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1. CYTOLOGY

A branch of biology that deals which deals with the study of the structure and function of cells of plants and animals.

COMMON TERMS USED IN THIS BRANCH

1. **Cytology**; Study of cells by means of light and electron microscopes;
2. **Cell theory**; All living matter composed of cells; all cell arise from pre-existing cells; all metabolism occurs in cells;
3. **Protoplasm**; Living contents of the cell consisting of the cytoplasm and one or more nuclei
4. **Organelle**; Structurally and functionally discrete component of a living cell frequently membrane bound.
5. **Tissue**; A collection of cells physically linked and associated with intercellular substance specialized to perform a particular function;
6. **Cytogenetic**; Linking cytology with genetics; relating structure and behaviour of chromosomes during cell division;
7. **Primary lysosome**; Refers to the vesicle that has just budded off from the Golgi body containing processed enzymes
8. **Glycosylation**; Process of combining carbohydrates with proteins forming glycol-proteins;
9. **Eukaryotes**; Organisms with DNA enclosed by the nuclear envelope
10. **Prokaryotes**; Organism with DNA not enclosed by the nuclear membrane
11. **Polyribosomes**; Chains of ribosomes (polysomes)
12. **Cytosol**; Fluid part of the cytoplasm
13. **Compartmentation**; Refers to the development of separate organelles performing specific roles in a cell
14. **Glycocalyx**; Long carbohydrate molecule attached to membrane lipids and proteins
15. **Cytoskeleton**; Complex network of fibers throughout the cytoplasm enabling maintenance of cell shape and support. Composed of micro-tubules, micro-filaments and intermediate filaments such as keratin.
16. **Cytoplasmic inclusions**; these are the insoluble, non-living substances suspended in the cytosol of a cell not capable of carrying out any metabolic activity. Such as glycogen granules, lipid droplets, water filled vacuoles, etc.

THE CELL.

A cell is the basic functional and structural unit of an organism. All living organisms no matter their size are made of cells.

Cells are responsible for carrying out all body processes such as respiration, excretion, osmo regulation, locomotion, circulation etc in the body of the organism.

Cells aggregate (unite) in groups to form body structures.

Note:

When studying the detailed structure of the cell, an instrument called a microscope is used.

THE MICROSCOPE.

There are two main types of microscopes:

i) The light microscope.

These are also divided into two: a simple microscope e.g a hand lens and a compound microscope.

ii) The electron microscope.

THE LIGHT MICROSCOPE.

This type of microscope that uses light to illuminate the specimen under investigation. There are two kinds under this type;

Simple microscope

The simplest form of a light microscope is the one with a single lens that has low power magnification. This is known as a hand lens (a magnifying lens).

A compound light microscope.

This is a type of microscope that uses light to investigate structures. Two lenses are used i.e. objective lens and the ocular lens (eye piece lens).

Light from an object passes through the first lens (objective) and produces a magnified image which acts as the object for the second lens (eye piece lens) which further magnifies it.

The degree of detail which can be seen with a microscope is called its resolution (resolving power). This measures its ability to distinguish objects that are close together.

Diagram of a hand lens

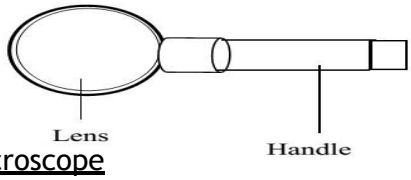
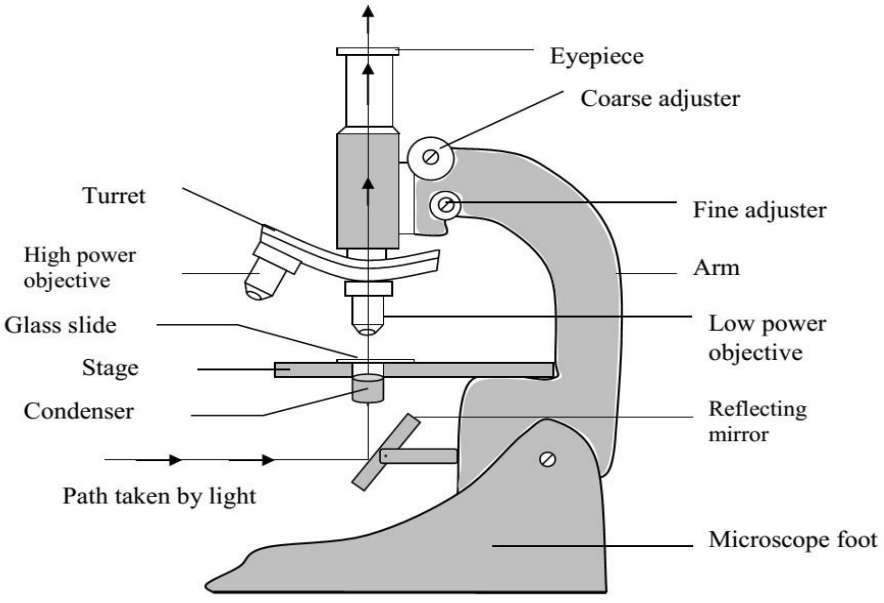


Diagram of a compound light microscope



Magnification in a compound light microscope.

Magnification is the number of times an image is made bigger or smaller compared to the object.

The total magnification of both lenses is the product of objective lens magnification and the eye piece lens magnification. For example if the eye piece has the magnification of X10 and the objective lens has X40, then the total magnification is;

Total magnification = eye piece magnification X objective lens magnification.

= (X10) x (X40)

= X400.

The resolution (resolving power) of the light microscope.

- ✓ This is the ability of the microscope to distinguish between two separate and very close objects so that they are distinct.
- ✓ It can also be defined as the degree to which the details of the objects are shown. Or a measure of clarity of the image.

If two separate objects cannot be resolved, they will be seen as one object.

The difference between the magnification and resolution of a microscope is that magnification can be changed (i.e increased or decreased) while resolution is always the same.

The resolving power of the light microscope is always lower (200nm) compared to that of an electron microscope (0.5nm).

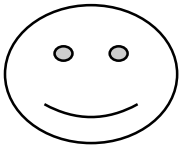
This resolution is limited by the wave length of the visible light used to illuminate the object. The light microscope can magnify effectively to about 1000 times that of the actual specimen since greater magnification above this increases blurredness.

Advantages of a light microscope;

- It is cheaper and easier to operate since it uses little or no electricity.
- It can be used to observe living specimens directly and as well dead materials.
- It does not result in the destruction of cellular organization in preparation.
- It is small and portable
- Preparation of materials for investigation is quick
- The natural colour of the specimen can be observed.

Disadvantages of a light microscope;

- It has a low resolving power.
- It has a low magnifying power.



Based on your study may you please give more of the advantages and disadvantages of light microscopes.

Modifications of the light microscope.

Type of microscope	Mode of operation	Main use
Ultra violet microscope	Uses quartz lenses	Study chromosome changes during cell division
Dark field microscope	Uses light at right angles to its optical axis and depends on the scattering of light by Different particles.	Study very small particles about 8nm
Phase contrast Microscope	Depends on the refraction of light by parts the cell basin on their refractive indices.	Study transparent cell Parts e.g cytoplasm.
Polarizing microscope	Uses polarized light.	Study layer-like structures in the cell e.g spindle fibres, myosin filaments in stratified muscle, cellulose in cell wall etc.

ELECTRON MICROSCOPE.

In electron microscope a beam of electrons is used. Electrons are negatively charged particles that can be found in orbit around nucleus of atoms.

Under certain circumstances they can behave as waves. They have two great advantages over light i.e they have extremely short wave length, about the same as X-rays and the beam electrons can easily be focused through specimen using electro-magnets.

This involves bending the beam of electrons just as glass lenses are used to bend light with electron microscope magnification have x250,000 are commonly obtained with biological materials.

Advantages of electron microscope.

- High resolution (0 - 5nm in practice).
- It magnifies very tiny objects.

Disadvantages of electron - microscope.

- The specimen must be dead because it is viewed in vacuum.
- It is difficult to be sure that the specimen resembles a living cell in all its details because preservation and staining may change or damage the structure.
- Expensive to buy and run.
- Preparation of material is time consuming and requires expert training.
- The specimen is gradually detoriated in the electron beam therefore photographs must therefore be taken if future study is required.

Comparison between a light and an electron microscope.

(i)Similarities between a light and an electron microscope.

- ✓ In both, specimens are magnified to be seen clearly.
- ✓ In both, specimens to be observed are illuminated.
- ✓ Both have an eye piece where an observer views the specimen.
- ✓ Both have a condenser to control the amount of illuminating agent.
- ✓ Both have a stage.
- ✓ Both have lenses.

(ii) Differences:

Light microscope.	Electron microscope.
✓ Uses light to illuminate the specimen.	✓ Uses electron to illuminate the specimen.
✓ Has low magnifying power (x1500).	✓ Has high magnifying power (x3000)
✓ Produces images in their natural colours	✓ Produces all images in black and white
✓ Small and portable.	✓ Very large and only operated in a special place.
✓ Not affected by magnetic field.	✓ Affected by magnetic field.
✓ Has low resolving power (200nm).	✓ Has high resolving power (0.5nm).
✓ Used to view living and non-living specimens.	✓ Used to view non - living specimens.
✓ Uses glass lenses.	✓ Uses electromagnetic coils as lenses.

Types of electron microscope

- ✓ Scan electron microscope.
- ✓ Transmission electron microscope.
- ✓ Phase contrast microscope.
- ✓ Scan electron microscope

Principles of recording biological drawings

- ❖ Drawing paper of suitable quality must be used. It must be capable of standing some rubbing out of incorrect pencil lines.
- ❖ Pencils should be sharp and of HB quality. No coloured pencils should be used.
- ❖ Drawing must be large enough, accurate, drawn with lines sharp and labelled.
- ❖ Make two drawings if necessary, i.e a simple drawing of the main features, and details of small parts only.
- ❖ Draw what you see and not what you think you should see.
- ❖ Every drawing should have a title.
- ❖ Label lines should finish exactly at the structure names.

THE CELL THEORY.

The cell theory states that:

1. All known living things are made up of one or more cells.
2. The cell is the structural and functional unit of all living things.
3. All cells arise from pre-existing cells by cell division.
4. Cells contains hereditary information which is passed from cell to cell during division.
5. All cells are basically the same in chemical composition.
6. All metabolism and biochemistry of life (organism) occurs within cells.

Exceptions to the cell theory

The following show properties of life but their features are not of typical / regular cells:

- Viruses; are obligate intracellular parasites capable of replicating only inside host cells using the machinery of the host. Viruses are therefore considered biotic but not organisms.
- Coenocytic algae; like Vaucheria and many fungi have a body that is a continuous mass of protoplasm with many nuclei but without cell wall separations i.e. are aseptate.
- Skeletal muscles; have very long cells (up to 300 mm long) with hundreds of nuclei i.e. are Syncytia
- Giant algae; is an organism made of one long cell (up to100 mm long) but with only one nucleus.

TYPES OF CELLS

There are two types of cells viz;

- Prokaryotic cells
- Eukaryotic cells.

Organisms are also divided in to 2 major groups depending on these type of cells.

PROKARYOTES

These are organisms that contain prokaryotic cells. Prokaryotic cells are cells which have no distinct nucleus and their DNA material is not enclosed with in the nuclear membrane.

Characteristics of prokaryotes

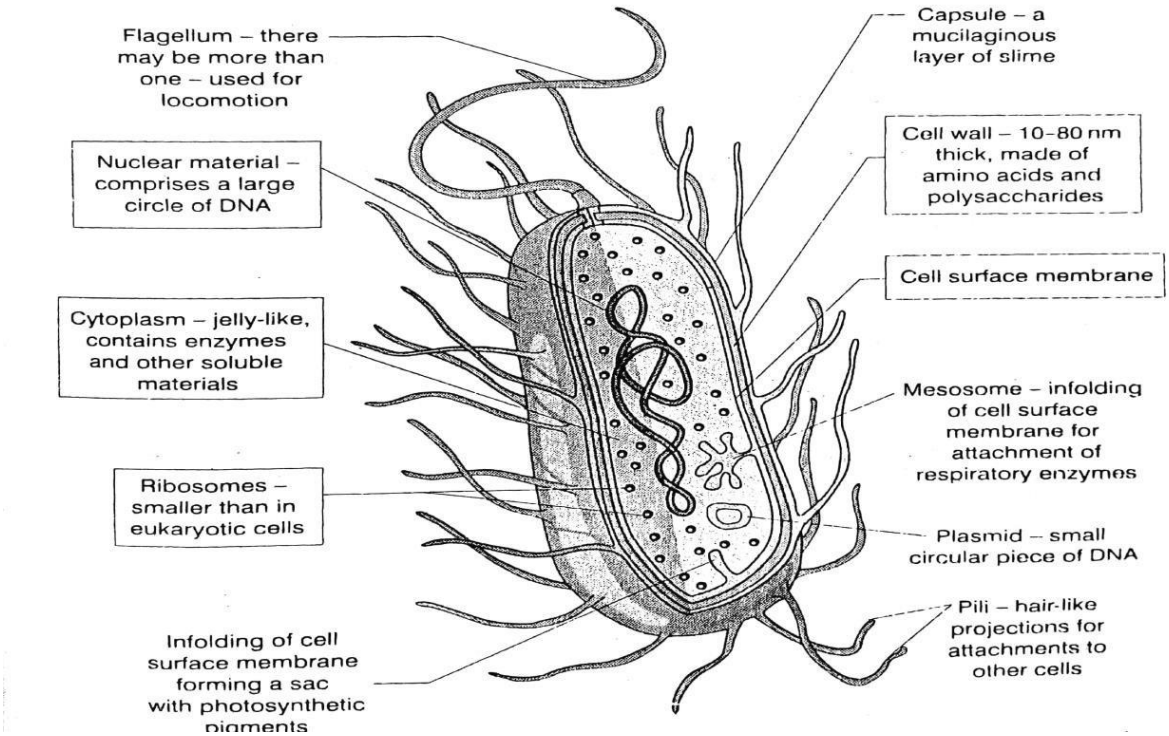
- ✓ Does not have any membrane bound organelles.
- ✓ Genetic material is not enclosed by a nuclear membrane
- ✓ DNA is not complexed with histones. Histones are not found in prokaryotic cells
- ✓ Respiratory system is closely associated with its plasma membrane and
- ✓ Sexual reproduction does not involve mitosis or meiosis.

The prokaryotic cell.

Pro means before and karyo means nucleus. These were the first forms of life on the earth.

The genetic material DNA in this cell is concentrated with in a region called the nucleoid but there is no membrane that separates this region from the rest of the cell.
Examples of organisms with prokaryotic cells are bacteria and blue green bacteria.

The structure of a prokaryotic cell is shown below.



Or one could adopt that **diagram in F.A page 30 fig 2.24, understanding biology page 50 fig 4.1**
The parts of the prokaryotic cell and their functions.

Cytoplasm	It's where other granules are suspended.
Cell wall.	Protects inner parts against mechanical damage. Controls entry of the some substances.
Ribosomes	For tissue respiration.
Pilli	For sensitivity and attachment on to surfaces.
Flagellum.	Movement of the cell.
Circular DNA	Control all activities of cell.
Mesosome.	Site for respiration. May be involved in cell division and DNA up take.
Chromosome/ DNA.	Contains genetic information required to Replicate new cells.
Plasmids.	Contains genes that aid survival of the bacteria In the adverse conditions.
Glycogen Granules	Store carbohydrates for respiration.
Storage membrane	Storage of food materials e.g starch.

Capsule	It protects the cell against mechanical damage.
Lipid droplets	Store lipids for respiration.
Chloroplasts.	For photosynthesis.

Advantages of having the outer plasma membrane in a prokaryotic cell;

- Many metabolic processes involve enzymes that are embedded in the membrane and when the cell becomes larger, the proportion of membrane area to the volume is reduced. This can be increased by the presence of organelle membranes.
- Containing enzymes for a particular metabolic path way increases the rate of metabolic reactions since the products of one reaction are always in close proximity to the next enzyme in the sequence.
- The rate of any metabolic path way inside an organelle can be controlled by regulating the rate at which the membrane surrounding the organelle allows the first reactant to enter.
- Potentially harmful reactants or enzymes can be isolated inside an organelle so that they do not damage the cell.

EUKARYOTES

These are organisms that contain eukaryotic cells. Eukaryotic cells are cells which have a distinct nucleus and their DNA material is bound by a membrane.

THE EUKARYOTIC CELLS.

Eu means true and karyo means nucleus. These cells have a true nucleus enclosed by a nuclear membrane. These cells evolved from prokaryotic cells. Examples of organisms that contain eukaryotic cells are protists, fungi, plants and animals.
Structure of eukaryotic cell under light microscope.

The evolution of eukaryotic cells from prokaryotic cells

The theory that was put up to explain this evolution is known as the **Endosymbiotic theory.**

ENDOSYMBIOTIC THEORY

- ✓ The endosymbiotic theory suggests that mitochondria and chloroplasts were once separately existing small aerobic bacteria and photosynthetic bacteria respectively.
- ✓ Larger anaerobic bacteria engulfed the smaller bacteria by the process of endocytosis, but digestion failed.
- ✓ Initially, the smaller bacteria could have lived inside larger bacteria either as parasites or phagocytic vesicles, after which a mutually benefitting relationship called endosymbiosis resulted, where the larger cell provided protection and shelter while the smaller organisms removed oxygen which was toxic to the anaerobic larger cell.
- ✓ With time, mitochondria and chloroplasts were modified into organelles suited for respiration and photosynthesis inside the larger eukaryotic cells.

1. The cell membrane of a larger cell invaginated and a smaller bacterium was engulfed.
2. The bacterium on entering the cell attained a vesicular membrane.
3. The mitochondria was also engulfed and it also attained an outer membrane.
   Or the Endosymbiotic theory can be explained as;

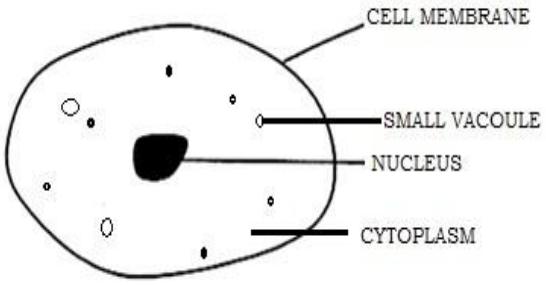
- Mitochondria and chloroplast were initially independent prokaryotic cells
- bacteria like organisms which gained access, by accident, to the host cell (larger prokaryotic cell) and entered symbiotic relationship
- Presumably conditions in the cell host were favorable for prokaryote whilst in return the prokaryotes provided increased capacity of cell to form ATP (mitochondria) and chloroplast increased cells capacity to form food by photosynthesis.

Evidences of Endosymbiotic theory

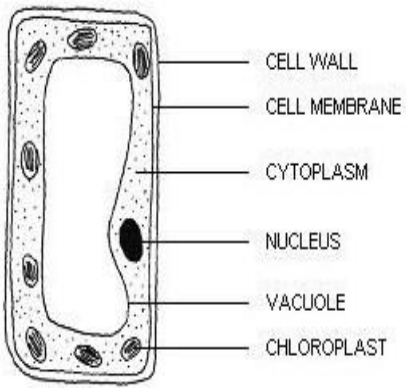
- Both mitochondria and chloroplast have naked and circular DNA
- Both mitochondria and chloroplast have 70S ribosome
- Both mitochondrial and chloroplast protein synthesis are sensitive to antibiotics for example chloramphenicol and streptomycin
- The ability of the mitochondria and chloroplast to divide themselves/self-replication;
- Ribosomes of mitochondria and chloroplasts resemble those of bacteria and cyanobacteria, with respect to size and nucleotide sequence
- Mitochondria and chloroplasts reproduce independently of their eukaryotic host cell by a Process similar to the binary fission of bacteria.
- The thylakoid membranes of chloroplasts resemble the photosynthetic membranes of cyanobacteria
- The great similarity between prokaryotic cells and organelles of eukaryotic cells.
- The timeline of life on Earth shows that from fossil evidence of bacterial life, the mitochondria, chloroplasts and eukaryotic cells emerged at about the same time, 1.5 billion years ago.

STRUCTURE OF EUKARYOTIC CELLS UNDER A COMPOUND LIGHT MICROSCOPE

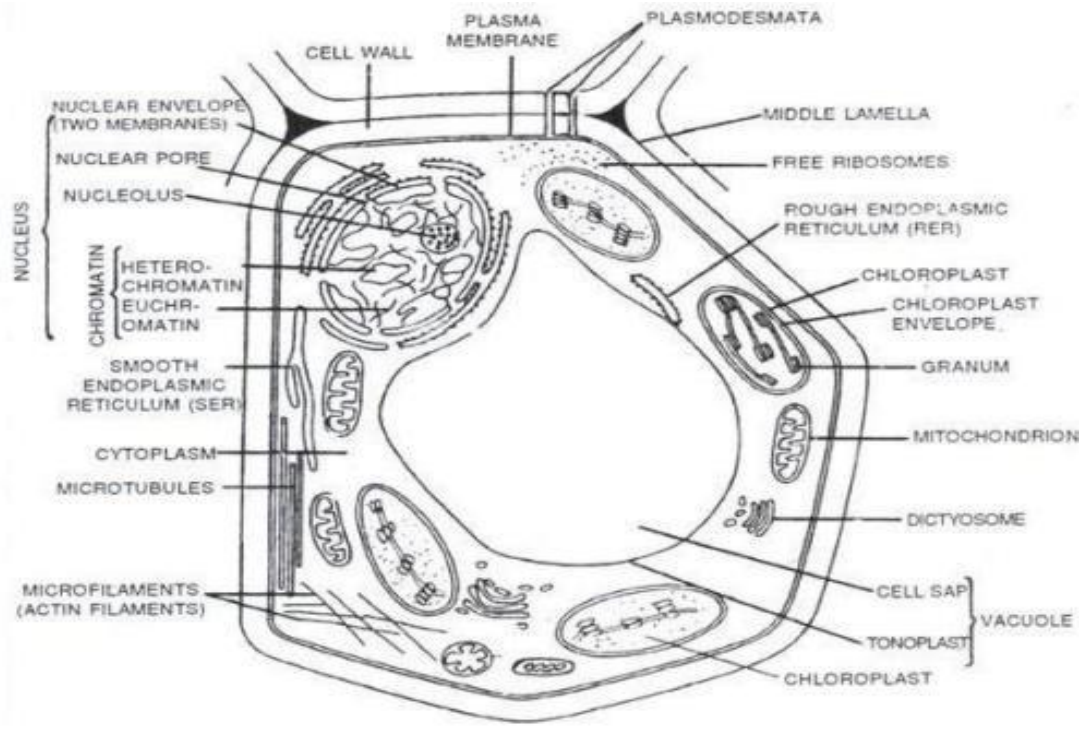
Animal cell

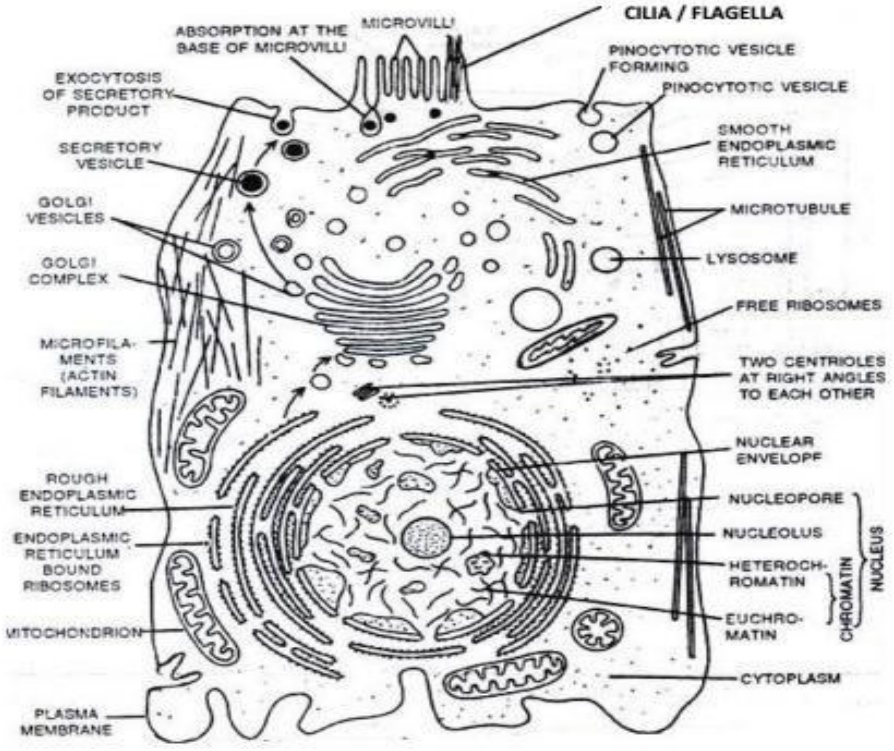


plant cell



ULTRA STRUCTURE OF EUKARYOTIC CELLS





- **Diagram in B.S page 135 fig. 5.10 & 5.10 or**
- **Diagram in understanding biology page 52 and 53 fig 4.2 & 4.3**

Comparison between prokaryotes and eukaryotes.

(a) Similarities;

- ✓ Both contain DNA molecules.
- ✓ Both contain ribosomes.
- ✓ Both have a cell wall.
- ✓ Both contain protoplasm bounded by a selectively permeable membrane.
- ✓ Both contain lipid- protein membrane surrounding the protoplasm.
- ✓ In both, energy is produced in form of ATP.

(b) Differences;

Prokaryotes	**Eukaryotes.**
No membrane bound nucleus.	Have membrane nucleus.
Lack membrane bound organelles Except ribosomes.	Have membrane bound organelles.
DNA is found in the cytoplasm.	DNA is found in the nucleus.
DNA is not associated with protein in Chromosomes.	DNA is associated with protein in Chromosomes.
DNA is single stranded.	DNA is double stranded.
Contain small amount of DNA.	Contain larger amount of DNA.
Energy production occurs on the cell Membrane.	Energy production occurs in the Mitochondria.
Lack endoplasmic reticulum.	Have endoplasmic reticulum.
Photosynthetic pigments are bound To the cell membrane.	Have chromatophores are enclosed in Plastids with in the cytoplasm.
Lack cell vacuoles and cytoplasmic Membrane system.	Have vacuoles, cytoplasmic membrane system and cytoplasmic Strands.
Are small in size (1-10 µm)	Are large in size (10-100µm)
Flagella do not have 9+2 arrangement Of the fibril.	Flagella have 9+2 arrangement of Fibril.
No mitosis or meiosis occurs.	Both mitosis and meiosis occur.
Have smaller ribosomes.	Have larger ribosomes.

Why cells are very small.

- Most cells are microscopic. The size and shape of cells are related to their functions.
- The size depends on what the cell must do to survive;
- Cells take in food and other materials through the plasma membrane.
- Inside the cell, substances must move to the correct locations in the cell where they are converted to other forms.
- Once the correct molecules are formed they must be transported to proper sites within the cell for use.
- Waste products from various metabolic reactions must be transported out of the cell before they accumulate to toxic levels.
- It is therefore important to note that the distance materials move is very short. This will speed up the cellular functions. Since these materials and waste products have to pass through the plasma membrane, the larger the surface area the faster a given amount of a substance can pass through it.

Note:

The factor that determines the cell size is the ratio of its surface area to volume ratio, since the volume increases more rapidly than its surface as the cell becomes large.

This places the upper limit on the size of the cells. Above that size, the number of molecules required by the cell could not be transported into the cell fast enough to sustain it.

Revision question:

Compare plant and animal cells. **Hint** give similarities and differences based on the structures of the cells.

DETAILED STUDY OF PARTS OF THE CELL.

1. **CELL MEMBRANE.**

This is an outer surface which covers the cytoplasm of the cell; it consists of lipids and proteins together with carbohydrates.

There are different theories have been put forward to explain the structure of cell membrane.

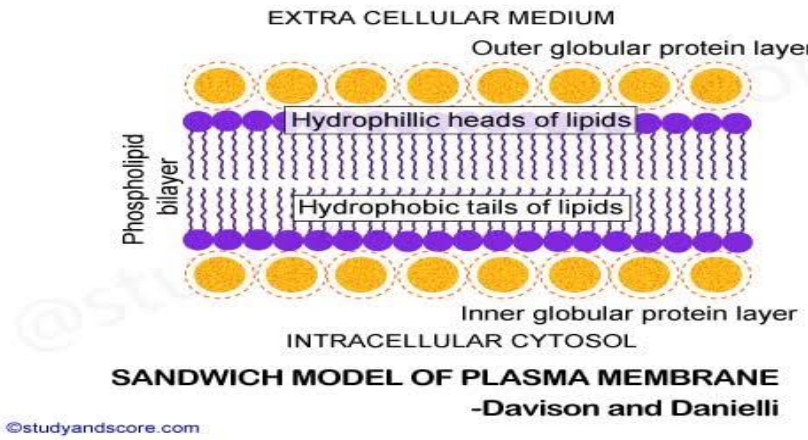
<u>Theories about the structure of the cell membrane</u>.

1. **Charles Overton.**

According to him, cell membranes are made up of lipids; basing on his observation the lipids that are in the form soluble molecules enter the cell more than those in form of insoluble molecules. Phospholipids are mostly dependent on lipids in cell membrane and have both hydrophobic and hydrophilic ends and are therefore said to be Amphipathic molecules.

2. **E. Gotter & F. Grendel (1925).**

Suggest that plasma membrane is made up of lipids by layers which are Fibrous molecules thick. It does not give note to the position of the proteins.



SANDWICH MODEL OF PLASMA MEMBRANE
-Davison and Danielli

3. **H. Davson & J. Daniel (1935).** Suggested the molecular model of the cell membrane and this model a phospholipid bilayer is arranged between two layers globular proteins. He proposes that the lipid bilayer was sandwiched between two protein layers.

Check diagram in F.A page 27 fig 2.21) or Campbell and Reece

Problems with Davson-Daniel model;

- It generalizes all cellular membranes as identical. This was challenged by the development of the electrons micro plasma membrane 7-8nm thick and thin. The inner membrane of mitochondria is only 6nm thick and it has a substantially greater layer of proteins than the plasma membrane.
- There are differences in the specific kinds of lipids and other lipids present. It also follows that membranes with different functions differ in chemical composition and structure.
- Placement of the proteins is disputed. Unlike the proteins dissolved in cytoplasm, member proteins are not very soluble in water. They are amphipathic as their phospholipids partner in membranes if proteins were layered on the surface of the membrane, their hydrophobic part would be in an aqueous environment.
- This arrangement the proteins separates the hydrophilic heads of the phospholipids from water.

4. S.J Singer and G. Nicolson (1972)

These scientists proposed the fluid mosaic model of a cell membrane.

Fluid; because the individual phospholipid and protein molecules can move laterally, giving the membrane a flexible structure that is constantly changing in shape.

Mosaic; because the proteins that are embedded in the phospholipid bilayer vary in size, shape and pattern of arrangement.

- ✓ According to this model the cell membrane consists of a fluid phospholipid bilayer; whose surfaces contain protein molecules; floating about them in a fluid mosaic pattern; the phospholipid bilayer contain phospholipid molecules ;that are arranged such that their hydrophobic tails face each other, in wards; and their hydrophilic heads face out wards;
- ✓ Some protein molecules extend into the phospholipid layers up to a certain level these are known as integral or intrinsic proteins; while others penetrate through the membrane these are known as trans membrane proteins;
- ✓ Some of the trans- membrane proteins are have pores and these are known as channel proteins.
- ✓ some protein molecules occur on the surface of the phospholipid layer these are the peripheral or extrinsic protein molecules
- ✓ Proteins are dispersed and immersed in a phospholipid bilayer which in is in a fluid state in a mosaic way.
- ✓ Some surface or peripheral protein molecules have branching carbohydrate portion or chains to form glycoprotein; and some lipid molecules also have branching carbohydrate chains to form glycolipids; The membrane also contains cholesterol that distort the close packing of phospholipids to keep them more fluid; Cholesterol also increases stability and flexibility of the membrane so that in its presence; the membrane cannot breakup;

Or the fluid mosaic model can be expressed as;

- The membrane is made of two phospholipid layers. The phospho lipid tails face inwards whereas the phospholipid head face outwards.
- Phosphate heads are polar, hydrophilic and form hydrogen bonds with water.
- Lipid tails are non-polar, hydrophobic and are attracted to each other by hydrophobic interactions and Van der Waals forces.
- Extrinsic (peripheral) proteins are found at the inner and outer surfaces.
- Some intrinsic proteins are partly embedded in any one of the phospholipid layers while others span across the two phospholipid layers.
- Some transmembrane proteins are porous. Some proteins conjugate with short, branched carbohydrates to form glycoprotein.
- Some phospholipids conjugate with short, branched carbohydrates to form glycolipid.
- In animal cells, cholesterol molecules squeeze between the phospholipid molecules.

<u>The diagram below shows the fluid mosaic model of the plasma membrane</u>.

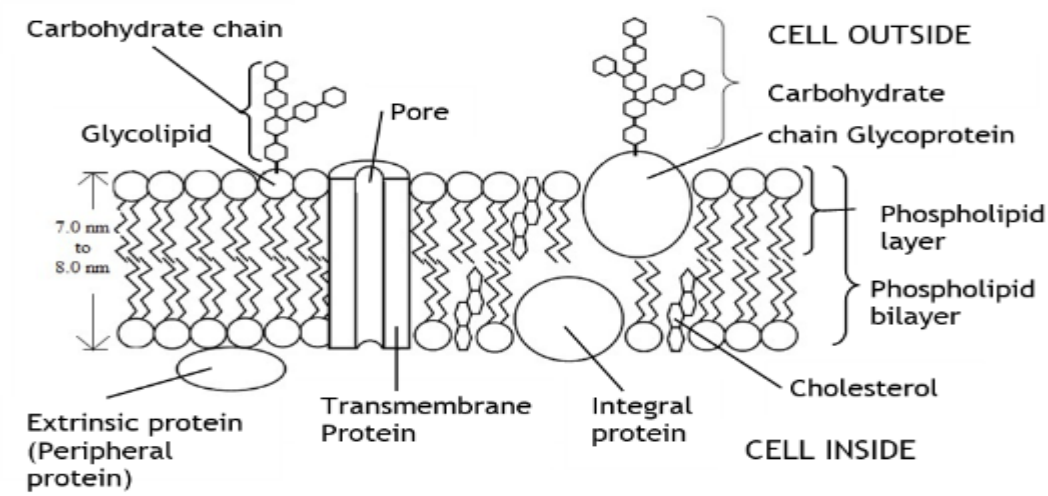


Diagram in F.A page 27 fig 2.22A
Understanding biology page 55 fig 4.4
NOTE;
The fluid mosaic model is now our most acceptable working model of the structure of a cell membrane.
The plasma membrane of a cell and membranes of the various organelles have unique connections of proteins. These proteins are dispersed and immersed in the phospholipids bilayer in an irregular arrangement.

Functions of the membrane proteins.

✓ They are transport proteins i.e proteins that spans a membrane may provide selective circulation and some transport proteins, hydrolyze ATP as energy source to actively pump substance across the membrane (active transport).

- ✓ They are enzymes whereby they carry out sequence steps of a metabolic pathway.
- ✓ Proteins are receptor sites. Proteins have very specific shapes. This makes them ideal as receptor molecules for chemical signaling between the cells e.g hormones are chemical messages which circulate in blood but only bind to specific target cells which have the correct receptor sites.
- ✓ They are intercellular junction which ensures that tissues and organs are formed.
- ✓ They enable cell-cell recognition.
- ✓ They are an attachment on the cytoskeleton and extra cellular matrix. Although animals lack cell walls they do have an elaborate extra cellular matrix whose main ingredients are glyco-proteins. These form very strong fibres outside the cell and these are the advantages of extra cellular matrix; they provide support and they control activities of the genes in the nucleus.
- ✓ They have networks of glycoprotein which transmits mechanical stimuli from extra cellular matrix.
- ✓ Energy transfer; in photosynthesis and respiration proteins take part in the energy transfer systems that exist in the membranes of the chloroplasts and mitochondria respectively.
- ✓ Cholesterol; Act like a plug, reducing even further the escape or entry of polar molecules through the membrane.
- ✓ Neural transmitters, the chemicals which enable nerve impulses to pass from one nerve cell to the next, also fit into specific receptor proteins in nerve cells.

NB. In animals, there are three main types of intracellular junctions;

- Tight junction.
- Desmosarries.
- Gap junctions.

FLUIDITY OF THE MEMBRANE.

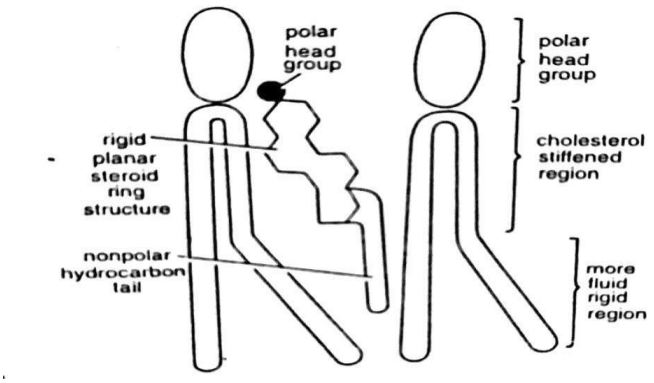
Membrane fluidity; refers to the viscosity of the lipid bilayer of a cell membrane

- ✓ Membranes are not static sheets of molecules locked rigidly in space. This is because the phospholipids and some of the proteins are held together by hydrophobic interactions that allow the molecules in the membrane to drift about laterally in the plane of the membrane.
- ✓ **Flip-flop movement;** where the phospholipids switch from layer to another is rare but possible. Lipids move along the plane of the membrane rapidly at an average speed of $2\mu ms^{-1}$.
- ✓ Proteins are much larger than lipids and they move more slowly but some do drift about. Many membrane proteins are unable to move far because of attachment to cytoskeleton. A membrane remains fluid as the temperature rises until finally at same critical temperature, it solidifies.
- ✓ The temperature at which membrane solidify depends on its lipid content or composition.
- ✓ It will remain fluid to a lower temperature if it is rich in phospholipids with unsaturated hydrocarbon tails which attain kinks which does not allow phospholipids to closely pack together.

FACTORS AFFECTING FLUIDITY OF THE PLASMA MEMBRANE

- **Temperature**; high temperature increases fluidity low temperature decreases fluidity. Low temperature decreases membrane fluidity because lipids are laterally ordered, the lipid chains pack well together, mobility reduces to allow many stabilizing interactions. Increase in temperature increases membrane fluidity because lipids acquire thermal energy to become mobile and reduce stabilizing interactions.
- **Length of fatty acids**; fluidity increases with decreasing length; long chain decreases fluidity, longer chain increases surface area for interactions between adjacent chains increasing vandar-waals forces of attraction
- **Unsaturated fatty acids**; these have kinks in the fatty acid tails which prevents close packing hence increasing fluidity; saturated fats lack kinks thus close packing hence decreasing fluidity.
- **Cholesterol**; this occurs between phospholipids and inhibits close packing at high temperature decreases fluidity and low temperature increases fluidity.
  At low temperatures, cholesterol increases membrane fluidity by preventing fatty acid hydrocarbon chains from coming together and crystallizing there by inhibiting the transition from liquid to solid (decreases the membrane freezing point).
  At warm temperature cholesterol decreases membrane fluidity by interacting with lipid tails to reduce their mobility, thereby increasing the melting point. At high concentrations, cholesterol also prevents fatty acid hydrocarbon chains from coming together and crystallizing.
  Note: the ratio of cholesterol to lipids in a membrane can be as high as 1:1

Illustration of the interaction of the phospholipids



MEMBRANE POROSITY

Porosity is the quality of the plasma membrane to have tiny pores. The possession of tiny pores is essential for membrane transport. This is affected by the phospholipids, cholesterol, glycoproteins, and proteins, unsaturated fatty acid chains of phospholipids which form kinks or bends that prevent close packing of the phospholipids.

When asked to talk or write about porosity, you relate the above factors to the packing of the membrane that either leaves pores or removes pores within the membrane.

Functions of plasma membrane.

- ✓ It allows exchange of materials between the cell and its surrounding.
- ✓ It contains protein molecules which act as carrier molecules for certain materials e.g mineral ions across the membrane.
- ✓ Impulse transmission in nerve cell occurs along the cell membrane.
- ✓ It offers protection to the inner parts against mechanical injury.
- ✓ It splits up at the centre during cell division to give rise to daughter cells.
- ✓ It also act as a sight in which certain reactions occur e.g in prokaryotes photosynthesis and respiration occur in cell membrane.
- ✓ It re-organizes foreign bodies during body defence.
- ✓ It also plays a role in energy transfer since it contain protein molecule.
- ✓ The cholesterol in it acts like a plug to reduce further escape on entry of polar molecules through the membrane.
- ✓ The glyco-protein in the molecules act as antigens or cell identity makers, this enables the cells to recognize other cells and behave in organized way.
- ✓ The protein molecules in the membrane specific shape that enables them to act as specific receptor molecules, allowing chemical signaling between the cells e.g neural transmitters the chemicals which enable the impulse to pass from one cell to the other, have specific receptor molecules in which other receptors can fit.
- ✓ The proteins at times act as enzymes e.g microvilli on epithelial cells lining some parts of the gut contains some digestive enzymes their surface membrane.
- ✓ It also separates the content of the cell from its surrounding.

Properties of the cell membrane.

- ▪ It is selectively permeable; this implies that it allows only small sized parts such as glucose, amino acids, fatty acids, mineral irons etc.
- ▪ It is made up of proteins and lipids each phospholipids consist of polar head contain the phosphate and 2 non-polar carbohydrate chains from fatty acids. The head is hydrophilic (water loving) while the head is hydrophobic (water hating).
- ▪ The Phospho lipids therefore gives the membrane its fluid nature and being dynamic.

Adaptations of cell membrane.

- It has globular proteins which are in constant motion to determine its flexibility.
- It contains some pores particularly in protein molecules to allow passage of materials in and outside. The pores are of particular size to allow only small sized particles and this makes the membrane to be selectively permeable.
- The membrane is thin and this reduces the distance over which materials diffuse.
- The membrane has a receptor site on its extrinsic proteins recognition by other cells.
- Note: adaptations are dependent on the parts of the membrane

DISTRIBUTION AND FUNCTION OF MEMBRANES OF CELLS

PLEASE

Membranes of cells does not only include the plasma membrane, which forms the cell boundary plus its various modifications, but also all other membranes enclosing some organelles and some cytoplasmic inclusions within cells.

- **Plasma membrane**; Selective transport in and out of cell, Cell to cell recognition, Antigen presentation, Hormonal signaling, Separating cytoplasm from the rest of the cells.
- **Nuclear membrane**; protects DNA, Allows outward diffusion of RNA/Entry of ATP into the nucleoplasm.
- **Mitochondria outer membrane**; allows entry of products of glycolysis into the mitochondrial inner membrane, Attachment of respiratory enzymes, Attachments of respiratory pigments for electron transport.
- **Endoplasmic reticulum membranes**; Intracellular transport/ Attachment of ribosomes/Synthesis of steroids.
- **Chloroplast outer membrane**; allows photosynthetic products out and substrates in Chloroplast lamellae; Reservoir for photosynthetic pigments.
- **Golgi membranes**; Sorting of ER synthesized material/Synthesis of glycoprotein/Synthesis of polysaccharides e.g. cellulose in plants.
- **Lysosomes**; Limiting escape of lytic enzymes.
- **Tonoplast**; enclosing cell sap/Selective entry of water and solutes.
- **Phagocytic/ micro-pinocytic vesicles**; Uptake of materials into cells.
- **Root hairs plasma membrane**; increasing surface area of epidermal cells.
- **Autolytic/autophagy vacuoles**; intracellular digestion.
- **Neurilemma**; diffusion of Na+ and K+ allowing electrical polarity.
- Myelin sheath membrane insulates nerve fibres to increase transmission speed.

2. **THE CYTOPLASM**

This is a jelly like matrix with in the cell in which cell organelles and structure are suspended. It's a fluid like substance also called cytosol and among other structures, which are found in the cytoplasm are; proteins fibres in form micro fibres and micro tubules, nucleus, chloroplasts for plant cell, Golgi apparatus, ribosomes, endoplasmic. The cytosol is a homogeneous solution but its highly organized structure that surrounds the organelles.

3. **THE CYTO-SKELETON**;

This is the lattice network of the cytoplasm of the cell that consists of microfilaments, Intermediate filaments and microtubules.

The micro-filament; Consists of actin and myosin proteins; the actin filaments are associated with fibre involved in the movement of the cells and its organelle.

The micro tubules; consist of alpha and beta tubulins.

The cytoskeleton it's not rigid but capable of quit rapid movement and reorganization.

Functions of Cyto-skeleton.

- ❖ It gives support to nuclear membrane and other organelles.
- ❖ It takes part in formation of cell junction.
- ❖ It is highly dynamic and can easily a symbol and di-symbol depending on the condition on which the cell is.
- ❖ It also takes part in the amoeboid movement.
- ❖ The micro-tubules in it and centrioles form spindle fibres used to pull chromosomes to the opposite role during cell division.
- ❖ The micro-tubules also form flagella and cilia which are used for locomotion.
- ❖ The micro-tubules also act as tracks along which the organelle moves.
- ❖ It maintains the shape of the cell
- ❖ The cytoplasm of same cells contains certain chemicals in aggregates e.g inclusions like glycogen granule in liver, ciliated muscles, melanin granules on skin, triglycerides in a pose cells.

MEMBRANE BOUND ORGANELLES.

Refer to table in B.S on pages 137 and 139

These are organelles found in the cell that are bound by membranes, some are single membrane bound organelles, and others are double membrane organelles.

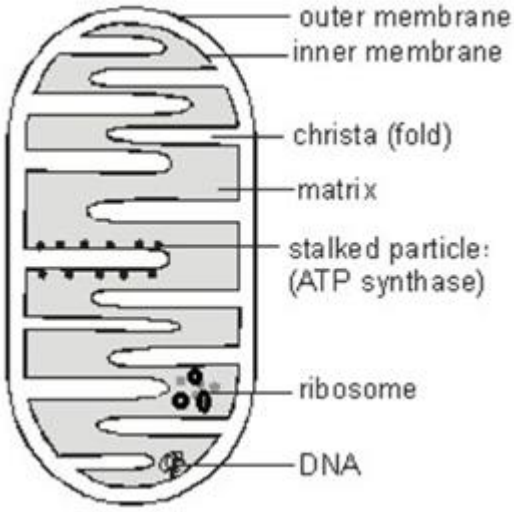
1. THE MITOCHONDRIA.

These are found in the cytoplasm of the eukaryotic cells.

Structure;

- ✓ A Mitochondrion has a sauce-shaped structure whose size varies and it's a double membrane bound organelle.
- ✓ When viewed in a transverse section, it's spherical/ round of about 0.2nm but in the side view it's elongated of about 5nm in length.
- ✓ It's surrounded by an inner membrane and outer membrane these are separated by inter membranous space. The outer membrane is smooth which the inner membrane is highly folded inner wards to give rise to extensions called cristae. The cristae increase the surface area on which the respiratory processes take place.
- ✓ The surfaces of the cristae have stalked granules along their length. The remainder of the mitochondrion is the matrix which is a semi liquid material containing proteins, lipids and traces of DNA
- ✓ The outer of which controls the entry and exit of chemicals.
- ✓ Mitochondria serve as signs for some stages of respiration. The numbers of mitochondria in the cell therefore vary with the metabolic activities of the cell. This means that highly active cells have more mitochondria than less active ones. Similarly the number of cristae increases according to how active the cell is.
- ✓ Each membrane is a phospholipid bilayer with varying phospholipid proportions and as well lipid-proteins ratios.

Longitudinal and transverse section of mitochondrion;



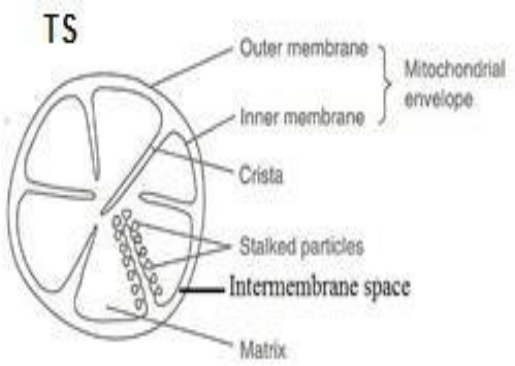


Diagram in B.S page 276 fig. 9.12

Adaptations of mitochondria to its functions;

→ The inner membrane of mitochondria is highly folded to cristae where by increasing the surface area for production of large amounts of energy (ATP).
→ Mitochondria contain many enzymes, hydrogen acceptors and electron transport system that are used in Kreb's cycle for energy production. Enzymes such as succinate dehydrogenase etc realize energy production within the matrix.
→ Mitochondria contain many small ribosomes which carry out protein synthesis by providing a firm support to messenger DNA.
→ Double membrane isolates the mitochondrion from interferences by processes in the cytoplasm.
→ Small size gives a large surface area to volume ratio for rapid uptake and release of materials.
→ The inner membrane contains stalked particle that make ATP.
→ Narrow inter-membrane space enables hydrogen ions concentration gradient to be rapidly established for chemiosmosis to occur.
→ Inner membrane contains molecules for the electron transport pathway.
→ DNA is present as a genetic material for controlling the synthesis of protein.

2. **THE CHLOROPLAST:**

This is an organelle found in a plant cell.

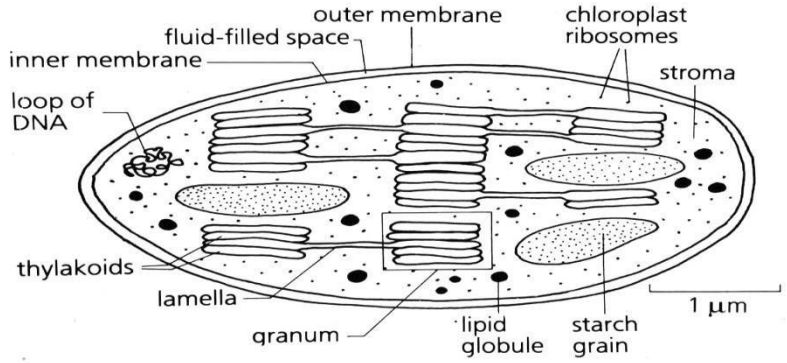
Structure:

- The two membranes are separated by small space.
- Chloroplast shape and size vary from biconvex in higher plants with length of ~5 μm to filamentous in algae, spherical, ovoid, etc.
- It is enclosed by an envelope of double membranes; outer membrane is semi-permeable. Inner membrane surrounds the Stroma, regulates entry and exit of materials to the chloroplast and is a manufacturing centre for fatty acids, lipids and carotenoids.

 chloroplasty8@gmail.com 0705561610/0789558972

- The outer membrane is smooth whereas the inner membrane is folded into series of lamellae and is highly selective in what it allows in and out.
- Both the inner and outer membranes are transparent and are separated by a small fluid filled space called the inter membrane space.
- The membranes enclose a jelly like colourless matrix called the stroma in which other structures and food reserves are embedded or suspended.
- It's where the dark stage of photosynthesis takes place because it lacks chlorophyll.
- It also consists starch granules, oil globules, circular DNA and small sized 70s ribosomes.
- Starch granules are temporary stores for starch containing enzymes like RUBP carboxylase. It also contains RUBP (Rubisco carboxylase) used in the photosynthesis.
- The stroma also contains system of interconnected system pilled and closed and flatted sac-like structures called thylakoids, one pile of these thylakoids form a granum, the thylakoids contain a photosynthetic coil called pigments and they form a site where a light stage of photosynthesis takes place to some of the thylakoids have tubular extensions called inter-granular lamellar which connect the adjacent grana.

A longitudinal section of chloroplast



Or Diagram in BS on page 201 fig. 7.7
Or diagram in Understanding biology page 56 fig 4.5a

Function of chloroplast;

It's an organelle where process of photosynthesis takes place.

Adaptations of chloroplast to suit its function;

- It's surrounded by transparent membrane to allow light pass through.
- Its thylakoids contains green pigment called chlorophyll.
- It has gelatinous ground matrix called stoma where the dark stage of photosynthesis takes place.
- The stoma contains starch granules which acts as temporary store for starch.
- The thylakoids are also numerous in numbers to increase surface area where the light stage of photosynthesis takes place.
- The grana are inter-connected with inter-granal lamellae to increase the surface area further more for process of photosynthesis.
- The grana give structural support and determine the shape of the chloroplast.

- Outer membrane is semi- permeable to regulate entry and exit of substances for maintaining internal chloroplast environment.
- Abundant light trapping pigments for photosynthesis
- Abundant enzymes catalyze photosynthetic reactions in the stroma.
- Narrow inter membrane space enables H^+ ion concentration gradient to be rapidly established for chemiosmosis to occur.
- Inner membrane contains molecules for electron transport pathway
- DNA is present as genetic material for synthesis of some protein
- Many ribosomes for protein synthesis to reduce on importing proteins from cytoplasm

NOTE:

Chloroplast belongs to a group of organelles called plastids.

A plastid is an organelle that contains either pigments or stored food material.

- ❖ Chromoplasts; these are the non-photosynthetic coloured plastids
- ❖ Chloroplast; these are associated with photosynthesis.
- ❖ Leucoplasts; these are colourless plastids; they consist of the protoplasts(store protein), amyloplasts (store carbohydrate such as starch), and lipidoplasts (store lipids)
- ❖ Elioplasts, these are chloroplasts that have not been exposed to light

COMPARISON OF A MITOCHONDRION AND A CHLOROPLAST.

Similarities;

- Both are double membrane organelles.
- Both have small sized 70s ribosomes.
- Both contain circular DNA.
- Both contain colourless ground matrix.
- They both have storage granules.

Differences;

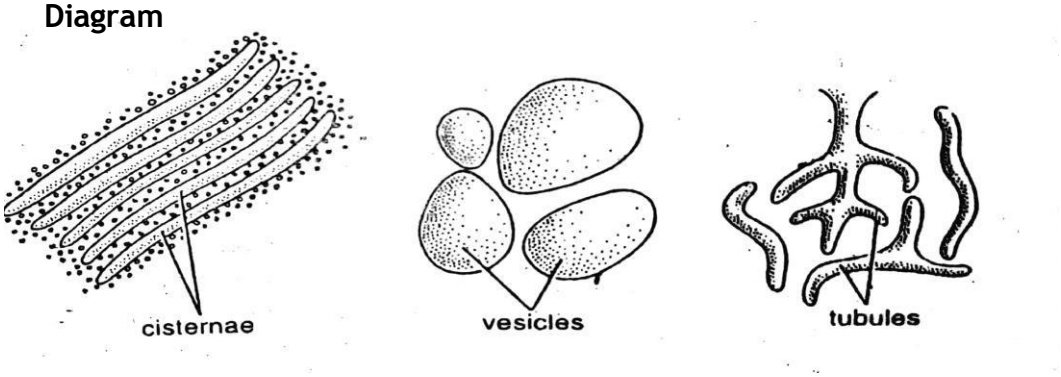
Mitochondria	**Chloroplast**
▪ The mitochondria contain cristae.	✓ It does not contain cristae.
▪ It does not contain starch grain.	✓ It contains starch grain.
	✓ It's unfolded.
▪ The inner membrane is highly folded.	
	✓ Has oval shape.
▪ It is a sauce shaped.	✓ It forms a site for manufacture of food by process of photosynthesis.
▪ It is an organelle where respiration takes place.	✓ It's found in plant cell.
▪ It's found in both cells.	✓ It contains inter-membrane that consists of thylakoids and grana.
▪ It does not have an inter-membrane system.	

3. **ENDOPLASMIC RETICULUM.**
   This is a network membrane of parallel lines running through the cytoplasm, it is a sheet like structure of a flattened membrane band sacs called **cisternae**, they are of two types namely;

   ROUGH ENDOPLASMIC RETICULUM
   This type has its cisternae covered with ribosomes. This is concerned with synthesis and transport of proteins.
   Proteins are made in ribosomes. A receptor in the membrane of endoplasmic reticulum provides a channel in to which proteins passes in to the end or as the proteins pass through the cisternae, they are modified in the root e.g converted into glycoprotein which travels to the Golgi
   body from where they are removed from the cell or passed to other organelle to other cells.
   Structure of the RER

- RER is an extensive membrane network of cisternae (sac-like structures), which are held together by the cytoskeleton.
- A phospholipid membrane encloses a space, the lumen from the cytosol, which is continuous with perinuclear space.
- The surface of the rough endoplasmic reticulum is budded with ribosomes which give it a rough appearance hence the name rough endoplasmic reticulum.
- A part of RER is continuous with the nuclear envelope

Diagram



Or check out diagram in Understanding biology page 59 fig 4.9
Functions of the RER

- Production and processing of specific proteins at ribosomal sites that are later exported the Golgi complex.
- Folds proteins into three dimensional shapes e.g. haemoglobin for further processing e.g. carbohydrates may be added.
- Transports ready proteins to the sites where they are required.
- Checks the quality of proteins formed, especially correct ordering and structure.
- Provides a pathway for transport of materials through the cell

SMOOTH ENDOPLASMIC RETICULUM;
This is the type of endoplasmic reticulum without ribosomes on the membrane. The cisternae are more tubular and the main function of this type is to synthesize lipids

E.g in the epithelium of small intestinal cell, the smooth endoplasmic reticulum synthesis form fats and glycerol absorbed form the gut and passes them to Golgi body.

Other functions are:

- It also makes steroids which are hormones e.g corticoid steroid made form adrenal cortex of the adrenal glands and sex hormones they are also steroids.
- Muscle cells have specific endoplasmic reticulum called sarcoplasmic reticulum essential in muscle contraction.
- They also play part in metabolism of carbohydrates.
- Detoxication of drugs and other poisons from other cells.
- They give structural support to the cell organelles.

Structure of smooth endoplasmic reticulum.

- The SER is a folded structure composed of a network of interconnected disc-like sacs and tubules called cisternae which are held in their place by the cytoskeleton.
- The SER is bound by a phospholipid membrane enclosing a fluid-filled space known as cisternal space or lumen. The lumen or cisternal space is continuous with the perinuclear space.
- Some part of SER is continuous with the nuclear envelope, some other part may be at the periphery of the cell.



Draw the diagram of a smooth endoplasmic reticulum basing on the RER

GENERAL FUNCTIONS OF THE ENDOPLASMIC RETICULUM

- Providing a large surface for chemical reactions.
- Providing a pathway for the transport of the materials in the cell.
- Producing proteins especially enzymes (RER)
- Producing lipids and steroids (SER)
- Collecting and storing synthesized materials
- Providing a structural skeleton to maintain cellular shape. E.g. the SER of the rod cell of the eye retina.



Now that you know the structure and function of the SER and RER, compare the two.

4. **GOLGI APPARATUS**.

- ✓ It's a complex structure that consists of several flattened sacks made of membrane.
- ✓ These sacks have cavities called cisternae in each sack. One side of the sack faces the endoplasmic reticulum that contains cellular products.
- ✓ There is only one Golgi apparatus in each animal but in plant cells there is large number of stacks called **dicotysomes**.
- ✓ Its position and size varies from one cell to another but it's well developed in secretory cells and neurons together and small in muscle cells.
- ✓ All product by endoplasmic reticulum are passed through Golgi apparatus in a particular sequence, cis Golgi network which returns endoplasmic reticulum any protein wrongly exported by it, they then pass through stack of cisternae which modify the proteins and lipids and add labels that allow them to be identified and sorted at the next stage.

✓ The trans Golgi network is where lipids and proteins are sorted and services to their final destination, the opposite size at the Golgi-starch of sacks faces towards the plasma membrane. The cellular membrane are then released that are budded off the sack depending on the nature of specific products, the vessels that lead to Golgi complex may become lysosomes, storage granules, secretary resides in addition to plasma membrane resides in addition to plasma membrane.

Functions of Golgi apparatus;

- The Golgi body produces secretary vessels as swellings.
- Bud off of the apparatus and usually contain enzymes, anti-bodies, hormones etc.
- It secrets carbohydrates eg of the new cell walls of cell membrane, such carbohydrates include amylo-pectin, pectin and cellulose etc.
- Sometimes the Golgi apparatus after budding off have occurred forms lysosomes, containing hydrolytic enzymes for cellular defence.
- It is also involved in the internal secretion of different chemicals such as glycoprotein like mucus.
- It's involved in transporting and transmitting lipids.
- It's involved in packaging and shipping vessels.
- It's also involved in separating different types of proteins basing in their function and destination e.g protein to be excreted incorporated and introduced in to the ribosomes.

STRUCTURE OF GOLGI APPARATUS;

- Golgi complex is made up of piles (stacks) of flattened sacs called cisternae (singular: cisterna) with vesicles budding (pinching) off at edges of sacs;
- One cisterna is a flattened sac, with a lumen enclosed by a single membrane.
- 4 to 8 cisternae pile up to form a stack which bends to form a semi-circle.
- A cell may have 40 to 100 stacks.
- An individual stack of the cisternae is sometimes referred as dictyosome. The Golgi complex contains a number of separate compartments, as well as some that are interconnected.
- The cisternae stack has 4 functional regions: the cis-Golgi network, medial-Golgi, endo-Golgi, and trans-Golgi network.
- The cisternae carry structural proteins important for their maintenance as flattened membranes which stack upon each other.
- The cis face is adjacent to the endoplasmic reticulum and the Trans points towards the plasma membrane.

Diagram of a golgi apparatus

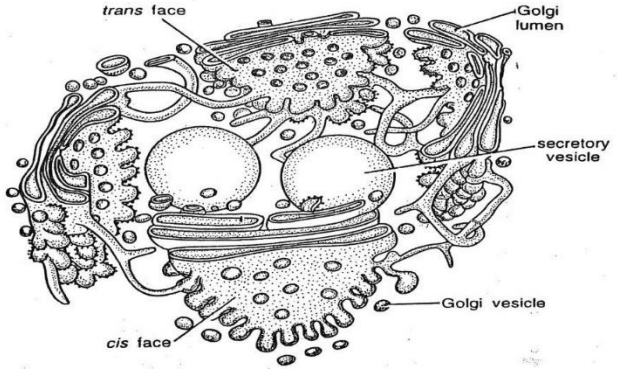


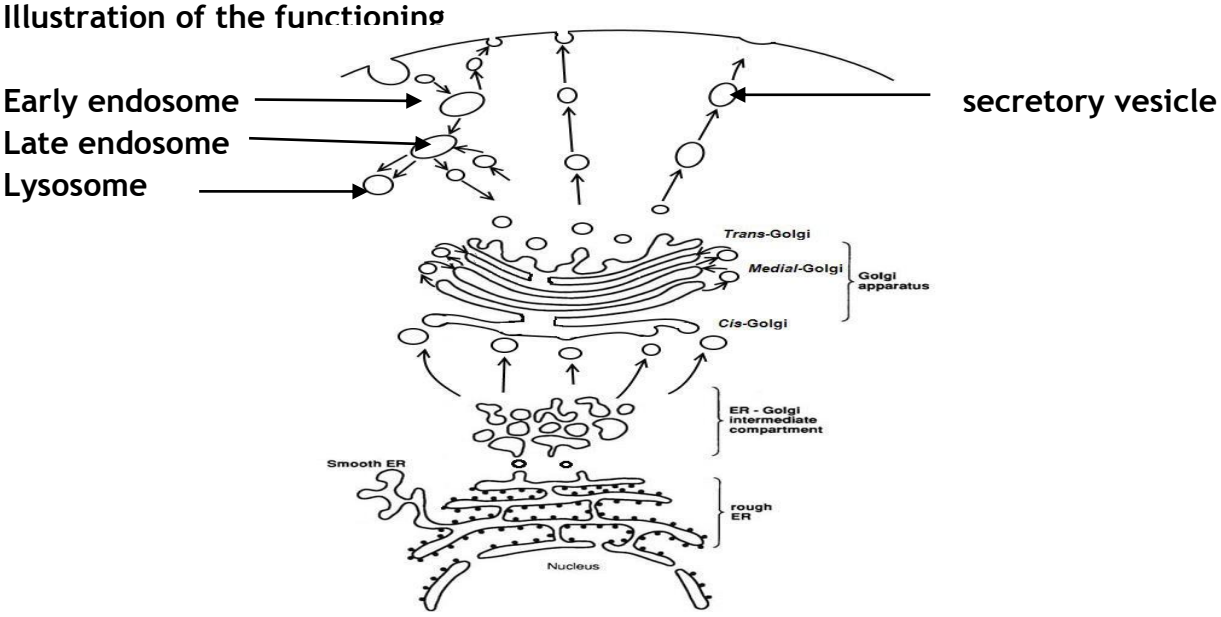
Diagram in F.A page 19 fig. 2.10

Diagram in understanding biology page 60 fig 4.10

FUNCTIONING OF THE GOLGI APPARATUS

- Proteins made at Rough Endoplasmic Reticulum (RER) have, as part of their amino acid sequence, a signal that directs them where to go, just like an address directs a letter to its destination.
- Proteins arriving at cis-Golgi but having RER retention signal (were wrongly sent), are repackaged into vesicles then returned to RER. Soluble or properly folded macromolecules (proteins, lipids and polysaccharides) from RER enter cis-Golgi network via transport vesicles i.e. carbohydrates are added to proteins (glycosylation), phosphate is added to protein (phosphorylation) etc.
- After partial modification, coated vesicles bud (pinch) off the swollen ends of cis-cisternae and fuse with ends of medial cisternae.
- Within medial-cisternae, different enzymes further transform macromolecules differently, depending on their structures and destination i.e. some are modified for secretion, others for the membrane, and some for lysosomes.
- After further modification within the medial-cisternae, coated vesicles bud (pinch) off the swollen ends of the medial-cisternae and fuse with the ends of trans-cisternae for further transformation.
- From trans-cisternae, the transformed macromolecules exit the Golgi and are sorted into different transport vesicles destined for lysosomes, plasma membrane or storage vesicles for secretion.
- Vesicles containing hydrolase enzymes fuse with membranes of growing lysosomes so that the contents of both structures fuse.
- Vesicles containing hormones e.g. insulin remain until when signaled by the cell, the vesicles then fuse with plasma membrane to release (secrete) the hormone outside the cell by exocytosis.
- Vesicles containing membrane proteins fuse with the cell membrane and some of the modified proteins become part of the cell membrane e.g. protein receptors.

Illustration of the functioning



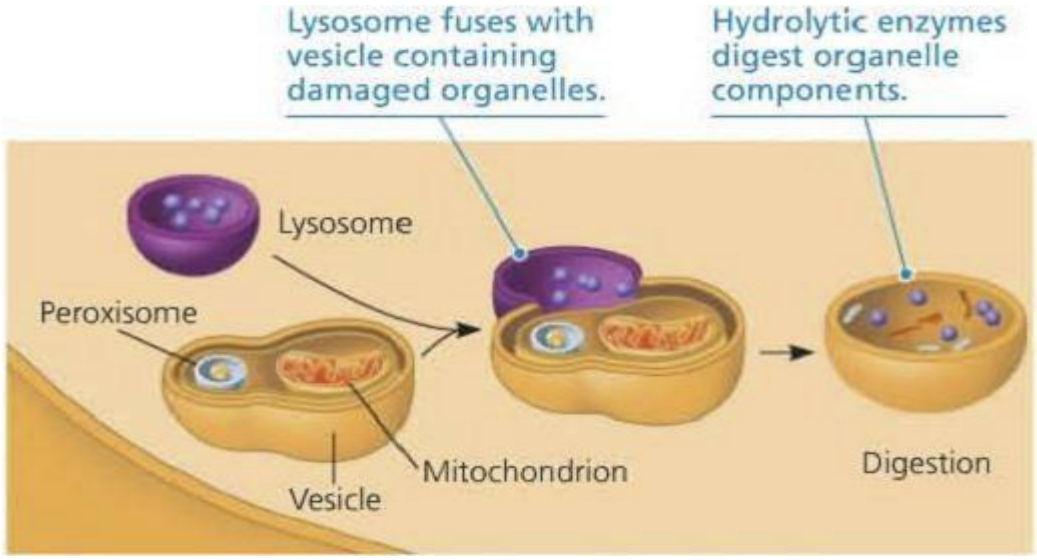
5. **LYSOSOMES.**

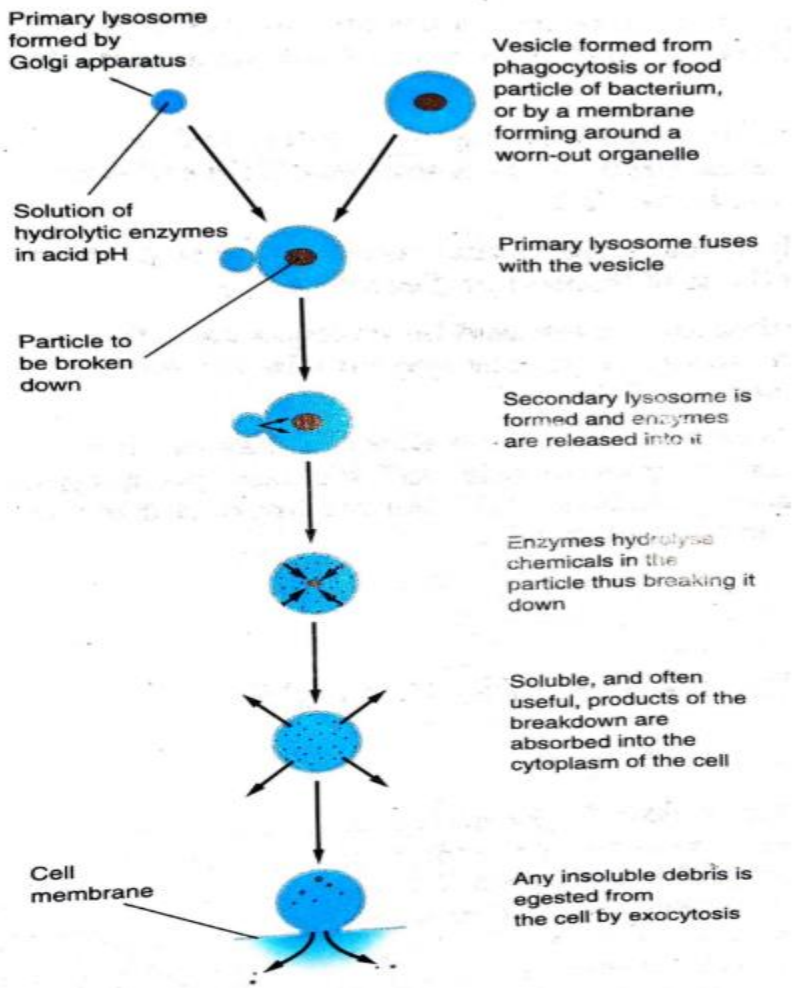
- These are simple spherical/ sack-like bodies with a diameter between 0.1-1.0μm and are surrounding a single membrane.
- They contain digestive enzymes mostly hydrolyses enzymes in acidic region or solution. They isolate enzymes from the remainder of the cell and by doing so; they prevent the enzymes from acting upon other chemicals and organelle from the cell.
- A **primary lysosome** is the one that contains only digestive enzymes with in an environment that is moved in acidic region than that surrounding the cytoplasm. A primary lysosome may fuse with food vacuole or another organelle to form a **secondary lysosome** in worn out organelles and the product of phagocytosis can be digested.
- Therefore lysosomes are connected with the destruction of cells and their structures.
- Lysosomes are bound by a single membrane and contain digestive hydrolytic enzymes like hydrolases in acid solutions.
- Enzymes containing lysosome are synthesized and transported to the Golgi in which are budded off as vessel.

Functions;

- They digest materials that enter the cell for example in a white blood materials digested are bacteria, fungi.
- They also digest the worn out organelles in a process known as **autophagy**.
- They release enzymes outside the cell in a process called exocytosis in order to break down other cells e.g it breaks down the **tadpole** tails during metamorphosis of an amphibian.
- They release lytic enzyme that resolves the membrane during fertilization.
- After cell death, the lysosomes are responsible for its complete breakdown a process known as **autolysis**

Functioning of the lysosomes





Or check out illustration in F.A page 21 fig 2.12.

6. MICRO BODIES (PEROXISOMES).

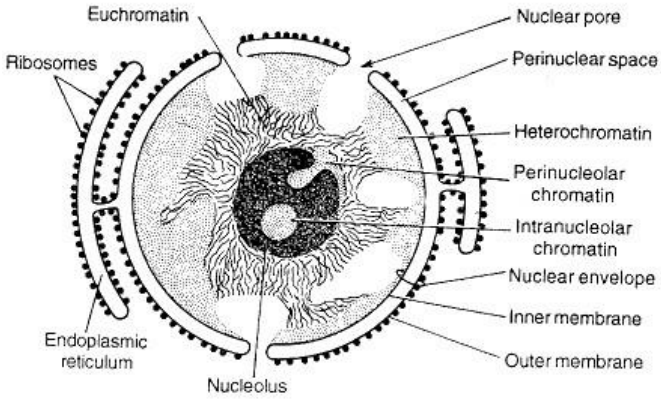
- ☑ These are also membrane bound organelles with a diameter between 0.5-1.5μM containing several specific enzymes that promote oxidative reactions and don't have internal structure.
- ☑ They are present in most cells particularly large and active cells such as in the liver. They contain one or more hydrogen from particular organelles and transferred to form hydrogen peroxide hence oxidizing the molecules e.g alcohol is oxidized to acetaldehyde by the liver.
- ☑ Peroxisome contain catalyses enzyme which prevents excessive accumulation of hydro-peroxide by catalyzing its breakdown to non-harmful products of oxygen and water.

7. THE NUCLEUS.

- ☑ Cell nucleus is enclosed / bound by a double-layered nuclear membrane (nuclear envelope); Outer membrane is connected to the endoplasmic reticulum;
- ☑ A fluid-filled space (perinuclear space) exists between the two layers of a nuclear membrane. Nuclear membrane is perforated by nuclear pores ~50 nm in diameter
- ☑ Enclosed within the inner membrane are the nucleoplasm (karyoplasm), nucleolus and chromosomes (chromatin);
- ☑ Nucleolus is a dense, spherical shaped structure; these are not distinct organelles and are essential in manufacturing of ribosomal RNA.
- ☑ Chromosomes (chromatin) are thread-like; they are of two kinds;

(i)**Heterochromatin**: stain darkly, genetically inactive, tightly coiled.
(ii) **Euchromatin**: loosely packed, genetically active and enriched

Diagram of the nucleus



Or diagram (Diagram in BS page 137)

FUNCTIONS OF NUCLEUS:

- It controls all other activities of the cell e.g cell division, growth and development, respiration.
- It contains the DNA material that determines the nature of an organisms or organisms of a given species.
- The nuclear membrane allows the exchange of materials.
- It contains ribosomal RNA required for protein synthesis.
- Carries instructions for the synthesis of proteins in the nuclear DNA.

Adaptations of the nucleus to its functions

8. VACOULE

These are fluid filled sacs bounded by a single membrane. Within mature plant cells, there is usually one large central vacuole with a single membrane called a Tonoplast. The vacuole contains a solution of mineral salts, sugars, amino acids, wastes e.g. tannins and pigments like anthocyanin.

Functions of vacuoles

- ✓ Sugars and amino acids which act as temporary food stores are stored within the vacuole.
- ✓ It stores anthocyanin which is of many colours and therefore may colour the petals to attract pollinating insects or fruits to attract animals for dispersal.
- ✓ They are temporary stores of organic wastes e.g. tannins. They accumulate in vacuoles of cells and are removed during leaf fall.
- ✓ They contain hydrolytic enzymes therefore perform functions similar to those of lysosomes.
- ✓ They support herbaceous plants and herbaceous parts of woody plants by providing the osmotic system which creates turgidity.

NOTE:

In animal cells, vacuoles are small, temporary and occur in large numbers. Common types include; food vacuoles, phagocytic vacuoles and contractile vacuoles which are important in osmoregulation in protozoa.

NON MEMBRANE BOUND STRUCTURES.

1. RIBOSOMES

- ❖ These are small round structures found free in a cytoplasm and also located on the surface of rough endoplasmic reticulum.
- ❖ Each ribosome is made up of two sub-units i.e the bigger unit and the smaller one. Each ribosome is composed of ribosomal RNA and proteins.
- ❖ Prokaryotes have 70S ribosomes (small subunit of 30S and large subunit of 50S) while Eukaryotes have mainly 80S ribosomes which are larger and more complex, each consisting of small (40S) and large (60S) subunit
- ❖ Ribosomes are divided into two major parts i.e 70s and 80s. The prokaryotes contain ribosomes 70s while Eukaryotes
- ❖ Contain ribosomes 80s, each ribosome is roughly containing equal amount of RNA and proteins.
- ❖ **Note:** S stands for the Svedberg unit for sedimentation velocity

Diagram of ribosome

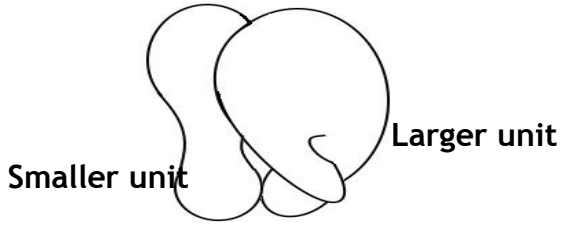
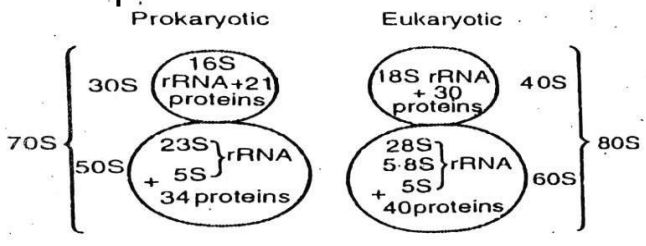


Diagram showing the composition of different ribosomes



2. CELL WALL

- Plant cells, like those of prokaryotes and fungi are surrounded by a relatively rigid wall which is secreted by the living cell (the protoplast) with in.
- Plant cell walls differ in chemical composition from those of the prokaryotes and fungi. The wall laid down during cell division of plant is called the **primary wall**. This may later be thickened to become a secondary wall. Formation of the primary wall is described in this section and an early stage of wall formation.

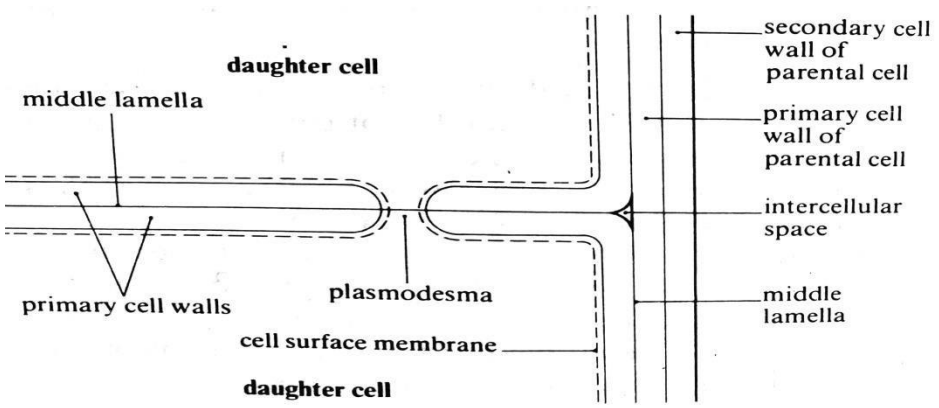
STRUCTURE OF THE CELL WALL:

- The cell wall is made up of primary cell wall, middle lamellae, secondary cell wall and tertiary cell wall; primary cell wall consists of cellulose micro fibrils running through matrix of polysaccharide, pectates and hemicellulose are deposited on either sides of the middle lamellae.
- Micro fibrils run in all directions; portion of the endoplasmic reticulum is trapped across the middle lamellae and forms the plasmodesmata; outermost layer that is comparatively thin elastic delicate and permeable simple and smooth.
- Secondary cell wall is formed by further deposition of cellulose on the inside of the primary cell wall causing the micro fibrils to become tightly packed thicker impermeable and found below primary cell wall.
- Cellulose cell walls oriented in the direction of the cell elongation; impregnated with chitin or suberin.
- Tertiary cell wall is found below secondary cell wall it thicker than secondary and primary; found in tracheids and gymnosperms.

FORMATION OF PLANT CELL

- Cell wall forms during telo phase stage of cell division when the cell plate forms between daughter cell nuclei.
- Cell plate forms from a series of vesicles produced by Golgi (Dictyosome).
- Vesicles migrate along the microtubules and actin filaments within the phragmoplast and move to the cell equator.
- Phragmoplast contains mitotic spindles, microtubules, microfilaments, and endoplasmic reticulum surrounded by nuclear envelopes.
- Vesicles join up their contents, and the membranes of the vesicle become the new cell membrane.
- Dictyosome synthesize the non-cellulosic polysaccharides like pectins and transported to build the middle lamella.
- Cellulose is made at the cell surface, catalyzed by the enzyme cellulose synthase.
- While the cell plate is growing, segments of smooth endoplasmic reticulum are trapped within it, later forming the plasmodesmata connecting the two daughter cells.

Illustration of cell wall formation



Functions of the cell wall:

- ✓ Mechanical strength and skeletal support is provided for individual cells and for the plant as a whole.
- ✓ Cell walls are fairly rigid and resistant to expansion and therefore allow the development of turgidity.
- ✓ Orientation of cellulose micro fibrils limits and to controls cell growth and shape.
- ✓ The system of interconnected cell walls is major path way of movement for water and dissolved mineral salts.
- ✓ Cell walls develop a coating of waxy outing, the cuticle on exposed epidermal surfaces reducing water loss and rise of infection.
- ✓ The walls of xylem vessels and sieve tubes are adapted for long-distance translocation of materials.
- ✓ The cell walls of root endodermal cells are impregnated with suberin that forms a barrier to water movement.
- ✓ Some cell walls are modified as food reserves as in storage of hemicelluloses in some seeds.

Adaptations of the cell wall to perform its function

- Cellulose fibres running parallel allowing maximum formation of the hydrogen bonds give the cell wall high tensile strength.
- Thick cell wall made up of three layers makes it strong or tough to resists bursting due to osmotic influx of water molecules
- Secondary walls may be cutinized or suberinised for preventing water loss or desiccation as a result of high temperature
- The cellulose microfibrils group forming macro fibrils which allow them to give much support.
- Primary cell wall is flexible to allowing cell expansion as water enters by osmosis.

3. THE CILIA AND FLAGELLA.

Cilia and flagella are organelles that have identical structures, although flagella are **longer**.

They are out growths from cells which can beat either in one direction (cilia) or like a wave (flagella).

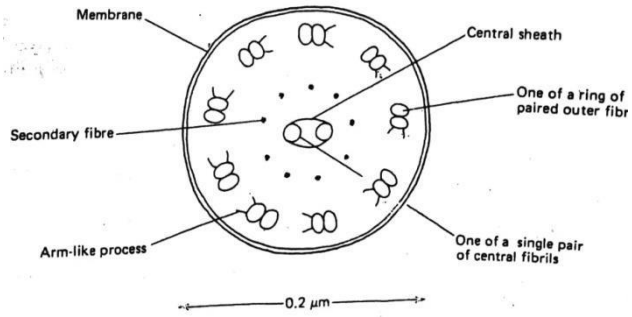
Cilia and flagella are responsible for movement of cells and materials. Cilia in paramecia beat rhythmically to propel the cell in a particular direction while flagella in bacteria and sperm cells beat side by side to propel the cells forward.

Cilia in the respiratory tract beat rhythmically to expel foreign bodies preventing them from reading the lungs. The oviduct is lined by ciliated epithelial cells whose cilia beat rhythmically to propel a mature egg towards the uterus.

STRUCTURE OF CILIA AND FLAGELLA

- Both the cilia and flagella arise from a small granular structure called basal body.
- Cilia and flagella are covered by a unit membrane, which is an extension of the cell membrane.
- There is a central filament called axoneme formed of 11 microtubules arranged in the pattern of 9+2 i.e. 2 central singlets (single microtubules) and 9 peripheral doublets (pairs of microtubules).
- Each of a pair of peripheral microtubules has extension of peripheral filaments.

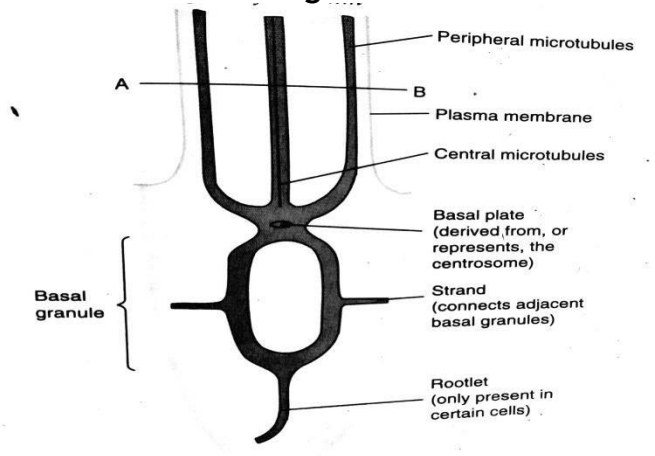
Transverse section of a cilium / flagellum.



Or Diagram in F.A page 23 fig. 2.16B

Or diagram in understanding biology page 63 fig 4.15b

Longitudinal section of a cilium or flagellum.



Or diagram in understanding biology page 63 fig 4.15a

Functions of cilia and flagella

- ❖ Ciliary movement enables paramecium to drive food into their gullet.
- ❖ In certain molluscs Ciliary movement facilitates gaseous exchange by passing water currents over the gills.
- ❖ In echinoderms Ciliary movement enables locomotion by driving water through the water vascular system.
- ❖ Cilia lining the respiratory tract of human drives away the microbes and dust particles towards the nose or mouth.
- ❖ Cilia in the oviduct or fallopian tubes of human female moves ova towards the uterus.
- ❖ Cilia in nephridia of annelids e.g. earthworms moves wastes
- ❖ Flagellum of sperms enables their swimming movement.
- ❖ Flagellum enables the movement in certain protozoans like euglena

COMPARISON OF CILIA AND FLAGELLA

Similarities;

- ✓ Both have 9+2 pattern.
- ✓ Both are used for locomotion
- ✓ Both are surrounded by cell membrane.
- ✓ Both are microscopic.
- ✓ Both are contractile.
- ✓ Both are filamentous.

Differences;

Cilia	Flagella
Numerous	Less in number
Short and hair-like organelle; 10µm	Long whip-like organelle;150 µm
Occur throughout the cell surface	Presence at one end
Beat in coordination	Beat independently
Show sweeping movement or pendular Stroke	Undulatory movement
Many functions such as locomotion, feeding, sensory etc	Locomotory only

4. **THE CENTRIOLES**.

- They are hollow, cylinders about 0.2 µm in diameter. They arise from a distinct region of the cytoplasm called the **centrosome** that contains only two centrioles.
- At cell division, the centrioles replicate and migrate to opposite poles of the cell where they synthesize the microtubules which form the spindle fibres.
- **NOTE:** Each centriole is made of nine triplets of microtubules arranged in a ring (9+0pattern)

Functions;

The spindle fibres perform two functions during cell division.

- They align the chromosomes in position at the equator.
- They contract and shorten to pull the chromosomes towards the opposite poles.

5. MICROFILAMENTS.

☑ They are very thin, long strands about 6nm in diameter. They consist of protein molecules known as **actin** and a small proportion of **myosin**.

- ☑ Therefore there are two types of microfilaments actin and myosin microfilaments.
- ☑ These microfilaments are involved in muscle contraction and relaxation.
- ☑ The myosin filaments move over the actin filament in skeletal muscles in order to cause contraction of the muscle thereby bringing about movement of the different parts of the body.
- ☑ Microfilaments also occur in the tail of sperm cell where they contract and relax causing side by side lashing of the tail in order to propel the cell.
- ☑ Microfilaments exist in sieve tubes of phloem vessels in woody plants.
- ☑ They are involved Cytoplasmic streaming i.e the filaments are in constant motion with in the sieve tubes.

6. INTERMEDIATE FILAMENTS

- These are smaller than microtubules. They are made up of myosin proteins.
- Filaments are so called as their diameter; 10 nm is intermediate between that of microfilaments and of microtubules.
- Intermediate filaments are formed from fibrous protein which varies with different tissue type.
- They play role in cell-to-cell attachment and stabilize the epithelium.
- They provide strength and rigidity to axons and connect adjacent cells.
- Intermediate filaments are divided into five groups; Keratins found in epithelial cells,

Glial filaments found in astrocytes, Neuro filaments found in nerve cells, Vimentin found in many types of cells and Desmin found in muscle fibers

7. MICRO VILLI.

They are tinny finger like projections. They are found on the membrane of certain cells such as those of the epithelium and proximal convoluted tubules of the kidney nephron.

Cells that bare micro villi are responsible for material absorption. The micro villi increase the surface area for absorption of sufficient amounts of materials.

8. MICRO TUBULES.

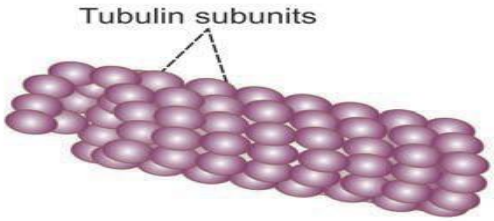
Has two alternating strands of alpha-tubulin and beta-tubulin (globular protein) each of which contains 450 amino acids which bind together in a helical shape to form a hollow, straight cylinder with length of 200nm-25µm and diameter of about 25nm.

Functions

- ✓ Serve as conveyor belts moving other organelles throughout the cytoplasm.
- ✓ Are the major components of cilia and flagella in cell motility
- ✓ They form spindle fibers during cell division.
- ✓ Give shape and mechanical support to the cell.
- ✓ Enable vesicles to move during cell wall formation in plants.

Diagram

Or check out diagram in understanding biology page 62 fig4.13



END OF SUB-TOPIC CELL STRUCTURE AND MICROSCOPY

I thank you so much that you have now understood cell structure and microscopy. We looked at what a microscope is, different types of microscopes including light and electron microscopes we went on further to give different kinds under each microscope type. We compared different types of microscopes.

We also defined a cell, gave the cell theory, looked at prokaryotic and eukaryotic cells, we compared them. We looked at a detailed study of the structure of the eukaryotic and prokaryotic cells, compared them. We further looked at plant animal cells based on their structure. Gave detailed study of the parts of a cell as membranous and non- membranous. Parts included;

Cytoplasm, nucleus, chloroplast, mitochondrion, endoplasmic reticulum, golgi apparatus, plasma membrane, lysosomes, ribosomes, micro bodies, vacuoles, cilia and flagella, centrioles, microtubules, micro filaments, microvilli, cell wall.

So you can now try out these questions

1. Explain the role of microfilaments and microtubules in movement.
2. Compare the structure of Eukaryotic and prokaryotic cells.
3. State the role of cell membrane in prokaryotic cells.
4. (a) Distinguish between cell organelle and cell inclusion
   (b) Describe the fine structure of the following;
5. a. (i) Golgi complex (ii) nucleus (iii) mitochondria
   b. Relate structures to the functioning in each of the structures in (b) above.
6. a) Describe the structure of the plant cell wall.
   (b) Compare the structures of plant cell wall and plasma membrane
   (c) Describe how membrane structure is related to traffic of materials across it.
7. a) Describe the functioning of the Golgi apparatus in animal cells.
   b) Give an account of roles of lysosomes in animal cells.
8. Give an account of the distribution and functions of membranes of cells.
9. (a) How do the components of the plasma membrane ensure its fluidity
   (b)Relate the function(s) of the following to the fluidity and porosity of their membranes
   (i) Plasma membrane
   (ii) Rough endoplasmic reticulum
   (iii) Golgi apparatus

DIVERSITY OF SPECIALISED CELLS AND TISSUES

Type of cell	Function
ANIMAL CELLS	
Epithelial cell	It possesses a form that makes it more suitable for it lining the surfaces of body organs and cavities e.g the gut.
Glandular cells.	They are responsible for producing some kind of body secretions e.g mucus hormones, antibodies etc. such cells have a prominent Golgi body.
Fibroblasts.	They secrete protein fibres that make up the connective tissue for holding the tissues and organisms together.
Chondroblasts and osteoblast	They produce cartilage matrix and bone matrix respectively.
Erythrocytes (RBCS).	They are responsible for conveying oxygen throughout the body.
Leucocytes (WBCS).	They are generally amoeboid and defend the body against infection.
Nerve cells.	They are slender and arm-like; they transmit impulses throughout the nervous system. They don't undergo cell division e.g rods and corns.
Sensory cells; Neurons	They are capable of electric activity generated by specific stimulation e.g sound, light etc.
Muscle fibre	They contain actin and myosin proteins (skeletal muscles). They are capable of electric conduction. They have elongated cells whose electrical activity is accompanied by contraction.
Spermatozoa.	A single cell with an elongated tail containing a 9+2 arrangement of microtubules. The flagellum tail is capable of power undulation hence the super metazoan cell is propelled forward.
Chromatophores	They are responsible for colour changes. They are stellate cells containing a pigment whose concentration changes hence changing the skin colour e.g in the skin of amphibians and reptiles there are many chromatophores.
Frame cells.	They are found in flat worms e.g liver flukes, fasciola hepatica. These cells are used for osmoregulation in flat worms.

Nematoblast cells (stinging cells).	They are thread like and contain a toxic fluid capable of piercing and poisoning prey hence mobilized for easy capture e.g in jelly fish, hydra and sea animals.
Ovum (egg cells).	This is a reproductive cell incapable of movement, lack flagella and it's large.
PLANT CELLS.	
Photosynthetic cells.	They are packed with chloroplasts. They contain chlorophyll a green pigment that traps light energy. They perform the function of building up complex sugars from CO_2 and H_2O.
Parenchyma cell.	They are packed tightly together to fill up any spaces between tissues. They are living cells responsible for food storage e.g starch.
Epidermal cells.	The outer walls possess a waxy cuticle that minimizes excessive water loss.
Root hair.	Absorb water and mineral salts from the soil. They are long, have thin epithelium and are tapering.
Collenchyma cells and sieve tube.	Both are elongated and Collenchyma is concerned with strengthening the plant while sieve tubes transport of soluble, food materials within the plant. They are also hollow.
Guard cells.	Control closing and opening air spaces like stomata, they are concentrated on the lower epidermis of the leaf in most terrestrial plants.
Vessels (tracheids and fibres).	Strengthen stems of higher plants, however tracheids transports water from roots to leaves as well as vessels.

I thank you for you have been able to understand a number of cells and tissues that exist in plants and animals and there main functions. Now keeping the idea about these cells is key in enabling you understand the study of a tissues on the next page.

HISTOLOGY

A tissue is a group of similar cells organized into a structural and functional unit. It is a group of cells of similar structure organized for carrying out a particular function(s).

Characteristics of tissues

- ❖ Cells of a tissue are physically linked.
- ❖ The cells of a tissue may be interspersed with intercellular substances.
- ❖ A tissue may comprise one or more types of cells.
- ❖ A tissue is specialized to perform a particular function(s).

