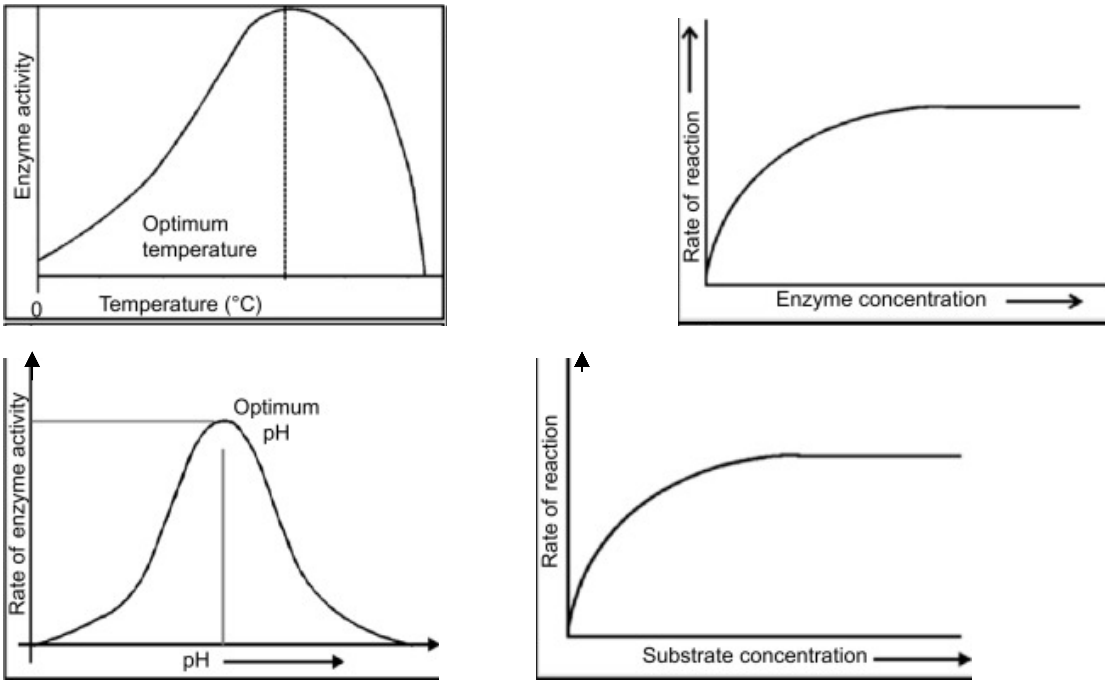
As temperature increases, the rate of reaction also I creases up to maximum when temperature exceeds optimum and the enzymes become denatured. The rate of reaction decreases due to alteration of changes of properties of enzymes.



<u>**PH and rates of reactions**</u>



Summary of the factors that affect the working of enzymes



Note; **coenzymes** are non protein organic molecules required for proper functioning of enzyme e.g. Nicotinamide Adenine Dinucleotide (NAD+) for oxidation or hydrogen transfer. Coenzymes often remove electrons from the substrate and pass them to other molecules.

Cofactors are inorganic molecules required by enzyme for proper functioning of enzyme e.g. copper (Cu+), zinc (Zn++), iron (Fe++), magnesium (Mg++), potassium (K+) and calcium(Ca++).

Cofactors bind to the enzyme and participate in the reaction by removing electrons, protons or chemical groups from the substrate.

A prosthetic group is a cofactor which binds tightly to the enzyme and assists in catalyzing the chemical reaction. They are non-protein molecules. They can be small organic molecules or metal ions. Due to the tight binding to the enzyme, prosthetic groups are difficult to remove from the enzymes. Hence, it is considered that the bond between prosthetic group and enzyme is permanent unlike in coenzymes. Upon binding, they can act as structural elements or as charge carriers. For example, prosthetic group heme in hemoglobin and myoglobin allows binding and releasing of oxygen as per the requirement of tissues. There are some vitamins which act as prosthetic groups for enzymes.

Prosthetic Group versus Coenzyme

Cofactors are the helper molecules of enzymes. They are not proteins and are either inorganic or organic molecules. Coenzymes and prosthetic groups are two types of helper molecules.

A coenzyme is an organic molecule which binds loosely with enzymes to help reactions. A prosthetic group is an organic molecule or a metal iron which binds tightly or covalently with the enzyme to assist chemical reactions. This is the difference between prosthetic group and coenzyme. Both groups are reusable and nonspecific to the enzymes.

Enzyme inhibitors
Enzyme activity can be inhibited in various ways.
Competitive inhibition occurs when molecules very similar to the substrate molecules bind to the active site and prevent binding of the actual substrate. Penicillin, for example, is a competitive inhibitor that blocks the active site of an enzyme that many bacteria use to construct their cell walls.

Noncompetitive inhibition occurs when an inhibitor binds to the enzyme at a location other than the active site. In some cases of noncompetitive inhibition, the inhibitor is thought to bind to the enzyme in such a way as to physically block the normal active site.

Allosteric inhibition; in other instances, the binding of the inhibitor is believed to change the shape of the enzyme molecule, thereby deforming its active site and preventing it from reacting with its substrate. This latter type of noncompetitive inhibition is called allosteric inhibition; the place where the inhibitor binds to the enzyme is called the allosteric site. Frequently, an end-product of a metabolic pathway serves as an allosteric inhibitor on an earlier enzyme of the pathway. This inhibition of an enzyme by a product of its pathway is a form of negative feedback.

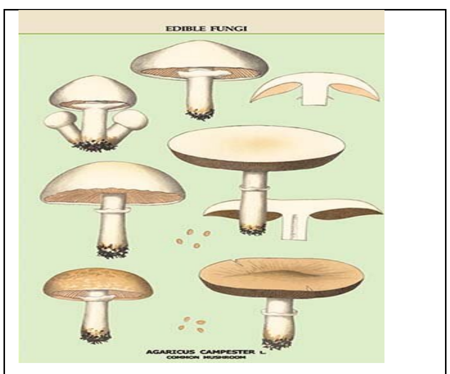
MACRO AND MICRO ORGANISMS OF AGRICULTURAL IMPORTANCE

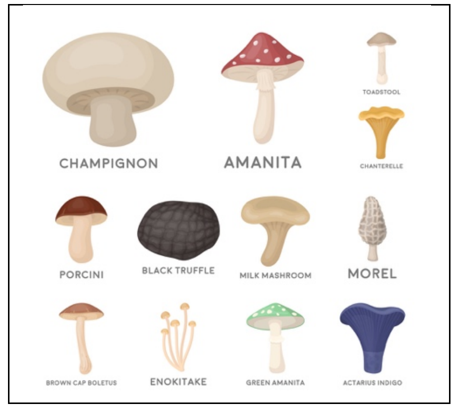
SOIL ORGANISMS

Soil Organisms are creatures that spend all or part of their lives in the soil. There are several criteria that can be used to classify soil organisms. For example, soil organisms are classified according to their size into:

(1) macro-organisms (> 2 mm in width),
(2) meso-organisms (0.2 to 2 mm in width), and
(3) micro-organisms (< 0.2 mm in width).

Based on the ecological functions that soil organisms perform they can be classified as:





(1) Herbivores that subsist/ survive on living plants,
(2) Detritivores that subsist on dead plant debris,
(3) Predators that consume animals,
(4) Fungivores that eat fungi,
(5) Bacterivores that eat bacteria,
(6) Parasites that live off, but do not consume, other organisms.

Another classification of soil organisms groups them into:
(1) Heterotrophs that rely on organic compounds for their carbon and energy needs, and
(2)Aautotrophs that obtain their carbon mainly from carbon dioxide and their energy from photosynthesis or oxidation of various elements.

Other organisms of agricultural importance include livestock parasites such as ticks tsetse flies, liver flukes and tape worms.

MICRO ORGANISMS

These are living organisms that can only be seen with aided eyes. They cannot be seen with naked eyes.

FUNGI

Belong to soil micro flora (heterotrophic, aerobic) and are eukaryotic organisms. As heterotrophy, fungi depend on living or dead organic materials for both their C and energy. They may be divided in the following three groups:
(1) Yeasts are single-celled organisms that live in waterlogged, anaerobic soils.
(2) Mushroom fungi.

Fungi may form symbiotic relationships with plants (mycorrhizae) or act as pathogens, and they are play a major role in humus formation and aggregate stabilization.

(3) Actinomycetes belong to soil microflora (heterotrophs, aerobic). They are single-celled, prokaryotic, filamentous and often profoundly branched organisms. They are of great importance in the decomposition of soil organic matter and the mineralization of nutrients, especially in alkaline soils.

(4) Molds

Suggest reasons why fungi are regarded as useful microorganisms in agricultural production.