ANIMAL TISSUES

Early in development, the cells of the growing embryo differentiate into three fundamental embryonic tissues called germ layers.

- ✓ Ectoderm which forms the outer layer of the skin and the nervous system.
- ✓ Mesoderm which forms muscles, connective tissues, skeleton, kidneys and circulatory and reproductive organs.
- ✓ Endoderm which forms the lining of the respiratory tract and urinary bladder. It also forms the glands associated with the guts and respiratory tract.

Therefore the germ layers in turn differentiate into different cell types and tissues that are characteristic of the vertebrate's body. Tissues are joined to each other by proteins. The point of connection between two cells is a junction.

In adult vertebrates, the **principle kinds** of tissues include; **epithelial tissue**, **connective tissue, muscular tissue, nervous tissue** and **reproductive tissue** (associated with ovaries and testes; concerned with production of gametes: eggs and sperm respectively)**.**

EPITHELIAL TISSUE

This is a collection of closely packed single and multilayered compound sheets of cells covering the external and internal surface of the body of an organism.

Characteristics of epithelial tissue

1. Epithelial tissue consists of **tightly packed cells** that are firmly attached to each other with little intercellular material between them.
2. Epithelial cells are held firmly together by small amounts of carbohydrate cementing substances and by special intercellular junctions between the cells.
3. The bottom of epithelial cells rest on a **basement membrane** composed of a network of fibres which include collagen. The portion of epithelial cells attached to the basement membrane is called the **basal surface,** the

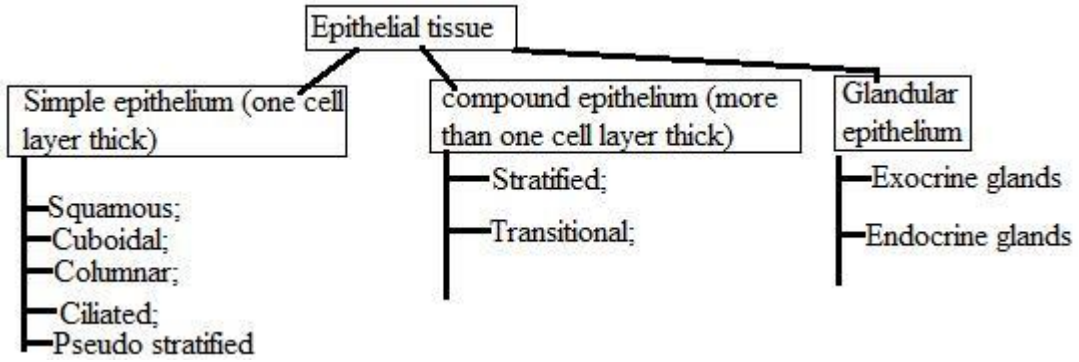
opposite end facing the external environment or the lumen of the body cavity is called the **apical surface/free surface.**

4. There are **no blood vessels** in the epithelial tissues hence the tissue lacks vascularity. As the epithelial cells are not supplied with blood vessels, **they rely on diffusion** of nutrients and oxygen from lymph vessels which run through nearby intercellular spaces. However, nerve endings may occur in the epithelium.

4. Regeneration- Epithelial cells have a **high regeneration capacity** due to rapid cell division. This gives the epithelial tissue quick recovery after any injury or abrasions.

CLASSIFICATION OF EPITHELIAL TISSUES

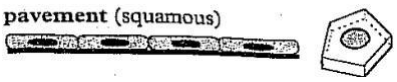
Epithelial tissues are classified according to the number of cells/layers and the shape of the individual cells.



SIMPLE EPITHELIAL TISSUES

A. Simple squamous/pavement epithelium

It consists of a single layer of cells. They are so thin that the nucleus causes a bulge and it is centrally placed, with a disc shape. Cells are irregular with tapering edges. Simple squamous epithelium is found in the following areas: Renal corpuscles of the kidney, lining of the alveoli of the lungs, lining of the blood vessels where it is referred to as the **endothelium**, blood capillary walls and lining of lymphatic vessels.



Functions

- Diffusion of materials
- Exchange of gases

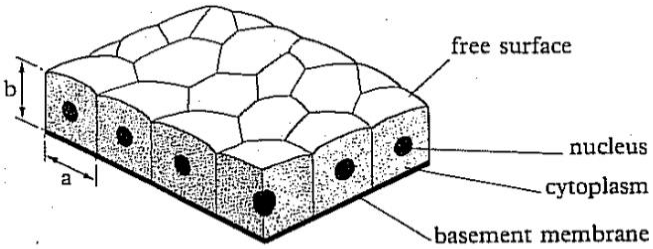
Adaptations

i. Thin flattened cells to reduce the distances across which materials diffuse.

ii. Possesses smooth lining to allow relatively friction free passage of fluids and materials through the hollow structures.

B. Simple cuboidal epithelium

The cells are roughly cube shaped and possess a central spherical nucleus. The upper surface of cuboidal cells is either pentagonal or hexagonal in outline. It is the least specialized of all the epithelial tissues.



Distribution

- Lining of salivary ducts, pancreatic ducts, convoluted tubules and collecting ducts of the nephrons of the kidney.
- Lining of the salivary glands, sweat glands and thyroid glands
- Lining of the retina

NB: The simple cuboidal epithelial tissue is non-secretary in the proximal convoluted tubule, distal convoluted tubule and pancreatic ducts.

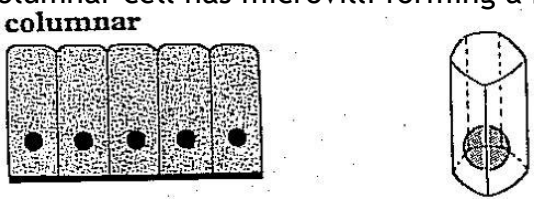
The functions include: **Protection, excretion, absorption and secretion**

Adaptations

i. Cells are tightly packed together with little intercellular spaces between them to offer protection from injury and infection.
ii. Possess many Golgi bodies which perform functions of secretion of hormones and enzymes.
iii. Some possess microvilli which increase the surface area for example reabsorption of materials from the renal fluids in the kidney tubules.
iv. Cells have numerous mitochondria for energy production to be used in active reabsorption of materials e.g from renal filtrate back into the bloodstream.

C. **Simple columnar epithelium**

It is a single layer of column like narrow elongated cells at right angles to the basement membrane. Each cell possesses a nucleus situated at the basal end and it is oval in shape. The epithelium is often interspersed with goblet cells. The free surface of each columnar cell has microvilli forming a brush border.



Distribution

- Lining of the stomach, small intestines, gall bladder, and kidney ducts.
- Lining of the gastric glands, intestinal glands, mammary glands, thyroid glands, salivary glands.

The **functions** include: Secretion, protection, absorption and brush border increasing surface area by having microvilli at the cell free surface.

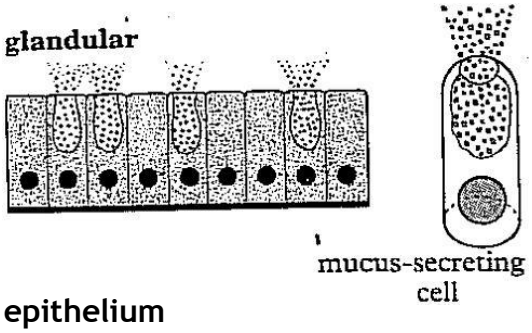
Adaptations

i) Possess fingerlike projections called microvilli which increase the surface area for absorption such as digested food in the intestines.

ii) Possess mucus secreting cells which secrete mucus. The mucus protects the gastric walls from hydrochloric acid and digestive enzymes.

iii) Mucus from goblet cells also lubricates the passage of food in the intestines.

Illustration of secretory columnar/glandular epithelium



D. Ciliated epithelium

Cells of this tissue are usually columnar in shape but bear numerous cilia at their free surfaces. The cells are usually associated with mucus secreting goblet cells.

Distribution

- Lines the oviduct
- Ventricles of the brain, spinal canal and respiratory passages (trachea, bronchi and bronchioles).

Functions

- Mucus protects lining and lubricates the passage of materials.
- Cilia set up currents to move materials in a certain direction.

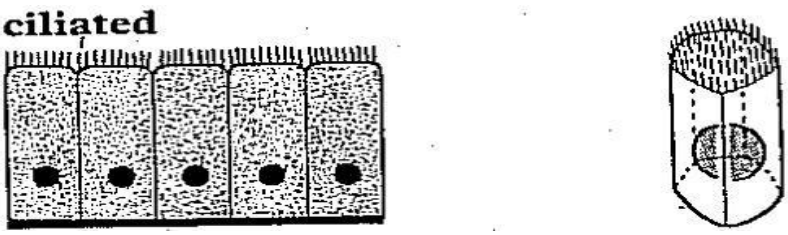
Adaptations

i) Interspersed with goblet cells which secrete mucus to protect the lining of the gut from enzyme and acidic action.

ii) Possess cilia which set up currents that move materials from one direction to another.

iii) Possess goblet cells which lubricate the passage.

Illustration

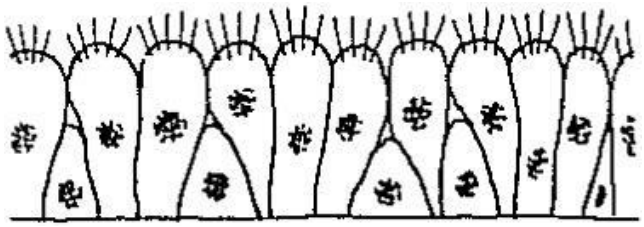


E. Pseudo stratified epithelium

This is a simple epithelium since all cells rest on a basement membrane, but some do not reach the free surfaces. This gives an appearance of the epithelium to be on different levels and the nuclei at different layers. Nevertheless, the epithelium is one layer of cells thick with each cell attached to the basement membrane.

Most cells are columnar, thus usually named pseudo stratified columnar epithelium. Where the cilia appear at the free surface (trachea, bronchi, bronchioles), it is called pseudo stratified columnar ciliated epithelium.
Pseudo stratified epithelium also lines the urinary tract and ducts of large glands (non-ciliated pseudo stratified).

Pseudo stratified ciliated columnar



COMPOUND EPITHELIAL TISSUES

1. STRATIFIED EPITHELIA

Have more than one layer of cells with only the bottom layer resting on the basement membrane. These cells form the germinative layer and continue to divide by mitosis and push other areas outwards. They are primarily found in areas where the epithelium has protective functions.

a) **Stratified squamous epithelium**

The cells first formed on the basement membrane are cuboidal in shape, but as they are pushed outwards the free surface of the tissue, they become flattened and these cells are called squamous. It is the thickest of all epithelia and its function is protection.

The cells of the surface layer may have keratin (cornified) or lack keratin (uncornified). Keratin is a tough protective protein which prevents water loss, is resistant to friction and repels bacteria.

Non-keratinized stratified squamous epithelium lines wet surfaces subjected to abrasion such as lining of the mouth, oesophagus, part of the epiglottis and vagina. Keratinized stratified squamous epithelium forms the epidermis of the skin.

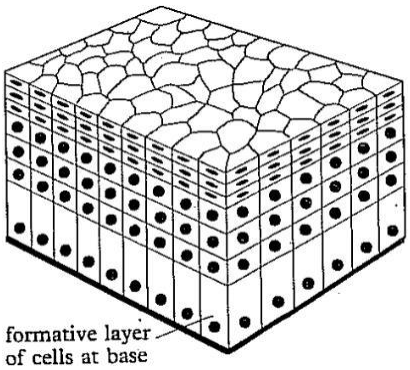
b) Stratified cuboidal epithelium

This epithelium has several layers of epithelial cells but the surface layer of this epithelium is composed of cuboidal cells. It is found in the largest ducts of sweat glands, mammary glands, salivary glands and in parts of the male urethra. Its role is protection and provides strength.

c) Stratified columnar epithelium

This epithelium has several layers of epithelial cells but the surface layer of this epithelium is composed of columnar cells. It is very rare. It lines parts of the urethra, larger ducts of some glands, portion of the conjunctiva of the eye. Its roles are protection and absorption.

ILLUSTRATION



2. TRANSITIONAL EPITHELIUM

This is a modified form of stratified epithelium. It comprises 3 to 4 layers of cells all of similar size and shape except at the free surface where they are more flattened. The cells do not slough off/flake off.

It is found in organs/structures which can expand like the bladder, girdles of women where they come back to normal after delivery, ureters and part of urethra. It allows for distension of the urinary organ.

Because the shape of the cells at the surface is transitory (changes depending on the degree of stretching of the organ), this epithelium is called transitional. It will look like a stratified squamous epithelium if it is stretched or stratified cuboidal epithelium if it is unstretched.

Adaptations of the transitional epithelium to its function

i) By changing its shape, the transitional epithelium allows expansion of the organ such as the urinary bladder. This increases the volume of the organ.

ii) Transitional epithelium is composed of many layers of cells making it impermeable to water from blood to urine.

iii) Due to its thickness, it prevents urine from escaping to the surrounding tissues.

GLANDULAR EPITHELIUM

It is formed by epithelial cells which are frequently interspersed with secretory cells e.g goblet cells or aggregates of glandular cells forming multicellular gland. There are two types of glands.

- Exocrine glands where the secretion is delivered to the free surface via ducts.
- Endocrine glands- Secretions are released and passed into the bloodstream (ductless glands).

Based on the mode of secretion, the exocrine glands are of three types;

a) Merocrine glands

Secretions produced by cells are simply passed through the cell membrane at the cell free surface without losing any of its cytoplasm. The cell therefore remains intact. Examples include; goblet cells, pancreatic glands, sweat glands.

b) Apocrine glands

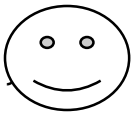
Here, the glandular epithelia shed their secretion by the top part of the cell loaded with the secretion breaking away from the rest of the cell eg mammary glands. The cell loses part of the cytoplasm while releasing its secretion.

c) Holocrine glands

In this case, the whole secretory cell disintegrates and the secretions are from the epithelium e.g the sebaceous glands of the mammalian skin.

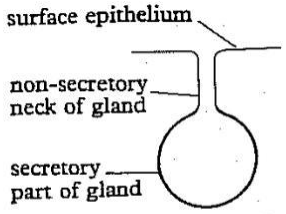
An epithelium containing goblet cells is called a mucus membrane. Multicellular exocrine glands exist in various forms which include;

Note:



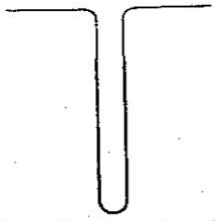
For proper understanding of the above discussed tissues there is a need that tabulate them in the space below in pencil

1. Simple saccular/alveolar gland



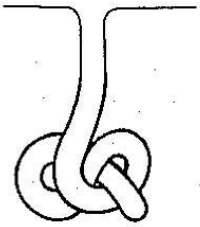
Simple saccular gland e.g. mucus glands in the skin of the frog and other amphibia.

2. Simple tubular gland-



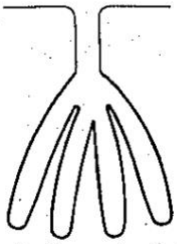
Simple tubular gland e.g. crypts of Lieberkühn in the wall of the mammalian small intestine.

3. Simple Coiled tubular gland



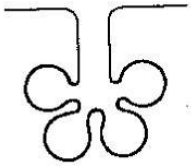
Coiled tubular gland e.g. sweat glands in the skin of humans

4. Simple branched tubular gland-



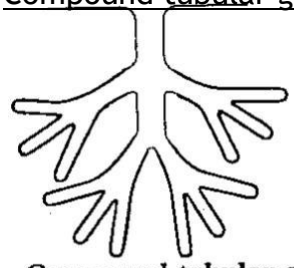
Simple branched tubular gland e.g. Brunner's glands in the wall of the mammalian small intestine and gastric glands in the wall of the

5. Simple branched saccular gland-



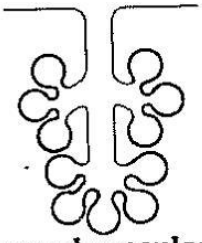
Simple branched saccular gland e.g. oil-secreting sebaceous glands in mammalian skin.

6. Compound tubular gland



Compound tubular glands e.g. salivary glands.

6. Compound saccular gland-



Compound saccular gland e.g. the part of the pancreas which secretes digestive enzymes, and the mammary glands.

Functions of the epithelial tissue

1. **Protection;** Epithelial tissue basically protects the underlying tissue from injuries by chemicals, pressure abrasion and infection.
2. **Secretion;** A number of epithelial cells are modified to produce secretions such as mucus, hormones etc.
3. **Excretion; -** The epithelial cells of the kidney tubules and sweat glands remove excessive and toxic metabolic wastes from the body thus helping the body in excretion.
4. **Absorption; -** Cuboidal and columnar epithelia are modified for absorption.
5. **Exchange of materials and gases**- Squamous epithelium is extremely thin and flattened promoting exchange of materials and gases by diffusion such as the alveoli of the lungs.
6. **Sensory-** epithelia bearing sensory cells and nerve endings are specialized to receive stimuli as in the skin and retina of the eye.
7. **Movement of materials-** Epithelia may be modified to aid movement of materials e.g Ciliated columnar epithelium lining the inside of the oviduct, ventricles of the brain, spinal canal and respiratory passages bears numerous cilia at their free surface. These are associated with mucus secreting goblet cells producing fluids in which the cilia beat up rhythmically setting up currents which move materials from one location to another.

CONNECTIVE TISSUES

Connective tissues are derived from the embryonic mesoderm.

Functions of connective tissues

a) It binds the various tissues together like the skin with muscles and muscles with bones.
b) It is a packing tissue forming sheath like bags around the body organs.
c) Areolar tissue protects the body against wounds and infections.
d) Adipose tissue stores fats, and insulates the body against heat loss.
e) Connective tissue is the major supportive tissue of the body, composed of bones and cartilage which provides the body with a supportive framework.
f) Haemopoitic tissue produces blood.
g) Lymphatic tissue builds body immunity by producing antibodies.
h) Connective tissue separates the body organs, so that they do not interfere with each other's activities.
i) Protects blood vessels and organs where they enter or leave organs.

Connective tissues occur in different forms which are divided into two major classes

- **Connective tissue proper** which is further divided into **loose** and **dense connective tissue**.

- **Special connective tissues** which include; **cartilage**, **bone** and **blood**. Cartilage and bone form the **skeletal tissue**.

LOOSE CONNECTIVE TISSUES

They include **areola**r, **adipose** and **recticular** connective tissues.

AREOLAR CONNECTIVE TISSUE

This is the most abundant type of connective tissue found all over the body beneath the skin, connecting organs together and filling spaces between adjacent tissues.

Areolar connective tissue consists of a gelatinous glycoprotein matrix or ground substance containing two types of protein fibres and four types of cells. The protein fibres include;

i) Collagen fibres

They are white fibres forming wavy bundles running parallel to each other and are not branched. They are flexible but inelastic (non-stretchable)

ii) Elastic fibres

They are thin yellow fibres which are highly branched forming a network in the matrix. They are flexible and elastic. The main function of fibres is to give the areolar tissue its strength and toughness. It also allows the tissue to be flexible and elastic.

The cells within the matrix include;

a) Fibroblasts

These are flattened and spindle like shaped cells containing an oval nucleus. They are generally closely applied to fibres but migrate to the wounded tissue to secrete more fibres in that region that effectively seal off the injured area. The function of fibroblasts is to secrete fibres.

b) Macrophages/histocytes

They are large cells capable of amoeboid movement for which reason; they are referred to as amoeboid cells. Their function is to engulf/ingest bacteria and other foreign particles. They are generally mobile but at times, they wonder to areas of bacterial invasion. Therefore, they serve to defend the body against diseases.

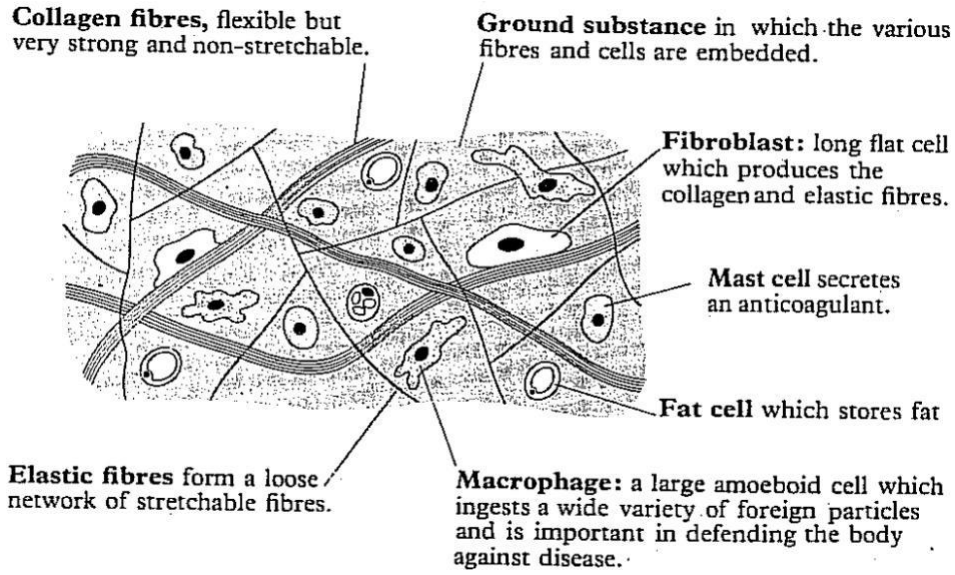
c) Mast cells

They are amoeboid cells which are oval shaped and contain granular cytoplasm. They are found in abundance close to blood vessels. They have the following functions

- ✓ Secretion of the matrix.
- ✓ Secretion of an anticoagulant, heparin.
- ✓ They secrete histamine, a substance attributed to the effects of allergy.

d) Fat cells

They are mainly filled by lipid droplets. The cytoplasm and nucleus of a fat cell are confined to the margins of the periphery.



Or check out diagram in FA page 36 fig.3.5

Areolar connective tissue is found in the skin and in most internal organs of vertebrates where it allows the organs to expand. It also forms the protective covering of muscles, blood vessels and verves.

Functions of the areolar connective tissue

1. Binds tissues and organs together.
2. Serves as a packing tissue filling spaces between adjacent tissues.
3. Support various tissues.
4. Provide tissues which resist strain and displacement.
5. Provides protection against wounds and infections.

ADIPOSE TISSUE

It is a type of connective tissue with reduced matrix material and contains enlarged fat cells that are numerous in number. Adipose tissue functions to store energy, insulate the body and provides shock absorption to delicate mammalian organs e.g the kidney. It also occurs beneath the skin, the buttocks. Adipose tissue occurs in two forms i.e the white and brown adipose tissue.

Recticular connective tissue

It contains an abundance of recticular fibres. It provides a supporting framework for organs such as those of the lymph nodes, spleen and the liver.

DENSE (FIBROUS) CONNECTIVE TISSUE (DCT)

DCT contains tightly packed collagen fibres making it stronger than the lose connective tissue. It consists of two types, regular and irregular.

The collagen fibres in the dense regular connective tissue are oriented in one direction to provide strength in that direction. It is found in tendons and ligaments. Tendons connect muscles to bones, ligaments connect bone to bone.

Irregular dense connective tissue contains collagen fibres oriented in many different directions. It is found in deep layers of the skin and the tough capsules that surround many of the organs e.g the kidney, adrenal glands, nerves, bones and covering of the muscles as epimysium and periosteum covering bones. It provides support and strength.

SPECIAL CONNECTIVE TISSUES

SKELETAL TISSUES

CARTILAGE/GRISTLE

This is a connective tissue consisting of cells embedded in a matrix called **chondrin**. The matrix is deposited by cells called **chondroblasts** and possess many fine fibres mostly collagen. Eventually, the chondroblasts become enclosed in spaces called **lacunae.** In this state, they are termed as **chondrocytes.**

The margin of a piece of cartilage is enclosed by a dense layer of cells and fibrils called **perichondrium** in which new chondroblasts are produced and constantly added to the internal matrix of the cartilage.

Cartilage is highly adapted to resist any strains that are placed on it. The matrix of cartilage is compressible and elastic. The collagen fibres resist any tensions which may be imposed on the tissue.

The cartilage in adults is restricted to the articular (joints) surfaces of bones that form freely moveable joints and other specific locations e.g the nose, pinna, intervertebral discs, larynx, etc.

Types of cartilage

There are three types of cartilage each with the organic components of the matrix quite distinct. They include; hyaline cartilage, yellow elastic cartilage and white fibrous cartilage.

Hyaline cartilage

It is the simplest form of cartilage which is elastic and compressible. It mainly comprises a semitransparent matrix and chondrocytes. It frequently contains fine collagen fibrils. It has no processes extending from the lacunae into the matrix and neither are there blood vessels. Therefore, exchange of materials between the chondroblasts and the matrix is by diffusion.

It is located in the ends of the bones, in the nose and the wall of the trachea and bronchi. It also forms the embryonic skeleton in many vertebrates.

Yellow elastic cartilage

It has a semi opaque matrix containing a network of yellow elastic fibres. The fibres confer greater elasticity than found in the hyaline cartilage. Due to high elasticity and flexibility, the tissue quickly returns to its shape after distortion.
It is located in the external ear, in the epiglottis and cartilages of the pharynx

White fibrous cartilage

In addition to chondrocytes in the matrix, there are large bundles of densely packed collagen fibres. This gives the tissue a greater tensile strength than hyaline cartilage as well as a small degree of flexibility.
It is located in the discs between adjacent vertebrae which provide a cushioning effect and the ligamentous capsules surrounding the joints.

BONE

This is very abundant providing support, protection and some metabolic functions. The bone has an organic matrix containing collagen fibres, and is impregnated with small needle shaped crystals of calcium phosphate in form of hydroxyapatite which is brittle but rigid giving bone great strength. Calcium carbonate is also contained within the matrix.

A bone is a dynamic living tissue that is constantly reconstructed through the life of an individual by bone cells called **osteoblasts.** Osteoblasts secrete the matrix in which calcium phosphate is later deposited. After calcium phosphate has been deposited, the osteoblasts become less active and are now called **osteocytes** and are energized in spaces called **lacunae.**

Another type of bone cells called **osteoclasts** exist in the matrix which play a role in dissolving the bone matrix to enable further reconstruction of a bone during growth. A bone is constructed in thin concentric layers called **lamellae** which are drawn around narrow channels called **haversian canals** that run parallel to the bone length.

Haversian canals contain nerve fibres and blood vessels which keep the osteocytes alive. The concentric lamellae and the encircled canal are termed as the **haversian system/osteon.**

The lacunae have very many fine channels called **canaliculi** containing cytoplasm which link up with the central Haversian canal, with other or press from one lamella to another. An artery and a vein run through the Haversian canal and capillaries branch from here through the canaliculi. A haversian canal also contains lymph vessels and nerve fibres. Covering the bone is a layer of dense connective tissue called **periosteum.** The inner region of the periosteum has blood vessels and contains cells that can develop into osteoblasts and osteoclasts.

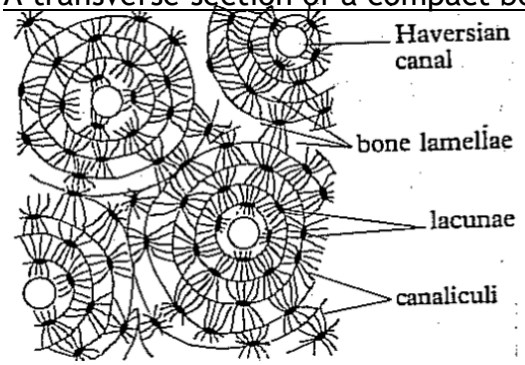
Types of bone

There are two types of bone i.e compact/dense bone and spongy bone

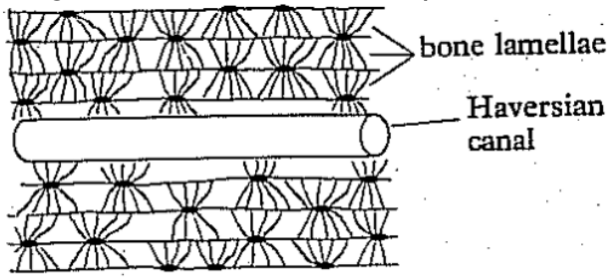
Compact bone/dense bone

They are mainly part of long bones and form the long shape of the bone between two swollen ends. The matrix of compact bones is composed of collagen and calcium phosphate, with large quantities of magnesium, sodium, carbonate, nitrate ions. The combination of organic with inorganic materials produces a structure of great strength. The lamellae are laid down in a manner that is suited to the force acting upon the bone and the load that has to be carried.

A transverse section of a compact bone



longitudinal section of a compact bone



SPONGY/ CANCELLOUS BONE

Spongy bone occurs within longer bones and is always surrounded by compact bone. Spongy bone consists of thin bars or sheets of bone called **trabeculae,** interspersed with large spaces occupied by the bone marrow.

The trabeculae contain osteocytes which are more or less irregularly dispersed in the matrix. The matrix contains rather a smaller proportion of inorganic material than does the matrix of the compact bone. The trabeculae develop along the lines of stress within the bone.

The spaces within the spongy bone at the head (epiphysis) of the long bones contain red bone marrow tissue. This very soft tissue is less dense than the bone, and is the site of red blood cell formation. Yellow marrow tissue, consisting principally of fat fills the spaces within the spongy bone of the shaft.



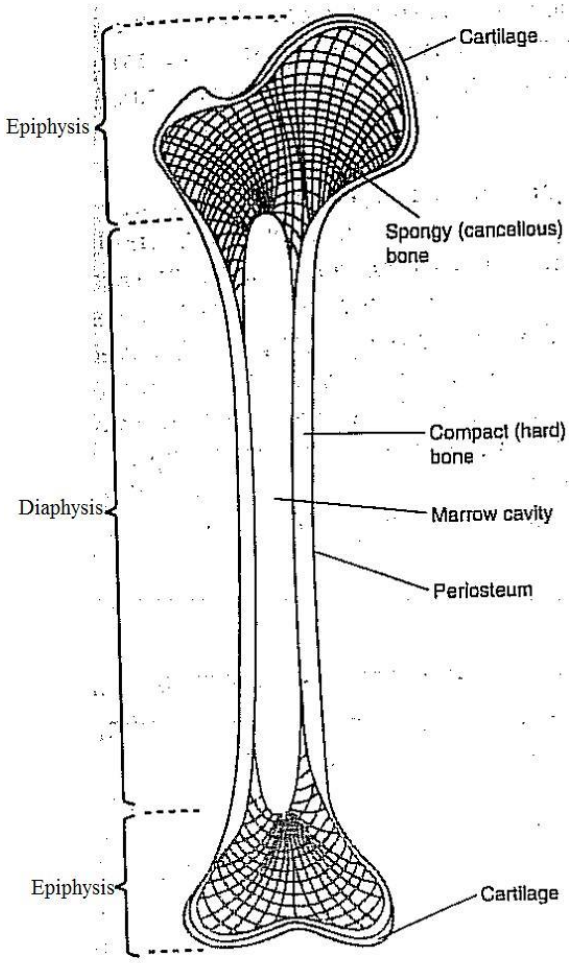
Based on your knowledge about a bone what are some of the functions of the bone and how is it adapted to its functions? (Check out your answers with those on the next pages)

Mention out some disorders due to bone problems.

NOTE:

For transverse section through a bone Diagram in FA page 38 fig. 3.7 A

Longitudinal section through a Long bone



The development of bone (ossification)

Ossification is the process of formation and development of bone. A bone originates in two ways; intramembranous ossification and endochodrial ossification.

Intramembranous ossification

The thin bony plates of the skull and parts of some other bones e.g clavicles are formed directly by clusters of ossification which appear inside fibrous membranes. The strands of bone formed by different clusters are called trabecullae and become linked to form a loose network described as spongy bone. Thus spongy bone is formed by intramembranous ossification.

As development continues, remodeling of the skull plates converts some of the spongy bone to compact bone and allows the plates to reach their adult shape and size.

Three basic **steps** involved in osteogenesis/ossification are:

(a) Synthesis of extracellular organic matrix (osteoid)
(b) Matrix mineralization leading to the formation of bone
(c) Remodeling of bone by the process of reabsorption and reformation

ENDOCHONDRIAL OSSIFICATION

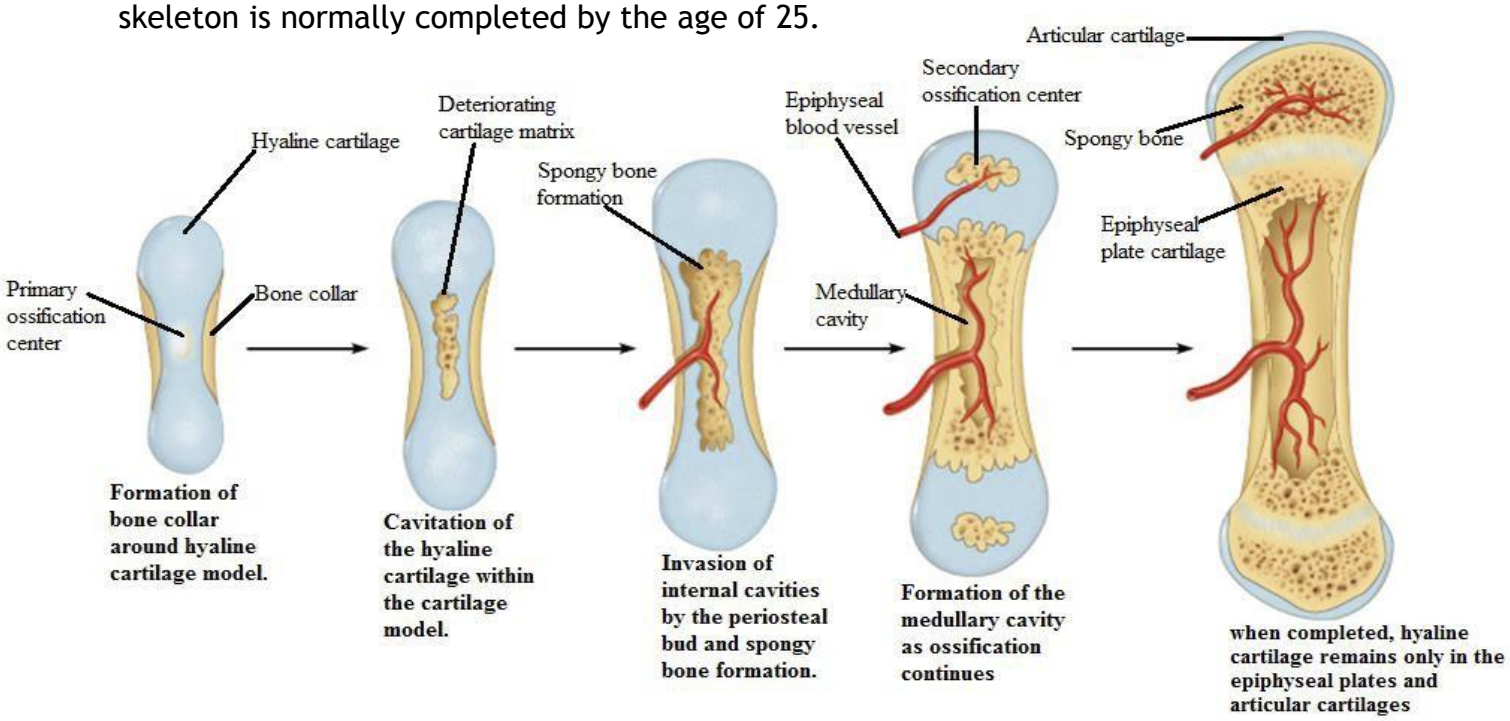
Endochodrial ossification is the process of replacement of cartilage by bone. The skeleton of the vertebral embryo consists of mainly hyaline cartilage. Each cartilage element is surrounded by a layer of dense connective tissue, the perichondrium. Ossification of bones (such as the long bones of the arms and legs) begins when blood vessels penetrate the perichondrium of the cartilage midway along the shaft/diaphysis of the cartilage model.

This stimulates some of the cells of the cartilage perichondrium to become osteoblasts which produce a **collar** of compact bone in the shaft region. The layer of dense connective tissue now surrounding the developing bone is called the periosteum.

A primary ossification centre appears inside the shaft and is progressively invaded by a proliferating number of blood vessels and osteoblasts. The matrix of the cartilage tends to become calcified by deposition of calcium and phosphate, but is eroded by the osteoclasts leaving spaces which eventually fuse to form the **marrow cavity.** Working in small groups, osteoclasts tunnel through the bone leaving cavities which are invaded by blood capillaries and new bone forming osteoblasts. Within the tunnel, osteoblasts lay down a new bone matrix in concentric rings forming an arrangement called Haversian system.
Cartilage continues to grow at either end producing an increase in length. Most of the cartilage is later replaced by a spongy bone.

In mammals, secondary ossification centres develop in the swollen ends/epiphyses of the cartilage models of long bones. The epiphyses ossify more or less completely except for a thin layer of cartilage called an **epiphyseal plate,** separating each epiphysis from the main shaft.

Increase in diameter of the bone shaft is achieved by continual remodeling and deposition of new bone by osteoblasts of the periosteum. As maturity approaches, the thickness of the epiphyseal plates is reduced and finally the epiphyses and the bone shaft fuse completely leaving a faint **epiphyseal line.** Ossification of all bones in human skeleton is normally completed by the age of 25.



Adaptations of bone to its function

a) A tough fibrous layer of dense connective tissue called periosteum provides a tough and hard covering that surrounds the bone and protects the inner cells.
b) Bundles of collagen fibres from the periosteum penetrate the bone giving more mechanical strength, providing an intimate connection between the underlying

bone and the periosteum and acting as a firm base for insertion of tendons, which contribute to movement and locomotion.

c) Osteoblasts are arranged in concentric rings around a series of haversian canals in compact bone thus lay down the matrix in a similar rigid and dense regular pattern to provide uniform mechanical strength.

d) Bone lamellae contain numerous lacunae containing living bone cells called osteoblasts which secrete the matrix of the bone.

e) Mature less active osteoblasts called osteocytes can be reactivated quickly regaining the structure of active osteoblasts and depositing bone matrix, when structural changes in bone are required.

f) Bone cells are embedded in a firm bone matrix which is rendered hard by deposition of calcium salts and other inorganic ions.

g) Bone cells called osteoclasts responsible for dissolving of the matrix as it is laid down enable reconstruction and remodeling of the bone during endochodrial ossification.

h) An artery, a vein and a lymph vessel pass through a haversian canal of a compact bone allowing the passage of nutrients, respiratory gases and metabolic wastes towards and away from the bone cells.

i) Each lacuna has fine cytoplasmic extensions called canaliculi which pass through lamellae and make connections with other lacunae and with the central Haversian canal, allowing communication between the lacunae in different lamellae, and with the central Haversian canal.

j) Presence of numerous nerve fibres in the Haversian canal allows co-ordination of bone reconstruction enabling each bone to adapt its structure to meet any change in mechanical requirement of an animal during its development.

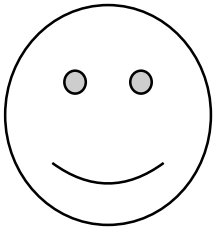
k) Bone releases calcium and phosphate into the bloodstream as required by the body under the control of the hormones parathormone and calcitonin.

l) Spongy bone has spaces between the trabeculae, reducing the weight of the bone, allowing less restricted movement and locomotion.

Differences between a cartilage and bone

Cartilage	Bone
No process extended from each lacuna into the matrix	Lacuna possesses canaliculi that extend into the matrix
No blood vessels and nerves in the tissue.	Blood vessels and nerves run through the Haversian canal
Exchange of material between chondrocytes occurs by diffusion	Osteoblasts exchange materials by help of blood capillaries passing through the canaliculi into the lacunae.
Elastic and compressible	Relatively incompressible as the matrix is highly composed of minerals e.g calcium ions, magnesium ions
Matrix is relatively semi-transparent with hyaline cartilage and semi opaque in yellow elastic cartilage.	Matrix is opaque

The matrix is not calcified.	Matrix is calcified with greater quantities of Mg^{2+}, Na^{+}, and $Ca2^{+}$ etc.
No concentric layers of lamellae and no haversian canals present.	Consist of concentric layers of lamellae surrounding the Haversian canal.
Rather inactive.	An active tissue with metabolic activity.
Matrix secreting cells are called chondroblasts.	Matrix secreting cells are called osteoblasts.
It is differentiated into hyaline, white fibrous and yellow elastic cartilage.	It is structurally differentiated into compact and spongy bones
It is flexible due to relatively soft and flexible matrix called chondrin.	It is rigid due to solid matrix called osteon.
It is less strong.	It is stronger.
Chondroblasts are randomly scattered in the matrix and occur in singles, pairs or fours.	Osteoblasts are in concentric layers around the Haversian canal.



Could you please give some similarities between a bone and cartilage? How is the cartilage adapted to its function?

SUMMARY OF ENDOCHONDRIAL OSSIFICATION

- It begins with rapid cell division and the cells arrange themselves in parallel column in the longitudinal axis of bone to be formed.
- A primary ossification center is then established in the middle/center.
- Chondroblasts arrange in rows, become hypertrophied and lay down calcium salts in the matrix.
- The process starts from the centre and works its way outwards.
- Another region of ossification occurs in the shaft where osteoblasts lay down fibres on the surface of cartilage.
- The region then becomes calcified gradually forming compact bones.
- Osteoblasts then erode through the bone forming channels of blood vessels and nerves.
- Osteoblasts deposit bone salts in the spaces created and lay down a matrix in layers.
- Osteoblasts are then enclosed in lacunae interconnected by canaliculi.

MUSCLE TISSUE

There are three types of muscular tissue which include: **voluntary muscle**, **involuntary muscle** and **cardiac muscle**.

Basic structure of a muscular tissue

a) All muscle fibres are made up of elongated and thin cells called muscle cells or muscle fibres.
b) The muscle fibres contain a specialized cytoplasm called sarcoplasm that contains a network of membranes called sarcoplasmic reticulum.
c) Muscle fibres may be bound by a cell membrane called sarcolemma.
d) Each muscle may contain numerous thin myofibrils.

VOLUNTARY/ SKELETAL /STRIATED OR STRIPED MUSCLE

It is said to be striated because its muscle cells have transverse stripes when viewed in longitudinal section.

Distribution of skeletal muscles

It is found attached to the skeleton in the head, trunk and limbs hence the name skeletal muscle.

Gross structure of a skeletal muscle

Skeletal muscle is composed of bundles of muscle fibres each surrounded by a connective tissue, **endomysium.** Each bundle of muscle fibres is surrounded by **perimysium,** a connective tissue, the various bundles are surrounded by an **epimysium,** a connective tissue sheath.

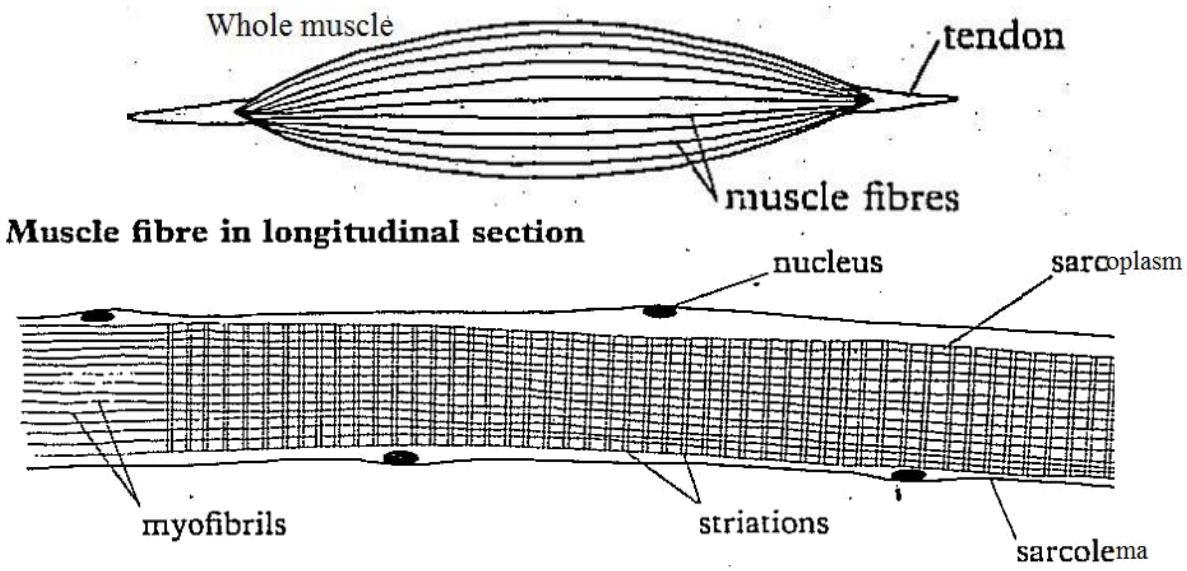
The skeletal muscle is attached to a bone in at least two places namely; the **origin**, a fixed non-moveable part of the skeleton and the **insertion**, a moveable part of the skeleton.

Attachment is by a means of tough relatively inelastic tendons made up of almost entirely collagen fibres. At one end, the tendon is continuous with the outer covering of the muscle while the other end is of the tendon combines with the outer layer of the bone called **periosteum** and forms a very firm attachment.

Histology of a striated muscle (skeletal muscle)

The muscle is made up of many hundreds of long muscle cells called **muscle fibres.** Each muscle fibre is filled with a cytoplasm called **sarcoplasm** in which about 100 nuclei are spaced out evenly just beneath the bounding membrane called **sarcolemma.**

In the sarcoplasm, there are many thin myofibrils which possess characteristic cross striations. The myofibrils line up perpendicular with the cross striations next to each other. The myofibrils are composed of protein filaments called **actin** and **myosin**.



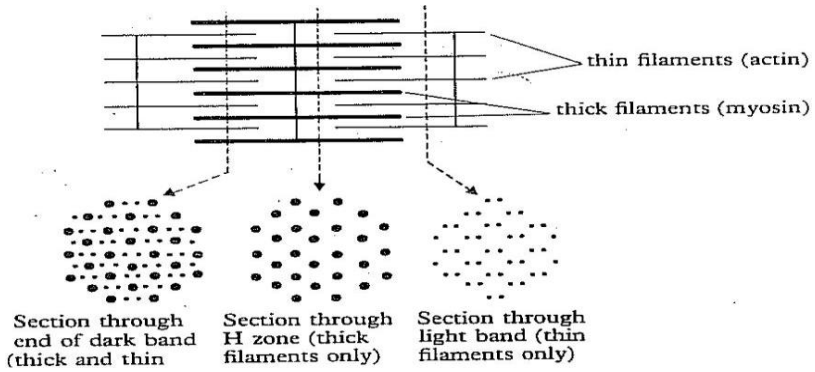
Fine structure of a striated muscle

Each myofibril is divided into light and dark bands. The dark band has a comparatively light region in the middle called **H- zone,** and it has darker regions on either sides. In the middle of the H- zone is a dark line called the **M- line**.

Running through the light bands in the middle is the **Z- line**. The dark and light bands are called **A** and **I** bands respectively. **I** means isotropic, as it allows light to pass through and so appears lighter. **A** means anisotropic as it does not allow light to pass through, so it appears darker.

The region of a myofibril between two Z-lines is called a **sarcomere** and is described as the basic functional unit of a myofibril. Alternating light and dark bands are due to two types of protein filaments which run longitudinally. These are the **thin actin** and **thick myosin** protein filaments. The thick myosin filaments are confined to the dark band and the thin actin protein filaments occur in the light band but extend in between the thick myosin filaments within the dark band.

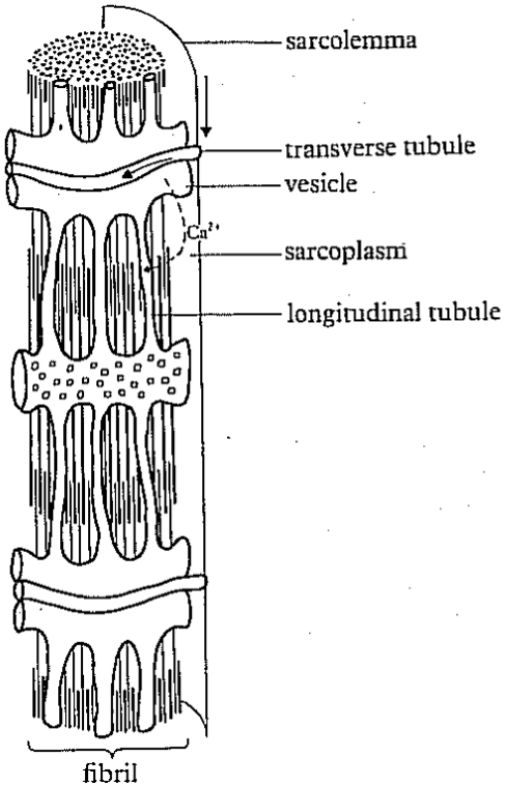
The darker segments on either side of the H- zone are due to both thick myosin and thin actin filaments **overlapping**. The H-zone consists only thick myosin protein filaments. The thin actin filaments alone are found in the light band.



Within each muscle fibre, there is an internal membrane system, the **sarcoplasmic reticulum** surrounding the myofibrils. The sarcoplasmic reticulum includes a system of **transverse tubules** (the **T- system**) which run into the muscle fibre from the sarcolemma at positions corresponding to the Z- lines.

Connected with the T- system are vesicles containing calcium ions in high concentration. Ca^{2+}helps in hydrolysis of ATP. After muscle contraction, calcium ions are actively removed into the longitudinal tubules thereby lowering the concentration to a level below that at which ATP hydrolysis can occur.

Diagram of a myofibril to show the transverse and longitudinal tubules of the sarcoplasmic reticulum (FA pg322)



There are four blood capillaries surrounding each muscle fibre. Each branch of the axon terminates at a plate like structure called **neuromuscular junction**. The motor end plate forms the neurone-to-muscle synapse, the connection between the motor neurone and the muscle fibre.

All the muscles served by the same motor neurone are called **motor unit** because they work as a unit contracting and relaxing at the same time. The motor unit is the basic functional unit of a skeletal muscle.

Adaptation of skeletal muscle tissue for its function/relationship between structure and function of a striated muscle

- ✓ It consists of elongated fibres, allowing considerable contractile length.
- ✓ Its fibres are parallel to give it maximum contractile effect and to allow each fibre to be controlled individually which gives ability to vary the length of the whole muscle contraction necessary for proper control of skeletal movement.
- ✓ The ends of the muscle fibre are tapered and interwoven with each other to provide adequate mechanical strength during muscle contraction.
- ✓ Its cells contain a large number of mitochondria to provide large amounts of ATP for muscle contraction.
- ✓ In their arrangements, the actin and myosin filaments fit into each other to allow them slide over each other to cause contraction.
- ✓ The cells have a rich blood supply to provide adequate supply of oxygen and nutrients.

- ✓ The muscle cells have myoglobin to store oxygen and release it for respiration when blood oxygen levels are low.
- ✓ Has a specialized region called the motor end plate where the axon of a motor neurone divides and forms fine non myelinated branches (dendrites) ending in synaptic knobs running in shallow troughs on the sarcolemma allowing nervous stimulation and control of the muscle.
- ✓ The sarcolemma folds inwards and forms a system of tubes called the T-system (transverse tubules) which run parallel through the sarcoplasm to the Z-lines allowing a nerve impulse arriving along a motor neurone at the neuromuscular junction at the surface of a muscle fibre to be propagated as a wave of depolarization (action potential) through the T- system causing release of calcium ions of the sarcoplasmic reticulum to activate the process of muscle contraction.
- ✓ The specialized endoplasmic reticulum of the muscle fibre called the sarcoplasmic reticulum forms the vesicles at the Z- line of the sarcomeres which contain calcium ions used to activate the process of muscle contraction.
- ✓ Ability to generate ATP using phosphocreatine during anaerobic conditions for a constant supply of ATP in the muscle.
- ✓ Ability to respire anaerobically for continued muscle contraction in anaerobic conditions.

VISCERAL/INVOLUNTARY/UNSTRIATED/UNSTRIPED/SMOOTH MUSCLE

- ❖ It consists of muscle cells called muscle fibres which are spindle shaped and tapering at both ends and uni-nucleated.
- ❖ The nucleus is single, elongated in shape, centrally placed and surrounded by little sarcoplasm.
- ❖ The muscle fibres lack a sarcolemma.
- ❖ Each muscle fibre consists of numerous inconspicuous, fine contractile myofibrils arranged longitudinally.
- ❖ The actin and myosin filaments are evenly distributed hence there are no striations or light and dark bands.
- ❖ Smooth muscle fibres are shorter than striated muscle fibres.
- ❖ Has sarcoplasmic reticulum but less extensive than in striated muscle.
- ❖ Has rings of smooth muscle fibres called sphincter muscle fibres for example; pyloric, cardiac and anal sphincters.
- ❖ Has prominent mitochondria but less numerous than in striated muscle.

Innervations and activity of the smooth muscle

- Smooth muscle is involuntary in action, so cannot be moved by ones will.
- Innervated by two sets of nerves from the autonomic nervous system (sympathetic and parasympathetic).
- Smooth muscle fibres undergo prolonged and slow, sustained rhythmical contractions and relaxations as in peristalsis, hence fatigues slowly.

The smooth muscle is located in the tracts of the intestines, genitals, urinary and respiratory systems and the walls of blood vessels

Functions of the smooth muscle

i. The anal sphincter controls the elimination of faeces from the body.

ii. The pyloric sphincter controls passage of food from the stomach to the duodenum.

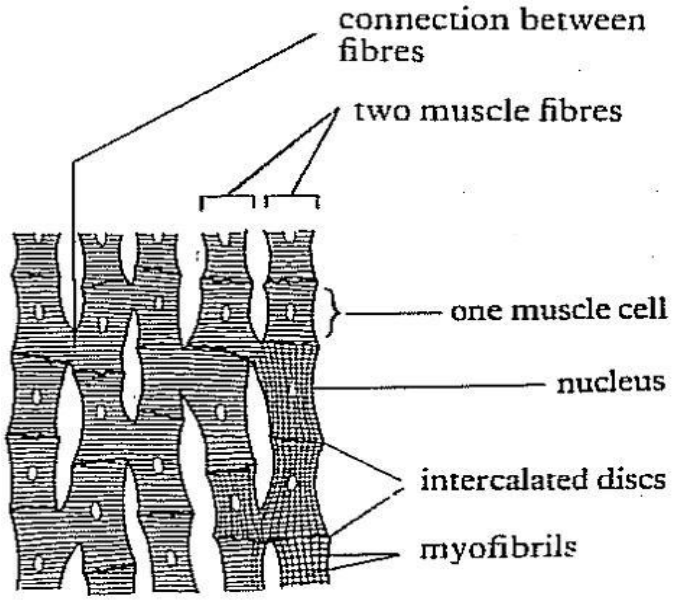
iii. Small sphincter muscle surrounds some blood vessels to control the distribution of blood and regulation of blood pressure.

iv. Control movement of materials with the body visceral organs.

CARDIAC MUSCLE

It is found only in the heart.

The structure of a cardiac muscle



A cardiac muscle consists of a network of interconnected cells called cardiac muscle fibres. Each muscle fibre is short, cylindrical and branched. Each muscle fibre possesses one large mitochondrion, with one nucleus or two nuclei, abundant cytoplasm, glycogen granules, well developed T system and poorly developed endoplasmic reticulum consisting of a network of tubules.

Cardiac muscle fibres are terminally branched and connected to each other by intercalated discs. Actin and myosin filaments are regularly arranged to give faint but regular cross striations. Muscle fibres branch and cross connect with each other to form a complex netlike arrangement.

Innervations and functioning of the cardiac muscle

- Cardiac muscle is myogenic meaning that the contractions are developed within the muscle.
- The rate of contraction can be influenced by the autonomic nervous system.
- Interconnections between the fibres (intercalated discs) ensure a rapid and uniform spread of the excitation.
- Have rhythmic rapid contractions and relaxation with a long refractory period and so do not fatigue as contraction is not sustained.
- Need a constant supply of large amounts of energy.
- A small number of cardiac muscle fibres and a few nerve endings form the Sino atrial node (SAN) located near the opening of the vena cava which stimulates heart beat on their own.

Adaptations of the cardiac muscle to its function

a) Cardiac muscle cells are highly branched terminally and connected to each other by intercalated discs to form a network that allows rapid spread of waves of electrical excitation from cell to cell, so that linked muscle cells rapidly contract rhythmically and simultaneously for fast heartbeat.
b) Dense network of blood capillaries ensures adequate supply of oxygen and food nutrients, for fast production of adequate ATP, for continuous rapid muscle contraction and rapid excretion of carbon dioxide and other metabolic wastes.
c) Numerous large mitochondria and glycogen granules rapidly provide adequate amounts of energy in form of adenosine triphosphate (ATP) by aerobic respiration for rapid contraction without fatigue.
d) Has the Sino atrial node (SAN) which emits waves of electrical excitation that initiate continuous and rhythmic contraction without fatigue, for continuous heartbeat.
e) Have striations for mechanical strength to support its fast and continuous contractions.
f) Undergoes rapid rhythmic contractions and relaxations with long refractory periods and thus does not fatigue as contraction is not sustained.
g) Well-developed T-system for rapid transmission of impulses thus rapid contraction and relaxation.
h) Branched muscle fibres offer a large surface area for fast spread of waves of electrical excitation for continuous contraction hence continuous heartbeat.



1. Why is the heart able to continue pumping blood even when out of the body for some time? Summarise your explanation below in pencil.

2. **Make a comparison of voluntary, involuntary and cardiac muscles (similarities and differences) or check out from Biological science**

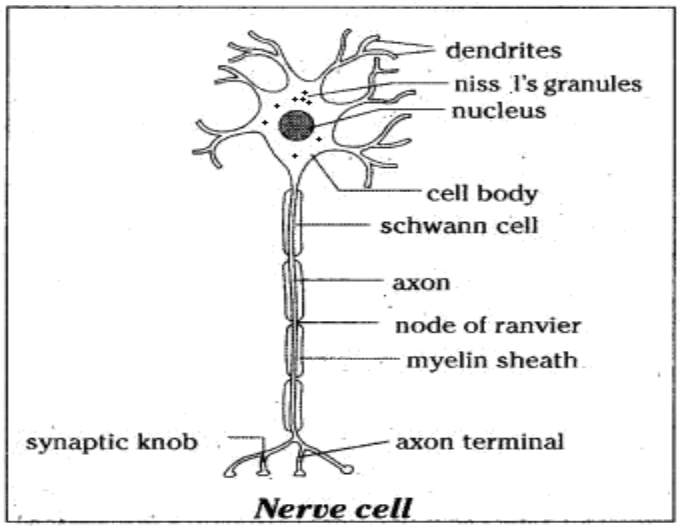
NERVOUS TISSUE

It comprises of an intricate network of interconnected nerve cells called neurons which are specialized for conduction of nerve impulses. The neurons are the basic functional units of the nervous system.

Structure of a neuron

Each neuron possess a cell body and cytoplasmic extensions (nerve fibers'). Each cell body contains a nucleus and abundant granular cytoplasm. The cytoplasm also contains prominent conical granules called **Nissls granules** which are groups of ribosomes and rough endoplasmic reticulum rich in RNA and associated with protein synthesis.

From the cell body extends out two types of cytoplasmic extensions; a Dendron and axon.



Nerve cell

General functions of the parts of a neuron

1. **Cell body**; this consists of a nucleus surrounded by a mass of cytoplasm. The nucleus controls all activities of the neuron.
2. **Axon**; this is one or more long cytoplasmic extensions running from the cell body. Axons carry impulses over long distances in the body. Each axon is filled with cytoplasm called **axoplasm**.
3. **Myelin sheath**; this is a fatty material that covers the axon. The myelin sheath is secreted by cells called **Schwann cells**. The myelin sheath insulates the axon and speeds up transmission of impulses. It also protects the axon from any injuries especially which may be as a result of contraction from muscles.
4. **Dendrites**; these are fine structures on the neuron that link up nerve cells to form a complex network of communication.
5. **Schwann cell**; this is a cell which secretes the myelin sheath.
6. **Nissl's granules**; these are groups of ribosomes responsible for protein synthesis.

7. **Node of Ranvier**; this is the space on the axon between two adjacent myelin sheaths. It speeds up nervous transmission.
8. **Cytoplasm**; this is a site for chemical reactions in the neuron.
9. **Dendron**; it is a branch through which impulses are transmitted to the body.

POLARITY OF NEURONES

Depending on the number and arrangement of these processes from the cell body, the neurons are said to be unipolar, pseudo-unipolar, bipolar or multipolar.

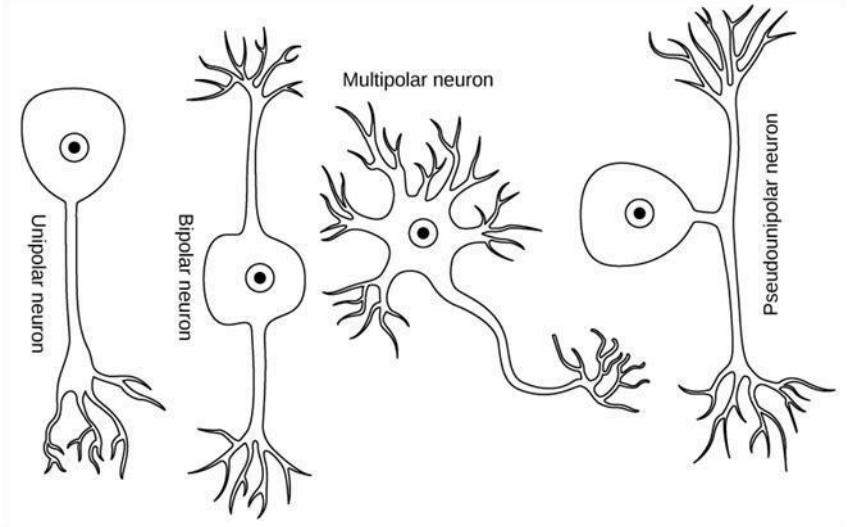
Unipolar:-It is a neuron with the axon as the only large branch from the cell body e.g arthropod motor neuron.

Bipolar neuron:-It is one where two processes, an axon and a Dendron project from the cell body.
Examples of bipolar neurons are found in the retina of the mammalian eye.

Multipolar neuron:-It is one which has one axon and several dendrons from the cell body. An example is the motor neuron.

Pseudo unipolar: - It is where the cell body is not found along the axis/end of the axon. Instead, it is connected by a short side branch of the axon e.g sensory neuron.

DIAGRAMS



Types of neurons/nerve cells

- Sensory/afferent neurons: - These conduct impulses from the receptors to the central nervous system.
- Motor /efferent neurones: - These conduct impulses from the central nervous system to the effectors.
- Relay/intermediate neurons: - These transmit impulses from the sensory neuron to the motor neurone. They are only found in the central nervous system.

Diagram of a motor neuron

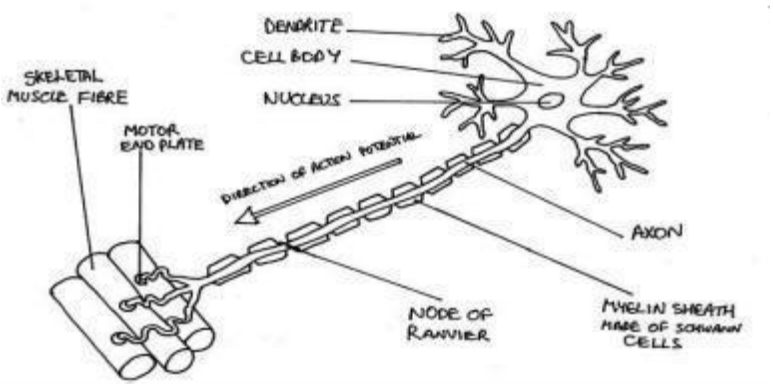


Diagram of a sensory neuron

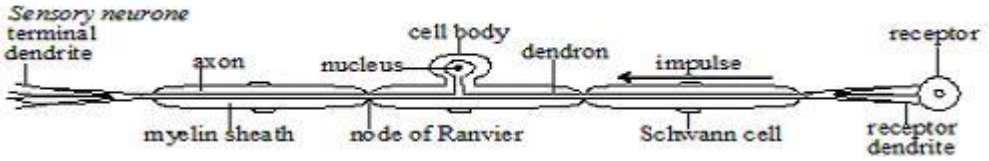
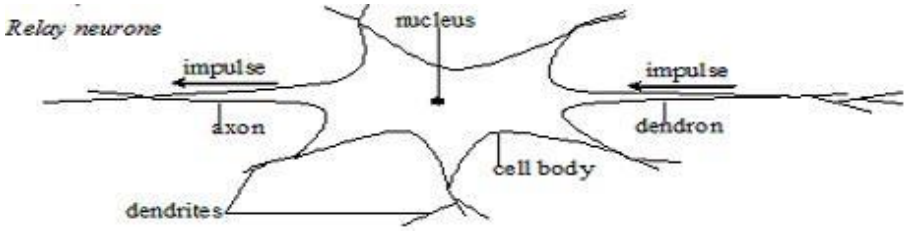


Diagram of a relay neuron



Diagrams in BS page 193

NB: The process which brings impulses towards the cell body is called a Dendron and the one which conducts impulses from the cell body is called the axon.

Compare the structure of a motor neurone and a sensory neurone.

PLANT TISSUES

1) MERISTEMATIC TISSUE

It is a plant tissue consisting of actively dividing cells which give rise to cells that differentiate into new tissues of the plant.

Meristem

A meristem is a group of plant cells which remain with the ability to divide by mitosis producing daughter cells which grow to form the rest of the plant body.

Types of meristems

Apical meristems: - They are found at the shoot tip and root tip. They divide continuously by mitosis leading to primary growth of the plant body that is increase in length of the shoot or root.

Lateral meristems (cambium):- These are found in a cylinder towards the outside of stems and roots. They are responsible for secondary growth and cause an increase in girth. They include the **vascular cambium** which gives rise to secondary vascular tissue including secondary xylem and phloem. They also include the **cork cambium** (**phellogen)** which gives rise to **periderm** which replaces the epidermis and includes the cork.

Intercalary meristems: - These are found at the nodes in monocotyledonous plants. They allow an increase in length in positions other than the tip. Ensures continued growth where tissues are damaged such as when eaten by herbivores in grasses.

SIMPLE PLANT TISSUES

They are tissues consisting of one type of cell. They include the parenchyma, collenchyma and sclerenchyma

2) **PARENCHYMA**

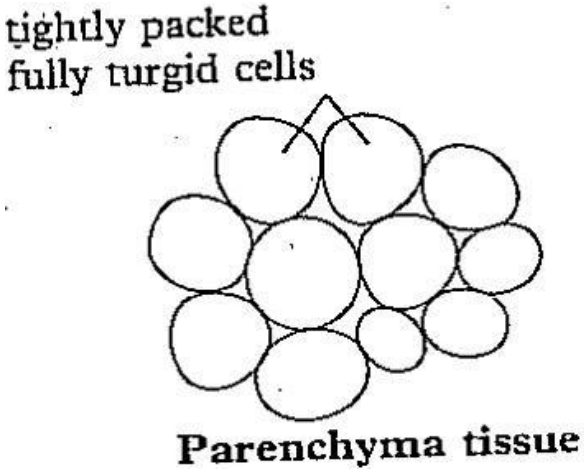
It consists of living cells which are relatively undifferentiated. The cells are either roughly spherical or elongated. The cells have thin cell walls made up of cellulose, pectins and hemicelluloses. The cells also have large sap vacuoles with dense but peripheral cytoplasm.
Parenchyma tissue is located in the cortex, pith and medullary rays of wood. It also serves as a packing tissue in xylem and phloem

Functions of the parenchyma tissue

a) Acts as a packing tissue i.e cells of the parenchyma fill spaces between other specialized tissues e.g in the cortex, pith, between the xylem vessels and phloem.
b) When they are turgid, parenchyma cells become closely packed thus provide support for the organs in which they occur. For example in the leaves and in stems of herbaceous plants.
c) It is a storage tissue due to possession of starch granules and large food vacuoles. Therefore, the tissue is abundant in storage organs eg the Irish potato.
d) It allows transportation of materials through cells by symplast pathway or apoplast pathway.
e) The parenchyma tissue is metabolically active as it is composed of living cells for example some parenchyma are photosynthetic.
f) Growth of the pericycle in the roots where it retains the meristematic activity producing lateral roots and contributing to secondary growth.

g) In the endodermis, cells are covered by a fatty substance (suberin) that forms the casparian strip that prevents apoplast transportation of water through the root thus directing the flow of water into xylem.
h) It contains intercellular air spaces which allow gaseous exchange.

Transverse section of a parenchyma tissue



Parenchyma tissue

Relationship between structure and function of the parenchyma tissue

i) The cells are unspecialized to perform a variety of functions.
j) Many intercellular spaces to allow diffusion and exchange of gases.
k) Thin cellulose cell walls to allow passage of materials for transport.
l) Transparent cell walls to allow light penetration for photosynthesis.
m) The cells are large and contain large vacuoles with a thin layer of cytoplasm to provide storage space for materials of the plant.
n) Have isodiametric, roughly spherical or elongated cells to serve as a packing material between specialized cells.
o) Cells have permeable walls to allow entry of light for photosynthesis.
p) Cells have leucoplasts such as amyloplasts to store food such as starch.
q) Cells have chloroplasts to allow photosynthesis.
r) Cell walls contain cellulose, pectins and hemicelluloses for support.
s) The cells have chromoplasts such as in petals to provide bright colour to attract insects for pollination.

Modified parenchyma

They include; epidermis, mesophyll, endodermis, pericycle, companion cells and transfer cells.

a) Epidermis/epidermal cells

It is a layer of one cell thick that covers the whole primary plant body.

Functions

✓ The basic function is to protect the plant body from desiccation and infection. This is achieved by secreting cutin and forms the cuticle that is impervious to water.
✓ Specialized epidermal cells (the guard cells) bound/guard the stomata and are important in opening and closing of stomata.

- ✓ Hair like structures on cuticle (epidermis) serve various purposes for example, root hairs increase on the surface area for absorption of water and mineral salts by the roots.

✓ Hooked hairs of climbing stems prevent them from slipping off their supports.
✓ Glandular cells on the cuticle secrete sticky substance that traps and kills insects and they may also secrete scent.
✓ The epidermal hairs of leaves reduce water loss from the plant as well as reflecting the sun's radiations.

- ✓ Being transparent, the epidermis allows passage of light in the mesophyll cells for photosynthesis.



State the various modifications of the epidermis to serve different functions

b) Mesophyll cells (chlorenchyma)

Mesophyll is a packing tissue located between the upper and lower epidermis of leaves. There are two types of mesophyll cells.

- Palisade mesophyll cells:-They are located in the upper layer called the palisade mesophyll layer. Cells are elongated and columnar in shape. They contain a large number of chloroplasts. The cells are tightly packed with very few and narrow air spaces.
- Spongy mesophyll cells:-They are located in the lower layer called the spongy mesophyll layer. Cells are spherical and irregularly shaped with fewer chloroplasts. They possess large intercellular air spaces between the cells.

The functions of the mesophyll include**: photosynthesis**, **gaseous exchange and Storage of starch.**

Adaptations of the mesophyll to its function

i. Palisade mesophyll cells are column shaped with numerous chloroplasts in a thin layer of cytoplasm to carry out photosynthesis.
ii. Palisade mesophyll cells are tightly packed together forming a continuous layer that traps incoming light.
iii. The chloroplasts within the mesophyll cells can move towards light allowing them to be in the best positions to receive light.
iv. Spongy mesophyll cells are irregularly shaped hence fit together loosely leaving large air spaces to allow efficient gaseous exchange via the stomata.
v. The mesophyll cells contain numerous amyloplasts for storing starch.

c) Endodermis

It is the innermost layer of the cortex surrounding the vascular tissue of the roots and stems. It consists of living, elongated and flattened cells. The cell wall of endodermal cells comprises cellulose, pectins, hemicelluloses and deposits of suberin.

Functions of the endodermis

- Acts as a selective barrier to movement of water and mineral salts between the cortex and xylem in roots.
- In dicot stems, it stores starch forming a starch sheath with a possible role in the gravity response of stems.

Adaptations of the endodermis to its functions

- ✓ The endodermis of roots has the casparian strip (made up of suberin) which is impermeable to water and prevents water and solutes from flowing through the air spaces of the cell walls of the endodermal cells (apoplast pathway). This forces water through the cell surface membrane into the cytoplasm of the endodermal cells, hence allowing the endodermal cells to regulate the movement of solutes into the xylem.
- ✓ Active pumping of salts by endodermal cells into the xylem allows rapid movement of water by osmosis into the xylem leading to a buildup of root pressure.
- ✓ Control of movement of water and solutes by endodermal cells acts as a protective measure against the entry of pathogens and toxic substances into the xylem.
- ✓ In dicots, the endodermal cells contain amyloplasts for storing starch grains forming a starch sheath.

d) Pericycle

It is a layer of modified parenchyma, one to several cells thick, located in roots between the central vascular tissue and the endodermis. It consists of one to several layers of living, roughly spherical and elongated cells. Their cell walls are composed of cellulose, pectins and hemicelluloses.

Functions of the pericycle

- ➢ Produces lateral roots.
- ➢ Contributes to secondary growth

Adaptations of the pericycle to its function

- It retains its capacity for cell division (meristematic activity) to produce lateral roots.
- Due to its meristematic activity, it contributes to secondary thickening of the roots.

e) Companion cells

They are specialized parenchyma cells found adjacent to the sieve tubes.

They have a prominent nucleus, dense cytoplasm with numerous small vacuoles, plastids and the usual cell organelles. They are metabolically very active with numerous mitochondria and ribosomes. Each companion cell is connected to a sieve element by plasmodesmata.

Functions of the companion cells

- Control of the activity of the adjacent metabolically inactive sieve tube elements.
- Provide energy needed for the active processes which occur during translocation of organic solutes in the sieve tubes

Adaptations of the companion cells to their function

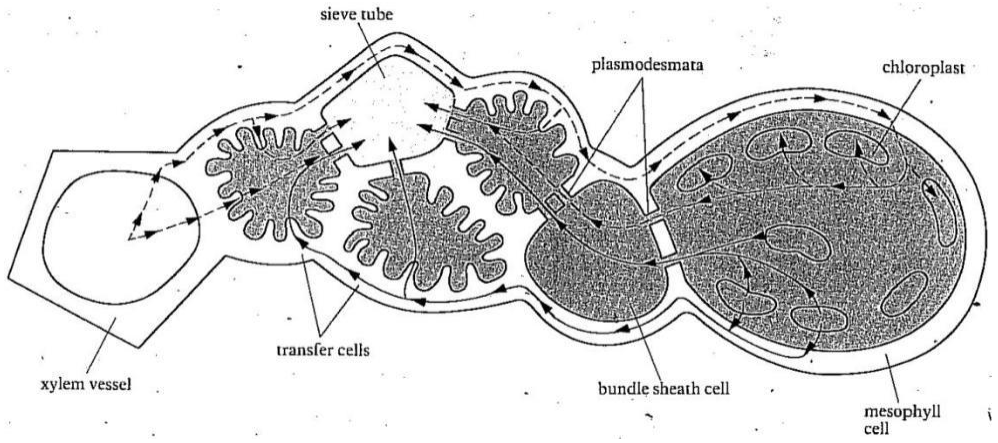
- Plasmodesmata connect sieve elements with companion cells allowing communication and exchange of materials between companion cells and sieve tube elements.
- Companion cells have large nucleus to effect metabolic activity of both companion cells and sieve tubes.
- Companion cells contain numerous mitochondria to produce energy for active transport of materials in the sieve elements.

f) Transfer cells

They are modified form of parenchyma cells which have numerous internal projections (irregular in tuckings) of the primary cell wall and plasma membrane. They possess numerous mitochondria in the dense cytoplasm. Like companion cells, they are associated with phloem sieve tubes. However transfer cells are not confined to the phloem. They are found in a number of places where active transport is thought to occur, for example in the water-secreting glands (hydathodes) at the edges of certain leaves, and in the secretory tissues inside nectarines. They also occur in salt-secreting glands in the leaves of the saltbush Atriplex, a halophyte which lives in dry, saline soil.

- → In the leaf, transfer cells are responsible for moving the products of photosynthesis from the mesophyll cells to the sieve tubes (phloem loading).
- → They also carry water and salts from xylem vessels to the mesophyll cells and to the sieve tubes too.

DIAGRAM {FA pg197, fig 12.18}



Adaptations of transfer cells to their function

- Numerous internal projections of the cell wall and cell membrane increase the surface area and bring the cell membrane to closer association with the cytoplasm.

- Numerous mitochondria in their cytoplasm provide energy for active transport of organic solutes such as sugars from neighbouring cells.
- Have a large amount of starch granules which are broken down to glucose for aerobic respiration.

3) COLLENCHYMA

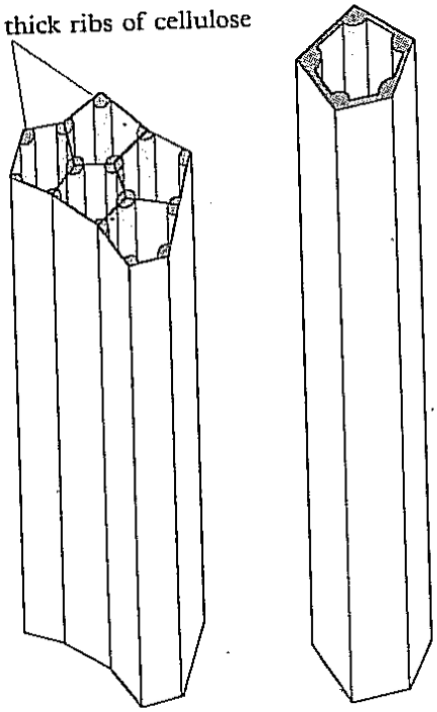
Collenchyma consists of living cells modified to give support and mechanical strength. The collenchyma is the first mechanical tissue to develop in the primary plant body.

Structure of collenchyma tissue

The cells are closely packed without air spaces between them. The cells are elongated and polygonal with tapering ends. The cell walls consist of cellulose, pectins and hemicelluloses.

The cells have extra deposits of cellulose at the corners of the cells causing uneven thickening of the cell walls. Cells are elongated, parallel to the longitudinal axis of the in which they are found.

Diagram of Collenchyma tissue cells



Distribution and functions

- ✓ Collenchyma cells which are relatively flexible provide support for plant organs allowing them to bend without breaking.
- ✓ It is mainly found in young plants, herbaceous plants and in organs such as the leaves in which secondary growth does not occur.
- ✓ In the leaves, they are mainly found in the midribs of dicotyledonous leaves.
- ✓ They are also located at the periphery of the organs usually under the epidermis.

Adaptations of collenchyma to its function

- ☑ Deposition of extra cellulose at the corner of the cells leads to development of unevenly thickened cell walls to provide support and mechanical strength.
- ☑ Cells are living and can grow and stretch, thus provide mechanical strength without imposing limitations on the growth of the other cells around it, allowing continued growth in young stems and leaves.
- ☑ Cells are located towards the periphery of the organ just below the epidermis in the outer regions of the cortex to increase its support value in stems and petiole.

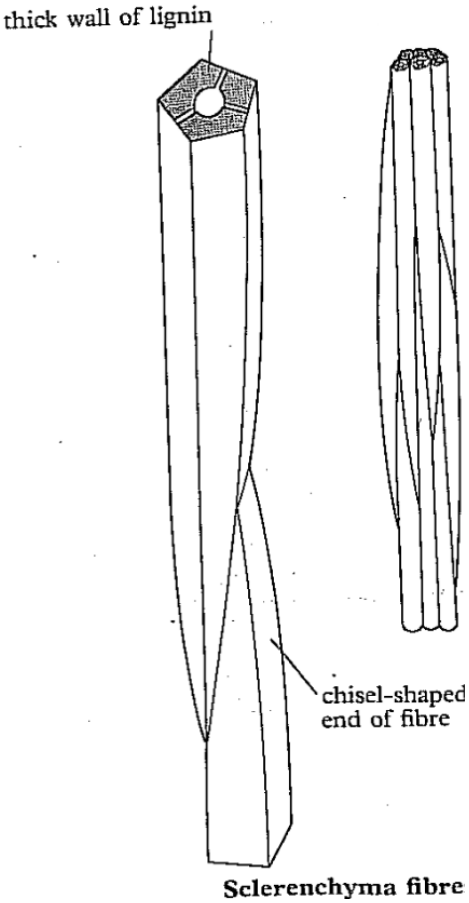
4) SCLERENCHYMA

These can only elongate when they are young. The mature cells are dead, incapable of elongation and contain no cytoplasm. The primary cell wall is composed of cellulose, pectin and hemicelluloses and thickened with deposits of lignin. Its thick cell walls contain simple pits, areas where lignin is not deposited on primary wall due to presence of a group of plasmodesmata.

There are two types of sclerenchyma cells that is **fibres** and **sclereids.**

Fibres

The cells are elongated and hollow with narrow lumens. The cells are polygonal in shape with tapering interlocking ends. The fibres are found in the outer regions of the **cortex, pericycle of stems, xylem and phloem**. Its structure is as illustrated below;



Sclerenchyma fibre

Adaptations of sclerenchyma to its function

- ✓ Have elongated fibres and spherical sclereids closely packed together to provide mechanical support.
- ✓ The primary cell wall is heavily thickened and lignified with heavy deposits of lignin, with great tensile strength and compression strength for support and mechanical protection.
- ✓ High tensile strength of lignified walls prevents breakage on stretching.
- ✓ High compression strength of the lignified walls prevents buckling or crushing under pressure.
- ✓ Fibres are arranged into strands or sheets of tissue that extends longitudinally to provide combined collective strength.
- ✓ Ends of cells of fibres interlock with the tapering ends of one another increasing combined supportive strength.

Sclereids (stone cells) which are roughly spherical or irregular in shape they are found in the **cortex, pith, phloem, shells and stones of fruits, seed coats**.

XYLEM

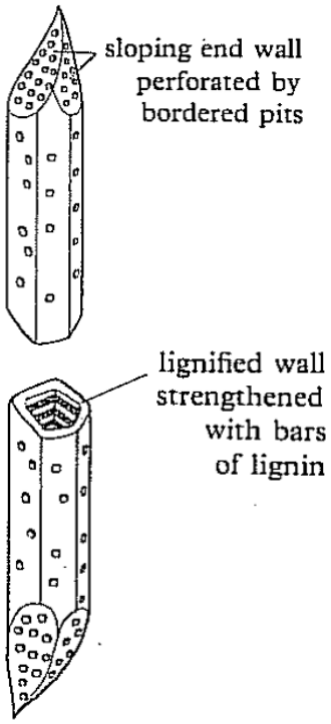
It is a vascular tissue with two main functions; conductance of water and mineral salts and providing mechanical support to the plant. The xylem consists of four types of cells; tracheids, vessels elements, parenchyma and fibres.

Tracheids

They are single cells with thick walls extensively lignified by heavy deposits of lignin. Some parts are not lignified forming bordered pits. They have tapering end walls that overlap with adjacent tracheids. They are dead with empty lumens when mature. The cells are polygonal in cross section with 5 or 6 sides.

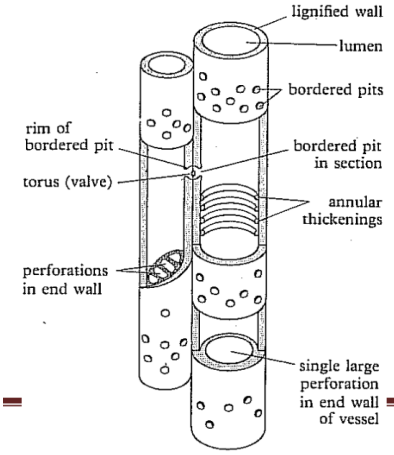
The tracheids represent the original primitive water conducting cells of vascular plants. They are the only cells found in the xylem of the more ancestral vascular plants and are the only conducting elements in conifers.

Structure of a tracheid

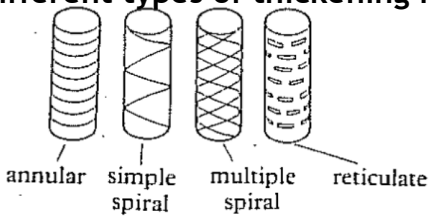


Xylem Vessels; A vessel is formed from a chain of elongated cylindrical cells (vessel elements) placed end to end. The cellulose side walls of the vessel elements are heavily lignified rendering them impermeable to water and solutes. The lignified walls are perforated by numerous pits called bordered pits where lignin fails to be deposited and only the primary cell wall remains. In the course of development the horizontal end walls of vessel elements break down partially or completely so that the cells are in open communication with each other. Mature vessel elements (cells) lack cell membrane and cytoplasmic contents. Vessel elements are shorter and wider than tracheids.

The xylem vessel elements of higher plants



Different types of thickening found in vessels



Differences between vessels and tracheids

Vessels	Tracheids
They are cylindrical in shape.	They are 5 or 6 sided in cross section
Have open ended walls on either sides	Have perforated closed end walls.
Have no tapering ends.	Have tapering ends.
Offer less resistance towards water passage.	Offer a significant or more resistance to water Passage.
Fast conduction of large volume of water.	Conduction of less volume of water.

Protoxylem and metaxylem

The first vessels of the xylem to form are the protoxylem. They are small in cross section and not lignified. They are found on the part of the apex just below the apical meristem where elongation of surrounding cells is still taking place. They undergo stretching and they collapse as they mature being replaced by metaxylem. Mature metaxylem vessels cannot stretch or grow because they are dead, rigid and fully lignified tubes. They become part of the permanent tissues of the plant.

NB:

1. The xylem fibres provide additional mechanical strength to the xylem.

2. The xylem parenchyma serve functions such as food storage, deposition of tannins, crystals and other chemical compounds, radial transport of food and water and gaseous exchange through intercellular spaces.

Adaptations of xylem to its functions

1. Xylem vessels and tracheids consist of long cylindrical cells joined end to end, hence are continuous with each other ensuring continuous flow of water in a continuous unbroken column.
2. Endwalls of the xylem vessels are completely broken down to form continuous tubes that allow uninterrupted flow of water.
3. Tracheids are perforated with numerous cellulose bordered pits that allow water to pass from one cell to another in lateral directions.
4. During development, the protoplasmic contents of vessels and tracheids die and disappear leaving empty hollow lumens, permitting uninterrupted flow of water without obstruction by living content.
5. Impregnation of cellulose walls with lignin increases adhesion of water molecules to walls thereby facilitating the rise of water by capillarity.

6. Lignifications of walls confer rigidity preventing walls from collapsing under large tension forces set up by the transpiration pull.
7. Narrowness of lumens of vessels and tracheids increases the rise of water by capillarity.
8. Xylem fibres have extremely thick walls which are heavily lignified and with narrow lumens to provide additional mechanical strength and support to the xylem.

5) PHLOEM

It is a vascular tissue modified for translocation of manufactured food. It is composed of five types of cells i.e sieve tube elements, companion cells, parenchyma, fibres and sclereids.

Sieve tubes

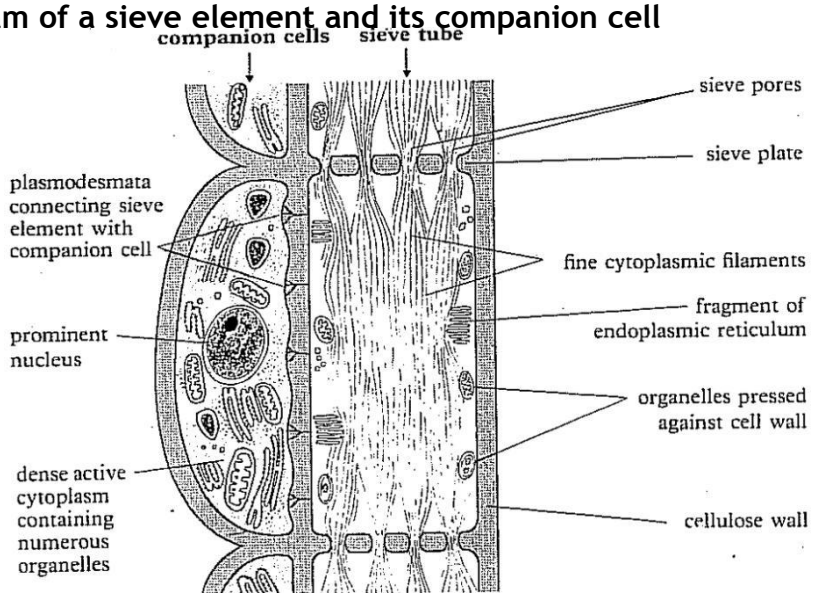
They are long tube-like structures formed by end to end fusion of cells called **sieve tube elements/sieve elements.** The sieve elements have walls made of cellulose and pectins, but their nuclei degenerate and are lost as they mature.

The cytoplasm is confined to a thin layer around the periphery of the cell. Sieve elements are living but metabolically depend on adjacent companion cells. In between the sieve tube elements are **sieve plates**, formed from the two adjoining end walls of neighbouring sieve elements.
The sieve plates are perforated by sieve pores formed by enlargement of plasmodesmata. The sieve plates are made up of a polysaccharide called **callose.**

Companion cells

They have a thin cell wall and dense cytoplasm with a prominent large nucleus, numerous mitochondria, plastids and small vacuoles and extensive endoplasmic reticulum. Companion cells are metabolically active and essential for the survival of sieve elements.

Diagram of a sieve element and its companion cell



Or Diagram in FA page 193

Protophloem and metaphloem

Protophloem is the first phloem formed in the zone of elongation of the growing root or stem. Protophloem becomes stretched and eventually collapses becoming non-functional as the tissue around it grows. As more phloem is produced, the protophloem matures after elongation has stopped to produce the metaphloem.

Adaptations of the phloem to its function

- ☑ Sieve tube elements are joined end-to-end; their walls are perforated with sieve pores in sieve plates allowing passage of materials unimpeded from one cell to another.
- ☑ Sieve elements lack nuclei and possess a thin cytoplasm pushed to the sides of the cell, creating room for passage of organic materials in solution with minimal obstruction.
- ☑ Plasmodesmata connect sieve elements to companion cells which are metabolically active allowing communication and exchange of materials between sieve elements and companion cells.
- ☑ Sieve elements contain cytoplasmic filaments continuous with similar filaments in other sieve elements via sieve pores in the sieve plate, which consist of a contractile phloem protein capable of streaming and sliding organic materials from one sieve element to another by wave like movements of the filaments.
- ☑ Companion cells possess numerous mitochondria to provide energy in form of ATP for active transport of materials.
- ☑ Modified parenchyma companion cells called transfer cells found next to sieve tubes bear numerous internal projections increasing surface area of the cell membrane and also contain numerous mitochondria producing energy for active uptake of solutes from neighbouring cells during loading of sieve tubes.
- ☑ Phloem consist of living cells allowing live active transport of materials since the mechanism of loading sieve tubes and transport of solutes requires energy.
- ☑ Sclereids are lignified to provide support to the vascular tissue of the phloem.
- ☑ The companion cells are elongated and thin walled to provide a large surface area for diffusion of materials to the neighbouring cells.

END OF TISSUE BIOLOGY

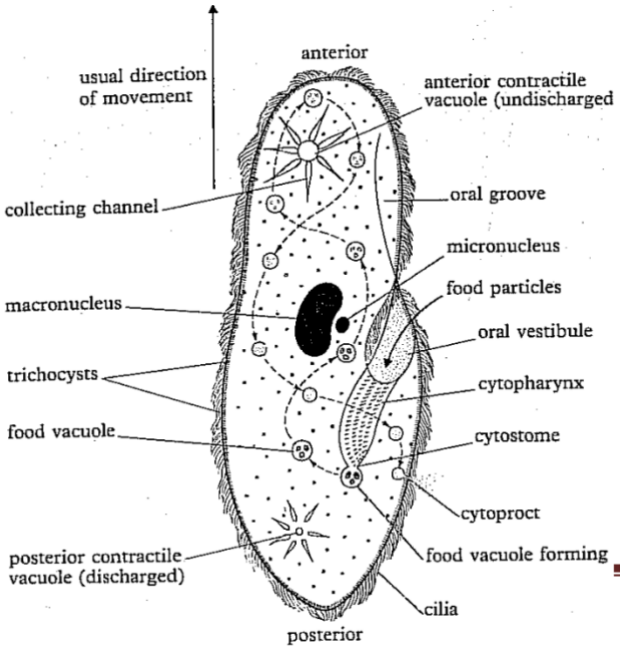
Let me hope that you now well versed with details of all tissues. I now welcome you to levels of organization

LEVELS OF ORGANISATION

1. Unicellular level of organization

It is one where the physiological functions/processes of an organism are mainly performed by cell organelles. It is represented by single celled organisms such as paramecium.

Paramecium structure



Or Check diagram in FA page 43

The paramecium has the following main parts and their functions.

- Macronucleus- It controls metabolic functions including growth.
- Micronucleus- It is responsible for sexual reproduction.
- Cilia- It is responsible for locomotion and creation of food currents.
- Contractile vacuoles (anterior and posterior vacuoles) - Are for osmoregulation. They eliminate excess water from the cell to the exterior.
- Trichocysts- They are tiny explosive sacs containing needle shaped thread. They are used for defense in some species. They are used for paralyzing the prey.
- Food vacuoles-They contain food particles at the base of cytoproct and it is where digestion takes place.
- Cytoproct- They are sites through which undigested food is expelled to the exterior.

Advantages of unicellular organization

i. The distance from the surface of the organism to its centre is very short, that allows quick and efficient diffusion of materials in and out of the cell.
ii. It exposes a large surface area to volume ratio which also makes diffusion of materials easy.
iii. Easy reproduction through fission.

Disadvantages

i. There is inefficiency in the processes of an organism due to lack of specialization.
ii. It is not possible for an organism to grow to a large size.

Advantages of small size

i. It allows fast locomotion.
ii. It presents a larger surface area to volume ratio hence allowing faster exchange of gases with the surrounding medium.
iii. Organisms can easily pass through limited spaces.
iv. The organism can occupy a variety of habitats.
v. It has a high reproductive rate with a high survival chance.
vi. Organisms cannot easily be noticed by the predator/enemy.

Disadvantages of small size

i. The organisms lose a lot of heat because of having a large surface area to volume ratio.
ii. The organisms usually have a high metabolic rate hence eat a lot.
iii. The organism cannot intimidate/scare the predator/enemy.
iv. The organism can easily be consumed by the predator wholly.

Advantages of big size

i. It allows the organism to have a low metabolic rate hence eats less relative to body size.
ii. The organism loses less heat because it has a small surface area to volume ratio.
iii. The organism can easily intimidate/scare the predator/enemy.
iv. A large organism cannot easily be consumed, only parts of it can be consumed.

Disadvantages of big size

i. The locomotion is usually slow.
ii. It presents a small surface area hence slower exchange of materials with the surrounding medium.
iii. There is a problem of passing through limited space hence can occupy limited habitats.
iv. It usually allows a low reproductive rate with low survival chances.
v. A large organism can easily be noticed by the predator/enemy.