- **Improve nutrient absorption**
  Symbiotic association between plant roots and Mycorrhizae fungi improve nutrient absorption by the host plant e.g. phosphorus absorption by producing acids that convert phosphorus into available form for plant uptake.
- **Decomposition of organic matter**; Mushroom fungi play an important role in decomposition of organic substances containing cellulose, hemicelluloses and lignin leading to formation of humus that stabilizes soil aggregates.

- **Biological pest control**; Actinomyctes produce antibiotic compounds that kill other microorganisms like streptomycin that can cause diseases.
- **Degrading toxic chemicals in pesticides** Penicillium, aspergillus, rhizopus and fusarium degrade toxic chemicals in pesticides applied to soil reducing negative residual effects.
- **Fermentation**; Yeast is useful in production of lactic acid during fermentation in formation of alcohol e.g. wine from grapes and in formation of cheese; it is also used in synthesis of maltase enzyme during baking process.
- **Yeast is useful in baking industry**, yeast respires CO2 that forms bubbles inside the dough that cannot escape making the dough to swell and expand.
- **Some fungi provide food to man** e.g. mush room.

Harmful effects of fungi

- Some fungi cause diseases to plants e.g. smuts, blights, rusts, wilts, and mildews on crops like onions, tomatoes, maize and potatoes (P*hytopthora infestans*).
- Some cause diseases to farm animals and man e.g. ring worms in man and foot rot in animals.
- Some fungi cause rotting of timber and wood lead to deterioration of farm structures.

BACTERIA

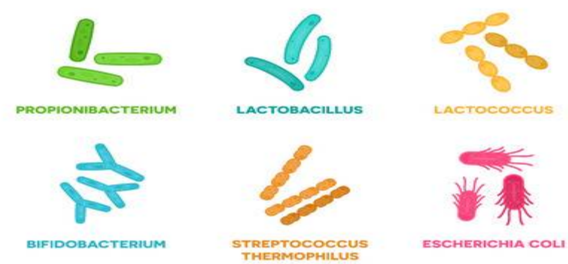
Bacteria belong to the kingdom Monera and can be either autotrophic or heterotrophic and can be both aerobic and anaerobic.

They are single-celled, prokaryotic organisms and are the most diverse group of soil organisms. A gram of soil may contain 20,000 different species. They have evolved mechanisms to adapt to life in the most extreme of environments. Due to their diversity they play many roles in the soil and are involved in all of the organic transactions. Their most important role is in decomposition of dead organic matter and mineralization of nutrients such as N and S to forms available to plants. Another critical process in which bacteria are prominent is N-fixation.

Species of bacteria that are beneficial in agricultural production.

- *Lactobacilli spp* which breakdown lactose sugar contained in milk into lactic acid, which adds flavour during fermentation of whole milk into yoghurt.

Examples of species of bacteria

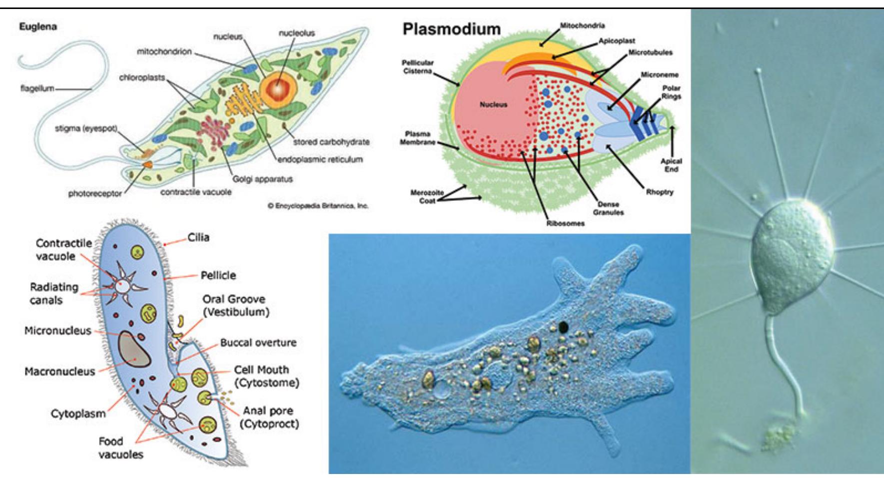


- *Lactobacilli spp* also produce lactic acid that gives good flavour to silage during herbage preservation.
- *Streptococcus thermophilus* that add creamy flavour to yogurt.
- *Methanococcus and methanobacteria* that produce methane gas from carbon dioxide and water in production of biogas from animal manure and by-products of sugar in sugar factories.
- *Thiobacilli spp* convert insoluble metal compounds into soluble metal compounds for example copper sulphate. These release mineral elements such as copper and sulphur for plant use.
- *Ruminococcus albus* and *fibrobater spp* secrete cellulose enzyme which hydrolyses cellulose into volatile fatty acids (acetic and butyric acid) that are absorbed through rumen walls and used by ruminants to produce energy.
- Cyanobacteria (formerly called blue-green algae) belong to soil micro flora e.g., *Anabaena spp* that belongs to genera of cynobacteria/ blue green bacteria fix nitrogen into soils especially wet land soils in paddy rice fields.
- *Azotobacter* non- symbiotic bacteria species fix atmospheric nitrogen into nitrates in soil, nitrogen in nitrate form is then absorbed by plants.

PROTOZOA

They belong to soil microfauna.

All protozoans are heterotrophic, and usually obtain their food through some form of ingestion followed by intracellular digestion. They are either bacterivores or fungivores. A few are capable of alternating between a heterotrophic and autotrophic mode of nutrition, depending upon the resources available.



The subdivision of this group into different phyla is based on how they feed and move. The general trend in the taxonomy is to distinguish between those that;

(1) That move by "cilia" ciliates (the largest soil protozoa),

(2) Flagellates (move by flagellum), and

(3) Amoebas (move by pseudopodia).

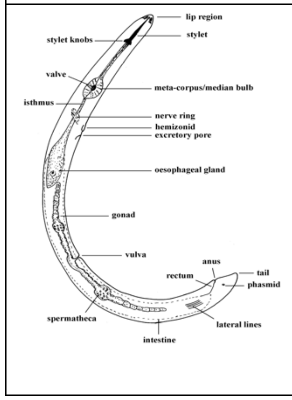
Protozoa are commonly found near roots and other places where bacteria congregate. Typically when bacterial populations increase (i.e. following rainfall) protozoan populations also increase. Because protozoa have lower N requirements than many bacteria, they excrete excess N obtained from the consumption of bacteria as ammonia (inorganic N). Hence protozoa (together with nematodes) are important in enhancing mineralization in soil by releasing the N taken up by bacteria.

Finally, some are internal or external parasites of animals. Some species actively prey on live bacteria, whose population they control.

NEMATODES

Commonly known as threadworms or roundworms belong to soil microfauna, they are found in almost all soils in surprisingly large numbers.

Drawing of a nematode



Nematodes are basically aquatic organisms that live in the thin water films or capillary pores of aggregates preying or grazing on other aquatic microfauna such as amoebas

Some are plant parasites that infest roots, some are predators that feed on other nematodes or bacteria, fungi, and protozoa.

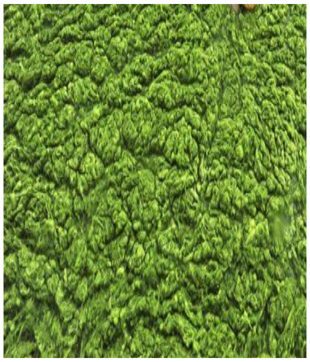
The root knot nematode, for instance, stimulates parasitized plants to form root galls. The galls choke off the flow of water and nutrients to the above-ground portion of the plant. Plants infected by root gall nematodes may live through the season but crop yields will be dramatically reduced.

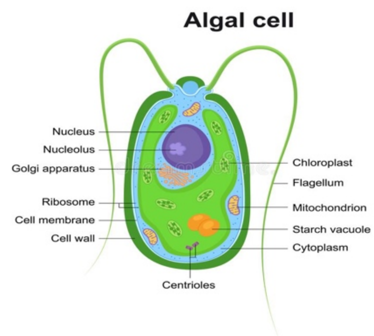
Like protozoa, nematodes have lower N requirements than many bacteria. Soil compaction generally reduces the populations of nematodes, which need adequate space between soil aggregates to move around.

Algae belong to soil micro flora. They are autotrophic (i.e. have chlorophyll and are capable of performing photosynthesis) and eukaryotic organisms. Algae are most active and abundant in wet soils.

In dry soil, the water film that surrounds soil particles becomes too thin for them to move freely. Because they need light for photosynthesis, algae are most common at or very near the soil surface. Some algae make symbiotic associations with fungi forming lichens that are important in colonizing bare rocks and other low-organic-matter environments (deserts). The most common groups of algae present in soil are:

(1) Green algae 2. Yellow-green algae





MACRO ORGANISMS

These are living organisms that can be seen with naked eyes.