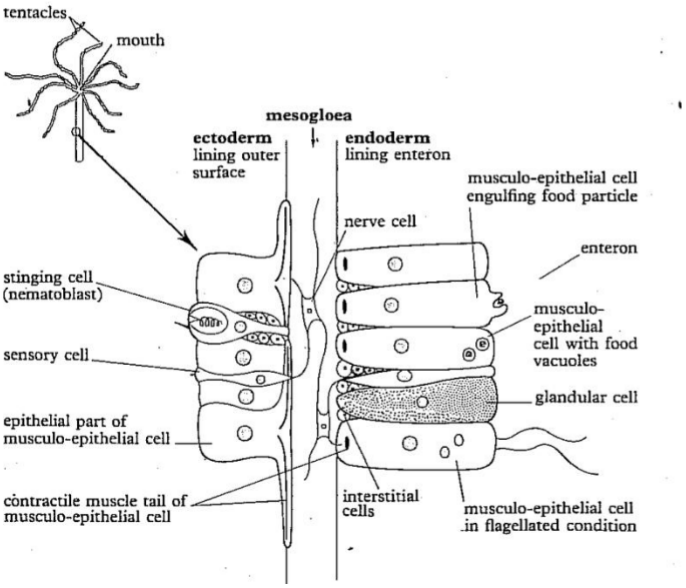
2. Tissue level of organization

It is the level of organization where the physiological processes are only carried out by isolated cells and tissues. Organisms in this level are mainly primitive multicellular animals. Such animals have very few organs. Example is the hydra.

HYDRA

It has a simple sac like body. Its cells are interdependent and to some extent integrated by the nervous system.

Structure of the wall of the hydra



The wall of the hydra

It is composed of seven different types of
cells arranged in two sheet like layers called
Ectoderm and **endoderm**. The ectoderm
lines the external surface whereas the Endoderm lines the body cavity/enteron.
Between the ectoderm and endoderm is an
intersurface called the **mesogloea** in which
there are nerve cells that are interconnected
To form a nerve net. Each of the different
cells performs a specific function as stated
Below.

Musculo epithelial cells- These are cells
lining the upper surface in the ectoderm
And are mainly for protection.

- **Nematoblasts-** (stinging cells). It contains a thread which contains a toxic fluid. It is used in the piercing and poisoning of prey.
- **Sensory cells**- They are for detecting changes in the surrounding environment and pass impulses to the nerve cells.
- **Nerve cells-** They are interconnected to form a nerve net. They are connected to the contractile muscle tail of the musculo epithelial cell. Therefore, their role is to pass on the information ie conducting impulses to those muscle tails of the musculo epithelial cells.
- **Muscle tails-** They are contractile muscles at the base of each musculo epithelial cell. They are concerned with bringing about the movement or beating of the tentacles and flagella when they contract.
- **Glandular cells**-They secrete enzymes that carry out digestion in the enteron.
- **Phagocytic musculo epithelial cells**- For taking in small particles from the enteron so that digestion is completed intracellularly.

- **Flagellated musculo epithelial cells**- Are important for effective movement of materials eg food materials and stirring it up in the enteron.
- **Interstitial cells**- For generation or production of new cells.

Feeding mechanism in a hydra

Food of a hydra is usually water fleas. The water fleas are immobilized by the stinging cells and pulled to the mouth by the tentacles under the influence of the contraction of the muscle tails which are controlled by the nerve net in the mesogloea.

When the food reaches in the enteron, digestion starts by the enzymes secreted from the glandular cells. Digestion is completed inside the musculo epithelial cells which take up food particles from the enteron by phagocytosis.

3. **Colonial organization**

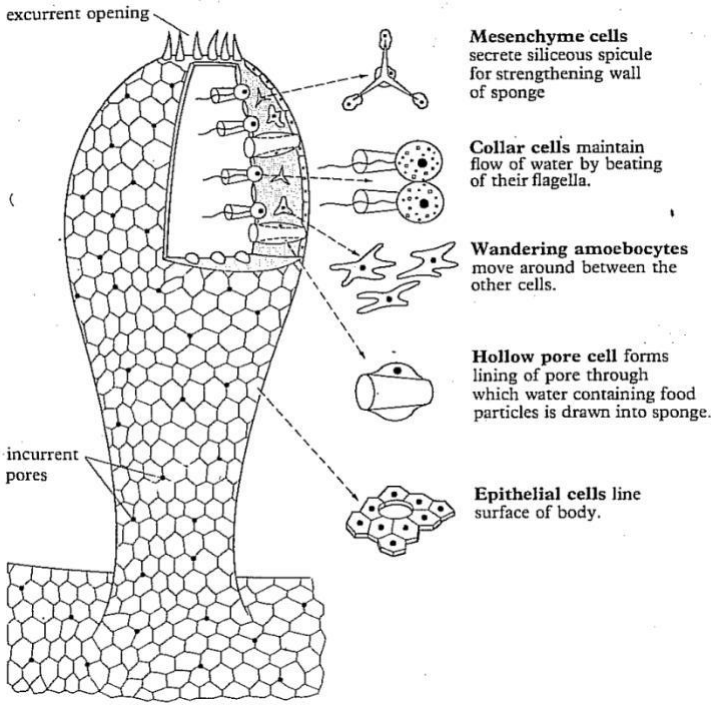
In colonial organization, cells are functionally isolated i.e their activities are not coordinated. Each cell when isolated can exist on its own for example in a sponge.

4. **Organ level of organization**

It is a level of organization where the physiological functions are mainly performed by organs and organ systems. An example is mammals. This form of organization occurs mainly in the higher multicellular animals.

Or **diagram in FA page 44**

Structure of a sponge



Advantages of being multicellular

a) It allows increase in size.
b) It brings about specialization of specific cells for a particular function, thus improving efficiency of an organism as a whole.
c) It permits exploitation of environment in which single celled organisms cannot live.
d) It allows development of better tissues for example muscles for quick movement, skeleton for support and quick movement.
e) There is also development of sophiscated physiological mechanisms e.g maintenance of body temperature.

In this sub-topic, we have been able to discuss the meaning of histology, gave the different types of tissues in plants and animals we saw that in animals we have epithelial tissues, reproductive tissues, nervous tissues, connective and we also saw that in plants we have parenchyma, collenchyma, sclerenchyma, xylem, phloem tissues.

It came to our notice that different tissues have features that make them adapted to specific functions and thus are able to carry out these functions due to the modifications in these features.

We also appreciated that there was evolution from unicellurity to multicellularity. In these we were able to give the challenges of being multicellular and as well the advantages of being multicellular.

We had a case study of hydra and went in detail to look into its wall structure and saw different modifications of cells.

I thank you very much for having taken consideration of a variety of tissues.

You can now try out the following questions to find out your capacity as far as histology is concerned

1. (a) For each of the following, show how its structure is related to its function:

i. a red blood corpuscle;
ii. a motor neurone;
iii. a xylem vessel.

(b) What advantages do organisms gain from cell differentiation?

2. By means of labelled diagrams only, illustrate the microscopic structure of mammalian bone and cartilage.

Show how these tissues give support to the body.

3. (a)Give an illustrated account of the structure of a meristematic cell of a plant

(b) How do the structure and function of each of the following differ from that of a meristematic cell?

i. a xylem fibre
ii. a sieve tube.
iii. a guard cell

4. Describe how each of the following tissues are related to their functions.

(a) Parenchyma
(b) Collenchyma
(c) Sclerenchyma

5. Discuss how structure and function are related for each of the following tissues.

(a) Voluntary muscle tissue
(b) Parenchyma tissue in plants

6. (a) Describe the structure of cartilage and bone.

(b) How is cartilage replaced by bone?

7. (a) Name two areas in plants where each of the following tissues is found

(i) Sclerenchyma
(ii) Collenchyma

(b) Give three structure adaptations of the sclerenchyma tissues for its function.

(c) Explain the importance of the collenchyma tissue in leaves and young stems.
(d) Outline three structural differences between the collenchyma and sclerenchyma tissue.
8. Describe the adaptations of each of the following tissues.
(a) Stratified tissue
(b) Collagen tissue.
9. (a) Describe the structure of the vascular systems in higher plants.
(b) How is the system in (a) adapted to its functions.
10. Discuss how structure and function are related for each of the following tissues.
(a) Voluntary muscle tissue.
(b) Parenchyma tissue in plants

END OF SUB-TOPIC THANK YOU

NUCLEIC ACIDS AND PROTEIN SYNTHESIS

NUCLEIC ACIDS

These are organic molecules whose role is to regulate cell activities that is to say they are carriers of genetic information. The main types of nucleic acids are **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**.
DNA is mainly found in the nucleus whereas RNA is found mainly but not exclusively in the cytoplasm. Other nucleic acids include AMP, ADP, ATP, NAD, FAD, NADP and coenzymes.

GENERAL STRUCTURE OF A NUCLEIC ACID

It consists of 3 types repeating sub-units i.e.
iv) Nitrogenous bases (purines and pyrimidines)
v) Pentose sugars
vi) Phosphate units.

1. PURINES AND PYRIMIDINES (NITROGENOUS BASES)

These are organic bases which belong to a series of related compounds in which the rings contain both carbon and nitrogen atoms.
The ***purines*** i.e. Adenine (A) and Guanine (G) are made up of two interconnecting rings while the *pyrimidines* i.e. Uracil (U). Cytosine (C) and Thymine (T) possess a single ring.
Note: purines; they have double carbons and nitrogen rings
Pyrimidines; they have single carbons and nitrogen rings

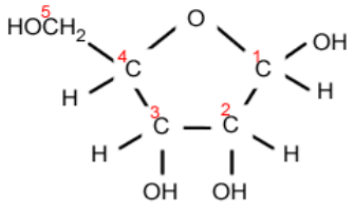
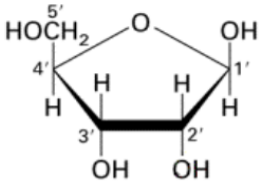
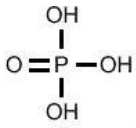
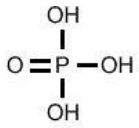
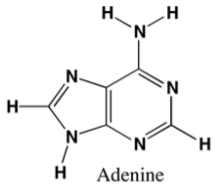
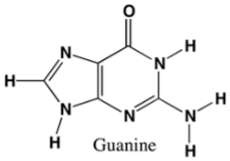
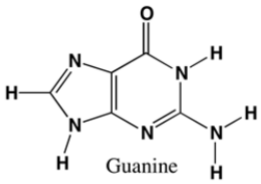
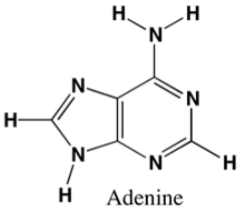
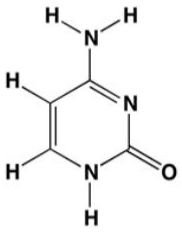
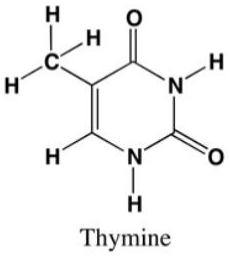
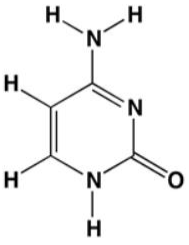
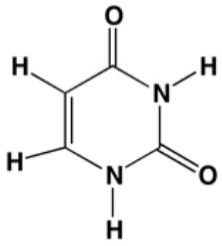
2. THE PENTOSE SUGAR UNITS

The pentose sugars are found in nucleic acids and are of two types i.e. ribose and deoxyribose. They differ only in that ribose sugars contain an additional oxygen atom

3. PHOSPHATE UNITS

These act as alpha links between one sugar group and the next.
In nucleic acids, these 3 groups are linked together in a specific way to make a larger group as a nucleotide.

A summary table of the components of the nucleic acids

MOLECULE	DNA	RNA
Pentose sugar	 deoxyribose	 **Ribose**
Phosphoric acid	 Phosphoric acid	 Phosphoric acid
Purines Double ringed	 Adenine  Guanine	 Guanine  Adenine
Pyrimidine Single ringed	 Cytosine  Thymine	 Cytosine  Uracil

Many nucleotides are then joined by condensation to form a long chain known as a nucleic acid.

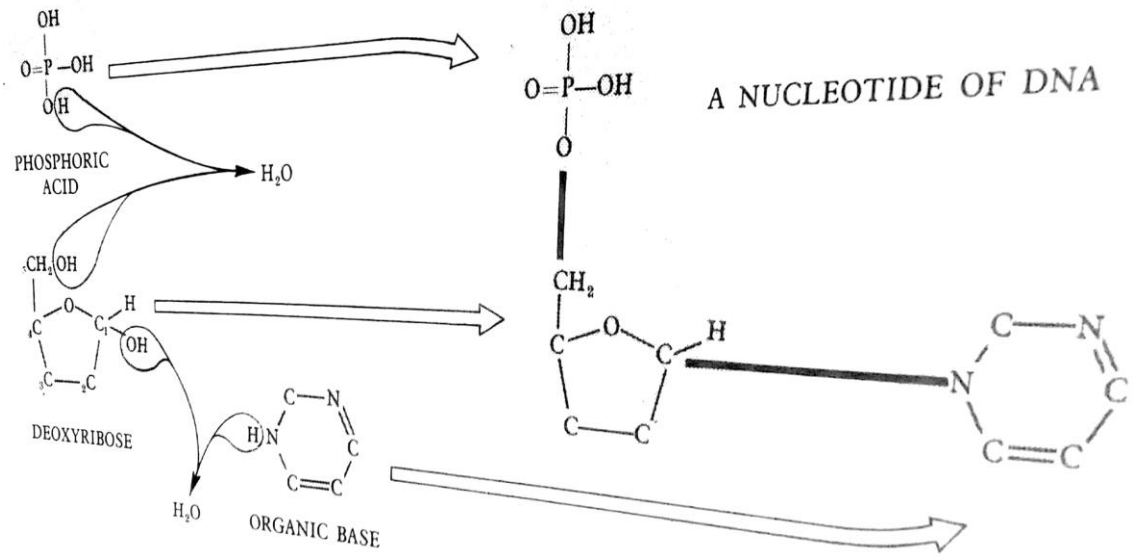
DNA STRUCTURE

The description of the double helical structure of DNA was first done by Watson and Crick in 1953.

- ✓ DNA is a double strand of polynucleotide chains; each strand has a helical (spiral) shape, so DNA forms a double helix.
- ✓ Each DNA strand is a polymer made up of nucleotide subunits which join together to form a long unbranched polynucleotide chain.
- ✓ Each nucleotide consists of deoxyribose, a pentose sugar, an organic nitrogen containing base and phosphoric acid.
- ✓ The sugar and organic base join together by a condensation reaction to form a **nucleoside.** Another condensation reaction joins the nucleoside with phosphoric acid to form a **nucleotide**. This bond between carbon 5 of the sugar and a phosphate is called a **phospho-ester bond.**

- ✓ The organic bases present in DNA are either purines or pyrimidines.
- ✓ Purines have a double ring structure comprising a six sided and a five sided ring. Purines are guanine (G) and adenine (A).
- ✓ Pyrimidines have a single ring structure which is six sided. The pyrimidines include cytosine (C) and thymine (T).
- ✓ The nucleotides are joined together by a **phospho-diester bond** which can be repeated to form a polynucleotide chain. Each chain has two distinct ends, a 3' end and a 5' end.
- ✓ The polynucleotide chains run in opposite directions and are joined by pairs of bases. The bases are held together by hydrogen bonds between hydrogen atoms of a base in one chain and oxygen or nitrogen atoms of a base on the other chain.

Illustration of formation of a nucleotide



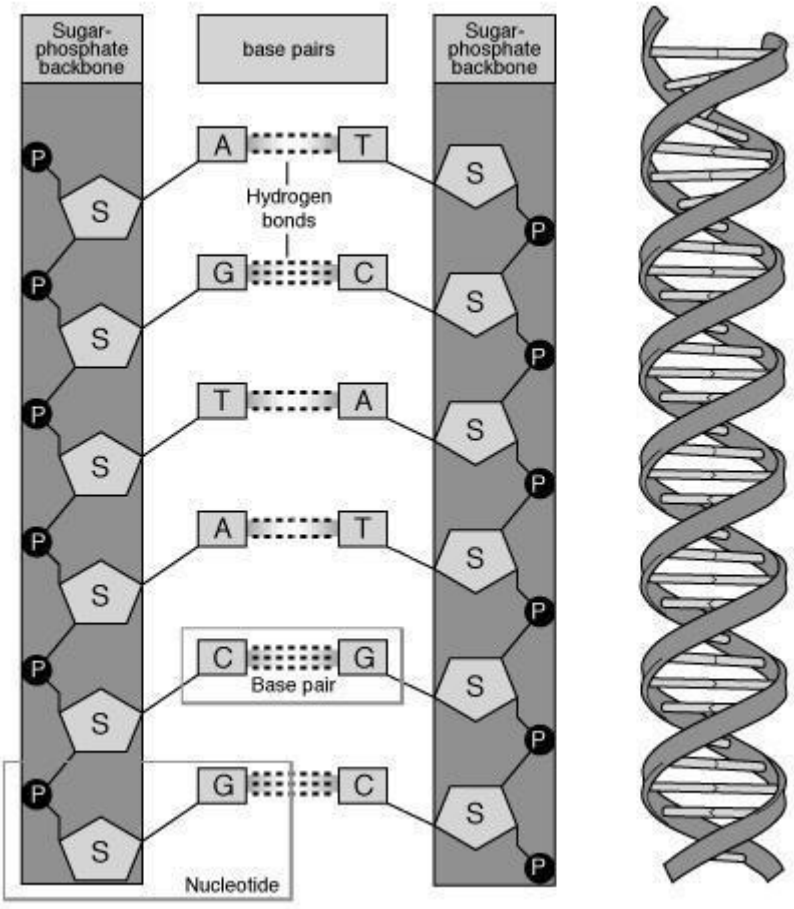
- ✓ DNA consists of two polynucleotide chains coiled around each other to form a double helix.
- ✓ The double helix is held together by hydrogen bonds between pairs of bases in the two chains.
- ✓ The pairing depends on the shape of the bases whereby a purine can only pair with a pyrimidine and depending on the ability of the bases to form hydrogen bonds. Adenine, a purine pairs with thymine, a pyrimidine forming two hydrogen bonds i.e A = T. Guanine, a purine pairs with cytosine, a pyrimidine forming three hydrogen bonds.

COMPLEMENTARY BASE PAIRING IN THE DOUBLE HELIX

- ☑ Complementary base pairs are the only ways the bases can bond and join the two polynucleotide chains. Thus the sequence of bases along one polynucleotide chain determines the sequence along the other i.e adenine on one chain means that there must be a thymine on the other chain at that point and so on.
- ☑ Complementary base pairing forms a basis of DNA replication and its ability to form messenger RNA during protein synthesis.
- ☑ Complementary base pairing can only happen if the two polynucleotide chains are anti-parallel.

- ☑ Anti-parallel chains run in opposite direction whereby one chain runs from 3' - 5' and the other runs from 5'- 3'.
- ☑ The two polynucleotide chains twist to form a double helix cross liked at regular intervals whereby one complete turn of the double helix is 3.4nm and has 10 pairs of nucleotides.

Illustration of the double helix



Adaptations of DNA to its functions

- Sugar-phosphate backbone is held together by strong covalent phospho diester bonds to provide stability.
- The two sugar-phosphate backbones are antiparallel which enables purine and pyrimidine nitrogen bases to project towards each other for complimentary pairing.
- Sugar-phosphate backbones are two / it is double stranded to provide stability.
- The two sugar-phosphate backbones form a double helix to protect bases/hydrogen bonds.
- Long/large molecule for storage of much information.
- Double helical structure makes the molecule compact to fit in the nucleus.
- Base sequence allows information to be stored.
- Double stranded for replication to occur semi-conservatively/ strands can act as templates.
- There is complementary base pairing / A-T and G-C for accurate replication/identical copies can be made;
- Weak hydrogen bonds enable unzipping/separation of strands to occur readily.
- There are many hydrogen bonds which increase stability of DNA molecule.

DNA REPLICATION (DNA DUPLICATION)

This is the process by which DNA makes exact copies of itself which is controlled by the enzymes helicase, DNA polymerase and DNA ligase.

There are three theories that have been suggested to describe DNA replication

***1*. Fragmentation hypothesis (Dispersive hypothesis)**

The parent DNA molecule breaks into segments and new nucleotides fill in the gaps precisely.

***2*. Conservative hypothesis**

The complete parent DNA molecule acts as a template for the new daughter molecule, which is assembled from new nucleotides. The parent molecule is unchanged.

***3*. Semi-conservative hypothesis**

The parent DNA molecule separates into its two complementary strands, each of which is a template for the formation of a new complementary strand. The two daughter molecules therefore contain half the parent DNA and half new DNA.

Based on this theory which highly accepted;
DNA replication involves the following steps.

- ✓ The hydrogen bonds between the complementary bases of the two strands of the parent DNA molecule break. The breaking of the double helix is controlled by the enzyme **helicase**. This forms a replication fork
- ✓ The two strands unwind/unzip, each strand becomes a template for the synthesis of a new strand, complementary to itself.
- ✓ **Single-strand binding protein** stabilize the separated parental DNA strands to prevent them from rejoining/ re-annealing.
- ✓ **DNA polymerase enzyme** moves down the two strands catalyzing the linkage of free nucleotides in the nucleoplasm to their complementary bases on the templates.
- ✓ It does so by bonding the phosphate group of one nucleotide to the sugar molecule of the adjacent nucleotide; forming the side rail of the new DNA.
- ✓ Each time DNA polymerase meets the next base on the DNA template, free nucleotides approach the DNA strand, and the one with the correct complementary base **hydrogen bonds** to the base in the DNA. Thus adenine bonds with thymine and cytosine bonds with guanine.
- ✓ The free nucleotide is then held in place by the enzyme until it binds with the preceding nucleotide, thus extending the new strand. The enzyme continues to move along one base at a time with new DNA strands growing until all the nucleotides on the templates have joined with appropriate free nucleotides and the two identical daughter molecules of DNA are formed.
- ✓ The leading strand is synthesized continuously, towards the replication fork in the 5'-3' direction which is also the direction of activity of DNA polymerase.
- ✓ The lagging strand is synthesized discontinuously in a piecewise fashion in the 3'-5' direction as it proceeds away from the replication fork.
- ✓ These pieces are known as Okazaki fragments, **Primase** catalyzes the synthesis of a short RNA primer which is extended by DNA polymerase to form Okazaki fragments.
- ✓ After an RNA primer is replaced by another nucleotide by activity of DNA polymerase an enzyme **DNA ligase** closes the gaps left by joining the 3' end to the 5' end.

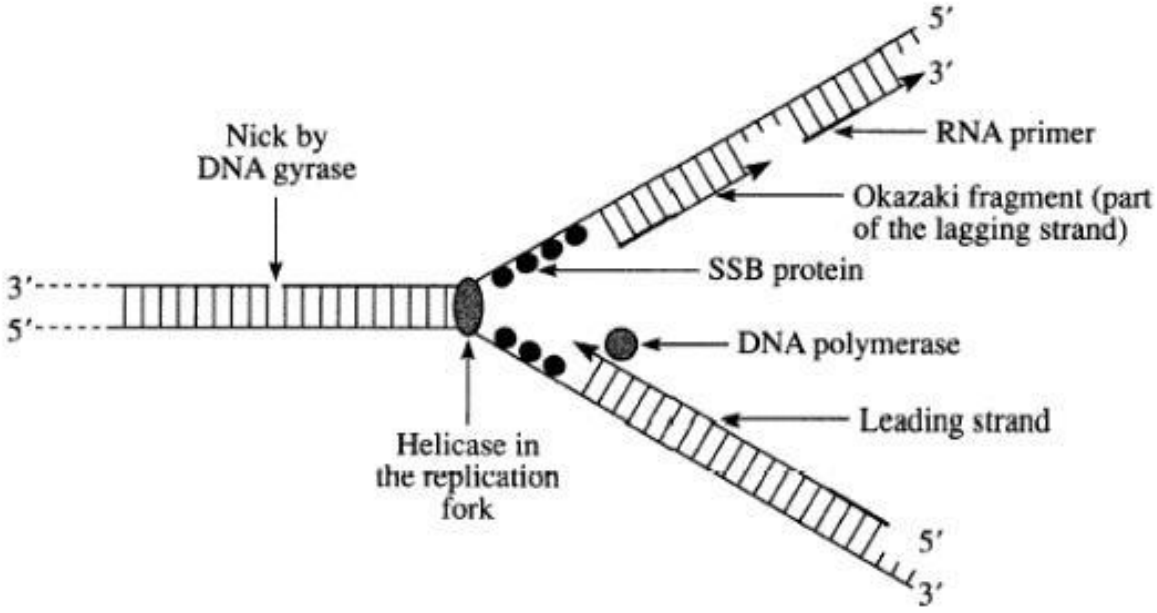
- ✓ Two molecules of DNA identical to each other and which are replicas of the original copy are formed. The two new daughter molecules then coil up again to reform the double helix structure.

NOTE

- ✓ This is because half of the original parent molecule is conserved in each of the new strands produced. This is important because the cell can provide identical copies of all its genetic instructions to be passed onto daughter cells during cell division.

Illustration of DNA replication

Check out illustrations in understanding biology page 114 fig 7.9



THE RIBONUCLEIC ACID (RNA)

RNA usually consists of a single polynucleotide chain that forms an alpha helix. The pentose sugar in the RNA molecule is a ribose sugar rather than deoxyribose that occurs in the DNA.

RNA nucleotides contain four types of bases adenine (A), guanine (G), cytosine (C) and uracil (U) which replaces thymine of DNA. There are several types of RNA which include: **messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA).** Each differs in length and shape but all share the same basic structure.

Messenger RNA (mRNA)

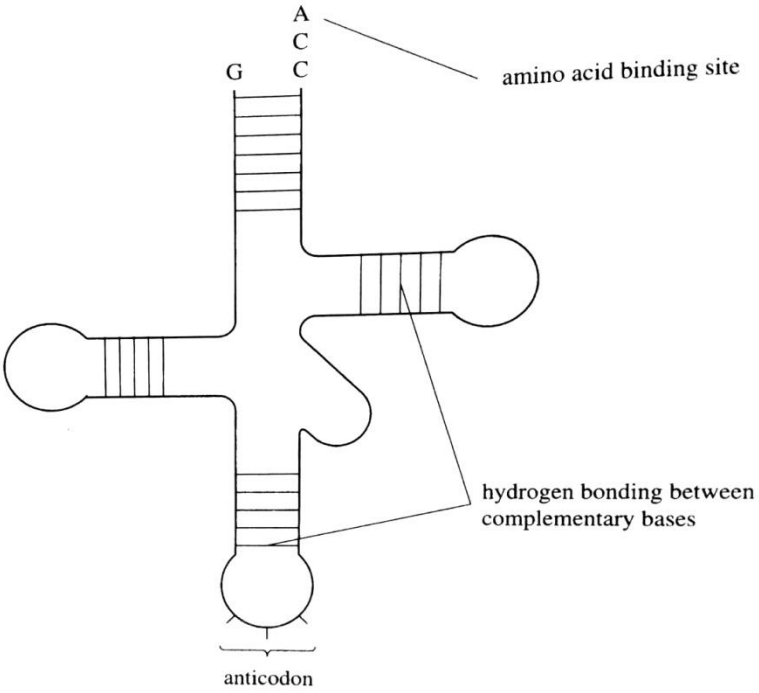
- × Messenger RNA molecules are mobile templates of the protein coding part of the cistron. mRNA is a long single stranded molecule of up to 1000 of nucleotides which is formed into a helix.
- × It is manufactured in the nucleus. It is a mirror copy of part of one strand of the DNA helix. Messenger RNA is dispatched out of the nucleus after its synthesis through the nuclear pores into the cytoplasm.
- × mRNA associates with ribosomes to form a **polysomes or polyribosome** which directs protein synthesis.

Transfer RNA (tRNA)

Transfer RNA molecules transport specific amino acids to the polysome (ribosome on mRNA) during protein synthesis. There are 20 groups of tRNA, each specific for one kind of amino acid. They all have the same **basic structure**.

Structure of tRNA

Transfer RNA molecules are 70 – 90 bases long. They have a 'clover' leaf structure. They consist of four major arms with an optional arm giving a total of 5 arms.



a. <u>The first arm (anticodon arm-</u> It contains a sequence of three bases known as the anticodon and these are complementary to the bases on the mRNA. It is these bases on the mRNA which specify the amino acids.

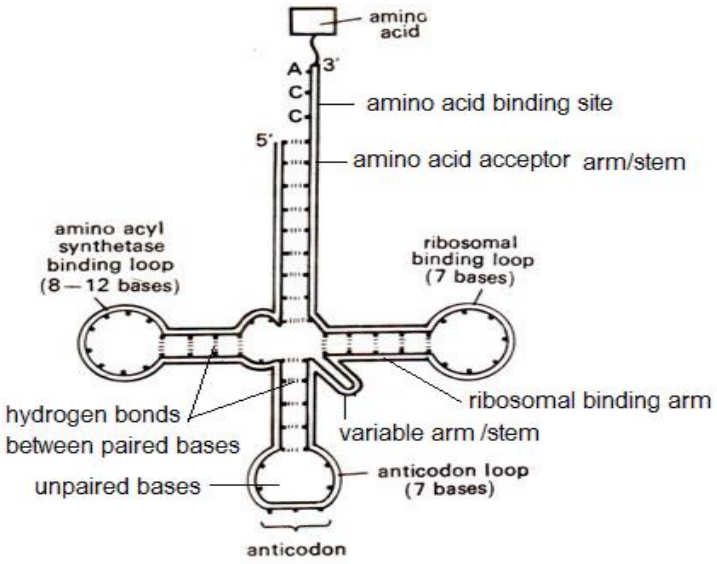
b. <u>The acceptor arm-</u> The amino acid to be transferred to the ribosome so that it is linked to the polypeptide chain or initiate translation is attached to the acceptor arm. The acceptor arm has the base sequence CCA.

c. <u>Third arm (pseudo uracil) -</u> It contains a pseudo uracil surrounded by thymine and cytosine (T...C). It is at this arm that the tRNA binds with the ribosome.

d. <u>Dihydro-uracil arm (DH...)/D- loop-</u> It contains an unusual base dihydro-uracil. This arm binds with the enzyme during translation.

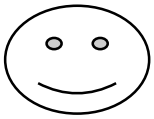
e. <u>Optional arm/ variable arm-</u> It is also known as the extra arm or variable arm. In some species, it is longer and in others, it is short.

Diagram of transfer RNA structure in understanding biology page 111 fig 7.5



Ribosomal RNA (rRNA)

It consists of many nucleotides wound into a complex structure consisting of partly single and double helices. It is made in the nucleus under the control of the nucleolus.
After being synthesized, rRNA moves to the cytoplasm where it binds with the protein molecules to become ribosomes. Over 80% of RNA consists of rRNA in the cell.



Please having taken notice of DNA and RNA may you please compare the two. (**Hint**; give similarities and differences based on structure and function) **check** your answers.

COMPARISON OF DNA AND RNA

Similarities

Both:

(1) Polymers of nucleotides.
(2) Carry genetic information
(3) Have same purine bases adenine and guanine plus pyrimidine bases cytosine
(4) Originate from the nucleus
(5) Occur in the cytoplasm

Differences between DNA and RNA

RNA	DNA
It is a single polynucleotide chain.	It is a double polynucleotide chain.
It has a smaller molecular mass ranging from 200000 to 2000000.	It has a larger molecular mass from 100000 to 150million.
It may be single or double helix.	It is always a double helix.
The pentose sugar is ribose.	The pentose sugar is deoxyribose.
Organic bases present are adenine, guanine, cytosine and uracil.	Organic bases present are adenine, guanine, cytosine and thymine.
RNA is manufactured in the nucleus but found throughout the cell.	DNA is found entirely in the nucleus.
RNA is chemically less stable.	DNA is chemically very stable
The ratio of adenine and uracil to cytosine and guanine varies.	The ratio of adenine and guanine to cytosine and guanine is one.
The amount of RNA varies from cell to cell in an organism and within a cell according to metabolic activity.	The amount of DNA is constant for all cells of a species except gametes and spores.
RNA may temporarily exist for short periods.	DNA exists permanently throughout the organism's life.
There are three basic forms of RNA which include mRNA, tRNA, and rRNA.	Only one basic form of DNA exists but with an almost infinite variety within that form.

GENE

A gene is a segment of DNA that specifies the structure of a protein during protein synthesis.
Thus a gene is a unit of heredity composed of DNA or it is a discrete particle forming part of a chromosome that determines a particular characteristic.

THE GENETIC CODE

- All cells in an organism contain all the information required to determine the characteristics of that whole organism. This information is stored in DNA and it is known as the **genetic code.**
- The genetic code is a means by which the genetic information in DNA controls the manufacture of specific proteins by the cell.
- The code takes the form of a series of triplets of bases in DNA from which it is transcribed a complementary sequence of codons in the mRNA. The sequence of these codons determines the sequence of amino acids during protein synthesis.
- The genetic code is held in the order of bases along the DNA molecule.
- Sections of DNA called **cistrons** (commonly referred to as genes) contain the information needed to make a particular polypeptide.
- When the DNA in the cistron is activated, the information is transferred to a molecule of messenger RNA which acts as a template for the synthesis of the polypeptide.
- A template is any molecule that acts as a pattern for the synthesis of anew molecule.

A triplet of nucleotides within a molecule of mRNA functions as a unit of genetic coding usually by specifying a particular amino acid during the synthesis of proteins; and this is called a **codon.**

NB: A **codon** is a triplet of bases represented in the mRNA that specify a particular amino acid.

An **anticodon** is a group of three bases next to each other on the transfer RNA molecule that pairs with a complementary codon of 3 bases on the messenger RNA molecule.

Features of the genetic code

1. The code is a **triplet** code of three nucleotides in which each of the 20 amino acids used to make proteins is represented by a three letter abbreviation (a base triplet).
2. The code is **linear** reading from a starting 5' end to a finishing 3' end point directions.
3. The code is **degenerate** i.e there are more codons than the amino acids, and as such, most of the amino acids are coded for by more than one codon. For example CCA, CCC, CCG and CCT all code for the same amino acid proline. The first two bases of the code are more important than the third base in specifying a particular amino acid.
4. The **start** and **end** of the coding sequence in a cistron is determined by specific codons. Thus the genetic code is punctuated by the start codon which is **AUG** for methionine amino acid; and the three stop codons which are **UAA, UAG** and **UGA**.

   NB: The stop codons cannot code for any amino acid and therefore there are no anticodons that complements them.
5. The code is **universal** in that the same triplets code for the same amino acids in all organisms.

6. The genetic code is **non-overlapping** in which each triplet in DNA specifies one amino acid and each base is part of only one triplet and therefore involved in specifying only one amino acid.
7. The code is **comma-less;** this means that no codon is reserved for punctuations. After one amino acid is coded, the second amino acid will be automatically coded by the next three letters that means no letters are wasted as punctuation marks
8. The code is **non-ambiguous**; in this a particular codon will always code for the same amino acid. No codon will ever code for two different amino acids.

REASONS WHY THE GENETIC CODE IS TRIPLET

- Proteins almost have infinite variety. This variety likewise depends on upon a sequence of amino acids in the protein.
- There are just 20 amino acids which regularly occur in proteins, each of which has its own code of bases on DNA.
- With only ***four*** different bases, if each coded for a different amino acid, only four amino acids could be coded for (4^1).
- Using a ***pair*** of bases, 16 codes are possible thus 16 different amino acids could be coded for (4^2) which are still inadequate.
- Using a ***triplet*** of bases produces 64 codes are possible (4^3), these are more than enough to satisfy the requirements of 20 amino acids and thus the code is triplet

Table of genetic code showing the base sequences of the triplet code in mRNA and the amino acids for which they code

FIRST BASE	SECOND BASE: U	SECOND BASE: C	SECOND BASE: A	SECOND BASE: G	THIRD BASE
U	UUU: Phenylalanine	UCU: Serine	UAU: Tyrosine	UGU: Cysteine	U
	UUC: Phenylalanine	UCC: Serine	UAC: Tyrosine	UGC: Cysteine	C
	UUA: Leucine	UCA: Serine	UAA: Stop	UGA: Stop	A
	UUG: Leucine	UCG: Serine	UAG: Stop	UGG: Tryptophan	G
C	CUU Leucine	CCU: Proline	CAU: Histidine	CGU: Arginine	U
	CUC: Leucine	CCC: Proline	CAC: Histidine	CGC: Arginine	C
	CUA: Leucine	CCA: Proline	CAA: Glutamine	CGA: Arginine	A
	CUG: Leucine	CCG: Proline	CAG: Glutamine	CGG: Arginine	G
A	AUU: Isoleucine	ACU: Threonine	AAU: Asparagine	AGU: Serine	U
	AUC: Isoleucine	ACC: Threonine	AAC: Asparagine	AGC: Serine	C
	AUA: soleucine	ACA: Threonine	AAA: Lysine	AGA: Arginine	A
	AUG: Methionine	ACG: Threonine	AAG: Lysine	AGG: Arginine	G
G	GUU: Valine	GCU: Alanine	GAU: Aspartic acid	GGU: Glycine	U
	GUC: Valine	GCC: Alanine	GAC: Aspartic acid	GGC: Glycine	C
	GUA: Valine	GCA: Alanine	GAA: Glutamic acid	GGA: Glycine	A
	GUG: Valine	GCG: Alanine	GAG: Glutamic acid	GGG: Glycine	G

CENTRAL DOGMA OF MOLECULAR BIOLOGY

The relationship between DNA, mRNA and polypeptides in eukaryotic cells is called the **central dogma of molecular biology**, which states that: "The genetic information is transferred from **DNA to DNA** during transmission from generation to generation and from **DNA to RNA** for protein phenotypic expression in an organism".

- Thus mRNA is made is made on a DNA template in the nucleus in a process called **transcription.**
- The mRNA then moves into the cytoplasm where it combines with ribosomes to direct protein synthesis in a process called **translation**.
- When the information in a cistron is used to make a functional polypeptide chain by transcription and translation, then gene expression (phenotypic expression) is said to have taken place.

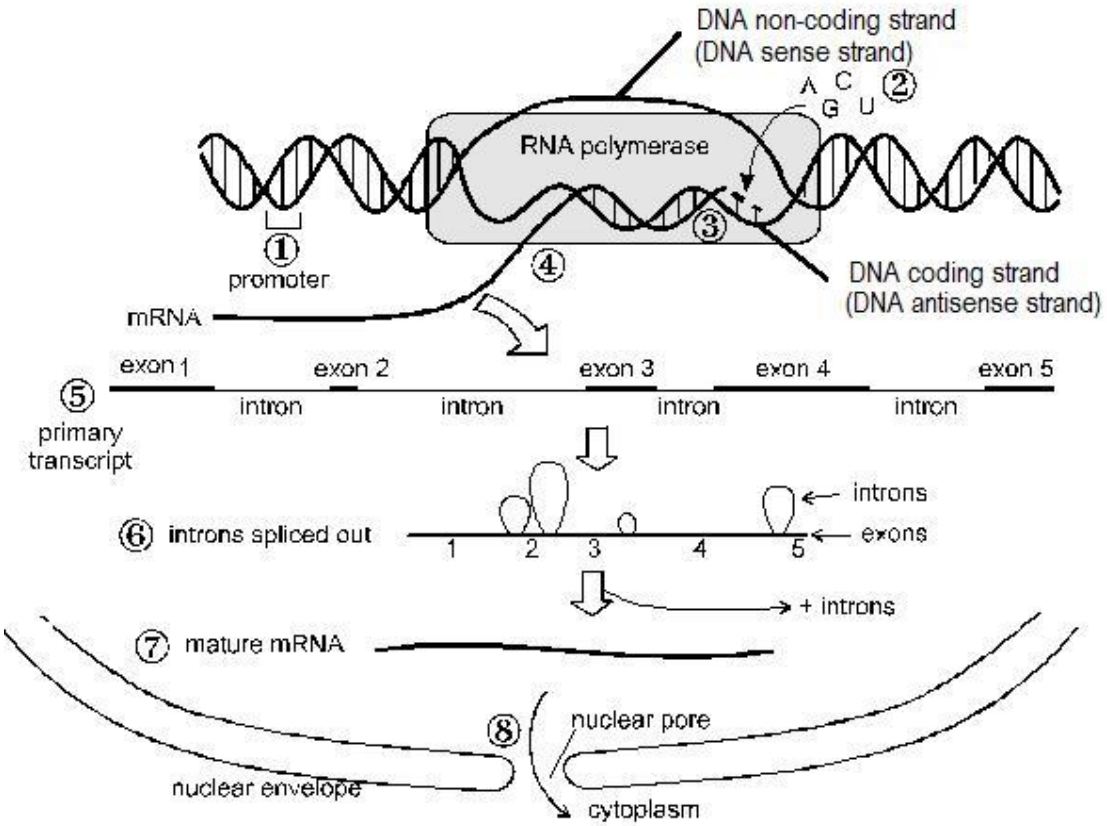
PROTEIN SYNTHESIS

- ✓ This is the process by which living cells manufacture proteins from their constituent amino acids in accordance with the genetic information carried in the DNA of the chromosomes.
- ✓ This information is encoded in the mRNA which is transcribed from DNA in the nucleus of the cell.
- ✓ The sequence of amino acids in a particular protein is determined by the sequence of nucleotides in mRNA. At the ribosomes, the information carried by mRNA is translated into the sequence of amino acids of the protein in a process called **translation**.
- ✓ DNA instructs protein synthesis on the basis of **one gene one polypeptide hypothesis** which states that each gene is responsible for the synthesis of a single polypeptide.
- ✓ The process generally involves two stages including **transcription** and **translation.**

TRANSCRIPTION

- ☑ This is the process by which a complementary mRNA copy is made from the specific region of DNA molecule which codes for a specific polypeptide.
- ☑ Transcription involves a specific region of DNA molecule called **cistron** unwinding, by which hydrogen bonds holding the double helix together are broken by the enzyme **helicase,** exposing the bases in the transcribing strand.
- ☑ **RNA polymerase** enzyme attaches to the transcribing strand at a particular base sequence called the **promoter site** which is always a triplet **TAC** initiating transcription.
- ☑ RNA polymerase moves along the transcribing DNA strand adding one complementary RNA nucleotide at a time to the newly unwound portion of DNA in the direction of 5' to 3'.
- ☑ When the enzyme moves onto another region of the transcribing DNA strand, the double helix of DNA reforms behind it; thus DNA acts as a template against which mRNA is constructed.
- ☑ On reaching a specific stop sequence called **terminator,** the enzyme detaches and the mRNA molecule peels away from the DNA.
- ☑ **Introns** ; a sequence of nucleotides between the cistrons which do not code for amino acids are removed, and the remaining sections of mRNA called **exons;** sections of nucleotides that code for amino acids are spliced together to form the final strand of mRNA.
- ☑ The mRNA molecule leaves the nucleus through the nuclear pores into the cytoplasm.

Ilustration of transcription



Or illustration in understanding biology page 117 fig 7.11

TRANSLATION

- This is the process by which information encoded within the mRNA is used to make a specific polypeptide chain in the cytoplasm.
- A group of ribosomes become attached to mRNA to form a structure called a **polyribosome** or **polysome.**
- Each ribosome has two tRNA binding sites i.e the decoding site A (amino acyl site) and the condensing site P (Peptidyl site).
- A site binds the incoming tRNA amino acid complex, and the P site binds to the tRNA to which the growing polypeptide is attached.

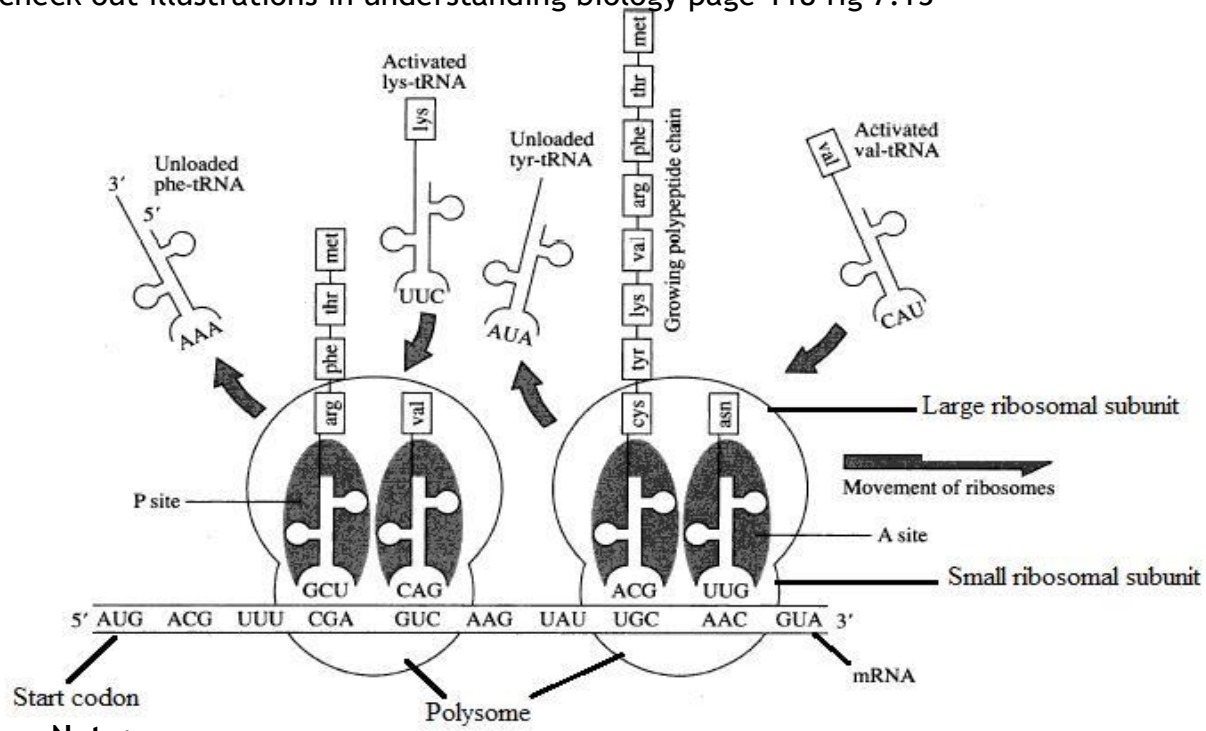
Translation process consists of the following steps

- ✓ Activation of amino acids.
- ✓ Transfer of activated amino acids to tRNAs.
- ✓ Initiation of polypeptide chain synthesis.
- ✓ Elongation of polypeptide chain.
- ✓ Termination of polypeptide chain.
- × The amino acids in the cytoplasm are activated by ATP in the presence of **aminoacyl tRNA synthetase** enzyme making them collide with specific tRNA molecules to form tRNA amino acid complexes called **aminoacyl tRNA**.
- × The complementary anticodon of a tRNA amino acid complex is attracted to the first codon of mRNA to initiate polypeptide chain synthesis.
- × The start codon on mRNA is always AUG, so tRNA with anticodon UAC enters the A site carrying amino acid methionine which in many cases does not remain permanent part of the finished protein.

- The second codon on mRNA likewise attracts its complementary anticodon on the second tRNA amino acid complex. When the second codon attracts the second tRNA amino acid complex, the methionine tRNA complex is moved and bound to the P site making the A site available for the second tRNA. This is known as **translocation.**
- Translocation involves movement of tRNA molecules from the A to P sites and movement of the mRNA exactly three nucleotides or movement of the position of ribosomes so that the codon formerly located in the A site moves to the P site.
- A peptide bond is then formed between methionine and the second amino acid, a reaction catalysed by **Peptidyl transferase or synthetase** enzyme forming a dipeptide which de-touches from $tRNA_1$ but remaining attached to $tRNA_2$ carrying the dipeptide.
- $tRNA_1$ is released into the cytoplasm and $tRNA_2$ carrying the dipeptide moves and shifts from the A site to the P site leaving the A site available for the third tRNA amino acid complex.
- A peptide bond is again formed between the dipeptide and the third amino acid to form a tri-peptide and $tRNA_2$ is then released into the cytoplasm.
- The process occurs until the termination codon or stop codon is reached, and the process is terminated with the polypeptide chain released in the cytoplasm to perform a functional role in the metabolism. The stop codons are always UAA, UAG and UGA.

Illustration of translation

Or check out illustrations in understanding biology page 118 fig 7.13



Note:

The polypeptide formed undergoes several modifications in which the amino acid methionine is removed and the polypeptide processed further to achieve its native biological structure forming either a primary structure, secondary structure, tertiary structure, tertiary structure or quaternary structure.

NB: Animals usually obtain their amino acids from the food they ingest, although they have some capacity to synthesise their own non-essential amino acids.

In plants, the formation of amino acids occurs in the mitochondria and chloroplasts in a series of stages:

- Absorption of nitrates from the soil.
- Reduction of these nitrates to the amino group (NH_2)
- Combination of these amino groups with a carbohydrate skeleton eg α-ketoglutarate from the Kreb's cycle).

Transfer of the amino groups from one carbohydrate skeleton to another by a process called **transamination.** In this way, all the 20 amino acids can be formed.

CHROMOSOME

The chromosome structure depends upon the complexity of an organism. There are two levels of complexity and two types of chromosomes:

1. **Prokaryotic chromosomes:**

Prokaryotes have simple chromosomes but with a naked structure. Simple chromosomes are also found in chloroplasts, mitochondria of higher plants, blue green algae (cyanophyta).

2. **Eukaryotic chromosomes:**

They are in higher plants and animals. Each cell contains several pairs of chromosomes. The chromosomes are large and they change their form and structural organization at different stages of the cell cycle.

Each chromosome is made up DNA and an equal quantity of protein weight by weight. The DNA protein complex found in chromosomes is known as nucleoprotein or chromatin.

Note: each chromosome is seen to consist of two threads called chromatids that are joined at a point called **centromere.**

Detailed structure of a chromosome in understanding biology page 135 fig 8.2

Proteins in a chromosome

There are two types:

1. **Histones:**

These are basic or non-acidic proteins that form the back bone structure of a chromosome on which the DNA is wrapped. The back bone structure of the chromosome on which the DNA is wrapped is called **octamer.** The types of histones are H_1, H_2A, H_2B, H_3 and H_4.

2. **DNA:**

Eukaryotic chromosomes contain double helical DNA in large quantities.

I thank you very much for you have been able to understand nucleic acids in detail. We have discovered that there are a variety of nucleic acids but only DNA and RNA were considered in this we were able to discuss the structure of DNA and RNA. We gave the distribution, compared the two and as well looked at the applicability of them in protein synthesis.

Having known this you should know that nowadays questions that require comparison of stages under the same process are common such as translation and transcription and it will be to your benefit if you practice answering them.

You can try out the questions on the next page

1. a) Compare DNA transcription with translation
   b) Explain briefly the advantages and disadvantages of the universality of the genetic code to humans.
2. Compare the processes of DNA replication and transcription
3. a) How does DNA regulate the synthesis of proteins?
   b) Outline the role played by the different types of RNA in protein synthesis.
4. a) describe how DNA replicates according to semi conservative hypothesis
   b) Outline the events that occur during the following processes:
      i. transcription
      ii. Translation.
5. a) describe the structure of DNA
   b) Explain the properties of the genetic code
   c) Explain why the genetic code is triplet.
6. a) compare DNA and RNA molecules.
   b) Describe the role of mRNA and tRNA in protein synthesis in a cell.
7. Describe the process of protein synthesis.

CELL DIVISION

This is the process by which new cells are derived from pre-existing ones.
There are two basic types of cell division;
Mitosis; this results in the daughter cell having the same number of chromosomes as the parent cell.
Meiosis; this results in the daughter cell having only half the number of chromosomes found in the parent cell.
It should be noted that cells in division undergo a regular pattern of events known as the cell cycle.

THE CELL CYCLE

The cell cycle is divided into two basic parts,
1. **Interphase**, which is divided into: Gap 1 phase (G 1), Synthesis phase (S), and Gap 2 phase (G 2).
2. **Mitosis phase (M),** which is sequenced as Prophase, Metaphase, Anaphase and Telophase.

INTERPHASE.
This is a stage when the cell undergoes a period of intense chemical activity
A dividing cell spends about 90-95 % of time in interphase.
G1 phase:
- ✓ Occurs before DNA synthesis.
- ✓ Cell increases in mass and organelle number.
- ✓ Organelles are synthesized such as mitochondria, cytoskeletal elements, endoplasmic reticula, ribosomes, Golgi apparatus, and cytosol.
- ✓ Centriole replication starts but is completed in G2.
- ✓ All chromosomes exist in single-chromatid form as they are uncoiled.
- ✓ Biochemical are produced such as energy stores

S phase:
- ✓ DNA replicates.
- ✓ Chromosome content doubles.

- ✓ Each chromosome replicates into two identical sister **chromatids** joined at **kinetochores**.
- ✓ Histones and other nuclear proteins are synthesized.

G2 phase:

- ✓ Occurs after DNA synthesis, before the start of mitosis.
- ✓ There is more protein synthesis
- ✓ Completion of centriole replication
- ✓ ATP synthesis occurs and thus energy stores are increased
- ✓ Cell size increases
- ✓ Errors in replicated chromosomes are corrected.

MITOSIS

Type of nuclear division whereby one diploid or haploid parent cell produces two genetically identical daughter cells each with same chromosome number like the parent cell.

Prophase: make illustrations aside and compare yours with those on the next page

- ➢ Changes occur in both the **cytoplasm** and **nucleus**
- ➢ Chromatin **condenses** into discrete chromosomes.
- ➢ Centrioles move towards poles.
- ➢ Chromosomes begin to migrate toward the cell centre.
- ➢ Nuclear envelope breaks down
- ➢ Spindle fibers begin to form at opposite poles of the cell.
- ➢ Nucleolus fades.

Metaphase:

- ➢ Nuclear membrane disappears completely.
- ➢ Centriole pairs reach the poles
- ➢ Spindle fully develops
- ➢ Chromosomes condense further
- ➢ Chromosomes align at the metaphase plate

Anaphase:

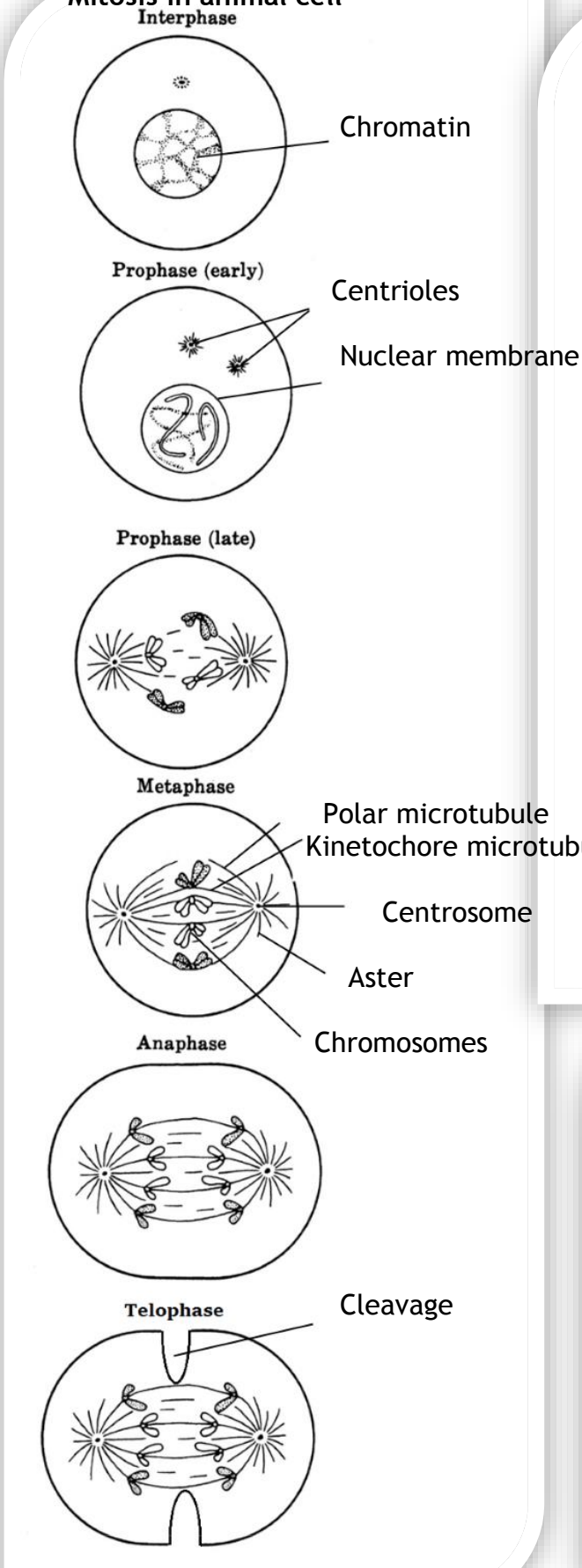
- ➢ Sister chromatids separate and orient towards opposite Poles.
- ➢ Chromatids make a “V” shape as the arms of the
- ➢ chromatid drag behind the centromere, which leads Towards its pole.
- ➢ Polar microtubule – which run from one centriole to another (without attachment to chromosomes) pull and
- ➢ Lengthen the cell. Therefore, the shape of animal cell Changes.

Telophase:

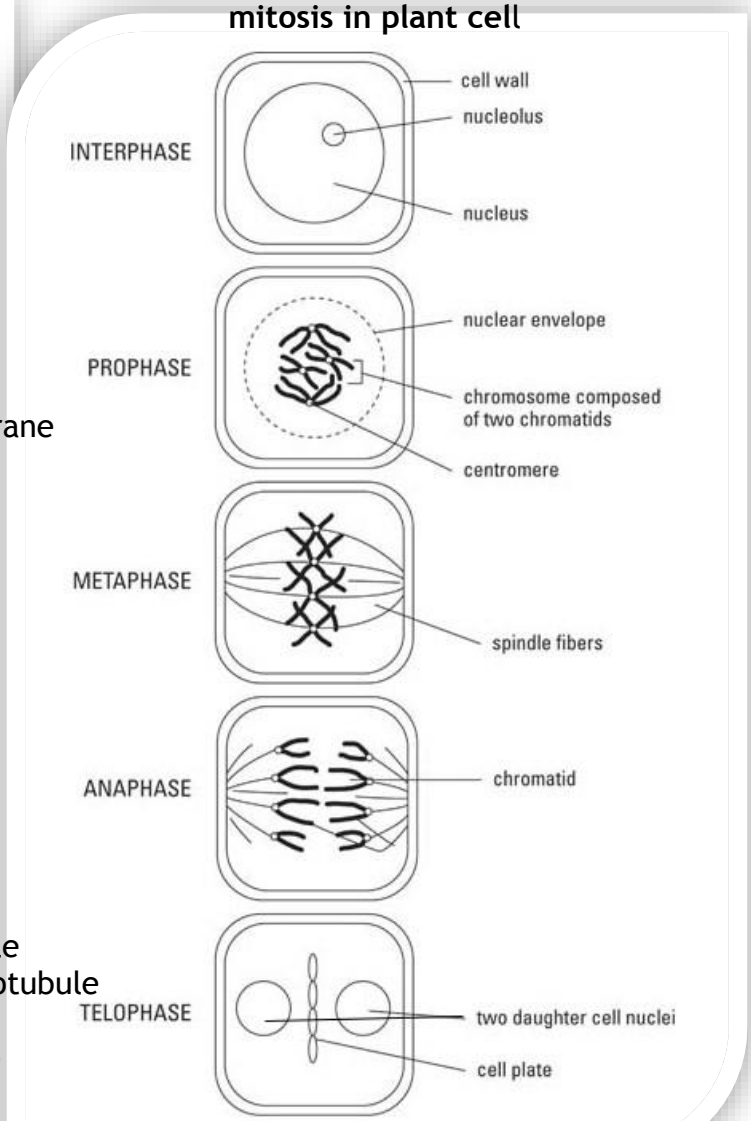
- ➢ Sister chromatids (now called Chromosomes) reach Opposite poles.
- ➢ Chromosomes de-condense
- ➢ Nucleolus begins to appear
- ➢ Nuclear envelope appears.
- ➢ Spindle disappears.
- ➢ Cell surface membrane folds in (invaginates) to divide the Genetic content of the cell equally into two parts.
- ➢ Cytokinesis begins prior to the end of mitosis and Completes shortly after telo-phase.

Illustrations of the cell cycle

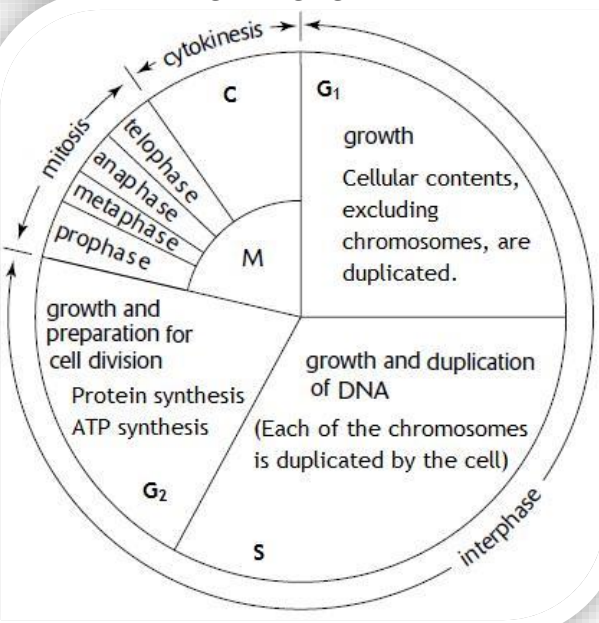
Mitosis in animal cell



mitosis in plant cell



CELL CYCLE



Or for the illustration about the cell cycle check out in understanding biology page 136 fig. 8.3 and page 137 fig.8.4



Now that you have looked at mitosis in plant and animal cells may you please compare the process in the cells? (**Hint**; give similarities and differences based on how the process occurs) **check** your answers.

Differences between mitosis in plant and animal cells

Mitosis in animal cells	Mitosis in plant cells
Occurs almost all over the body	Occurs at apical, lateral and intercalary meristems only.
Centrioles present	Centrioles absent
At telo-phase a contractile ring of actin and myosin forms half way between the two nuclei	At telo-phase a phragmoplast of actin, myosin, and microtubules forms at the future site of the cell wall
Cytokinesis occurs by cleavage	Cytokinesis occurs by cell plate method
Cell becomes rounded before division	Cell shape does not change before division
A furrow is formed between two daughter cells	A solid middle lamella forms between two daughter cells
Mitotic apparatus contains asters	Mitotic apparatus lacks asters
Spindle degenerates at cytokinesis	Spindle in form of phragmoplast persists at cytokinesis.
Several hormones induce cell division, not one specifically	It is induced by a specific hormone called cytokinin

Similarities between mitosis in plant and animal cells

It should be noted that in both;

- At metaphase, the chromosomes align at the equator
- At anaphase, chromosomes move towards opposite poles
- At telo-phase, the nuclear envelope appears again, chromosomes de-condense, and the spindle breaks down
- Spindle fibres form
- During Prophase, chromosomes condense
- Before metaphase, the nuclear envelope breaks down.
- Spindle attaches to chromosomes at centromeres

NOTE:

When talking about cytokinesis in plant cells it should hit your mind that we are going to use knowledge in formation of the cell wall that we discussed in the cell structure in the first sub topic on page 32 as follows

Cytokinesis in plant cells

This is the Cleavage of the cytoplasm of the parent cell into daughter cells following nuclear division.

- Cell wall forms during Telophase stage of cell division when the cell plate forms between daughter cell nuclei
- Cell plate forms from a series of vesicles produced by Golgi apparatus; dictyosomes.
- Vesicles migrate along the microtubules and actin filaments within the phragmoplast and move to the cell equator.

- Phragmoplast contains mitotic spindles, microtubules, micro filaments and endoplasmic reticulum surrounded by nuclear envelopes.
- Vesicles join up their contents and the membranes of the vesicle become the new cell membrane.
- Dictyosomes synthesize the non-cellulose polysaccharides like pectins and are transported to build the middle lamella.
- Cellulose is made at the cell surface by the catalytic activity of cellulose synthetase.
- While the cell plate is growing, segments of smooth endoplasmic reticulum are trapped within it, later forming the plasmodesmata.

CHANGES THAT OCCUR IN QUANTITY OF NUCLEAR DNA AND CELL MASS DURING CELL CYCLE

A cell cycle may take as little as **20 minutes** in a bacterial cell although it typically takes **8 to 24 hours**.
Within this time of 24 hours, there are various changes which occur as follows

Changes in Quantity of nuclear DNA

- DNA mass remains constant from 0 hour to 12 hours and this is because the cell is in the first growth (G1) phase in which the cell contents are synthesized except that DNA doesn't replicate it then,
- Increases rapidly to about 18 hours this is because the cell is in the synthesis (S) phase in which DNA replicates to double original mass and,
- Remains constant up to about 24 hours this is because the cell is in the second growth (G2) phase in which no DNA synthesis takes place and as well the cell is undergoing some mitosis and,
- Finally decreases suddenly to original mass at about 24 hours and this is because cytokinesis occurs halving the DNA mass in each new cell to the original mass.

Changes in cell mass

- ✓ From 0 hour to 24 hours, Cell mass increases rapidly because this period marks the period of interphase and mitosis**;** during which organelles like mitochondria, cytoskeletal elements, endoplasmic reticula, ribosomes, Golgi apparatus, centriole, etc replicate and increase in number**;** and the cell grows (***G1 phase***)**;** DNA replicates**;** and the chromosome content doubles**;** histones and other nuclear proteins are synthesized (***S phase***)**,** Synthesis of additional proteins that support cell metabolism occurs (***G2 phase***)**.**
- ✓ At 24 hours cell mass decreases suddenly to original mass because cytokinesis divides the parent cell into equal sized daughter cells.

SIGNIFICANCE OF MITOSIS

Note: The significance of mitosis is based on majorly three factors; growth, repair, asexual reproduction**.**

- ❖ During growth in multicellular organisms, the number of cells within an organism increases by mitosis.
- ❖ Enables cell replacement when old cells die or get damaged.
- ❖ Maintains genetic properties of new cells when damaged tissues are repaired hence retains normal function of cells.
- ❖ Enables regeneration of body parts in some animals e.g. lizard tails.
- ❖ Produces a clone of offspring; genetically identical to parents during vegetative reproduction in some plants.

MEIOSIS

- Type of nuclear division whereby one diploid parent cell produces four genetically non-identical daughter cells each with chromosome number half that of the parent(haploid).
- Meiosis is common in reproductive cells and due to this in m*ammals;* seminiferous tubules of testes in males and Ovaries of females and in f*lowering plants;* Anthers and Ovary of flowers

Meiosis comprises of two divisions;
Meiosis I; this is similar to mitosis except for a highly modified prophase stage.
Meiosis II; this typically a mitotic division

MEIOSIS I

1. **Interphase;** this is also known as the resting stage. In this the cell is in non-dividing condition in which it replicates its DNA and organelles.

Many cases this stage is not considered to be the first in meiosis I but instead prophase I due to the state of the cell being non-dividing.

2. **Prophase I;** It is the longest phase, taking 90% of the time for meiosis and is divided into five sub-divisions:
   - **Leptotene;** chromosomes condense as mass of long coiled threads and spindle starts to form



   - **Zygotene;** nucleolus has disappeared, homologous chromosomes pair to form bivalents and this is called synapsis



   - **Pachytene;** homologous chromosomes shorten and thicken.



   - **Diplotene;** each chromosome now appears as 2 sister chromatids, homologous chromosomes begin to repel each other, breaks occur in opposing non-sister chromatids to cause **crossing over.** Crossing over is the **exchange or swapping** of genetic material between non-sister homologous chromatids. A point of crossover is called a chiasma.

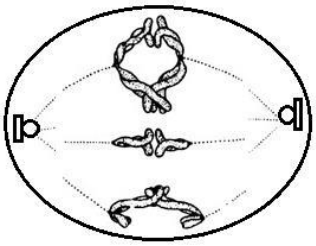


   - **Diakinesis;** homologous chromosomes unwind as repulsion continues, centromeres are the repulsion centres, chromosomes are held together until they align at the equator, nuclear envelope breaks down



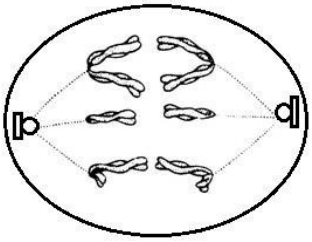
More illustrations in understanding biology page 142.

3. **Metaphase I**



- ✓ The bivalents arrange themselves on the equator of the cell with each of a pair of homologous chromosomes oriented to opposite poles.
- ✓ Microtubules attach to the kinetochore of each homologous pair.
- ✓ The spindle fibres attached to the centromeres at the kinetochore contract slightly, pulling the chromosomes apart as much as the chiasma allows.
- ✓ Centrioles are at opposite ends of the cell.

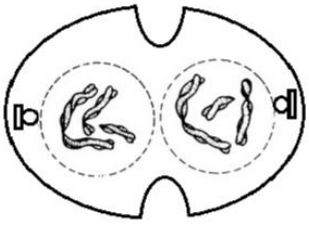
4. **Anaphase I**



- ✓ The spindle fibres which are attached to the centromeres contract and pull the homologous chromosomes apart. One of each pair is pulled to the one pole its sister chromatid to the opposite one.

5.

5. **Telophase I**

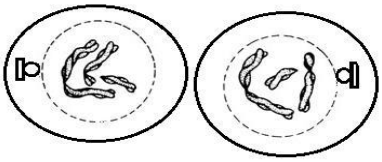


- ✓ Chromosomes reach their own poles.
- ✓ Nuclear membrane forms around each chromosome set.
- ✓ Spindle fibre disappears, cytokinesis follows.
- ✓ In animal cells, a cleavage furrow pinches the cell into two.
- ✓ Daughter nuclei contain haploid chromosomes but each chromosome will have two chromatids.

Note: the nucleus may enter interphase although no replication of DNA takes place. In some cells this stage does not occur and the cell passes from anaphase I directly into prophase II.

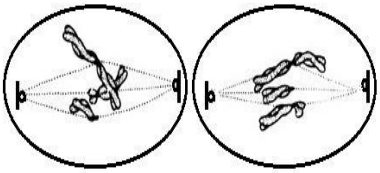
MEIOSIS II

1. **Prophase II**



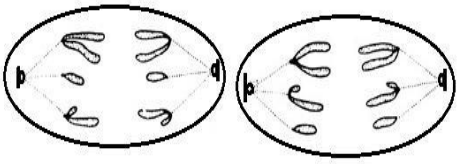
- ○ Nuclear envelope breaks, spindle develops.
- ○ Centrioles duplicate and move to opposite poles.
- ○ The poles are at right angles to the plane of the
- ✓ previous cell division.
- ✓ Spindle start to form, usually at right angles to the spindle axis in meiosis I.

2. **Metaphase II**



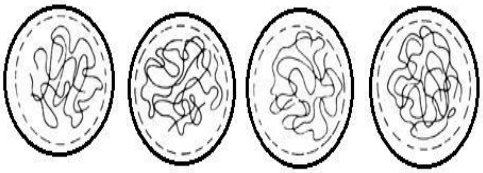
- ✓ Single chromosomes align on metaphase plate.
- ○ Spindle apparatus for both daughter cells are formed. Kinetochore microtubules attach to kinetochores of each sister chromatid.

3. **Anaphase II**



- ○ Chromosomes are pulled apart into two chromatids towards opposite ends by the microtubules of
- ✓ spindle apparatus.
- ○ The centromeres separate.

4. **Telophase II**



- ○ The chromatids unwind and become distinct.
- ✓ Nuclear envelope surround each chromosome set.
- ○ Nucleolus reform.

- ✓ Spindle disappears.
- ○ Cytokinesis occurs, forming 4 haploid daughter cells collectively called **tetrad** which are genetically non-identical due to crossing-over during Prophase I.

NOTE: also the bivalents in prophase I can be called tetrads as they contain two homologous chromosomes each composed of two sister chromatids

More illustrations in understanding biology page 141 fig 8.6

Significance of meiosis

- × It is important in formation of gametes.
- × It halves the chromosome number to ensure that the total number is restored during fertilization.
- × It introduces variations within cells through crossing over during prophase I these variations are crucial in enabling the organism colonize a range of habitats.
- × It results into rapid multiplication of cells since four cells are produced in a single division.
- × Since it occurs in reproductive cells, it results into varied offspring during sexual reproduction. This provides a basis for natural selection, which ensures evolution of the species.

Ways through which variety is brought about in organisms by meiosis

1. **Production and fusion of haploid gametes**; variety of the offsprings is increased by mixing the genotype of one parent with that of the other. Since each gamete contains half the number of chromosomes of the adult, if the chromosomes from different adults fuse, it brings about variety thus it permits variety in organisms giving them potential to evolve. The number of possible combinations of maternal and paternal homologues is $\mathbf{2^n}$, where **n** = the haploid number of chromosomes. In humans it produces $\mathbf{2^{23}}$**, 8,388,608** different combinations of chromosomes these are more than expected.

2. **The creation of genetic variety by the random distribution of chromosomes during metaphase I**; when the pairs of homologous chromosomes arrange themselves at the equator of the spindle, they do so randomly. The random distribution and consequent independent assortment of these chromosomes produces new genetic combinations.
3. **The creation of genetic variety by crossing over between homologous chromosomes**; during prophase I of meiosis, equivalent portions may be exchanged. In this way, new genetic combinations are produced and linked genes are separated.
   With this there are many individuals that have varied phenotypes which permits natural selection to take play selecting those best suited to the existing conditions and so ensures that species constantly change and adapt to the condition prevailing. This is a basis for evolution.

Illustration of crossing over

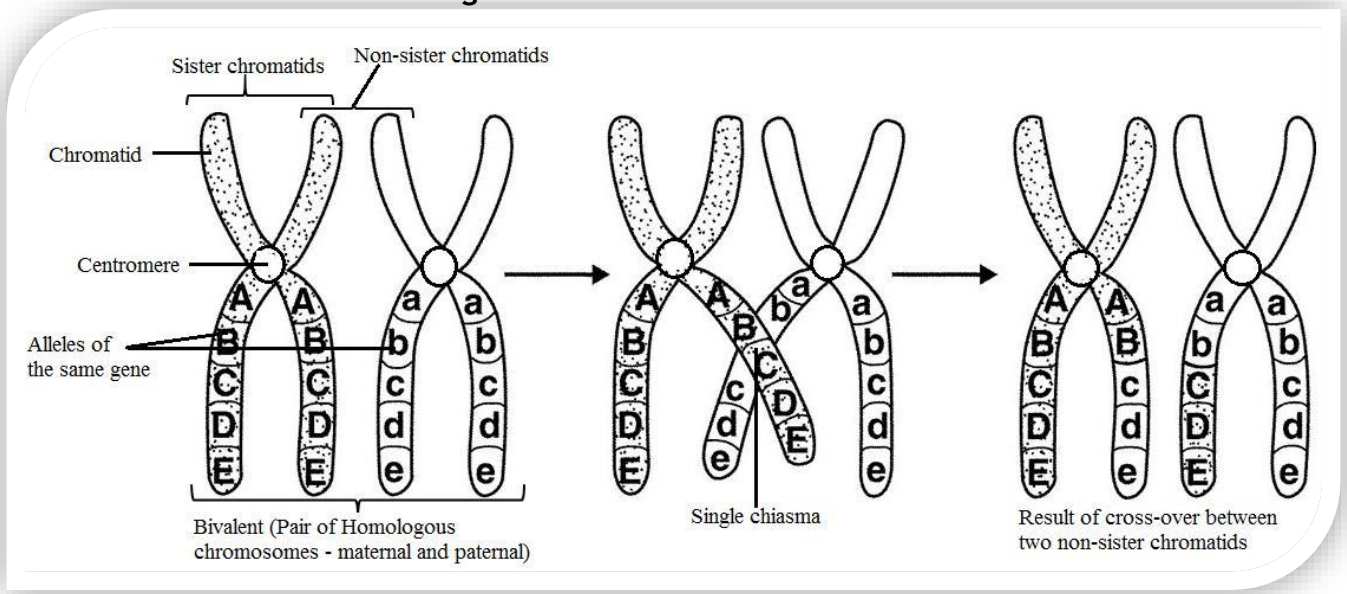
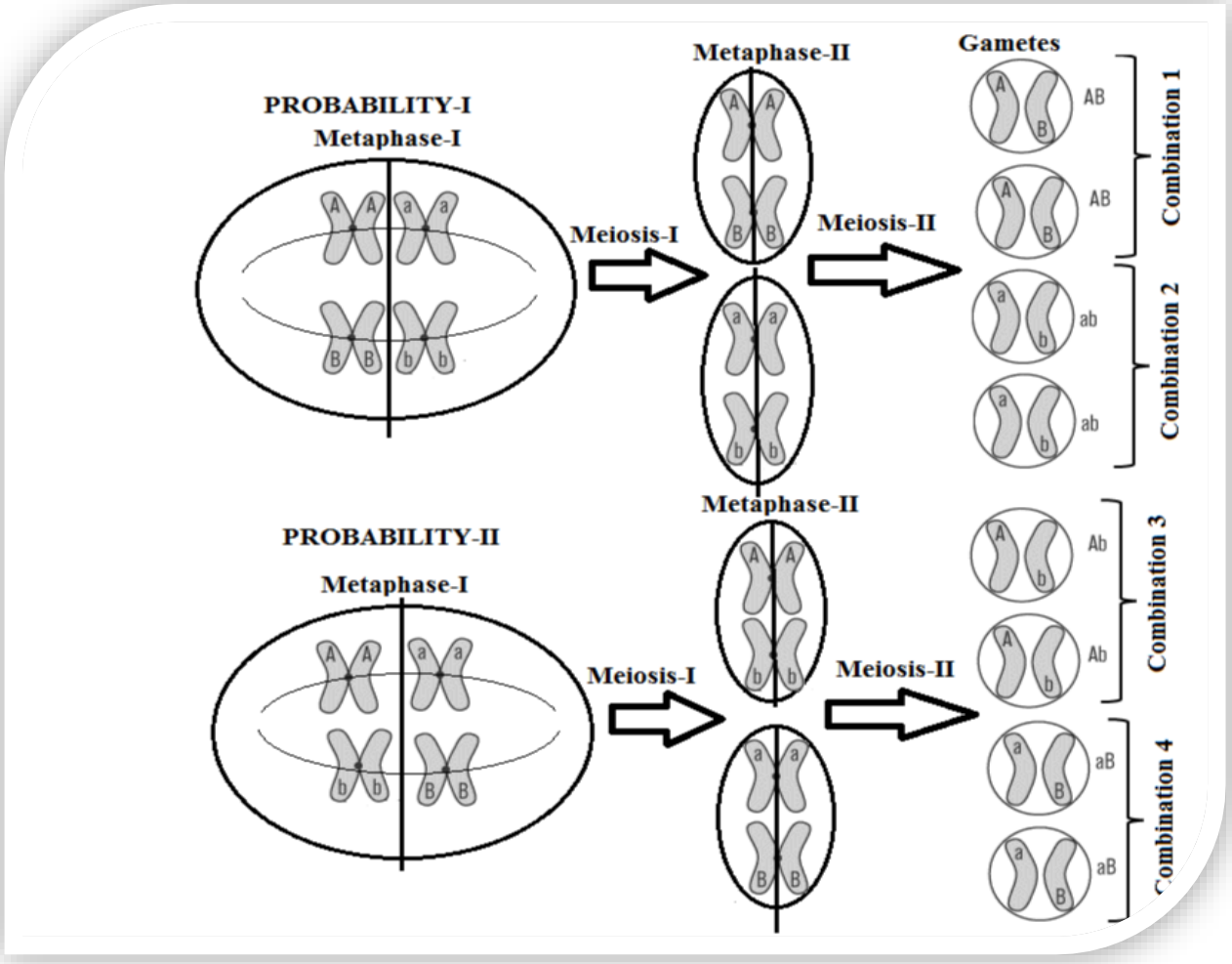


Illustration of independent assortment and random segregation



For more illustrations about how variety is brought about by meiosis check out in understanding biology page 145 fig. 8.7



Now that you are well versed with mitosis and meiosis can you please make a comparison between the two processes? **Check** your answers.

COMPARISON OF MEIOSIS AND MITOSIS

Similarities;

- ✓ Involve cytokinesis to form daughter cells from a parent cell.
- ✓ Follow the same fundamental sequence of events i.e. Interphase, prophase, metaphase, anaphase and telo-phase.
- ✓ Include the breakdown of the nuclear membrane during prophase.
- ✓ Involve the separation of genetic material into two groups, followed by cell division.
- ✓ Involve the reformation of the nuclear membrane in each cell during telo-phase.
- ✓ Involve alignment of chromosomes on metaphase plate

Differences;

MITOSIS	MEIOSIS
A single division of chromosomes and nucleus	A single division of the chromosomes but a double division of the nucleus
Number of chromosomes remains the same	Number of chromosomes is halved
Homologous chromosomes do not associate/ no synapsis	Homologous chromosomes associate to form bivalents in prophase I/ synapsis
Chiasmata are never formed	Chiasma may be formed
Crossing over never occurs	Crossing over may occur
Daughter cells are identical to the parents	Daughter cells are genetically different from the parental ones.
Two daughter cells are formed	Four daughter cells are formed
Chromosomes shorten and thicken	Chromosomes coil but remain longer than in mitosis
Chromosomes form a single row at the equator of the spindle	Chromosomes form a double row at the equator of the spindle.
Chromosomes move to opposite poles	Chromosomes move to opposite poles during the first meiotic division.
Diploid cells are produced	Haploid cells are produced
Cytokinesis occurs once	Cytokinesis occurs twice
Occurs in somatic cells	Occurs in reproductive cells



Could you think of some more?

I thank you so much for we have been able to understand cell division in detail. We have seen that two types of cell division exist i.e mitosis and meiosis. We went into detail of each process and further so the advantaged of cell division in organisms putting in mind both processes. Furthermore we looked at hoe meiosis brings about variation that is basis for evolution and concluded by comparing mitosis and meiosis.
Thank you can now try out questions on the next page

END OF SUB TOPIC AND AS WELL TOPIC CELL BIOLOGY THANK YOU

1. Explain the significance of meiosis in causing genetic variation.
2. (a) Give an account of mitosis in an animal cell.
   (b) Compare mitotic anaphase and anaphase I of meiosis.
3. How is genetic variation achieved in organisms?
4. Outline the events involved in nuclear division during meiosis I.
5. State the stages of meiosis where the following occurs.
(i) Crossing over.
(ii) Synapsis.
(iii) Independent assortment.
(iv) Cytokinesis.
(b) State the role of genetic variation in organisms.
6. a) Describe the main features of the 2^{nd} meiotic division
   (b) What is the importance of meiotic division?
7. How does the behavior of chromosomes in mitosis differ from that in the 1^{st} meiotic division?
8. a) outline the function of the cell nucleus.
   (b) Describe the changes that occur in the nucleus during meiosis.
   (c) Explain the significance of meiosis and mitosis in organisms.
9. Give an account of meiosis in a reproductive cell. (Diagrams not required)

2. CHEMICALS OF LIFE

All organisms are made up of inorganic and organic compounds that required for proper functioning these are known as chemicals of life.

Inorganic chemicals	Organic chemicals
Water	Carbohydrates
Acids , bases, salts	Lipids
Mineral salts	Vitamins
Gases	Proteins

MINERAL SALTS

Minerals are the elements which are present in small amounts. About 4% of human body weight constitute minerals.

They play important role in metabolism of body.

Categories of minerals: there about 25 types of element found in the body. On the basis of their amount required by body, these are grouped into 2 categories:

i. **Macro elements:** These are required in large amount (more than 1gm). These include Calcium, Magnesium, potassium, and sodium, Chlorine, Sulphur and Phosphorous and iron

ii. **Micro elements:** these are required only in small amounts (less than 1 gm). These are also known as trace elements. These includes Copper, Chromium, Zinc, Se, molybdenum, Manganese, Iodine, Fluorine, cobalt etc.

MACRO ELEMENTS:

a) **Calcium-** It is found mainly in dairy products, egg, wheat germ, and dark green vegetables. It is useful for the formation of bone and teeth.
   It helps in blood clotting and keeps muscles and nerve activity normal. Its deficiency causes rickets and muscle spasms and in plants causes death of growing points
b) **Magnesium-** Its main sources are dairy products, cereals, green leafy vegetables, seafood, chocolate, and wheat germ. It helps in release of energy. It also acts as catalyst. It helps in muscle relaxation and keeps nerves relaxed. Its deficiency causes convulsion and hallucinations and in plants its deficiency leads to chlorosis.
c) **Potassium:** It is found in most of fruits and vegetables, and wheat germ. It is important for normal muscle and nerve activity. It is an alkalinizing agent and hence prevents acidosis. Its deficiency causes muscle disorders including cardiac muscle and nerves.
d) **Sodium-** its main sources are table salt, food, and wheat germ. It works with potassium. It maintains pH balance of body fluid. It helps in muscle activity and transmission of nerve impulses. Its deficiency causes cramps, diarrhoea and dehydration.
e) **Chlorine-** it is found in salt, seafood vegetables, and chlorinated water. It is essential for pH balance of body fluid.
f) **Sulphur**- its sources are meat, dairy products and eggs. It is essential for synthesis of vitamin B1 and essential for healthy for healthy hairs, skin, nails. Its deficiency may interfere with healthy growth of hair and nail.

g) **Phosphorus-** its sources are meat, fish, egg, dairy product and wheat germ. It is important for formation of bone, teeth, and bio membranes and it keeps muscles and nerve activity normal.
It is a part of energy carriers (ATP, ADP, and AMP) nucleic acids (DNA, RNA) and coenzymes (NAD, NADP, FMN, FAD). Its deficiency causes loss of bone minerals and many metabolic disorders.

h) **Iron**- it is found in most meats, dried nuts, cereals, beans, honey, green leafy vegetables, etc. It is constituent of electron carriers such as cytochromes, needed in respiration and photosynthesis.
It's a constituent of some enzymes such as dehydrogenases, decarboxylases, peroxidases and catalase. Required in chlorophyll synthesis. Forms part of the haem group of respiratory pigments. Its deficiency in plants leads to chlorosis and anaemia in animals.

MICRO ELEMENTS:

a) **Chromium-** it is found in meat and animal proteins except fish, soybeans, carrots, brown nuts and tomatoes. It works with insulin in the metabolism of sugar. Its deficiency causes diabetes like problems.

b) **Cobalt-** it is obtain from milk, meats. It is a part of vitamin B_{12} which is important in synthesis of RNA, nucleoprotein and red blood cells and in the action of certain enzymes. Deficiency in animals causes pernicious anaemia.

c) **Copper-** it occurs in peanuts, beet, barley, soybeans, peas etc. it promotes utilizations of iron in the hemoglobin. It's a constituent of respiratory pigment haemocyanin. Its deficiency causes anaemia in animals and in plants young shoots die back at an early age.

d) **Fluorine-** it is found in fish, tea and in most city water supplies. It maintains healthy teeth. Its deficiency causes weak teeth which are prone to decay.

e) **Iodine**- it is found in iodized salt, seafood, drinking water, and onions. Iodine is a component of thyroxin hormone of thyroid gland which controls metabolism in animals. Its deficiency cause goiter.

f) **Manganese-** it is present in liver, nuts, legumes and wheat grams. It is important for normal reproduction, function of mammary glands and synthesis of hemoglobin. Its deficiency causes infertility. Spongy bones, menstrual problems and unpaired causes infertility, spongy bones menstrual problems and unpaired fat metabolism.

g) **Molybdenum**- it is present in wheat, black gram, peas, wheat, black grams, peas, cabbage etc. it is essential for the synthesis of hemoglobin and absorption of iron. In plants it's essential for the reduction of nitrate to nitrite in the formation of amino acids. Essential for nitrogen fixation by prokaryotes. Its deficiency causes some disturbances in iron metabolism and in plants reduced crop yields

h) **Zinc-** it is present in soybeans, black grams, wheat, groundnuts, coconut, onions, peas, almonds, milk and eggs. It is a co factors of many enzymes such a

carbonic anhydrate and alcohol dehydrogenase. It is also essential for metabolism of vitamin A and hastens healing of wounds.

- In plants it's required for leaf formation, synthesis of Indole acetic acid (auxin) and anaerobic respiration.
- Its deficiency in diet causes poor growth, slow sexual development, impaired wound healing.

For more, check table 2.1 in understanding biology page 10 and 11

ACIDS, BASES AND SALTS

ACIDS

- Acid is a substance that ionizes in aqueous solution to release hydrogen ions as the positively charged ions. It is a proton donor.
- The strength of an acid is determined by how easily it can release hydrogen ions into solution; strong acids ionize completely while weak acids partially ionize in aqueous solutions.
- Strong acids include hydrochloric acid, sulphuric acid etc. whereas weak acids include ethanoic acid, carbonic acid etc.

BASES

- A base is a substance that accepts protons from the acid. For example,
- Sodium carbonate dissociates and releases hydrogen carbonate ions.
- These ions accept protons from the acid. In this way, it neutralizes the hydrogen ions and thus it acts as a buffer.
- Even if moderate amounts of the base are added, it accepts the OH^- ions to form water and carbonate ions.

Salts; these are products of the reaction between acids and bases except water

Acids bases and salts are essential in buffering mechanisms within the body of an organism.

BUFFER

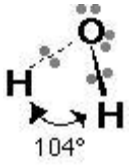
- This is a solution that can resist pH change upon the addition of an acidic or basic components. It is able to neutralize small amounts of added acid or base, thus maintaining the pH of the solution relatively stable.
- This is important for processes and or reactions that require specific and stable pH ranges.
- In the human body, many substances play a role in buffering the body. This is important to enable chemical reactions to proceed without alteration of pH.
- Phosphate salt is one of the salts used during the regulation of blood pH by the kidney. Organic substances like proteins and haemoglobin also accept ions.
- The biological importance of this is that cells and tissues can only function properly at round neutrality, they cannot tolerate fluctuations in pH.

WATER

Water has many useful properties, and so it is ubiquitous/found everywhere in life on earth. The useful properties of water arise from its structure.

STRUCTURE

- ☑ A Water molecule consists of two Hydrogen atoms covalently bonded to an Oxygen atom. Because oxygen is more electronegative than hydrogen, it has a greater pull on the shared electrons.
- ☑ Thus the oxygen atom is slightly negative (δ-) (because of the closer electrons), and hydrogen is slightly positive (δ+).
- ☑ Water is therefore called a Polar Molecule.



PROPERTIES OF WATER

- ✓ It is liquid at room temperature.
- ✓ It has a high heat capacity therefore much energy is used to raise its temperature because it is used to break the hydrogen bonds which restrict the mobility of the molecules. As a result water is relatively slow to heat up or to cool down thus a high heat capacity.
- ✓ Water expands as it freezes unlike other liquids which contract on cooling.
- ✓ Water reaches its maximum density above its freezing point at 4°C hence when water freezes, the ice formed is less dense than the water and hence floats on top of the surface. In this way, ice insulates water below making it less dense and able to float hence the water will be warmer than the air above.
- ✓ Water has a high surface tension. Surface tension is the force that causes the surface of a liquid to contract so that it occupies the least area. It is high due to the fact that molecules are oriented so that most hydrogen bonds point inwards towards other water molecules.
- ✓ It has a high latent heat of fusion i.e. much heat must be removed before freezing occurs.
- ✓ It has high adhesive and cohesive properties preventing it from breaking under tension.
- ✓ It is colourless and transparent.
- ✓ It has a low viscosity i.e. water molecules slide over each other very easily.
- ✓ It dissolves more substances than any other liquid i.e. it is a universal solvent.

FUNCTIONS OF WATER

- It is a component of cells.
- It is a solvent and a medium of transport.
- It is a reagent in hydrolysis.
- It enables fertilization by swimming gametes.
- It enables dispersal of seeds, fruits, gametes and larvae stages in aquatic organisms.
- It is important in transpiration in plants.
- It is important in translocation in plants.
- It enables germination to proceed by activating enzymes, transporting hydrolyzed stored food, swelling and breaking open the testa.
- It is involved in Osmo-regulation in animals.

- It enables cooling by evaporation as a result of sweating and panting.
- It is a component of lubricants at joints e.g. the synovial fluid.
- It offers support in hydrostatic skeleton.
- It offers protection as a component of mucus and tears.
- It enables migration to occur as a result of river flow or ocean currents.

RELATION BETWEEN THE PROPERTIES OF WATER AND ITS BIOLOGICAL FUNCTIONS

- Water is transparent and this allows light penetration in aquatic habitats to enable photosynthesis of aquatic autotrophs and visibility of aquatic animals.
- Water has a low viscosity and this allows for smooth flow of water and other dissolved substances in an aquatic medium for easy transport.
- It has a high surface tension providing support to aquatic organisms and allowing movement of living organisms on water surface.
- Has a high latent heat of vaporization hence a cooling effect on the body surface since evaporation of water from the body of an organism draws out excess heat.
- It has a high boiling point thus provides a stable habitat and medium since a lot of heat which is not normally provided in the natural environment is needed to boil the water.
- It has a high latent heat of fusion and hence a low freezing point thus providing a wide range of temperature for survival of aquatic organisms since it prevents freezing of cells and cellular components.
- It has a high specific heat capacity which minimizes drastic temperature changes in biological systems and provides a constant external environment for many plant cells and aquatic organisms.
- It has a maximum density at 4^{o}C hence ice floats on top of water insulating the water below hence increasing the chances of survival of aquatic organisms below the ice.
- Water is liquid at room temperature providing a liquid medium for living organisms and metabolic reactions and a medium of transport.
- It has high adhesive and cohesive forces creating enough capillarity forces for transport in narrow tubes of biological systems.
- It is a universal solvent hence providing a medium for biochemical reactions.
- Water is a polar molecule allowing solubility of polar substances, ionization or dissociation of biochemical substances.
- Water is incompressible thus providing support in hydrostatic skeleton and herbaceous stems.
- Water is neutral hence does not alter the pH of cellular components on their environment.
- A water molecule is relatively small for easy and fast transport across a membrane.



Think about more functions, properties of water in detail, and as well think about its detail in movement and support.

CARBOHYDRATES

- Carbohydrates consist of the following elements carbon, hydrogen and oxygen.

  They have a general formula of $C_n (H_2O)_y$ where **n** and **y** are integers. They are often shown as aliphatic or linear structures, but exist in nature as ringed structures. They are found as aldehydes or ketones derived from polyhydric alcohols.

Carbohydrates are grouped into

1. Monosaccharides
2. Disaccharides
3. Polysaccharides

MONOSACCHARIDES

These are simple sugars, which are the building block of all larger sugars. They cannot be hydrolyzed into simpler units.

Examples of Monosaccharides:

The most common monosaccharides maybe triose, pentose or hexose sugars.

Properties of monosaccharides

- They have a sweet taste
- They dissolve in water
- They are white crystals
- They have a low molecular mass
- Can pass through a selectively permeable membrane.
- They change the colour of benedict's solution from blue to orange when boiled with the solution thus they are known as **reducing sugars**.

Table showing some of monosaccharides

Hexose sugars	Triose sugars	Pentose sugars
Glucose	Glyceraldehyde	Ribose
Galactose	Dihydroxyacetone	Deoxyribose
Fructose		Ribulose
mannose		Xylose

HEXOSE SUGARS

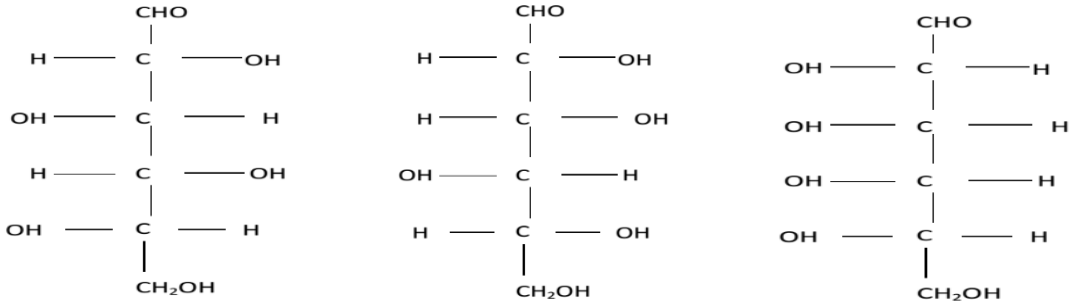
1. GLUCOSE

This is a form of simple sugar used by all cells. It's obtained from grapes & honey. Glucose is characterized by being sweet.

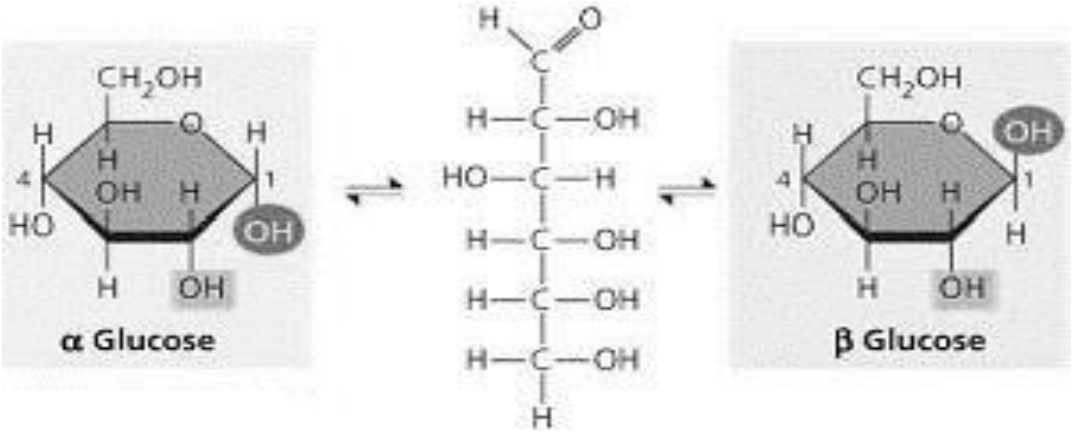
Chemical structure of glucose

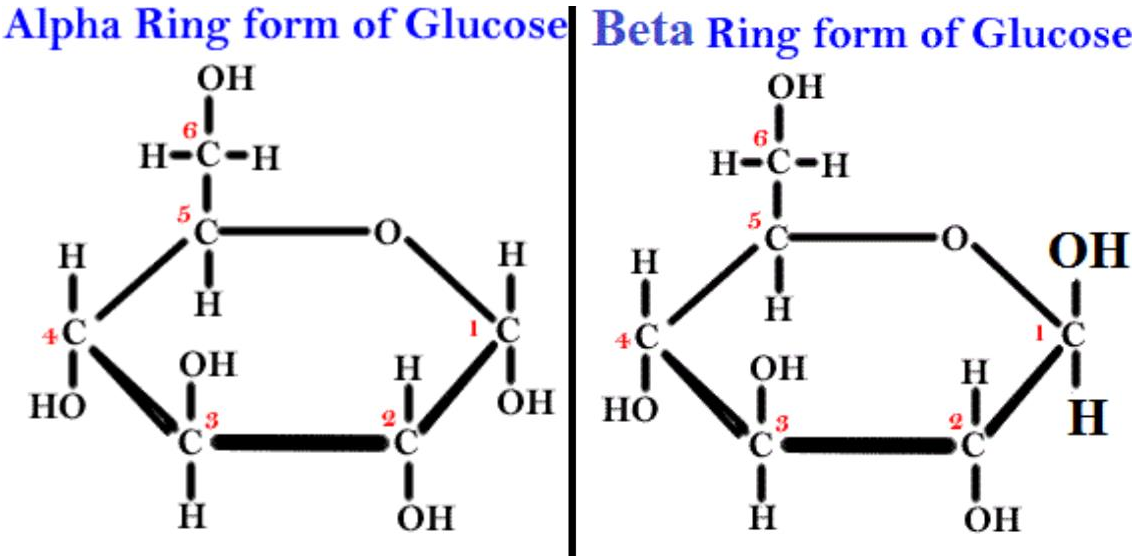
Glucose has a molecular formula of $C_6H_{12}O_6$. It can exist as a long chain or round/ ring structure. Therefore glucose can exist as isomers. It has got two common isomers based on the position of its hydroxyl group on C_1: ie **alpha** and **beta** glucose.

Linear structures of glucose



Ring structure of glucose





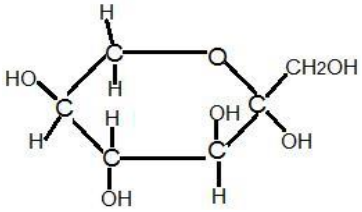
NOTE: **α** and **β** glucose isomers are more stable than straight chain isomers, and **β** glucose isomer is more stable than **α** isomer.

2. FRUCTOSE

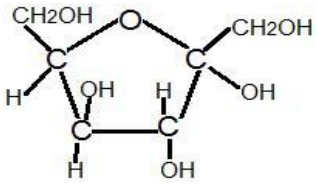
This is a fruit sugar. It is a simple sugar like glucose, characterized by a sweet taste. It also possesses straight chain and ring structures. In the ringed form, it maybe 5 (furanose) sided or 6 sided (pyranose)

Structures of fructose

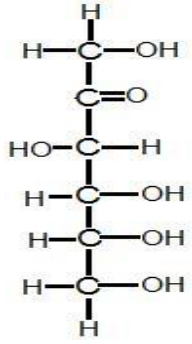
Pyranose



furanose



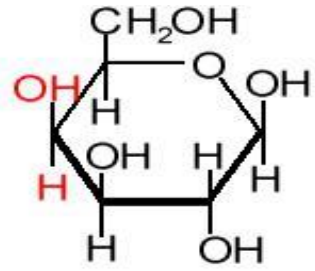
straight



3. GALACTOSE

This is a simple sugar obtained from dairy products & gums. It is characterized by a less sweet taste compared to fructose and glucose. Its ring structure differs from that of **β** glucose on carbon number 4, where in galactose the OH group on C_4 is pointed upwards while that of **β** glucose is pointed downwards.

Structure



DISACCHARIDES

Is the carbohydrate formed when two monosaccharides undergo a condensation reaction it involves the elimination of a small molecule, such as water, from the functional groups only.

Disaccharides are macromolecules consisting of two monosaccharides connected by a glycosidic bond. Glycosidic bonds form when the anomeric carbon of one sugar reacts with a hydroxyl group belonging to a second sugar.

Properties of disaccharides

- They are sweeter than monosaccharides
- They can be crystallized
- They are soluble in water
- Do not change the colour of Benedict's solution when heated with it (apart from maltose)- they are known as non-reducing sugars
- Can be broken down into simple sugars by dilute mineral acids and enzymes

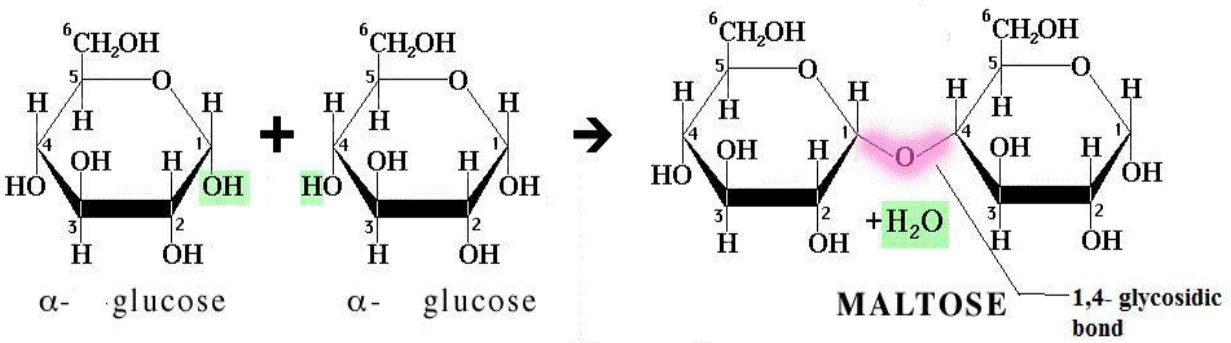
Examples of Disaccharides:

The common examples of disaccharides are:

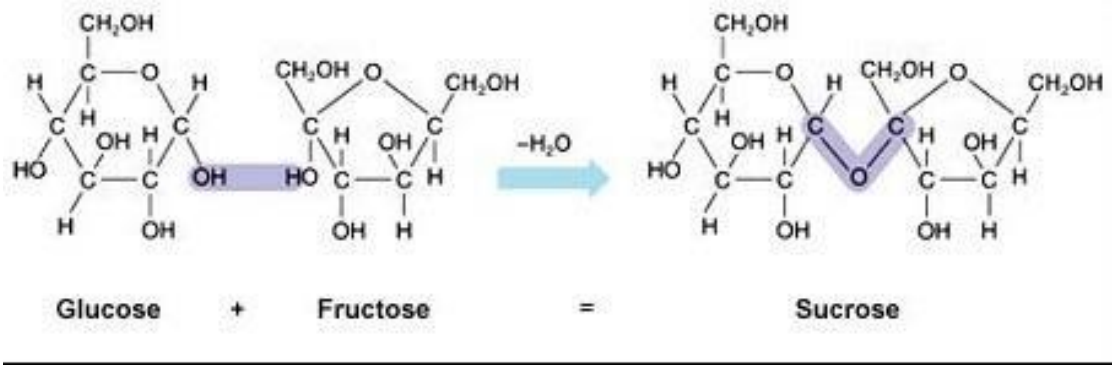
- Maltose: this is formed by a combination of α-glucose + α-glucose
- Sucrose: (table sugar); this is formed by a combination of glucose + fructose
- Lactose: (milk sugar); this is formed by a combination of glucose + galactose

Formation of some disaccharides

Maltose; Two alpha glucose molecules combine by a 1, 4- linkage or 1, 6- linkage to form α-1, 4- glycosidic bond or 1, 6- glycosidic bond. A water molecule is released/ produced, and this is called **condensation reaction**.



Sucrose; $C_{12}H_{22}O_{11}$



Note;
Maltose can also be formed as a product of starch **hydrolysis**.
Hydrolysis; is the breakdown a large compound into its constituent smaller compounds by addition of water onto the compound.

Types of disaccharides;

I. Reducing sugar disaccharides:

These include maltose and lactose, among others. Here one monosaccharide, the reducing sugar, still has a free hemiacetal unit with free anomeric carbon. Sugars with free anomeric carbons can reduce **ferric** (Fe^{3+}) and cupric (Cu^{2+}) ions, Fehling's solution, benedict's solution, etc

NB: A **hemiacetal** is a sugar containing a free aldehyde group which can be oxidized into a carboxylic acid.

II. Non reducing sugar disaccharides:

Sucrose and trehalose are a good examples of a non-reducing sugar disaccharide. Here the monosaccharides bond through an acetal linkage between their anomeric carbons and neither monosaccharide has a free hemiacetal unit/ anomeric carbon.

POLYSACCHRIDES

Polysaccharides are large high-molecular weight molecules constructed by joining many monosaccharide units together by glycosidic bonds. Their formulae can be expressed as $C_n (H_2O)_{n-1}$. Polysaccharides are formed by condensation reactions.

Properties of polysaccharides;

- ❖ Are not sweet
- ❖ Are insoluble in water
- ❖ Cannot be crystallized
- ❖ They have a high molecular mass.
- ❖ They are non-reducing sugars

Note:

- ✓ Upon hydrolysis polysaccharides can be converted to their constituent monosaccharides ready for use as respiratory substrates.
- ✓ The number of monosaccharides that combine is variable, and the chain produced may be branched or unbranched.
- ✓ The chains may be folded thus making them compact and therefore ideal for storage.
- ✓ The size makes them insoluble in water.

- ✓ Starch and glycogen are storage polysaccharides whereas cellulose gives strength and support in cell walls.

Examples of Polysaccharides:

STARCH:

This is made up of a long chain of α- glucose molecules. It is a major storage form of food in plants. It consists of two components ie **amylose** and a**mylopectin.**

a) **Amylose**:

This is simple plant starch (energy storage) has a straight chain structure/ un branched, made up of α-glucose molecules, linked by 1,4- glycosidic bonds. The chain coils helically making it more compact.

b) **Amylopectin**:

This is branched plant starch (gelling agent). It has a branched structure, made up of many α-glucose molecules. These molecules are joined together by 1, 4 and 1, 6 glycosidic bonds, which makes the compound branched and less compact.

Differences between amylose and amylopectin

Amylose	Amylopectin
Consists of unbranched chains.	consists of branched chains
Comprises of only 1,4 glycosidic bonds	Comprises of both 1, 4 and 1, 6 glycosidic bonds.
Gives a blue-black colour with iodine solution	Gives a red-violet colour on addition of iodine solution
Has a lower RFM	Larger RFM
Has less glucose units.	Has more glucose units

Adaptations of starch as a storage compound:

- It is insoluble in water, therefore it exerts no osmotic influence in the cell.
- It exerts no chemical influence in the cells due to its insoluble chemical nature.
- It can fold into compact shape, thus minimizing the space occupied.
- It can easily be converted back to glucose by hydrolysis by breaking glycosidic bonds. The glucose can be used in respiration.

GLYCOGEN

This is a branched polysaccharide used for energy storage. Glucose molecules are linked together linearly by α (1, 4) glycosidic bonds from one glucose to the next. It is found in animals and thus known as animal starch

Branches are linked to the chains from which they are branching off by α (1, 6) glycosidic bonds between the first glucose of the new branch and a glucose on the stem chain. It is similar to amylopectin in structure only that it has shorter chains and is more highly branched.

It stored mainly in the liver and muscles. Glycogen is more soluble than starch

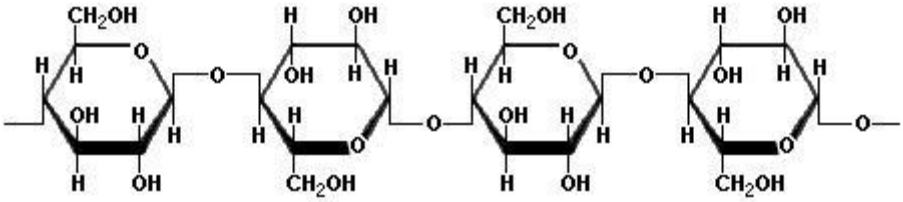


Now that you have learnt starch and glycogen may you give a comparison between the two?

CELLULOSE

It is a polymer of about 10000 ß-glucose molecules forming long unbranched chains which are parallel to each other with cross linkages between them which give it its stability and a good structural material.
It is indigestible by most organisms, mainly forms structures in plants; cell wall, some invertebrates, annelids, fungi, etc

Structure;
It is a polymer with straight chains of ß-glucose units held by ß-1, 4-glycosidic bonds with the OH group projecting out wards from each chain forming cross linkages of hydrogen bonds with adjacent chains.
The cross linking binds the chains together which associate to form micro fibrils that are arranged in larger bundles to form macro fibrils.



Cellulose

Or diagram in understanding biology page 18 fig 2.4

Uses of cellulose

- Rayon produced form cellulose extracted from wood is used in the manufacture of tyre cords.
- Cotton is used in the manufacture of fibres and closes.
- Cellophane used in packaging is produced from cellulose.
- Paper is a product of cellulose.
- Celluloid used in photographic films is also a derivative of cellulose.

Adaptations of cellulose to its functions:

- It is formed by only straight chains due to the 1, 4- glycosidic bonds which make it rigid.
- The hydroxyl groups project outwardly from its chain in alternate directions. These form hydrogen bonds with neighbouring chains that make them linked rigidly together.
- The chains in cellulose are linked together before groups of about 60- 70 microfibrils. This gives the cell great tensile strength that makes the cell able to resist pressure changes.
- The chains are permeable to water and solutes thus allow water molecules and dissolved solids to pass in and out of the cell via the cell wall.

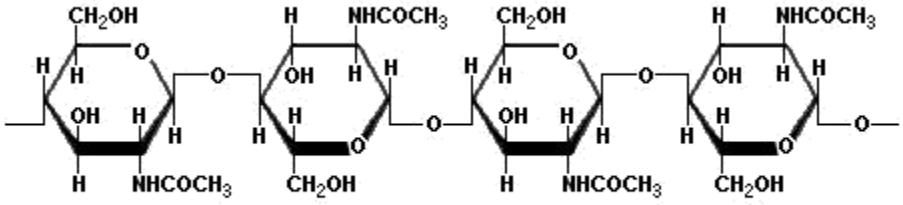
Differences between cellulose and starch

Cellulose	Starch
✓ Consists of a straight chain of beta glucose.	✓ Consists of long chains of 1-4 linked alpha glucose
✓ It's a structural polysaccharide in plant cell walls	✓ It's a storage polysaccharide
✓ Hydroxyl groups project in all directions of the chain. ✓ Consists of unbranched chains ✓ Neighboring chains form cross linkages. ✓ It is not easily hydrolysed into constituent monosaccharides and disaccharides. ✓ The polysaccharide chains are straight and parallel.	✓ Hydroxyl groups in the polysaccharide chain Project into the interior. ✓ Consists of branched chains in amylopectin. ✓ Does not form linkages between neighboring chains. ✓ It is easily hydrolysed into constituent monosaccharides and disaccharides. ✓ The polysaccharide forms are coiled to form helices.

CHITIN

Chitin chemically and structurally resembles cellulose. It only differs in a way that the hydroxyl groups of the second carbon of each glucose unit have been replaced with acetyl amino (**-NH(C=O) CH_3**) groups instead of the hydroxyl (**-OH**) groups.

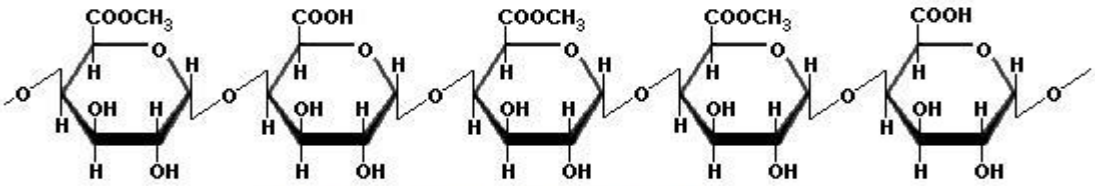
It is found in fungi and is the principal component of arthropod and lower animal exoskeletons, e.g., insect, crab, and shrimp shells.



Chitin

PECTIN

Pectin is a polysaccharide that acts as a cementing material in the cell walls of all plant tissues. The white portion of the ring of lemons and oranges contains approximately 30% pectin. Pectin is the methylated ester of polygalacturonic acid, which consists of chains of 300 to 1000 galacturonic acid units joined with α 1→4 linkages.



Pectin is a polymer of α-Galacturonic acid with a variable number of methyl ester groups.

INULIN:

It is a polymer of fructose and found as a storage carbohydrate in some plants.

MUCOPOLYSACCHARIDES:

These are carbohydrate derivatives derived from a combination of sugar molecules and amino acids in a condensation reaction. This group includes hyaluronic acid which forms part of the matrix of vertebrae connective tissue.

Heparin, an anti-coagulant also contains mucopolysaccharides. It is found in cartilage, bones, vitreous humour of the eye and synovial fluid.

REASONS WHY CARBOHYDRATES FORM A VARIETY OF POLYSACCHARIDES

- They form both 1, 4 and 1, 6 glycosidic bonds. This increases the variety of polysaccharides since branching can occur e.g cellulose has only 1, 4 while glycogen and starch have both 1, 4 and 1, 6 glycosidic bonds.
- They use both pentoses and hexoses to form polysaccharides. In some cases one monosaccharide is used while in other cases, two or more different monosaccharides are used in alternating sequences.
- The difference in the level of branching shown by carbohydrate polymers, leads to the formation of different polysaccharides e.g glycogen is more branched than starch.
- The existence of both alpha and beta forms of certain monomers increases the variety of polysaccharides. This causes the difference between starch and cellulose.
- The high chemical reactivity of monomers makes them combine with other groups to form related monomer units. These combine to form different polysaccharides e.g cellulose differs from chitin.
- The existence of both ketoses and aldoses which form both five numbered and 6 numbered rings. This causes the difference in certain polysaccharides e.g insulin is different from starch.

FUNCTIONS OF CARBOHYDRATES

- ✓ Glucose is a key metabolic fuel; energy source of all cells.
- ✓ Animal Starch (Glycogen) is a long term energy storage for animal cells it stores the glucose molecules in a form that is not easily used.
- ✓ Plant Starch (Amylose) is a long term energy storage for plant cells; it stores the glucose molecules in a form that is not easily used
- ✓ Cellulose is a structural polysaccharide of cell walls.
- ✓ Chitin is structural polysaccharide of exoskeletons of insects and crustaceans.



May you please give more functions of carbohydrates taking in mind of all the kinds discussed!

Hint; check table 2.3 in understanding biology page 19.

LIPIDS

☑ These are organic compounds containing carbon, hydrogen and oxygen. The ratio of hydrogen to oxygen is very high compared to the carbohydrates. They are organic molecules insoluble in water due to numerous non polar C-H bonds, but soluble in an organic solvent (e.g., ether, benzene, acetone, chloroform).

☑ They include Fats, oils, steroids & waxes. Fats are solid at room temperature while oils are liquids at room temperature.

Properties of lipids

- ✓ They are insoluble in water but soluble in non-polar solvents like benzene, chloroform, diethyl ether, etc. The low solubility is due to the low oxygen content which results into a small number of polar hydroxyl groups in lipids hence very few hydrogen bonds.
- ✓ They have a high proportion of hydrogen in their molecules.
- ✓ They are non-polar compounds.
- ✓ They are less dense than water.
- ✓ They can be solids or liquids at room temperature.
- ✓ Their melting point increases with increase in saturation.
- ✓ They undergo high oxidation in respiration to yield large amounts of energy.
- ✓ They are poor conductors of heat.

TYPES OF LIPIDS:

1. Triglycerides

Triglycerides usually include a mixture of fatty acids. They are nonpolar (don't dissolve well in water). Only the ends of the fatty acids can be attracted to water. They tend to form circular blobs in water with the nonpolar glycerol inside, the fatty parts facing to water.

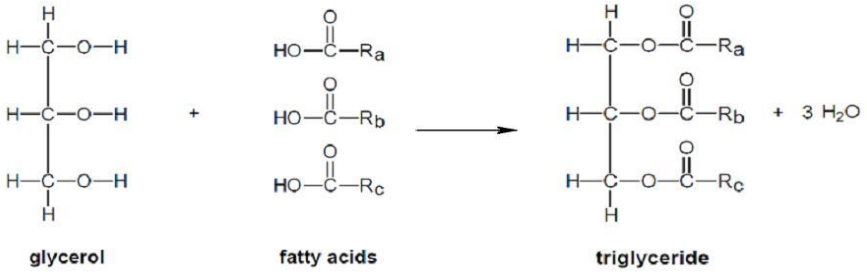
How Triglycerides are formed:

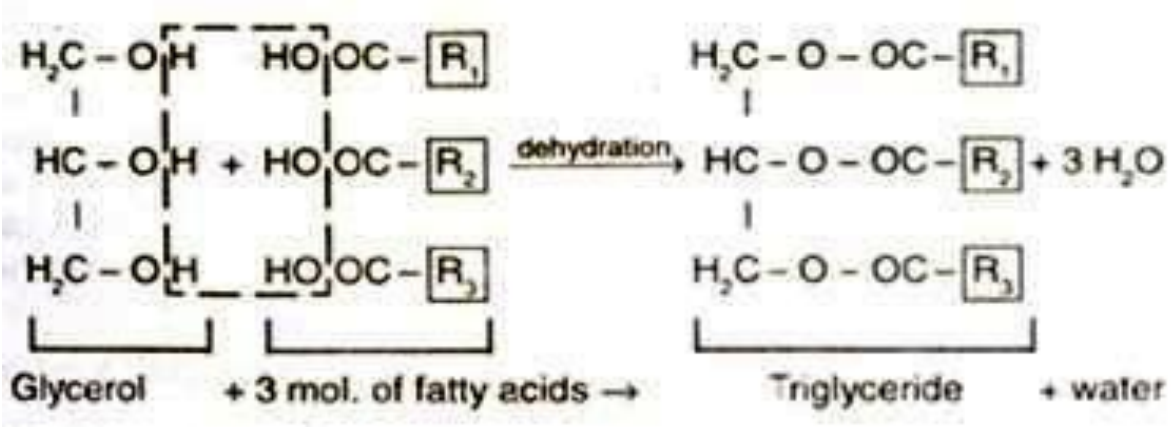
- × Triglycerides are built from fatty acids and glycerol by condensation reaction.
- × Glycerol has 3 OH groups and each combines with a separate fatty acid to form a lipid chemically known as a triglyceride.
- × This is a condensation reaction that leads to liberation of 3 water molecules.
- × Metabolic water is formed and an ester bond is formed between the glycerol and fatty acid.
- × Since the glycerol possesses 3 hydroxyl groups to which 3 fatty acids attach themselves, 3 water molecules are formed. In this reaction, the fatty acids may all be the same or different, saturated or unsaturated.

Note:

a) **Glycerol** is a type of alcohol with a hydroxyl group on each of its **three** carbons

b) A **fatty acid** is simply a carboxylic acid in which the R group is very long. It consists of many carbons chained together with hydrogen atoms completing their octet.





Fatty acids are of two types;

a) **Saturated fatty acids (or lipids)**:

These comprise of only single bonds. They have many C-H bonds. They are always hard, and they are commonly animal fats.

b) **Unsaturated fatty acids (or lipids)**:

These comprise of single bonds and some double bonds. They possess less C-H bonds. They are usually liquids at room temperature, and are commonly plant oils.

Sat. Fatty Acids	Formula	Melting Point (°C)
Butyric	$C_4H_8O_2$	Liquid
Palmitic	$C_{16}H_{22}O_2$	63
Stearic	$C_{18}H_{36}O_2$	70
Unsat. Fatty Acids	**Formula**	**Melting Point (°C)**
Oleic	$C_{18}H_{34}O_2$	Liquid
Linoleic	$C_{18}H_{32}O_2$	Liquid
Linolenic	$C_{18}H_{30}O_2$	Liquid

Fatty acids may be;

a. **Essential**

These are fatty acids which cannot be synthesized by the body and must be supplied in the diet.

Common sources of essential fatty acids are; vegetables and seed oils. A deficiency of these fatty acids results in retarded growth, reproductive disorders and kidney failure.

b. **Non-essential**

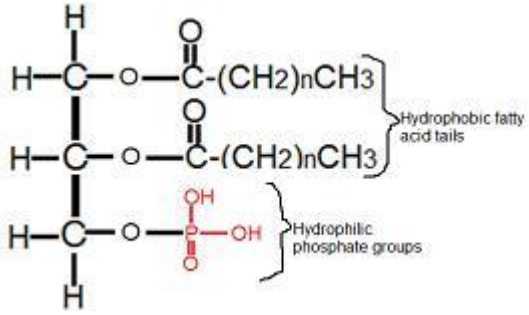
These fats can be synthesized by the body from metabolism of other compounds such as carbohydrates and proteins.

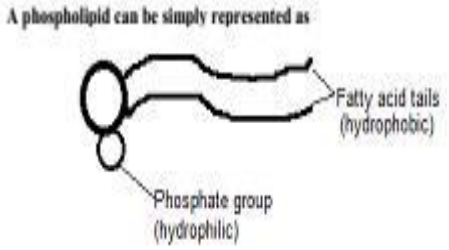
2. PHOSHOLIPIDS

- ✓ These are lipids containing a phosphate group. In the formation of a phospholipid, a phosphate group is added to the third carbon atom in the position of the hydroxyl group. The other two hydroxyl groups of the glycerol react with fatty acids.
- ✓ A phospholipid therefore has a phosphate group and two fatty acid chains. The phosphate group carries an electric charge and hence contributes to the polarity of the phospholipid molecule.
- ✓ The phosphate group forms the polar end i.e water soluble hydrophilic head while the fatty acid hydrocarbon chains form the nonpolar water-insoluble hydrophobic end of the phospholipid molecule.

- ✓ Phospholipids are able to dissolve in both water and non-polar solvents. This property is important in determining the structure and function of the plasma membrane.
- ✓ The Polar phosphate group (hydrophilic/ water loving) faces outward, and the nonpolar fatty acids (hydrophobic/ water hating) face inward. This means that phospholipids are soluble in both water and oil.

Diagram showing a phospholipid





3. STEROIDS

- These are biologically important substances in both plants and animals. The skeleton of a steroid molecule consists of four complex rings of carbon atoms. Three of these are six sided while one is 5 sided.
- The various steroids differ in the side groups attached to the carbon atoms of the skeleton. Like lipids, they contain hydrogen atoms and oxygen atoms but do not contain any fatty acid.

Examples of steroids include;

- ✓ Cholesterol which is a component of the plasma membrane and a raw material
- ✓ for many other steroids like bile acids.
- ✓ Bile acids e.g glycolic acid and taurochloric acid used in the emulsification of
- ✓ fats during digestion.
- ✓ Vitamin D (calciferol) which promotes phosphorous and calcium absorption and metabolism.
- ✓ Lipid hormones e.g testosterone and oestrogen progesterone, cortisone and
- ✓ aldosterone
- ✓ Hormones from adrenal cortex i.e are referred to as corticosteroids.

EFFECTS OF CHOLESTEROL

- × Cholesterol is produced by the liver and is used as the starting point for the synthesis of other steroid molecules. The major source of cholesterol is diet and many dairy products are rich in cholesterol or fatty acids from which cholesterol can be synthesized.
- × Thyroxin stimulates cholesterol production in the liver and also increases the rate of excretion of bile. Excessive amounts of cholesterol in blood can be harmful. It can be deposited in walls of arteries leading to arthesclerosis and increased risk of formation of a blood clot which may block blood vessels, a condition known as thrombosis.
- × This is often fatal if it occurs in the coronary artery in the wall of the heart (coronary thrombosis or heart attack) or brain (cerebral thrombosis). Although cholesterol is harmful in excess, it is essential to have some in the diet for reasons stated.

4. WAXES

These are formed from fatty acids and a long chain of alcohol instead of glycerol. They are used as water proofing materials in plants and animals e.g the cuticle in insects, the epidermis in plants, etc. wax prevents excessive water loss from plants and animals.

5. LIPOPROTEINS

- **Lipoproteins** are clusters of proteins and lipids all tangled up together. These act as a means of carrying lipids, including cholesterol, around in our blood. Lipoproteins have a single layer of phospholipid molecules on their outside, surrounding a central core.
- The outer layer of the lipoprotein also has a protein molecule called an Apo lipoprotein. This protein serves to identify the specific lipoprotein. For example, some lipoproteins transport dietary lipids from the small intestine to adipocytes and the liver. Other lipoproteins transport cholesterol between different parts of the body. Each type of lipoprotein can be identified because it has a different Apo lipoprotein.

6. GLYCOLIPIDS

- These are a combination of lipids and carbohydrates. The carbohydrate can make up anywhere from less than one percent to more than 80 percent of the total protein mass. They act as receptors on cell surfaces and bring other cells and proteins (collagen) together giving strength and support
- They are also essential in the transport of materials across the plasma membrane.

FUNCTIONS OF LIPIDS

Structural functions:

- Chemical messengers- Steroid hormones (testosterone & estrogen, etc)
- They are constituents of the cell membrane ie lipid bilayers of cell membranes (phospholipids)
- They form subcutaneous fat in the dermis of the skin which insulates the body against excessive heat loss.
- They constitute the waxy cuticle of plants and insects that prevents excessive water loss.
- They constitute the myelin sheath of nerve fibres which increase the speed of impulse transmission across the axon.
- They constitute the adipose tissue which is important in protecting internal organs from shock.
- They are components of hormones and precursors for prostaglandin synthesis
- They protect delicate organs e.g. the heart and kidney from injury.
- They coat on fur of animals enabling it to repel water which would otherwise wet the organism.

Physiological functions:

- They are good sources of energy in the body.
- They are solvents for fat soluble nutrients e.g sterols, vitamins A, D, E and K during their absorption into the body.
- They are sources of metabolic water to desert animals, young birds and reptiles while still in their egg shells.
- They are components of electron transport system during photosynthesis and respiration.
- They are a constituent of the brown adipose tissue which provides heat for temperature regulation (thermogenesis).

Other functions

- Some lipids provide a scent in plants which attracts insects for pollination.
- Wax is used by bees to construct honey combs.
- Wax from bees is used in the manufacture of candles.

STORAGE PROPERTIES OF LIPIDS

- They are compact taking up little space.
- They are insoluble in water hence cannot be lost in solution.
- They are light to keep the weight to a minimum and allow buoyancy.
- They have a high calorific energy value.
- They have a high hydrogen-oxygen content hence can yield a lot of water on oxidation.

PROTEINS

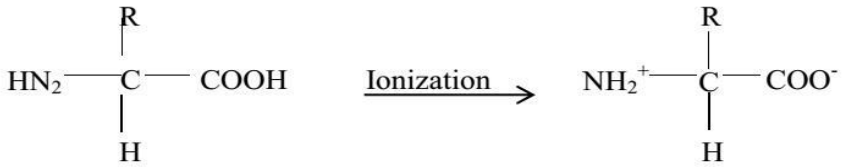
- Proteins are polymers. The monomers of proteins are amino acids.
- All proteins have the same basic structure. They consist of an **Amino Group** at one end, an **Acid Group** at the other end, and a Carbon in the middle which bonds with a Hydrogen atom and an 'R' group, which is specific to individual amino acids. In addition to C, H and O, they always contain N, usually S and sometimes P.
- Whereas there are few carbohydrates and fats, the number of proteins is limitless e.g. a single bacterium may have around 800 types of proteins while man has 10,000 types. This is because there are several amino acids which may join in different patterns hence forming the various types of proteins. Proteins are specific to each species hence determine the character of the species.
- Proteins are not stored in the organism except in eggs and seeds where they are used to form new tissues.
- Proteins form the structural basis of all living cells as they are building blocks are the amino acids.
- Proteins are partially soluble in water forming colloidal suspensions.

AMINO ACIDS

These are groups of many chemicals of which around 20 occur in proteins. They contain an amino group (NH_2) and a carboxyl group (COOH). Most amino acids have one of each and are therefore neutral but a few have more amino groups than carboxyl making them alkaline or may have more carboxyl than amino groups making them acidic.

Structure of amino acids

- Amino acids are soluble in water and ionize to form ions.
- The carboxyl end of the amino acid is acidic in nature. It will ionize in water to give H^+. This will make the COOH group negatively charged.
- The amino end (NH_2) is basic in nature. It attracts the H^+ in solution making it positively charged. The ion is now dipolar i.e. having a negative and a positive pole. Such ions are called zwitter ions i.e. the negative and positive charges exactly balance and the amino acid ion has no overall charge i.e.



- Therefore in acidic solutions, an amino acid acts like a base and in alkaline solutions, it acts as an acid. In neutral conditions found in the cytoplasm of most living organisms, the amino acid acts as both.
- Amino acids therefore show both acidic and basic properties i.e. they are amphoteric.
- The overall charge of the amino acid depends on the pH of the solution.
- At some characteristic pH, the amino acid has no overall electric charge i.e. it exists as a zwitter ion. This pH is called the iso-electric point of an amino acid.

ACTIONS OF PROTEINS AS BUFFERS

- Proteins are made up of amino acids which are amphoteric and thus are buffers.
- If the pH falls below the iso-electric point i.e. the solution becomes more acidic, H^+ are taken up by the carboxyl ion. This reduces the concentration of the H^+ in solution making the solution less acidic and the amino acid gains an overall positive charge.
- $NH_2CHRCOOH\ (aq) + H^+\ (aq) \longrightarrow NH_3^+CHRCOOH\ (aq)$
- If the pH rises above the iso-electric point i.e. it becomes less acidic or more alkaline, hydrogen ions are lost by the amino group. This increases the concentration of free H^+ in the solution making it more acidic and the amino acid gains an overall negative charge.
- $NH_2CHRCOOH\ (aq) + OH^-\ (aq) \longrightarrow NH_2CHRCOO^-\ (aq) + H_2O(l)$
- In this behaviour, they resist any changes in pH that would have occurred.

CATEGORIZATION OF AMINO ACIDS

Amino acids are grouped into essential and non-essential amino acids depending upon where they can be synthesized.

a. **Essential amino acids;**

These are amino acids that cannot be synthesized by the body and therefore got from the diet that a given organism feeds on. They include, histidine, isoleucine, leucine, proline, phenylalanine, valine, arginine, lysine, methionine, and tryptophan.

b. **Non- essential amino acids;**

These are amino acids that are synthesized by the body through a process of transamination. They include; tyrosine, alanine, glycine, serine, theonine, cysteine, cystine, aspartic acid, glutamic acid and asparagine.

POLYPEPTIDES

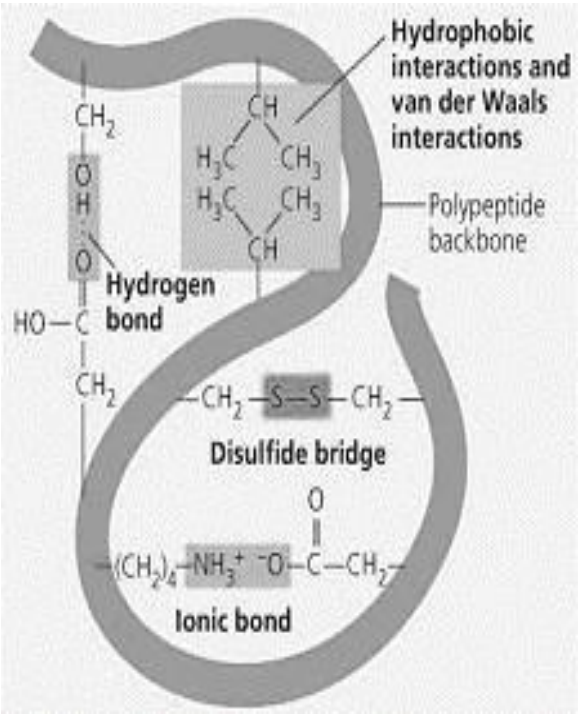
- They are formed as a result of condensation reaction between the amino group of one amino acid and the carboxyl group of another amino acid to form a dipeptide.
- Further combinations of this type extend the length of the chain to form a polypeptide which usually contains many amino acids.
- The shape of the polypeptide molecule is due to four types of bonding which occur between the various amino acids in the chain.
- The polypeptide chains in a protein are joined together by bonds of different types. The bonds are formed between the amino acids in the chains due to their different properties i.e acidic, basic, etc. these bonds include;

Note: Amino acids can be joined together, forming **Peptide Bonds**. All amino acids are joined in exactly the same way. When two amino acids are joined together in this way, a dipeptide molecule is formed.

Illustration in understanding biology page 28 fig 2.9

a. b. **Ionic bonds:**
   - These are formed between basic and acidic groups of some amino acids forming a strong interaction. These bonds are formed between acidic amino acids and basic amino acids e.g between aspartic acid and lysine.

c. d. **Disulphide bonds:**
   - These occur between amino acids that have sulphur. These amino acids contain the sulphurdyl group (-SH) in their R groups. If two molecules of cysteine line up alongside each other, the neighbouring sulphurdyl groups are oxidized to form a disulphide bond.
   - Disulphide bonds may be formed between different chains of amino acids (interchains) or between different parts of the same polypeptide chain (intrachain). These are the strongest bonds and are not easily broken.



e. **Hydrogen bonds:**
   - These are weak bonds formed between hydrogen atom in one amino acid and a highly electronegative element in another amino acid.
   - Though they are weak, their occurrence is frequent and their total effect makes a considerable contribution to the stability of the protein molecule.

f. g. **Hydrophobic bonds/interactions:**
   - These are as a result of non-polar R groups of amino acids in polypeptide chains. They are weak forces of attraction and point inward to the protein.
   - If a polypeptide chain has hydrophobic groups and is in an aqueous environment, the chain folds because of the attraction between the hydrophobic groups. The hydrophobic groups come into close contact and exude water, hence pointing inwards. On the other hand, the hydrophilic groups point outwards.

Note: the protein which makes up the human hair has a high percentage of amino acid cysteine. The disulphide bridges formed between cysteine molecules are largely responsible for the shape of the hair.

PROTEIN STRUCTURE

There are four levels of protein structure viz;

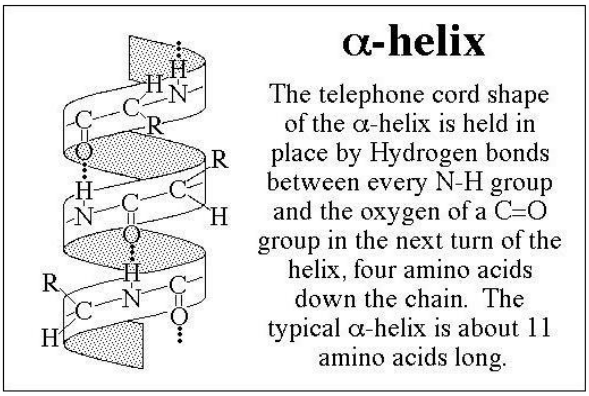
- ✓ Primary, Secondary, tertiary and quaternary.

PRIMARY STRUCTURE

- ✓ Proteins are made up of polypeptide chains, which are amino acids joined together with peptide bonds.
- ✓ The unique sequence of amino acids that make up a protein or polypeptide chain is called the Primary Structure and this determines that biological role of the protein.
- ✓ Peptide bonds are created by enzyme catalysed condensation reactions and broken down by enzyme catalysed hydrolysis reactions. Breaking down proteins is important in many areas of the body, not merely in digestion. For example, in hormone regulation, cells that are targeted by hormones contain enzymes to break down those hormones. This stops their effects from being permanent and allows them to be controlled.

SECONDARY STRUCTURE

- ✓ After synthesis, polypeptide chains are folded or pleated into different shapes, called their Secondary Structure.
- ✓ Two common examples of secondary structures are Alpha Helices and Beta Pleated Sheets. Secondary structure is held together by many Hydrogen bonds, overall giving the shape great stability.



a. Alpha helices/spiral

Proteins in this shape take the form of an alpha helix. They are hard but stretchable. The helical structure is maintained by hydrogen bonds. Examples of such proteins include; keratin, collagen, etc. keratin is found in hair, beaks, nails, feathers, claws, horns, etc.

b. Beta pleated sheets

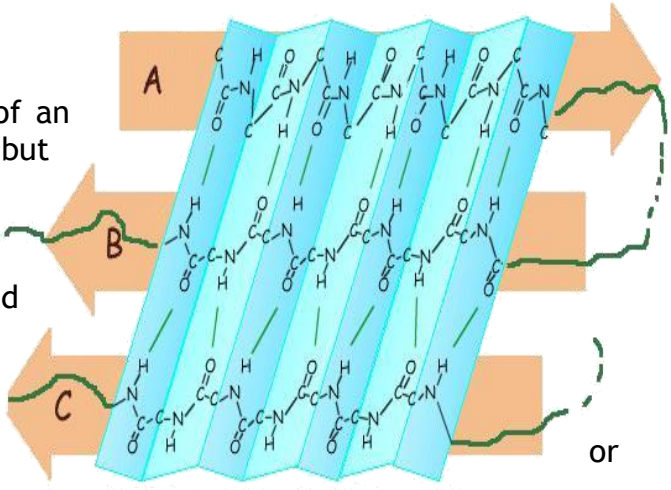


Diagram 1: Beta pleated sheet. The lateral groups (R) are not shown.

These result from the folding of two or more adjacently joined parallel polypeptide chains which are stabilized by hydrogen bonds. They then get arranged into sheets.

Proteins with this structure are very stable and rigid or stretchable e.g fibroin protein found in silk. Beta pleated sheets have a flat zig zag structure. They

commonly occur in insoluble structural proteins but also in parts of some soluble proteins.

TERTIARY STRUCTURE

- ✓ The polypeptide chain coils extensively forming a compact globular shape. This is also known as the 3 dimensional structure of a protein. This structure is maintained by interaction of the four types of bonds i.e. ionic, hydrogen, di sulphide bonds and hydrophobic interactions.
- ✓ The hydrophobic interactions are quantitatively the most important and occur when a protein folds to shield the hydrophobic side groups from the aqueous surrounding and at the same time exposing hydrophobic side chains.

NOTE: the precise globular structure is key to the specificity of enzymes.

- ✓ Tertiary structure can be broken by the action of heat. Increasing the kinetic energy of protein with a tertiary structure makes it vibrate more, and so the bonds that maintain its shape (which are mainly weak, non-covalent bonds) will be more likely to break.
- ✓ When a protein loses its shape in this way it is said to be denatured. Even when cooled the protein will not form its original complex shape.

QUATERNARY STRUCTURE

Some proteins are made up of multiple polypeptide chains, sometimes with an inorganic component for example, a haem group in haemoglobin called a Prosthetic Group. These proteins will only be able to function if all subunits are present.

TYPES OF PROTEINS

Proteins are categorized as fibrous, globular or conjugated.

a. Fibrous proteins;

They have a primary structure of regular repetitive sequences.
These form long chains which may run parallel to one another being linked by cross bridges.
They are very stable molecules and have structural roles within the organism e.g. collagen and keratin.

COLLAGEN

- It is a fibrous protein consisting of three polypeptide chains it has repeat of tri peptide sequence of glycine, proline and alanine wound around each other. Each of the three chains is a coil itself.
- Hydrogen bonds form between these coils, which are around 1000 amino acids in length, which gives the structure strength. This is important given collagen's role, as structural protein.
- This strength is increased by the fact that collagen molecules form further chains with other collagen molecules and form Covalent Cross Links with each other, which are staggered along the molecules to further increase stability. Collagen molecules wrapped around each other form Collagen Fibrils which themselves form Collagen Fibres.

Functions of collagen

- × Form the structure of bones
- × Makes up cartilage and connective tissue

- Prevents blood that is being pumped at high pressure from bursting the walls of arteries
- Is the main component of tendons, which connect skeletal muscles to bones

b. Globular proteins

These are proteins with an irregular sequence of amino acids in their polypeptide chains.

These tend to form ball-like structures where hydrophobic parts are directed towards the centre and hydrophilic are towards the edges, which makes them water soluble.

They usually have metabolic roles, for example: enzymes in all organisms, plasma proteins and antibodies in mammals.

Differences between fibrous and globular proteins

Fibrous proteins	Globular proteins
Insoluble in water	Soluble in water
Have a stable structure	Have unstable structure
Support and structural roles	Metabolic functions
Repetitive regular sequences of amino acids	Irregular amino acid sequences
Polypeptide chains form long parallel strands	Polypeptide chains folded into a spherical shape.
Length of the protein may vary in two examples of the same protein.	Length of the protein is always identical in two examples of the same protein.
Not easily denatured by high temperature	Easily denatured by high temperatures

c. Conjugated proteins

These are complex compounds consisting of globular proteins and tightly bonded non-protein material; prosthetic group. They include:

- **Phosphoprotein**; It involves phosphoric acid combining with a protein. It is found in casein of milk and vitelline of egg yolk.
- **Glycoproteins**; they are found in membrane structure and mucin (component of saliva). Also in mucus, egg white and thyroid hormones. The prosthetic group is a carbohydrate.
- **Nucleoproteins**; the prosthetic group is nucleic acid. It is found in chromosomes, ribosome structures.
- **Chromo protein**; the prosthetic group is a pigment. It is found in haemoglobin (haem iron, Fe^{2+}), phytochrome (plant pigment), cytochrome (respiratory pigment), chlorophyll (magnesium, Mg^{2+}).
- **Lipoprotein**; the prosthetic group is a lipid. It is found in membrane structures. Lipids are transported in blood as lipoprotein.
- **Flavoprotein**; the prosthetic group is FAD; Flavine Adenosine Dinucleotide. It is mostly important in electron transport chain in respiration.
- **Metal protein**; the prosthetic group is a metal. E.g nitrate reductase the enzyme in plants which converts nitrates to nitrites and cytochrome oxidase which is essential in electron carrier pathways, prosthetic group is copper.

FUNCTIONS OF PROTEINS

1. **Repair and Maintenance**

Protein is termed the building block of the body. It is called this because protein is vital in the maintenance of body tissue, including development and repair. Hair, skin, eyes, muscles and organs are all made from protein.

2. **Energy**

Protein is a source of energy. If you consume more protein than you need for body tissue maintenance and other necessary functions, your body will use it for energy. If it is not needed due to sufficient intake of other energy sources such as carbohydrates, the protein will be used to create fat and becomes part of fat cells.

3. **Hormones**

Protein is involved in the formation of some hormones. These substances help control body functions that involve the interaction of several organs. Insulin, a small protein, is an example of a hormone that regulates blood sugar. It involves the interaction of organs such as the pancreas and the liver. Secretin, is another example of a protein hormone. This substance assists in the digestive process by stimulating the pancreas and the intestine to create necessary digestive juices.

4. **Enzymes**

Enzymes are proteins that alter the rate of chemical reactions in the body. In fact, most of the necessary chemical reactions in the body would not efficiently proceed without enzymes. For example, one type of enzyme functions in digesting large protein, carbohydrate and fat molecules into smaller molecules, while another polymerase in the replication of DNA.

5. **Transportation and Storage of Molecules**

Protein is a major element in transportation of certain molecules. For example, hemoglobin is a protein that transports oxygen throughout the body. Protein is also sometimes used to store certain molecules. Ferritin is an example of a protein that combines with iron for storage in the liver.

6. **Immune Response**

Protein forms antibodies that prevent infection, illness and disease. These proteins identify and assist in destroying antigens such as bacteria and viruses. They often work in conjunction with the other immune system cells. For example, these antibodies identify and then surround antigens in order to keep them contained until they can be destroyed by white blood cells.

7. **Acid-Base Balance**

Proteins also serve as buffers, helping maintain the pH of a solution. When your blood becomes too acidic, protein side chains pick up excess hydrogen ions to increase the pH of your blood. If your blood becomes too basic, or alkaline, other protein side chains donate hydrogen ions to decrease the pH.

8. **Fluid Balance**

The body contains approximately 60 percent water, making it the most abundant substance in your body. For it to stay healthy, this water must disperse properly throughout your body, and proteins help do this. Proteins attract water, so they can pull fluid into capillaries and prevent it from accumulating in your body tissues.

For more functions check table 2.9 in understanding biology page 32

RELATION BETWEEN PROTEIN STRUCTURE AND PROTEIN FUNCTIONS

- Some proteins have a structural function, these are fibrous proteins with a secondary structure insoluble in water and physically tough e.g. collagen in connective tissues, bone, tendons and cartilage. Other structural proteins include keratin in feathers, nails, hair, horns, beaks and skin.
- Some proteins function as enzymes. These have a globular structure and are soluble in water e.g. digestive enzymes like pepsin, respiratory and photosynthetic enzymes.
- Some proteins function as hormones regulating metabolic processes. These are globular and soluble in water e.g. insulin which regulates metabolic activity.
- Some proteins functions as respiratory pigment. These are globular proteins with a quaternary structure that increases their surface area for transport or storage of respiratory gases e.g. haemoglobin which transports oxygen in blood and myoglobin that stores oxygen in muscles.
- Some proteins are involved in transport and are globular with primary or tertiary structures e.g. serum albumen that transports fatty acids and lipids in blood.
- Some proteins are involved in immunological responses hence protecting the body. These are globular e.g. antibodies, fibrinogen and thrombin.
- Some proteins are contractile e.g. they are fibrous with a secondary structure e.g. myosin and actin filaments in muscles.
- Storage proteins are toxins and soluble and water with a globular structure e.g. snake venom, bacteria toxins, etc.
- Some proteins are insoluble in water e.g. ovalbumin that occurs in egg white, casein in milk, etc.
- Globular proteins form colloidal suspensions that hold molecules in position within cells e.g. proteins in the cytoplasm of most cells where they are soluble in water and have a large surface area.

DENATURATION OF ENZYMES

- This is the process by which the three dimensional structure of the protein which is due to fairly weak ionic and hydrogen bonds is altered making a globular structure more fibrous.
- In this case the actual sequence of the amino acid is not altered but only the overall shape of the molecule is changed. It should be noted that this is sufficient to prevent the molecule from carrying out its usual functions within an organism.
- Any agent capable of breaking the above bonds is called a denaturing agent.

Factors causing protein denaturation;

a. **Heat;** this causes the atoms of the protein to vibrate more as it increases the kinetic energy thus breaking hydrogen and ionic bonds.
b. **Acids;** additional H^+ combine with the COO^- groups on amino acids and form COOH, the ionic bonds are thus broken.
c. **Alkalis;** reduced number of hydrogen ions causes the NH_3^+ groups to lose H^+ and form NH_2 in this ionic bonds are broken.
d. **Inorganic chemicals;** the ions of heavy metals such as mercury, lead and silver are highly electropositive. They combine with COO^- groups and disrupts ionic bonds. Similarly highly electronegative ions such as cyanide CN^- combine with NH_3^+ groups and disrupt ionic bonds
e. **Organic chemicals;** organic solvents alter hydrogen bonding within a protein.
f. **Mechanical force;** physical movement along the protein may break the hydrogen bonds.

VITAMINS

Vitamins are organic compounds and a vital nutrients that an organism requires in limited amounts. They are synthesized by plants but animals obtain them from their diets. They are chemically different and cannot be synthesized by the body in sufficient amounts.

However, some are synthesized in the skin of human beings in the presence of sunlight e.g vitamin D.

CLASSIFICATION OF VITAMINS

Vitamins are classified into two: ie water soluble vitamins and fat soluble vitamins.

a. Fat soluble vitamins

- ✓ Fat soluble vitamins are those that are normally stored in the body. They include Vitamins A, D, E and K.
- ✓ When these vitamins are ingested, they dissolve in fat. In a person with a healthy digestive system, the body uses what it needs at that time and stores the rest for future use.
- ✓ Since people with cystic fibrosis often have pancreatic insufficiency and do not digest or store fats properly, the excess is not stored but excreted in the stool. Due to this, people with cystic fibrosis need a continuous supply of fat soluble vitamins just as they do with water soluble vitamins.

b. Water soluble vitamins

- ✓ Water soluble vitamins are vitamins that our bodies do not store. They include Vitamin C and all of the B vitamins.
- ✓ These vitamins dissolve in water when they are ingested, then go in to the blood stream. The body keeps what it needs at that time, and excess amounts are excreted in the urine.
- ✓ Since they can't be stored, everybody needs a continuous supply of water soluble vitamins in order to stay healthy

Table showing more detail of fat soluble vitamins

Vitamin	Best sources	Function	Deficiency Symptoms
A	Liver, dairy products, egg yolks, fish oils, dark green leafy vegetables, yellow vegetables, yellow fruits	Repair & maintenance of cells. Maintenance of immune system. Essential for normal eyesight	Dry skin, shortness of breath, weakened bones, depressed immune system, night blindness
E	Vegetables oils, whole grains, wheat germ, liver, dark green leafy vegetables, nuts, legumes	Powerful antioxidant. Protects the walls of red blood cells from becoming fragile	Anemia, breakdown of red blood cells
D (D3)	Fish liver oils, fortified milk, exposure to sunlight	Necessary for the formation of bones and teeth. Aids in the absorption and utilization of calcium	Weakened bones, enlarged joints, muscle spasms
K	Liver, egg yolks, dark green leafy vegetables	Controls 4 of the proteins needed for blood to clot	Long blood clotting time

TABLE SHOWING DETAILS ABOUT MOST WATER SOLUBLE VITAMINS

Vitamin	Best sources	Function	Deficiency Symptoms
B-1 (Thiamin)	Whole wheat products, pork, liver and peas	Helps convert carbohydrates to energy	Loss of energy, nerve damage, muscle weakness
B-2 (Riboflavin)	Meats, fish, whole grains, dairy products, vegetables, legumes	Aids many enzyme reactions that convert food into energy	Dry, scaly skin, cracks on lips & corners of mouth, light sensitivity
Niacin	Whole grains, dairy products, liver	Aids many enzyme reactions that convert food into energy	Mental impairment, delirium, diarrhea, swelling of mouth
B-6	Meats, fish, nuts, whole grains, fruits, vegetables, legumes	Helps convert protein's amino acids into energy. Synthesizes: amino acids, muscle proteins, hemoglobin, insulin & immune proteins	Depression, loss of energy, loss of appetite, nausea, vomiting, swelling of mouth and tongue
Folate (also known as: F, B9, Folic Acid, or Folacin)	Liver, kidney, dark green leafy vegetables, fruits, peas & beans	Required for DNA metabolism, important for genetic functions such as cell division and growth	Anemia, swelling of tongue, diarrhea. In pregnancy, anemia, miscarriage and birth defects
B-12	Liver, kidney, red meats, diary products, eggs, fish	Required for DNA metabolism, red blood cell formation, maintains central nervous system	Anemia, degenerative changes in the nervous system
Pantothenic Acid	Liver, kidney, yeast, egg yolks, peanuts, whole grains, beef, skim mild, potato, tomato	Helps convert fatty acids into energy. Synthesis of fatty acids, cholesterol, hormones	No appetite, nausea, indigestion, moods, cramps, depressed immune system, rapid pulse, fainting
Biotin	Liver, kidney, egg yolks, milk, yeast	Helps digest carbohydrates and make fatty acids	No appetite, anemia, scaly skin, weight loss, hair loss
C (Ascorbic Acid)	Fruits (especially citrus) & vegetables	Aids in wound healing, improves immune system, helps make amino acids, helps iron absorption	Anemia, depressed immune system, bruising, weakened bones, & cartilage, muscle degeneration

ENZYMES

Enzymes are biochemical catalysts made up of globular proteins. An enzyme is always associated with a non-protein component known as co-factor which is tightly bonded to the enzyme.

Enzymes are organic compounds protein in nature that speed up the rate of biochemical reactions in the body of an organism and remains unchanged at the end of the reaction.

Importance of enzymes

- The rate at which some reactions occur in the body without enzymes is too slow to sustain life. Enzymes therefore speed up the rate of the reaction without changing the product formed and the nature of reaction i.e. an enzyme cannot make a reaction that would not occur to take place and it cannot make an endothermic reaction exothermic but only ensures that products are formed in the shortest time possible.
- They also control metabolic processes hence promoting normal body functions.

COMPARISON OF ENZYMES WITH INORGANIC CATALYTS

SIMILARITIES:

- ✓ **Enzymes and inorganic catalysts both affect the rate but not the equilibrium constant of a chemical reaction.**

Reactions proceed downhill energetically, in accord with the Second Law of Thermodynamics. Catalysts merely reduce the time that a thermodynamically favored reaction requires to reach equilibrium. Remember that the Second Law of Thermodynamics tells whether a reaction can occur but not how fast it occurs.

- ✓ **Enzymes and inorganic catalysts increase the rate of a chemical reaction in both directions, forward and reverse.**

This principle of catalysis follows from the fact that catalysts can't change the equilibrium of a reaction. Because a reaction at equilibrium occurs at the same rate both directions, a catalyst that speeds up the forward but not the reverse reaction necessarily alters the equilibrium of the reaction.

- ✓ Enzymes and inorganic catalysts bind their substrates, not permanently, but transiently for a brief time. **There is no action at a distance involved**.

DIFFERENCES:

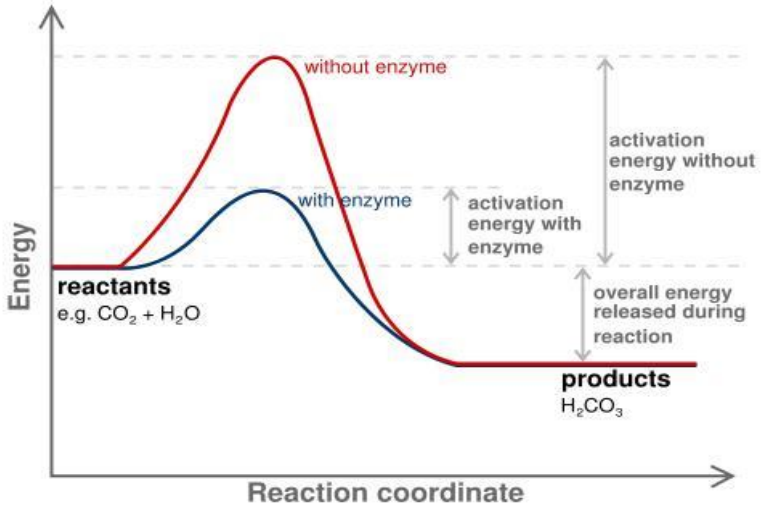
- ✓ **Enzymes are specific** whereas inorganic catalysts can react with a variety of substrates. For example, hydroxide ions can catalyze the formation of double bonds and also the hydrolysis of esters. Usually enzymes catalyze only a single type of reaction, and often they work only on one or a few substrate compounds.
- ✓ **Enzymes work under mild conditions** whereas inorganic catalysts often require high temperature and/or pressure to function. For example, nitrogen can be reduced to ammonia industrially by the Haber process, catalyzed by iron at 500° C. and at 300 atmospheres pressure of N_2. In contrast, the same reaction is carried out enzymatically at 25°C and less than 1 atmosphere pressure of N_2. These gentle conditions of temperature, pressure, and pH characterize enzymatic catalysis, especially within cells.
- ✓ **Enzymes are stereospecific** whereas inorganic catalysts of a reaction usually leads to a mixture of stereoisomers. For example, the addition of acid-catalyzed water to a double bond leads to an equimolar (50:50) mixture of D and L isomers where the water is added. In contrast, catalysis of water addition by enzymes results in complete formation of either the D or L isomer, but not both.

- ✓ **Enzymes are macromolecules;** the macromolecules are composed of protein, or in a few cases, RNA whereas most inorganic catalysts are either surfaces, for example, metals like platinum, or else small ions, such as hydroxide ions.

HOW ENZYMES WORK

- Before a reaction can take place, it must overcome an energy barrier by exceeding its activation energy.
- Enzymes operate by lowering this activation energy and thus permit the reaction occur more readily.
- As heat is often the source of activation energy, enzymes often dispense with the need for this heat and therefore allow reactions to take place at lower temperatures.
- Due to this many reactions that would not occur ordinarily at the temperature of an organism, do so readily in the presence of enzymes.

Illustration of how enzymes lower the activation energy



MECHANISM OF ENZYME ACTION

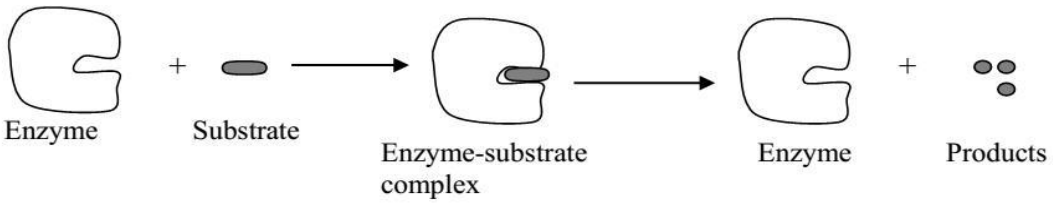
Each enzyme has a unique surface structure which provides a precise position known as active site, at which the substrate can join the enzyme molecules to form an enzyme substrate complex.

This infinite contact is maintained until the reaction is complete. The precise and specific fit between enzyme and substrate is sometimes compared with the lock and key mechanisms. There are two theories put forward to describe the mechanism of enzyme action i.e. **lock** and **key** hypothesis and induced fit hypothesis.

LOCK AND KEY HYPOTHESIS

- The theory suggests that the enzyme has a specific region known as the active site where the substrate fits like a key fits in a lock.
- It further states that the shape of the Active Sites of Enzymes are exactly complementary to the shape of the Substrate.
- When a substrate molecule with a complementary shape to the active site of the enzyme collides with an enzyme, the substrate will fit into the Active Site and an Enzyme-Substrate Complex will form.
- This breaks down to release the products and the enzyme, can now pick other substrates.

Illustration of the lock and key hypothesis



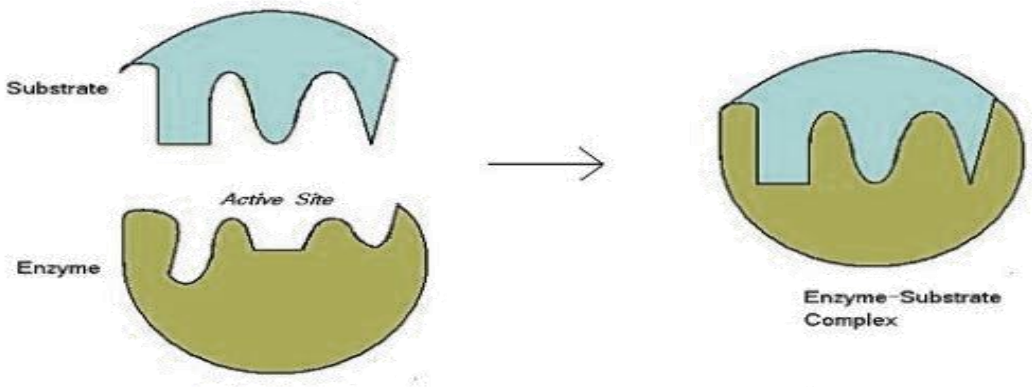
NOTE: the lock and key hypothesis is important because;

- It explains why enzymes are specific in action i.e. only substrates with complementary shapes to the active site fit into the active sites and are converted to products.
- It explains why the rate of enzyme controlled reaction is affected by substrate concentration. If all the active sites are in use, no more substrates can fit or occupy the active site hence the rate is constant.
- It explains why enzymes can be inhibited.
- It explains why enzymes are able to lower the activation energy in a chemical reaction.

INDUCED FIT HYPOTHESIS

- This is a more recent model in describing the way enzymes work. It states that the shape of Active Sites are not exactly Complementary, but change shape in the presence of a specific substrate to become Complementary.
- When a substrate molecule collides with an enzyme, if its composition is specifically correct, the shape of the enzyme's Active Site will change so that the substrate fits into it and an Enzyme-Substrate Complex can form.
- The reaction is then catalysed and an Enzyme-Product Complex forms.
- This is because the bonds between the amino acids of the active site of the enzyme are relatively flexible and thus when the substrate combines with an enzyme, the active site may mould into the shape of the substrate.

Illustration of induced fit hypothesis



Induced-fit Model. - The enzyme active site forms a complementary shape to the substrate after binding.

CLASSIFICATION OF ENZYMES

Enzymes can be classified based on the **type reaction** they catalyze.
The following are some of the examples,

1. **Isomerase;** these catalyze reactions involving rearrangement of groups within a molecule. They include isomerases and mutases.
2. **Phosphorylases**; these catalyze reactions involving addition of a phosphate
3. **Hydrogenases;** these catalyze reactions involving addition of hydrogen.
4. **Dehydrogenase;** these catalyze reactions involving removal of hydrogen.
5. **Kinases;** these catalyze reactions involving movement of molecules from one area to another.
6. **Carboxylases;** these catalyze reactions involving addition of Carbon dioxide.
7. **Oxidoreductases;** catalyze reactions that involve transfer of oxygen and hydrogen atoms between substances i.e oxidation-reduction reactions. Such as oxidases and dehydrogenases.
8. **Transferases;** these catalyze reactions that involve transfer of a chemical group from one substance to another such as Phosphorylases and transaminases.
9. **Hydrolases;** these catalyze reactions that involve hydrolysis. They include peptidases, lipases and phosphatases.
10. **Lyases;** these catalyze reactions that involve addition or removal of a chemical group by a method other than hydrolysis. They include decarboxylases.
11. **Ligases;** these catalyze reactions that involve formation of bonds between two molecules using energy derived from breakdown of ATP. They include synthetases.
12. **Polymerases;** These catalyze reactions involving joining together small units called monomers in order to form a long chain called polymer e.g DNA polymerase and RNA polymerase.

PROPERTIES OF ENZYMES

- They are all protein in nature.
- They are specific in their action i.e. they operate only on specific substrates.
- They speed up the rate of chemical reactions (they are catalysts).
- They are effective even in small amounts.
- They remain unchanged at the end of the reaction.
- They are denatured by high temperatures since they are protein in nature and are inactivated by low temperatures.
- They are inactivated by inhibitor chemicals such as poisons e.g. cyanide).
- They work at a specific pH. (Either neutral or acidic or alkaline).
- Their reactions are reversible.
- Their activity can be enhanced by enzyme activators e.g. chloride ions activate amylase.

CO-FACTORS

A co-factor is a non-protein substance which is essential for some enzymes to function efficiently. They may be;

- Organic groups that are permanently bound to the enzyme; **prosthetic groups** such as haem; haem is a ring-shaped molecule with iron at its centre, apart from being an oxygen carrier in haemoglobin, it is also a prosthetic group in electron carrier cytochrome and the enzyme catalase.

- Cations (positively charged metal ions); **activators**, which temporarily bind to the active site of the enzyme, giving an intense positive charge to the

enzyme's protein. Such as an enzyme thrombokinase, which converts prothrombin to thrombin during blood clotting is activated by calcium ions.

- Organic molecules, usually vitamins or made from vitamins; **coenzymes**, which are not permanently bound to the enzyme molecule, but combine with the enzyme-substrate complex temporarily. Such as derivatives of vitamins e.g nicotinamide adenine dinucleotide is a coenzyme by acting as a hydrogen acceptor.

ALLOSTERIC SITES

- An allosteric site is a site on an enzyme, unrelated to its active site, which can bind an effector molecule. This interaction is another mechanism of enzyme regulation. Allosteric modification usually happens in proteins with more than one subunit.
- Allosteric interactions are often present in metabolic pathways and are beneficial in that they allow one step of a reaction to regulate another step.
- They allow an enzyme to have a range of molecular interactions, other than the highly specific active site

INHIBITORS

The tare of enzyme controlled reactions maybe decreased by the presence of inhibitors. There are two types of inhibitors viz;

- ✓ Reversible inhibitors
- ✓ Irreversible inhibitors

REVERSIBLE INHIBITORS

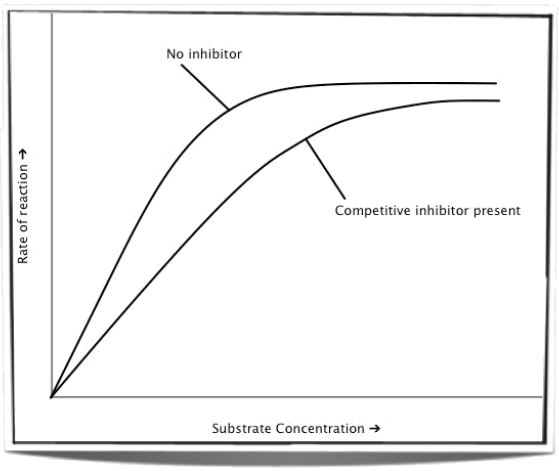
- The effect of this type of inhibitor is temporary and causes no permanent damage to the enzyme because the association of the inhibitor and the enzyme is loose and thus the inhibitor can easily be removed.
- Removal of the inhibitor restores the activity of the enzyme to normal. There are two types of reversible inhibition;

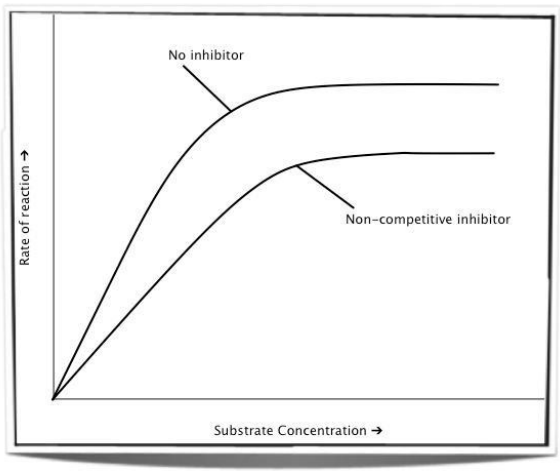
a. Competitive/ active site directed inhibitors;

- ✓ These compete for the active site as are structurally similar to the substrate of the enzyme and are able bind to the active site. This means that when a competitive inhibitor binds to the active site of an enzyme, it prevents the substrate from binding to the active site.
- ✓ Only once the inhibitor has been released from the active site can the substrate bind.
- ✓ The effects of a competitive inhibitor can be reduced by increasing the substrate concentration. More substrate would successfully bind to the active site than inhibitor and therefore reducing the effect of the inhibition. The maximum rate of reaction or a level very close to the maximum rate of reaction can be reached.
- ✓ This is because the substrate and the inhibitor are in direct competition, the greater the proportion of substrate molecules, the greater their chances of finding the active sites, leaving fewer to be occupied by the inhibitor.
- ✓ An example of a competitive inhibitor is malonate/ malonic acid. Malonate is structurally similar to the substrate succinate. Succinate is found in the Krebs cycle of aerobic respiration and binds to the active site of the dehydrogenase enzyme. Malonate can compete with succinate for the active site and in doing so it can prevent succinate from binding.

Graph illustrating the effect of reversible inhibitors

Competitive inhibition **non-competitive inhibition**





b. Non-competitive / non-site directed inhibitors

- ✓ These are not similar to the substrate and they do not bind to the active site of the enzyme. Instead they bind to a different site usually an allosteric site on the enzyme and change the conformation of the active site.
- ✓ The substrate may still be able to bind to the active site however the enzyme is not able to catalyse the reaction or can only do so at a slower rate. This is because the active site can no longer properly accommodate the substrate.
- ✓ In this an increase in substrate concentration will not therefore reduce the effect of the inhibitor.
- ✓ An example of a non-competitive inhibitor is ATP. When ATP accumulates it binds to a site other than the active site on the enzyme phosphofructokinase. In so doing, it changes the enzyme conformation and lowers the rate of reaction so that less ATP is produced.

Note;

1. Competitive Enzyme Inhibitors work by preventing the formation of Enzyme-Substrate complexes.
2. Non-competitive Enzyme Inhibitors work by preventing the formation of Enzyme-Product Complexes.
3. Non-competitive inhibitors are mostly non reversible inhibitors. Noncompetitive inhibitors include; heavy metals such as mercury, lead, silver, etc, cyanide, nerve gas, insecticides, herbicides, etc.

IRREVERSIBLE INHIBITOR

- × These are inhibitors that leave the enzyme permanently damaged and so unable to carry out its catalytic function.
- × They include heavy metal ions that cause breakage of the disulphide bonds, these bonds to maintain the shape of the enzyme molecule therefore once broken the enzyme molecule's structure becomes irreversibly damaged with the loss of its catalytic properties.

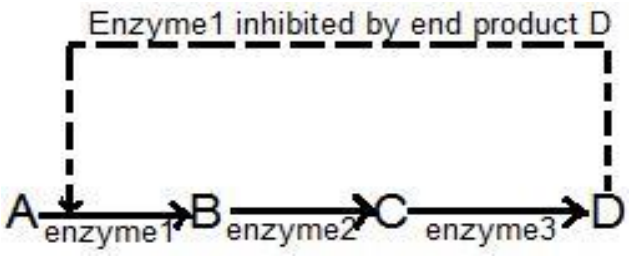
Importance of inhibition; enzymes;

- ☑ can be used in medicine and agriculture
- ☑ control metabolic pathways by regulating the different stages in them
- ☑ Provide important information about the shapes and properties of enzymes.

CONTROL OF METABOLIC PATHWAYS

1. END PRODUCT INHIBITION

- Metabolic pathways are made up of many chemical reactions and these reactions are catalysed by enzymes. Often, the product of the last reaction in the pathway inhibits the enzyme that catalyses the first reaction of the pathway. This is called end-product inhibition and it involves non-competitive inhibitors.
- The product of the last reaction of the metabolic pathway will bind to a site other than the active site of the enzyme that catalyses the first reaction. This site is called the allosteric site.
- When it binds to the allosteric site it acts as non-competitive inhibitor and changes the conformation of the active site. Therefore, it makes proper accommodation of the substrate by the enzyme's active site unlikely. Once the inhibitor is released from the allosteric site, the active site returns to its original conformation and the substrate is able to bind again.
- There is a clear advantage in using end-product inhibition for controlling metabolic pathways. When there is an excess of end-product, the whole metabolic pathway is shut down as the end product inhibits the first enzyme of the pathway. Therefore less of the end product gets produced and by inhibiting the first enzyme it also prevents the formation of intermediates.
- When the levels of the end product decrease, the enzymes start to work again and the metabolic pathway is switched on.



2. NEGATIVE FEEDBACK MECHANISM

- It follows a principle that the information from the end of a pathway which is fed back to the start has a negative effect; that's a high product concentration reduces its own production rate.
- In this mechanism, the product concentration/level has a direct effect on the reactants in a way by inhibiting the enzyme's catalytic activities;
- If the level of the product falls below normal, the inhibition is reduced thus causes more of the reactants to react to form the products to set the level back to normal.
- If the level of the product rises above the normal, the inhibition of the enzyme increases and in so doing the level of the product is reduced.

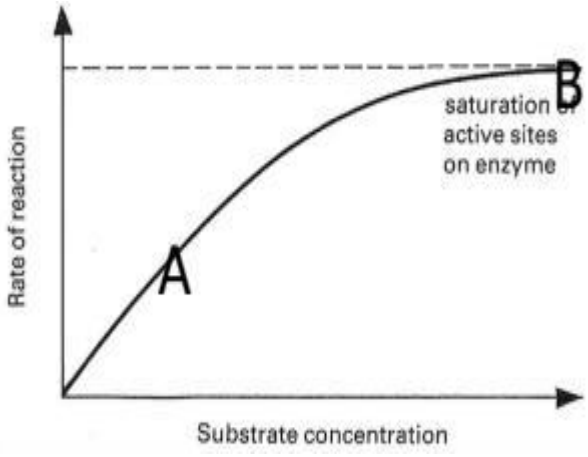
FACTORS AFFECTING ENZYME ACTIVITY

- The activity of an Enzyme is affected by its environmental conditions. Changing these alter the rate of reaction caused by the enzyme.
- In nature, organisms adjust the conditions of their enzymes to produce an Optimum rate of reaction, where necessary, or they may have enzymes which are adapted to function well in extreme conditions where they live.

a. **Substrate concentration**;

The rate of enzyme controlled reaction increases with increase in substrate concentration until all the active sites of the enzyme are occupied by the substrate

molecule. At this point the rate of reaction can only be increased by increasing the enzyme concentration.



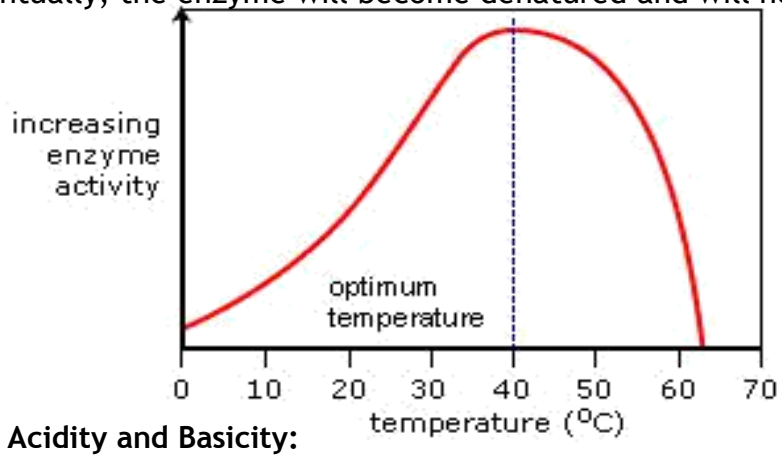
At A the rate of reaction increases with enzyme concentration because there are free active sites into which more substrates fit increasing the rate of product formation.

At B the rate of reaction is constant because all the enzyme active sites are occupied by substrates. Any more substrate molecules added will have no active sites to be occupied hence constant rate of reaction. The limiting factor at this point is the low enzyme concentration.

b. **Temperature**;

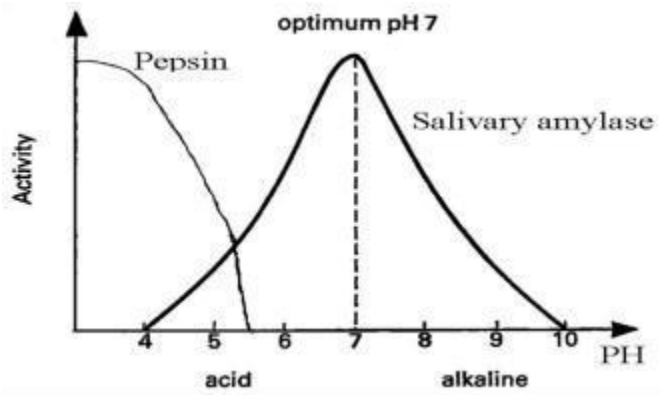
- ✓ Within the physiological range (4^0c-40^0c) the rate of the enzyme controlled reaction increases with increase in temperature. Increasing temperature increases the Kinetic Energy that molecules possess. In a fluid, this means that there are more random collisions between molecules per unit time. Since enzymes catalyse reactions by randomly colliding with Substrate molecules, increasing temperature increases the rate of reaction, forming more product.
- ✓ Beyond 40^0c (optimum), the rate of the reaction decreases increasing temperature as the temperature increases the Vibrational Energy that molecules have, specifically in this case enzyme molecules, which puts strain on the bonds that hold them together.
- ✓ As temperature increases, more bonds, especially the weaker Hydrogen and Ionic bonds, will break as a result of this strain. Breaking bonds within the enzyme will cause the Active Site to change shape.
- ✓ This change in shape means that the Active Site is less complementary to the shape of the Substrate, so that it is less likely to catalyse the reaction. Eventually, the enzyme will become denatured and will no longer function.

c.



c. pH - Acidity and Basicity:

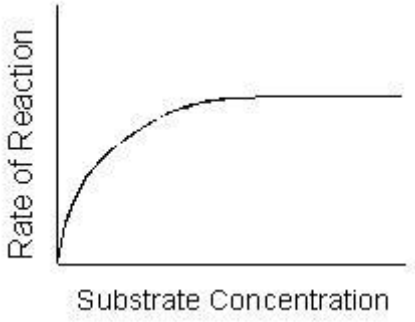
All enzymes work efficiently within a particular PH range. However there is an optimum PH for each enzyme. Any deviation from the optimum PH results in Denaturation of the enzyme hence decrease in the rate of reaction. Most enzymes work well under specific pH such as; pepin-2.0, sucrase-4.5, enterokinase-5.59, salivary amylase-4.8, catalase-7.6, chymotrypsin-7, pancreatic lipase-9.0

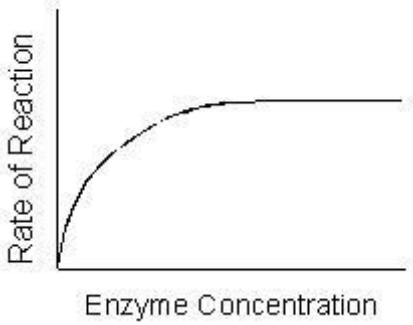


d. Enzyme concentration;

Provided there is an excess of substrate molecules, the rate of an enzyme controlled reaction increases with increase in enzyme concentration. This is because the number of active sites increases which leads to increase in number of substrate molecules that fit into and occupy the active sites hence increase in the rate of product formation.

Graphs showing effect of concentration on enzyme controlled reactions.





e. Enzyme inhibitors;

These lower the rate of enzyme controlled reactions or they may stop enzyme action altogether.

f. Presence of cofactors;

For some enzymes, the rate of enzyme controlled reaction depends on cofactors.

COMMERCIAL APPLICATION OF ENZYMES

- Used in biological washing powders. The powders usually contain proteases which remove food stains such as food, blood, allergens and bacteria.
- Used in meat tenderizers to soften meat e.g papain
- In baking industry α-amylase is used.
- Used in sweeteners. Glucose isomerase is used to make the soft drinks and cakes taste sweet.
- Many are used in industry to make cheese and other dairy products.
- Used in photographic industry. Protease ficin is used to digest the protein coat on the film when developing the image.
- Used in paper in paper industry. Amylase is used to remove starch from the raw materials.

I thank you very much for you have been able to complete the topic chemicals of life. In this chapter we have looked at what chemicals of life mean, considering organic and inorganic chemicals that make up organisms. We looks at acids, bases and salts, mineral salts, water, carbohydrates, vitamins and proteins. In each we have been able to critically look at the detail and how it has been able to serve biological functions. We concluded the chapter by looking at enzymes which we considered as biological catalysts, looked at their properties, factors that affect their activity, how they operate, control of metabolic pathway and their classification among other aspects.
Am sure you can now try out the questions below

1. (a) Describe the significance of physical properties of water to organism.
(b) Explain why lipids are better storage material in animals than carbohydrates.
2. (a) Giving examples, describe the use of nitrogen to plant and animal bodies
3. Relate the properties of water to its biological roles.
4. explain how the following are related to the protein structure of enzymes
   i. The effect of high temperature on an enzyme controlled reaction
   ii. Substrate specificity
   iii. The effect of inhibitors
   b. describe how an enzyme controlled reaction can be affected by a non-competitive inhibitor.
5. a) describe the chemical composition and variety of carbohydrates in nature
b) outline the roles of carbohydrates
6. describe the structure of cellulose and glycogen and as well compare the two carbohydrates
7. a) describe the biological function of amino acids
b) describe how amino acids form a polypeptide
c) how do inhibitors change the rate of enzyme controlled reaction?
8. a) outline the causes of nutrient deficiencies in soils
b) explain how plants have overcome the problem of nitrogen and phosphorous deficiencies in soils they grow in.

END OF TOPIC CHEMICALS OF LIFE

3.CELL PHYSIOLOGY

MOVEMEMNT IN AND OUT OF THE CELL

- The various organelles and structures within a cell require a variety of substances in order to carry out their functions.
- In turn they form products, some useful and some wastes. Most of these substances must pass in and out of the cell. This is satisfied by majorly four processes viz;

× Active transport
× Diffusion
× Osmosis
× Phagocytosis
× pinocytosis

DIFFUSION

This is the process by which molecules and ions (substances) move from a region of their high concentration to a region of their low concentration.
This is possible because molecules of which substances are in a random motion as explained by kinetic theory. This process is fully passive and thus does not require energy to occur.

Where does diffusion occur?

✓ Diffusion occurs across fully and partially permeable membranes such as those surrounding cells and anywhere for as long there is a diffusion gradient; difference in concentration of diffusing molecules.

Importance of diffusion

- Gaseous exchange across respiratory surfaces.
- Absorption of food substances, such as glucose such as amino acids and mineral salts via the got walls into the blood stream occurs by diffusion.
- Removal of waste substances from body tissues occurs in aqueous solution by diffusion.
- Movement of chloride and hydrogen carbonate ions into and out of red blood cells during the chloride shift occurs by facilitated diffusion.

FACTORS THAT AFFECT THE RATE OF DIFFUSION

☑ **Concentration gradient, t**he concentration gradient is the difference in concentration of particles of a substance between two regions. The greater the difference in concentration between two regions of a substance, the greater the rate of diffusion and thus the steeper the concentration gradient the faster the rate of diffusion.

☑ **Distance over which diffusion occurs: t**he shorter distance between two regions of different concentrations the greater the rate of diffusion. Rate of diffusion is proportional to the reciprocal of the square of the distance. Rate of diffusion is faster over very short distances.

☑ **Surface area over which diffusion occurs:** the larger the surface area the greater the rate of diffusion.

- ☑ **Nature of the structure across which diffusion occurs**, diffusion usually takes across epithelial layers or cell membranes, variation in the structure across which diffusion occurs for example, the greater the number and life of pores in cell membranes the rate of diffusion.
- ☑ **Nature and size of diffusing molecules or ions,** small molecules and ions diffusion faster than larger ions. Fat soluble molecules diffuse faster through the cell membranes than water soluble molecules.
- ☑ **Temperature,** Increase in temperature increases the rate of diffusion this is because increase in temperature increases the kinetic energy of molecules and ions, thereby increasing the number of collisions of molecules or ions with the same surface membrane. This increase the rate of diffusion through the membrane.
- ☑ **Electrical Charges**: Movements of charged particles; ions also influenced by electrical attraction or repulsion
- ☑ **High Pressure of environment**, surrounding a cell, high pressure of the surrounding increases the speed or kinetic energy of particles increasing the rate of diffusion through a membrane.

FICK'S LAW

- × It states that the diffusion of a substance across a membrane is directly proportional to the surface area of the membrane and to the difference in concentration in on either side, and inversely proportional to the thickness of the membrane

$$\text{Rate of diffusion} = \frac{\text{Surface area} \times \text{difference in concentration}}{\text{Thickness of membrane}}$$

Note;

1. Increasing the factors on the numerator of the equation will make diffusion faster, while increasing that in the denominator will slow it down
2. Fick's law applies to situations where there is no barrier to the movement of substances. Like the diffusion of a dye in a container of water, the diffusion of a substance into or out of a cell is a form of passive transport

TYPES OF DIFFUSION

Diffusion maybe simple or facilitated;

a. SIMPLE DIFFUSION;

- ✓ This is a process by which solutes are moved along a concentration gradient in solution or across a semipermeable membrane/ partially permeable membrane without help from other substances.
- ✓ Simple diffusion is carried out by the action of hydrogen bonds forming between water molecules and solutes.
- ✓ Water molecules move in to surround the individual solute molecules and maximizes hydrogen bonding.
- ✓ However hydrogen bonds are temporary. In this helps distribute the solute evenly throughout the solution.

Examples of simple diffusion applicability;

- Uptake of carbon dioxide by plant cells.
- Uptake of nutrients by bacteria
- Uptake of oxygen by cell
- Movement of ethanol across cells etc.

b. FACILITATED DIFFUSION;

✓ This is a process by which substances are moved from a region of their higher concentration to a region of their lower concentration with the help of a transport molecule.
✓ Since molecules move along their concentration gradient, chemical energy is not required.
✓ The transport molecules maybe **carrier proteins** or **channel proteins.**

Channel proteins; the channels form water filled connections across the lipid bilayer which allow water soluble substances to move across.
Due to this they are therefore important in transporting ions.
These channels are selective in that they will open or close in response to certain signals such as change in voltage or binding of another molecule. Thus controlling exit and entry of molecules and ions.
Carrier proteins; these bind molecules to themselves and then change shape as a result of this binding in such a way that the molecules are released to the inside of the membrane.

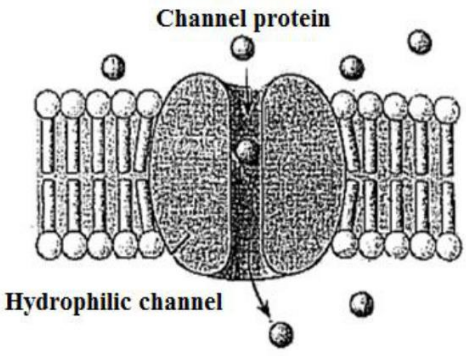
Differences between carrier and channel proteins

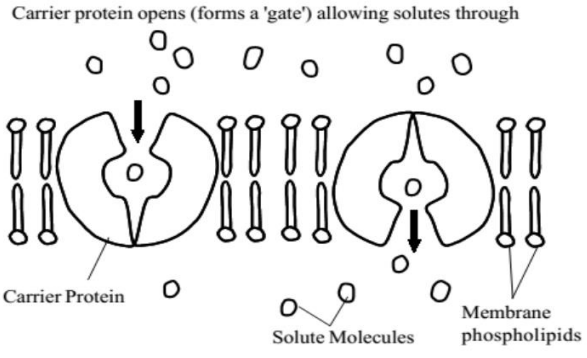
CHANNEL PROTEINS	CARRIER PROTEINS
Position is fixed	Changes conformation
Solute molecules diffuse through pores	Solute molecules are bond to one side and released to the other
Have high transport rates	Have low transport rates
They are lipoproteins	They are glycoproteins
Only transport water soluble molecules	Transport both water soluble and insoluble molecules
Synthesized in the rough endoplasmic reticulum	Synthesized in the free ribosomes in the cytoplasm

Examples of facilitated diffusion applicability;

- Movement of glucose molecules across the cell
- Movement of sodium and chloride ions across the cell

Illustration of facilitated diffusion





Or check illustration in understanding biology page 67 fig 4.18

OSMOSIS

This is the net movement of freely moving solvent molecules from a region of their higher concentration to a region of their lower concentration through a partially permeable membrane. Since solvent in biological systems, we can now define osmosis as;

This is the net movement of freely moving water molecules from a region of their higher concentration to a region of their lower concentration through a partially permeable membrane.

Note; a semi permeable membrane is not only permeable to water molecules but as well solutes. However it should be noted that in osmosis we base explanation on the water molecules movement.

TERMS USED IN OSMOSIS

1. **Water potential (ψ);**

- This the measure of the relative tendency/ capacity of a system to lose water by osmosis. Or is the pressure exerted by freely moving water molecules in a system
- Water molecules possess kinetic energy, both in liquid or gaseous form they move rapidly and randomly from one location to another.
- The greater the concentration of water molecules in a system, the greater the total kinetic energy of water molecules in that system and the higher its water potential.
- Consider a solution with a higher water potential separated from a solution with a lower water potential by a partially permeable membrane. More water molecules move from the region of higher water potential to the region of lower water potential than in the other direction.
- The movement continues until the water potentials on both sides of the membrane are equal. Water molecules continue to move in both directions after equalization, but there is no net movement.
- The more concentrated a solution is the more negative is its water potential and thus water will move from a region of less negative (higher) water potential to one of more negative(lower) water potential.

NOTE; the water potential of pure water is zero. This is because under standard conditions of temperature 25^{0}C and pressure 100kPa pure water has no solutes and therefore there is no pressure in the container.

2. **Osmotic pressure;** is the amount of hydrostatic pressure that must need be applied to a solution to prevent it from osmotically drawing water into itself across a semi -permeable membrane.

3. **Osmotic potential/ solute potential (ψ_s);**

This the measure of the relative tendency/ capacity of a system to take in water by osmosis

- Osmotic pressure increases as osmotic potential decreases.

- Addition of solute molecules in pure water reduces the concentration of water molecules and hence to lower the water potential. This is because water molecules cluster around the solute molecules.
- As the concentration of solutes increases, clustering also increases, further lowering the water potential.
- In other words, solute potential is a measure of the change in water potential of a system due to the presence of solute molecules. **This is always negative**.

Note; the more solute molecules present in a system the lower or more negative the solute potential becomes.

4. **Pressure potential(ψ_p);**

This is a hydrostatic pressure created by water entering the cell by osmosis outwards onto the cell wall.