Macrofauna

Vertebrates e.g. mice, moles, ground squirrels.

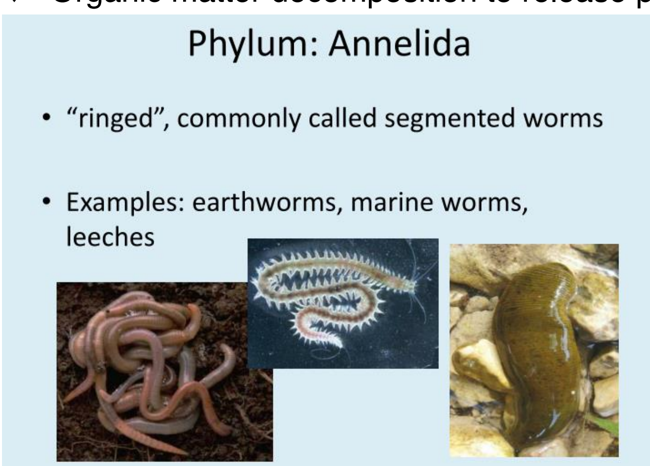
They mix soil through their burrowing activity and contribute to the formation of an A- horizon.

Annelida (segmented worms)

They are decomposers (detritivores). The most important species of Annelida are earthworms especially those from genera *Lumblicoids*.

Importance of earth worms

- Improve water infiltration; earthworms are the original tillers of soil and can thus improve the rooting environment for plants and increase the amount of water that infiltrates the soil.
- Improve soil structure; earthworms mix soil and organic matter and leave casts (their wastes) in the soil to become soil aggregates.
- They make tunnels in soil which improve soil aeration
- Organic matter decomposition to release plant nutrients in soil.

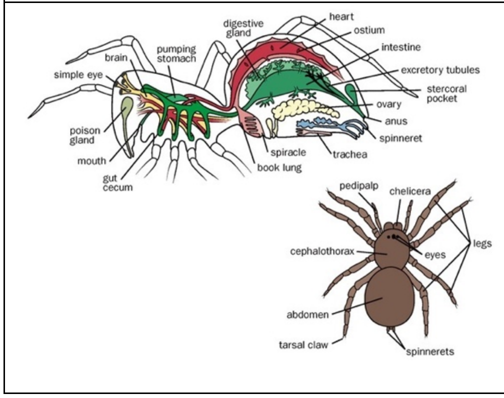


SEGMENTED WORMS

Phylum Annelida

Ex. Earthworms, leeches, polychaete (marine) worms

Scorpion



Arthropods are fauna with a jointed exoskeleton and can belong to the macro or meso group. They are a diverse group of bizarrely/ unusually shaped spiders, mites, pseudo-scropions, and insects (termites and dung beetles).

Many arthropods prey on disease-causing pests.

Others help to shape soil structure and thus can improve root development, water infiltration, drainage, and aeration.

Some arthropods are the front line in decomposition of organic matter. They shred plant residues, mix them with soil, and stimulate decomposition within their intestines.

They are especially important in forests, rangelands, no-till cropland, and in other areas where the soil is minimally disturbed and covered all year.

The activity of soil organisms can be divided into five functions:

1. Regulation of organic matter turnover/ accumulation

   Macro organisms such as earthworms, termites, insects etc. plays important role in the process of decomposition of organic matter and release of plant nutrients in soil.

   The rate of OM breakdown relates to the soil environment, the number and type of organisms present and the chemical structure of the plant residues. Breakdown may occur in months or several thousand years.

Termites mixing soil layers

2. Nutrient recycling and transformation, whilst decomposing OM to obtain carbon, other nutrients are released. These may be soluble and leached (e.g. nitrate [NO_3]), volatile and lost to the atmosphere (e.g. nitrogen as N_2 & N_2O, sulphur as H_2S) or readily available to the plant (e.g. nitrates, phosphates and sulphates).
3. Biological degradation, Soil organisms can act as bio-filters by cleaning up soil pollutants. Many agrochemicals are broken down by soil biota. Their effectiveness will be modified by the soil environment. Herbicide degradation is faster in soils with high microbial activity.
4. Maintenance of soil structure

   Movement of organisms e.g. earthworms and arthropods through the soil improves the structure by mixing and aerating the soil. This also increases water infiltration.

   Water repellance in sands is due to waxes from plant material and from products of microbial decomposition of OM. These waxes are naturally degraded by specific wax degrading bacteria, which can be introduced into soils by inoculation.
5. Pest control.