WATER RELATION

Water potential = solute potential + pressure potential

$\Psi = \psi_s\ (-) + \psi_p\ (+)$

5. **Isotonic;**

An isotonic solution has the same concentration of water and solute molecules as is inside the cell. Water moves at a constant rate in and out of the cell and the cell maintains its original shape.

In animal and plant cells, the cell keeps its shape when in an isotonic solution. Most cells live in an isotonic environment and they are able to maintain their shape and survive

6. **Hypotonic solution;**

This is a solution that has a lower concentration of solute molecules than inside the cell. This causes the solution to have more water than the cell.

When a cell is placed in a hypotonic solution there is an osmotic influx of water into the cell.

7. **Hypertonic solution;**

This is a solution that has a higher concentration of solute molecules than inside the cell. This causes the solution to have less water than the cell.

When a cell is placed in a hypertonic solution there is an osmotic outflow of water from the cell.

OSMOSIS IN PLANT AND ANIMAL CELLS

A. ANIMAL CELLS

- A single-celled organism living in the sea is bathed in fluid which has the same water potential as its cytosol.
- Thus it causes no change in the volume of the cell. This is because the water potential inside and outside the cell is the same and there is no net flow of water in or out. A similar situation applies to organisms, such as the malarial parasite *Plasmodium,* which live in blood.
- An animal cell placed in fresh water has to deal with a very dilute medium which has a higher water potential than the cytosol. The fresh water is hypotonic to the cytosol. Water tends to enter the cell by osmosis causing the cell volume to increase.

- If the cell cannot eliminate the excess water such as a red blood cell, it bursts a process known as **lysis**.
- Organisms living in fresh water have mechanisms for eliminating excess water which enters by osmosis. Amoebae that live in ponds, for example, have a contractile vacuole which collects and gets rid of excess water, keeping the volume of the cell constant.
- An animal cell placed in a very salty solution copes up with the risk of losing water. When the external solution is of a sufficiently of a high solute concentration, its water potential is lower than that of the cell.
- In this water tends to be drawn out of the cell, causing it to shrink and shrivel.

B. PLANT CELLS

- Plant cells generally have a solute concentration which is markedly higher than that of their surroundings. The solutes are located mainly in the sap vacuole which is surrounded by the tonoplast.
- The cytoplasm has selectively permeable membrane enclosing the sap vacuole.
- When a plant cell is immersed in a solution which has a higher solute concentration than the cell sap, the volume the cell decrease since water passes out of its sap vacuole.
- This causes the protoplast to shrink to such an extent that it fully pulls away from the cell wall, leaving a perceptible gap between the cell wall and the protoplast a condition known as plasmolysis at this point the cell is flaccid.
- Plasmolysis sometimes happens to plants exposed to extremely salty water, but otherwise it rarely occurs in nature.
- The point at which plasmolysis, is just about to happen is called incipient plasmolysis. At incipient plasmolysis the protoplast has just ceased to exert any pressure against the cell wall so pressure potential at this point is zero.
- Water will continue to leave the protoplast until its contents are of the same water potential as the external solution. No further shrinkage then occurs.
- If a plasmolysed cell is placed in pure water or a solution of higher water potential than the contents of the cell, water enters the cell by osmosis.
- As the volume of the protoplast increases it begins to exert pressure against the cell wall and stretches it. The wall is relatively rigid, so the pressure inside the cell rises rapidly.
- As the pressure potential of the cell gradually increases, due to water entering by osmosis, the cell becomes turgid.
- When the tendency for water to enter a cell is exactly balanced by pressure potential, the amount of water leaving the cell equals that entering the cell. There is no further net uptake of water and the cell is now in equilibrium with the surrounding solution at this point the cell is at full turgor.
- At full turgor the cell can expand no more; the water potential of the cell reaches zero and the osmotic potential of the sap is exactly counterbalanced by the pressure potential.

Importance of cell turgidity

- ☑ The stems of herbaceous plants and non-woody plants (such as maize, banana and sugarcane) are maintained in an erect position by fully turgid cells tightly packed together to provide support.
- ☑ Turgor pressure holds the leaves in flat and horizontal position to receive sun.
- ☑ Enhances cell enlargement and stretches the stems leading to increase in growth.
- ☑ The opening and opening of stomata is governed by turgidity of guard cells.
- ☑ The quick nastic response of some plants such as thigmo nastic and sasmo nastic collapse of leaves and shoots of ***mimosa pudica*** are controlled by turgidity.

WILTING

- ✓ This is the loss of more water by transpiration than what the plant can absorb that eventually reduces turgor and the plant visibly droops.(stems and leaves)
- ✓ It Takes place on hot and dry days.
- ✓ Wilting is different from plasmolysis. Both involve the cells losing water, but for different reasons.
- ✓ In plasmolysis only the protoplast shrinks, leaving the cell wall behind. In wilting the whole cell, including the wall, shrinks, and no gap develops between the plasma membrane and the cell wall.

WATER STRESS

This is the excessive loss of water by a plant via transpiration than what the plant can absorb from the soil. In this the rate of loss is greater than the rate of replacement.

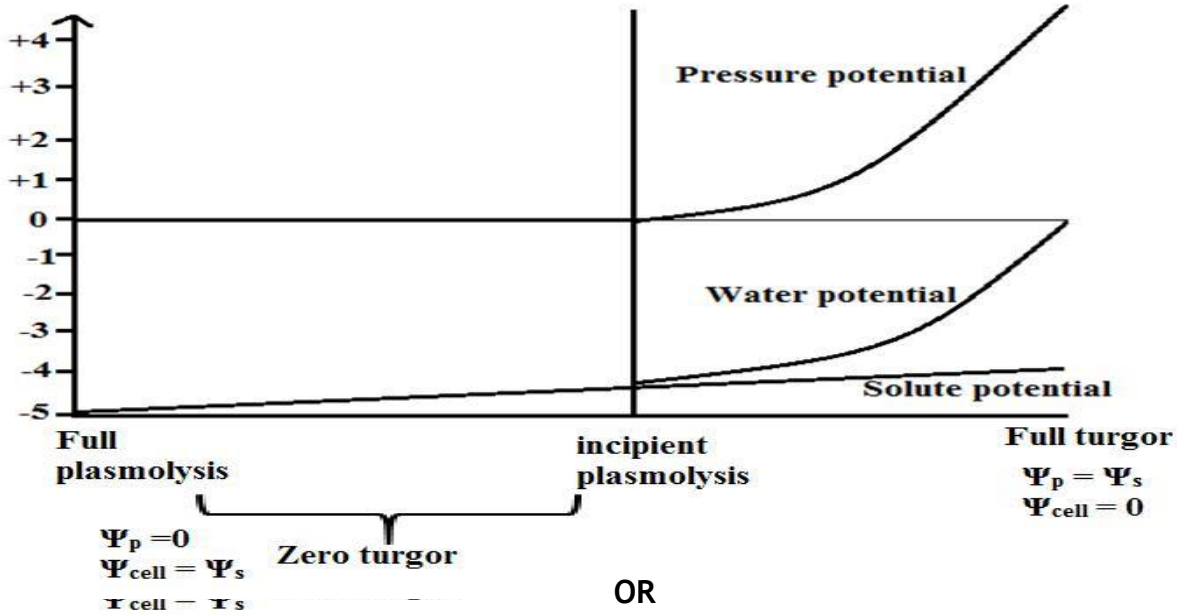
Effect of water stress

- ✓ Excessive water loss leads wilting.
- ✓ Stomata rapidly close due to secretion of Abscissic acid by cells in the wilted leaves. Stomatal closure reduces the rate of photosynthesis due to lack of carbon dioxide.
- ✓ Reduced photosynthesis causes a reduced growth rate leading to stunting.
- ✓ Excessive water loss can lead to desiccation and drying up of a plant which often leads to death.

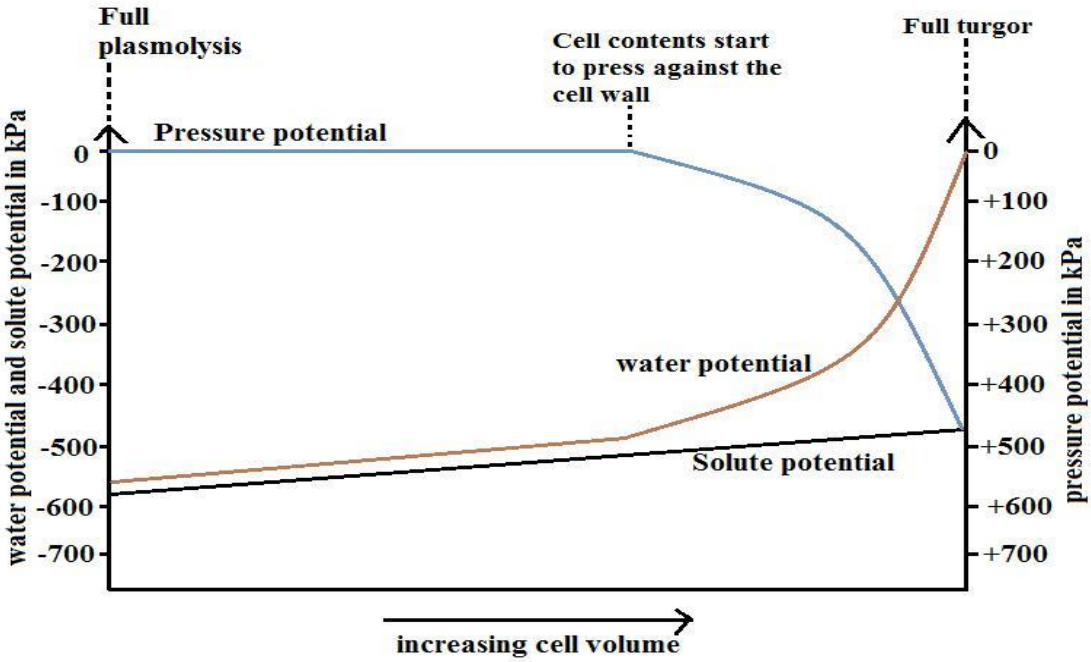
Differences between wilting and plasmolysis

Wilting	Plasmolysis
Occurs due to high temperature	Occurs due to presence of an osmotic gradient
The entire cell including the cell wall shrinks	Only the protoplast pulls from the cell wall
Water loss is great leading to desiccation which can cause death	Water loss is not a great can hardly result into death
Results drooping of the shoot and leaves of the plant	Does not result into drooping of the shoot and leaves of the plant

Graphs illustrating of water relations in plants



OR



OR check out graph in functional approach page 52



Now that you are well versed with water relation please;

- Compare water potential and solute potential
- Describe the changes in pressure potential, water potential and solute potential
- Explain your description

Based on graph number 2 above

ACTIVE TRANSPORT

This is the process by which molecules are transported from a region of their low concentration to a region of their high concentration **against** a concentration gradient.
This process is energy dependent and due to this cells that carry out active transport have numerous mitochondria, high concentration of ATP, a high respiratory rate.

Importance of active transport;

- Active loading of sugar into the phloem for transport in the plant.
- Selective reabsorption of glucose and sodium from the proximal convoluted tubules and sodium from the kidney cortex occurs by active transport.
- The Na-K pump responsible for development of a resting potential across cell surface membranes occurs by active transport. This enables conduction of nerve impulses and muscle contraction.
- Calcium ion responsible for muscle contraction in response to a nerve impulse is actively pumped by the calcium ion pump.
- Sodium pumps actively transports glucose and amino acids during their absorption from the gut into the blood stream.
- The absorption of mineral salts from the soil solution across the endodermis by root hairs occurs mostly by active transport.
- Fresh water fish carry out the active uptake of mineral ions from the external environment by special cells called chloride secretory cells in the gills.
- Removal of excess water from the amoeba by contractile vacuoles occurs by active transport.

Factors that affect active transport

- The energy (ATP) content of the cell will affect the functioning of active transport, as active transport requires energy.
- High Concentrations of the transporting substance will result in a quicker rate of active transport.
- Temperature; required energy comes from respiration, which requires the diffusion of oxygen which is high at high temperatures. Respiration also requires enzymes, which are sensitive to temperature changes where increase in temperatures to the optimum increase their activity.

Note:

- Due to the fact that active transport is affected by ATP concentration which ATP comes from respiration, any factor that reduces that rate of respiration or causes it to cease, will directly cause the slowing or stopping of active transport altogether.
- For example, cyanide that that attaches to copper prosthetic group of cytochrome oxidase making it unable to catalyze the combination of hydrogen atoms to oxygen in the electron transport system causes inhibition of respiration and thus active transport as well.
- Active transport involves protein carriers.

Check illustration in understanding biology page 69 fig. 4.21

Carriers involved in active transport;

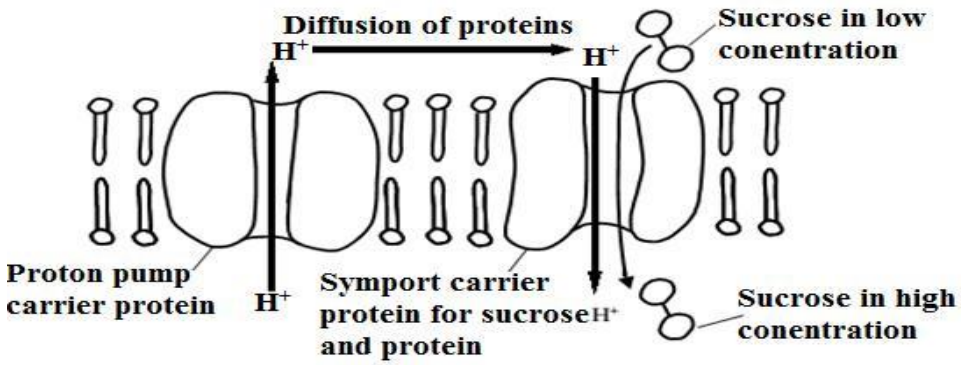
1. **Uniport carriers**; transport a single substance in a single direction. For example, some calcium pumps.
2. **Symport carriers**; transport two substances in the same direction for example, glucose-sodium pumps
3. **Antiport carriers**; transport two substances in opposite directions for example sodium-potassium pumps.

Detail of different pumps involved in active transport;

A. PROTON PUMP

- These are active transport mechanisms use to transport hydrogen ions; protons across membranes. Proton pumps are present in the vacuolar membranes of plant cells, yeasts and fungi, in the endoplasmic and lysosomal membranes of animal cells, in the inner mitochondrial membrane and in chloroplast thylakoid membranes.
- In many cases proton pumps enable other molecules to be transported with the protons. For example:
- sucrose is transferred across membranes (for example, chloroplast membranes, cell surface membrane) in conjunction with protons,
- ATP in the mitochondria is released by a proton pump mechanism during aerobic respiration,
- ATP in the chloroplasts is released by a proton pump mechanism during the light-dependent stage of photosynthesis.
- This is an example of co-transport in which the active transport of one substance indirectly drives the movement of another substance against a concentration gradient.
- The proton pump actively drives protons across the membrane using energy from ATP. This forms a high concentration of protons which then diffuse back across the membrane via the Symport carrier protein. This, by an unknown mechanism, enables sucrose to be actively transported across the membrane via the Symport carrier, against the sucrose concentration gradient

Illustration of co-transport



- The proton pump operating across the inner mitochondrial membrane uses energy from the electron transport chain to pump protons from the mitochondrial matrix into the compartment between the inner and outer mitochondrial membranes.
- The protons accumulate so that a steep concentration gradient exists between the compartment and the matrix.
- The inner membrane is impermeable to protons except through channels located in the stalked particles of the inner membrane. The protons diffuse back to the matrix through these channels and this provides energy to drive the synthesis of ATP from ADP and phosphate. The enzyme ATP-ase, in the stalked particles catalyses the ATP synthesis

Note; compare with that in advanced biology by Micheal Kent page 109

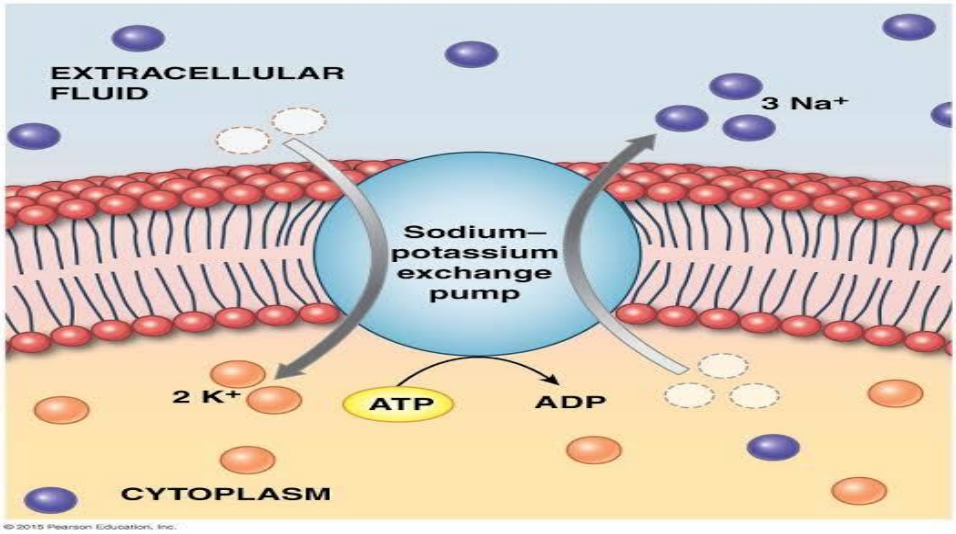
B. SODIUM-POTASSIUM PUMP;

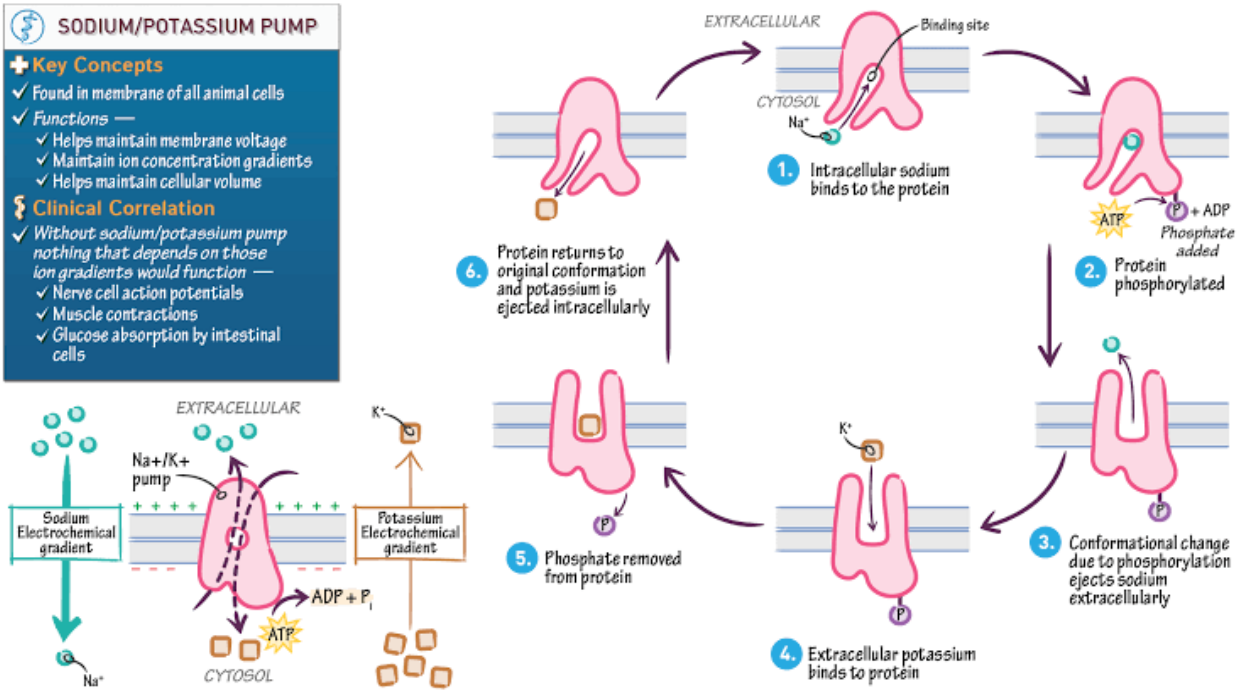
- The sodium –potassium pump is found in most plasma membranes.
- It is powered by ATP. The pump moves sodium and potassium ions in opposite directions each against its concentration gradient.
- In a single cycle, three sodium ions are extruded from and two potassium ions are imported into the cell.
- It is made up of Antiport carriers.

Mechanism of action

- The pump binds ATP, after binding ATP, binds 3 intracellular sodium ions.
- ATP is hydrolyzed, leading to phosphorylation of the pump at a highly conserved aspartate residue and subsequent release of ADP.
- A conformational change in the pump exposes the sodium ions to the outside. The phosphorylated form of the pump has a low affinity for sodium ions, so they are released.
- The pump binds 2 extracellular potassium ions. This causes the dephosphorylation of the pump, reverting it to its previous conformational state thereby transporting potassium ions into the cell.
- The unphosphorylated form of the pump has a higher affinity for potassium ions than potassium ions, so the two potassium ions are released.
- ATP binds and the process starts again.

Illustrations of action of sodium potassium pump





Differences between active transport and facilitated diffusion

Facilitated diffusion	Active transport
Passive process	Active process
Occurs along a concentration gradient	Occurs against a concentration gradient
Entropy increases	Entropy decreases
Does not utilize energy	Utilizes energy

Similarities, both;

- ✓ Highly specific in nature
- ✓ Need a carrier molecule
- ✓ Inhibited by competitive inhibitors
- ✓ Transport molecules and ions.

EVIDENCE THAT ACTIVE TRANSPORT IS AN ACTIVE PROCESS

(i) It is only found in living systems which are continuously producing energy by respiration.

(ii) Increase in temperature and oxygen concentration increases the rate of active transport.

(iii) When formation or use of ATP is inhibited by such agents as cyanide, active transport will not take place.

(iv) Cells that take part in active transport contain large number of mitochondria.

BULK TRANSPORT

This is the movement of macro molecules/ large molecules into or out of the cell. There are two kinds of bulk transport;

1. Exocytosis: moving materials out of the cell.
2. Endocytosis: moving materials into the cell.

EXOCYTOSIS;

- This is the process of exporting materials out of the cell by forming secretory vesicles. The materials to be exported are taken to the Golgi body where the materials are packaged into a membrane bound vesicle.
- The vesicle then move to and fuses with the cell membrane, this fusion causes the vesicle to spill its content out of the cell.
- It is the final step in the secretory pathway that typically begins in the endoplasmic reticulum (ER), passes through the Golgi apparatus, and ends at the outside of the cell.
- Important in expulsion of waste materials out of the cell and in the secretion of cellular products such as enzymes, peptide hormones and antibodies from cells and release of neurotransmitter from presynaptic neurons.

ENDOCYTOSIS;

Endocytosis is the movement of materials into the cell through membrane bound vesicles. There are 3 types of endocytosis;

- ✓ Pinocytosis; cell drinking
- ✓ Phagocytosis; cell eating
- ✓ Receptor mediated endocytosis

a. Pinocytosis, or cell drinking;

- × Pinocytosis is the movement of small molecules or liquids into the cell.
- × The cell forms an invagination and engulfs drops of fluid by pinching in.
- × It then forms small vesicles known as pinocytic vesicles than are released inside of the cell.
- × Pinocytosis is how animal cells make vacuoles (water filled sacs) and as well the process is used for intake of liquids rather than solids.

Significance of pinocytosis;

- ⌦ It's used by the human egg cell to take up nutrients from the surrounding follicle cells.
- ⌦ In the thyroid, the hormone thyroxine is stored as thyroglobulin in hollow structures called follicles when required thyroglobulin is taken up by pinocytosis by the follicle cells and then converted to thyroxine for release into the blood.

b. Phagocytosis or cell eating;

- Phagocytosis is the movement of large molecules into the cell that are too large to be transported by diffusion and active transport.
- The materials to be transported make contact with the cell membrane.

- The cell invaginates to form a cup-shaped depression in which particle is contained.
- The depression is then pinched off or budded off to form a vacuole or phagosome.
- The lysosomes then fuses with the phagosome whose hydrolytic enzymes break down the large molecules into useful contents that can be absorbed.

Where phagocytosis occurs;

- Certain unicellular organisms, such as the protists, use this particular process as means of feeding. It provides them part or all of their nourishment.
- In white blood cells where harmful bacteria can be ingested.

Feeding in amoeba

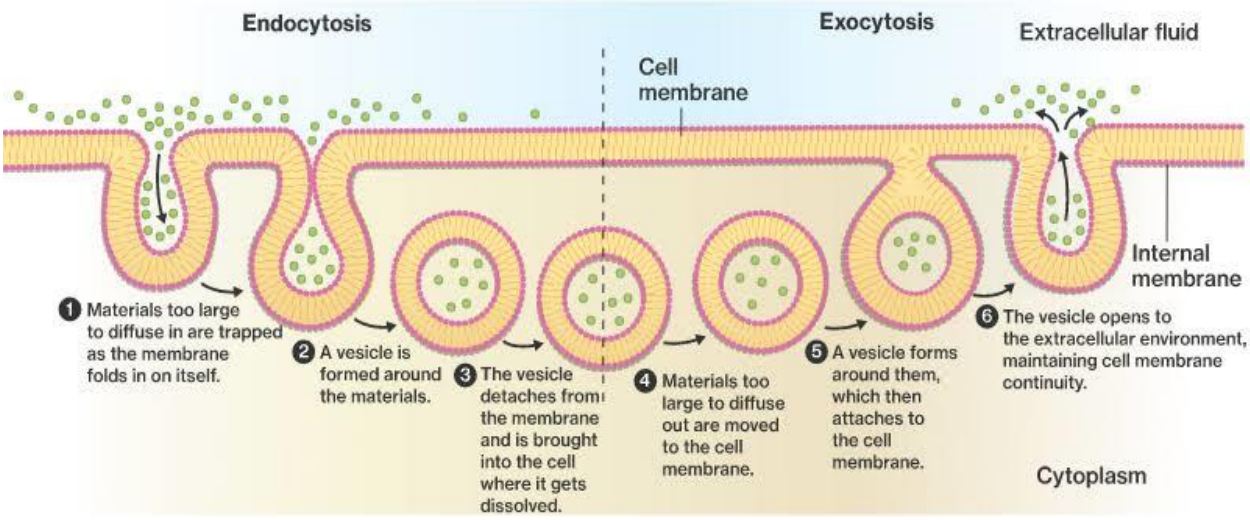
- This mode of nutrition is known as phagotrophic nutrition. In amoeba, phagocytosis takes place by engulfing the nutrient with the help of pseudopods that are present all over the cell.
- When the solid particle binds to the receptor on the surface of the phagocytic cell such as amoeba, then the pseudopodia extends and later surrounds the particle. Then their membrane fuses to form a large intracellular vesicle called phagosome.
- These phagosomes fuse with the lysosome, forming phagolysosomes in which ingested material is digested by the action of lysosomal enzymes.
- During its maturation, some of the internalized membrane is recycled to plasma membrane by receptor mediated endocytosis.

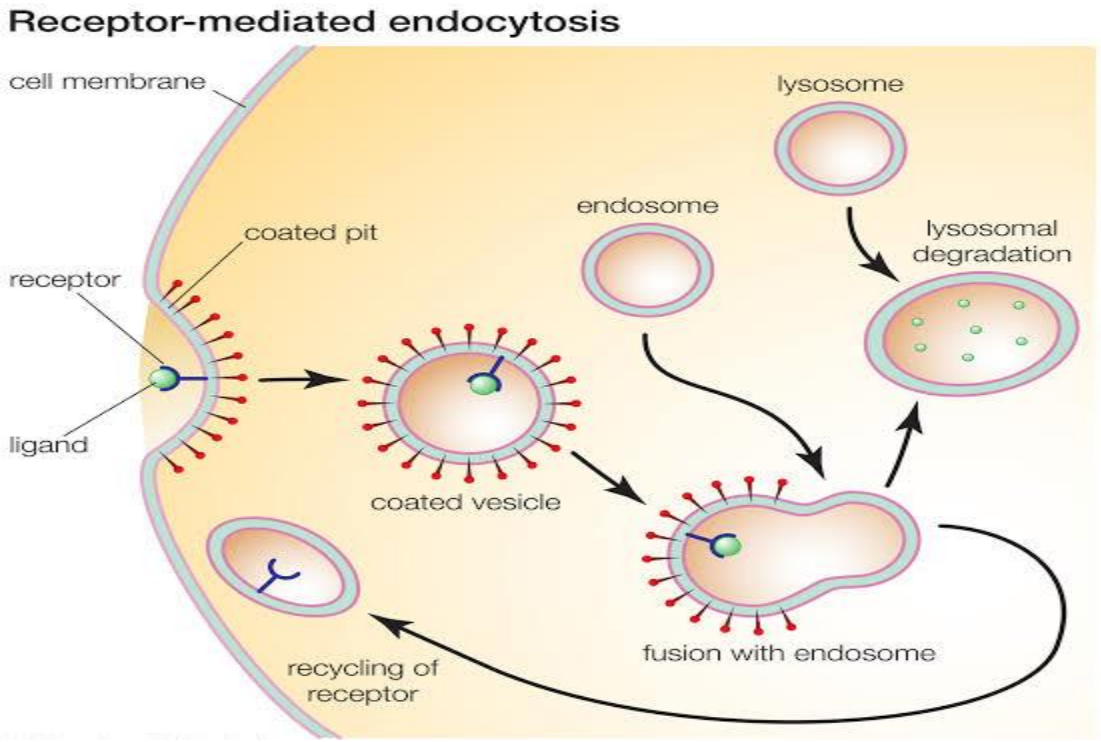
Note; for phagocytosis in white blood cells check in transport, sub-topic immune systems that will be discussed later.

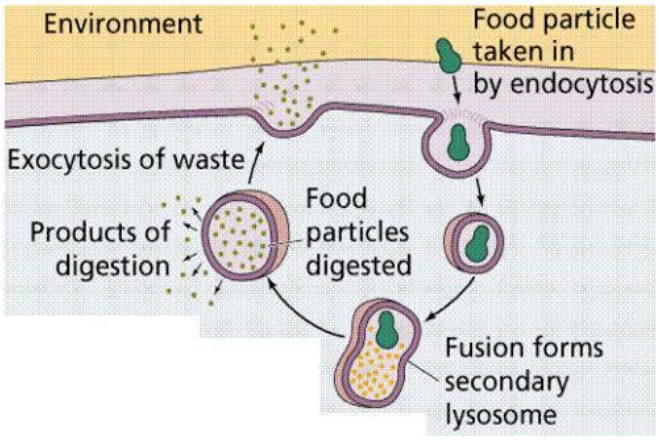
c. Receptor mediated endocytosis;

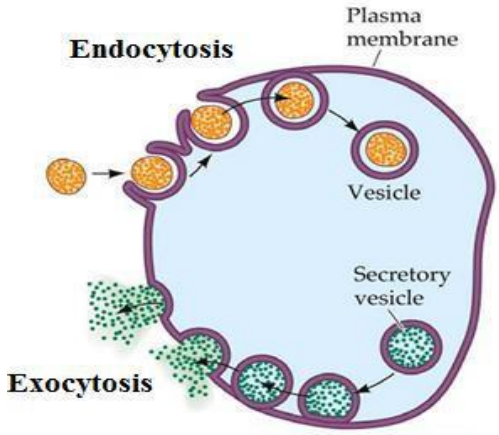
- Unlike phagocytosis and pinocytosis, receptor mediated endocytosis is a highly selective process of importing materials into the cell.
- This specificity is mediated by receptor proteins located on depressed areas of the cell membrane called coat pits whose cytosolic surfaces are covered by coat proteins.
- In receptor mediated endocytosis, the cell will only take in an extracellular molecule if it binds to its specific receptor protein on the cell surface this molecule is called a ligand
- Once bound, the coated pit on which the bound receptor protein is located invaginates and pinches in to form a coated vesicle.
- Like in non-phagocytosis, this coated vesicle then fuses with a lysosome to digest the engulfed material and release the contents into the cytosol.
- Mammalian cells use receptor mediated endocytosis to take cholesterol into cells.
- This is so because cholesterol in blood is usually found in lipid-protein complexes called low-density-lipoproteins which bind to specific receptor proteins on the surface, thereby triggering their uptake by receptor mediated endocytosis.
- It is the major process by which cells absorb metabolites, hormones and proteins among others.

Illustrations of bulk movement





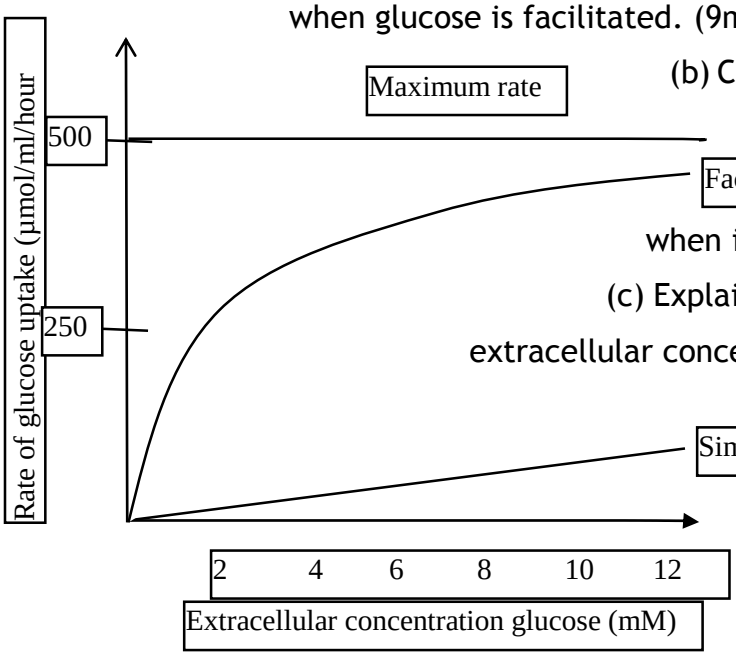




I thank you that you have been able to understand this topic to completion. We have looked at what movement in and out of the cell means by definition an detail study of all the processes involved starting with diffusion in which we were able to look at its application, factors affecting it and facilitated diffusion, osmosis in both plants and animal cells, active transport and its applicability in both plants and animals and we concluded with bulk movement looking at both exocytosis and endocytosis. With this am sure you can now try out the questions below.

Questions;

1. (2015/2/1) In an experiment, the rate of glucose uptake by the blood using simple and facilitated diffusion at varying extracellular concentration of glucose was measured. The results are shown in the figure below. Study the information and answer the questions that follow.



(a) Describe the rate of glucose uptake with increasing extracellular concentration when glucose is facilitated. (9marks)

(b) Compare the rate of glucose uptake when diffusion is facilitated and when it is not. (8mark)

(c) Explain the effect of increasing extracellular concentration of glucose on the uptake of glucose, when diffusion is facilitated. (8marks)

(d) Suggest what would happen to the rate of glucose if a respiratory poison was introduced into the cell membrane. Give an explanation for your answer. (06marks)

(e) Explain why

(i) Facilitated diffusion occurs (06marks)

(ii) The membrane is able to carry out facilitated diffusion (3marks)

2. Figure 1 shows changes in the different potentials of a fully plasmolysed plant cell placed in a hypotonic solution, and Figure 2 shows the rate of uptake of glucose by blood using simple and facilitated diffusion at varying extracellular concentration of glucose.

Figure 1

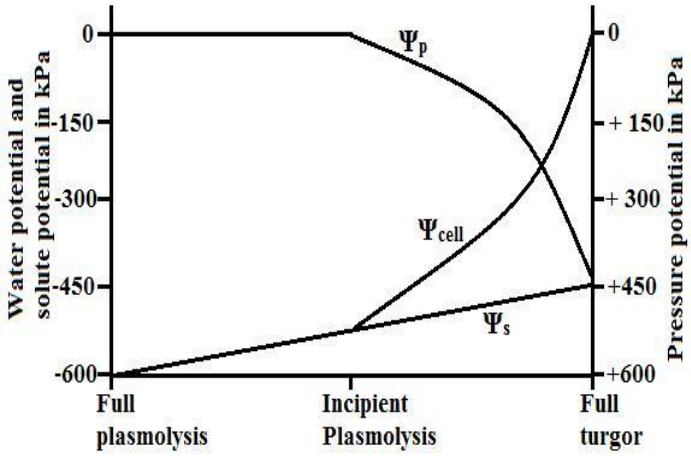
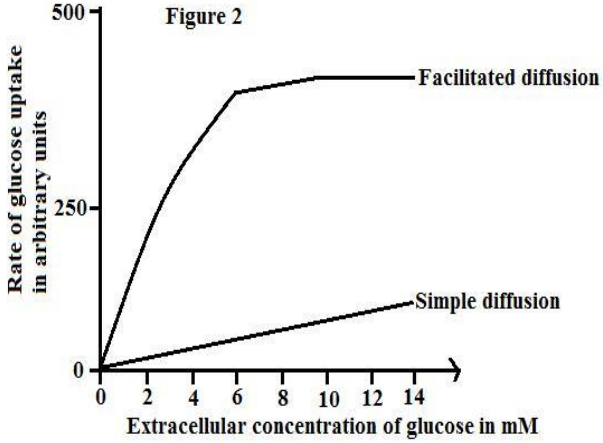


Figure 2



a. Compare the changes in pressure potential and water potential from full plasmolysis to full turgor.
b. Explain the change in water potential from full plasmolysis to full turgor.
c. Explain the effect of increasing extracellular concentration of glucose on the uptake of glucose when the diffusion is facilitated.
d. Outline the differences between the functioning of carrier proteins in facilitated diffusion and those in active transport.
e. Using a specific example, describe the functioning of anti-port carriers.

3. Mammalian red blood cells transferred from blood plasma to a less concentrated solution swell, and if they swell sufficiently, they burst; in which case they are said to have haemolysed. And when comparable discs of potato tuberare placed in sucrose solutions of varying concentrations, their mass changes. The table below shows the percentage of red blood cells haemolysed and the percentage change in mass of discs of potato tuber separately placed in a series of sucrose solutions ranging from 0.0 to 0.6M in covered dishes at a constant temperature of 20^0C:

Concentration of sucrose solution (mol/dm^3)	Percentage of red cells haemolysed	Percentage change in mass of potato tuber discs
0.0	100	+22
0.1	90	+17
0.2	80	+9
0.3	68	+3
0.4	30	-3
0.5	16	-10
0.6	0	-15

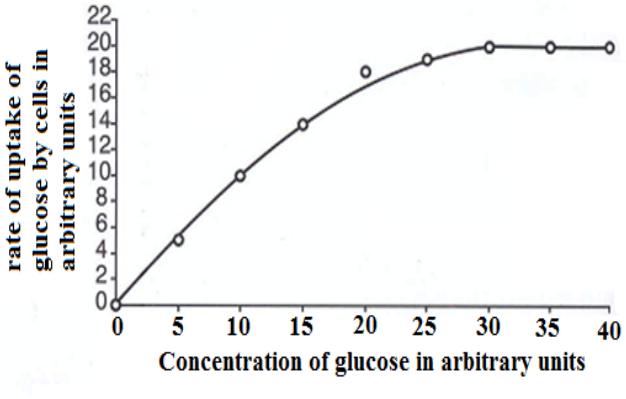
(a) Represent the information graphically using the same set of axes.
(b) From your graph determine:
(i) The sucrose concentration at which the proportion of haemolysed to non-haemolysed cells are equal.
(ii) The sucrose concentration that has an osmotic potential equal to the mean water potential of the cells of the potato tuber tissue.
(c) Fully explain how you arrived at your answers in (b) (i) and (b) (ii).
(d) Give an explanation of each of the following :

(i) Red blood cells placed in a 0.0M sucrose solution swell and burst while plant cells do not.
(ii) Red blood cells haemolysed over a range of sucrose solution concentrations rather than at one particular sucrose concentration.

(iii) Positive percentage changes in mass of potato tuber discs.
(iii) Negative percentage changes in mass of potato tuber discs.
(e) Suggest reasons why:
(i) The dishes containing the red blood cells or potato tuber discs are covered during the experiments.
(ii) The solutions are kept at a constant temperature of 20^0C during the experiments.
(iii) The change in mass of potato tuber discs is expressed as a percentage change.

(f) Other than change in mass, briefly explain three other observable changes that are registered when potato tuber discs are treated with sucrose solutions of varying concentrations.

4. (a) (i) describe how water passes through cell surface membranes.
    a. Describe the process by which ions can be taken up to establish an internal concentration higher than that of the surrounding solution.
    b. Why are mitochondria essential for the maintenance of water balance in organisms?
5. In an investigation, animal cells were exposed to different concentrations of glucose. The rate of uptake of glucose into the cells across the plasma membrane was determined for each concentration.



(a) What is the effect of increasing concentration of glucose on rate of uptake?
(b) Explain the effect above.
(c) What will be the effect of application of poison to the above process?
(d) State how active transport differs from facilitated diffusion.

6. If a cell is equilibrated with pure water and then transferred to a sucrose solution with a water potential of - 800KPa.
    a. What is the difference in µcell between the cell contents and the external solution at the time of transfer?
    b. Would water enter or leave the cell?
    c. Would the µp of the cell increase or decrease?
7. (a) Distinguish between plasmolysis and wilting. (4marks)
    (b) How are xerophytes adapted to survive water shortage? (16marks)
8. (a) Differentiate between osmosis and active transport.
    (b) What is meant by water potential of a plant cell?
9. Discuss the various forms of entry of materials into a cell. **THANK YOU**

4. DIVERSITY OF LIFE

- There is a great diversity of life in nature because all around there is an enormous variety of living form. To understand such a variety, there is need to organize such diversity into manageable groups.
- Such grouping is known as classification and the biological study of classification is known as taxonomy.

CLASSIFICATION

- ✓ It refers to the grouping of organisms together by basing on their similar characteristics traits or characters after studying their similarities and differences.
- ✓ Organisms with shared traits or characters are placed together in one group.

Importance of classifying organisms

- ✓ To quickly identify organisms belonging to the same group and easily establish their characteristic features.
- ✓ To provide a single scientific name for every group of organisms in the world.
- ✓ To demonstrate an evolutionary relationship existing among organisms
- ✓ To provide a coherent and universal system of grouping organisms.

NOTE: in order to come up with a more standard form of classification that would cater for the enormous variety of organisms, various scientists came out to suggest how it could be achieved and their suggestions are as follows;

1: TWO KINGDOM CLASSIFICATION SYSTEM

This is an old system of classification. It only recognizes two groups of organisms i.e. plants and animals. This first scheme of classification was proposed by Aristotle in the 4^{th} century.

Kingdom Plantae

- It included organisms fixed in one place
- It consisted organisms with a spread appearance and make their own food
- It included organisms like plants, mosses fungi and lichen and bacteria (prokaryotes) and algae.

Kingdom Animalia

- It included organisms which could move about.
- Had organisms with a compact body
- Had organisms that lacked a rigid cell wall
- Examples included; vertebrates, invertebrates and protozoans.

Limitations of this system.

- Many single celled organisms like euglena have features of both plants and animals.
- Some unicellular organisms like slime mould have a cellulose cell wall in their vegetative stage.
- Fungi lack chlorophyll and feed saprophytically on dead matter.
- Prokaryotes and eukaryotes were put together.

2. THREE KINGDOM CLASSIFICATION SYSTEM

In 1866, E Haeckel proposed the three kingdom system. This was due to studies that reflected the differences between prokaryotic and eukaryotic cells. These included;

- Kingdom Animalia
- Kingdom Plantae
- Kingdom Protista; algae, bacteria, fungi and protozoans.

Limitations of this system

- It fails to place some organisms like bacteria and euglena in definite kingdoms.

3. THE FIVE KINGDOM CLASSIFICATION

This is the modern system of classification whose grouping is based on the knowledge that different organisms have differences in, cell structure, body form and mode of nutrition.

The system includes five kingdoms;

- Kingdom Monera; bacteria and some algal forms
- Kingdom Protoctista; protozoans like amoeba and paramecium
- Kingdom Fungi; mushroom
- Kingdom Plantae; mosses, ferns, seed plants
- Kingdom Animalia; sponges, invertebrates and vertebrates

WAYS OF CLASSIFYING ORGANISMS

Classification maybe done naturally or artificially based on phonetic or phylogenetic system.

a. Artificial classification;

- This is based on a limited range of observable characteristics for simplicity and convenience. Animals in this system were classified into two basing on their flying ability.
- Unrelated animals like bats, flies and birds were grouped together.
- Plants were classified on the basis of height i.e. herbs, shrubs and trees.

b. Natural classification;

It is based on biological relationships among organisms putting in consideration of their external and internal features.

It takes into account of very many characteristics so that evolution trend is respected.

Factors based on are; embryology, physiology, biochemistry, cell structure and behaviour of organisms.

c. Phonetic classification;

This is based on observable characteristics of which all are considered to be of importance.

Characters from different organisms are obtained and only grouping is based on the degree of similarity between these organisms.

d. **Phylogenetic classification**;

This is based on the evolutionary history of organisms. It is based on fossil record with belief that organisms belonging to the same group have a common ancestor.

Taxonomic categories

- Organisms are placed in various categories which indicate their specific relationship. They include:
- Kingdom, Phylum, Class, Order, Family, Genus, Species

NOMENCLATURE OF ORGANISMS

The system of naming organisms is known as binomial system of nomenclature, here an organism's name consists of two names.
The first name is a genus name which starts with a capital letter and the second name is a species name which starts with a small letter for example, man is ***Homo sapiens***

TAXONOMIC CATEGORIES

1. **Species**

This is the basic unit of taxonomy. It is a group of closely related organisms, which if sexually reproducing can interbreed freely to produce viable or fertile off springs.

2. **Genus**

If the species are closely related, they are placed in the same, showing that they evolved from a common ancestor.
The generic name shows the genus where the organism belongs e.g. Homo is the genus for both humans and Apes.

3. **Family**

The related genera are placed together in the same family, such as genera panthera and genera felis are both in family Felidae because of the similarities they have.

4. **Order**

Related families are put together in the same order e.g. Family Felidae the cats and family Carnidae the dogs are both in order carnivora**.**

5. **Class**

Related orders are placed in the same class e.g. order Carnivora and order Primates i.e. man and gorillas are put in class Mammalia.

6. **Phylum**

Related classes are placed in the same phylum e.g. class Aves; birds, Reptilia, Pisces; fish are put in phylum Chordata

7. **Kingdom**

This is the highest taxonomic category and all organisms have been put in five kingdoms.

VIRUSES (AKARYOTAE)

- A virus is a sub microscopic intracellular parasite that consists of either RNA or DNA but never both.
- It is an infectious agent found in virtually all life forms including humans, animals, plants and fungi and bacteria.
- Virus are very small obligate intracellular parasites; that is their replication can take place only in actively metabolizing cells.
- Outside living cells, viruses exist as inert macro molecules (very large molecules), virus are not considered living since they cannot reproduce outside of a living cell. The inert form of virus particle outside the cell called the virion.

Characteristics of viruses

- ✓ Are the smallest living things
- ✓ They have no cellular structure i.e they are neither eukaryotes nor prokaryotes.
- ✓ Reproduce only in other living cells
- ✓ They are obligate endo parasites because they can only live parasitically in other cells
- ✓ Have nucleic acid which is capable of replicating
- ✓ They have both living and nonliving characteristics.
- ✓ They depend on host cells for reproduction.
- ✓ They are highly specific i.e a virus only recognizes and infects a particular host.

GENERAL STRUCTURE OF VIRUSES

- ❖ Viruses are extremely small individual organisms.
- ❖ They are between 20-100 times smaller than the bacteria and hence are too small to be seen by light compound microscope.
- ❖ Viruses vary in their smallest size from 20nm to 300nm.
- ❖ Viruses consist of genetic material either DNA or RNA surrounded by protective coat of protein combined with lipid or carbohydrate components called a capsid.

VARYING CHARACTERISTICS OF LIVING AND NON-LIVING CHARACTERISTICS OF VIRUSES

Living characteristics	Non- living characteristics
Capable of self-replication inside other cells	Are incapable of metabolism on their own
They can mutate	Have no fixed shape/ structure
Can transmit their character from one place another	They can be crystallized and stored for many years
Have nucleic acid capable of replicating	Cannot reproduce outside the host
Can respire inside other living cells.	

Effects of viruses on hosts

- → They often damage, produce proteins or kill the cells that they infect, causing diseases in infected organisms
- → Stimulate cells to grow uncontrollably and produce cancers
- → Some viral diseases such as rabies, hemorrhagic fevers, encephalitis, polio, yellow fever and immune deficiency syndrome can result in death.
- ➢ Plant diseases; Cassava mosaic disease, tobacco mosaic disease, tomato bush stunt disease, southern bean mosaic disease etc.
- ➢ Animal diseases; Small pox, The Acquired Immune Deficiency Syndrome (AIDS), Rabies, Measles, New castle, etc disease

TRANSMISSION OF VIRUSES

- ✓ Viruses infect body cell, incorporate their DNA into the host DNA and manipulate the cell to synthesize the viruses.
- ✓ Sometimes incorporation of Virus DNA into host DNA or **transduction** result into new characteristics in the hosts such as antibiotic resistance in bacteria.
- ✓ Most viruses are those attacking bacteria which are known as bacteriophages.

BACTERIOPHAGES

- A bacteriophage is a virus that parasites bacteria or infects bacteria.
- It consists of a head, containing the genetic material protected by a protein coat called a capsid and a tail, which attaches to the exterior of a bacterium.
- The genetic material of the bacteriophage passes from its head through its tail into the bacterium.
- The genetic material then directs the bacterium to create new bacteriophages which eventually burst from their host and in the process, destroy the bacterium.
- The released bacteriophages attack nearby bacteria and the infection process continues. The most common bacteriophages are those of T-group e.g. T_1, T2, T3, T4 etc

Structure of a bacteriophage

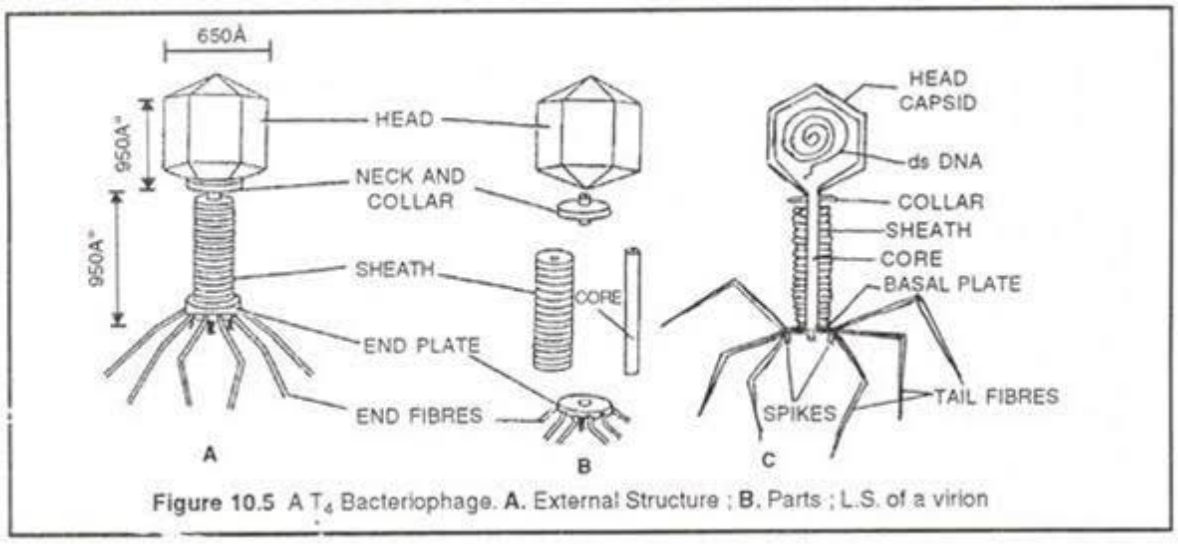


Figure 10.5 A T_4 Bacteriophage. **A.** External Structure ; **B.** Parts ; L.S. of a virion

Or check out diagram in understanding biology page 76 fig 5.2

RETROVIRUSES

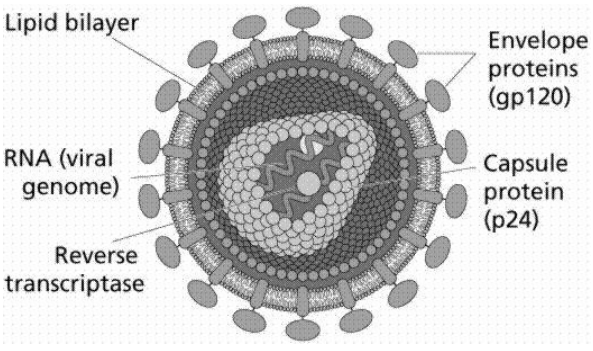
- These are viruses who genetic information is in RNA. Although many viruses possess RNA the difference with retro viruses is that they can use RNA to synthesize DNA as they have an enzyme reverse transcriptase.
- The reverse transcriptase enzyme catalyzes the conversion of single stranded RNA into double stranded DNA copies which is known as reverse transcription.
- The viral DNA made is then inserted into the host's DNA where it directs the production of more viral properties
- DNA form of retrovirus genes is called a <u>provirus</u>

Examples of retroviruses include;

Human immunodeficiency virus (HIV) this causes AIDS.

Structure of HIV

- ✓ The HIV virus is spherical and about 1000nm in diameter.
- ✓ The core region contains 2 molecules of single stranded RNA and reverse transcriptase enzyme surrounded by a cone shaped protein capsid.



- ✓ The capsid is enclosed by an envelope composed of a lipid and glycoprotein.
- ✓ The envelope contains glycoproteins which bind specifically to helper T-cell receptors, enabling the virus to enter the helper T-lymphocytes.

Check out illustration in understanding biology page 78 fig 5.5 for more about the lifecycle of retro viruses.

Economic importance of viruses

- Viruses cause diseases to plants such as tobacco bright and tomato mosaic by Tomato virus mosaic (TMV)
- Viruses cause diseases to animals as rabies, flue, polio, HIV and cancers.
- May lead to antibiotic resistance by bacteria.
- Used in genetic engineering.

Note; since viruses have higher rates of mutation, viral diseases are difficult to overcome although we can control their spread in the following ways;

- Burning infected plants
- Abstinence or use of a condom to prevent HIV
- Quarantine for highly infectious virus such small pox.
- Vaccination

KINGDOM MONERA

- They are the most abundant organisms. They are almost everywhere on earth.
- Examples include; cyanobacteria, bacteria and blue green algae.
- All are microscopic organisms whose cells lack membrane bound organelles.

BACTERIA

Characteristics of bacteria

- They are unicellular organisms
- Are the smallest cellular organisms
- They are prokaryotes.
- Produce asexually by binary fission and sexually by conjugation.
- Respire both anaerobically and aerobically.

Importance of bacteria

- ⌦ They bring about decay of dead organic materials during their saprophytic feeding.
- ⌦ Some bacteria e bacteria in the soil and those that live in guts of herbivores eg ruminants can digest cellulose using an enzyme cellulase and use it as a carbon source
- ⌦ Bacteria fix nitrogen in the soil hence providing nitrates to plants for growth by nitrogen fixing bacteria
- ⌦ Some bacteria fix nitrogen in the atmosphere hence stabilizing the nitrogen percentage eg denitrifying bacteria
- ⌦ They cause diseases and their diverse biochemistry can be used in many bio technological processes.
- ⌦ Are used in the making of drugs.
- ⌦ Used in the fermentation of alcohol.
- ⌦ Used in the formation of butter, cheese and yoghurt
- ⌦ Used in the treatment of sewage.

Reasons for the enormous distribution of bacteria/ survival of bacteria

- Have a high reproductive rate hence high chances of survival
- Produce cysts around their bodies for protection during adverse conditions
- Can reproduce both asexually and sexually
- Are very light and can be carried by any medium
- Can respire both anaerobically and aerobically
- Because of their large surface area to volume ratio, they have low food requirements
- Feed both autotrophically and heterotrophically.
- They have the ability to mutate and evolve

Structure of a bacterium

Refer to cell biology on page 8

CLASSIFICATION OF BACTERIA

1. **Classification by stain**;

Bacteria can be divided into two natural groups due to their cell wall structural differences into gram positive or gram negative bacteria;

Gram-positive;

- ✓ These stain purple with gram stain.
- ✓ They have a thick cell wall containing mainly polysaccharides and proteins. They may form endospores.
- ✓ Examples of include; Bacillus, clostridium, lactobacillus and staphylococcus and streptococcus species

Gram negative bacteria;

- ✓ These stain pink with gram stain.
- ✓ They have thin and more complex membrane made up of lipids and polysaccharides which protect them from lysosomes which are antibacterial enzymes found in secretions eg tears, saliva and in egg white.
- ✓ Examples include; Salmonella, Azotobacter and Escherichia

Note: gram positive bacteria are more susceptible to antibiotics and lysozymes than the gram negative ones.

2. **Classification by shape**

Bacteria can be grouped into three according to their shapes, ie cocci, bacilli and spirilla

- ❖ **Cocci**

These are spherical bacteria. Cocci include;

- Diplococci: these occur as a pair of spherical cells enclosed by a capsule e.g Diplococci pneumoniae which causes pneumonia



- Streptococci: these occur as several cells organized in a chain eg. Streptococcus pyogenes which case sore throat.



- Staphylococci; these are spherical shaped bacteria occurring in a cluster or group eg staphylococcus aureus which cause boils, food poisoning.



- **Bacilli;** These are rod-shaped bacteria, they include;
  - Bacillus: this is a single rod-shaped bacterium existing as a single cell eg Escherichia coli



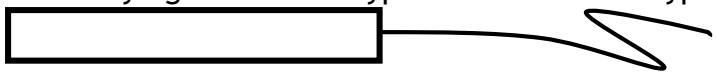
  - Diplobacillus: these are two rod-shaped bacteria eg bacillus anthracis.



  - Streptobacilli: These are rod- shaped bacteria existing in a chain eg Azotobacter



  - Flagellated bacilli; these are bacteria that have flagella around their body eg salmonella typhi which causes typhoid.



- **Spirilla (spillum species);** these are spiral shaped bacteria (coiled and twisted) eg Treponema pallidum which causes syphilis.



- **Vibrio;** These bacteria are curved like a comma shape eg vibrio cholera which causes cholera



3. Classification by nutrition type;

- Autotrophic bacteria; these bacteria manufacture their own organic food from carbon dioxide.
- Photoautotrophic bacteria use energy of sun light to convert carbon dioxide into carbohydrates. Examples include; the blue-green bacteria, sulphur bacteria and cyano bacteria.

  $CO_2 + 2H_2S \longrightarrow CHO + H_2O + 2S$
- Chemoautotrophic bacteria use energy from chemical reactions to convert carbon dioxide into carbohydrates. Inorganic substances such as ammonia, methane and hydrogen sulphide are oxidized to release energy. Examples include Nitrobacter and Nitrosomonas.

  $2NH_4 + 3O_2 \longrightarrow 2NO_2^- + 4H^+ + 2H_2O$ + energy Nitrosomonas

  $2NO_2^- + O_2 \longrightarrow 2NO_3^-$ + energy Nitrobacter
- Heterotrophic bacteria; these feeds on already made organic food but in different ways.
- Chemo-heterotrophic bacteria obtain energy from chemicals in food.
- Saprotrophic bacteria obtain their food from dead and decayed organic matter. Such bacteria secrete enzymes into the food, and absorb the soluble products of extra cellular digestion with the saprotrophic body for assimilation.
- Parasitic bacteria live on other organisms; hosts from which they obtain food as the host suffers harms.
- Mutualistic bacteria live in close associations e.g with legumes in the root nodules there's nitrogen fixing bacteria, *Escherichia coli* contribute vitamins B and K groups. Rhizobium fixes nitrogen into the plants as it is provided with a shelter.

4. **Classification by mode of respiration;**

- Aerobic bacteria; these bacteria require oxygen for respiration. Obligate aerobes cannot survive without oxygen but facultative aerobic bacteria can survive in the absence of oxygen.
- Anaerobic bacteria; they respire without oxygen and obligate anaerobes are killed in the presence of oxygen but facultative anaerobic bacteria can use oxygen but can respire without it.

CYANOBACTERIA

- These are photosynthetic bacteria.
- They are also known as blue-green bacteria.
- Feed by photosynthesis which is carried out on membranes around the peripheral of the cells.
- Photosynthetic pigments include; chlorophyll, red pigments; phycoerythrin and blue pigments; phycocyanin)
- Reproduce by binary fission

KINGDOM PROTOCTISTA

Characteristics

- Protoctista is a kingdom of lower and mostly single celled organisms with eukaryotic cells, formerly called Protista. However, some protists form colonies that contain many cells and may be visible to the naked eye.
- Such colonies represent a complexity of organization similar to higher organisms.
- Protists inhabit many different environments, fresh water, sea water, soils and in the intestinal tracts of animals.
- Like plants, many species of protists can make their own food by a process of photosynthesis eg Euglena.
- Like animals, many protists can move using flagella, pseudopodia or cilia.
- Some members practice holozoic nutrition and many have elaborate structures for ingestion, digestion, egestion. Members here are Eukaryotic with membrane bounded nucleus.
- Unlike plants and animals, protists do not have cells organized into specialized tissues.
- Have double membrane organelles.

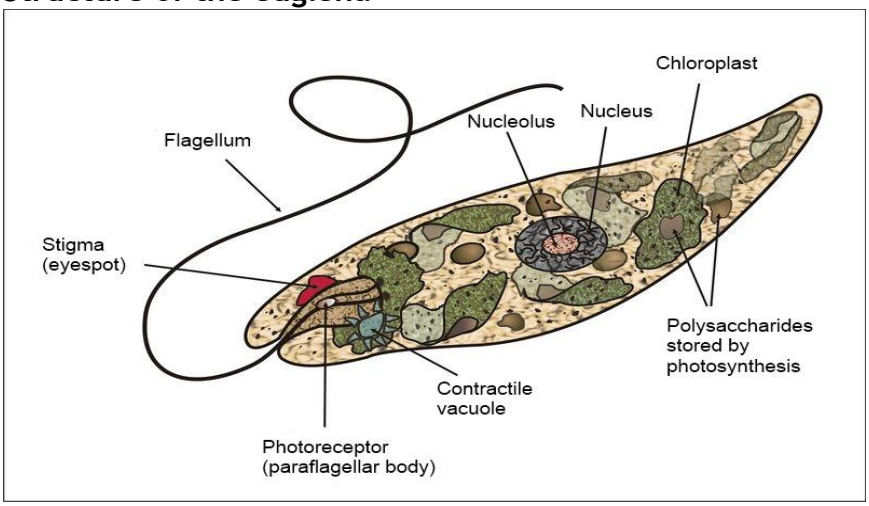
EUGLENOPHYTA

The only member is the euglena

Characteristics

- Has got chlorophyll for photosynthesis
- Can also ingest food particles hence behaves as a plant and as an animal.
- Lives in fresh water ponds and during unfavorable conditions it forms cysts.
- They are mostly unicellular
- They reproduce asexually
- They move by flagella

Structure of the euglena



ZOOMASTIGOPHORA (FLAGELLATES)

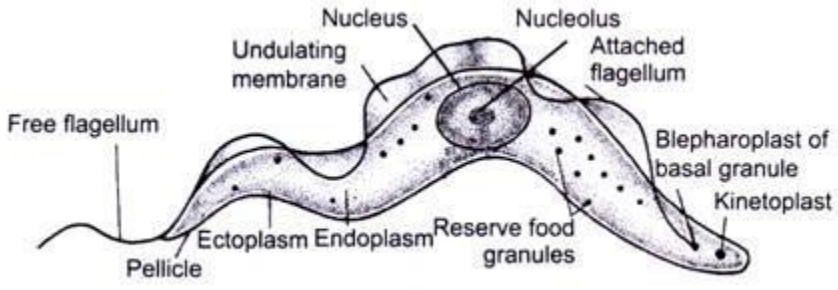
Examples include trypanasoma which causes trypanosomiasis (sleeping sickness), trichomonas.

Characteristics

- ❖ They bear flagella for locomotion.
- ❖ They are heterotrophic.
- ❖ They are unicellular.
- ❖ The reproduce both asexually and sexually.
- ❖ They bear a 9+2 tubule arrangement.

TRYPANOSOME

- ✓ Trypanosomes are parasites that live in the blood of the vertebrates and cause a number of diseases such as African sleeping sickness and Chagas disease.
- ✓ They are notorious parasites to man and his animals causing nagana, sleeping sickness.
- ✓ Uses flagella for locomotion hence zooflagellate.
- ✓ Have a slender, long undulating body.
- ✓ Have a tapering end at their anterior part.



PHYLUM RHIZOPODA

Examples under this are *Amoeba proteus* which lives in fresh water, *Entamoeba histolytica* which causes amoebic dysentery

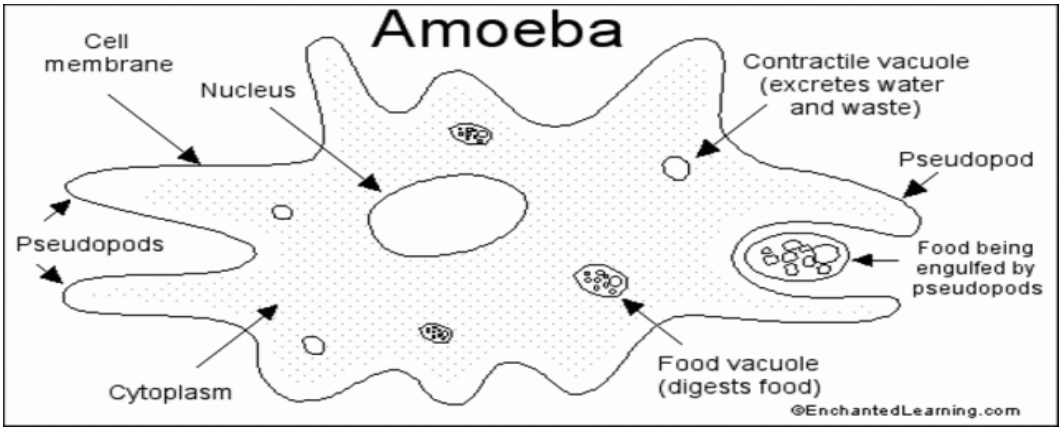
Characteristics;

- ➢ They are unicellular and bear pseudopodia (false feet) which enables movement and phagocytosis.
- ➢ They reproduce asexually.

- They feed heterotrophically.

STRUCTURE OF AMOEBA

- Moves by mean of pseudopodia
- Reproduces by binary fission
- Feeds by phagocytosis where it takes food particles.
- Are free living organisms
- Have a prominent food and contractile vacuole.
- Amoeba is composed of thin cell membranes surrounding a semi rigid layer of ectoplasm, a granular ectoplasm, a jelly like endoplasm, and an oval nucleus.



PHYLUM CILIOPHORA

Examples include Paramecium, Stentor, Vorticella, Didinia etc.

Characteristics

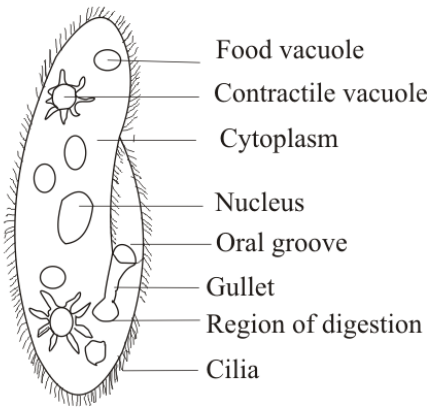
- They are unicellular
- They feed heterotrophically.
- Their cilia has a 9+2 tubule arrangement
- The cilia collects food and enable locomotion in water
- Their habitat is fresh water and marine water
- They have two types of nuclei, the larger macro nucleus which controls all cell metabolic activities and the micro nucleus which controls sexual reproduction called conjugation.
- The macro nucleus is polyploid i.e. it has more than two sets of chromosomes and the micro nucleus is diploid i.e. it has two sets of chromosomes.

PARAMECIUM

- Its body is covered by cilia.
- They are more advanced in evolution than other protists
- Paramecium belongs to the phylum ciliophora.
- They are often called shipper animalcules because of their shipper-like shape.
- Paramecia are found in fresh water ponds lives in stagnant water or slow moving fresh water containing decaying organic matter.
- Paramecium feed mostly on bacteria, which are driven in to the gullet by the cilia. Cilia are also used in locomotion.
- They possess two contractile vacuoles at a time that regulate osmotic pressure and also serves as excretory structures.
- A paramecium has a large nucleus called a macronucleus which controls body activities for its survival and one or two small nuclei called micronuclei which control reproduction.

- Reproduction is usually asexual by transverse binary fission, occasionally by conjugation.

Paramecium



PHYLUM APICOMPLEXAN/ SPOROZOANS

Examples include plasmodium

Characteristics

- they are unicellular
- they are heterotrophic
- they lack locomotory structures
- they are spore producing parasites of animals
- they reproduce sexually and asexually
- their lifecycles are complex involving several animal hosts

PLASMODIA

- It's a parasitic protozoan.
- It causes malaria in man.
- Its normally transmitted by a female anopheles mosquito

Lifecycle of plasmodium

- An infected anopheles mosquito bites a person, injecting plasmodium sporozoites in its saliva. The sporozoites enter the person's liver cells.
- After several days, the sporozoites undergo multiple divisions and become merozoites, which use the apical complex to penetrate red blood cells.
- The merozoites divide asexually inside the red blood cells. At intervals of 48 or 72 hours (depending on the species), large numbers of merozoites break out of the blood cells, causing periodic chills and fever.
- Some of the merozoites infect other red blood cells. Some merozoites form gametophytes. Another anopheles mosquito bites the infected person and picks up plasmodium gametophytes along with blood.
- Gametes form from the gametophytes; each male gametophyte produces several slender male gametes. Fertilization occurs in the mosquito's digestive tract, and a zygote forms. An oocyst develops from the zygote in the wall of the mosquito's gut.
- The oocyst releases thousands of sporozoites, which migrate to the mosquito's salivary glands.

KINGDOM FUNGI

- Fungi kingdom is a diverse group that ranges from unicellular (single-celled yeast to multicellular organisms like toadstools, puffballs and mushrooms.
- The kingdom fungi is divided into five phyla; oomycota, zygomycota, basidiomycota and deuteromycota.

Characteristics of fungi

→ Have a rigid cell wall made of chitin and not cellulose
→ Store their food as glycogen
→ They feed heterotrophically as saprophytes
→ They lack chlorophyll
→ Their cells have a true nucleus and thus are eukaryotes
→ Their body is usually organized into threat like hyphae
→ They reproduce asexually by releasing vast number of tiny reproductive units called spores
→ Examples of fungi include; mushrooms, truffles, yeasts, common mould (Rhizopus), Mucor grows on soils and bread, puffballs, penicillium, toadstools, mildews, plant rusts and smuts.

Characteristics of fungi that distinguish them from plants

⌦ Carbohydrates are stored as glycogen but not as starch
⌦ Their cell walls contain chitin but not cellulose
⌦ They have no chlorophyll hence they don't carry out photosynthesis
⌦ They reproduce by spores that lack flagella
⌦ They carry out heterotrophic nutrition as parasites and saprophytes on microorganisms.
⌦ Their bodies are usually made up of a mycelium of thread like multi nucleate hyphae without distinct cell bodies (aseptate) or they may have cross walls (septate)
⌦ They undergo nuclear mitosis i.e. their cytoplasm, nuclear membrane and cell membrane never divided
⌦ Fungal mitochondria have flattened cristae whereas plants have tubular ones

NUTRITION IN FUNGI

✓ They carry out extracellular digestion by producing enzymes to digest food outside their body
✓ The digested food is then absorbed by the hyphae
✓ Depending on how and where they obtain food, there are three types of nutrition;
✓ Saprotrophytism; this is where fungi obtain food from dead decaying matter e.g. Rhizopus
✓ Parasitism; fungi may live on or in another organism and this time cause disease e.g. ringworm
✓ Symbiosis; these live in association with other organisms e.g. lichens of fungi and green algae, mycorrhizas of fungi and plant roots.

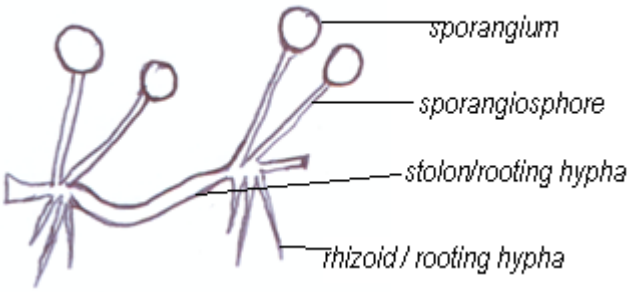
REPRODUCTION IN FUNGI

- Reproduce asexually by budding or spore formation
- Spores are light and normally dispersed by wind
- Budding is common in yeasts.
- Some fungi can reproduce sexually by conjugation

1. PHYLUM ZYGOMYCOTA

- These are zygomycetes and are terrestrials organisms. E.g. *Rhizophus stolonifer*; common bread mould, Mucor.
- Sexual reproduction is by conjugation, involving fusion of two gamentangia to produce a zygospore.
- Asexual reproduction is by conidia/sporangia contain spores.
- They live in damp organic places.

STRUCTURE OF A RHIZOPUS



Structural features of Rhizopus

✓ It consists of a mass on thin branching, threadlike structure known as mycelium, long stalk called sporangiophore, terminating into a brown or black spherical head when ripe and white when immature called sporangium or spore case.

Mycelium

- ✓ It consists of stolon or linking hyphae and rooting hyphae the rhizoids. Stolen is long, slender .and thin network of hyphae called mycelium. Mycelium has a large surface area for support.

Rhizoids/ rooting hyphae; are numerous, thin and slender .They are;

- Thin to easily penetrate the substratum.
- Many numerous to increase surface area for absorbing nutrients.
- To easily absorb nutrients easily by reducing diffusion distance.

Sporangium or spore capsule

- ✓ It is ball shaped or bulbous or spherical, swollen, and dull coloured or black.
- ✓ Rhizopus is found in moist places to avoid desiccation. It is smooth, thus it can easily lose water leading to desiccation if exposed to high temperatures.
- ✓ The nutrition of Rhizopus is heterotrophic due to lack of chlorophyll.

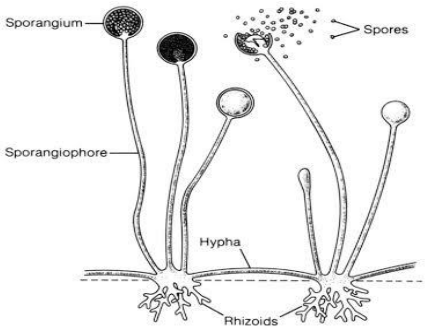
Adaptations of Rhizopus to survive in its environment

- It produces numerous spores for easy multiplication of for easy colonization of new areas.
- It has numerous rhizoids to increase surface area for easy absorption of nutrients.
- It has a network of hyphae for support.
- It has long sporangiophore so as to raise sporangia above the mycelium for spores to easily be blown by wind for easy dispersal.
- It has thin rhizoids for fast absorption of nutrients and anchorage.
- Has sporangia containing spores that are resistant to adverse conditions and thus resume the lifecycle when conditions become favourable.

Asexual reproduction in Rhizopus

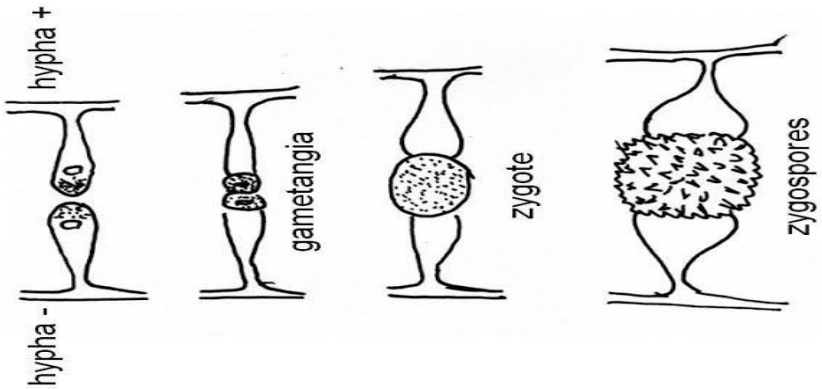
- × A swollen tip develops on the end of the sporangiophore, called a sporangium.
- × A cross wall called the columella separates the sporangiophore from the sporangium

- The sporangium contains spores.
- These spores contain one or more nuclei and are usually haploid that is, their nuclei contain one set of chromosomes.
- When it is ripe, the sporangium bursts, releasing the spores into the air. When spores land on a suitable substrate like bread they germinate into promycelium, which develops into a mycelium.
- The mycelium spreads rapidly, allowing the fungus to disperse and colonize new areas.



Sexual reproduction in Rhizopus

- Hyphae of different strains, adjacent to each other grow/ develop a swelling called gametangium which contains a gamete.
- The gametangia grow until they touch each other.
- The cell wall dissolves and the two gametes fuse to form a diploid zygote.
- A thick coat develops around the zygote called a zygospore that later germinates



2. PHYLUM ASCOMYCOTA/ SAC FUNGI

This is the largest phylum in the fungi kingdom. These are called ascomycetes. Examples include yeasts, penicillium and blue-green moulds, Morels, truffles, red bread mould.

PENICILLIUM

Characteristics

- Penicillium species forms blue, green or sometimes yellow mould on bread, decaying fruit among others.
- Their hyphae have cross walls called septa, therefore Penicillium is septate

- It reproduces asexually by means of spores called conidia formed at the tip of special hyphae called conidiophores.
- Penicillium produces penicillin which is an antibiotic.

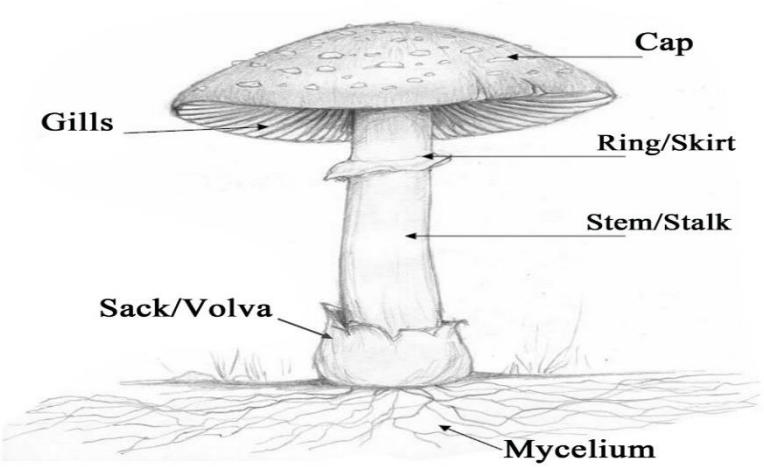
YEAST

- It has oval shaped cells
- It is unicellular
- Has thin cell wall
- Reproduces by budding
- Yeast produces ethanol during anaerobic respiration
- Reproduces normally by budding.

3. PHYLUM BASIDIOMYCOTA

- ✓ Are basidiomycetes or club fungi and are composed of masses of hyphae.
- ✓ They have cup shaped reproductive structures called basidia at the end of the hyphae.
- ✓ Basidium is the site for spore formation
- ✓ Their vegetative part lies below the ground in form of extensive mycelium.
- ✓ Examples include field mushrooms, *agaricus compestris*, saprotrophs, puffballs, bracket fungi, rusts, jelly fungi and toadstools.

Diagram showing a field mushroom



4. PHYLUM OOMYCOTA

These are water moulds. Mostly parasites on insects and plants. Examples include; *Phytophora infestans* that causes potato bright, water moulds and downy mildew.

5. PHYLUM DEUTEROMYCOTA

These are deuteromycetes, they include trichophyton which causes athlete's disease and ring worm. Some resemble ascomycetes and others resemble zygomycetes.

Economic and ecologic importance of fungi

- Source of food to man e.g. mushrooms and truffles.
- Used in brewing industries e.g. yeast is used in fermentation
- Bread making e.g. yeast is added to the dough to produce carbon dioxide. Carbon dioxide raises the dough and makes it appear bigger.

- A yeast like fungus is a source of riboflavin, vitamin B_2.
- Production of dye and ink
- Gibberellic acid which promotes increased growth of plant cells is formed by a fungus-causing disease in rice plants.
- They are pollutant detectors e.g. lichens increase in number as distance from polluted areas increases.
- They are decomposers; they participate in the natural decomposition of sewage.
- Soil is a natural habitat for saprophytic fungi, which live on organic remains. Many such fungi decompose cellulose and proteins thus important in the formation of humus.
- Certain fungi live in a symbiotic association with algae forming lichens which are pioneer organisms in ecological succession.
- Production of antibiotic penicillin is got from penicillium, molds.

KINGDOM PLANTAE

It includes algae and land plants

- Their cell walls contain cellulose
- They reproduce both sexually and asexually
- They are multi cellular
- They are photosynthetic except for some parasites that lack chlorophyll
- They have alternation of generations i.e. the haploid and diploid generations alternate in the lifecycle.

ALGAE

- They represent the oldest and first plants on earth.
- Are regarded as low ferns of plants because of their simple structure
- Are aquatic
- Their body is not differentiated into leaves, stem and roots.
- Most algae lack an internal system of tubes to move water and materials.
- Algae vary considerably in size ie unicellular to multicellular.

Algae are divided into three main phyla viz;

- Phaeophyta-brown algae
- Chlorophyta-blue green algae
- Rhodophyta-red algae

CHLOROPHYTA (BLUE-GREEN ALGAE)

The members include volvox, chlorella, spirogyra, and chlamydomonas

Characteristics

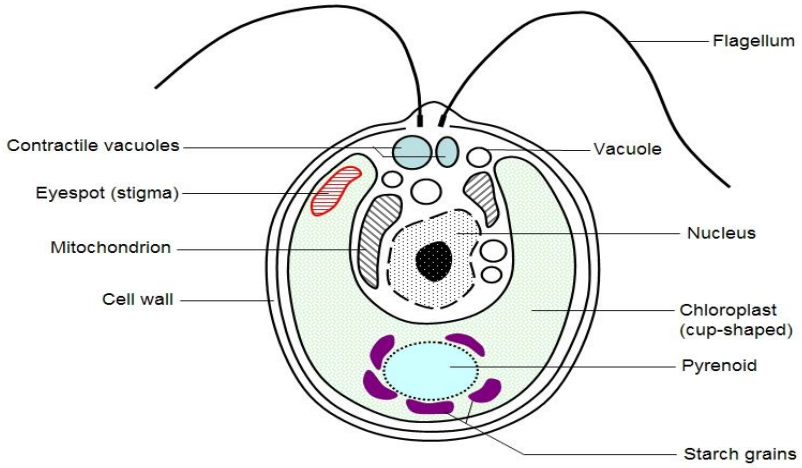
- Are aquatic
- Contain pigments such as chlorophyll a and b, carotenes and xanthophyll is more dominant.
- Store carbohydrates as starch in the pyrenoids
- Their cell wall contains cellulose
- They contain chlorophyll and therefore they are photosynthetic
- They reproduce sexually and asexually

Note;

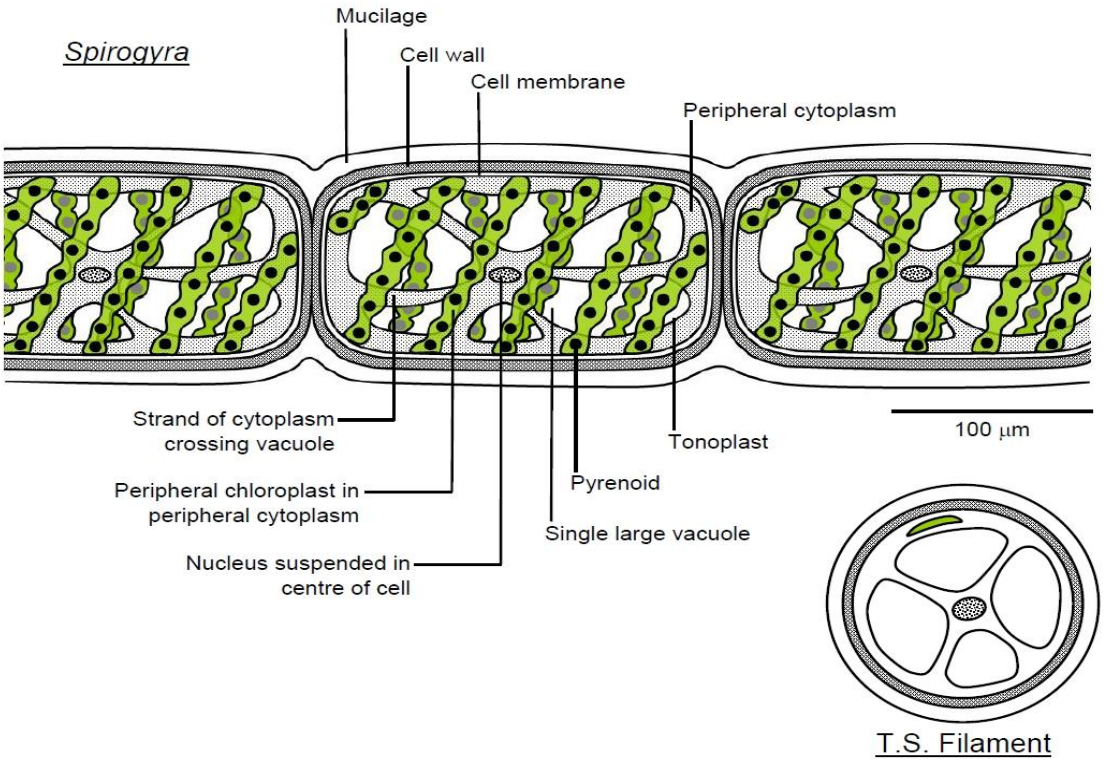
- Spirogyra is a filamentous algae that lives in fresh water ponds
- Chlorella is a unicellular non filamentous alga that lives in fresh water ponds.

- Chlamydomonas which is a motile unicellular algae

Chlamydomonas



Spirogyra



T.S. Filament

EVOLUTIONARY TREND OF GREEN ALGAE

Blue green algae are believed to be the ancestor of plants. This is because algae and plants have characteristics in common and these are;

- ✓ Both have chlorophyll a and b
- ✓ Both are eukaryotic
- ✓ Store food in form of starch
- ✓ Both have cellulose cell wall.

PHYLUM PHAEOPHYTA

These are the brown algae. The members include Fucus, Laminaria and Ascophyllum.

Characteristics

- ☑ They possess chlorophyll and therefore carryout photosynthesis
- ☑ They are multicellular

- ☑ They are marine and are therefore called the sea weed
- ☑ They contain a brown pigment called fucoxanithin which gives them a brown colour.

PHYLUM RHODOPHYTA

These are red algae and members include chondris.

Characteristics

- ☑ It is marine
- ☑ It contains chlorophyll hence it carries out photosynthesis
- ☑ It contains a red pigment called phycoerythin
- ☑ It also contains a blue pigment called phycocyanin
- ☑ It produces agar which is extracted from them for laboratory purposes such as culturing protozoa.

Importance of algae

- × Food for animals e.g. fish, poultry feeds.
- × They are used for study purposes.
- × Carry out photosynthesis by using carbon dioxide and releasing oxygen for use by aquatic animals for respiration and as well reduce carbon dioxide concentration in aquatic systems.
- × Take part in nutrient recycling forms such as anabaeria have the ability to fix nitrogen therefore thus converts nitrogen to ammonia.
- × Algae are also used in the manufacture of food products like ice cream, salad dressings, pan cake syrups
- × Tooth pastes, adhesives, hand lotions and finger paints all contain algae.
- × Chemicals from algae are used to make plastics, waxes, transistors, deodorants, paints and lubricants.
- × Can be used as fertilizers
- × Algal blooms result in pollution of water bodies.

LAND PLANTS

PHYLUM BRYOPHYTA

- Plants in this phylum are called bryophytes.
- These were the first plants to colonize land.
- They have chlorophyll and therefore photosynthesize.
- Bryophytes are generally small plants that live in moist conditions. They entirely rely on water for the dispersion of gametes.
- The motile gametes swim in a film of water to reach the female gametes.
- Bryophytes are regarded as the amphibians of the plant kingdom.
- There are three classes of bryophytes: Musci-the mosses, Hepaticeae-the liverworts, Anthocerotae-the hornworts

CHARACTERISTICS OF BRYOPHYTES

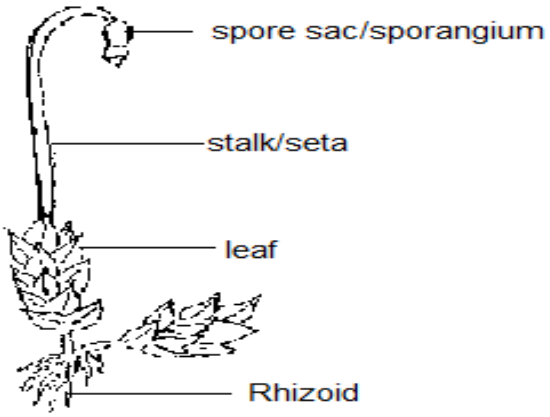
- ✓ Have a simple plant body called a thalloid and is not differentiated into leaves, stems and roots.
- ✓ Lack roots but are anchored to the ground by root like structures called rhizoids.
- ✓ Lack a vascular system that is no xylem and phloem.
- ✓ They live in moist or damp places to avoid desiccation.

- ✓ They are flowerless plants.
- ✓ Reproduce asexually by means of spores and sexually by gametes formation in their life cycles i.e. they undergo alteration of generation.
- ✓ They show a predominant alteration of generation from the gametophyte to sporophyte in their life cycle.
- ✓ The male gametes are called antherozoids produced by antheridia and the female gamete is oogonia produced by archegonia.

THE MOSS (FUNARIA)

- It's a land plant commonly found in moist grounds under shades.
- It has stems and leaves with chlorophyll to carry out photosynthesis.
- Has rhizoids for absorption of water, mineral salts as well as anchorage.
- Their body is made up of the gametophyte (gametes bearing) and sporophyte spore bearing)

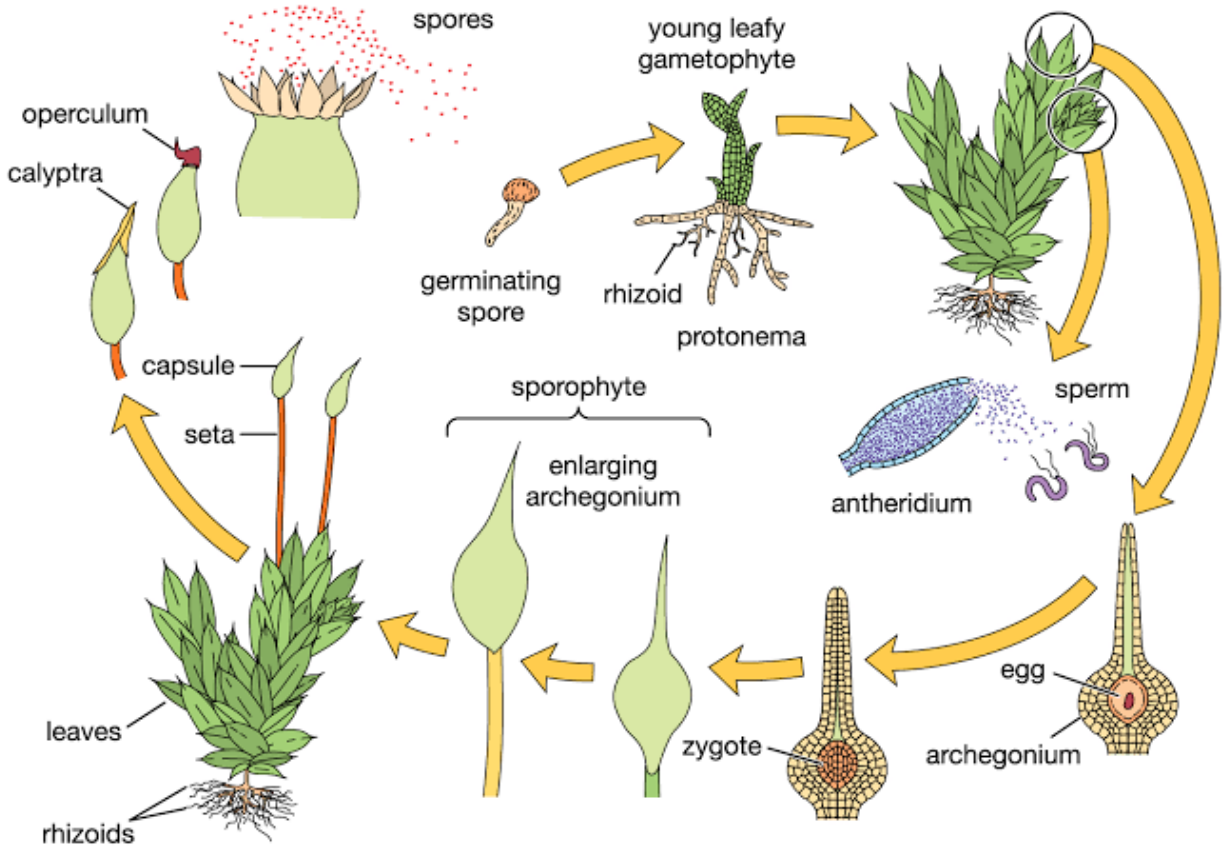
EXTERNAL STRUCTURE OF A MOSS



REPRODUCTION IN MOSS/ ALTERNATION OF GENERATION IN A MOSS

- It shows alternation of generation which involves two distinct phases i.e a haploid gametophyte and a diploid sporophyte generation.
- Here the gametophyte is the most prominent generation because it's the main vegetative stage in the life cycle.
- The sporophyte is attached to the gametophyte and depends on it for both support and nutrition.
- The neck of the archegonium produces specific proteins which attracts the sperms; antherozoids when mature
- The sperms then swim by their flagella through a thin film of water in the gametophyte till to the neck of the archegonium where one of them fertilizes the ovum.
- The resulting zygote is retained within the archegonium where it develops into a diploid embryo.
- The embryo develops into a sporophyte which grows upwards from the gametophyte.
- At maturity, the sporophyte produces haploid spores by meiosis within the spore capsule.
- The capsule splits open when dry and the spores are dispersed by wind.
- On landing on suitable ground, they germinate through protonema stage to form a new haploid gametophyte.

Illustration of alternation of generation in a moss



Or check illustration in biological science page 39
Or in understanding biology page 86 fig 5.14

Differences between gametophyte and sporophyte

Gametophyte	Sporophyte
Sexual stage	Asexual stage
Produces gametes by mitosis	Produces spores by meiosis
Haploid phase	Diploid phase
It is dominant and occupies most of the lifecycle	Takes only a short time

<u>Advancement of bryophytes over green algae</u>

- They have ability to exist on land and in places with little water.
- Have rhizoids for anchorage.
- Bryophytes are multicellular but some algae are unicellular.
- Their body is differentiated into leaves, stems and roots unlike algae.
- Sexually involves fusion of real gametes but in algae it is mostly by conjugation.

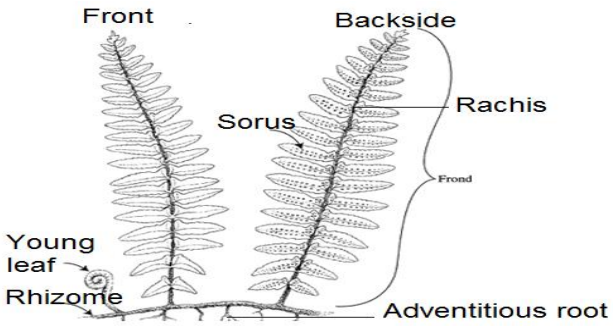
PHYLUM PTERIDOPHYTA

- Plants in this division are pteridophytes; these are flowering vascular plants with alternation of generation of two generations i.e. one asexual and the other sexual in each of the reproductive cycle.
- There are three common groups of pteridophytes namely; Lycopodophyta: the club mosses Sphenophyta: the horse tails Filicinophyta: the ferns

Characteristics of pteridophytes

- ✓ They are highly developed than bryophytes
- ✓ Have a vascular tissue; xylem and phloem though not well developed.
- ✓ Their body is fully differentiated into stems, roots and leaves. The leaves are fronds, stem is the rhizome and adventitious roots.
- ✓ Carry out sexual reproduction using swimming gametes.
- ✓ Grow mostly on moist. Shady and cool places though some species can grow in dry places.
- ✓ Have two plant forms i.e gametophytes and sporophytes with alteration of generation in their life cycle.
- ✓ The diploid sporophyte is dominant plant stage and haploid gametophyte called prothalus is short lived.
- ✓ Their leaves are called fronds and they may have sori on the underside which contains the sporangia in which spores are formed

EXTERNAL STRUCTURE OF A FERN



LIFE CYCLE OF A FERN

They also exhibit alternation of generation with the sporophyte being dominant over the gametophyte generation.

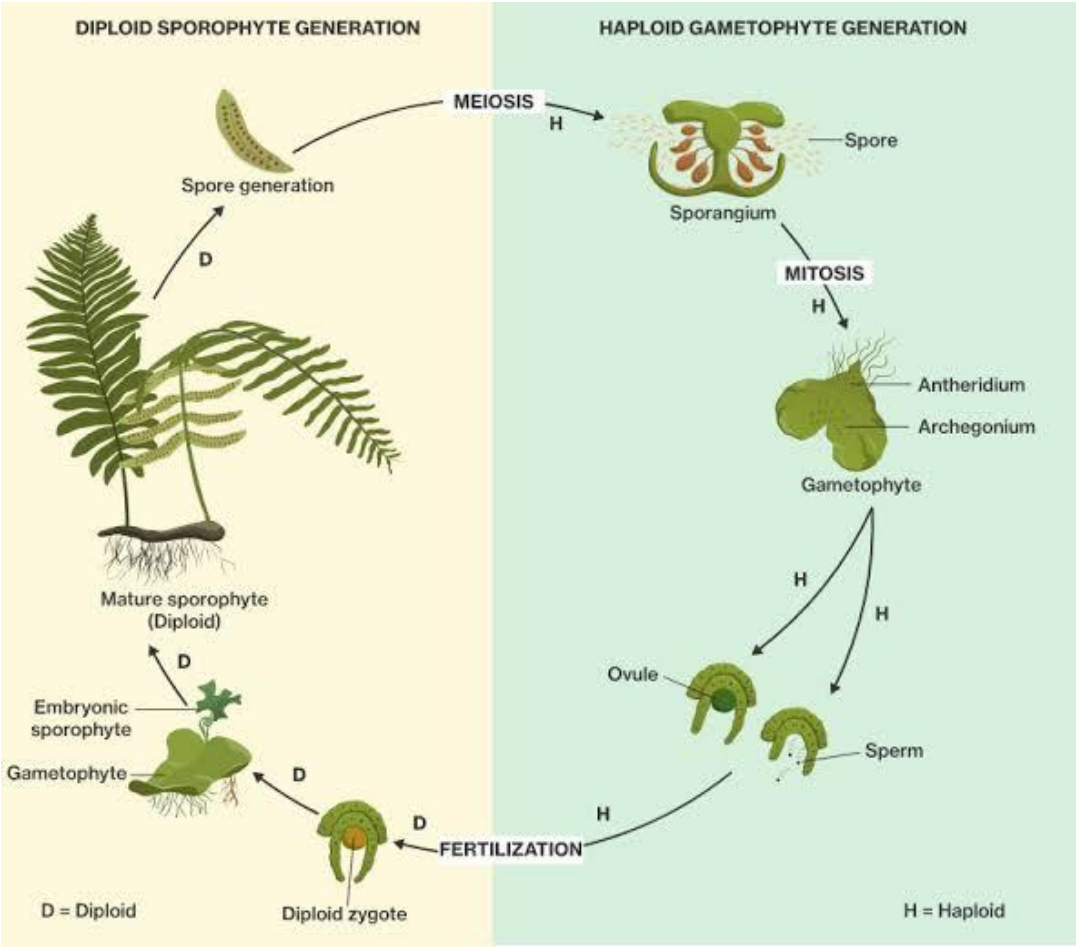
Sporophyte phase

- × the fern plant is a diploid sporophyte
- × the aerial fronds (leaves) mature and develop on the underside structures called sori in which there is the sporangia which produces a lot of haploid spores by meiosis.
- × Sporangia raptures to release the spores.

Gametophyte phase

- × The spores grow into short green filaments called prothalus or gametophyte which is a haploid stage.
- × The gametophyte contains chlorophyll and develops rhizoids on the under surfaces for anchorage.
- × The gametophyte starts to develop the antheridia and archegonia.
- × The female and male gametes fuse to form a diploid zygote.
- × The zygote forms an embryo and finally develops into a sporophyte plant.
- × The sporophyte establishes its roots, young leaves and develops into a mature fern plant independent of the gametophyte.
- × The gametophyte finally dies away.

Illustration of alternation of generations in ferns



Or check illustration in understanding biology page 87 fig 5.15

DIFFERENCES BETWEEN BRYOPHYTES AND PTERIDOPHYTES

BRYOPHYTES	PTERIDOPHYTES
Gametophytes is dominant generation	Sporophyte is the dominant generation
Lack vascular tissue	Has vascular tissue
Sporophyte is dependent on the gametophyte for nutrition and is attached to it	Sporophyte is independent of gametophyte and not attached to it
Spores are produced by sporophyte in spore capsules	Sporangia usually in clusters called sori
Roots, stems and leaves are found on the gametophyte	Roots, stem and leaves are found on the sporophyte
lacks roots, stems and leaves	Has true roots, stems and leaves

Make a comparison between moss and fern

REASONS FOR THE SUCCESS OF FERNS ON LAND

- Ferns have rhizomes or horizontal underground stems to survive unfavourable climatic conditions unlike mosses/for reproduction

- Sporophyte generations have true roots for anchorage/transport of absorbed minerals salts and water which are lacking in mosses.
- Sporangium of ferns produce more spores than in moss for greater reproductive rate.
- Have relatively large or broader leaves to present a large surface area for light absorption for photosynthesis.
- Ferns sporophyte generation are nutritionally independent while that of mosses depend on the gametophyte plant for nutrients.
- Ferns have true vascular tissues for transport and translocation of materials
- Ferns have true stems to support the leaves to absorb sunlight for photosynthesis.
- Leaves of ferns have cuticle to prevent desiccation.

REASONS WHY FERNS ARE STILL PRIMITIVE

- ✓ Growth is only limited to apical meristems i.e. no lateral meristems
- ✓ The xylem of ferns is dominated by tracheids whereas higher plants are dominated by vessels hence slow transportation of water and dissolved mineral salts.
- ✓ The fronds serve a dual purpose of photosynthesis and spore bearing organs for reproduction
- ✓ The gametophyte though independent and self-supportive still depends on water for fertilization
- ✓ The phloem tubes are not well specialized.

Significance of alternation of generation

- It enables the organisms to colonize more than one habitat with varying environmental conditions.
- The gametophyte produce gametes sexually ; thereby leading to variation
- The sporophyte produces spores which can survive in unfavourable conditions
- They produce spores which have less food stores hence light and can easily be dispersed to longer distances away from the parent thereby reducing overcrowding and risks of disease attack.
- It ensures rapid multiplication of plants since large numbers of spores are produced hence increasing chances of survival.
- Alternation between sporophyte and gametophyte generations ensures that the plant colonizes and explores different habitats in the ecosystem.
- Interdependency between gametophyte and sporophyte generation ensures existence of both generations and minimizes chances of extinction of the plant species.

SPERMATOPHYTA/ SEED BEARING PLANTS

These are divided into Coniferophyta or Gymnospermatophyta and Angiospermophyta

Characteristics of spermatophytes

- ❖ They show alternation of generations where the sporophyte is the dominant generation and the gametophyte being greatly reduced and short

- ❖ Have well developed vascular bundles with well-developed xylem; tracheids and phloem for conduction of food
- ❖ The body of the seed bearing plants is differentiated into true roots; stems and leaves.
- ❖ Seeds are formed after fertilization and do not require water for fertilization but facilitated by pollinating agents.
- ❖ The plants bear green leaves and therefore photosynthetic.
- ❖ The sporophyte is differentiated into shoot and root systems.
- ❖ They produce different spores i.e. heterospores e.g. embryo sac and microspores or pollen grains
- ❖ They are seed-bearing plants.

PHYLUM CONIFEROPHYTA/GYMNOSPERMOPHYTA

Examples: pines, fir, cedar, conifers, cycads

Characteristics of gymnosperms

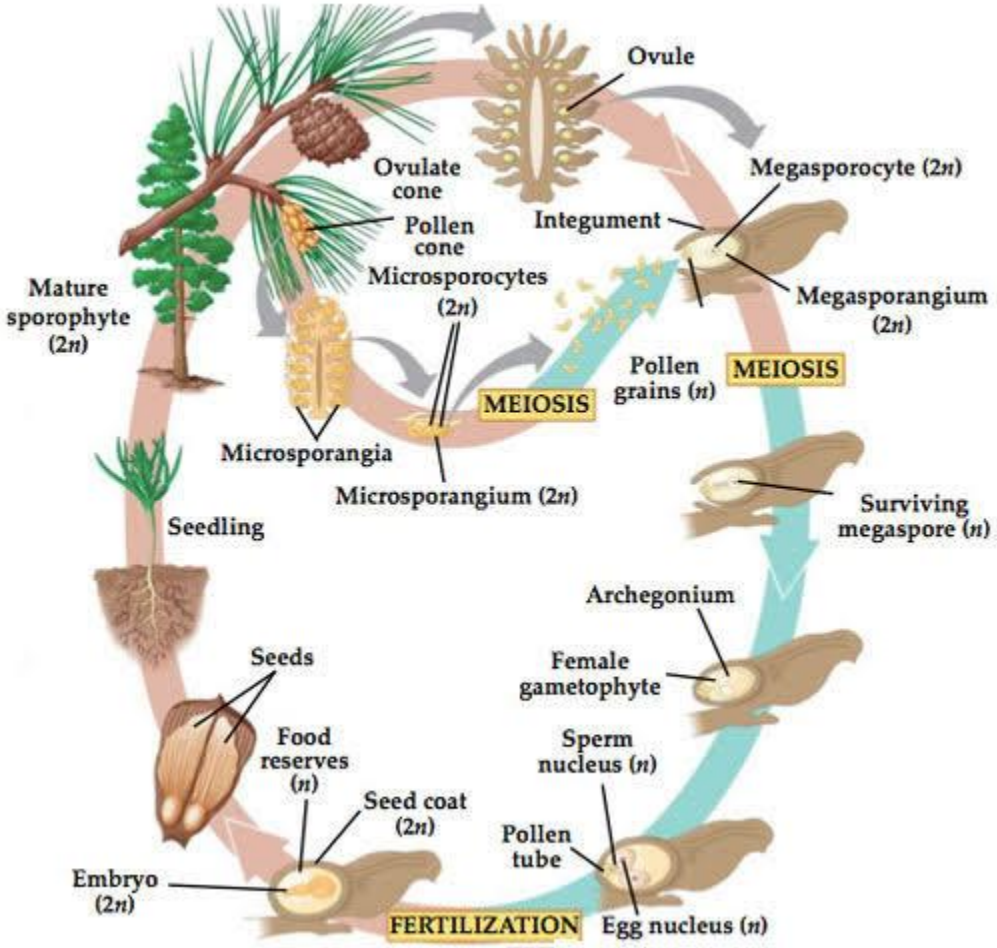
- Have no flowers instead they have unisexual cones.
- They have naked seeds i.e have no fruit wall
- They are Cone-bearing plants; female cones produce ovules and male cones produce pollen.
- They have true roots, stems and scale-like,
- Have narrow needle-like leaves protected by a waxy cuticle to reduce water loss in order to survive water shortage.
- Have simple conductive tissues i.e. xylem dominated by tracheids and phloem tubes and have no companion cells
- Have an alternation of generations
- Conifers reproduce by seeds; gametophyte generation is much reduced and never free living.

Reproduction/ Alternation Of Generations in Coniferophyta

- ✓ Mature dominant sporophyte generation develops male and female cones with sporophylls i.e. microsporophylls and megasporophylls which produce two different types spores a condition known as **heterospory.**
- ✓ The sporophylls produce the gametes or spores by meiosis. Female cones contain ovules which produce a single diploid megaspore or large spore.
- ✓ Megaspores divide meiotically to form a tiny haploid egg-containing female gametophyte which remains attached to the cone of the parent plant.
- ✓ Male cones contain microspore mother cells which divide by meiosis to produce four haploid microspores/small spores.
- ✓ The microspores of the male cone with air sac are transferred to the female cones by wind then a pollen tube develops and the haploid microspore divides mitotically to form the male gametophyte male gamete travels down the tube towards the female gametophyte in the ovule.
- ✓ After fertilization of the egg cell by one male gamete, a new diploid sporophyte embryo develops in the ovule and is released as a winged seed. When the winged seeds land on favourable moist grounds they germinate into the sporophyte plant to repeat the cycle.

- ✓ The female cones are normally brown in colour and scaly when mature.

Illustration of Alternation of generations in Coniferophyta



Conifers are better adapted to life on land than ferns;

- Do not need water as a medium for fertilization because they produce pollen.
- A pollen tube grows down from the pollen grain to an egg cell and fertilization can take place without the male gamete having to swim through water
- Reproduce using seeds which have more food store

ANGIOSPERMOPHYTA

These are flower bearing plants with the male and female reproductive structures enclosed in a flower. They are divide into **Monocotyledonous and Dicotyledonous plants.**

Characteristics of angiosperms

- They are flower bearing plants that produce spores/microspore/pollen grains and megaspores/macrospores/embryo sac
- Have well developed vascular bundles
- Seeds are enclosed in a fruit formed from and ovary i.e. produces seed enclosed by a seed coat which is dry or fleshy.
- Can also reproduce asexually by vegetative propagation
- They have true roots, stems and leaves

CLASS MONOCOTYLEDONEAE

Members include; palms and grasses; millet; rice; wheat; oats; barley; maize

Characteristics of monocotyledonous plants

- Have one cotyledon in the seeds
- Leaves have leaf sheath and parallel veins
- Their stem has no vascular cambium and the vascular bundles are scattered.
- Show no secondary growth/thickening due to lack of vascular cambium
- Have fibrous root system
- The floral parts often occur in multiples of threes
- The perianth is identical i.e. no distinct calyx and corolla.

CLASS DICOTYLEDONEAE

It's is divide into; trees e.g. Mango, avocado, cassia, Shrubs e.g. hibiscus and Herbs; e.g. beans, cow peas, ground nuts

Characteristics of Dicotyledonous plants

- × Have two cotyledons in the Seeds
- × Leaves have network veins
- × Have tap root system.
- × Have vascular bundles arranged in a ring around the cambium in the stem
- × Show secondary growth/thickening due to presence of vascular cambium
- × Their leaves have a petiole/leaf stalk
- × The floral parts usually occur in fours or fives and other multiples

Differences between Monocotyledonous and Dicotyledonous plants

Monocotyledoneae	**dicotyledoneae**
Embryo has one cotyledon	Embryo has two cotyledons
Narrow leaf with parallel venation	Broad leaf with net-like venation
Scattered vascular bundles in the stem	Ring vascular bundles in the stem
No vascular cambium/ secondary growth	Vascular cambium present/ secondary growth
Many xylem groups in the roots	Few xylem groups in the root
Flower parts usually in threes	Flower parts usually in fours or fives
Calyx and corolla not distinguishable	Calyx and corolla distinguishable
Often wind pollinated	Often insect pollinated

Reasons for diversity and success of Angiospermophytes

- ✓ Have well developed conductive tissues for faster transportation of materials
- ✓ Have thick waxy cuticle to reduce on the rate of water loss
- ✓ Have photosynthetic pigments in their leaves for sun light absorption for photosynthesis
- ✓ Have leaves with numerous stomata for easy gaseous exchange
- ✓ Have well developed supporting tissues to offer maximum support on land
- ✓ Formation of seeds that contain a lot of food nutrient to withstand dry conditions
- ✓ Fertilization does not need water because the non-motile gametes are transferred by pollinators to the female organs to enhance fertilization.
- ✓ Have well developed floral structure with attractive colours and nectarines that facilitate pollination.

- ✓ Growth of the embryo and germination of the seeds is assured due to presence of large food reserves.

Challenges faced by plants on land

1. Desiccation or drying out.
2. Support in air or on land.
3. Obtaining nutrients.
4. Obtaining gases for respiration.
5. Movement of the reproductive gametes.
6. Environmental variables such as light intensity, temperature, pH etc.

KING DOM ANIMALIA

- Most can move from one place to another i.e. they are motile
- They are multicellular eukaryotes
- They have a nervous common system except the sponges
- Contains multicellular eukaryotic animals with the following characteristics
- Show a great deal of differentiation i.e. division of labour
- Most of them have nervous and endocrine systems for irritability
- Have heterotrophic nutrition
- Their cells lack a cell wall
- They mainly reproduce sexually by producing heterogametes that fuse to form a zygote.
- Some animals reproduce asexually i.e. earth worm by fragmentation and hydra by budding.

They are divided into various phyla i.e.

Acoelomates

1. Porifera i.e. sponges
2. Coelenterata or cnidaria i.e. hydra and sea anemone
3. Platyhelminthes i.e flat worms
4. Nematoda i.e round worms.
5. Annelida .i .e. earth worms.

Coelomates

6. Mollusca e.g snails , slugs , octopus
7. Arthropoda
8. Echinodermata i. e star fish
9. Chordata

PHYLUM PORIFERA /SPONGES

- ✓ These are the animals with simplest division of labour.
- ✓ They consist of a group or colony of cells with a lot of intracellular spaces making it compressible hence the name **sponges.**
- ✓ The animals in this phylum are characterized by;
- ✓ They have cellular differentiation but without tissues.
  - Lack endocrine and nervous systems.
  - They have a porous body to allow circulation of water currents that supply nutrients to each cell.
  - They are all marine and are immobile.

- They have intracellular digestion and their cells have silica.
- Reproduce asexually by budding and fission and sexually to a less extent as they are hermaphrodite.
- Their body consists of two layers
- They show a great deal of regeneration powers due to the possession of undifferentiated tissue.

For the structure check page 81

PHYLUM COELENTERATA/ CNIDARIA

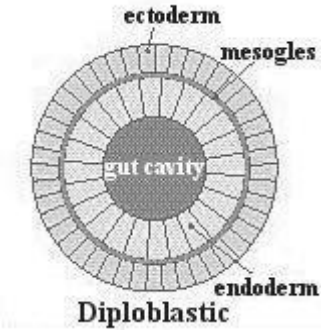
The phylum cnidaria is divided into i.e.

1. Hydrozoa i.e. hydroids
2. Scyphozoa i.e. jelly fish
3. Anthozoa i.e. corals and sea anemones

These are lower animals at tissue level of organization with the following characteristics.

- They are diploblastic i.e have two cell layers.
- The outer ectoderm and inner endoderm are jelly like with less developed mesoderm called the mesogloea.
- Are aquatic animals and mostly marine.
- Have radial symmetry i.e body can be divided into equal halves in more than one plane through the central body.
- Have a hollow gut called enteron/ gastro vascular cavity with one opening used for ingestion and egestion or both as mouth and anus.
- They exhibit polymorphism i.e. they exist in 2 or more forms i.e. the sessile form which is called the polyp and the free moving medusa form. The 2 forms alternate in their life cycle i.e. the polyp and medusa.
- They have tentacles with stinging cells called nematoblasts for protection. Nematoblasts occur in the ectoderm and when touched, can inject toxins into the prey/ predator which results into paralysis of the small animals.
- They a simple nervous system.
- They reproduce both asexually through budding and sexually.
- They are heterotrophic animals with intracellular digestion

Transverse section of cnidarians



Some coelenterates live in mutualistic relationship with the hermite crab i.e. the sea anemone

HYDRA

- ✓ Hydra belongs to the tissue level of organisation which enables cells to act together in a relatively coordinated manner so as to carry out various functions effectively. **Check page 80**

PHYLUM PLATYHELMINTHES

These are flat bodied unsegmented animals with a branched gut, with a mouth but without the anus.

Characteristics

- Are triploblastic i.e body has three layers the ectoderm, mesoderm and endoderm
- Have bilateral symmetry i.e body can be divided into mirror images/ similar parts if divided along one plane.
- Are unsegmented.
- They are acoelomate.
- The adult flat worms have a simple nervous system.
- Have networking tubes that collect food waste material s into the flame cells for excretion.
- The body is flattened dorso – ventrally to shorten the diffusion distance for effective diffusion.
- They are hermaphrodites.
- Most of them are parasites.

CLASSES UNDER THIS PHYLUM

1. Turbellaria; include planarians

- × Free living
- × Are aquatic
- × Have a delicate soft body
- × Suckers rarely present
- × Outer surface covered with cilia for locomotion
- × Have sense organs in adult.

2. Class trematoda

- ❖ These are endo parasitic or ecto parasitic.
- ❖ They have a leaf like shape.
- ❖ Usually have a ventral sucker in addition to the sucker on the head for attachment to the host,
- ❖ Thick cuticle which spines for protection.
- ❖ No cilia in the adult.
- ❖ Sense organs are only in the free living larval stages examples; fasciola, Schistosoma; blood fluke.

3. **Class cestoda/ tape worms**

- ✓ They are endo parasitic.
- ✓ Elongated body divided into proglottids which are able to break off.
- ✓ They suckers and hooks on the head (scolex) for attachment to the host.
- ✓ Have a thick cuticle for protection and no cilia in the adult.
- ✓ Sense organs are only in free living larval stage i.e. Taenia or tape worm.

Adaptations of Platyhelminthes to parasitic mode of life

1. They have a flat body that enables them gain entry into the body of the host although locomotory structures are generally reduced or absent.
2. They have structures which anchor them onto their host. Liver flukes have suckers; tapeworms have both hooks and suckers.
3. They protect themselves against the internal environment e.g Flatworms produce inhibitory substances to prevent their being digested by host enzymes.
4. They have complex lifecycles e.g Fasciola has snails and Taenia have pigs, fish and dogs as secondary host which transfers one parasite from the primary host to another.
5. They have a very high reproductive output i.e Adults devote much of their energy and body space to sexual reproduction.

PHYIUM NEMATODA

- Members include; Ascaris lumbricoides, wuchereria bancroftii /filarial worms. Thread worms, hook worms.
- These are worms with round bodies tapering at both ends with a cuticle for protection.

Characteristics

- They are triploblastic. i.e. They have three layers of cells
- Have bilateral symmetry
- Unsegmented body
- Are elongated round worms with a pointed end.
- Have an alimentary canal with a mouth and anus.
- They have separate sexes
- Some are free living but many are important plant and animal parasites
- The anterior end shows a degree of cephalization.
- Have unbranched gut from mouth to anus.

PHYIUM ANNELIDA/ TRUE WORMS

Members include; earthworms, leeches, bristle worms
Also known as annelids

- They are hermaphrodites and metamerically segmented

Note; metameric segmentation is a form of segmentation in which there is repetition of the organ and tissues at intervals causing the division of the body into similar parts.

- Annelids are coelomates.
- They are triploblastic and coelomate
- Have metameric segmentation
- Are bilaterally symmetrical
- Have a definite cuticle.
- Have a prostomium
- Have chaetae i.e. hair like structures made of chitin and arranged segmentally.
- Are monoecius
- They used nephridia for excretion
- Have a simple gut and simple transport system

COELOM

- This is an extensive internal space or body cavity in which the gut is suspended. It arises as a result of a split in the mesoderm during development of the embryo.
- The mesoderm has 2 layers i.e. the somatic mesoderm and splanchnic mesoderm.
- The somatic mesoderm is attached to the ectoderm and together they form the body wall.
- The splanchnic mesoderm is attached to the endoderm to form the muscular wall of the gut.
- The coelom is separates the body wall from the gut wall.

Biological significance of the coelom

1. The coelom provides the cavity in which other organs can grow and develop function independent of other organs.
2. It makes increase in size and complexity possible i.e. digestion in the gut in which the cells of the body wall are separated from the gut by the coelom.
3. Because the coelom separates the gut from the body wall, muscular movements of the body wall associated with locomotion can be separated from muscular movements of the gut wall.
4. The coelom performs an additional specialized function in Annelids where it acts as a hydrostatic skeleton, the fluid is called coelomic fluid.
5. The coelomic fluid circulates food, waste materials and respiratory gasses

Problems of coelom

- ☑ It separates the body wall from the gut, causing difficulty in transporting digested food and respiratory gases resulting into the development of transport system
- ☑ Increased size and complexity requires a more complex coordination system, therefore a more elaborate nervous system

CLASSES UNDER PHYLUM NEMATODA

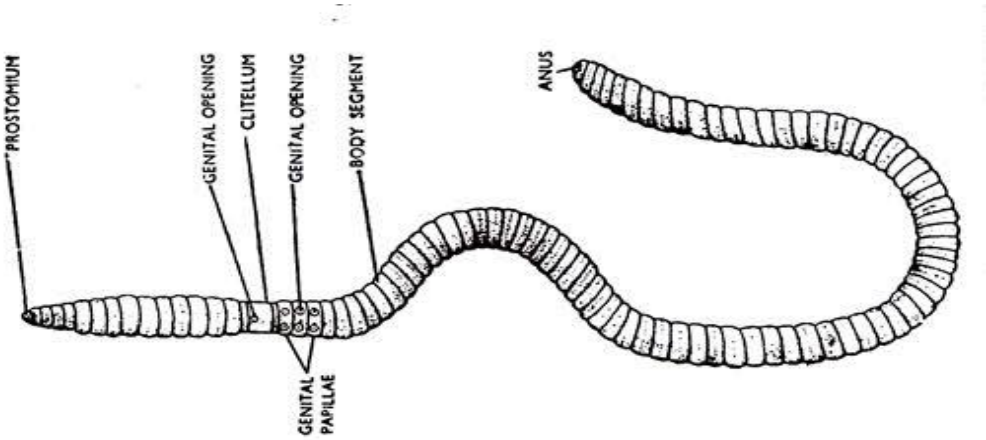
1. Class polychaeta i.e. bristle worms
2. Class Oligochaeta i.e. earth worms.
3. Class Hirudinea (leaches)

SOME REPRESENTATIVE OF THE PHYLUM

EARTH WORM

- This belongs to class Oligochaeta.
- Has a hydrostatic skeleton for locomotion. Locomotion is by waves of contraction and relaxation of longitudinal and circular muscles.
- Live in damp terrestrial habitats and fresh water to avoid dying of its body which would in turn lead to insufficient respiration.
- No distinct head.
- Have few chaetae.
- They hermaphrodite with cross fertilization.
- Has a well-developed coelom.
- External segments correspond with the inner septa.
- No suckers

Diagram showing an earth worm



Ecological importance of earth worms

- They improve on the soil aeration through the burrowing activities which lead to formation of tunnels.
- Improve on soil fertility by mixing and charming of soil.
- The soil they deposit on the surface as they burrow provides good medium for seeds to germinate.
- They enable growth of plant roots down wards in the soil.

PHYLUM MOLLUSCA

These are molluscs characterized by the following features;

- ✓ They are triploblastic coelomates.
- ✓ Have unsegmented bodies.
- ✓ Their body is divided into three parts namely; head, foot and visceral hump.
- ✓ The visceral hump is covered by a soft skin called mantle which secretes a hard calcium carbonate (calcareous shell).
- ✓ Aquatic molluscs respire by gills and the terrestrial ones use simple lungs in the mantle cavity.
- ✓ Most are bilaterally symmetrical
- ✓ They have an open circulatory system.
- ✓ Their blood contains a pigment haemocyanin which contains copper hence green in color.
- ✓ The mouth has a radula with many rows of small teeth for scraping food off solid surfaces.

CLASSES UNDER THIS PHYLUM

There are majorly seven classes under this phylum viz;

- Class gastropoda include snails, slugs, and limpets.

- × These are terrestrial and fresh water.
- × They are asymmetrical due to torsion of visceral mass
- × Have a single shell that is usually coiled.
- × Well-developed head with tentacles.
- × Have radula or rasping tongue for feeding.
- × Slow moving.

- Class bivalvia/ pelycopoda e.g. oyster, clams, mussels.

- Are marine, carry out external fertilization, feed with their gills.
- Have a poorly developed head.
- Bilaterally symmetrical
- Shell in two halves
- Reduced head and no tentacles.
- Gills with cilia used for filter feeding.
- Sedentary with limited powers of locomotion

- Class cephalopoda e.g. octopuses, squids, cuttle fish.

- ☑ They are bilaterally symmetrical
- ☑ Carry out internal fertilization
- ☑ Have a highly developed head and a reduced foot and shell.
- ☑ Have sexes different.
- ☑ They are predators with radula and horny jaws.
- ☑ Active and thus fast moving due to efficient gaseous exchange system.

- Other classes include aplacophora, monoplacophora, polyplacophora and scaphopoda.

PHYLUM ARTHROPODA

- Species under this phylum make up almost three quarters of the existing animal life.
- They have adapted to live successfully in both aquatic and terrestrial habitats and maybe free living or parasitic.

Characteristics

- Bilaterally symmetrical and segmented.
- Have a hard exoskeleton made up of chitin.
- Have jointed limbs/ appendages.
- Body can be differentiated into head, thorax and abdominal region.
- Have a dorsal heart and open circulatory system
- Cephalization is pronounced
- Triploblastic coelomates but the coelom is filled with blood; haemocoel.
- Coelom is reduced by existence of gonads and excretory organs. So the body cavity consists of a haemocoel.
- Have a developed nervous system with a high degree of cephalization.
- They undergo ecdysis or molting to allow growth.
- Free living parasitic and sedentary forms occur.

CLASSES OF ARTHROPODS

1. Class crustacean

- × Members include; Cray fish, crabs, water fleas, wood louse, lobsters, prawns, shrimps and Cyclops.
  Characteristics;
- × Body is divided into two, cephalothorax; fused head and thorax and abdomen.
- × Have two pairs of antennae and the small and short pair is called antennules.
- × Have five or more pairs of legs
- × Use gills and body surfaces for respiration
- × Dorsal part of their body is protected by hard plate.
- × Have three pairs of mouth parts.

- × Strong exoskeleton

2. **Class myriapoda**

This class is divide into two sub-classes i.e. chilopoda and diplopoda

Characteristics include;

- ✓ Have an elongated body with several segments
- ✓ They have a pair of antennae
- ✓ Breath through spiracles
- ✓ They live on land
- ✓ They have several les
- ✓ Have only simple eyes.

Chilopoda; centipedes

- × Body slightly flattened
- × One pair of legs on each segment
- × Possesses poisonous claws; these paralyze prey and as well for protection.
- × They are carnivorous; feed on insects, small invertebrates and cockroaches
- × Head has one pair of antenna and three pairs of appendages modified into mouth parts.

Diplopoda; millipedes

- × Body is cylindrical
- × Two pairs of legs on each segment.
- × They are omnivorous
- × Live in dark, damp places and feed on leaves and decaying plants.
- × Have one pair of mandibles

3. **Class arachnida**

These are arachnids. Examples include; spiders, scorpions, mites, ticks, and harvestman.

Characteristics

- Body is divided into two parts, cephalothorax and abdomen.
- Have four pairs of legs attached on the cephalothorax
- Have simple eyes on cephalothorax e.g spider has eight simple eyes.
- No antennae
- Have no wings
- Mainly terrestrial
- Mainly carnivorous
- No true mouth parts but a pair of appendages are used for capturing prey and the second pair is used as sensory palps.
- No larval form

4. **Class insecta**

Insects occupy most habitats on earth and they are atleast as many different kinds of insects as all other animals put together. It divided into Pterygota which are winged insects and Apterygota which are wingless.

General characteristics

- Body divided into head, thorax and abdomen
- Have three pairs of jointed legs
- The thorax is made of three segments i.e. prothorax, mesothorax and metathorax.

Other characteristics

- The head is has a pair of antennae and three pairs of mouth parts
- Have a pair of compound eyes
- Have spiracles for breathing
- Have malpighian tubules for excretion
- Most are terrestrial
- Have an open blood system with colorless blood
- The body development involves metamorphosis which is either complete (holometabolous) or incomplete (hemimetabolous) in growth. Growth in size occurs in stages known as instars.
- All insects have been restricted to a small size
- Have separate sexes
- Adults have one to two pairs of wings except in some few members

PTERYGOTA

This is divide into two groups viz;

- **Exopterygota**
  - ✓ This is whereby the wings develop externally.
  - ✓ They undergo incomplete metamorphosis i.e. Hemimetabolous (egg- nymph- adult).
  - ✓ Examples include; Locusts, cockroach, dragon flies.
- **Endopterygota**
  - ✓ The wings develop internally.
  - ✓ They undergo complete metamorphosis i.e. holometabolous(egg- larva- pupa- adult)
  - ✓ The larval stage is specialised for eating and growing and they are known by such names as caterpillars and grab
  - ✓ The adult is specialised for dispersal and reproduction
  - ✓ Examples include; butterfly, honey bee, housefly.

Problems of having an exo skeleton

1. The insect's weight to strength ratio decreases with the size of the animal making it less efficient as the animals becomes larger.
2. It resists growth and therefore periodical moulting/ ecdysis is required if the animal is to grow.
3. During moulting, the body of the arthropod is soft and very vulnerable to attack by predators and pathogens.

Reasons for success of arthropods on earth

- ❖ Their body is covered with a waxy cuticle which does not allow water to pass through, because of this, they have a great ability to retain water so that they are not restricted to humid conditions.

- Have a wide range of modification in their mouth parts that are adapted for feeding on different foods even among members of the same species. Some insects show this adaptation eg adult butterfly feed on plant nector while their caterpillar feed on leaves. This reduces completion for food as well as having different ecological niches.
- Have developed wings in addition to legs and so can fly. This enables insects to disperse successfully and escape from enemies and easy means of looking for food.
- Most insects are small in size. This means that they occupy small habitats and require little food to sustain their size.
- Possession of a tracheal system which provides efficient system of gaseous exchange that is related to a small size.
- Possess a variety of colors for camouflage and some spots that have false aggressive and warming appearance to predators (mimic). This gives them high survival chances.
- They have various shapes to fit their mode of life in the locality where they live e.g cockroaches' body is dorsal ventrally flattened to pass through narrow cracks.
- Their legs have various modifications ranging from claws and pads for running and holding tightly on backgrounds. Long hind legs have developed muscles for jumping. Some insects undergo a state of dormancy during unfavourable conditions i.e. hibernation in cold and aestivation during hot weather conditions.
- They do not require much water in their body since they have malpighian tubules that require less water to excrete uric acid.
- They have defensive structures like spines on legs, offensive smells to drive away their enemies.

DETAILED STUDY OF SOME ORDERS IN CLASS INSECTA

1. **Order Orthoptera;**

Examples include crickets, grasshoppers and walking sticks. Characteristics include;

- ✓ Chewing mouth parts
- ✓ Straight wings
- ✓ Complete metamorphosis
- ✓ Two pairs of wings with the front wings being narrow and leathery. The hind wings are broad, membranous and folded when at rest

2. **Order Dictyoptera;**

Examples include cockroaches and mantis and their characteristics include;

- ✓ They are dorso ventrally flattened
- ✓ They undergo incomplete metamorphosis
- ✓ Two pairs of wings with the front wings being narrow and leathery. The hind wings are broad, membranous and folded when at rest.

3. **Order Isoptera;**

- ✓ Members include termites and their characteristics include;
- ✓ Chewing mouth parts
- ✓ Workers and soldiers are wingless
- ✓ They undergo incomplete metamorphosis
- ✓ Reproductive termites possess two pairs of similar membranous wings which are held out flat when at rest and the wings are shed off after the mating

4. Order Hemiptera;

It includes all the bugs, and their characteristics include;

- ✓ Piercing and sucking mouthparts
- ✓ Two pairs of membranous wings

5. Order Homoptera;

It includes aphids and cicadas. Their characteristics include the following;

- ✓ They have piercing and sucking mouth parts
- ✓ Incomplete or complete metamorphosis
- ✓ Some species can reproduce without mating
- ✓ Some are wingless, others possess one or two pairs of membranous wings

6. Order Hymenoptera

Members include ants, wasps, bees and sawflies. Their characteristics include;

- ✓ Chewing and lapping mouth parts
- ✓ Worker ants and few others are wingless
- ✓ Two pairs of small stiff and membranous wings that interlock during flight
- ✓ The front wings are larger than the hind wings
- ✓ They undergo complete metamorphosis

7. Order Lepidoptera

Members include butterflies and moth.

- ✓ Long antennae
- ✓ Complete metamorphosis
- ✓ Sucking mouth parts shaped like a coiled tube when at rest
- ✓ The front wings are usually larger than the hind wings
- ✓ Possess two pairs of usually broad wings which possess scales

8. Order Diptera

Members include houseflies, mosquitoes and midges. Characteristics include;

- ✓ Two large compound eyes
- ✓ Piercing mouth parts
- ✓ Complete metamorphosis
- ✓ The two front wings are transparent and the two hind wings are reduced to halters which serve as balancing organs during flight

9. Order Siphnoptera

This order includes the fleas and their characteristics include;

- ✓ They are wingless
- ✓ They lack eyes
- ✓ They exhibit incomplete metamorphosis
- ✓ They possess piercing mouthparts

10. Order Odonata

Members include dragon flies and damsel flies. Their adult characteristics include;

- ✓ Chewing mouthparts
- ✓ Two pairs of equal sized transparent membranous wings that cannot be folded.
- ✓ They have huge eyes
- ✓ They possess very small antennae
- ✓ Legs cannot walk but are used to capture prey in air
- ✓ They mate in flight

- ✓ They exhibit incomplete metamorphosis

Economic importance of arthropods

Arthropods are economically important because they are;

- ❖ Vectors
- ❖ Pollinators
- ❖ Source of food
- ❖ Aeration of soil
- ❖ Source of organic manure
- ❖ Pests

PHYLUM ECHINODERMATA

Examples include; sea urchins, star fish, brittle star, sea cucumbers.

Characteristics

- ✓ Have a radial symmetry with axes
- ✓ Triploblastic coelomates
- ✓ Not segmented and no head
- ✓ Have a calcareous exo-skeleton
- ✓ No special excretory organ
- ✓ Have a tubular foot
- ✓ Have a water vascular system which is part of coelom
- ✓ Have separate sexes and are marine
- ✓ Nervous system and sensory organs are not well developed
- ✓ Food is detected by chemoreception
- ✓ Adults show Penta-radiate symmetry

PHYLUM CHORDATA

- × Chordates are animals showing the following characteristics at some stage in their development.
- × They have a dorsal flexible supporting rod called a notochord
- × Have a hollow nerve cord usually with a well-developed brain in the head
- × Have a set of pharyngeal gill slits or visceral cleft
- × Have a post anal tail which may remain or absorbed and reduced
- × Have a closed blood circulatory system.
- × They are bilaterally symmetrical.
- × Have segmented myotomes or muscles blocks.

SUB-PHYLA OF PHYLUM CHORDATA

- Urochordata/ tunicates e.g sea squirts
- Notochord present only in larva where it is confined to the tail.
- Adults are sessile, filter-feeders and enclosed in a protective tunic
- Note: adult stage loses most of the chordate features during metamorphosis.
- Cephalochordate, for example ampixioxus.
- Notochord extend into head.
- Vertebrata/craniate
- Have vertebral column/backbone which replaces notochord
- Have skull/brain case
- Brain enclosed in a cranium
- Have internal skeleton.

SOME CLASSES UNDER CHORDATA

a. Class Pisces i.e fish

Characteristics of Class Pisces

- ❖ They are aquatic vertebrates that live in water.
- ❖ Their body is stream lined and they swim with the help of tail.
- ❖ They have paired appendages in the form of fins but unpaired fins are also present
- ❖ They have lateral line as a sense organ in water.
- ❖ They respire with the help of gills.
- ❖ Fishes have a two chambered heart and there is a single circulation of blood.
- ❖ Skin is generally covered by scales.

b. Class Amphibia

Characteristics of Class Amphibian;

- Amphibians live well on land and in water.
- Amphibians are ectothermic animals.
- The skin is smooth and hairless, and contains both mucus glands and poison glands.
- They have and endoskeleton.
- Gaseous exchange can be by use of lungs, skin, and gills
- A three-chambered heart consisting of two atria and one ventricle.
- Reproduce by laying Eggs usually in water or in a moist environment and fertilized externally.

c. Class Reptilia

Characteristics of Class Reptilia

- Reptiles are tetra pods with two sets of paired limbs.
- They have a well-developed brain and a central nervous system.
- Most of them have two lungs, except some snakes.
- All reptiles have three-chambered hearts, except crocodiles, which have four-chambered hearts (2 atria, 2 ventricles).
- Reproduce by laying eggs
- Respiration by lungs only.

d. Class Aves i.e birds

Characteristics of Class Aves

- ✓ They are Endothermic
- ✓ Two pairs of limbs; forelimbs usually modified for flying; posterior pair variously adapted for perching, walking, and swimming; foot with four toes.
- ✓ No sweat glands.
- ✓ No teeth.
- ✓ Possess a four-chambered heart and in general exhibit high metabolic rates.

e. Class Mammalia

Characteristics of Class Mammalia

- × Possess hair which is made of keratin. Hair provides insulation.
- × Endothermic. The majority of the heat energy is used to maintain their high body temperature.
- × Four chambered heart.
- × Mammary glands are used to produce milk to nourish their young.
- × Most are viviparous (give birth to live young ones) though some are oviparous (lay eggs).

- Well-developed brain.

Problems faced by animals on land.

- ✓ Obtaining support
- ✓ Water loss
- ✓ Gaseous exchange
- ✓ Homeostasis
- ✓ Reproduction

END OF TOPIC DIVERSITY AND TAXONOMY

I thank you so much that you have understood the diversity and taxonomy of organisms. We have looked at what classification and taxonomy are in detail we further looked at the history of classification starting from a 2 kingdom to 5 kingdom classification. We looked at viruses and virion, Monera, protoctista, Plantae and animal in great detail. You can now try out the questions below.

1. a) What is meant by alternation of generations?

   b) With the aid of a named bryophyte, describe alternation of generation.

   c) Compare the alternation of generation between moss and fern.

2. (a) State dangers of parasitic mode of life?
   (b) Describe how a tape worm is adapted to the mode of life
   (c) Describe parasitic mode of life

5. ECOLOGY

It is the scientific study of the interactions that determine the distribution and abundance of organisms within a particular environment.

Some of the important terms encountered in ecological studies:

1. Ecosystem

- ✓ A natural unit composed of living; biotic and non-living; abiotic components whose interactions lead to a self-sustaining system e.g. ponds, lakes, forest, desert, stream.

2. Species

- ✓ Group of organisms showing resemblance among themselves in appearance, behaviour, chemistry and genetic makeup.
- ✓ Organisms that reproduce sexually are classified as members of the same species if, under natural conditions, they can actually or potentially breed with one another and produce fertile offspring.

3. Population

- ✓ Total number of members of a species occupying a specific area at the same time. E.g. tilapia fish in a pond, mahogany trees in a forest, people in a country all at a specific time.

4. Community

- ✓ All the organisms of different species that interact in a given well defined area e.g. all organisms within a pond, animals in a national park.

5. Synecology

- ✓ Study of many species within an ecosystem and thus the study of community ecology.

6. Autecology

- ✓ Study of single organisms or populations of single species and their relationship to their environment e.g. considering a lion in the bush, what does it feed on?, how does it reproduce?, what are its competitors?, what are its predators?, etc

7. Habitat

- ✓ Specific locality where an organism normally lives within the environment e.g. the underside of a log for earthworms, intestines of man for tapeworms, ponds for frogs, kitchen for cockroaches, etc.

8. Microhabitat

- ✓ Small locality within the habitat with particular conditions collectively called microclimate that support specific organisms e.g. mosses can grow at the upper side of a fallen log, while the underside supports earthworms.

9. Niche also Ecological niche

- ✓ The role an organism or a population plays in the habitat, and its interactions with other organisms.
- ✓ The sum of all environmental factors that influence the growth, survival and reproduction of a species.

10. Fundamental niche

- ✓ The physical conditions under which a species might live, in the absence of interactions with other species.
- ✓ Physical conditions required for survival without competitors by a given species.

11. Realised niche

- ✓ The role an organism plays in the habitat, and its interactions with other organisms in the presence of competition and other constraining factors.
- ✓ Therefore is the set of conditions under which an organism exists in nature.

12. Native species

- ✓ Species that normally lives and shrives in a particular ecosystem

13. Invasive/alien/exotic species

- ✓ Species that migrate into the ecosystem.
- ✓ Or are deliberately or accidentally introduced into an ecosystem by humans e.g. crops and game species

14. Indicator species

- ✓ Species that serve as early warnings of damage or health to a community or an ecosystem.

15. Keystone species

- ✓ Species that play more important roles than others in maintaining the structure and function of ecosystems of which they are a part.
- ✓ It is a dominant species that dictates community structure by affecting abundances of other species.
- ✓ **Note**; all species can be keystone depending upon the community.

Examples:

- × Top predator keystone species like lions, crocodiles and great white slarks exert a stabilizing effect on their ecosystems by feeding on and helping regulate the populations of certain species.
- × Bats and birds regenerate deforested areas by depositing plant seeds in their droppings.
- × Elephants uproot and break trees, creating forest openings in the savannah grasslands and woodlands, which promotes growth of grasses for grazers and also accelerates nutrient recycling.
- × Dung beetles remove, bury and recycle animal wastes; dung

16. Atmosphere:

- ✓ It is a thin envelope or membrane of air around the planet.

17. **Biosphere**:

- ✓ The part of the earth in which living organisms exist and interact with one another and with their nonliving environment.

18. Troposphere:

- ✓ Inner layer of the earth containing most of the planet's air, mostly nitrogen (78%) and oxygen (21%).

19. Hydrosphere:

- ✓ It consists of the earth's liquid water; both surface and underground, ice; polar ice, icebergs, and ice in frozen soil layer and water vapour in the atmosphere.

20. **Lithosphere**:

- ✓ This is the earth's crust and upper mantle. The crust contains non-renewable fossil fuels and minerals as well as renewable soil nutrients needed for plant life.

BIOMES

- These are large regions of the biosphere characterized by a distinct climate and specific life-forms as vegetation adapted to it.

Examples of the major terrestrial biomes of the world:

- ❖ Tropical rainforests; occur at low latitudes where the rain falls abundantly all year long and temperature is warm.
- ❖ Tropical seasonal forests; occur where climate is rather drier, and trees may lose their leaves during the dry season.
- ❖ Savannah; warm and dry grasslands with few trees, typically supporting grazing of animals

- ❖ Deserts; areas of very little rainfall, ranging from entire barrenness to seasonal rainfall that supports growth of some vegetation.
- ❖ Temperate shrub-land; grow where summers are hot and dry, and the winters are cool and wet. Vegetation is composed of mainly dense spiny shrubs with tough evergreen leaves.
- ❖ Temperate grassland; are similar to savannas but occur in cooler climates e.g. Canadian prairies and pampas of Argentina.
- ❖ Temperate forests; include deciduous and evergreen forests but contain far fewer species than a tropical rainforest.

FORESTS

These are the most existing ecosystems and enormous variety of species shrive in forests. With present day industrialization and increase in population of humans, there has been limited space and eventually the forest have been encroached. This has led to destruction of habitats for most organisms among other effects.

Ecological importance of forests

1. Through photosynthesis forests convert inorganic carbon dioxide to organic compounds some of which are food, to man and other animals.
2. Photosynthesis by forests releases oxygen the animals use during respiration.
3. Carbon dioxide extraction from air during photosynthesis reduces the effects of global warming.
4. Evapo-transpiration results into rain formation.
5. Modification of microclimate by providing cool and humid conditions.
6. They are habitats for terrestrial species.
7. Source of scientific information.
8. Provides genetic resources and biodiversity

Effects of deforestation

1. Reduced absorption of carbon dioxide increases effects of global warming.
2. Habitats of organisms get destroyed.
3. Biodiversity reduces due to migration and death.
4. Preys get exposed to their predators.
5. Species extinction may occur.
6. Increased soil erosion results.
7. Microclimate of the area gets altered.
8. Reduction in the food available to herbivores.
9. Reduction in rain formation in the area.

- ❖ Fresh water life zones; such as lakes and streams
- ❖ Ocean / marine life zones; such as estuaries, coastlines, coral reefs, and the deep ocean.

THE MAJOR CCOMPONENTS OF AN ECOSYSTEM

a) **Abiotic or nonliving components**; these are physical and chemical factors that influence living organisms in terrestrial ecosystems and aquatic life zones

b) **Biotic or living components**; these are the plants, animals and microorganisms.

ABIOTIC/ NON-LIVING COMPONENTS

Terrestrial	**Aquatic**
Sunlight; intensity, quality and duration	Light penetration
Temperature	Water currents
Wind/ air current	Dissolved nutrient concentrations
Latitude/ distance from the equator	Suspended solids
Soil/ edaphic factors	salinity
Fire	

Altitude/ distance above sea level	
Temperature	
Water/ rainfall	

EFFECTS OF ABIOTIC FACTORS ON THE ECOSYSTEM

1. Temperature

- Alternate heating and cooling of rocks causes them to shatter into smaller pieces that finally form soil.
- Changes in environmental temperature may result in migration of organisms e.g. birds to avoid overheating or freezing.
- Low temperature inactivates enzymes while excessive heat denatures enzymes, which is fatal to organisms the basis being the optimum temperature.
- High temperature results in increased transpiration in plants and sweating in mammals. Since a 10^0C rise in temperature causes enzyme reaction to double, increased temperature results in increased photosynthesis in plants.
- Low temperature stimulates flowering in some plants e.g. cabbages. A process known as Vernalisation.
- Exposure to low temperature stimulates germination in some seeds after water imbibition.
- Low temperature breaks dormancy of buds in some plants e.g bud-break in vines.
- When environmental temperature is low, small sized animals hibernate e.g. bats, dormice, hamsters, hedgehogs, and rodents like mice.

✓ **Hibernation** is seasonal response by animals to cold temperature during which they become dormant, body temperature and metabolic rate fall to the minimum required for maintaining the vital activities of the body.

✓ The animals, said to be in 'deep sleep' ably reduce energy needs to survive the winter when food is scarce.

✓ When environmental temperature is high, some animals aestivate.

✓ **Aestivation** is seasonal response by animals to drought or excessive heat during which they become dormant, and the metabolic rate followed by body temperature fall to the minimum required for maintaining the vital activities of the body.

✓ E.g. African lungfish burrows into mud till the dry season ends, earthworms and garden snails also aestivate

2. Light; Intensity, Quality and Duration

Intensity; brightness of light
Quality; composition of light in terms of wavelengths.
Duration; also photo period; length of day and night.
These factors were based on either the presence or absence of light

- It is a source of energy for photolysis of water during photosynthesis.
- Induces flowering in long-day plants e.g. barley, but inhibits flowering in short-day plants e.g. tobacco.
- It is necessary for the germination of certain seeds e.g. lettuce.
- Excessive light bleaches chlorophyll in plants.
- Stimulates mating of certain organisms e.g. fireflies.
- Absence of light causes etiolation in plants i.e. elongation and thickening of shoot internodes.
- It induces onion bulb formation but inhibits tuber formation in potatoes.

- It affects leaf fall from deciduous trees and formation of winter buds in temperate trees.
- Light breaks dormancy of buds.
- Sun light stimulates the manufacture of vitamin D in the skin. The dermis contains lipids called sterols/ steroid alcohols, which are converted by ultraviolet light into vitamin D.
- Ultraviolet light causes skin cancer in humans
- Light enables the mechanism of photoreception in eyes.
- Ultraviolet light breaks hydrogen bonds of biological molecules and drives out electrons from atoms.
- Increased illumination causes stomatal opening, which results in increased transpiration, or stomatal closure, which reduces transpiration.
- Photoperiod affects migratory and reproductive behaviour in various animals e.g. sunlight polarised by water acts as a compass for migration of salmon fish.
- Absence of light results in failure of chlorophyll formation in plants i.e. plant remains yellow, and leaves fail to expand.

3. **Wind**

- × Wind increases transpiration by blowing away water vapour around stomata hence increasing evaporation but still air results in decreased transpiration because it allows build-up of water vapour around stomata.
- × Wind increase causes reduction in sweating because it allows evaporation from the skin.
- × It influences the dispersal or migration of flying animals.
- × Dispersal of seeds and spores aided by wind increases the spread of non-motile organisms like plants, fungi and some bacteria.
- × It causes stunted and distorted growth of trees on windward slopes of highlands.
- × It aids pollination in certain plants e.g. most grasses, hence their distribution may be dependent on wind pattern.
- × It takes part in rainfall formation.
- × It circulates atmospheric gases e.g. carbon dioxide, oxygen and water vapour.
- × It is important in current and wave formation in seas, lakes that enables the generation and distribution of mineral salts.
- × It causes physical damage to vegetation, animals and buildings.

4. Humidity

- ✓ Low humidity results in increased evaporation from leaves while increased humidity causes low rate of evaporation, and much heat retention in the body.
- ✓ It greatly affects transpiration in plants and thus affects their distribution.

5. **Topography; altitude (height), inclination(steepness and aspect(slope)**

- ❖ Higher altitudes are associated with lower average temperatures, higher precipitation, increased wind speed, more intense radiation, lower atmospheric pressures, all of which influence plant and animal lives.
- ❖ Mountains also act as barriers to dispersal and migration, and act as isolating mechanism to cause speciation.
- ❖ Slope reduces water logging in soil, but encourages soil erosion, which prevents proper plant establishment, especially at steep slopes.

- ❖ In the northern hemisphere, south facing slopes receive more light and heat energy than north facing slopes and valley bottoms. This encourages plant growth in more illuminated areas than elsewhere.

6. FIRE:

This is a major disturbance to the savannah communities.
Fire originates from carelessness, lightning strikes and eruptions from volcanoes.

Effects of fire on the ecosystem:

- ☑ By removing old leaves, it stimulates trees and grasses to produce new buds.
- ☑ It breaks seed dormancy in some plants.
- ☑ It causes the release of mineral nutrients from stems in the form of ash
- ☑ It results in steady growth of vegetation.
- ☑ Since leaf litter and ground cover plants are burnt, soil erosion increases severely.
- ☑ There is reduction in population density of plants and animals. The later run away from the area burning or get preyed upon; those that burrow suffocate by smoke.
- ☑ It destroys habitats for predatory animals or even kills them reducing their survival chances these predators would pose a problem to other animals and plants e.g. aphids
- ☑ The new palatable vegetation that grows acts as food for herbivores.
- ☑ It stimulates flowering in some plants e.g. spear grass.

Adaptations of plants to fire:

- × Grasses grow in tussocks to protect the young growing buds.
- × Some tree stems are succulent i.e. store in parenchyma cells to reduce on the effects of fire heat.
- × Many plants are annuals to avoid fire severity in form of seeds, which may be underground.
- × Some trees have heat resistant tissues.

7. SOIL/ EDAPHIC FACTORS:

- ⌦ Soils are derived from rocks by physical and chemical weathering processes coupled with decay of plant and animal bodies.

Components of soil:

- ⌦ Inorganic particles; these enable soil to be categorized as silt, loam, clay, and sand, depending on particle sizes.
- ⌦ Soil air; it fills the pores in soil and is usually saturated with water vapour, more carbon dioxide and less oxygen, and sometimes ammonia and methane may be present.
- ⌦ Dissolved minerals in soil/ inorganic salts; these are derived from either bacterial action or rock breakdown by chemical weathering.
- ⌦ Soil pH; water logged soils are usually nitrogen and phosphorus deficient; hence plants growing in such areas tend to be carnivorous/ insectivorous to satisfy their needs.
- ⌦ Soil water; Water is essential for growth of plants and animals, holds dissolved minerals in solution and contributes to weathering of rocks.

  Capillary water; it is the most important source of water to plants, bound around soil particles by surface tension.

Hygroscopic water; forms a thin layer tightly bound by surface tension on soil particles and is unavailable to plants.
Osmotic water: forms a thin layer around hygroscopic water and is utilized by roots of a few plants.
Gravitational water: water that drains through soil to the bottom layers after rain, under the influence of gravity.
Field capacity: the total amount of water that a soil can hold against the force of gravity.

- ⌦ Organic matter in soil; this comprises two main constituents, dead organic material (DOM) and living organisms, which when dead are decomposed by bacteria and fungi to humus.
  The decomposition; biodegradation of detritus releases inorganic nutrients into soil for plants to absorb.
- ⌦ Soil living organisms include termites, rodents, snakes, but of all earthworms are particularly important:
  - × They feed on DOM and also ingest mineral particles, and as a result their activity tends to mix plant material intimately with soil.
  - × The faecal pellets, which they drop, contain mucus and bacterial polysaccharides that hold together the fine particles so as to produce faecal crumbs that improve soil structure.
  - × Their burrows also improve aeration in soil.

AQUATIC ECOSYSTEMS

These include; lakes, rivers, ponds, streams, wetlands, estuaries, reservoirs and open sea.

Types of aquatic life zones:

- Marine or saltwater; coastlines, coral reefs, coastal marshes, mangrove swamps and oceans
- Fresh water; lakes, rivers, ponds, streams, and inland wetlands.
- Blackish water; estuarine.

A. FRESH WATER LIFE ZONES

- ❖ Fresh water is the water with a dissolved salt concentration of less than 1% by volume.
- ❖ Fresh water may be lentic; standing e.g. lakes, ponds, inland wetlands or lotic; flowing e.g. rivers and streams

The major ecological and economic roles of fresh water systems

i. **Ecological**

- ✓ Moderation of climate.
- ✓ Taking part in nutrient cycling.
- ✓ Dilution of wastes and enabling of waste treatment.
- ✓ They are habitats for aquatic and terrestrial species.

ii. **Economical**

- ✓ Source of scientific information.
- ✓ Provides genetic resources and biodiversity.
- ✓ Recharging of ground water.
- ✓ Source of food.
- ✓ Provision of drinking water.
- ✓ Provision of irrigation water.
- ✓ Generation of hydroelectric power.
- ✓ Provide transportation routes.

- ✓ Provision of recreation.
- ✓ Source of employment.

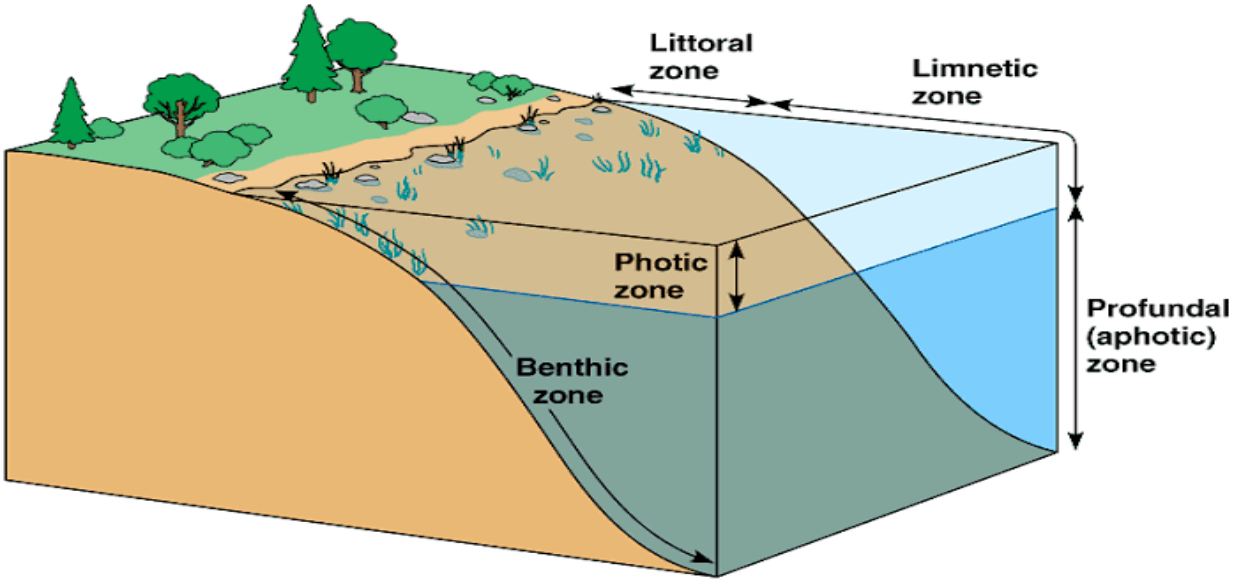


Reflect on the properties of water and check out only ecologically important properties in chemicals of life.

THE STRUCTURE OF LAKE ECOSYSTEM

Because ponds are shallow, sunlight often penetrates to the bottom so ponds usually have one zone.

In contrast, lakes normally consist of four distinct zones that are defined by their depth and distance from the shore.



a) **Littoral zone**: is characterised by closeness to the shore, much illumination, strong wave action, abundant populations of animals e.g. snails, frogs, turtles and plants, firm attachment of organisms to rocks or plants, rocky or mobile sand substrate, shallowness, high rate of decomposition that releases nutrients into water, much photosynthesis coupled with oxygen production.

b) **Pelagic (limnetic) zone**: is characterised by an absence of contact with either lake bottom or shore, inhabitants are good at swimming e.g. fish like perch and pike, and whales to avoid sinking to the bottom, much illumination, much photosynthesis from planktons coupled with oxygen production.

c) **Pro-fundal zone**: the deep, open, cooler water where it is too dark for photosynthesis, hence very low oxygen level. Some fish are found in this zone.

d) **Benthic zone**: it is at the bottom of the lake inhabited mostly by organisms like bloodworms, oysters, barnacles, crabs and lobsters that tolerate cool temperature and low oxygen levels

Factors that determine the nature and number of aquatic organisms

1. Temperature
2. Access to light for photosynthesis
3. Dissolved oxygen content – the amount of oxygen gas dissolved in a given volume of water at a particular temperature and pressure
4. Availability of nutrients such as carbon as dissolved CO2 gas, nitrogen as NO_3^-, phosphorus mostly as PO_4^{3-} for producers.
5. Salinity - amounts of various inorganic minerals or salts dissolved in a given volume of water.

LIGHT PENETRATION IN A LAKE

- Based on light penetration, different zones can be established within a lake.
- **Euphotic/ photic zone**; this is a sunlit zone extending to a depth where light dims to about 1% of that at the surface,
  Characterised by net oxygen production during day which reduces at night. All the littoral zone and upper parts of limnetic zone form the photic zone.
- **Aphotic**; there is low illumination for photosynthesis but respiration occurs at all depths. The photic zone's lower boundary varies daily and seasonally with changing solar intensity and water transparency, which greatly depends on algal blooms or suspended sediment.
- **Sub-littoral zone**: this is a transition between littoral and pro-fundal zones, characterised by low illumination of less than 1% of that at the surface to favour some plant growth at great depth.

THERMAL PROPERTIES OF LAKES

Heat transmitted with light in aquatic ecosystems performs two major functions;

- ✓ Regulation of rates of chemical reactions and biological processes,
- ✓ Establishment of thermal stratification

Note; Thermal stratification is the formation of different temperature layers in deep water

THERMAL STRATIFICATION OCCURS IN LAKES

- ☑ In warm weather the surface of a lake is heated by the sun. The warmed surface becomes less dense, and so remains at the surface, floating on the colder water beneath.
- ☑ The surface continues to gain heat from the sun, while the bottom water remains cold. If this surface heating continues for some days, without storm winds to stir the lake, a marked temperature difference can develop between the top and bottom water and the following compartments are recognised:
- ☑ Epilimnion: upper warmer water, usually well oxygenated.
- ☑ Metalimnion or thermocline: middle portion between Epilimnion and Hypolimnion where the rate of temperature change with depth is rapid.
- ☑ Hypolimnion: the deepest portion, with denser and cooler water, usually with low oxygen concentration.

OLIGOTROPHY, EUTROPHY AND DYSTROPHY IN LAKES

- ✓ Oligotrophic lake is one which is infertile; contains few nutrients.
- ✓ Eutrophic lake is one whose nutrient concentration is high
- ✓ Dystrophic lake is one which contains a very high concentration of humic acids leached from decaying aquatic vegetation in the watershed, causing water to be brown coloured.
  Dystrophic lakes are usually acidic, shallow and unproductive because brown colour reduces light penetration. The fertility of water depends on the concentration of dissolved nutrients, which depends on seasons.

How nutrients enter lakes

- In runoff water
- Inlet streams carrying components of sewage and leached ions from land
- From air
- From decomposition of organic matter

How nutrients are lost from lakes

- Outlet streams
- Absorption by autotrophs
- Incorporation into mud.

NOTE:

1. The most abundant cations of lake water are sodium, potassium, magnesium, and calcium.
2. The most abundant anions are carbonate, sulphate and chloride.
3. Other essential nutrients that are scarce in lake waters are phosphorus and iron

Reasons for the scarcity of phosphorus and iron in fresh water

- ✓ The fate of phosphorus and iron that enter lake water and reach the mud depends on whether the mud is oxidised or reduced.
- ✓ Dissolved Iron (II) when deposited at the bottom of an Oligotrophic lake gets oxidised by oxygen to insoluble iron (III), which remains fixed and insoluble in the mud. But iron falling into Eutrophic Lake lies on the reduced mud as iron (II) and is easily dissolved into the bottom waters hence available to autotrophs.
- ✓ When a lake has anoxic bottom water, the top mud is chemically reduced, a condition that allows the mud to release phosphorus back to the water. The bottom water thus becomes phosphorus-rich.
- ✓ Stirring of the lake brings the phosphorus-rich water to the surface and thus fertilizing the lakes for a plant growth

Characteristics of oligotrophic and eutrophic lakes

Oligotrophic lakes

- × Contain low concentration of dissolved nutrients.
- × Water appears transparent or blue.
- × Algal blooms at surface not visible.
- × Productivity is low.
- × Deep water retains oxygen at all seasons.
- × Sediment at mud/water interface is oxidised at all seasons.
- × There is some plant production throughout the water column and on the mud surface

Eutrophic

- × Concentration of dissolved nutrients is high.
- × Water is turbid, opaque and green or brown.
- × There are dense algal blooms in the surface water.
- × There is reduced photosynthesis down the water due to dense shadow cast by surface plankton.
- × Productivity is high.
- × Community respiration and BOD are high.
- × There is strong fertilizing effect when nutrient-rich water is brought to the surface.

NOTE:

B.O.D "Biological oxygen demand"

- ☑ Mass of oxygen consumed by microorganisms in a sample of water in a given time measured as the mass in mg of oxygen used in one litre of water stored in darkness at 20^0C for 5 days.
- ☑ B.O.D indicates the oxygen not available to more advanced organisms. Therefore a high B.O.D indicates anaerobic conditions; low oxygen availability.

OXYGEN AND CARBONDIOXIDE AVAILABILITY IN WATER

- Oxygen enters an aquatic system from the atmosphere and through photosynthesis by aquatic producers, and is removed by aerobic respiration of plants, animals and decomposers.
- Carbon dioxide enters an aquatic system from the atmosphere and through aerobic respiration by plants, animals and decomposers, and is removed by photosynthesising plants.
- Some dissolved carbon dioxide forms carbonate ions, which are stored as calcium carbonate for long periods in sediments, minerals and shells and skeletons of aquatic animals.

MOISTURE AND SALINITY

- ❖ Water is one of the limiting factors for most activities in terrestrial environment.
- ❖ It is a habitat for plants and animals, a raw material for photosynthesis and germination, an agent of seed and fruit dispersal, a medium for reproduction of aquatic organisms and a medium for recycling materials in nature.
- ❖ Therefore water provides necessary condition for plant growth and distribution.
- ❖ Rapid drainage, low rainfall and evaporation cause limited amount of water in the soil while the reverse leads to water lodging.
- ❖ By determining the kind of plants in a particular environment, availability of water indirectly determines other organisms inhabiting that environment.
- ❖ Plants are classified according to their water supply into;
- ✓ **Mesophytes;** which live in areas readily available water
- ✓ **Xerophytes;** living in areas of short supply of water and high temperature
- ✓ **Hydrophytes;** living in fresh water or very wet environment.
- ✓ **Halophytes;** in areas close to the sea with high salt concentration making water absorption difficult.

Note; salinity is the saltiness or dissolved inorganic salt content of a water body.

Adaptations of hydrophytes to aquatic life

- ☑ They are categorized as; submerged if completely under water e.g. Elodea, floating e.g. Pistia, Lemna, Eichorhnia, Nymphaea/ water lily and amphibious if growing in shallow and muddy waters e.g. Typha, Alisma.
- ☑ Development of tissues with large intercellular spaces for floating/ aerenchyma
- ☑ Poor development of roots coupled with lack of root hairs.
- ☑ Absence of cuticle to allow much water loss.
- ☑ Poor functioning of stomata or reduced number.
- ☑ Poor development of mechanical tissues.
- ☑ Dimorphism of leaves i.e. some submerged plants bear under water leaves that are thin while the leaves above water are broad for floating.
- ☑ Formation of coiled pedicels and petioles to keep flowers and leaves above water surface.
- ☑ Development of water proofing waxy cuticle to avoid decay.

XEROPHYTIC ADAPATATIONS IN TEMPERATURE REGULATION

In this both animals and plants have adapted to survival due to different modifications as follows;

Animals' adaptations to high temperatures

Structural adaptations;

- ✓ Large body extremities e.g ear lobes; to increase surface area over which heat is lost.
- ✓ Small sized; to increase the surface area to volume ratio, for heat loss
- ✓ Some animals like the camel, have long skinny non fatty legs to increase heat loss during locomotion
- ✓ Little or no fur to reduce on insulation, and increase amount of heat lost
- ✓ Thin subcutaneous fat layer under the skin to increase heat loss from the body
- ✓ Have tissues tolerant to extreme temperature changes, maintaining the body's main functions

Physiological adaptations

- ✓ Enzymes work under a high optimum temperature range to maintain metabolism during day and night.

Behavioral adaptations

- ✓ Most are nocturnal, i.e most active at night, when temperatures are relatively low
- ✓ Aestivation
- ✓ Movement with some body parts raised to minimize direct contact with hot grounds e.g desert snakes
- ✓ Salivation of the neck and legs; increasing heat loss by evaporation e.g in tortoise

Animals' adaptation to cold temperatures

Structural adaptations;

- ✓ Thick layer of fat under the skin; to increase on insulation by avoiding heat loss
- ✓ Small body extremities to reduce the surface area over which heat is lost
- ✓ Large sized; thus small surface area to volume ratio; reducing amount of heat lost to the surrounding
- ✓ Thick fur; to increase on insulation
- ✓ Tissues tolerant to extreme changes in temperature; maintaining their normal functions in the body

Physiological adaptations

- ✓ Enzymes work under a high optimum temperature range to maintain metabolism during day and night

Behavioral adaptations

- ✓ Hibernation
- ✓ Gathering in groups to warm themselves e.g penguins

XEROMORPHIC ADAPTATIONS OF PLANTS

- × Some have a thick cuticle of the leaves and stem to reduce cuticular transpiration such as pinus plants.
- × Some have a layer of hair on the epidermis that traps moist air and reduces diffusion gradient such as
- × Some have a mass of leaves at ground level that are organized into a mosaic to trap moist air between them such as dandelion.
- × Some have Leaves that have reduced number of stomata this reduces the pores exposed to transpiration such as pinus.
- × Leaves have sunken stomata to reduce the rate of transpiration such as pinus.
- × Some have leaves that are reduced into spines or scales in photosynthesing stem trapping moist air outside the stomata such as broom plants.
- × Some have leaves with reversed stomatal rhythm, closure of stomata in light and opening in the dark this reduces the rate of water loss as carbon dioxide is fixed in the dark such as CAM plants.
- × Some have succulent leaves and stems for storage of water such as cactus and brophyllum.

- Some plants roll up their leaves when flaccid reducing surface area for transpiration such as marram grass.
- Some have deep and extensive root system such that they can tap the water table such as acacia plants.
- Some have superficial roots for absorbing overnight condensed water such as cactus plants.

MESOPHYTES

- Most of the flowering plants are adapted to soils which are neither extremely wet nor extremely dry. These are called mesophytes.
- In dry conditions they often suffer water stress (losing more water to air than they can absorb from soil) which leads to wilting (loss of cell turgor due to excessive water loss leading to dropping of the whole plant structure).
- They respond to water stress respond to water tress by closing their stomata. Some herbaceous plants lose their aerial parts to survive drought conditions.

HALOPHYTES

- ✓ They are found in areas with high salinity such as salt marshes and estuaries.
- ✓ They tend to be rooted in water logged muddy areas but are faced with physiological drought problem (when water is unavailable to plant tissues due to low water potential of the environment of roots).

They overcome this by

- Actively pumping salts into roots to low their water potential so that water can flow into roots by osmosis
- Storing water in succulent tissues in leaves when it is freely available
- Having a higher concentration of the cell sap than that of their environment
- Evolving many xeromorphic features which reduce water loss.eg thick epidermis, waxy cuticle and reduced number of stomata
- Excreting salts from salt gland s at their margins

THE MAJOR BIOTIC / LIVING COMPONENTS OF ECOSYSTEMS

They are classified as either producers or consumers based on how they get food. They maybe animals, plants or decomposers.

1. **Producers / autotrophs**;

These are the green plants, algae and phytoplanktons which capture sunlight to make carbohydrates like glucose by photosynthesis releasing oxygen gas in the process, or some chemosynthetic bacteria which convert simple compounds like hydrogen sulphide (H_2S) and CO_2 into organic nutrient molecules using sources of energy other than light e.g. geothermal energy.

2. **Consumers / Heterotrophs**;

These are the animals that get energy and nutrients by feeding on other organisms or their remains. Consumers are classified as:

a) Herbivores/primary consumers – if they feed directly on producers
b) Carnivores - if they feed on other consumers
c) Secondary consumers feed only on primary consumers
d) Tertiary and quaternary (higher level) consumers feed on other carnivores
e) Omnivores – eat plants and animals e.g. cockroaches, humans, pigs, rats, bears, foxes
f) Scavengers – feed on dead organisms e.g. vultures, flies, hyenas, and some species of sharks and ants

g) Detritivore (detritus feeders and decomposers) – feed on detritus or parts of dead organisms and cast off fragments and wastes of living organisms.

Note;

1. Detritus feeders extract nutrients from partly decomposed organic matter in leaf litter, plant debris and animal dung e.g. crabs termites, earthworms, woodlice, sea cucumbers etc.
2. Unlike decomposers, detritivores are larger and digest food internally rather than externally. **Detritus** refers to fragments of organic remains.

h) Decomposers / Saprobionts – mostly certain types of bacteria and fungi, which recycle organic matter in ecosystems by:

- Biodegrading (breaking down) dead organic material (detritus) to get nutrients. This enables the disposal of plant litter, dead animal bodies, animal wastes and garbage, which would accumulate everywhere.
- Releasing the resulting simpler inorganic compounds into the soil and water, where they can be taken up as nutrients by producers.

LIFE ON EARTH

Three interconnected factors sustain life on earth:

a) The one-way flow of high quality energy from the sun:

Through materials and living organisms in their interactions

Into the environment as low quality energy – mostly heat dispersed into the air or water molecules at low temperature.

Eventually back into space as heat.

b) The cycling of matter through parts of the biosphere

c) Gravity, which: Allows the planet to hold on to its atmosphere and as well causes the downward movement of chemicals in the matter cycles.

How the sun sustains life on earth

- ☑ Lights and warms the planet.
- ☑ Supports photosynthesis in plants and some bacteria.
- ☑ Powers the cycling of matter.
- ☑ Drives the climate and weather systems that distribute heat and fresh water over the earth's surface.

ENERGY FLOW THROUGH AN ECOSYSTEM

The process of energy flow through the ecosystem

- ✓ The primary source of energy is the sun.
- ✓ Of the energy received by the earth, less than 0.1% is fixed by green plants as chemical energy in biomass in organic substances during photosynthesis this is gross primary production; the rest is reflected by the atmosphere, heats the earth's surface or causes evaporation of water.
- ✓ Part of gross primary production is used by green plants for aerobic respiration while what remains now called net primary production is used as food by primary consumers, during which only about 5 – 10% of the energy is transferred from producer to primary consumer.
- ✓ A loss of 90 – 95% occurs, because much of plant biomass is indigestible to herbivores.
- ✓ The energy obtained by herbivores through feeding on producers is less than what producers get from the sun because some is lost in egestion, excretion, and not all parts are eaten.

- ✓ When carnivores eat herbivores still the energy they obtain is less than what herbivores obtain from feeding on producers, and the trend is maintained even as top carnivores feed on secondary consumers.
- ✓ Therefore, with each energy transfer some usable energy is degraded and lost to the environment as low quality heat, thus the energy available to each successive trophic level declines, and the more trophic levels in a food chain or web, the greater the cumulative loss of energy during its flow through the various feeding levels.
- ✓ This limits the number of feeding levels to 3 or 4, or very rarely 5 or 6.

ENERGY BUDGETS

An energy budget shows the percentage allocation of energy consumed by an individual organism to the various processes in the body such as respiration, growth and reproduction.

Terms associated with energy budgets

1. **Gross primary productivity (GPP)**
   - It is the rate at which producers convert solar energy into chemical energy stored in organic substances.
   - It is the total amount of energy fixed by producers per unit area of photosynthetic surface per unit time.
   - GPP is greatest:

   (i) In shallow waters near continents.

   (ii) Along coral reefs where abundant light, heat and nutrients stimulate the growth of algae.

   (iii) Where upwelling currents bring nitrogen and phosphorus from the ocean bottom to the surface.
   - GPP is lowest in:

   (i) deserts due to low precipitation and intense heat.

   (ii) The open ocean due to lack of nutrients and sunlight except near the surface.

2. **Net primary productivity (NPP)**
   - It is the rate at which energy for use by heterotrophs or consumers is stored in new organic substances.
   - NPP is the energy that remains to be used by consumers after producers have used part of GPP for their own respiration.

     NPP = GPP – (respiration + metabolism)
   - NPP most productive ecosystems are:
     - Estuaries
     - Swamps and marshes
     - Tropical rainforests
   - NPP least productive ecosystems are: Open ocean and Desert.
   - Despite its low net productivity, the open ocean produces more of the earth's NPP per year than any other ecosystem because of its large size.

3. **Secondary production**
   - It is the rate which energy is used to make new biomass in consumers.
   - This the energy remaining in heterotrophs available for production; growth, repair and reproduction after losses through egestion, excretion and respiration
4. **Biomass**
   - It is the dry weight of all organic matter contained in organisms per unit area of ground or water.

5. **Standing biomass (Standing crop biomass)**
   - It is the dry weight of all organic matter contained in organisms at a given trophic level per unit area of ground or water at a given moment in time
6. **Trophic efficiency (Ecological efficiency)**
   - It is the percentage of energy at one trophic level that is converted into organic substances at the next trophic level
   - Trophic efficiencies range from less than 1% (e.g. herbivores eating plant material) to over 40% (e.g. zooplanktons feeding on phytoplanktons)

NOTE:

a) Of the energy received by the earth, averagely less than 3% is fixed by green plants.

b) Energy transfer from producer to primary consumer is typically in the order of 5 – 10% of NPP (a loss of 90 – 95% occurs) because:
(i) Much of plant biomass (NPP) is indigestible to herbivores – e.g. no animal enzymes can digest lignin and cellulose
(ii) An individual herbivore may not eat much of the plant biomass – e.g. roots may be inaccessible.

c) Energy transfer from primary consumers (herbivore) to secondary consumers (carnivores) is typically 10 – 20% of herbivore mass (a loss of 80 – 90% occurs).
This more efficient than in (b) above because:
(i) Animal tissue is more digestible than plant tissue
(ii) Animal tissue has a higher energy value.
(iii) Carnivores may be extremely specialized for prey consumption.

But still less than 100% because:
(i) Some animal tissue e.g. bones, hooves, hides is not readily digestible
(ii) Feeding is not 100% efficient because much digestible material e.g. blood and food fragments may be lost to the environment.

d) The number of trophic levels rarely exceeds five because:
The more trophic levels in a food chain or web, the greater the cumulative loss of usable energy as it flows through the various trophic levels, leaving very little energy to support organisms feeding at the high trophic levels.
This explains why:
(i) There are so few top carnivores e.g. eagles, hawks, tigers, white sharks.
(ii) Such species are first to suffer when the systems that support them are disputed
(iii) these species are so vulnerable to extinction.

e) The longest food chains can only be supported by an enormous producer biomass e.g. in oceans.

FOOD CHAIN

A linear sequence of energy flow from producers through a series of organisms in which there is repeated eating and being eaten.
Two types exist i.e
(i) Grazing food chain
(ii) Detritus food chain

Grazer food chain,

- This starts with autotrophs (producers) such as green plants which convert carbon dioxide and water into chemical compounds. These are grazed upon by herbivores. Energy is further transferred to carnivores.
- It can be in grass land or water body (aquatic).

Examples include;

Grass ⟶ millipede ⟶ toad ⟶ snakes hawks

Green algae ⟶ haplochromics (small fish) ⟶ tilapia ⟶ kingfisher

Think about and create more!

Detritus food chain

- This is the one where the consumers obtain energy from fragments of dead decaying organic matter.
- Exists in both aquatic and terrestrial habitats. first trophic level is occupied by a decomposing organic matter

Examples include;

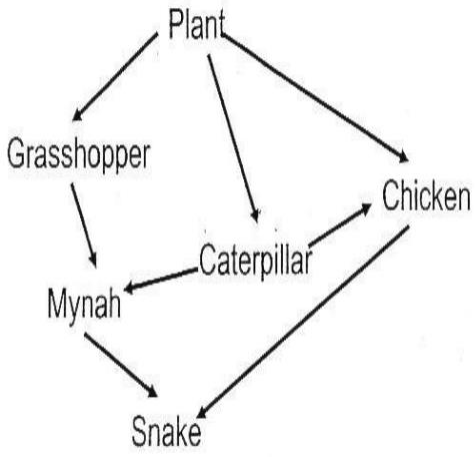
Tree log ⟶ wood lice ⟶ toad ⟶ python

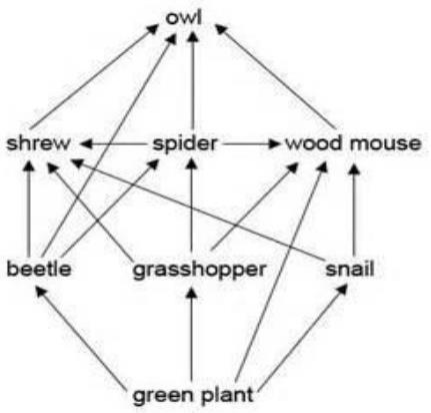
Dead animal ⟶ maggot ⟶ bird ⟶ python

Think and create more!

FOOD WEB

This is a complex nutritional relationship showing alternative sources of food for each organism in a food chain i.e. a complex network of food chains linked to one another.





Or check Figure 32.16 Biology a functional approach Page 534

Or check fig.17.2 understanding biology page 336.

Note; the direction of the arrow in the food chain indicates the direction of flow of energy when one organism feeds on another.

ECOLOGICAL PYRAMIDS

These are histograms that provide information about trophic levels in ecosystems.

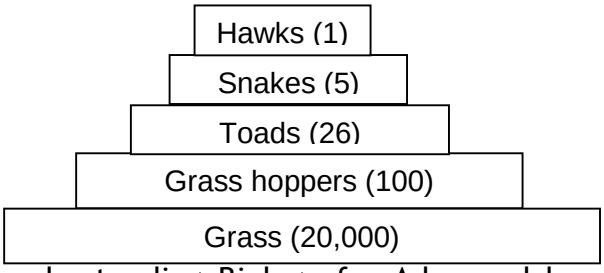
They maybe;

1. Pyramid of numbers; based on relative number of organisms present at each trophic level

2. Pyramid of biomass; based on the total dry weight of organisms present at each trophic level
3. Pyramid of energy; based on amount of energy present in organisms at each trophic level

PYRAMID OF NUMBERS

It is a histogramatic representation of the numbers of different organisms at each trophic level in an ecosystem at any one time.
For example



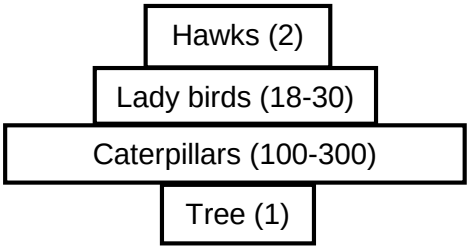
Or check New understanding Biology for Advanced level, 4th ed. 1999 pg. 338 fig. 17.3a

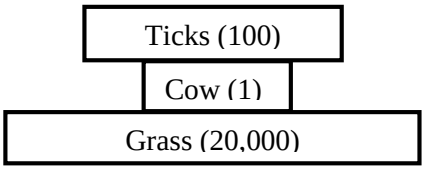
Note:

- ✓ The number of organisms at any trophic level is represented by the length of a rectangle.
- ✓ Generally, as the pyramid is ascended, the number of organisms decreases, but the size of each individual increases.

Disadvantages of pyramid of numbers

- × Drawing the pyramid accurately to scale may be very difficult where the range of numbers is large e.g. a million grass plants may only support a single top carnivore.
- × Pyramids may be inverted; particularly if the producer is very large e.g. an oak tree or parasites feed on the consumers e.g. fleas on a dog.





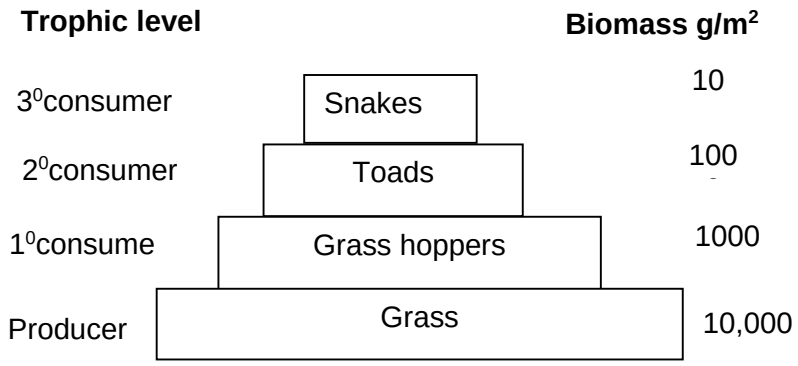
- × The trophic level of an organism may be difficult to ascertain.
- × The young forms of a species may have a different diet from adults, yet they are considered.
- × Organisms that feed on more than one source of food hence not easy to ascertain a trophic level.

Or. **Check New understanding Biology for Advanced level, 4th ed. 1999 pg. 338 fig. 17.3b**

PYRAMID OF BIOMASS

- It is a histogramatic representation of the biomass which is obtained as number of individuals multiplied by mass of each individual at each trophic level in an ecosystem at any one time.

- Since some inorganic compounds may be included and because the water content in organisms varies so much, it is better to use dry mass. This can be estimated from wet mass or obtained by destructive analysis which involves heating.
- The amount of dry mass measured at a time is called the standing crop. Therefore, length of each bar in a pyramid of biomass indicates total dried mass of organisms each trophic level per unit area.



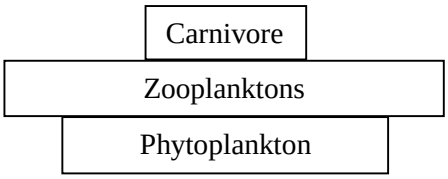
Advantage of using pyramid of biomass

- ✓ It eliminates scale problems encountered when constructing a pyramid of numbers.

Disadvantages:

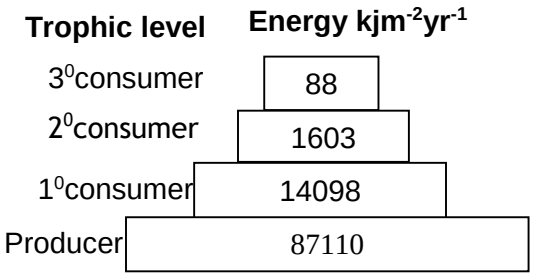
- An inverted pyramid of biomass can occur if the producer level includes organisms with a high turnover rate (rapid reproduction) so that they have a high productivity over a period of time e.g. in open water of oceans, the zooplankton biomass can exceed that of phytoplankton because the former eat the latter almost as fast as they are produced, so the producer population is never very large.
- The sampling situation at any one time deals with standing crop biomass (amount of material present at a particular instant) rather than with productivity (the capacity of any trophic level to produce biomass over a period of time) e.g. zooplankton in a marine ecosystem.

Illustration of an inverted pyramid



PYRAMID OF ENERGY FLOW

- ✓ It is a histogramatic representation of the flow of energy through each level of an ecosystem during a fixed time period.
- ✓ Its data is obtained combusting the previously dried and weighed samples to obtain the estimates of their energy content.
- ✓ Each bar of a pyramid of energy represents the total amount of energy utilized at each trophic level.
- ✓ The total productivity can be measured for a given period such as one year. From this the proportion of it utilized by the primary consumer can be calculated and so on up the food chain.



Note:

A. Because such pyramids represent energy flows, not energy storage, they should not be called pyramids of energy (a common error in some books)
B. Energy flow pyramids explain why the earth can support more people if they eat at lower trophic levels by consuming grains, vegetables and fruits directly rather than passing such crops through another trophic level and eating grain eaters.

Advantage of pyramid of energy flow

- ✓ It compares productivity because a time factor is incorporated.
- ✓ Biomass may not be equivalent to energy value, e.g. 1g of fat has many more kJ than 1g of cellulose or lignin.
- ✓ No inverted pyramids are obtained because of the automatic degradation of energy quality.
- ✓ The solar input of energy may be included as an extra rectangle at the base.

Disadvantages

- ✓ Obtaining the necessary data required in constructing pyramids of energy flow is difficult.

*Check Biological science 3rd edition pg307 fig.10.9

BIOGEOCHEMICAL CYCLING/ NUTRIENT CYCLING

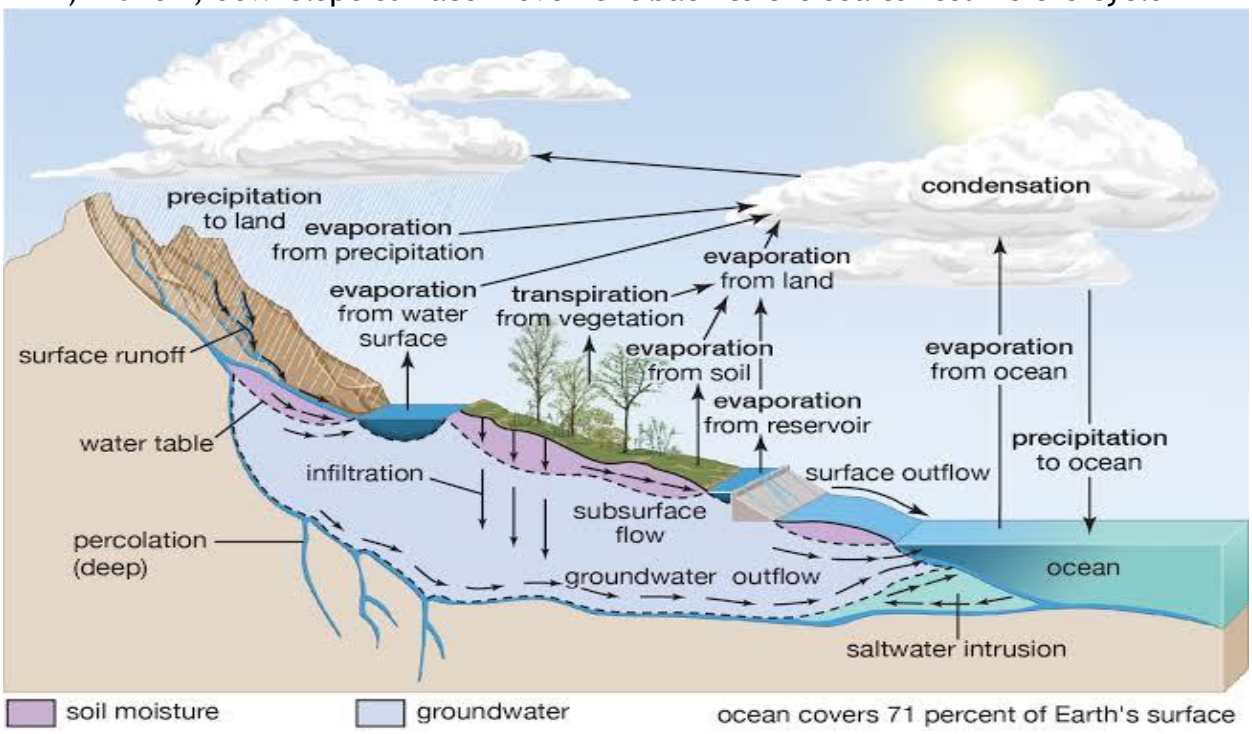
- This the process by which chemical compounds of a particular element that constitutes living matter are transferred between living organisms and non-living environment.
- These cycles driven directly or indirectly by incoming solar energy and gravity include the carbon, nitrogen, phosphorus, oxygen, Sulphur and hydrological (water) cycles.

HYDROLOGICAL/ WATER CYCLE

The water cycle is powered by energy from the sun and by gravity, and it involves the following main processes:

1) Evaporation; conversion of water into water vapour.
2) Transpiration; evaporation from leaves of the water extracted from soil by roots and transported throughout the plant.
3) Condensation; conversion of water vapour into droplets of liquid water.
4) Precipitation; rain, hail, snow and sleet.
5) Infiltration; movement of water into soil.
6) Percolation; downward flow of water through soil and permeable rocks to ground storage areas called aquifers.