   Insects and other predatory organisms help control the population levels of their prey and prevent any single species from becoming dominant.

TERMS USED IN RELATION TO STUDY OF SOIL FAUNA AND SOIL FLORA

Aggregates: The arrangement or structure of soil particles held in a single mass or cluster. Aggregates are defined by their shape size and distinctness.

Anaerobic: Cellular respiration that occurs without oxygen.

Anoxic: Without oxygen.

Archaea: A group of prokaryotes (single celled organisms) phylogenetically distinct from bacteria.

Autotrophic nitrification: Carried out by nitrifying bacteria and archaea. It is a process in which ammonium is oxidized and converted to nitrite and nitrite is converted to nitrate. Inorganic N serves as the energy source. Nitrous oxide is a by-product of this process.

Biogeochemical cycling: The transformation and cycling of elements between non-living (abiotic) and living (biotic) matter across land, air, and water interfaces.

Collembolan are micro arthropods: Wingless insects a few millimeters in length and 0.2 to 2 mm in width. They are found on or near the surface of the soil and in plant litter. Populations range between 10^3 m^{-2} in agricultural soils to 10^6 m^{-2} in forest soils.

Chemoheterotrophs: Organisms that obtain energy and carbon from the oxidation of organic compounds.

Denitrification: A form of anaerobic respiration that results in the conversion of NO_3^- to primarily N_2O and elemental N (N_2).

Field moisture capacity or field moist soil: The moisture content of a soil, expressed as a percentage of the oven dry weight, after the gravitational, or free, water has drained away; the field moisture content 2 or 3 days after a soaking rain; also called n*ormal field capacity, normal moisture capacity,* or *capillary capacity*.

Hyphae: Long and often branched tubular filament that constitutes the vegetative body of many fungi and fungus like organisms.

Macro arthropod: Larger insects and spiders are examples of this group of organisms. Typical body lengths range 10 mm to as much as 15 cm. (Coleman *et al*. 2004)

Microbial biomass: Total mass of micro-organisms alive in a given volume or mass of soil.

Micro flora: Bacteria and fungi have diverse metabolic capabilities and are the principle agents for the cycling of nutrients (e.g., nitrogen, phosphorous, and sulphur). They may be free living or symbiotic and active in the decomposition or build-up of organic matter.

Micro fauna: Protozoa and nematodes are a crucial link between micro flora and larger fauna.

Mineralization: Conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Mites: Micro arthropods with oval bodies, four pairs of legs, and a cuticle that acts as an exoskeleton.

Soil fauna: The collection of all the micro- and macroscopic animals in a given soil.

Mesofauna: Mites and collembola feed on litter and help fragment organic residues.

Mucilages: Gelatinous secretions and exudates produced by plant roots and many microorganisms.
Nematodes: also known as roundworms, are cylindrical, unsegmented worms with tapered ends. Pedology: "The study of soils as natural bodies, the properties of soil horizons, and the relationships among soils within a landscape"
Protozoa: Unicellular eukaryotic microorganism that moves by either protoplasmic flow (amoeba), flagella (flagellates), or cilia (ciliates).
Rhizosphere: The zone of soil under the influence of plant roots
Soil: The naturally occurring unconsolidated material on the surface of the earth that has been influenced by parent material, climate (including the effects of moisture and temperature), macro- and micro-organisms, and relief, all acting over a period of time to produce soil that may differ from the material from which it was derived in many physical, chemical, mineralogical, biological, and morphological properties.

Soil biota: Consists of the micro-organisms (bacteria, fungi, and algae), soil animals (protozoa, nematodes, mites, springtails, spiders, insects, and earthworms) and plants living all or part of their lives in or on the soil.
Soil structure: The arrangement of soil particles into small clumps, called peds.
Soil water holding capacity: The ratio of the volume of water which the porous medium, after being saturated, will retain against the pull of gravity to the volume of the porous medium.
Trophic levels: Levels of the food chain. The first trophic level includes photosynthesizers that get energy from the sun. Organisms that eat photosynthesizers make up the second trophic level. Third trophic level organisms eat those in the second level.

Questions

1. a) Distinguish between macro and micro organisms giving examples.
   b) Outline importance of macro and micro organisms in agricultural production.
   c) Describe the structure of bacteria and virus.
   d) Why is a virus regarded as non- living?
2. a) State any 4 bacterial, viral, and fungal diseases of crops.
   b) Name any 4 bacterial and viral animal diseases.
   c) How are viral diseases transmitted?
   d) State ways of controlling plant and animal viral diseases.

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