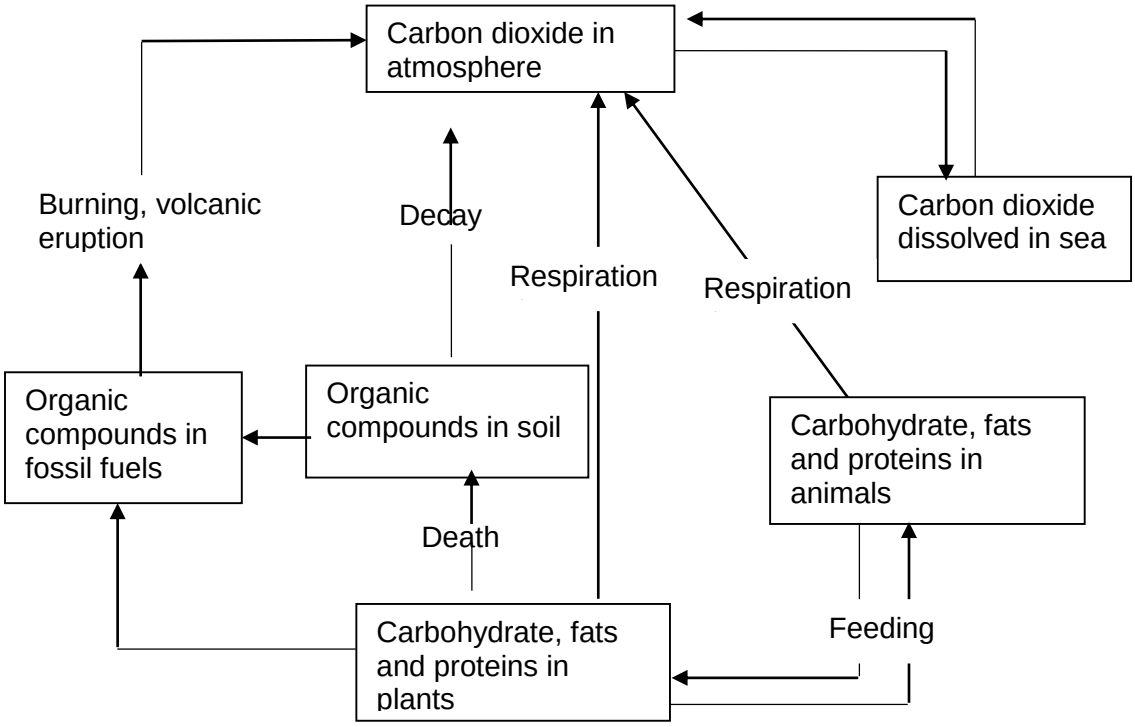
7) Runoff; downslope surface movement back to the sea to resume the cycle



Or check Advanced Biology by simpkins & Williams page 674-675

CARBON CYCLE

1) The carbon cycle is based on carbon dioxide gas, which makes up 0.036% of the volume of the troposphere and is also dissolved in water.
2) Carbon fixation involves the reduction of carbon dioxide to large organic molecules during photosynthesis and chemosynthesis.
3) During aerobic respiration, the carbon in glucose and other complex organic compounds is converted to carbon dioxide into the atmosphere or dissolves in water.
4) Over millions of years, buried deposits of dead plant debris and bacteria are compressed between layers of sediment to form the carbon-containing fossil fuels e.g. coal, oil and natural gas, which when burnt release carbon dioxide into air.
5) In aquatic ecosystems, carbon dioxide may;
   (i) remain dissolved
   (ii) be utilised in photosynthesis
   (iii) React with water to form carbonate ions and bicarbonate ions. As water warms, more dissolved carbon dioxide returns to the atmosphere.
6) In marine ecosystems, some organisms take up dissolved carbon dioxide molecules, carbonate ions and bicarbonate ions and these ions react with calcium ions to form calcium carbonate to build their shells and skeletons.
7) When the animals with calcium in shells and skeletons die and drift into deep bottom sediments of oceans, immense pressure causes limestone and chalk to form after a very long period of time.
8) Weathering processes release a small percentage of carbon dioxide from limestone into the atmosphere.



Or check in new understanding Biology for Advanced level, 4th ed. 1999 pg. 340 fig. 17.4

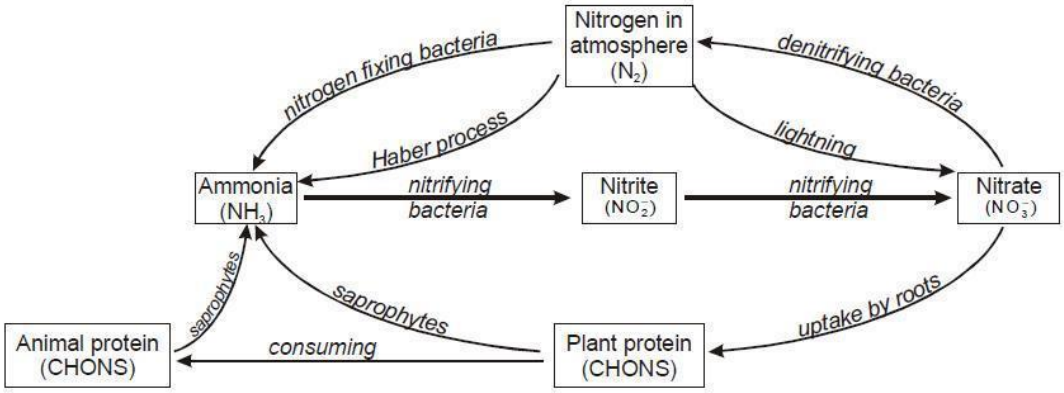
How human activities affect the carbon cycle

- ✓ Clearing of trees and other plants that absorb carbon dioxide through photosynthesis results in its increased concentration.
- ✓ Burning of fossil fuels and wood adds large amounts of carbon dioxide into the troposphere.

NITROGEN CYCLE

1) Nitrogen is the atmosphere's most abundant element, with chemically unreactive nitrogen gas making up 78% of the volume of the troposphere.
2) However, nitrogen cannot be absorbed and metabolized directly by multicellular plants and animals.
3) Atmospheric electrical discharges in the form of lightning causes nitrogen and oxygen in the atmosphere to react and produce oxides of nitrogen, which dissolve in rainwater and fall to the ground as weakly acidic solutions e.g. nitric acid.
4) Nitrogen fixation occurs when the nitrogen in soil is reduced to ammonium ions, catalysed by nitrogen-fixing bacteria which may be free-living e.g. Azotobacter, symbiotic in root nodules e.g. Rhizobium or cyanobacteria e.g. Nostoc.
5) Nitrification occurs when ammonium compounds in soil are converted first to nitrite ions by Nitrosomonas bacteria and later to nitrate ions by Nitrobacter bacteria.
6) Ammonification or putrefaction occurs when decomposers e.g. some bacteria and fungi convert nitrogen-rich organic compounds, wastes like urea and dead bodies of organisms into ammonia and ammonium ion-containing salts.
7) Assimilation occurs when inorganic ammonia, ammonium and nitrate ions are absorbed by plant roots to make DNA, amino acids and protein.
8) Denitrification occurs when mostly anaerobic bacteria e.g. Pseudomonas denitrificans and Thiobacillus denitrificans in water logged soil and deep in ocean, lake and swamp bottoms convert ammonia and ammonium ions back

into nitrite and nitrate ions, and then into nitrogen gas and oxygen. Nitrogen gas is released into the atmosphere while oxygen is used for the respiration of these bacteria.



Or check New understanding Biology for Advanced level, 4th ed. 1999 pg. 341 fig. 17.5

How human activities affect the nitrogen cycle

- ✓ Burning of fuels forms nitric oxide, which reacts with atmospheric oxygen to form nitrogen dioxide gas that reacts with water vapour to form acid rain containing nitric acid.
- ✓ Nitric acid together with other air pollutants, damages trees, corrodes metals and upsets aquatic ecosystems.
- ✓ The inorganic fertilizers applied to soil are acted upon by anaerobic bacteria to release nitrous oxide into the stratosphere, where it contributes to ozone depletion and contributes to greenhouse effect.
- ✓ Nitrogen is removed from top soil when we harvest nitrogen-rich crops, irrigate crops and burn or clear grasslands and forests before planting crops
- ✓ Adding nitrogen compounds to aquatic ecosystems e.g. sewage algal blooming, which upon death, their decomposition causes oxygen shortage resulting into death of aerobic organisms e.g. some fish.
- ✓ The accelerated deposition of acidic nitrogen containing compounds e.g. nitrogen dioxide and nitric acid onto terrestrial ecosystems stimulates growth of weeds, which outcompete other plants that cannot take up nitrogen as efficiently.

PHOSPHORUS CYCLE:

1) Phosphorus typically is found as phosphate salts containing phosphate ions in terrestrial rock formations and ocean bottom sediments.
2) Phosphorus enters food webs in the form of inorganic phosphates, which are then built up into organic molecules such as nucleic acids, phospholipids and ATP.
3) When plants and animals die or excrete wastes, phosphatising bacteria release inorganic phosphate back into the soil.
4) The cycling of phosphorus is a very slow process because it is stored in crystalline rocks, which only appear at the surface by geological movements.
5) Very little phosphorus circulates in the atmosphere because at the earth's normal temperatures and pressure phosphorus and its compounds are not gases, but as small particles of dust.

Note:

- Bacteria are less important in the phosphorus cycling, as compared to nitrogen cycling Because most soils are contain little phosphate, it is often the limiting factor for plant growth, necessitating application of phosphate fertilisers obtained from mining phosphate salts from the earth.
- Adding phosphate compounds to water bodies increases their biological activity e.g. algal blooming because phosphate salts are only slightly soluble in water, so phosphorus is a limits the growth of producer populations.
- Phosphorus and Sulphur have the dominant sedimentary phase as the sediment reservoir unlike the carbon and nitrogen cycles that have the dominant atmospheric phase.

How human activities affect the phosphorus cycle

- Mining phosphate rocks for use in commercial inorganic fertilisers and detergents.
- Cutting of trees in forested areas depletes the soil of phosphorus through erosion by heavy rains.
- Adding excess phosphate to aquatic ecosystems in runoff of commercial fertilisers and sewage discharge results in algal blooming, whose decomposition depletes water of oxygen this disrupts aquatic ecosystems.

BIOTIC FACTORS

There are various biotic/ living factors that affects the distribution and abundance of a given organism in a particular area due to the relationships with them that arises;

1. PREDATION:

In predation, members of one species; the predator feed on all or part of a living organism of another species; the prey. Therefore, predators are only found where there is prey e.g. herbivores are found where there is suitable plant material.

2. **COMPETITION**: this maybe intra or interspecific competition;

- ☑ Intraspecific competition is the competition between members of the same species for the same resources, while Interspecific competition is the competition between members of two or more different species for food, space, good hiding place, water, sunlight, nesting sites or any other limited resource.
- ☑ Competition is very intense when there is significant overlap of niches, and in this case, one of the competing species must either

(i) Migrate to another area if possible,

(ii) Shift its feeding habits or behaviour through natural selection and evolution

(iii) suffer a sharp population decline,

(iv) Become extinct in that area, otherwise two species can never occupy exactly the same ecological niche in accordance to the competitive exclusion principle to be discussed later.

Details to be discussed later;

3. In **commensalism** one species neither harms nor helps the other species much it interacts with e.g. white eaglet on cattle. There is no harm caused to large trees when epiphytic plants like orchids attach on the branches to get support and be elevated to access sunlight and water vapour in air.

4. The **pollination and dispersal** relationship between flowering plants and animals such as insects, birds and bats may be highly elaborate and species-specific.

This Coevolution ensures that the distribution of the plants and their pollinators or agents of dispersal is related e.g. arum lily flower is pollinated by dung flies.

Note; **co-evolution**

This is the long term evolutionary adjustment of two or more groups or organisms that facilitate those organisms living with one another.

Examples:

(i) Many features of flowering plants have evolved in relation to the dispersal of the plant's gametes by animals, especially insects. The animals have in turn evolved a number of special traits that enable them to obtain nectar.

(ii) Grasses have evolved the ability to deposit silica in their leaves and stems to reduce their risks of being grazed. In turn, large herbivores have evolved complex molars with enamel ridges for grinding up grass.

5. **Mimicry**; Some species gain protection to avoid predation by mimicking; looking and acting like other species that are distasteful to the predator. This ensures that the distribution of the mimic and mimicked species is related e.g. the non-poisonous viceroy butterfly mimics the poisonous monarch butterfly.

6. In the course of evolution preyed upon species have evolved deceptive looks to avoid predation e.g. span worms have shapes that look like twigs, some insect pupae may look like tree thorns. Therefore such animals are distributed where there are plants that ensure their survival.

7. **Antibiosis**;

This is the secretion by organisms chemicals that may be repellant to members of the same species or different species e.g. many mammals use chemicals to mark their territories with intention of deterring away other members of the species from entering, penicillium; a fungus secretes antibiotics that inhibit bacterial growth, ants release pheromones to warn off other members of a species in case of danger.

Note; there are two types of antibiosis

(i) **Intraspecific antibiosis;** secretion by organisms chemical substances into their surrounding that may be repellant to members of the same species

(ii) **Interspecific antibiosis**; secretion by organisms chemical substances into their surrounding that may be repellant to members of the different species.

8. **Human activity**; humans influence the distribution of other organisms more than any other species. As hunters, fishers, farmers, developers and polluters and many other activities, they dictate which organisms shrive where.

9. Mutualism; is an interspecific association in which both organisms benefit.

Examples include.

(i) Cellulose digesting bacteria in gut of ruminants such as goats, cattle and sheep. In this; Ruminants obtain sugars, amino acids while bacteria obtains shelter and food.

(ii) Leguminous plants e.g clover and nitrogen fixing bacteria (rhizobium). The plants obtain nitrates while bacteria obtains shelter, sugars, and vitamins.

(iii) Mycorrhizas (fungus and root of higher plants). Two types exist;

- ☑ In **ectotrophic mycorrhizas**, the fungus forms a sheath covering lateral roots of forest trees such as oaks, beech, conifers, while depending on photosynthesis by the tree to provide organic materials.
- ☑ **Endotrophic mycorrhizas;** involves most of fungi inside the root of orchids with the fungi digesting lignin and cellulose in the soil; and passing the end products into the roots of plants.

(iv)Lichens; green algae and fungus. Green Algae carries out photosynthesis, providing nutrients to the fungus while it is protected by the fungi from intense sunlight and desiccation, minerals absorbed by the fungus are passed onto it.
(v) Hermit crab and sea anemones, with the hermit crabs obtaining defence from the stinging cells of anemones and camouflaging from its predators. Sea anemones feed on food remains of the crab and obtains free transport from one area to another.

10. **Parasitism**

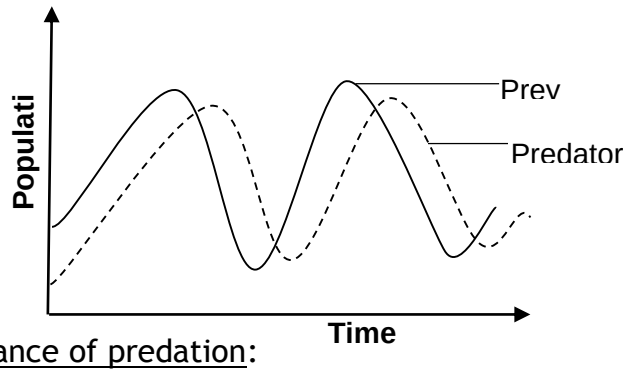
i. An organism called parasite obtains part or all its nutrients from the body of another organism of different species called host.
ii. The parasite is usually smaller than its host in size.
iii. Parasites do not usually kill their hosts, but the host suffers harm.
iv. Many parasites live permanently on; ecto parasites or in their hosts; endo parasite while some visit their hosts only to feed.
v. Some parasites are facultative, live on or in the host for some time e.g. a fungus Pythium that causes damping off seedlings, on killing the seedlings, lives as a saprophyte on their dead remains.
vi. Obligate; live on or in the host for their entire lives.

DETAILED STUDY OF SOME BIOTIC FACTORS

PREDATOR-PREY INTERACTIONS

A predator is an organism which capture, kills and eats another organism of a different species; prey to obtain food and energy.

A prey is an organism captured and fed upon by another organism; predators. Predation reduces the size of population of prey. The population of predators and their prey show cyclic changes with the species being slightly out of phase with one another. These are illustrated in the graph below



Evolutionary importance of predation:

- Predation usually eliminates the unfit prey; the sick, weak and aged.
- This gives the remaining prey access to the available food supply and also improves their genetic stock, which enhances the chances of reproductive success and long-term survival.
- Prey species with best defensive strategies are more likely to escape predation while predators with best hunting strategies and offensive weapons are more likely to catch prey. Through natural selection this has led to co-evolution of predator and prey.

How predators are suited for capturing prey:

- ✓ Herbivores simply walk, swim, or fly up to the plants they feed on.
- ✓ Some carnivore like cheetah and lions run very fast to catch prey.
- ✓ Other carnivores like bald eagles, hawks, lions etc have keen eyesight for locating prey.
- ✓ Carnivores like wolves and African lions cooperate in capturing prey by hunting in packs.
- ✓ Other predators have characteristics that enable them to hide and ambush their prey e.g. praying mantises sit in flowers of similar colour and ambush insects, alligators lie at stream bottom and dangle worm-like tongue to entice fish into its powerful jaws, a chameleon has a cryptic colouration that enables it walk to prey unnoticed.
- ✓ Some predators have a highly developed sense of smell for locating prey e.g. meerkat locates insects by smelling.
- ✓ Some nocturnal predators like bats and owls have a highly developed sense of detecting sound made by prey at a distance
- ✓ Electric fishes such as cat fish and electric rays produce high voltage discharge of up to 350V that stun their prey while the electric fish Gymnarchus produces a low electric potential of less than 0.1v to detect prey.
- ✓ Web-spinning spiders use their silky cob webs to catch small sized ground walking or flying insects.
- ✓ Ant-lions; lacewing fly larvae lay traps by making pits in the ground where preys fall.
- ✓ Some snakes e.g. puff adder, cobra and mamba have glands that secrete poison; venom, which the fangs inject into the prey to immobilise it.

Strategies of protection by prey against predation

- ✓ Ability to run, swim or fly fast.
- ✓ Possession of highly developed sense of sight or smell for alerting the presence of predators.
- ✓ Possession of protective shells e.g. turtles and snails for rolling into armour-plated ball
- ✓ Possession of spines e.g porcupines or thorns e.g cacti and rose-bushes for pricking predators.
- ✓ In some lizards tails break off when attacked, giving the animal enough time to escape.
- ✓ Some prey camouflage by changing colour e.g. chameleon and cuttlefish, or having deceptive colours that blend with the background e.g. arctic hare in its winter fur blends into snow.
- ✓ Some prey species discourage predators with chemicals that are poisonous e.g. oleander plants, irritating e.g. bombardier beetles, foul smelling e.g. stinkbugs and skunk cabbages or bad tasting e.g. monarch butterflies and buttercups.
- ✓ Some prey species have evolved warning colouration; contrasting pattern of advertising colours that enable predators to recognise and avoid such prey e.g. the poisonous frogs, some snakes, monarch butterflies and some grasshoppers.
- ✓ Some species gain protection to avoid predation by mimicking; looking and acting like other species that are distasteful to the predator e.g. the non-poisonous viceroy butterfly mimics the poisonous monarch butterfly.

Note;

1. Batesian mimicry; occurs when the palatable species mimics other distasteful species e.g viceroy butterfly mimics the poisonous monarch butterfly, the harmless hoverfly mimics the painful stinging wasp.
2. Mullerian mimicry; occurs when both the mimic and mimicked are unpalatable and dangerous e.g. the five spot Burnet and related moths.

- ✓ Other preys gain some protection by living in large groups e.g. schools of fish, herd of antelope, flocks of birds.
- ✓ Some prey scare predators by puffing up e.g. blowfish, or spreading wings e.g. peacock.
- ✓ The flesh of some slow-moving fish is poisonous e.g. porcupine fish.
- ✓ Some preys secrete poisonous or repellant substances e.g. scorpions, caterpillars, some grasshoppers, culex mosquito eggs.
- ✓ The electric fish Malapterurus; a cat fish produces high voltage discharge of up to 350v that shocks any predator that makes contact with it.
- ✓ Other preys employ alarm signals and calls e.g. ants, various fish, small birds and mammals.

MODEL EXPERIMENTS ON PREDATOR-PREY INTERACTIONS
Gause's three experiments using paramecium and didinium

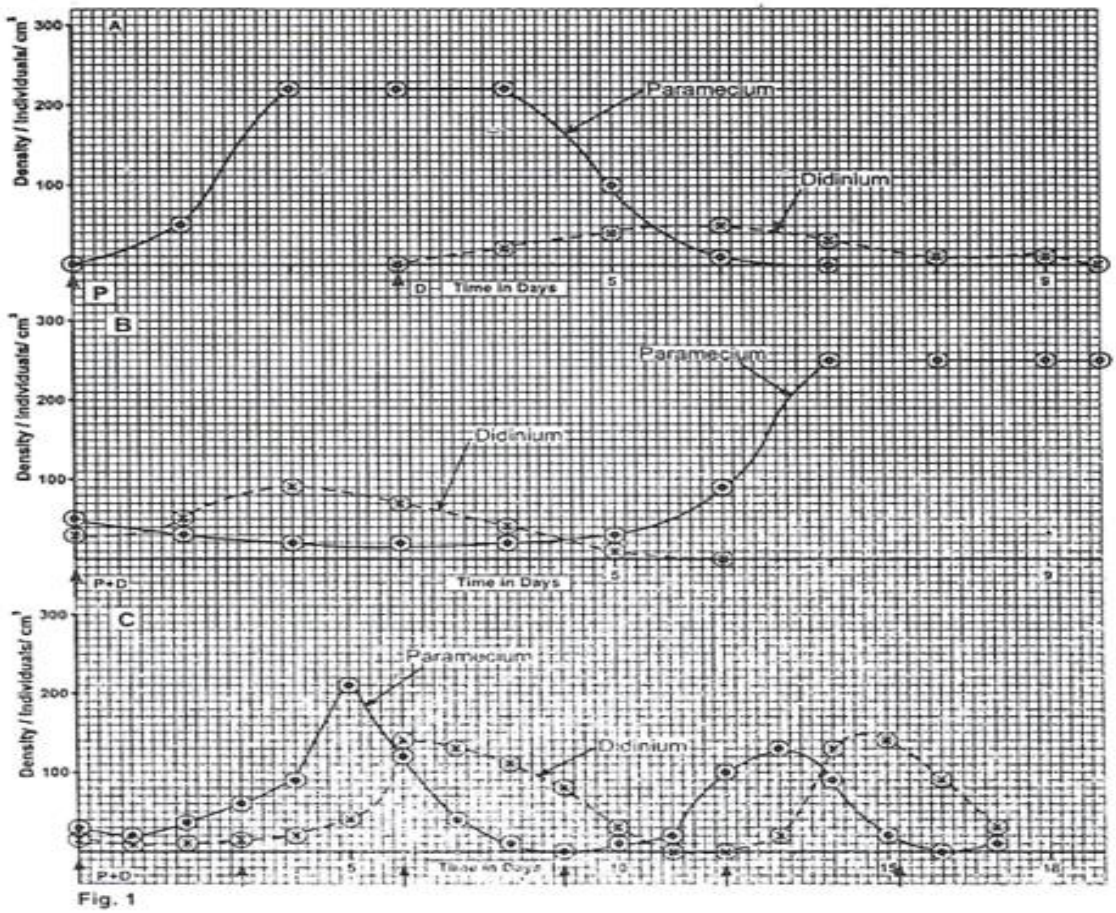


Fig. 1

Or. Refer to the graph in UACE 2004 biology paper 2 number 1 fig.1

Figure A

- The population of paramecium increases gradually on the first day then steeply to the maximum on the 2nd day. It becomes constant between the 2nd and 4th day and then decrease to very low level by the 6th day.
- The population of Didinium increased gradually to 2 ½ gay to reach a maximum and remains constant up to the 3rd day. It declines gradually by the 5th day, remained constant up to the 6th day before finally reducing to zero by the 9 ½ day
- Paramecium population rapidly decreased to extermination because it was being preyed upon by the introduced Didinium
- The gradual increase in Didinium population was supported by food (Paramecium) presence, what resulted was starvation as soon as food depleted.

Figure B

- The population of paramecium declines gradually up to the 3rd day, increases gradually up to the 5th day and then increases steeply up to a maximum by the 6th day. It then remains constant up to the 10th day.
- The population of Didinium increases gradually between 1st and 2nd day. It then declines gradually up to the 5th day before declining to zero by the 6th day
- Paramecium population decreases gradually for the first day because all of it that was in the clear-fluid medium was preyed upon by Didinium, which gradually increases and later starves to death. The increase in Paramecium population is because of its emergency from the sediment.

Figure C

- Equal populations of paramecium and Didinium were introduced on same day, after which the populations of both prey and predator show periodic oscillations with time.
- The population of paramecium declines slightly in the first. It increases gradually up to the 4th day, then steeply up to a maximum by the 5th day before declining sharply by the 7th day. It decreases to zero by the 9th day followed by a gradual increase up to 11th day. It sharply to the 2nd maximum on the 13th day before reducing gradually to zero by the 16th day then increases slightly by the 17th day.
- The population of Didinium decreases in the first day, then remain constant up to the 2nd day. It then increases up to the 5th day and reaches a peak on the 6th day. It then declines gradually to zero by the 11th day and then remain constant up to the 12th day, it then increases gradually by the 13th day and then sharply increases to a 2nd maximum value by the 17th day.
- Periodic oscillations (cyclic changes) in both populations result from Didinium preying on paramecium, reducing its population periodically.
- The shortage of paramecium then reduces the Didinium population, which allows the paramecium population to build up again.
- At some point the Didinium population increases to take advantage of the increased paramecium population, starting the cycle again.

General observations:

- ✓ In all experiments, paramecium population is higher than that of Didinium.
- ✓ In all experiments, paramecium population increases rapidly only after a brief period of stay in the medium.
- ✓ In experiments (a) and (b) Didinium population decrease gradually to zero.

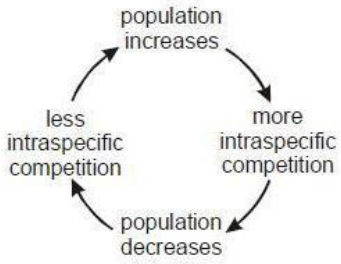
- ✓ The increase in Didinium population follows the increase in paramecium population, except in (b).
- ✓ In experiments (a) and (b) there is no periodic oscillation in populations, yet these cyclic changes are observed in (c).
- ✓ In experiments (c), periodic crushes in paramecium population are followed by crushes in Didinium population.

EXPERIMENTS ON INTERACTIONS INVOLVING COMPETITION

Competition may be either;

a. Intraspecific competition

- This is competition between members of the same species for the same resources.
- Intraspecific competition tends to have a stabilizing influence on population size.
- If the population gets too big, intraspecific population increases, so the population falls again.
- If the population gets too small, intraspecific population decreases, so the population increases again.



b. Interspecific competition

- This is competition between members of two or more different species for food, space, good hiding place, water, sunlight, nesting sites or any other limited resource.

Ways of competition by species

i. Interference competition; in which one species may limit another's access to some resource, regardless of its abundance, using the same types of methods found in intraspecific competition e.g. a hummingbird species may chase away other hummingbirds from its territory; many desert plants secrete substances into soil, which inhibit the growth of competing species or germination of seeds.

ii. Exploitation competition; in which competing species have roughly equal access to a specific resource but differ in how fast or efficiently they exploit it. The most competitive species gets more of the resource and inhibits the growth, reproduction or survival of the other species.

THE COMPETITIVE EXCLUSION PRINCIPLE/ GAUSE'S EXCLUSION PRINCIPLE

- Two species or populations that require identical resources cannot coexist indefinitely in the same habitat.

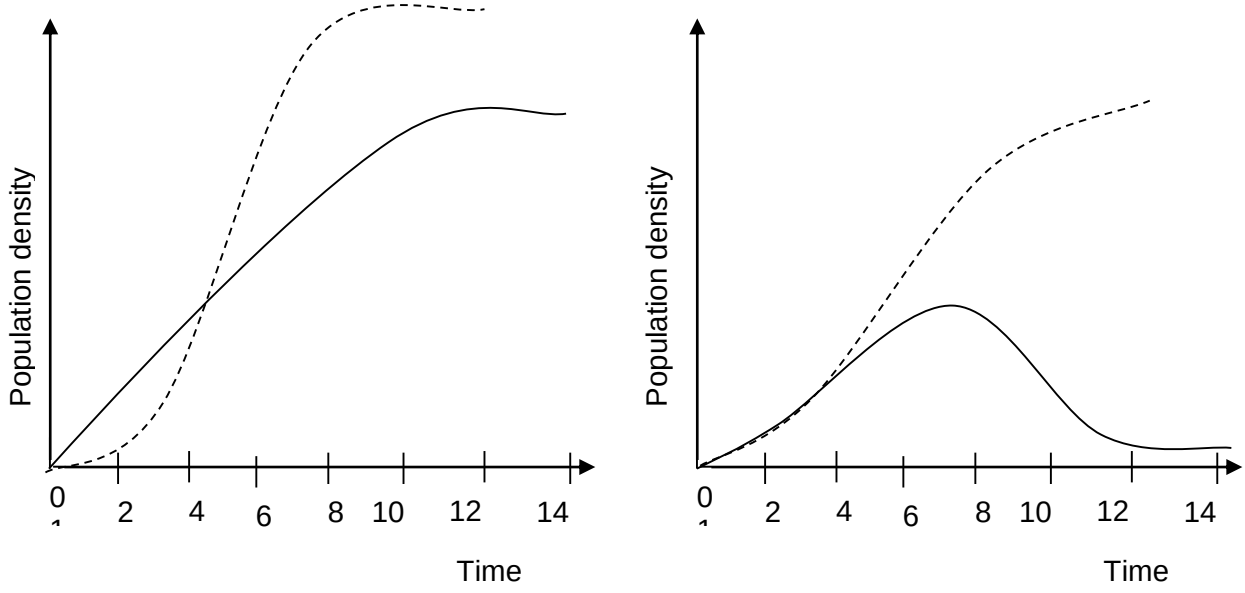
1. **Experiments with Paramecia**:

Two closely related species of single-celled, bacteria eating Paramecia were grown, first separately and then together in culture tubes.

For the graph you can check in New understanding biology 4th edition page 359 fig.17.16

Graph showing the interaction of *Paramecium aurelia* and *Paramecium caudatum* in separate growth culture and mixed growth cultures

Each species grown alone **both species grown together**



Each species grown alone

Population density of Paramecium aurelia:

- ✓ Increases very slowly for the first 3 days, very rapidly to a maximum on the 9th day, remains relatively constant till the 12th day, then declines very gradually thereafter.
- ✓ Grew faster than that of Paramecium caudatum

Population density of Paramecium caudatum:

- ✓ Increases first less rapidly but later more rapidly for the first 11 days, remains more or less constant till the 14th day and then declines very gradually thereafter.
- ✓ Increase less rapidly when compared with Paramecium aurelia.
- ✓ Remains lower than that of Paramecium aurelia, except for the first five days.

General conclusions

- ☑ There is rapid growth of population densities of both organisms because of:
  Abundance of food.
  Absence of interspecific competition for food.
- ☑ Stable populations are established afterwards for both organisms because of intraspecific competition for food.
- ☑ Population density of Paramecium aurelia grew faster than that of Paramecium caudatum because the former used the available food supply more efficiently than the latter.

Species in mixed culture

Population density of Paramecium aurelia:

- ✓ Is lower than that of Paramecium caudatum for the first 3 days.
- ✓ Increases slowly for the first three days, very rapidly till day 9 and then gradually thereafter.

Population density of Paramecium caudatum:

- ✓ Remains higher than that of Paramecium aurelia for the first 3 days only.
- ✓ Increases rapidly to a maximum in the first 7 days, decreases gradually till day 11, and more gradually to a very low number at day 14.

Conclusion

- ✓ The population density of P. caudatum decreased to extinction because of being out multiplied and outcompeted for food by P. aurelia. This is attributed to the smaller size of P. aurelia.

Other observations:

- ✓ The maximum population density of Paramecium aurelia attained in separate cultures is higher than that of mixed cultures.
- ✓ The rate of population density increase for both organisms is higher in separate cultures than in mixed cultures.
- ✓ The initial population density of Paramecium aurelia in both experiments is lower than that of Paramecium caudatum.
- ✓ The decrease in population density of P. caudatum is very gradual in separate cultures in comparison with mixed culture.
- ✓ The population density of P. caudatum in mixed cultures decreases to extinction but that in separate culture remains higher even at carrying capacity.
- ✓ Paramecium aurelia out multiplied and eliminated Paramecium caudatum when grown together.

2. **Experiments with Flour Beetles:**

Tribolium, beetles of the family Tenebrionidae, attack stored grains and grain products. An experiment was carried out to identify;

Interspecific competition between Tribolium confusum and Tribolium castaneum. The variables studied included climate, initial density, and food, volume of floor and presence or absence of a parasite called Adelina.

Table showing a summary of the generalised results of the investigations

Environmental conditions		Percentage remaining	
Temperature (^oC)	Relative humidity (%)	*T.castinum*	*T.confusum*
34	70	100	0
34	30	10	90
29	70	86	14
29	30	13	87
24	70	29	71
24	30	0	100



Represent the above information graphically!

Deductions and interpretations of results:

- Cool-dry conditions appear to favour Tribolium confusum
- Under a particular set of conditions, either Tribolium confusum or Tribolium castaneum was usually favoured, but not always.
- Under intermediate environment conditions, each species did well when grown alone but the outcome of interspecific competition was not completely predictable. Sometimes T. confusum won, sometimes T. castaneum won
- Growing the two species separately showed that the fundamental niche of Tribolium castaneum includes five of the six environmental conditions in the experiment, while the fundamental niche of Tribolium confusum includes all the six environmental conditions.

- Growing the two species together suggests that interspecies competition restricts the realized niches of both species to fewer environmental conditions.
- Interspecific competition restricts the realized niches of species in nature.

Note: you should try your best to acquaint yourself with the required language in describing and explaining graphs involving competition.

RESOURCE PARTITIONING

- It is one of the major ways the species with the same resource requirement have avoided competition.
- Resource partitioning is the dividing up of scarce resources so that species with similar needs use them;
  (i) At different times
  (ii) In different ways
  (iii) In different places.
- Over a time scale long enough for evolution to occur, some species that are in competition for the same resources evolve adaptations that reduce or avoid competition or an overlap of their fundamental niches.
- Resource partitioning decreases competition between two species leading to increased **niche specialisation**

Examples of resource partitioning:

- When living in the same area, lions prey mostly on larger animals while leopards on smaller ones.
- Hawks and owls feed on similar prey, but hawks hunt during the day and owls hunt at night.
- Each of the five species of common warblers; insect-eating birds minimises competition with the others by;
  (i) Spending atleast half its feeding time in a different part of spruce tree branches e.g. some hunt at the extreme top, others at the lower portion, some mid-way etc
  (ii) Consuming somewhat different insect species.
- Different species of eagles in a forest feed at different times of the day e.g. bald headed eagles are most active early mornings and evenings while the white-breasted eagles feed vigorously towards noon.
- Paramecium aurelia and paramecium bursaria can coexist in a tube containing yeast because the former feeds on yeast suspension in the upper layers of the fluid whereas the latter feeds on the bottom layers.
- When three species of ground finches of Galapagos Islands occur on separate islands, their bills tend to be the same intermediate size, enabling each to feed on a wider range of seeds, but where they co-occur, there is divergence in beak size to suit each finch species to feeding on seeds of either small, medium or large size, but not all sizes.
- Various bird species in a coastal wetland feed in different ways e.g. flamingos feed on tiny mud organisms, brown pelicans from air dives for fish, herons wade into water to seize small fish, herring gulls are tireless scavengers, and piping plovers feed on insects and tiny crustaceans on sandy beaches.
- In an abandoned field, drought tolerant grasses with shallow, fibrous root system grow near the soil surface to absorb moisture; plants with a taproot system grow in deeper soil while those with a taproot system that even branches to the topsoil and below the roots of other species grow where soil is continuously moist.

Note:

1. The more the two species in the same habitat differ in their use of resources, the more likely they can coexist.
2. Two competing species also may coexist by sharing the same resource in different ways or at different times.
3. The tendency for characteristics to be more divergent when populations belong to the same community than when they are isolated is termed **character displacement** for example the Galapagos finches.

POPULATION AND COMMUNITIES

Community structure

- It is the spatial distribution of individuals and populations within the community.
- Community structure is characterised by different species each with different number, sizes, stratification and distribution of individuals, different ecological niches, which may resemble or differ from each other and interactions between species.

BIOLOGICAL DIVERSITY

- The different life forms and life-sustaining processes that can best survive the variety of conditions currently on earth.
- **Species abundance**: the number of individuals of each species

COMMON TERMS.

1. **Immigration**; movement of individuals into a population from neighbouring populations.
2. **Emigration**; Departure of individuals from a population.
3. **Rare species**; Species with small populations either restricted geographically with localized habitats or with widely scattered individuals.
4. **Endangered species**; Species with low population numbers that are in considerable danger of becoming extinct.
5. **Extinct species**; Species, which cannot be found in areas they previously inhabited nor in other likely habitats.

FACTORS THAT AFFECT SPECIES DIVERSITY IN AN ISLAND ECOSYSTEM

- The number of species found on an island is determined by a balance between two factors:

1. The rate at which new species immigrate to the island.
2. The rate at which species become extinct on the island.

- At some point the rates of immigration and extinction will reach an equilibrium point that determines the island's average number of different species; species diversity
- The model also predicts that immigration and extinction rates (and thus species diversity) are affected by two important features of the island:

1. Size of the island.
2. Distance of the island from the nearest main land.

Size of the island

Larger islands tend to have higher species diversity than Small islands because of two reasons:

- Small islands generally have lower immigration rates since they are a smaller target for potential colonizers
- Smaller islands should have a higher extinction rate because they generally have fewer resources and less diverse habitats for colonizing species.

Distance of the island from the nearest main land:

- For two islands of about equal size and other factors, the island closest to the main land source of immigration species will have the higher immigration rate and thus a higher species diversity.

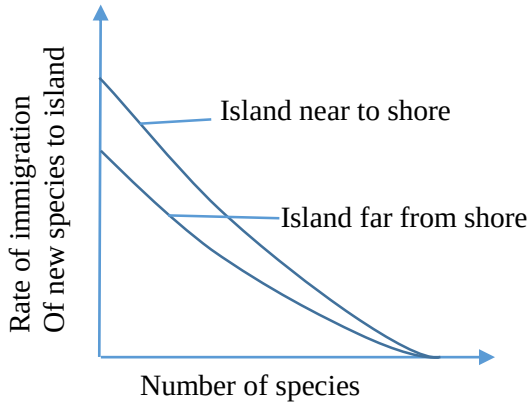


Figure c

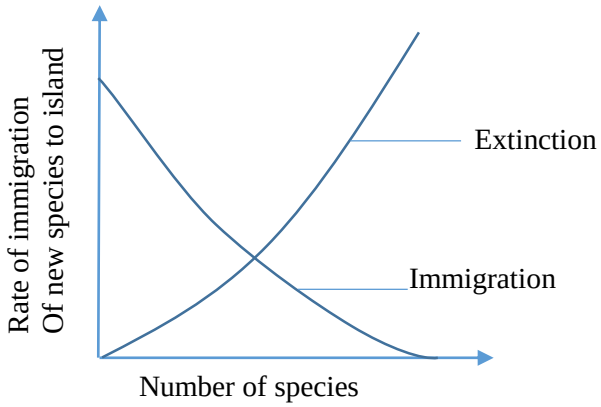


Figure a

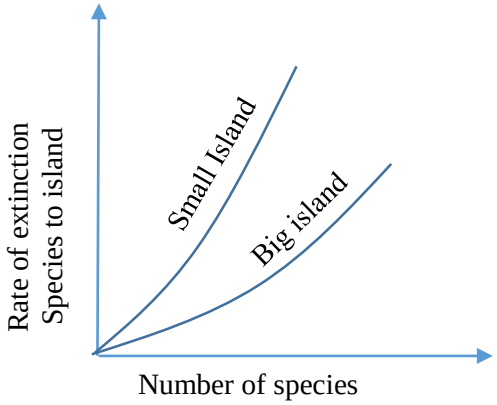


Figure b

Or for the graphs refer to UACE 2006 biology paper 2 number 1

Explanations from the observations made from the graphs

a) **Immigration and extinction rates:**

- The rate of immigration decreases with increase in species number. This is because;
- Competition; interspecific and intra specific competition for resources such as food, mates and shelter increases. Only the better adapted species survive while the less adapted ones either die or escape from the island. Therefore, few of such less adapted species immigrate to this island where competition is stiff.

- × Resources eventually get exhausted and this discourages more species immigrating to the island.
- × The number of predators increase and feed on the prey on the islands as a result fewer prey immigrate to the island, thus the population of the prey reduce which discourages predators for immigration.
- × Diseases outbreaks associated with high population on the Island discourages immigration of organisms to the Island
- × Natural calamities such as earthquake, fire, floods may also discourage immigration of organism to the Island.
- ✓ The rate of extinction of organism on Islands increases with increase with the number of species on the island. This is because;
- ✓ Environment resistance in form of diseases reduces the number of organisms on the island.
- ✓ The producing population on the island may be so small that the chances of finding a mate is very low. This makes the organism to dies before producing young ones leading to extinction.
- ✓ The number of predators increase on the island eat the prey to extinction.
- ✓ Natural calamities such as flood may cause massive death of organism leading to their extinction.
- ✓ Competition for resources such as food, shelter and mates increase as the population increases. The better adapted species survive while the less adapted die or escape from the island and eventually become extinct.

b) **Effect of island size on extinction rates**:

The rate of extinction of organism from small and large islands increase with increase in the number of species on the island. However, this occurs at a higher rate on Small Island.

Explanation

- Environmental; resistance in form of diseases reduce the number of organism on island greatly. Since the number of organisms accommodated by Small Island is less than that on big island, the intensity of resistance on Small Island is stiffer than that of the bigger island.
- The reproducing population on the small island is so small that chances of successful reproduction in animals is small. This makes many of the organisms to die before they have had a chance to pass on their genes, leading to extinction.
- The number of predator increases with increase in the number of the prey. The predator feed on the prey and cause extinction. A large island provide more hiding spaces for the prey to escape and may explain why extinction from large island is a slower rate.
- Competition for resources such as food, shelter and mates increase as the population increases. The better adapted species survive while the less adapted die. A smaller island has fewer resource overall and so has a higher rate of extinction.

c) **Effect of distance from mainland on immigration**:

The rate of immigration is higher for the island near the shore than that far from the shore. However, the rate of immigration decreases rapidly on both islands as the number of species on the islands increase. This occurs as a faster rate on the island far from the shore.

Explanation

- The island nearer the shore is more accessible to organisms than that far from the shore. More species of organism especially from the main land move and occupy the island near the shore. On the other hand, only species capable of swimming or flying are able to access the island far from the shore. These are fewer than the rest of all the other organism.
- As the number of species on the island increases;
  - Competition for resource such as food, mates and shelter increases. Only the better adapted species survive while the less adapted ones either die or escape from the island. Therefore, a few less adapted species immigrate to this island where there is stiff competition.
  - Resource eventually get exhausted and this discourages more species from immigrating to the island
  - The number of predators increases and feed on the prey on the island. As a result, few prey organisms immigrate to such island and the population of the prey decrease.
  - Disease outbreak associated with high population on the island discourages immigration to such island.

Factors that bring about immigration into a virgin island

- ✓ Availability of food
- ✓ Availability of shelter
- ✓ Absence of predator
- ✓ Favorable environmental conditions such as good temperature, adequate rain fall, etc.
- ✓ Distance from the shore
- ✓ Fleeing from over population in the cradle land
- ✓ Accidental movement of organisms to the island.

ECOLOGICAL SUCCESSION:

- This is a long-term directional change in the composition of a community brought about by the actions of the organisms themselves.

Types of succession:

- ❖ Primary succession
- ❖ Secondary succession

- Succession proceeds via several stages called seral stages to a climax community, and the complete succession is called a sere.
- Climax community: final community at the end of succession, which a particular environment can sustain. It is characterized by;
  (i) Diverse species
  (ii) Complex feeding relationships.
  (iii) Progressive increases in biomass.

Succession occurs on different environments and given names as follows;

i. Hydrosere; succession in an aquatic environment
ii. Xerosere; succession on dry land.
iii. Halosere; succession in a salty environment.
iv. Lithosere; succession on a rocky surface.

Note;

- During succession each species facilitates the emergence of other species by modifying the environment, making it more suitable for new species with different niche requirements.

- Early species inhibit or hinder the establishment and growth of other species by releasing toxic chemicals that reduce competition from other plants.
- Late successional plants are largely unaffected by plants at earlier stages of succession thus explaining why late successional plants can thrive in mature communities without eliminating some early successional and mid successional plants.
- **Plagioclimax climax community**; one that is gradually established after human interference, and it appears very different from the original climax. This is kind of succession is termed deflected succession:

PRIMARY SUCCESSION

- This is the gradual change in species composition of an area that has never had any vegetation growing on it.

Where it occurs;

- ☑ Bare rocks exposed by erosion.
- ☑ Newly cooled larva, abandoned highway or parking yard.
- ☑ Newly created shallow pond.
- ☑ Sand dunes.

Description of succession on land

Primary succession and occurs in three stages.

Pioneer stage

- Before a community of producers, consumers and decomposers can become established on land, soil forms first.
- Soil formation begins when hardy pioneer species; lichens attach to bare rocks.
- The pioneer species form soil by trapping wind-blown soil particles, producing tiny bits of organic matter and secreting mild acids that slowly break down the rock.
- Bare rock breaks down physically and chemically during the process of weathering
- Rain water assist in weathering because it is acidic. It dissolves some minerals leading to rock disintegration
- The death of lichens leads to addition of humus to the soil formed. This makes it possible for invasion of mosses.
- Moss form a dense mat which trap tiny particles of rock, some organic debris and water.

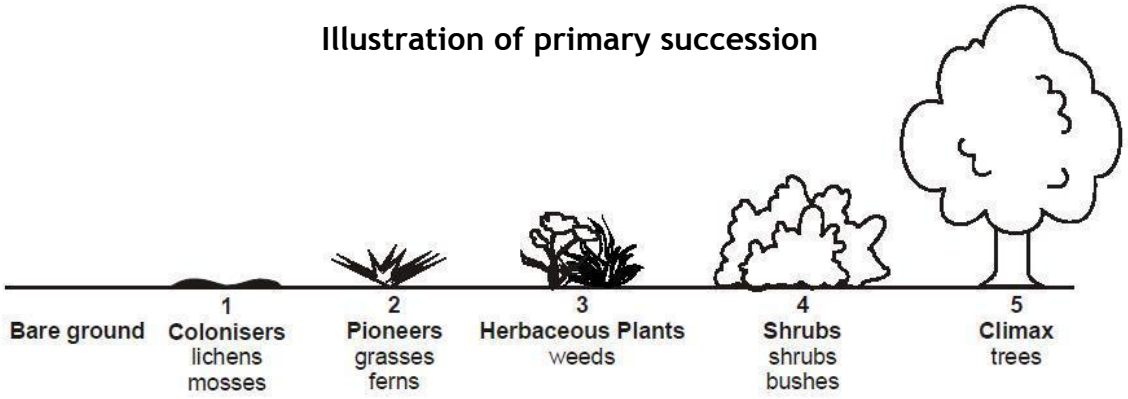
Spruce stage/ early and mid-succession

- Death of the moss add to the nutrient content of the mat so that eventually the mat support early successional plant species like small grasses and ferns, whose seeds and spores respectively germinate after arriving by wind or in droppings of birds. Some of their roots penetrate and break rocks into soil particles, and the decay of their wastes and dead bodies increases nutrients in soil.
- After a long period of time, the soil becomes deep, moist and fertile enough to support the growth of mid successional plant species like herbs, grasses, low shrubs and small trees that need a lot of sunlight.

Climax stage/ late succession

- Soon large woody shrubs begin to grow in the newly formed soil
- Lichen and moss may be covered by decaying leaves causing their death.
- Eventually thicker layer of soil develops, leading to growth of big trees
- Animal species immigrate into the forming fauna and the size of animals that invade increase as the size of the vegetation increase.
- After a long time, the mature forest community grows this is called climax community. Unless natural or human processes disturb the area, the complex forest community remains.

Illustration of primary succession



Or check illustration in Biological science pg320 fig. 10.17

CHARACTERISTICS OF THE STAGES OF PRIMARY SUCCESSION

a) **Early succession**

- Species grow very close to the ground and have low biomass.
- Species have short lifespan.
- Species are simple and small sized.
- Species diversity is very low.
- The community is open i.e. allows space for further colonizers.
- Species may show symbiotic relationships to aid their establishment.
- Species are poor competitors and hence get replaced by higher, more demanding plants like grasses, shrubs and eventually trees.
- Species can establish large populations quickly under harsh conditions like lack of moisture and soil nutrients, hot and cold temperature extremes.
- The community is mostly composed of producers and a few decomposers.
- Net productivity is high.
- Feeding relationships are simple, mostly herbivores feeding on plant with few decomposers.

b**) Late succession**

- Plants are of large size and complex.
- Species diversity is high.
- The community is a mixture of producers, consumers and decomposers.
- Biomass is high.
- Net productivity is low.
- Community takes a long time to establish.
- The climax community is often determined by one dominant species.
- There is increased soil depth and nutrients.
- Interspecific competition is very high.
- There is little space for new species.
- The climax community is stable and is in equilibrium with its environment.
- Feeding relationships are complex, dominated by decomposers.

SECONDARY SUCCESSION

- This is the gradual change in species composition of an area where the natural community of organisms has been disturbed, removed or destroyed but some soil or bottom sediment remains.

Where it occurs

Abandoned farmlands, burnt or cut forests, heavily polluted streams, flooded land.

How it occurs

- Because some soil or sediment is present, new vegetation usually can begin to germinate within a few weeks.
- Seeds, spores can be present in soil or they can be carried from nearby plants by wind, birds or animals.
- The ground may even contain resistant plants that survived the changes.
- When conditions required for growth are availed, the resistant plants can grow into new plants that occupy the area forming a climax community.

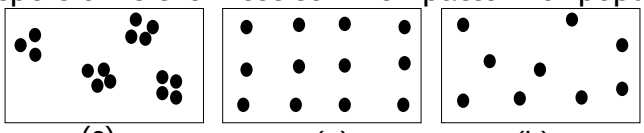
POPULATION DYNAMICS

These are changes in populations in response to environmental stress or environmental conditions.

Terms encountered in population studies:

1. **Population size**; number of individuals in a population.

2. **Population density**; total number of organisms of a species per unit area of land for terrestrial organisms or per unit volume of water for aquatic plants.
3. **Population growth**; a change in the number of individuals it may be increase where it is a positive growth or decrease where it is negative growth negative.
   Population change = (birth + immigration) – (deaths + emigration)
   It is dependent on which factors outweigh others for growth to either be positive or negative.
   Therefore a population grows if B+I>D+E, reduces if B+I< D+E
4. **Population growth rate**; a change in the number of individuals per unit time.
   Population growth rate = $\frac{\text{(final population – initial population)}}{\text{Given period of time}}$
5. **Dispersion**; distribution of organisms in a habitat.
   a) Uniform distribution; organisms are equidistantly placed due to severe struggle for resources in the environment.
   b) Random distribution; organisms are dispersed by chance, with neither forces of attraction nor repulsion, and the environment provides uniform factors.
   c) Clumped distribution; organisms aggregate into groups to gain better protection, feeding, reproduction etc.
   Clumped dispersion is the most common pattern of population distribution.



(c) (a) (b)

6. **Age distribution**; proportion of individuals of each age in a population.
   i) The young; age group before reproduction.
   ii) Middle age; reproductive age.
   iii) Old age; age after reproductive stage
7. **Birth rate/ natality**; number of offspring produced in a given time, usually expressed as a percentage. In humans it is based on number of births per 1000 per year e.g 36 births per 1000 people per year.
8. **Death rate/ mortality**; number of individuals dying per unit of time per unit of population. In humans it is based on number of deaths per 1000 per year e.g 20 deaths per 1000 people per year
9. **Biotic potential**; this is the maximum capacity of growth of members of a population given unlimited resources and favourable environmental conditions.

10. **Intrinsic rate of increase**; the rate at which a population would grow if it had unlimited resources.
11. **Environmental resistance**; all the environmental factors acting jointly to limit the growth of a population.
12. **Carrying capacity**; maximum number of individuals of a given species that can be sustained indefinitely in a given area of land or volume of water.
13. **Sex ratio**; ratio of males to females in a population in Humans: it is calculated basing on 100 females e.g. 89 males to 100 females)
14. **Fertility rate**; number of new individuals produced by one organism per unit time in Humans it is based on one year.
15. **Fecundity**; this the physiological maximum potential reproductive output of an individual usually a female over her life time.

Major characteristics of populations

They change;

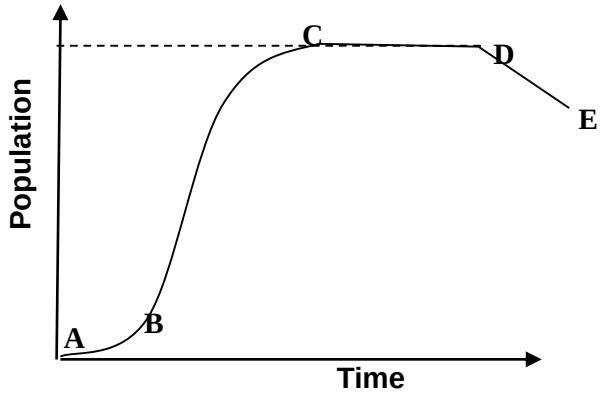
- ✓ in size
- ✓ density,
- ✓ dispersion
- ✓ Age structure.

POPULATION GROWTH PATTERNS

These are graphs in which the total number of organisms of same species is plotted against time. Two basic forms of growth curves can be identified i.e. sigmoid (s-shaped) growth curve and J-shaped growth curve.

SIGMOID (S-SHAPED) GROWTH CURVE

It describes a situation in which a population is adapting to a new environment.



Lag phase (AB)

- The population density of an organism increases slowly initially. The gradual increase is due few reproducing organisms, which are scattered with members of opposite sex far apart to easily find a mate; some organisms might not have reached reproductive age and as well few individuals have adapted to the environment.

Log phase or **exponential phase** (BC)

Population density increases rapidly approaching exponential growth rate provided no factor limits it. As numbers increase more individuals become available for reproduction, many have reached reproductive age or there is increased chance of finding mates for those that require two sexes. The population has fully adapted to the environment.

Stationary/ constant phase (CD)

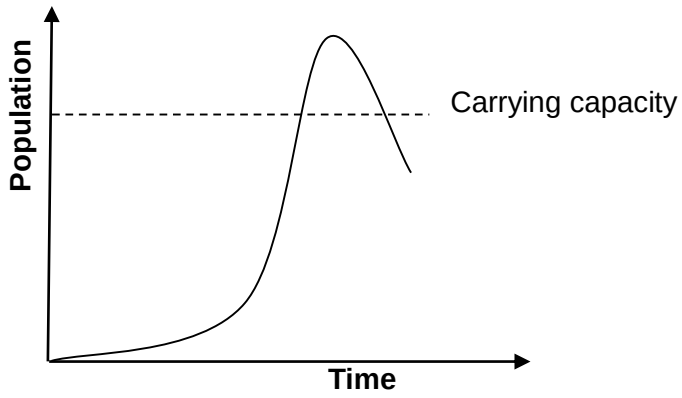
As the population size approaches carrying capacity, growth rate becomes gradual as environmental resistance sets in from increasing competition for resources such as food, nesting material etc.

Decelerating phase (DE)

- ✓ This results into increased mortality rate and reproductive failure (fewer mating, stress induced abortions) until a point of stabilization (carrying capacity) is reached when growth rate reduces to zero. This type of population growth is also said to be density dependent since growth rate depends on number of individuals present in a population.
- ✓ Many populations of microorganisms, plants and animals in both laboratory and field conditions follow the sigmoid curve. However, in a laboratory condition the population reduces rapidly after the stationary phase due to lack of food, intense competition for food and space accumulation of wastes/toxic substance such as alcohol in yeast and also due to old age there are few reproducing individuals

J-SHAPED GROWTH CURVE

- × It describes a situation in which after the initial lag phase population continues to increase exponentially up to a maximum and suddenly starts to decrease rapidly. The slow increase is due to few reproducing individuals.
- × The rapid growth is due to many reproducing individuals, availability of resources, and no environmental resistance until a point when carrying capacity is reached.
- × The rapid decrease after the carrying capacity is due to severe environmental change.
- × The type of population growth is density independent since regulation of the population is not determined by the population density until the final crush. This may be because of seasonality or end of breeding season. It may be associated with stages in life cycle such as seed production, or induced by human intervention e.g. after spraying insecticides, from a crash such populations show fluctuating recovery patterns consisting of boom and bust cycles typical of insect species and algal blooms



CARRYING CAPACITY

- Population increase tends to decrease when the carrying capacity of a particular habitat is reached.
- However if the carrying capacity is exceeded, the population suffers a dieback or crash, unless the excess individuals switch to new resources or move to an area with more favourable conditions.

FACTORS THAT AFFECT POPULATION THE SIZE OF A POPULATION

Factors that cause a population to grow/ Biotic potential

- ✓ Favourable light – mostly for plants.
- ✓ Favourable temperature.
- ✓ Favourable chemical environment (optimal level of critical nutrients and toxic wastes).
- ✓ High reproductive rate.
- ✓ Adequate food supply
- ✓ Ability to compete for resources.
- ✓ Ability to hide from or defend against predators.
- ✓ Ability to resist disease and parasites.
- ✓ Ability to adapt to environmental changes.
- ✓ Ability to migrate and live in other habitats.
- ✓ Suitable habitat.
- ✓ Generalised niche

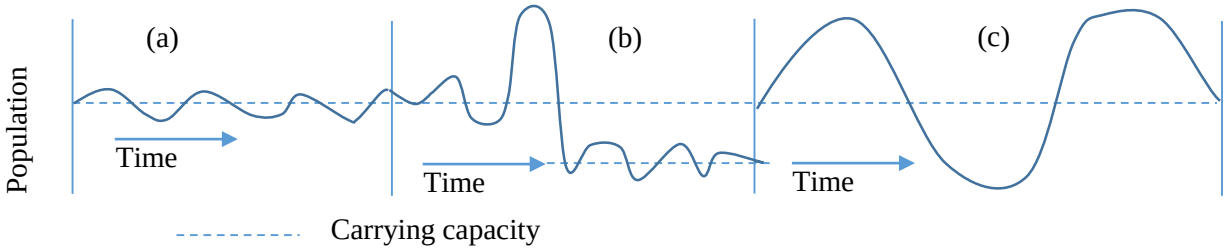
Factors that cause population size to decrease/ Environmental resistance

- Too much or too little light – mostly for plants.
- Too much or too little temperature.
- Unfavourable chemical environment (too much or too little of critical nutrients and high waste accumulation).
- Low reproductive rate.
- Inadequate food supply
- Too many competitors for resources.
- Insufficient ability to hide from or defend against predators.
- Inability to resist disease and parasites.
- Inability to adapt to environmental changes.
- Inability to migrate and live in other habitats.
- Unsuitable or destroyed habitat.
- Specialised niche

How population density affects population growth

1. **Density-dependent population control**; involves factors whose effectiveness depends on the number of individuals present in a unit of space i.e. the more individuals there are in the population, the greater the percentage of the population that dies or fails to reproduce.
   Examples: Competition for resources like food, disease, predation, parasitism they are biotic factors mainly.
2. **Density-independent population control**: involves factors whose effectiveness is not related to the density of the population. Any change in the factor affects the same proportion of the population regardless of population density. Examples: temperature, rainfall, light, floods, soil nutrients, pollution, fires, drought, hurricanes, habitat destruction e.g. clearing a forest or filling in a wetland, pesticide spraying etc they are mainly abiotic factors.

KINDS OF POPULATION CHANGE CURVES IN NATURE



a. Stable population growth curve:

- Show small rapid cyclic variation of population about the carrying capacity this is because of; Rapid changes in environmental resistance occur in the population in either direction.
- A positive change is rapidly cancelled by an equal negative population change leading to equilibrium maintenance of population about the carrying capacity.
- For example trees in a tropical rain forest where there is little variation in temperature and rain fall from year to year.

b. Irruptive population growth curve:

- Shows cyclic variation at first followed by a very high population rise and big drop to a new lower carrying capacity. This is because;
- In an equilibrium population, there appear a factor that temporarily increases the carrying capacity e.g. more food, favourable weather, or fewer predators causing a rapid rise in population density. The large numbers of the population depletes the resource available to such a low level that it can support fewer numbers than before.
- For example; some algal populations in freshwater habitats, raccoon and feral house mouse.

c. cyclic population growth curve:

- Show cyclic variation of population, of large amplitude, about the carrying capacity because;
- The population is controlled by presence or absence of another organism acting as a predator or prey. Increase in either causes reduction in the population of the other or vice versa over a long period of time,
- For example; lemmings; small rodents whose populations rise and fall every 3-4 years, grouse, lynx and snowshoe hare; whose populations generally rise and fall on a 10-year cycle.

SURVIVORSHIP CURVES

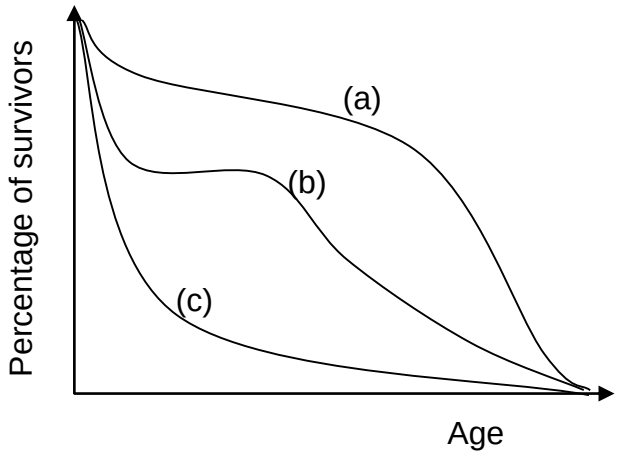
Survivors; this is the percentage of an original population that survives to a given age.
Survivorship curve: is a graph which shows the percentage number of surviving individuals of each age group of a population for a particular species.

Importance of plotting survivorship curves:

- Enables determination of mortality rates of individuals of different ages and hence to determine at which age they are most vulnerable.
- Enables identification of factors causing death at different ages so as to plan regulation of population size.

Note; r-species are species that reproduce highly in large numbers but the offsprings experience high juvenile mortality. K- Species are species that reproduce few

offsprings that grow up to around the carrying capacity of the habitat. Because each offspring has a high chance of survival.



Late loss curves (a)

- ❖ Humans, elephants, rhinoceroses, mountain sheep
- ❖ These are organisms with stable populations close to carrying capacity of the environment (K).
- ❖ They produce few young ones which are cared for until reproductive age, thus reducing juvenile mortality and therefore enabling high survivorship to a certain age, then high mortality at later age in life due to senescence

Early loss curves (c)

- ❖ Most annual plants, most invertebrates and most bony fish species
- ❖ These are organisms with a high intrinsic rate of increase.
- ❖ They produce many offspring which are poorly cared for resulting into high juvenile mortality.
- ❖ There is high survivorship once the surviving young reach a certain age and size.

Constant loss (b)

- ❖ Many song birds, lizards, small mammals and hydra
- ❖ This is characteristic of species with intermediate reproductive patterns with a fairly constant rate of mortality in all age classes and thus a steadily declining survivorship curve.
- ❖ There is an equal chance of dying at all ages.
- ❖ These organisms face a fairly constant threat from starvation, predation and disease throughout their lives.
- ❖ The individuals do not die of old age that's there's no senescence

Note; different organisms have different survivorship curves depending upon the nature of the organism.

DETERMINATION OF POPULATION SIZE OF ORGANISMS

Importance of estimating population size

- It enables monitoring of population growth.
- It enables determination of habitat requirements of a species.
- It enables determination of carrying capacity of the area i.e. to determine whether existing populations are likely to be sustainable
- It enables determination of age structure and sometimes sex ratio of the population.
- It enables projection of how population size is likely to change with time for proper planning e.g. determining the peak populations of pests enables control measures to be prepared.

FACTORS TO CONSIDER BEFORE COUNTING ORGANISMS

- The area of land or volume of water or air under study must be determined.
- The nature of vegetation cover of the habitat.
- Size of the organisms under study.
- Facilitation in terms of equipment to be used.
- Behaviour of the organisms e.g. their hostility and level of excitement when disturbed.
- Topography of the area.
- Whether the habitat is terrestrial or aquatic.
- Risks expected to be faced during the exercise.
- The duration the exercise is expected to last.

METHODS OF DETERMING POPULATION SIZE OF ORGANISMS

1. **TOTAL COUNT**
   - ✓ This is the physical counting of every individual of a population in a specified area of ground.

Example; Census of people after every ten years

Ways of making a total count;

AERIAL COUNTING

- ⌦ Aerial counting from a low flying aircraft of large, sessile, slow moving animals and mobile but large animals e.g. giraffes, elephants, lions, etc.
- ⌦ Accuracy results from conducting several aerial counts in the area and then the average is computed and expressed as numbers per unit area of ground.

Advantages of aerial counting;

- Population size is quickly estimated.
- Hostile animals are less likely to harm the researcher
- It provides a lot of other information on the species.

Disadvantages of aerial counting;

- It may cause discomfort to animals resulting in hiding.
- Can only be used in clear weather conditions.
- Aircraft is expensive to buy or hire and operate.
- Can only be used on large animals.
- The calculations involved may cause inaccuracy

AERIAL PHOTOGRAPHY.

- ✓ Requirements; Low flying air craft and Good camera
- ✓ Photographs are taken from a low flying air craft over the whole study area.
- ✓ Photographs are then developed, printed and number of animals in each photograph counted
- ✓ Population density is then expressed as number per unit area

DRIVE AND COUNT METHOD

- × Requirements; man power and special area
- × A number of people drive animals into a particular space/area and count them.

Advantages

- It is quick and more accurate especially for slow moving animals and those that live in herds e.g. antelopes.
- There is reduced likelihood of not counting an animal or counting a given animal more than once.

Disadvantages

-It cannot be applied to aggressive animals e.g. lions, tigers, etc

-Limited to slow moving animals

-Restricted to animals moving in herds

STRIPE CENSUS

- ☑ Requirements; Map of the area and Vehicle
- ☑ While driving, animals are counted in a given strip /besides the road.
- ☑ The number of organisms in each strip is obtained by direct counting and the population density of the strip is obtained.
- ☑ Such is repeated for several strips and the average population density for the strips is calculated.
- ☑ The population of total population of the area given is calculated as; average population area of each strip x total area.

Advantages

- It's quick
- It's cheap compared to aerial means

Disadvantages

- Moving vehicles scare away animals that may run into hiding
- Some animals avoid roads and paths commonly used by man in the park.
- There is increased likelihood of counting fast moving animals more than once.
- Very many counts should be made in order to come up with a reliable number.

2. COUNTING BY SAMPLING

- This is when the number of organisms is determined in several sample plots that represent a known fraction of the total area under investigation from which estimation of the total population size of the whole area is made by simple calculations.
- Sample counting is applied when the number of the organisms is large, covers a large area or where the behaviour of organisms does not allow easy contact.

N.B for determining population of micro- organisms check back page

a. QUADRAT METHOD

Quadrat sampling is suitable for slow moving animals and plants.

Procedure;

- A metallic, plastic or wooden frame of known area e.g. $1m^2$ or $0.25m^2$ is randomly thrown several times in the area under investigation and all individuals within the quadrat are counted each time and recorded
- The procedure is repeated several times each time the quadrat lands organism enclosed are counted and recorded.
- The average number of organisms, N is calculated

$$N = \frac{\boldsymbol{Total\ number\ of\ organisms\ \ in\ all\ throws}}{\boldsymbol{total\ number\ of\ throws}}$$

- The size of the study area is also estimated, A
- The total population is calculated from $\boldsymbol{totalpopulation} = \frac{\boldsymbol{axN}}{\boldsymbol{A}}$ Where a, is the area of quadrat, A is total area of study area and N is the average number of organisms in the quadrat.

This method provides a means of calculating three aspects of species distribution

i) **Species density**; the number of organisms of a given species in an area. This can be obtained by counting number of organisms in randomly thrown quadrats. It is accurate and allows different species to be compared. It also provides absolute measure of abundance. However it is time consuming and requires individuals to be defined.

ii) **Species frequency**; chance/ probability of finding a given species within any one throw of a given species. It is obtained by recording presence or absence of species in a randomly thrown quadrat. For instance if 1plant occur in every 10 quadrats, the species frequency is 10%. The method is quick, easy and useful in large ecosystems. It is however affected by quadrat size, plant size and spatial distribution.

iii) **Species cover**; the proportion of ground occupied by the species and gives an estimate of species as a percentage of the total area.

Advantages*:*
(1) The method is relatively accurate
(2) It enables comparison of species density in different areas
(3) It provides an absolute measure of abundance.

Disadvantages; it is
(1) Time consuming
(2) Not suitable for fast moving animals
(3) Not suitable for large sized animals.
(4) Grass in tussocks appear indistinguishable and may disturb

b. CAPTURE-MARK RELEASE-RECAPTURE METHOD/ LINCOLN INDEX METHOD

- This method is used on highly mobile animals like fish, small mammals e.g. rats, birds, and arthropods e.g. insects like butterflies, grasshoppers, cockroaches.
- It involves capturing and counting the organisms (N1), marking them in a way that causes no harm, and returning them to the natural environment.
- After allowing sufficient time for the population to mix thoroughly, a second catch (N2) is made and the number of marked individuals recaptured is recorded as N3
- Estimated total population (P) = $\frac{N1 \times N2}{N3}$

Example:
In estimating the number of fish in a small lake, 625 fish were caught, marked and released. After one week, 920 fish were caught and of these, 150 bore marks. What was the estimated size of fish population?

$P = \frac{N1 \times N2}{N3}$

$P = \frac{625 \times 920}{150} = 3833$ fish

Note; when calculations are made and answer for the population size obtained in points, we consider the limit of 0.4 beyond which we consider a whole number and thus instead of the point organism we consider a whole organism.

Assumptions which the method bases on:

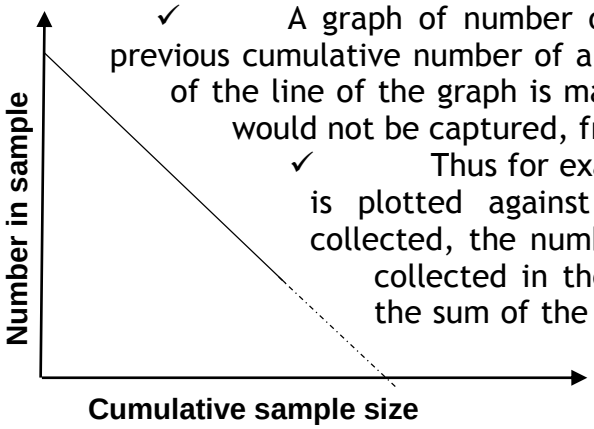
- ✓ That organisms mix randomly within the population.
- ✓ That the time allowed for random mixing is enough.
- ✓ That changes in population size due to immigration, emigration, death and birth are negligible.
- ✓ That the movement of organisms is restricted geographically.
- ✓ That there is even dispersing of organisms within the study area.
- ✓ That the mark does not hinder the movement of the organisms or make them conspicuous to predators.

Disadvantages / Limitations:
(1) It is only reliable when the organisms' range of movement is relatively restricted and defined.
(2) Animals often move in groups whose members recognise one another and avoid mixing with those of other groups
(3) Many animals have particular localities where they confine, so the marked animals may not spread widely
(4) Loss of marked individuals reduces those recaptured and this causes inaccuracy.

c) **Aerial photography**
Using a light aircraft aerial photographs of large animals in herds e.g. elephants are taken after which numbers of animals are counted on the photographs.

d) **Transect sampling**
It is used to investigate the transition of one community to another, particularly when the communities occur in a linear sequence e.g. up a rocky seashore.
i) Line transect involves laying down a calibrated tape or string along the ground in a straight line between two poles across the area of study and then all individual organisms touching the line are recorded. A profile of the area is made on reduced scale noting the position of individuals, their height, branching and horizontal spread. On completion a vertical and horizontal distribution of a community is made.
ii) Belt transect involves setting up two line transects at fixed width, say 0.5m or 1m apart between which all individuals are recorded, after which the findings are presented just like it is with line transect.
iii) Continuous transect is a line or belt transect in which the whole belt or line is sampled.
iv) Interrupted transect involves taking samples at regularly spaced vertical or horizontal intervals.

e) **Removal method**
- ✓ This is suitable for small organisms like insects within a known area of grassland or volume of water.
- ✓ After sweeping with a heavy net, counting and recording of the animals captured is done.
- ✓ The procedure is repeated several times and the gradually decreasing numbers of organisms is noted.
- ✓ A graph of number of animals captured per sample against the previous cumulative number of animals captured is plotted and extrapolation of the line of the graph is made to the point at which no further animals would not be captured, from which the population is estimated.
- ✓ Thus for example the number collected in the 1st sweep is plotted against zero as no previous animals had been collected, the number collected in the 2nd sweep against that collected in the 1st, the number in the 3rd sweep against the sum of the 1st and 2nd and so on. See the graph below on the left



Or Check illustration in Biological science page 363 fig. 11.16

NATURAL RESOURCES

- A resource is anything obtained from the environment to meet human needs and wants. Natural resources are those not made by man.
- While some resources are directly available for use e.g. solar energy, fresh air, wind, fresh surface water, fertile soil, wild edible plants.
- Others become available after processing has been done e.g. petroleum, metallic elements like iron, ground water, modern crops.

Classification of natural resources

1. **Perpetual resources;** Resources that are replaced or renewed continuously on human time scale. These include solar energy, wind, tides.

2. **Renewable resources**; resources that are replenished or replaced fairly rapidly from hours to decades through natural processes as long as the usage is not faster than the replacement. These include; Fresh water, fresh air, fertile soil, animals and plants; Forests and grasslands

3. **Non-renewable resources**; Resources that exist in a fixed quantity or stock in the earth's crust.
   On the shorter human time scale, they depleted much faster than they are formed. These include; Fossil fuels e.g. coal, oil, natural gas, metallic minerals e.g. copper, iron, aluminium, non-metallic minerals e.g. salt, clay, sand, phosphates.

TERMS USED IN NATURAL RESOURCES

1. **Sustainable yield**; the highest rate at which a renewable resource can be used indefinitely without reducing its availability supply. Although in spite of the renewability, renewable resources can be depleted or degraded.
2. **Environmental degradation**; the process when the resource's natural replacement rate is exceeded resulting into a decline in its availability. This is commonly due to,

- Urbanization of productive land, excessive soil erosion, deforestation, ground water depletion, overgrazing of grasslands by livestock, reduction in the earth's forms of wildlife by elimination of habitats and species, pollution, water logging and salt buildup in soil.

3. **Recycling of resources**; this is the reprocessing of a resource into new products. For example Old aluminium saucepans and copper items can be recycled.
4. **Reusing of resources**; Using of resources over and over in the same form.
5. Glass bottles of alcoholic and soft drinks can be collected, washed and refilled many times.
6. **Wildlife**; This is includes plants and animals that occur in their natural environment for example forests and wild animals.
7. **Conservation** involves sensible use of natural resources to avoid excessive degradation impoverishment of the environment un-like **preservation** which stops human interference, it involves managing biotic and abiotic factors to ensure maximum number of species and biodiversity survive. It also involves taking action to prevent extinction or permanent detrimental effects on the natural resources
8. **Wildlife conservation** is the practice of protecting wild species and their habitats. In many case human activities and wild life are always in conflict. Biological conservation adapts a system where humans can exploit natural

resources while minimizing environmental damage and maintaining the overall integrity of the ecosystem.

Reasons for conservation of natural resources

a) Utilitarian reasons involve conserving biological resources for their usefulness or economic value e.g. a source of income through tourism ,supply of food and medicine for humans, new varieties of crops, industrial products etc.
b) Aesthetic reasons involve conserving wild life for pleasure it brings hence it is important to preserve the beauty of the environment
c) Ecological/scientific reasons involves need to maintain material in ecosystem in order to have it functional for wellbeing of humans. It is important to maintain balanced biochemical cycles by avoiding pollution e.g. acidification, eutrophication and regulate climatic systems by preventing deforestation, loss of vegetation cover etc.
d) Ethical reasons some people conserve because of religious, cultural, political reasons. They believe that all species have a right to coexist with humans on earth. Therefore it is morally wrong to destroy the ecosystem or allow species to become extinct.

Problems associated with conserving wildlife

- Wild fires destroy vegetation and other organisms.
- Pests and disease kill wild life
- Drought leads to lack of water and food which kills animals or force them to migrate
- Natural calamities such as earth quake, volcanic eruption, and landslide kill wild life.
- Wars
- Extraction and mining destroy habitats
- Illegal hunting due to lack of sensitization
- Human interference through settlement, industrialization,
- Pollution due to use of pesticides, fertilizer which poison plants and animals.

Humans interfere with wild life through many ways and cause many species to become endangered. These include:

- Habitat destruction e.g. overgrazing, deforestation, bush burning, which the soil to erosion and reduce the area where they live
- Over hunting and collection reducing the populations to very low numbers, overfishing is also a form of over hunting.
- Introduction of exotic species, e.g. water hyacinth
- Destruction by humans because of being health risks
- Competition from humans and their domestic animals which restricts them to small area
- Pollution e.g. oil pollution threatens bud species

How to conserve wild life

- Development of conservation area e.g. national parks, game reserves, forest reserve
- Planned use of land with controlled human activities to prevent habitat destruction
- Legal protection, taking international laws and national regulations into action to burn trade in products of wild life.
- Commercial farming e.g. of deer, zebra or domestication of some wild animals
- Removal of wild animals from threatened area

- Breeding them in zoos or botanical gardens
- Control of introduced species
- Pollution control
- Educational programs on conservation
- Restoration of habitats by reforestation.

POLLUTION

- It is the release of substances or energy into the external environment in such quantities and for such duration that they cause harm to living organisms or their environment.
- Pollutants include noise, heat and radiation as different forms of energy, many chemical compounds and elements and excretory products.
- The parts of the external environment affected include air, water and land.

Harm caused by pollutants:

- ✓ Disruption of life support systems for living organisms.
- ✓ Damage to wildlife, human health and property.
- ✓ Nuisances such as noise and unpleasant smalls, tastes and sights.

CATEGORIES OF POLLUTANTS

Degradable/ non-persistent pollutants:

- These are the pollutants that are broken down completely or reduced to acceptable levels by natural physical, chemical and biological processes.

NOTE:

- Biodegradation is the breakdown of complex chemical pollutants into simpler chemicals by living organisms usually specialised bacteria e.g. sewage is a biodegradable pollutant.

Slowly degradable/ persistent pollutants:

- These are those that take a longer time to degrade e.g. DDT an insecticide, and plastics.

Non-degradable pollutants:

- These cannot be broken down by natural processes e.g. the toxic elements lead, mercury, arsenic, selenium

Types of pollution

1. Air pollution
2. Water pollution
3. Land pollution
4. Noise pollution
5. Sound pollution

Table showing details of some pollutant

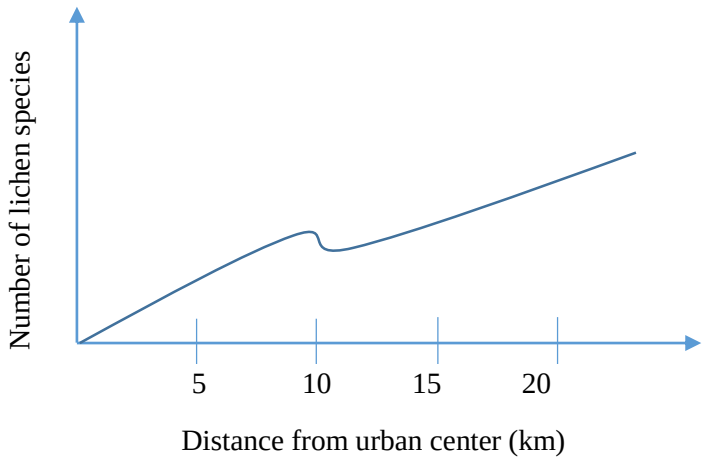
Pollutant	Source	Effects
Smoke (tiny soot particles in air)	Burning of oil coal, plastics, wood, garbage	• Blocks alveoli and aggravates respiratory ailments like bronchitis • In air it can reduce light intensity at ground level which lowers rate of photosynthesis • Coat plant leaves blocking stomata and reduces light penetration • Deposited on cars, buildings, clothes which are costly to clean

		• Reduced visibility leads to accidents
Sulphur dioxide	Burning of fossil fuels, volcanic eruptions smelting ores	• Can combine with water and ammonia form sulphates which increase soil fertility. It also acts as a fungicide reducing fungal diseases in plants. • Causes irritation of respiratory system, and damages epithelium of respiratory tract. It also cause irritation of conjunctiva of the eyes • Reduces growth of many plants such as burley, wheat, while others organisms like liken may be killed. • Causes acid rain
Carbon dioxide	Formed naturally during respiration, decomposition and volcanic activity. Burning of fossil fuels	• Stimulate photosynthesis by bacteria and plants • It is a greenhouse gas it increase has led to global worming • Causes acid rain
Carbon monoxide	Incomplete combustion Cigarette smoking	Poisonous to human as it binds with hemoglobin reducing of blood to carry oxygen leading to collapse and finally death.
Chloroflorocarbons (CFCs)	Used in aerosol propellants, refrigerators, air conditioners, manufacture of foam plastics	• Poisonous to humans and other organisms • Cause greenhouse effect • Cause depletion of ozone layer
Lead	Burning of lead containing fuels	Lead poisoning when it accumulates in the body which causes cramps loss of control of hands and feet.
Nitrogen oxides	Industrial fumes, car fumes volcanic eruptions	• Formation of photochemical smog which reduces visibility • Causes eye irritation and breathing difficulties. • Causes acid rain • React with water to form nitrates which improve soil fertility
Dust	Mining, quarrying , cement manufacture, Wind blowing in	• Causes irritation of respiratory tract and eyes • In air it can reduce light intensity at ground level which lowers rate of

	areas not covered by vegetation	photosynthesis • Coat plant leaves blocking stomata and reduces light penetration • Deposited on cars, buildings, clothes which are costly to clean • Can cause accidents due to blocked vision

SULPHUR DIOXIDE POLLUTION ON LICHEN

Graph showing lichen growth with increasing distance from the urban centre



Explanation of the curve;

- The number of lichen species generally increase with distance from urban center this is because;
- The level of pollution from urban industries reduces with increasing distance from the urban center. This leads to reduced levels of Sulphur dioxide promoting lichen growth.
- There is a reduction in the number of lichen species at a distance of 10km from the urban center probably due to presence of isolated factory, dumping of waste area or bush burning.
- After which the growth increases due to further decrease in levels of sulphur dioxide.

GREEN HOUSE EFFECT:

- ☑ This is a description of the condition which results when greenhouse gases i.e. gases in the troposphere; atmosphere's inner most layer extending about 17km above sea level) like carbon dioxide, water vapour, methane and nitrous oxide allow mostly visible light, some infrared radiation and ultraviolet radiation from the sun to pass through the troposphere to the earth, which transforms this solar energy to longer-wavelengths infrared radiation (heat), which then rises into the troposphere.
- ☑ Molecules of greenhouse gases absorb and emit this heat into the troposphere as even longer-wave length infrared radiation, which causes a warming effect of the earth's surface and air. The tropospheric gases act like a glass of large green house surrounding the earth.

GLOBAL WARMING:

This is the observed average global temperature rise.
The origins of greenhouse gases are:
(1) Combustion of fossil fuels by motor engines and industries releases carbon dioxide and methane into the troposphere.
(2) Deforestation and clearing of grasslands reduces the uptake of carbon dioxide in photosynthesis.
(3) Ruminant fermentation produces methane, which is released into the troposphere
(4) use of aerosol propellants, which contain CFCs that are 105 times worse than carbon dioxide as greenhouse gases.
(5) Cultivation of rice in swamps and paddy fields causes anaerobic fermentation, which produces methane.
(6) Use of inorganic fertilisers causes the release of nitrous oxide

Effects of global warming

- ✓ Rise in sea level due to melting of polar ice and thermal expansion of seas.
- ✓ Altered temperature gradients cause cyclones and heavy rains as water evaporates quicker.
- ✓ Species migrations which are likely to cause pests/diseases to extend their ranges.
- ✓ Reduced crop yields due to drier weather.
- ✓ Increased crop yields because of more rainfall and longer growing seasons in some regions.
- ✓ Flooding low-lying islands and coastal cities.
- ✓ Extinction of some animal and plant species.
- ✓ Increased death of the human population.
- ✓ Greatly increased wild fires in areas where the climate becomes drier.

ACID RAIN

Combustion of fossil fuels releases Sulphurdioxide and nitrogen oxides into the atmosphere. Catalysed by ammonia and unburnt hydrocarbons, these oxides react with water in the clouds to form solutions of sulphuric acid and nitric acid, which make up acid rain.

Effects

- ❖ Hydrogen ions bound to soil particles are displaced into runoff water by the SO_4^{2-} ions from sulphuric acid, causing formation of soft exoskeletons, which results into death of invertebrates
- ❖ Aluminium ions are displaced from soil by SO_4^{2-} ions into water where it interferes with gill functioning in fish causing their death.
- ❖ Aluminium ions displaced from soil by SO_4^{2-} ions into water are toxic when absorbed by plants.
- ❖ The leaching action of acid rain removes calcium and magnesium ions from soil causing poor formation of middle lamella and chlorophyll in leaves.
- ❖ Contributes to human respiratory diseases such as bronchitis and asthma.
- ❖ Can leach toxic metals such as lead and copper from water pipes into drinking water.
- ❖ Damages statues and buildings.
- ❖ Decreases atmospheric visibility, mostly because of sulphate particles.
- ❖ Promotes the growth of acid-loving mosses that can kill trees.
- ❖ Loss of fish populations when the PH lowers blow 4.5

Why high-altitude lakes quickly become acidic than low-altitude lakes.

- Low-altitude lakes are richer than high-altitude lakes in limestone which buffers against the effects of acid rain, and also the surrounding soils to low-altitude lakes are deeper.

How to reduce air pollution

- Encourage use of public transportation to reduce on cars producing fumes.
- Conserve energy by switching off fans and lights not in use and reducing the amount of fossil fuels burned.
- Reduce, reuse and recycle for other purpose.
- Use of clean energy resources like solar, wind and geothermal to reduce burning of fossils
- Use energy efficient devices. e.g. bulbs which consume less electricity.
- Education programs
- Strict regulations on smoking

WATER POLLUTION

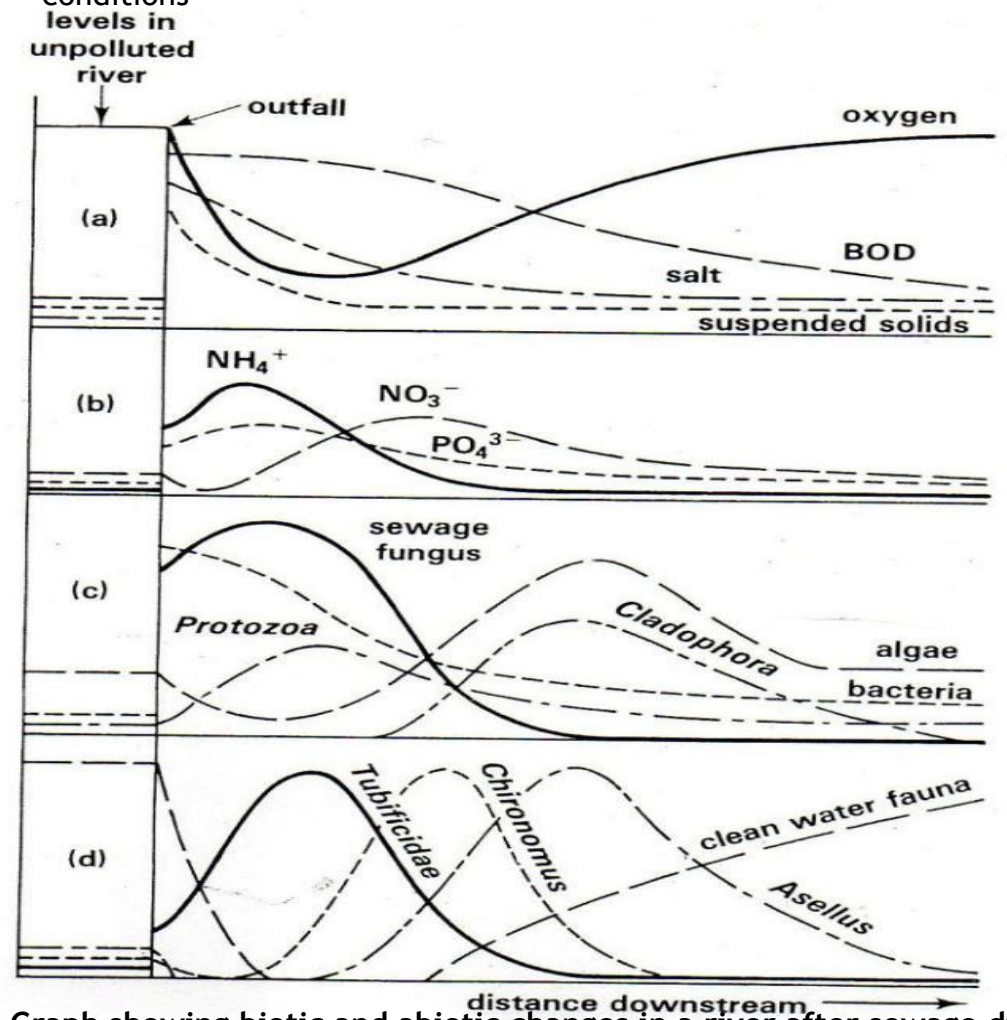
Common water pollutants

Pollutant	Source	Effects
sewage	Effluent from factories, abattoirs, Discharge of untreated domestic sewage containing urine, human faces, and detergents.	• Increased nitrates and phosphate levels in rivers and lakes (**eutrophication)** leads to growth of algae on the water body/algal bloom. • bad smell in water from decaying matter • Reduced light penetration due to suspended particles in water reduces photosynthesis submerged water plants. • Increased oxygen demand reduces dissolved oxygen causing suffocation and death of fish. • Poisoning of live stock • Disease causing agents cause outbreak of water borne diseases
Nitrate and phosphate	Use of fertilizers, detergents near water, Discharge of sewage,	• Causes eutrophication, • Algal bloom and excessive growth of aquatic plants
Oil	Washing oil storage tanks near water, Accidental spillage from damaged oil tankers Seepage from offshore installations	• Kills marine invertebrates especially those that feed by filter feeding • Clogs father of birds preventing their flight and insulation leading to death from hypothermia • Prevents light penetration and entry of oxygen into water. • Cots leaves of plants which prevents photosynthesis and killing them.

		• Covers gills of shellfish interfering with feeding and respiration. • Detergents used to disperse oil are toxic
Heavy metals e.g. mercury, copper, lead,	Industrial effluent, sewage, mines	• Lead is toxic, damages human brain, • Methyl mercury from methane producing bacteria is toxic to humans, damaging nervous system, and accumulates in food chain
Pesticides and herbicides	Use of pesticides and herbicides in mosquito control, snail control and agriculture	• Toxic or harmful to fish, predatory birds and mammals, • Concentrate in human fat
Hot water	Water used for cooling in industries e.g. power generating plants.	• Thermal pollution lowers dissolved oxygen in water and raises metabolic rate organisms increasing their oxygen demand

SEWAGE DISCHARGE INTO RIVERS:

✓ Sewage is liquid waste composed of faeces, urine, water, detergents and other substances from industries and or homes carried through pipes called sewers. Sewage discharge into water bodies causes changes in abiotic and biotic conditions



Graph showing biotic and abiotic changes in a river after sewage discharge

Dissolved oxygen and B.O.D (Biological or biochemical oxygen demand)

- ✓ Dissolved oxygen level is high in unpolluted water but decreases rapidly at sewage outfall (discharge) to the minimum and then increases gradually downstream, returning to a normal level further downstream.
- ✓ Decomposition of organic components of sewage by aerobic bacteria coupled with reduced photosynthesis because of low illumination caused by suspended solids in sewage rapidly reduce oxygen; cause oxygen sag and create a high BOD at outfall.
- ✓ The gradual increase of oxygen downstream is because of increased photosynthesis and dissolution from atmosphere.
- ✓ B.O.D is very low in unpolluted water, increases rapidly at outfall then decreases gradually downstream.
- ✓ The death of aerobic bacteria due to reduction in organic substances decreases BOD down stream

Suspended solids

- ✓ Suspended solids are very few before outfall, increase rapidly at the sewage discharge but progressively decrease downstream. This because;
- ✓ Sewage discharge adds decomposable organic matter into the water at the point of discharge, the progressive decrease downstream is due to bacterial consumption and dilution by water.

NH_4^+, NO_3^- and PO_4^{3-} (Ammonium, nitrate and phosphate ions)

- ✓ NH_4^+, NO_3^- and PO_4^{3-} ion concentration is very low before outfall.
- ✓ NH_4^+ions increase rapidly at discharge, then more rapidly to a maximum just after outfall, then decreases first rapidly and later gradually to a very low level downstream. This is because;
- ✓ Sewage contains NH_4^+ions. Putrefying (ammonifying) bacteria convert organic nitrogen-containing compounds in sewage to NH_4^+ just after outfall. Downstream, NH_4^+ions are converted to NO_3^- by nitrifying bacteria and further downstream there is dilution by water.

- ✓ NO_3^- ions first decrease gradually to a minimum concentration after outfall, gradually increase to a maximum a short distance downstream, then decreases gradually further downstream. This is because;
- ✓ NO3- ions first decrease due to consumption by sewage fungus abundant at outfall, then gradually increase because NH_4^+ions are converted to NO_3^- by nitrifying bacteria, then decrease gradually due to consumption by plants and algae.

- ✓ PO_4^{3-} ion concentration increases; rapidly at discharge, gradually just after outfall to a maximum, then decreases gradually to a very low level downstream. This because;
- ✓ Sewage contains PO_4^{3-} ions from; detergents and decomposition of organic matter, yet the consumption by autotrophs is very low at outfall, accounting for the high PO_4^{3-} ion concentration.
- ✓ PO_4^{3-} ion gradual decline downstream is caused by absorption by the progressively increasing populations of autotrophs and storage in sediments.

Aerobic bacteria, sewage fungus, algae.

- ✓ Aerobic bacteria are very few before, but very many at outfall, then their population decreases rapidly immediately and gradually after out fall downstream. This is because;
- ✓ Sewage contains aerobic bacteria that feed on organic substances, but population falls as availability of oxygen and nutrients diminishes.
- ✓ Sewage fungus is contained in sewage population increases to a maximum immediately after outfall, but decreases rapidly downstream to very low level.
- ✓ Population increases at outfall because the sewage fungus thrives in anaerobic conditions and is very tolerant of high ammonia concentrations.
- ✓ Algae decrease rapidly to a minimum at outfall but increase rapidly a short distance downstream and return to normal further downstream.
- ✓ The rapid decrease in population results from reduced photosynthesis because of the turbidity caused by suspended solids, the rapid increase is because of the high concentrations of NO_3^- ions and increased illumination because suspended solids reduce and water becomes clearer.

Clean water fauna

- ✓ These include; stonefly nymphs, may fly larvae, perch, trout,
- ✓ The populations of clean water fauna are high before outfall, decrease rapidly to zero at outfall only appearing and increasing to normal with distance downstream.
- ✓ Clean water species cannot tolerate anaerobic conditions at outfall, populations increase downstream because oxygen and food become available.

Asellus/ fresh water louse

- ✓ Asellus population decreases rapidly to zero at outfall, only appearing and increasing rapidly to a maximum a short distance downstream after which it decreases rapidly.
- ✓ Asellus cannot tolerate anaerobic conditions at outfall and therefore some dies and others migrates to the relatively less polluted water downstream where it shrives. The decrease thereafter is due to consumption after predation.

Tubifex

- ✓ Tubifex population increases rapidly to a maximum at outfall and then decreases rapidly downstream.

Chironomus/ bloodworm

- ✓ Chironomus population increases rapidly to a maximum at a slightly longer distance from outfall and then decreases rapidly downstream.
- ✓ Tubifex and Chironomus are; relatively inactive to reduce oxygen demand and have respiratory pigments with very high affinity for oxygen enabling them to be tolerant to anaerobic conditions.
- ✓ The increase in their population downstream indicates the level of pollution in the water.
- ✓ Tubifex, is the most tolerant to anaerobic conditions followed by Chironomus. The decrease in population downstream is partly due to predation.

Note:

a) Flowing rivers naturally undergo self-purification to recover from pollution through a combination of dilution and biodegradation, but the recovery time and distance depend on; volume of incoming degradable wastes in sewage, flow rate of the river, temperature of the water and pH level of the water.

LAND EROSION

Common land pollutants

Sources of pollution	Ecological effects
Use of pesticides in households or agricultural fields	• Kill pests to increase crop yield • Nonspecific ones may kill beneficial organisms and disrupt food chains • May get concentrated along a food chain and affect fertility of birds resulting from formation of thin shelled eggs • Slow to breakdown resulting into long term effects • Washed into water or to other areas causing pollution • Over use leads to resistance and resurgence
Heavy metals from industrial wastes, mines,	• Toxic to plants and animals • May be washed into rivers • Destroy soil organisms
Use of inorganic fertilizers	• Increase crop yield • Destroy soil texture and structure, which encourages soil erosion • Affect soil PH • Run off into rivers causing eutrophication • Harmful to plants and soil organisms
Domestic wastes e.g. sewage, plastics, rubbish hips	• Transmission of communicable disease • Destruction of habitats where rubbish is pilled • Rubbish heaps may harbor pest for human crops • Anaerobic decay may produce methane • Burning may cause air pollution • Untreated sewage may end up in water causing eutrophication

Land pollution control measures;

- Recycle and Reuse of non-biodegradable materials.
- Use organic wastes to produce fertilizers and generate power
- Use of fertilizers in agricultural activities.
- Use biodegradable packing materials.
- Ensure that you do not litter on the ground and do proper disposal of garbage
- Burning rubbish to reduce its bulk
- Create dumping ground away from residential areas.

HEAT (THERMAL) POLLUTION:

Main human sources:

✓ Water cooling of electric power plants and some types of industrial plants.

Harmful effects:

- Lowers dissolved oxygen levels since solubility of most gases reduces with temperature.
- Makes aquatic organisms more vulnerable to disease, parasites, and toxic chemicals.

- When a power plant shuts down for repair or opens, fish and other aquatic organisms adapted to a particular temperature range can be killed by the abrupt change in water temperature. This is known as **thermal shock**.
- Some aquatic animals may migrate to waters with favourable temperature.

PESTS

A pest is any animal or plant that causes harm to humans or human concerns including crops, livestock among others.
Or it is any species of plant or animal that causes injury to plants to plant products.

Some plant pests

WATER HYACINTH

Water bodies are also invaded by water weeds especially water hyacinth.

Characteristics of water hyacinth

- ❖ It is a flowering plant, with beautiful flowers
- ❖ Can also reproduce both sexually and asexually
- ❖ Has a high rate of reproduction.
- ❖ Grows rapidly in nutrient rich soils.
- ❖ Grows in temperature ranges from $3^{o}C$ to $30^{O}c$, pH between 6.5 and 8.5, salinity less than 2%

Due to these characters it inhabits fresh water bodies and has a high degree of survival and thus hard to eradicate.

Effects of water hyacinth on water bodies

- ✓ They hinder navigation
- ✓ They harbour dangerous animals e.g. snakes
- ✓ Reduction in the amount of fish in water bodies as some dies due to starvation.
- ✓ They reduce on the amount of light penetration in water column.
- ✓ Siltation of water bodies i.e. they become shallow as a result of death and decomposition of water hyacinth.
- ✓ Reduction in the amount of water in lakes as a result of increased rate of transpiration.
- ✓ They hinder smooth flow of water in lakes since they block the drainage channels.
- ✓ It has caused economic injuries to the country especially when trying to eradicate it.

Uses of water hyacinths

- ✓ Production of biogas
- ✓ Feeds for cattle and pigs.
- ✓ A good fertilizer when used as mulches.
- ✓ A good raw material for art and craft.
- ✓ Raw material for making manure.

Methods of controlling the water hyacinth

1. Physically or removing it manually by hand picking however it is not effective.
2. By use of machines (mechanical control) however the method is effective but expensive.
3. By using biological control methods e.g. use of beetles and fungus.
4. Use of herbicides (chemical control) and it involves the spraying of herbicides directly onto the weed. The method is quick but has the following demerits:
   - It contaminates water
   - Destruction of aquatic life especially fish
   - Pollution of water since the weed is not completely removed but decomposes in water.

- It is expensive since it involves the use of space air crafts to apply it.

METHODS OF CONTROLLING PESTS

Pests can be controlled using chemical or biological methods as follows

CHEMICAL PEST CONTROL

Include; herbicides kill weeds, insecticides kill insect pests, fungicides kill fungi among others

Properties of an ideal pesticide:

- ☑ Should be biodegradable / non-persistent so that toxic products are not left in or on crop plants.
- ☑ **Persistence,** the time pest remains in the environment or in organisms without being broken down. Though not desirable for food crops, it may be important in control animal parasites, and soil borne diseases. However long term persistence causes damaging effects including incorporation of pesticide in food chains where it can be mobilized more toxic forms or accumulating to toxic concentration in predators at the top of food chains. Non persistent ones should be able unstable to break down into harmless forms
- ☑ **Specificity,** the range of organisms that can be killed by the pesticide. Broad spectrum pests affect a wide range of organism while narrow kill narrow range of pests. Specific pesticides should be toxic only to the targeted organisms and harmless to others. Use of non -specific or broad spectrum pesticides can cause pest resurgence. Predators too are killed and the remaining few pests multiply rapidly in absence of their predators. However pest resurgence may also be caused by pest resistance to the pesticide.
- ☑ Should not accumulate either in specific parts of an organism or as it passes along food chains.
- ☑ Should effectively control the pest under field growing conditions.
- ☑ Should be easy to apply at the correct dosage.

☑ **Toxicity,** the ability of a pesticide to kill. It is defined by the lethal dose LD50, which is a single dose that kills 50% of the experimental pest population. In a field where organisms are subjected to more stress a higher number is killed. Toxicity is needed to clear all the pests since the survivor may form resistant population resulting into pest resurgence

Problems of using pesticides:

a) Accidental misuse of toxic chemicals results in death of humans and domestic animal.
b) Many are non-specific, killing non-target species, particularly natural predators of the pest species.
c) Pest resistance occurs i.e. genetic variation enables a few individuals in the pest population to survive and may quickly reproduce.
d) There is pest replacement i.e. since most crop are susceptible to attack by more than one pest species, and the pesticide may be more deadly to one species than another, elimination of one species may simply allow another species to assume major pest proportions.
e) Pest resurgence may occur i.e. non-specific pesticides may kill natural predators as well as pests, and so a small residual pest population may multiply quickly without being checked.

Pest resurgence; this a condition in which the number of target organism increases rapidly after spraying with a given pesticide than before spraying.

f) **Bioaccumulation**; some molecules of the pesticide may be stored in specific organs or tissues at levels higher than would be expected and **biological magnification;** the pesticide may get more concentrated as it passes along the food chains and webs may occur.

As illustrated below using DDT as the case study

Where the DDT level was measured	Amount of DDT/ppm
Water	0.0003
Phytoplankton	0.006
Zooplankton	0.004
Herbivorous fish	0.39
Carnivorous fish	1.8
Fish-eating birds	14.3

Concentration of DDT in water = 0.0003 parts per million (ppm)
Concentration of DDT in fish-eating birds = 14.3ppm
DDT concentration in osprey compared to water = 14.3/0.0003
DDT therefore was magnified by magnified = 47667 times

Effects of DDT	**Effects of other pesticides in general:**
i) Inhibits cytochrome oxidase enzyme. ii) Limits reproductive success, especially by causing formation of thin eggshells in birds of prey. iii) Kills organisms.	i) Inhibition of enzyme activity ii) Kill organisms. iii Reduce species diversity iv) It increase productivity at lower levels of the ecosystem v) It increase productivity at higher levels of the ecosystem

Note;

1. **DDT (**Dichlorodiphenyltrichloroethane**)** is highly persistent in the environment, will accumulate in fatty tissues, and can travel long distances in the upper atmosphere.
2. It is a broad spectrum pesticide that was previously used to combat malaria, typhus and other insect borne human diseases.
3. It causes pest resurgence.

Poison;

- A chemical that has an LD50 (median lethal dose) of 50 milligrams or less per kilogram of body weight.

LD50 median lethal dose

- The amount of a chemical received in one dose that kills exactly 50% of the animals in a test population, within a 14-day period.

BIOLOGICAL PEST CONTROL

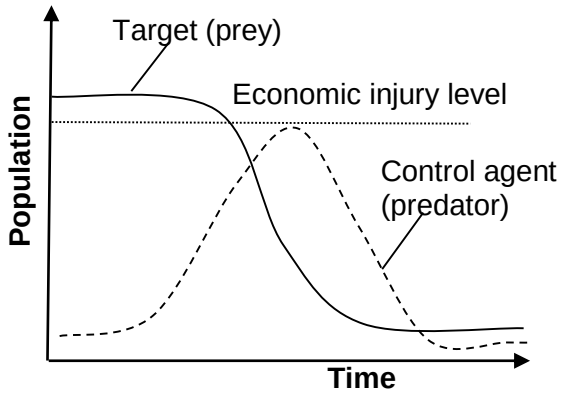
✓ Control of a pest population using its natural predator, parasite or pathogens.

Steps involved in biological control:

1. Identifying the pest and tracing its origins, i.e. where it came from.
2. Investigating the original site of the pest and identifying natural predators, parasites or pathogens of the pest.
3. Testing the potential control agent under careful quarantine to ensure its specificity.
4. Mass culturing of the control agent.

5. Development of the most effective distribution / release method for the control agent.

Graph showing Relationship between pest and control agent



Or check diagram in understanding biology page 360 fig 17.17

Precautions that have to be taken to ensure success of biological control include

- Study climatic conditions that affect the predator.
- Interactions of the predator with the rest of organisms in the environment to avoid providing many alternative sources of food.
- Introduce predator at maximum population of pest. Otherwise if the pest fails to provide adequate source of food to control agents; predators they would die and pests rapidly increase in their absence.

Advantages of biological control

- ✓ Control agent is specific to one pest;
- ✓ Control agent may become useful source of food material for other organisms;
- ✓ Only needs one application since control agent reproduces; therefore no recurrent costs
- ✓ Keeps population low; but does not lead extinction of target;
- ✓ Pests do not develop resistance;
- ✓ Does not leave chemical in environment/on crop / no bioaccumulation; hence can be used in organic farming
- ✓ There is no danger of pollution

Disadvantages of biological control

- Initial cost of treatment/biological control is high;
- Takes a longer time to act;
- The Pest is not completely removed;
- The control agent may become a pest to/damage/eat other non- targeted organisms;

I thank you for you have been able to understand ecology in detail. We have been able to look at diversity, population and communities, eco systems and influence of human activities on the ecosystem among others. Due to my belief am sure you can now answer the questions below.

1. (a)(i) outline the importance of population size of different organisms in a given area to an ecologist
   (ii) Differentiate between sample count and total count.
(b) Give five factors to be considered before carrying out counting. exercise
(c) Describe a suitable method you would use to estimate the population of
   (i) Fish e.g. tilapia
   (ii) Flying insects in a woodland.
   Give reasons for your choice

2. a. Describe the physiological and structural factors of the water hyacinth which enabled it to spread and persist on Lake Victoria.
   b. Outline the ecological dangers of this weed on the water
   c. Suggest three control methods of the water weed, and for each method point out one weakness.

3. a. Explain how plants living under the canopy of forest trees are able to survive
   b. Describe how herbaceous plants are supported of the ground

4. a. What is a food chain?
   b. Explain how energy flows through an ecosystem?
   c. How does temperature influence the distribution of organism?

5. Describe the influence of biotic factors, excluding man, on the distribution of organisms in nature.

6. How are vertebrates adapted to terrestrial life? (20 marks)

7. A study curried out on population growth of two species of duck weed (*Lemna minor* and *Lemna trisulsca)* which grow on or near the surface of ponds. The two species were grown separately in one experiment and together in another. The population was determined by counting number of fronds. The results are shown in the table below

Time (days)	Total number of fronds			
	Species grown separately		Species grown together	
	L. trisulsca	*L. minor*	*L. trisulsca*	*L. minor*
0	30	30	30	30
16	63	78	48	105
36	126	142	84	234
46	177	225	84	324
54	165	276	48	360
60	129	219	45	354

a) On the same axes, represent the above information graphically (14marks)
b) Compare the population curves of *L. minor* and *L. trisulsca* when the two were
   (i) Grown together (5marks)
   (ii) Grown separately (5marks)
c) Explain the shape of curves of *L. trisulsca* in the two experiments (10marks)
d) What principle is illustrated by species when grown together (01mark
e) What is the evolutionary significance of the above principle (02marks)
f) Suggest three abiotic factor which affect growth of both species (03marks)

8. Bush rats, guinea fowl, hawk, grass hoppers, Uganda kob and grass are organisms in a game park.
   a) Show the feeding relationship between them

b) What name is given to the feeding relationship between them
c) What would happen to the relationship if Uganda kob was removed?

9. a) Construct a diagram of a food web consisting of the following organisms

i) Tadpoles, green algae, heron, saprophytic bacteria, small fish, big fish and mosquito larva.
ii) Green plants, small insects, large insects, caterpillars, rabbits, hawk and small birds.

b) For each of the food webs you have constructed, identify the organisms in the four trophic levels.
c) Name the organisms, with reasons you would expect to be:
i) Most numerous
ii) Least numerous
iii) With least amount of energy
d) What is the most significant difference between nutrition of producers and other organisms in a food web?

10. a) What is meant by primary productivity?
b) Describe how primary production of a named ecosystem can be determined.
c) Discuss the factors which determine productivity of an ecosystem

11. In an experiment to investigate changes in population of two species of mites, spotted mites which feed on oranges and predatory mites which feed on spotted mites, a small number of spotted mites were placed in a box with some oranges. Three days later a small number of predatory mites were added. The number of mites was then estimated at weekly intervals. The results are shown in the table below.

Week	Number of spotted mites	Number of predatory mites
1	210	100
2	920	340
3	1400	1250
4	750	1900
5	300	950
6	170	750
7	280	360
8	580	130

a) Plot a graph to show changes in number of mites over time
b) Describe and explain the pattern
c) Predict what would happen over the next three weeks.
d) Suggest why farmers may decide not to use predatory mites in control of spotted mites

12. a. Explain how continued use of polythene bags may harm the environment
b. Suggest the ways of preventing the effects above
c. Explain how human activities may improve and degrade the soil

END OF TOPIC ECOLOGY

6. INHERITANCE AND EVOLUTION

DNA AND THE GENETIC CODE

We previously discussed what a genetic code is in cell biology. So here our main concern is why DNA is considered a hereditary material which is the backbone of genetics.

Evidence that DNA is the hereditary material

a) **Chromosome analysis;** since chromosomes only become visible during cell division, when they were examined, they were found to be made up of protein and DNA.
   Of the two, DNA must be the complex molecule which must carry an immense diversity of information.
b) **Metabolic stability of DNA**; any material which is responsible for transferring information from one generation to another must be extremely stable. Unlike proteins, DNA shows remarkable metabolic stability. This is because once DNA is labelled with a radioactive isotope, its rate of disappearance is very slow.
c) **Constancy of DNA within a cell**; almost all the DNA of a cell is associated with chromosomes in the nucleus. Small amounts do occur in the cytoplasmic organelles and analysis has that the amount of DNA remains constant for all cells within a species except for gametes, which have almost half of the quantity.
d) **Correlation between mutagens and DNA**; mutation is an alteration to an organism's characteristics which is inherited. All mutagens are found to alter the structure of DNA. This suggests that it is the alteration of DNA which is the source of mutation and DNA must therefore be the hereditary material.

GENETICS

Inheritance; refers to the process by which characters or traits are passed from parents to off springs.

DEFNITION OF TERMS USED IN GENETICS

1. **Gene**; A gene is the basic unit of inheritance that determines the organisms' characteristics. All the characteristic features of an organism are defined at fertilization by the genes inherited from parents but can be greatly modified by the environment in which the organism lives.
2. **Alleles**; Are alternative forms of the same gene.
3. Most of the genes occur in two alternative forms called alleles one of which is dominant and the other recessive both of which are represented by alphabetical letters just for study purposes
4. **Dominant gene/allele**; Is a gene/allele whose trait is expressed phenotypically even in presence of a different allele. Such genes are always represented by capital letters when performing a genetic cross.
5. **Recessive gene/allele**; is a gene/allele whose character is not expressed phenotypically in presence of a different allele but is only expressed in a homozygous recessive state. Recessive genes are always represented by small alphabetical letters in a genetic cross
6. **Genotype**; is the genetic makeup/constitution of an organism as inherited from the parents. It is determined at fertilization and does not depend on the environment.
7. **Phenotype;** Refers to the physical/outward appearance of an organism as determine by the interaction between its genotype and the environment in which it lives.

8. **Locus** (plural loci). This is the position on the chromosome where the genes are located.
9. **Homozygous;** this is a condition where an individual possess identical alleles for a particular gene e.g. TT, tt, AA.
   OR is when the alleles found at a given locus are identical
10. **Heterozygous;** this is a condition where an individual possess non-identical alleles for a particular gene e.g. Tt, Bb OR is when the alleles at a given locus are different.
11. **Pure breeding (true breeding)**, this is where the individuals being crossed are homozygous **Crossing(X)**. This refers to the mating of the male and female organisms under a consideration.
12. **First filial generation (F1)**; this refers to the set of offsprings obtained from crossing two pure breeding parents with contrasting characteristics. These individuals are therefore heterozygous hybrids
13. **Second filial generation (F2)**; this refers to the set of off springs that are obtained from crossing mature F1 hybrids.
14. **Selfing;** this refers to the crossing of offsprings of the same parents.
15. **Test cross** is a cross between an organism with an unknown genotype with a homozygous recessive organism so as to determine the unknown genotype.
16. **Back cross**. This is the mating of an offspring with one of its parent so as to prove the genotype of the parents.
17. **Reciprocal cross;** this is a cross in which the genotypes of the parents have been reversed

MENDEL'S GENETIC EXPERIMENTS
MONOHYBRID INHERITANCE

- Monohybrid inheritance refers to the inheritance of a single pair of contrasting characteristics.
- Examples include, inheritance of height, blood groups, albinism, sickle cell anaemia, and sex linked characteristics etc.
- This mechanism of inheritance was discovered by an Austrian monk and biologist Gregory Johann Mendel who carried out a number of genetic experiments using the garden pea plants *(Pisum sativum);* which he grew in the vegetable garden in his monastery.
- He later observed many sexually reproducing organisms and found out that they had variations among themselves despite being of the same species.

Why Mendel used garden peas

- They occurred in many varieties with distinct characters
- The plants were easy to cultivate
- All their offsprings were fertile
- They have a short life cycle that they reproduced so quickly
- The plants also had many contrasting characters with no intermediates
- Their reproductive structure were enclosed in petals which allowed for production of pure breeding plants due to self-pollination over many generations.

MENDEL'S EXPERIMENTS

- In one of his experiments, Mendel crossed tall pea plants with dwarf pea plants. In order to properly manage the cross, Mendel covered the stigma of all flowers of one group, and removed all the anthers from the flowers of another

group of pea plants in order to prevent self-pollination, and transferred pollen using a brush.

- The resultant seeds were planted and he observed that all the F1off springs were tall.
- He then selfed the F1 pea plants to get F2. This generation comprised of a mixture of tall and short pea plants in a ratio of 3 tall: 1short plants.
  Note: The 3:1 ratio is known as Mendel's monohybrid ratio of the dominant and recessive characters respectively in the F2 generation.

Observation;

- Mendel was able to observe that neither of the F1 nor F2 had intermediate phenotypes.

Conclusion;

- He then concluded that inheritance is not the mixing/blending of features to produce intermediates but rather the process by which internal factors of the body may or may not express themselves in the phenotype.
- From his conclusions, Mendel was able to formulate his first law of inheritance which is well known as the law of monohybrid inheritance/law of segregation/law of particulate inheritance

The first law of inheritance;

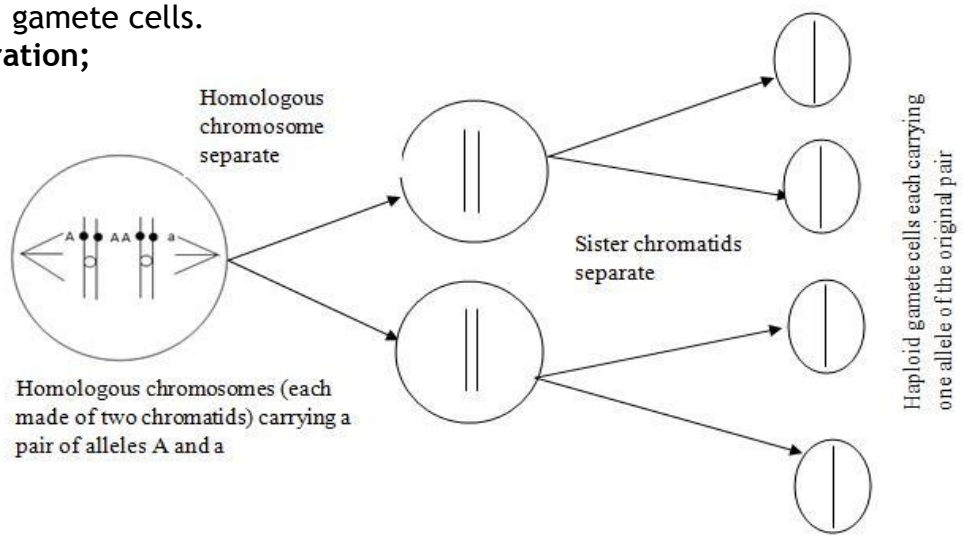
This states that "The characteristics of an organism are controlled by alleles which occur in pairs but only one can be carried in a single gamete".

Meiosis explains:

This was earlier discussed in cell biology however;

- Mendel's first law can currently be explained; accounted for in terms of meiosis. The genes which determine organisms' characters usually occur in two alternative forms called alleles located on homologous chromosome.
- During anaphase 1 of meiosis, these homologous chromosomes separate; segregate and move to opposite daughter nuclei.
- Subsequent cell division results into two gamete cells each containing one of the two alleles; therefore the alleles occur as pairs in body cells but singly in gamete cells.

Illustration;



I

A full genetic explanation of Mendel's first law and the 3:1 ratio

Let;

T represent the allele for tallness, t represents the allele for shortness

Parents : male x female

Phenotypes : Tall x short

Genotypes : TT x tt

Meiosis

Gametes : T T t t

Random fertilization :

F_1 genotypes : Tt Tt Tt Tt

Genotypic ratio : All Tt, Phenotypic ratio : All tall

To obtain F2 generation, F1 hybrids were selfed as shown below

Let;

T represent the allele for tallness, t represents the allele for shortness

Parents : male x female

Phenotypes : Tall x tall

Genotypes : Tt x Tt

Meiosis

Gametes : T t T t

Random fertilization :

F_2 genotypes : TT Tt Tt tt

Genotypic ratios: 1TT: 2Tt: 1tt; Phenotypic ratios: 3tall: 1 Short

Note;

- Mendel carried out many other experiments on peas and other organisms and all gave consistent results as shown below:

Character	Parental phenotypes	F_1 generation	F_2 generation	Ratio
Stem length	Tall X Short	All tall	787tall, 277short	2.84:1
Seed colour	Green X Yellow	All yellow	6022yellow, 2001green	3.01:1
Seed shape	Round X Wrinkled	All round	5474 round, 1850wrinkled	2.96:1
Seed coat	Coloured X White	All coloured	705 coloured, 224 white	3.15:1
Pod colour	Green X Yellow	All green	428 green, 152 yellow	2.82:1
Pod shape	Inflated X Constricted	All inflated	882 inflated, 299 constricted	3:1
Flower position	Terminal X Axial	All axial	651 axial, 207 terminal	3.14:1
Flower colour	Purple X white	All purple	705 purple, 224 white	3:1

Note;

- It became so obvious to predict which trait of a given pair is dominant over the other. In a cross starting with pure breeding parental stocks, all the F1 hybrids show the dominant trait.
- In addition, a larger proportion of the F2 hybrids show the dominant trait while those showing the recessive one are always fewer.

Note;

- ✓ Appropriate letters are the best to represent respective alleles involved.
- ✓ Letters that can clearly be distinguished should be used, avoid letters of the same shape.
- ✓ A cross**(X)** must be indicated to symbolize mating between the parents.
- ✓ Directive words must be indicated to define each step of the cross.
- ✓ In case of identical gametes, only one can be indicated.

TRY OUT

1. In a garden pea plant there are two forms of heights. When a pure breeding tall pea plant was crossed with a short pea plant all the offsprings obtained where tall when the offsprings were selfed a phenotype ration was obtained in F2.
   a. Using suitable genetic symbols, workout the genotypes and phenotypes of the F2 generation
   b. What are the phenotypic and genotypic ratios of the F2 generation
   c. Explain how you would determine the genotype of F1 tall pea plants formed
   d. Suppose 700 pea plants where produced in the F2 generation
      i. How many were tall?
      ii. How many were short?

WORKED OUT EXAMPLE;

Suppose a man who is a tongue roller marries a woman who is a non-tongue roller and all the children obtained in F1 are tongue rollers.

(a) Work out the phenotypic and genotypic ratio as obtained in F2 generation.

(b) What is the probability that the 4th born is a non-tongue roller?

Let;

A represent the allele for tongue rolling, t represent the allele for non-tongue rolling

Parents : Male X Female

Phenotypes : Tongue roller X Non-tongue roller

Genotypes : AA aa

Meiosis

Gametes : all A all a

Random fertilization :

F_1 genotypes : all Aa

F1 phenotypes: all tongue rollers

By Selfing the F1 hybrids to obtain F2

Parents : male X female

Phenotypes : Tongue roller X Tongue roller

Genotypes : Aa X Aa

Meiosis

Gametes : A a A a

Random fertilization :

F_2 genotypes : AA Aa Aa aa

Genotypic ratios: 1AA: 2Aa: 1aa; phenotypic ratios: 3tongue rollers: 1non-roller

Probability that the 4th born is a non-tongue roller.

Such crosses can be performed in terms of probability as follows·

Each gamete carrying any of the two alleles has 0.5 chance of fusing with the gamete from the other parent,

Genotypes : Aa X Aa

Meiosis

Gametes : $(1/2)$ A $(1/2)$ a $(1/2)$ A $(1/2)$ a

Random fertilization :

F_2 genotypes : AA Aa Aa aa

$(1/4)$ $(1/4)$ $(1/4)$ $(1/4)$

F_2 phenotypic ratios: $(3/4)$ rollers: $(1/4)$ non-rollers = 3rollers:1non roller

- ❖ In case of individuals showing the dominant trait, the genotype may either be homozygous dominant or heterozygous. Such genotypes can be determined by performing **a test cross;** that is, crossing the unknown with a homozygous recessive individual. If the unknown is homozygous, the resultant hybrids will all show the dominant trait but otherwise, a mixture of dominant and recessive traits are produced in a ratio of 1:1
- ❖ In a test cross, a homozygous dominant individual cannot be used because in such a case; regardless of the unknown genotype, all the resultant hybrids would show the dominant trait.

MONOHYBRID INHERITANCE IN MAN

- × There are many genetically determined abnormalities and diseases that affect man and other animals. Since these are genetic diseases, they can only be inherited from parents and their occurrence is determined by those genes inherited from parents during fertilization.

Examples of such diseases include:

- ✓ Sickle-cell anaemia
- ✓ Albinism
- ✓ Achondroplasia
- ✓ Cystic fibrosis.

NOTE;

- ➢ Research has showed that most of, though not all the genetic abnormalities are caused by recessive genes; alleles and the genes responsible for normal conditions are dominant.
- ➢ This implies that for an individual to suffer from such diseases, they must have two copies of the responsive genes; homozygous recessive.
- ➢ The heterozygotes and the homozygous dominant individuals are normal. Though the former are phenotypically normal but their cells contain a copy of the recessive allele and are described as carriers.

INHERITANCE OF SICKLE-CELL ANAEMIA

- Sickle-cell anaemia is a recessive character caused by a point substitution mutation in which glutamic acid in normal haemoglobin is replaced by valine.
- Normal haemoglobin (HbA) contains an amino acid glutamic acid at position 6 of the ß-chain. The amino acid is polar and hydrophilic which make normal haemoglobin soluble in water.
- It is coded for by the DNA triplet CTT and its complementary mRNA codon is GAA. A substitution mutation leads to replacement of T with A making the DNA triplet CAT and its complementary mRNA codon GUA.
- This triplet codes for valine which is non-polar and hydrophobic hence reduces the solubility of haemoglobin especially at low oxygen tensions.
- This abnormal haemoglobin crystallizes into rigid rod-like fibres which distort the normal biconcave shape of RBCs into a crescent/sickle shape. Such abnormal haemoglobin is called HbS.
- It has a very low oxygen-carrying capacity leading to symptoms of anaemia thus the disease is known sickle-cell anaemia.

Note;

- × Being a recessive character, for a person to be a sufferer they must possess two copies of the faulty gene; homozygous recessive, i.e. HbSHbS or ss.
- × Heterozygotes; carriers, i.e. HbAHbS or Ss have one copy of the responsive gene whose effects are masked by the other dominant gene. They don't suffer

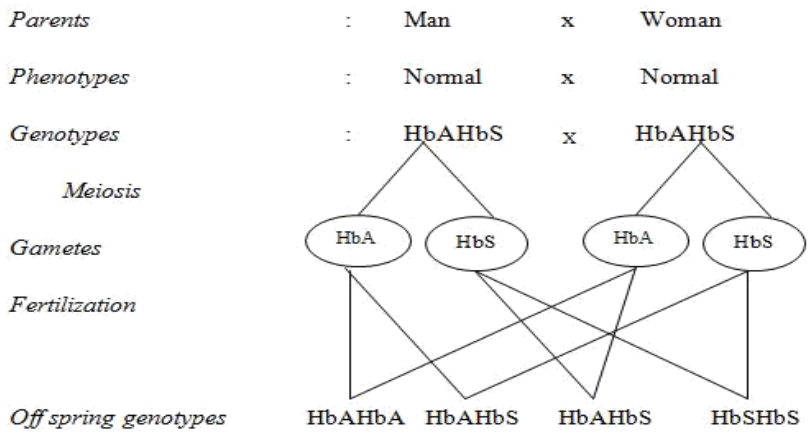
from the disease symptoms except at exceptionally low oxygen tensions; this is known as sickle-cell trait.

- It is therefore advisable to avoid exposure of such people to low oxygen environments like crowded places, high altitudes and flying in unpressurised aircrafts.

Applications;

If two people suffering from sickle cell trait are married, what is the probability that they will produce a child with sickle cell anaemia?

Let *HbA represent the allele for normal haemoglobin; HbS represent the allele for abnormal haemoglobin*



Genotypic ratios: 1HbAHbA:2HbAHbS:1HbSHbS
Phenotypic ratios: 1normal:2 carriers: 1sickler
Probability of a sickler is $^1/_4$ = 0.25.

Effects of sickle cell anaemia

- Anaemia this occurs because the sickle cells are destroyed which lowers the amount of oxygen to be carried leading to acute anaemia. This leads to; Fatigue (weakness), Poor physical development and Dilation of the heart which may lead to heart failure.
- Interference with circulation of blood because sickle cells get jammed in tiny capillaries and small arteries. This leads to; Heart damage which leads to heart failure, Lung damage which leads to pneumonia, Kidney damage which leads to kidney failure and Liver damage.
- Enlargement of the spleen because the sickle cells collect in the spleen for destruction.

N.B

1. The effects above make the homozygous sufferers to often die before reproductive age.
2. Despite the above complications suffered by sufferers of sickle cell anaemia, the heterozygotes tend to have an advantage of showing increased resistance to the plasmodium parasite that causes malaria much more than both the sufferers and the normal. This resistance is as a result of two factors:

- The consistent change in oxygen levels between normal and sickle cells makes it difficult for the parasite to adapt. In such cases, the immune system of the body eliminates the parasites before the disease is established rendering resistance to the heterozygotes
- This is referred to as the **heterozygous advantage** which increases chances of survival for heterozygotes especially in the tropics where malaria is one of the leading causes of death.

- In this the heterozygous genotype has a higher relative fitness than either the homozygous dominant or homozygous recessive genotype.

INHERITANCE OF ALBINISM

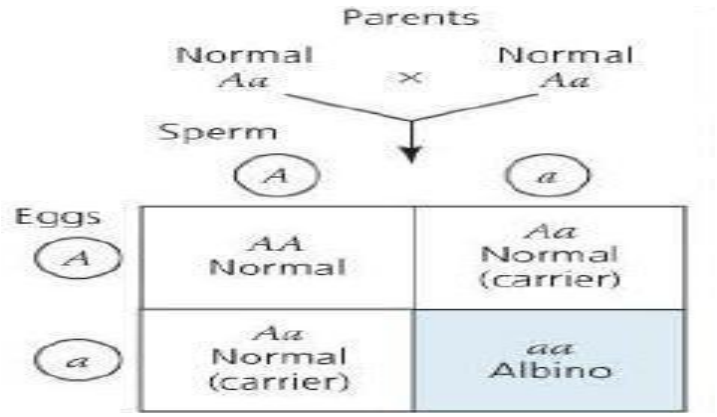
- Albinism is a recessive character which results into failure of formation or formation little of body pigment melanin, which determines the colour of the skin, hair and eyes.
- Albinism is transmitted in an autosomal recessive manner

Albinos have the following characteristics as a result;

- ✓ Light-coloured skin
- ✓ White hair
- ✓ Pink eyes

Example;

Man with normal skin marries a carrier for albino skin. What is the probability that some of their children will be albinos?



What is the probability that the sister with normal colour is a carrier?

INHERITANCE OF CYSTIC FIBROSIS

- This is a recessive character caused by a mutation resulting into accumulation of abnormally thick and sticky mucus that blocks the pancreatic duct, bile duct and air passages.
- The mutation occurs on an autosomal chromosome 7 affecting the gene that codes for a chloride channel protein in epithelial cells. This results into total absence or malfunctioning of this channel protein hence interfering with chloride ion flow.
- Chloride ions accumulate in the cells and attract sodium ions towards the opposite charge; this increases the ion concentration, hence osmotic potential of the cells which prevents osmotic outflow of water.
- As a result, the mucus secreted is dry, thick and sticky; blocking small tracts of some body organs a condition known as cystic fibrosis.
- In the pancreas, fibrous patches called cysts develop and complications include digestive problems due to poor release of pancreatic enzymes, poor absorption of digestive products, chronic lung diseases, and reduced fertility among others.

INHERITANCE OF ACHONDROPLASIA (DWARFISM)

- Although many harmful alleles are recessive, a number of human disorders are due to dominant alleles.
- One example is *Achondroplasia,* a form of dwarfism that occurs in one of every 25,000 people in the world. Heterozygous individuals therefore have the dwarf phenotype.
- Since this character is dominant; caused by a dominant allele, all people who are not achondroplasiac i.e 99.99% of the population are homozygous for the recessive allele.
- Achondroplasia is a trait for which the recessive allele is much more prevalent than the corresponding dominant allele.

Another disease due to the dominant gene mutations is **Huntington's disease**.

- This is characterized by involuntary muscular movement and progressive mental deterioration.
- The mutant gene is so rare that around 1 in 100000 people carry it that means it occurs exclusively in the heterozygous state.

DIHYBRID INHERITANCE AND MENDEL'S SECOND LAW OF INHERITANCE

Dihybrid inheritance refers to the inheritance of <u>two pairs of contrasting characteristics simultaneously.</u>

- ☑ For instance, in one of his experiments; Mendel crossed pure breeding tall pea plants with red flowers with pure breeding dwarf plants having white flowers. All in the F1 progeny were tall with red flowers. This showed just like Mendel had discovered before that the alleles for tallness and red flowers were dominant to those for dwarfness and white flowers respectively.
- ☑ Mendel went ahead to self-pollinate the F1 plants and obtained an F2 progeny, this comprised of a variety of phenotypes as summarized below.
  - 315 Tall with red flowers
  - 101 Tall with white flowers
  - 108 Dwarf with red flowers
  - 32 Dwarf with white flowers
- ☑ These give the respective phenotypic ratios as 9:3:3:1. This is known as Mendel's Dihybrid ratio; the ratio of phenotypes in the F2 generation for a Dihybrid cross.
- ☑ From this and many other similar crosses, Mendel was able to make the following observations:
  - Both phenotypes/characters (height and flower colour) combined in the F1 but separated and behaved independently in the F2.
  - Two of the F2 phenotypes resembled one or the other of the parental phenotypes while two new combinations of phenotypes appeared in the F2; (Tall/white and Dwarf/red). These are known as <u>recombinants</u>.
  - The allelomorphic pairs of characteristics; controlled by different alleles of the same gene occurred in a phenotypic ratio of 3 dominant: 1 recessive. E.g. 3tall: 1 dwarf and 3red: 1 white.

Basing on these observations, Mendel formulated his second law known as the law of independent assortment.

The law states that; "Any **one of a single pair of contrasting characters may combine randomly with either one from another pair"**
Currently stated as; **each member of an allelic pair my combine randomly with either of another pair.**

Below is a full genetic explanation of the 9:3:3:1 ratio of phenotypes in the F2generatioon of a Dihybrid cross.

Let; *T represent allele for tallness, t for dwarfness*

R represent allele for red flowers, r for white flowers

Parents	:	Male	X	Female
Phenotypes	:	Tall, red flowered	X	Dwarf, white flowered
Genotypes	:	TTRR	X	ttrr
Meiosis	:	↓		↓
Gametes	:	all (TR)		all (tr)
Random fertilization	:			
F₁genotypes	:	All TtRr		

Phenotypic ratios : All Tall with red flowers.

By Selfing F₁ plants;

Parents	:	Male	X	Female
Phenotypes	:	Tall, red flowered	X	Tall, red flowered
Genotypes	:	TtRr	X	TtRr
Meiosis	:			
Gametes	:	(TR) (Tr) (tR) (tr)		(TR) (Tr) (tR) (tr)

Random fertilization

	(TR)	(Tr)	(tR)	(tr)
(TR)	TTRR	TTRr	TtRR	TtRr
(Tr)	TTRr	TTrr	TtRr	Ttrr
(tR)	TtRR	TtRr	ttRR	ttRr
(tr)	TtRr	Ttrr	ttRr	ttrr

Note;

1. Alleles of the same gene cannot pass into the same gamete (they segregate during meiosis). I.e. T can only be present with Y or y but not t while t can only be present with y or y but not T as in the above case
2. The possible combination of gametes during fertilization is shown in a Punnett square; after the Cambridge geneticist R. C. Punnett. This minimizes errors when listing the combinations. Like in the case above.

In summary; the following can be noted from Mendel's hypotheses:

- ✓ Each characteristic of an organism is controlled by a pair of alleles.
- ✓ During meiosis, each pair of alleles segregate (separates) and each gamete receives one of each pair. This is known as the law of segregation.
- ✓ During gamete formation, either one of a pair of alleles can pass into the same gamete with either one from another pair. This is known as the law of independent assortment.
- ✓ Each allele is transmitted one generation to the next as a discrete unit
- ✓ Each diploid organism inherits one allele for each character from each of the two parents.
- ✓ If an organism has two unlike alleles for a given gene, one may be expressed (dominant) at total exclusion of the other (recessive).



Please reflect on how independent assortment in meiosis!

Example/ application;

1. When a pure breeding broad and long winged female fly was crossed with a narrow and vestigial winged male fly all the F1 offsprings obtained head broad abdomen and long wings.

a) Using suitable genetic symbols work out the phenotypes and genotypes that were obtained in F2 generation.

b) Suppose 480 flies were obtained in F2 work out the numbers of the flies for each phenotype class.

How many of these flies were recombinants.

Let; *B represent allele for broad abdomen, b for narrow abdomen*

L represent allele for long wings, l for vestigial wings

Parents	:	Male	X	Female
Phenotypes	:	Broad abdomen,		Narrow abdomen,
		Long wings	X	vestigial wings
Genotypes	:	BBLL	X	bbll
Meiosis	:			
Gametes	:	all BL		all bl
Random fertilization	:			
F1 genotypes	:	All BbLl		

For the F_2 generation

Parents	:	Male	X	Female
Phenotypes	:	Broad abdomen		Broad abdomen
		Long winged	X	vestigial winged
Genotypes	:	BbLl	X	BbLl
Meiosis	:			
Gametes	:	BL Bl bL bl		BL Bl bL bl

Random fertilization

	BL	Bl	bL	bl
BL	BBLL	BBLl	BbLL	BbLl
Bl	BBLl	BBll	BbLl	Bbll
bL	BbLL	BbLl	bbLL	bbLl
bl	BbLl	Bbll	bbLl	bbll

(b) Phenotypic ratios = 9:3:3:1, Total ratio = (9+3+3+1) = 16

Number of flies = $\frac{Ratio}{total}$ × 480 Flies

i. Broad abdomen, long winged = $\frac{9}{16}$×480 = 270 flies

ii. Broad abdomen, vestigial winged = $\frac{3}{16}$×480 = 90 flies

iii. Narrow abdomen, long winged = $\frac{3}{16}$×480 = 90 flies

iv. Narrow abdomen, vestigial winged = $\frac{1}{16}$×480 = 30 flies

(c)Number of recombinants = (90 + 90) flies = 180 flies



Please try out;

1) In guinea pigs, there are two alleles for hair colour and two for hair length. In a breeding experiment, all the F1phenotypes produced from a cross between pure breeding short black-haired and long white-haired parents had short black hair. Explain
   a) Which alleles are dominant
   b) The expected F2 phenotypes
2) Flower in sweet pea plants is determined by two allelomorphic pairs of genes (R, r and S, s). Presence of at least one dominant gene from each pair makes the

flowers purple while all other genotypes are purple. If two plants heterozygous for both genes are crossed, what will be the phenotypic ratio of the offsprings?

EXCEPTIONS TO MENDEL'S LAWS

i. It should however be noted with concern that Mendel's laws of inheritance are not of universal application to all processes of inheritance in organisms.
ii. For the work that led to his two laws of inheritance, Mendel chose pea plant characters that turn out to have a relatively simple genetic basis:
iii. Each character is determined by one gene, for which there are only two alleles, one completely dominant and the other completely recessive. But these conditions are not met by all heritable characters, and the relationship between genotype and phenotype is rarely so simple.
iv. In this section, we will extend Mendelian genetics to hereditary patterns that were not reported by Mendel. These are referred to as exceptions to Mendel's laws of inheritance because they never produce the 3:1 or the 9:3:3:1 ratios of phenotypes in monohybrid and Dihybrid crosses respectively.

LINKAGE

- This is the condition when two or more genes are carried on the same chromosome
- Such genes form a linkage group and pass into the same gamete during meiosis and are therefore inherited together. As a result, these genes do not show independent assortment; applies to genes on non-homologous chromosomes and fail to produce the 9:3:3:1 ratio.

NOTE:

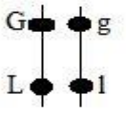
Linked characteristics; traits are characters controlled by genes found on the same chromosomes and therefore inherited together

Applications;

In drosophila, the alleles for grey body and long wings are dominant to those for black body and vestigial wings respectively. If pure breeding grey bodied long winged drosophilae are crossed with pure breeding black bodied vestigial winged drosophila; all in the F_1 are grey with long wings. Surprisingly in the F_2, a 3:1 ratio of grey long winged and black vestigial winged (the original parental) phenotypes are obtained as follows.

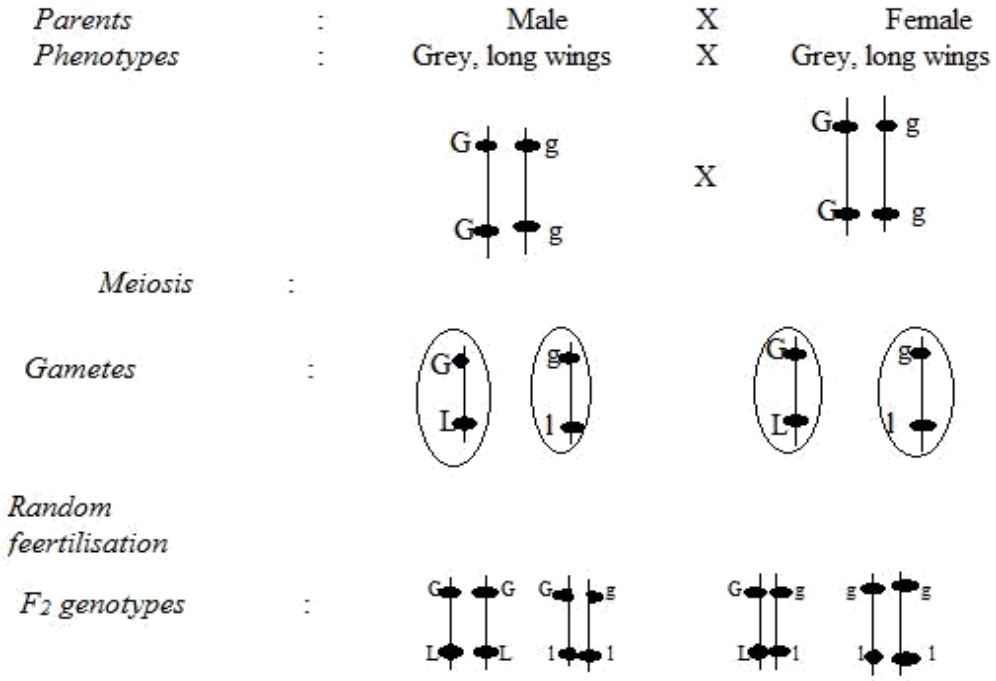
Let: G represent allele for grey body, g for black body

L represent allele for long wings, l for vestigial wings

Parents	:	Male	X	Female
Genotype	:	Grey, long winged	X	Black, vestigial winged
		G G L L	X	g g l l
Meiosis	:			
Gametes	:	*all* 		*all* 
Random fertilisation	:			
F1 genotypes	:			

F1 phenotypes: all grey with long wings

Obtaining F2 generation



Phenotypic ratio is 3 grey long winged: 1 black vestigial winged.

It should be noticed that the 3:1 ratio of parental phenotypes is never obtained in practice.

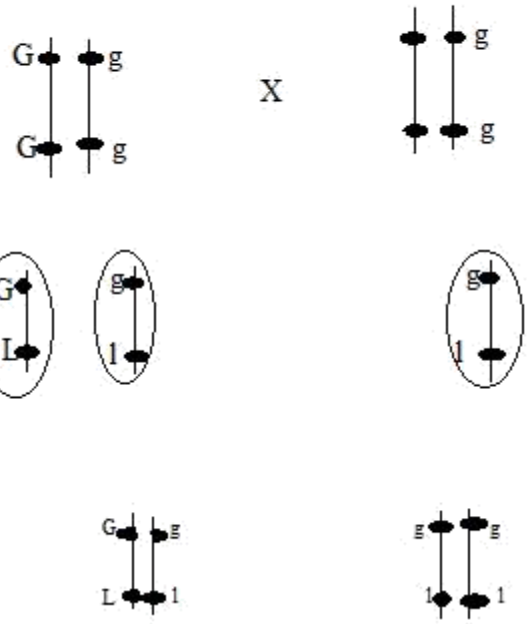
- ✓ This is because total linkage is rare. Instead approximately equal numbers of parental phenotypes are obtained with significantly few recombinant phenotypes also in approximately equal numbers.
- ✓ Two or more genes are said to be linked if recombinant phenotypes occur much less frequently than parental phenotypes.
- ✓ Total/ complete linkage is when the distance between linked genes is not sufficient to allow for successful crossing over.

Explanations;

- These results were explained by an *American scientist Thomas H. Morgan*. In a cross between a grey, long winged drosophila heterozygous for both traits with a black, vestigial winged drosophila (This is a test cross); Morgan predicted that in the normal Mendelian inheritance. Parental; phenotypes and recombinants would be obtained in a ratio of 1:1:1:1. If genes were completely linked, parental phenotypes would be obtained in a ratio of 1:1 as shown on the next page.
- To his disappointment; even after performing the test cross several times, Morgan never obtained the predicted outcomes.
- He instead obtained approximately equal numbers of the parental phenotypes with significantly few recombinant phenotypes also in approximately equal numbers as summarized below.

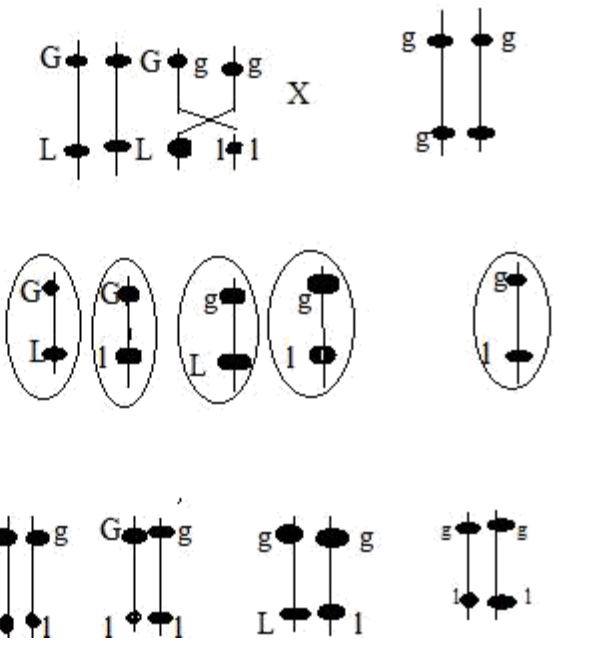
41.5% grey, long winged
41.5% black, vestigial winged
8.5% grey, vestigial winged
8.5% black, long winged

Parents : Male X Female
Phenotypes : Grey, long wings X Grey, long wings



- Morgan explained his results in terms of **crossing over**; the responsive genes are located on the same chromosomes; linked with the alleles of each gene on homologous chromosomes.
- Alleles were exchanged between homologous chromosomes during meiosis, leading to new gene combinations in gametes hence producing recombinant phenotypes; as shown below.

Parents : Male X Female
Phenotypes : Grey, long wings X Grey, long wings



Applications;

A homozygous purple-flowered short stemmed plant was crossed with a homozygous red-flowered long stemmed plant and all the F_1plants had purple flowers and short stems. When the F_1generation was taken through a test cross, the following progeny was produced

- 53 purple flowered short stemmed
- 47 purple flowered long stemmed
- 49Red flowered short stemmed
- 45 red flowered long stems. Explain the results fully.

CROSSING OVER AND CROSS OVER VALUES

- During crossing over, the frequency of crossovers which take place was found to be dependent on the distribution and arrangement of chromosomes.
- This is given by the cross over value/frequency aka recombination frequency. This is calculated as a percentage ratio of recombinants to the total number of offsprings.

$$C.O.V = \frac{Number\ of\ recombinants}{total\ number\ of\ offsprings} \times 100\%$$

Example;

Phenotype	**Number of offsprings**
Grey, long winged	965
Black, vestigial winged	944
Black, long winged	206
Grey, vestigial winged	185

C.OV = 17% following the above formula.

Note;

- The COV also indicates the relative distance between linked genes and the possibility of successful crossing over during meiosis, in the above case the distance between adjacent genes is 17 units.
- These values can also be used to position genes along the chromosome a process called gene mapping.

Application;

Consider the cross over values involving for different genes P, Q, R and S.
The distance separating these four genes is shown below;

P-Q = 24% R-S = 8%

R-P = 14% S-P = 6%

Draw the chromosome map to show the position of these chromosomes following the steps below;

a. Insert the positions of the genes with the smallest cross over value first in the middle of the chromosome map
b. Examine the next largest cross over value and insert both possible positions of its genes on the chromosomes relative to either S or P.

c. Repeat the procedure for the entire remaining cross over values until you reach the largest cross over values.

Application;

In maize, the genes for coloured seed and full seed are dominant to the genes for colourless and shrunken seed. Pure breeding strains of double dominant variety were crossed with a double recessive variety and a test cross of the f1 generation produced the following results;

Coloured full	380
Colourless shrunken	396
Coloured shrunken	14
Colourless full	10

Calculate the distance between the genes for coloured seed and seed shape

DEGREES OF DOMINANCE

- ✓ In the conventional Mendelian inheritance, each trait is controlled by a pair of alleles located at the same locus of homologous chromosomes, one dominant and the other recessive.
- ✓ In such cases, offsprings always resemble one or the other of the parents and phenotypes of the heterozygote and the dominant homozygote are indistinguishable. This condition is called **complete dominance.** Some traits however are controlled by alleles neither of which shows complete dominance or recessiveness over the other. Such alleles are either equally dominant; codominant or incompletely dominant.

INCOMPLETE DOMINANCE

This is when alleles fail to show complete dominance or recessiveness such that their phenotypes blend; mix to produce an intermediate in the heterozygote.

For example;

When red snapdragons are crossed with white snapdragon plants (*Antirrhinum);* all the F_1 hybrids have pink flowers, while F_2 hybrids produced 1 red: 2pink:1white plants As shown below;

Note:

Given that both alleles of the same gene are dominant, we let a single letter for the gene and alleles attached as superscripts. I.e. C^R and C^W or simply R and W represent alleles for red and white petals respectively.

The third phenotype results from flowers of the heterozygotes ($C^R C^W$ or simply RW) having less red pigment than the red homozygotes.

Let;

R represent the allele for red petals, W represents the allele for white petals

Parents	:	male	x	female
Phenotypes	:	Red petals	x	White petals
Genotypes	:	RR	x	WW
Meiosis				
Gametes		R R		W W
Random fertilization	:			
F_2 genotypes	:	RW RW		RW RW

F_1 phenotypes: all pink

Obtaining F_2

Let;

R represent the allele for red petals, W represents the allele for white petals

Parents : male x female

Phenotypes : Pink petals x Pink petals

Genotypes : RR x WW

Meiosis

Gametes : R W R W

Random fertilization :

F_2 genotypes : RR RW RW WW

Genotypic ratios: 1RR: 2RW: 1WW
Phenotypic ratios: 1 Red: 2pink: 1 White

More applications of incomplete dominance

Characteristic	**Allelomorphic characteristics**	**Heterozygous phenotype**
Mirabilis Japalla (4-oclock flower)	Red and White	Pink
Angora rabbit hair length	Long and short	Intermediate
Plumage colour in Andalusian fowls	Black and splashed white	Blue

CODOMINANCE

This is when alleles fail to show complete dominance or recessiveness such that their phenotypes are independently present in the heterozygote.

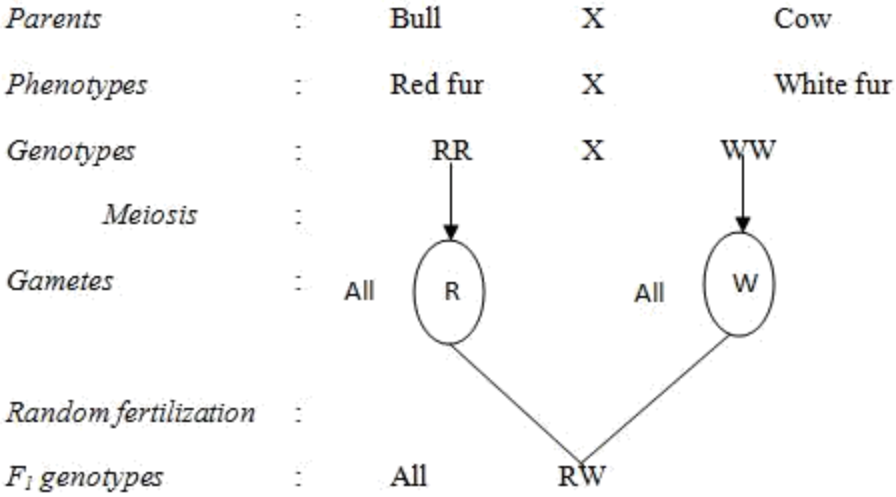
For example;

During the inheritance of fur/coat colour in short-horned cattle, when red and white cattle are mated, the F1 hybrid has white fur thickly interspersed with red fur. This phenotype is referred to as roan

This cross is illustrated below.

Let;

R represent allele for red fur, W represents allele for white fur



Other applications;

- ABO blood groups
- Sickle-cell trait

MULTIPLE ALLELES

- ✓ These are three or more forms of the same gene occurring at the same locus
- ✓ Most genes are known to occur in two alternative forms (allelic forms) located on the same locus of homologous chromosomes.
- ✓ Some genes are known to occur in more than two allelic forms called multiple alleles of which any two can occupy the gene locus in a diploid organism. This is easily noticed for the gene responsible for blood groups in man.

INHERITANCE OF BLOOD GROUPS

- × The gene for human blood group is known to occur in three allelomorphic forms; A, B and O. Alleles A and B are codominant while O is recessive to both.
- × This is known as the ABO blood grouping system, with three alleles producing six possible genotypes and four phenotypes.
- × In humans the inheritance of the ABO blood groups is determined by a gene, I, which has three different alleles. Any of these two can occur at a single locus at any time.
- Allele A causes the production of antigen A on red blood cells
- Allele B causes the production of antigen B on red blood cells
- Allele O causes no production of antigens on red blood cells

Blood group	Possible genotypes
A	I^AI^o, I^AI^A
B	I^BI^o, I^BI^B
AB	I^AI^B
O	I^OI^o

Application;
The father and a mother are known to be heterozygous for blood groups A and B. Show the possible genotypes of their children. If they bear non-identical twins, what is the probability that both twins are of blood group A.

Let;

A, B and o represent the alleles for blood groups A, B and O respectively

Parents	:	Father	x	Mother
Phenotypes	:	Blood group A	x	Blood group B
Genotypes	:	Ao	x	Bo
Meiosis				
Gametes		A, o		B, o
Random fertilization	:			
Offspring genotypes	:	AB, Ao, Bo, oo		

Offspring phenotypes: Blood groups AB, A, B and O
Probability for a child with blood group A = ¼
Probability for both twins with blood group A = ¼ * ¼ =1/16 = 0.0625
N.B some crosses can be done when the 'I' is ignored but preferably should be include when you are crossing.



Work out the possible blood groups of the offsprings produced if a man of blood group A marries a woman of blood group AB.
2. Suppose a man having blood group A marries a woman who is heterozygous for blood group B what are the possible genotype and phenotypes.
3. A boy has blood group A and his sister has blood group B. what are the possible phenotypes and genotypes of their parents.
4. If a father has blood group A and the mother blood group AB what are the possible genotypes and phenotypes of the offspring.

THE RHESUS BLOOD GROUP SYSTEM

- The rhesus blood group system is also inherited in a similar way to the ABO blood group system. Individuals with red blood cells with the D-antigens (Rhesus factor) are said to be rhesus positive (Rh+) while those without are called rhesus negative (Rh+). The allele for Rh+ allele is dominant over the one for rhesus negative (Rh-).
- If a Rh+ man marries a Rh- woman, most of their children are likely to die immediately after birth or before birth because the mother's immune system produces antibodies (anti-D agglutinins) which pass into the foetus and attack the antigens causing haemolyge/ red-blood cell breakdown that results into death.

- The first child usually survives because the time is too short for the mother to produce enough antibodies known as anti-D agglutinins which can pass to the foetus to cause death.

The problem may be solved in two major ways;

a. The mother may be injected with anti-D-agglutinins in the first 72 hours after her first born so as to make her immune system insensitive towards D-antigens.

b. By carrying out proper intermarriages where by Rh+ man marries Rh+ woman and Rh- woman gets married to Rh- man.

LETHAL GENES

- Genes are usually known to control a single pair of contrasting traits. Some genes may affect more than one characteristics including mortality. Such genes are responsible for some features necessary for survival but they are simultaneously responsible for lethal effects in the organisms and are therefore called lethal genes.
- An example is clearly illustrated in the inheritance of fur colour in mice. Wild mice are known to have grey coloured fur; a condition called agouti or yellow fur. A cross between two yellow mice produces yellow and agouti offsprings in a ratio of **2: 1** respectively.
- These results can be explained by the fact that allele for yellow fur is dominant over that for agouti and all living yellow mice are heterozygous for fur colour. The 2:1 ratio of phenotypes is due to the death of the yellow mice that are homozygous for fur colour before birth. This allele is therefore lethal in the homozygous condition.

Let;

Y represent the allele for yellow fur, y represents the allele for grey fur

Parents	:	Male	x	Female
Phenotypes	:	Yellow fur	x	Yellow fur
Genotypes	:	Yy	x	Yy
Meiosis				
Gametes		Y y		Y y
Random fertilization	:			
Offspring genotypes	:	YY Yy		Yy yy

The homozygous dominant mice die before birth producing a genotypic ratio of 2: 1 as the phenotypic ratio.

Examination of the uteri of yellow mice pregnant of yellow males revealed dead yellow mice; which are not revealed in yellow mice pregnant of agouti males.

Note:

- The allele for yellow fur is dominant for fur colour but recessive for mortality.
- It can therefore persist within the population over generations in heterozygous genotypes without phenotypic exposure to environmental elimination.

- Dominant lethal genes are very rare in a population because they are phenotypically expressed for elimination by environmental selective pressures.

THE GENE COMPLEX

- Many characteristics in plants and animals are produced by an interaction of several genes located on different loci; forming a gene complex.
- A single characteristic may be produced by the interaction of two or more genes occurring at different loci. A good example is shown by the inheritance of comb shape in domestic fowl
- In this case, two genes on different chromosomes (loci) interact to produce four distinct phenotypes of combs.
  - Pea and rose combs are each produced by presence of the dominant forms of their respective genes (P and R respectively) but in absence of the other dominant gene. The walnut and single combs are produced by the interaction of the genes at both loci as summarized below:

Name of comb	**Production**	**Possible genotypes**
Pea comb	Dominant allele P but without dominant allele R	PPrr, Pprr
Rose comb	Dominant allele R but without dominant allele P	ppRR, ppRr
Walnut comb	Dominant alleles for both P and R	PPRR, PpRR, PPRr, PpRr
Single comb	Only by homozygous double recessive condition	pprr

If pure breeding occurs;

Let; *P represent allele for pea comb, p for absence of pea comb*

R represent allele for rose comb, r for absence of rose comb

Parents	:	Male	X	Female
Phenotypes	:	Pea comb	X	Rose comb
Genotypes	:	PPrr	X	ppRR
Meiosis	:	↓		↓
Gametes	:	all Pr		all pR
Random fertilization	:			
F_1 genotypes	:	All PpRr		

All walnut combed

Selfing F_1

Parents : Male X Female

Phenotypes : Walnut comb X Walnut comb

Genotypes : PpRr X PpRr

Meiosis :

Gametes : PR Pr pR pr PR Pr pR pr

Random fertilization

	PR	Pr	pR	pr
PR	PPRR ●	PPRr ●	PpRR ●	PpRr ●
Pr	PPRr ●	PPrr ■	PpRr ●	Pprr ■
pR	PpRR ●	PpRr ●	ppRR ▲	ppRr ▲
pr	PpRp ●	Pprr ■	ppRr ▲	pprr ○

Phenotypic ratios: 9 walnut: 3Pea: 3rose: 1single

Application;

In poultry, the allele for white feathers (W) is dominant over the allele for black feathers (w). The alleles P, for pea comb and R, for rose comb produce their respective phenotypes. If they are present together, the comb shape is modified to walnut and if their recessive alleles are present in homozygous recessive condition, a single comb I produced. A cross between a black rose comb cock and a white walnut hen produced the following phenotypes:

3white walnut: 3black walnut: 3white rose: 3black rose: 1white pea: 1black pea: 1white single: 1black single.

Identify the possible parental genotypes and show clearly how they give rise to the above phenotypes.

EPISTASIS

- ✓ This is a form of gene interaction where one gene suppresses the effects of another gene at a different locus. The suppressing gene is referred to as an epistatic gene (inhibiting gene) while the suppressed gene is called a hypostatic gene.
- ✓ Fur color in mice depends on two non-allelic genes, the dominant form of one gene is responsible for coloured fur while its recessive form results into no colour deposition and the phenotype is white (albino).

- ✓ If colour is present, the nature is determined by another gene whose dominant allele produces grey fur (agouti) while the recessive allele produces black fur.
- ✓ Any of the two colours can be present only and only if their respective alleles are accompanied by the gene for coloured fur.
- ✓ Absence of this gene will result into albinos even if the genes for grey or white are present.
- ✓ This interaction produces three possible phenotypes as summarized below.

Phenotype	**Possible genotypes**
Grey (agouti)	AAGG, AAGg, AaGG, AaGg
Black	AAgg, Aagg
Albino (white)	aaGG, aaGg, aagg

Application;

In oat plants, the inheritance of color is controlled by the gene with two alleles, the dominant results into colour formation while the recessive results into no colour formation (white or albino). The other gene is responsible for the kind of colour, if present with the allele for grey being recessive to one for black.

Identify the nature of gene interaction and show the F_1 and F_2 outcomes starting with true breeding parental stocks.

Let; *A represent allele for colour, a for absence of colour*

B represent allele for black, b for grey

Parents : Male X Female

Phenotypes : Black X White

Genotypes : AABB X aabb

Meiosis :

Gametes : all AB all ab

Random fertilization :

F_1genotypes : All AaBb

F_1 phenotypes: All black

Obtaining F_2;

Parents	:	Male	X	Female
Phenotypes	:	Black oat	X	Black oat
Genotypes	:	BbAa	X	BbAa
Meiosis	:			
Gametes	:	BA Ba bA ba		BA Ba bA ba

Random fertilization

	BA	Ba	bA	ba
BA	BBAA	BBAa	BbAA	BbAb
Ba	BBAa	BBaa	BbAa	Bbaa
bA	BbAA	BbAa	bbAA	BBAa
ba	BbAa	Bbaa	bbAa	bbaa

INHERITANCE OF SEX AND SEX DETERMINATION

Did you know!

Some ancient Greeks thought that sex depends on the testicle from which the sperm comes, some European kings tied off or removed their left testes to ensure a male heir to the throne. Others believed that the sex depends on the phase of the moon during conception, wind direction or speaking certain words. Currently we know that sex is determined by sex chromosomes do you know it?

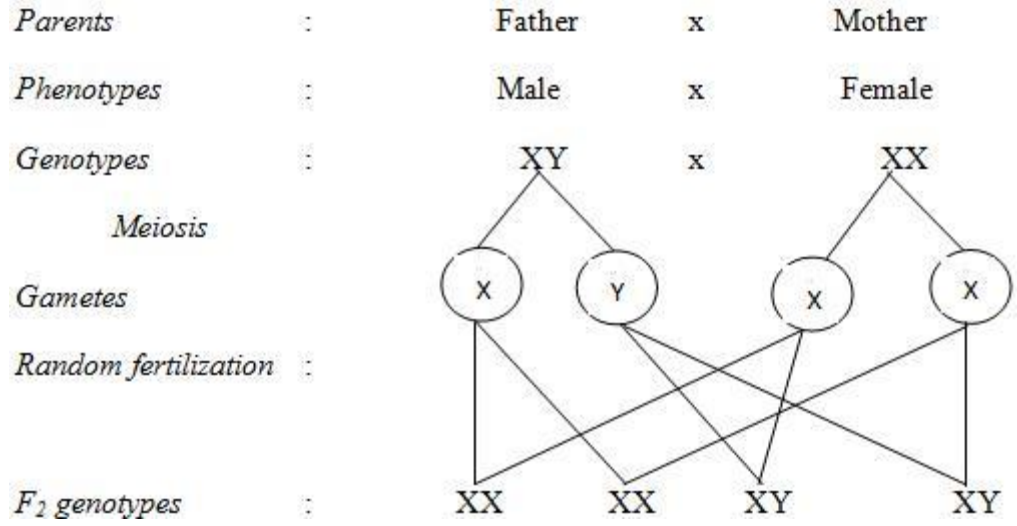
- In man, there are 23 pairs of chromosomes; of these only one pair carries genes for sex determination. These are called sex chromosomes; heterosomes designated X and Y, and the other 22 pairs are called autosomes and these are identical in both sexes.
- A genotype XX is described as homogametic and is female while XY is described as heterogametic and is a male. During meiosis, the two sex chromosome segregate such that each ovum carries one X chromosome, half of the sperms carry an X chromosome and the other half carry a Y chromosome.
- If a sperm carrying an X chromosome fuses with the ovum, the zygote is female and if the sperm is carrying a Y chromosome, the zygote is male.
- Sex is therefore determined by the sex chromosome carried in the sperm as a matter of chance.

- The Y chromosome determines maleness because it possesses several copies of a testicular differentiating gene, this codes gonads to become testis in its absence gonads develop into ovaries.
- This is called the X-Y system and occurs mainly in mammals with humans inclusive. The females are described as homogametic because all their gametes contain the same sex chromosome-the X chromosome while the males are heterogametic because 50% of the gametes produced contain an X chromosome and 50% contain a Y chromosome for sex.

Note;

1. In some animals like birds (including poultry), moths and butter flies, reptiles and some fish; the sex genotypes are reversed. The homogametic genotypes (XX) are male while the heterogametic genotype (XY) is female.
2. In some cases, the Y chromosome is completely absent and the heterogametic sex (XO) is male. This is the X-O system as in grass hoppers, cockroaches and some other insects. The sex of the offsprings is determined by whether the sperm cell contains an X chromosome or no sex chromosome. This implies that the Y chromosome does not carry genes needed for survival of the organisms.
3. In the fruit fly Drosophila, the female is XX and the male is XY; however the is not smaller like in humans but simply a different shape.
4. In some species of bees and ants, there are no sex chromosomes. Females develop from fertilized eggs and are thus diploid while males develop from unfertilized eggs and are haploid, without feathers.
5. Sex is primarily genetically determined as described above but in some lower animals, sex can be determined by environmental factors such as temperature, salinity, type of food etc. for example in some turtles the eggs laid in warm sand develop into females while those laid in cool sand develop into females.

Application;



Genotypic ratios: 1XX: 1XY
Phenotypic ratios: 1female: 1male
This shows that there is a 50% chance of any child being a male or female

Summary

- The sex chromosomes are called heterosomes because they are non-identical and are designated X and Y.
- The X chromosome is rod shaped and much bigger than the Y chromosome which is hook shaped.

- The Y chromosome carries genes responsible for secondary male sex characteristics, differentiation of testes and development of genital organs in humans.
- Actually in some organisms, the Y chromosome is absent and is believed not to carry genes necessary for survival of the organism and is described as genetically inert.

SEX LINKAGE

- In humans, there are several thousands of characteristics each genetically controlled. With only 23 pairs of chromosomes, each chromosome must therefore carry many genes; a phenomenon that does not exclude sex chromosomes. These in addition to genes responsible for sex differences may carry genes determining some other features in the body.
- Sex-linked genes are genes carried on sex chromosomes and inherited together with those determining sex.
- **Sex linked traits (characters)** are traits determined by genes carried on sex chromosomes and inherited together with those determining sex.

Note:

- The Y chromosomes don't carry genes, sex linked genes are specifically carried on the X sex chromosomes but not on the Y chromosome.

Some experiments carried out about sex linkage

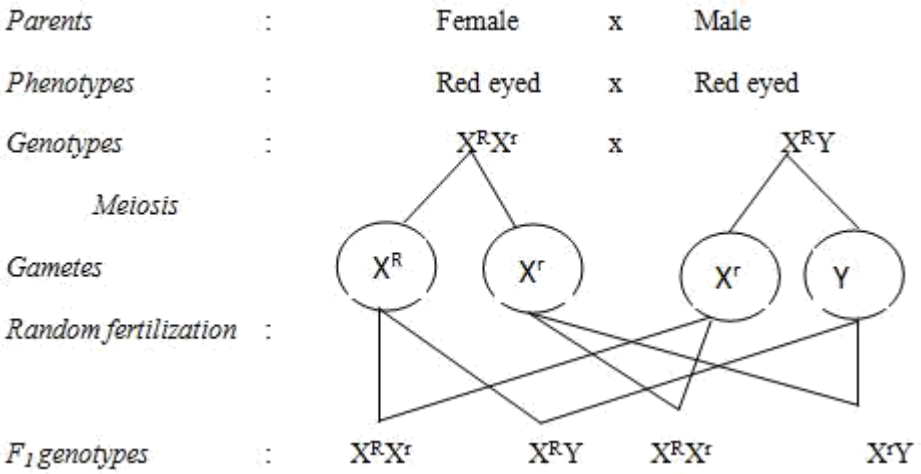
- Many experiments were carried out by Thomas Morgan about sex-linked genes in drosophila. In one of his experiment, Morgan mated a wild type (pure breeding) red-eyed female with a mutant (white eyed) male.
- All the F_1 hybrids were red eyed. He went on to interbreed the F_1 males and females to obtain an F_2 generation which consisted of red eyed and white eyed offsprings in a ratio of 3:1 respectively. However, all female were red eyed and all the white eyed flies were males though some males were red eyed.
- In conclusion, all the F_1 were red eyed; implying that this allele is dominant over that for white. Since in the F_2 all the white eyed were males, this indicates that the gene for eye colour is located on the X chromosome and there is no corresponding locus on the Y chromosome; otherwise some females would also be white eyed.

Let;

R represent the allele for red eyes, r represents the allele for white eyes

Parents	:	Female	x	Male
Phenotypes	:	Red eyed	x	White eyed
Genotypes	:	X^RX^R	x	X^rY
Meiosis				
Gametes		X^R		X^r , Y
Random fertilization	:			
F_1 genotypes	:	X^RX^r		X^RY

F2 generation;



Phenotypic ratios: 3 red eyed: 1 white eyed

Note that <u>all the white eyed are males</u> yet some red eyed are males

Sex linked characters

- Haemophilia
- Colour blindness
- Pre-mature balding
- Eye colour in drosophila



1. If the gene for eye colour was autosomal, predict the phenotypes of the F_2 hybrids (including sex) in this hypothetical cross. (Show your working).
   a. Perform a test cross on the F_1 female fly obtained in the above cross.
   b. What would be the phenotypes of the reciprocal cross between the original parents?
2. In drosophila, the genes for wing length and eye colour are sex-linked; with normal wings and red eyes being dominant to miniature wings and white eyes respectively.
   a. In a cross between a miniature-winged red eyed male and a homozygous normal wing white eyed female; explain the expected appearance of F_1 and F_2 generations.
   b. Crossing a female from the F_1 generation above with a miniature wing white eyed male gave the following results:

   Normal wing white eyed males and females = 35
   Normal wing red eyed males and females = 17
   Miniature wing red eyed males and females = 18
   Miniature wing white eyed males and females = 36

   Account for the appearance and numbers of the phenotypes listed above.

HAEMOPHILIA (BLEEDERS' DISEASE)

- Haemophilia is a recessive sex-linked blood disorder that leads to absence of one or more blood clotting factors, leading to prolonged bleeding even from minor cuts.
- Just like other sex-linked traits, haemophilia is carried on the X chromosome and the responsive allele is recessive to the normal allele. The condition interferes with formation of blood clotting factors; commonly factor VIII (Anti-Haemophiliac Globulin) whose absence greatly delays the blood clotting process. This results into prolonged bleeding and excess blood loss even from minor cuts which may lead to death.
- The allele being recessive, haemophiliac females must inherit two copies of the defective allele while males inherit one copy. The heterozygous females show normal blood clotting and are described as carriers. This is because the other X chromosome carries a dominant allele needed for normal blood clotting which suppresses the recessive allele for haemophilia.
- The males lack the alternative allele and the recessive allele is automatically expressed phenotypically.

Application;
A cross between a normal man and a carrier.

Let;

H represent the allele for normal blood clotting, h represents the allele for haemophilia

Parents	:	Female	x	Male
Phenotypes	:	Normal	x	Normal
Genotypes	:	X^HX^h	x	X^HY
Meiosis				
Gametes		X^H X^h		X^H Y
Random fertilization	:			
F_1 genotypes	:	X^HX^H X^HY X^HX^h X^hY		

Note;

1. There is a 50% chance of a daughter being a carrier and a 50% chance of a son being haemophiliac.
2. Sons can only inherit haemophilia (and other sex linked traits) from their mothers but not fathers as they only inherit the father's Y chromosome and not the X chromosome that carries sex linked genes.
3. Girls can inherit from both parents.

COLOUR BLINDNESS

- It is a recessive sex linked character that leads to inability of the individual to distinguish between colours.
- It is caused by a recessive allele, carried on the X chromosome and inherited in the same way as haemophilia.

- Colour vision is due to presence in the retina of red, blue and green cones needed for seeing the respective colours. The recessive alleles result into absence of some of these cones which renders inability to identify such colours from other related colours.
- This is results colour blindness; the commonest being red-green colour blindness where individuals lack red and green cones in their eyes.

Application;



Green colour blindness is sex linked in man. A normal man married a colour blind woman. Using suitable genetic symbols workout the genotypes and phenotypes of their children

REASONS WHY COLOUR BLIND INDIVIDUALS ARE MORE COMMON THAN HAEMOPHILIACS

- Colour blind individuals are more common in the population than haemophiliacs despite the two being inherited in the same way.
- This is because haemophilia is associated with many lethal effects due to excessive internal and external bleeding which increases chance of dying before reproductive maturity to pass on their genes to the next generations.
- Colour blindness exerts less lethal effects as colour vision is not much necessary for survival. Colour blind individuals usually survive to reproductive age and pass the allele to subsequent generations hence increasing the number of colour blind individuals in the population.
- Also haemophiliacs are advised to desist from reproducing as they may end up bleeding to death which further reduces the numbers of haemophiliacs.

REASONS WHY SEX LINKED CHARACTERS ARE COMMON IN MALES

- Being caused by recessive alleles, the other X chromosome in females may carry a dominant allele to mask the defective allele hence preventing its phenotypic expression in the population.
- In males however, these genes are carried on the non-homologous portion of the X chromosome for which there is no alternative gene on the Y chromosome. Such genes are automatically expressed in males leading to higher frequencies in males as compared to females.

SEX LIMITED CHARACTERISTICS

- Sex limited characters are characters that are more pronounced in one sex than the other.
- Though both sexes may carry genes responsible for these characteristics, pronounced expression is strictly limited to one of the two sexes. They are usually carried on autosomes but may largely be influenced by the level of sex hormone in the body.
- In males; Facial hair, deep voice, baldness etc in females Breasts, lactation, widening of hip bones, high pitched sound etc

PEDIGREE ANALYSIS

- Unable to manipulate the mating patterns of people, geneticists must analyze the results of mating that have already occurred.
- They do so by collecting information about a family's history for a particular trait and assembling this information into a family tree describing the traits of parents and children across the generations-the family pedigree.

Application 1;

- ❖ Fig a shows a three-generation pedigree that traces the occurrence of a pointed contour of the hairline on the forehead. This trait, called a widow's peak, is due to a dominant allele, W because the widow's peak allele is dominant; individuals who lack a widow's peak must be homozygous recessive *(ww)*.
- ❖ The two grandparents with widow's peaks must have the *Ww* genotype, since some of their offspring are homozygous recessive.
- ❖ The offspring in the second generation who *do* have widow's peaks must also be heterozygous, because they are the products of *Ww* x *ww* mating.
- ❖ The third generation in this pedigree consists of two sisters. The one who has a widow's peak could be either homozygous (WW) or heterozygous *(Ww)*, given what we know about the genotypes of her parents (both *Ww)*.

Application 2;

- → Figure b is a pedigree of the same family, but this time we focus on a recessive trait, attached earlobes.
- → We'll use *f* for the recessive allele and *F* for the dominant allele, which results in free earlobes.
- → As you work your way through the pedigree, notice once again that you can apply what you have learned about Mendelian inheritance to understand the genotypes shown for the family members.

Application 3;

- Transmission of haemophilia from queen Victoria
- **Check understanding biology page 167 fig. 9.3**

IMPORTANCE OF PEDIGREE ANALYSIS

- × An important application of a pedigree is to help us calculate the probability that a child will have a particular genotype and phenotype.

i. Suppose that the couple represented in the second generation of Figure. a decides to have one more child.

ii. What is the probability that the child will have a widow's peak? This is equivalent to a Mendelian fashion monohybrid cross *(Ww* x *Ww)*, and thus the probability that a child will inherit a dominant allele and have a widow's peak is ¾ (¼ WW + ½ Ww).

iii. What is the probability that the child will have attached earlobes? Again, we can treat this as a monohybrid cross *(Ff* x *Ff)*, but this time we want to know the chance that the offspring will be homozygous recessive *(.ff)*. That probability is ¼.

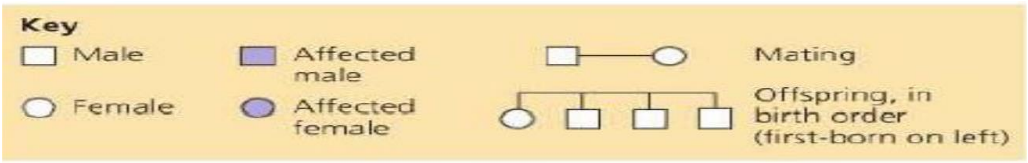
iv. Finally, what is the chance that the child will have a widow's peak *and* attached earlobes? Assuming that the genes for these two characters are on different chromosomes, the two pairs of alleles will assort independently in this Dihybrid cross *(WwFf* x *WwFf)*.

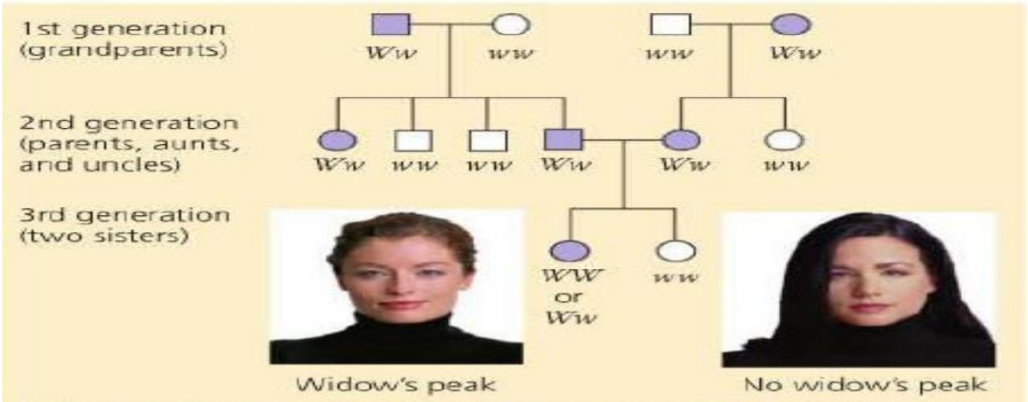
v. Thus, we can use the multiplication rule: ¾ (chance of widow's peak) x ¼ (chance of attached earlobes) = 3/16 (chance of widow's peak and attached earlobes).

Note;

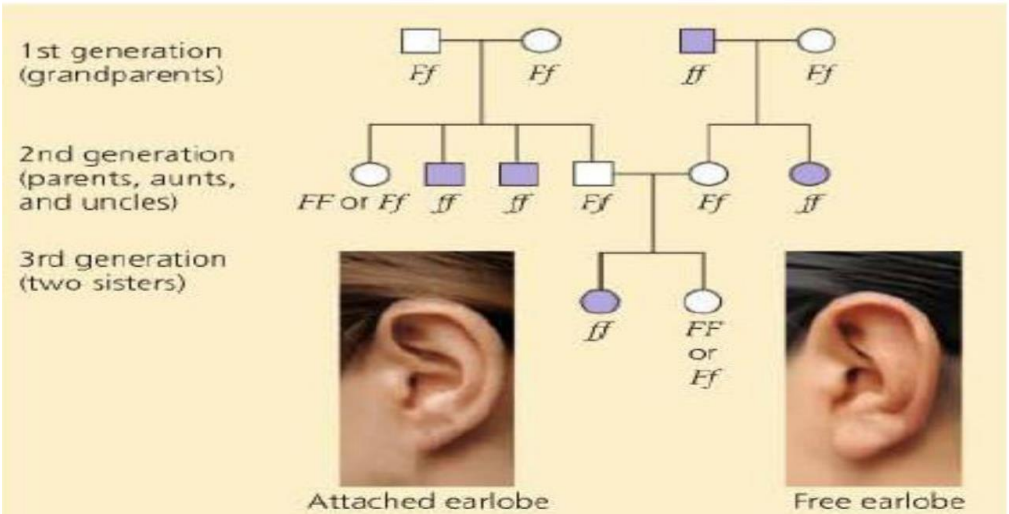
- ✓ Pedigrees are a more serious matter when the alleles in question cause disabling or deadly diseases instead of innocuous human variations such as

hairline or earlobe configuration. However, for disorders inherited as simple Mendelian traits, the same techniques of pedigree analysis apply.





(a) Is a widow's peak a dominant or recessive trait?
Tips for pedigree analysis: Notice in the third generation that the second-born daughter lacks a widow's peak, although both of her parents had the trait. Such a pattern of inheritance supports the hypothesis that the trait is due to a dominant allele. If the trait were due to a *recessive* allele, and both parents had the recessive phenotype, then *all* of their offspring would also have the recessive phenotype.



(b) Is an attached earlobe a dominant or recessive trait?
Tips for pedigree analysis: Notice that the first-born daughter in the third generation has attached earlobes, although both of her parents lack that trait (they have free earlobes). Such a pattern is easily explained if the attached-lobe phenotype is due to a recessive allele. If it were due to a *dominant* allele, then at least one parent would also have had the trait.



It's now your turn to try out these questions!

1. Mercy and Joseph each have a sibling with cystic fibrosis, but neither Mercy nor Joseph nor do any of their parents have the disease. Calculate the probability that if this couple has a child, the child will have cystic fibrosis.
   What would be the probability if a test revealed that Joseph is a carrier but Mercy is not?
2. Joan was born with six toes on each foot, a dominant trait called polydactyl. Two of her five siblings and her mother, but not her father, also has extra digits. What is Joan's genotype for the number-of-digit character? Explain your answer. Use D and d to symbolize the alleles for this character.
   What would you suspect if Peter was born with polydactyl, but neither of his biological parents had extra digits?
3. Incomplete dominance and epistasis are both terms that define genetic relationships. What is the most basic distinction between these terms? In detail
4. If a man with type AB blood marries a woman with type 0 blood, what blood types would you expect in their children?
5. A rooster with gray feathers is mated with a hen of the same phenotype. Among their offspring, 15 chicks are gray, 6 are black, and 8 are white. What is the simplest explanation for the inheritance of these colors in chickens? What phenotypes would you expect in the offspring of a cross between a gray rooster and a black hen?
6. A white-eyed female Drosophila is mated with a red eyed (wild-type) male, the reciprocal cross of the one shown in Figure 15.4. What phenotypes and genotypes do you predict for the offspring?
7. Genes A, B, and C are located on the same chromosome. Testcrosses show that the recombination frequency between A and B is 28% and between A and C is 12%. Can you determine the linear order of these genes? Explain.

VARIATION

After having a background of genetics, there is need for us to see how your genetics can cause the difference in individuals of the same or different species and this is what we call variation.
Variation; these are differences that exist in living organisms as a result of their **genotypes** or **the environment**.

TYPES OF VARIATION

There are two types of variation that exist; continuous and discontinuous variation.

CONTINUOUS VARIATION

This is a type of variation in which organisms do not fall into distinct categories/ there are no clear cut differences but there are gradations from one extreme to another.

- This shows clear gradation of characteristics from one extreme to another via intermediates. It is under the control of both the genotype and the environment therefore it is important in bringing about changes that are used in evolution.
- Examples of continuous variations include weight, height, skin colour, intelligence in humans and milk, beef, and egg yields in animals etc. it is under

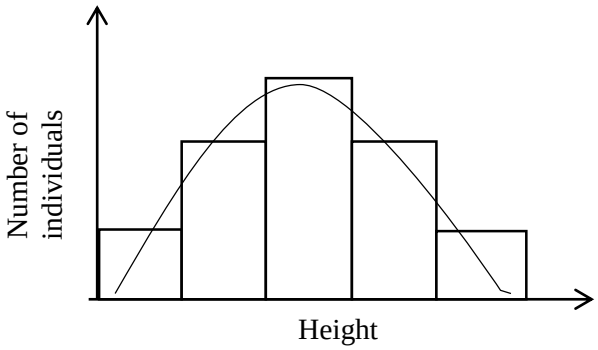
the control of many genes which act in an additive fashion. If for example a sample of 100 men is taken, it is difficult to find that they are of the same weight but their weights vary very light ones through intermediates to the very heavy ones.

- If a graph is to be plotted, their weights give a normal distribution curve which is always ell shaped.

Note:

1. Characteristics which show continuous variation are controlled by a combined number effect of a number of genes called polygenes thus called polygenic characters.
2. The effect of an individual gene is small, but their combined effect is marked.
3. For examples; where a group of genes all favouring development of a tall individual combine, a very tall individual results and the same applies to very short individuals.
4. However these extremes are rare as an individual probably will possess genes from both extremes and thus the combined effect of these genes produces an intermediate effect

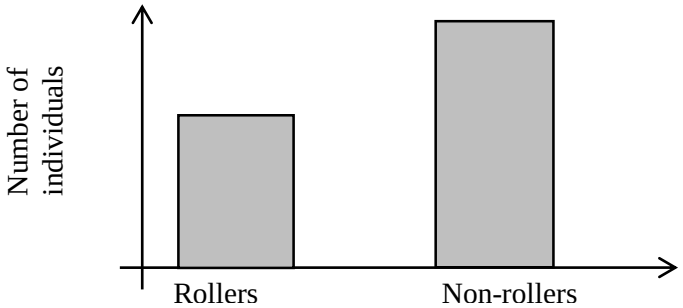
Illustration of continuous variation based on height.



DISCONTINUOUS/ DISCRETE VARIATION

This a type of variation where characters of organisms fall into distinct categories/ there is a clear cut difference in characters of organisms

- ✓ Characters like blood group, tongue rolling, sex and heights of plants are discontinuous traits. Individuals with such characteristics can be put into two distinct groups with clear cut out differences without intermediates being represented.
- ✓ Such characteristics are under the control of a few genes and only determined by the genotypes without the interplay of the environment.
- ✓ As an example, a graph of tongue rollers and non-rollers gives two separate groups.
- ✓ Features exhibiting discontinuous variation are normally represented on histograms, bar graphs or pie charts.



VARIATIONS DUE TO THE ENVIRONMENT

- ✓ It should be noted that however variations due to the environment cannot be passed from one generation to another and thus we can draw a conclusion that they are individual based and temporary depending on the environment a given organism lives in.

Environmental factors that cause variation include;

- Temperature
- Light intensity
- Food/ diet
- Exercise
- Water level etc. many factors around you can cause variation!

Effects of the environment

- × It should be noted that the final appearance of an organism is dependent upon the action of the environment on its genotype.
- × If organisms of identical genotype are subject to different environmental influences, they show considerable variety.
- × For example if one of a pair of genetically identical plants is grown in a soil deficient in nitrogen, it will not attain the height of the other plant grown in a nitrogen rich soil.
- × Due to the variety in environmental influences, they bring about gradations that are a basis for continuous variation within a population.

MUTATIONS

- These are any changes that occur in the structure or amount of DNA of an organism.
- Most of the mutations occur in somatic cells are thus not passed from one generation to another.
- Only those mutations that occur in the formation of gametes can be inherited such mutations produce sudden and distinct differences between individuals and are thus a basis for discontinuous variation.

Causes of mutations

- ❖ Mutations occur continually. It maybe natural mutation for example organisms with shorter life cycles have more frequent meiosis and thus show greater mutation.
- ❖ Mutation rate can be increased artificially by certain chemicals or energy sources.
- ❖ Any substance that induces mutation is called a **mutagen**

Examples of mutagens;

- Ultra- violet radiations
- x- Rays
- Gamma rays
- High energy particles; α and ß particles and neurons.
- Colchicine; inhibits spindle formation and thus causes polyploidy
- Formaldehyde
- Nitrous acid
- Mustard gas

CHANGES IN GENE STRUCTURE/ POINT MUTATION

- ✓ These are changes that occur at a single locus on a chromosome.
- ✓ As noted earlier, a genetic code which determines the characteristics of an organism is made of a sequence of nucleotides on the DNA.
- ✓ Any change to one or more of the nucleotides or any rearrangement of the nucleotides, will produce the wrong amino acids in the protein it makes. This may have profound effect on the organism.
- ✓ For example albinism as we saw earlier.

Forms of gene mutation

1. Duplication; in this a portion of a nucleotide chain becomes repeated
2. Addition/ insertion; in this an extra nucleotide sequence becomes inserted into the chain.
3. Deletion; in this a portion of the nucleotide chain is removed from the sequence.
4. Inversion; in this a portion of a nucleotide sequence becomes separated from the chain. It rejoins in its original position, but it is inverted.
5. The nucleotide sequence is thereby reversed.
6. Substitution; in this one of the nucleotides is replaced by another which has a different organic base.

 Illustrate the above mutations using either alphabetical letter or counting numbers.

Note;

However it should be noted that the mutations don't inhibit protein synthesis; it occurs but of a wrong protein.

Just imagine! Come for lunch at noon today

- ➢ Lunch come for noon today
- ➢ Noon for lunch at come
- ➢ Today for lunch come noon; you understand that I meant the message but not in the way it is intended.

CHANGES IN WHOLE SETS OF CHROMOSOME

1. **Polyploidy;** this occurs when there is an additional whole set of chromosomes. For example instead of having a haploid set in the sex cells and a diploid set in body cells there are complete sets. Polyploidy maybe;

- ✓ Triploidy; this occurs when there are three sets of chromosomes present.
- ✓ Tetraploidy; this occurs when there are four sets of chromosomes present.

2. **Autopolyploidy**; this is a type of polyploidy that occurs within the same species. In this the number of chromosomes is always an exact multiple of its haploid number. It can be induced by colchicine for genetic engineering.
3. **Allopolyploidy; formation of Hybrids**;
   This is a type of polyploid that occurs between different organisms.

- × Hybrids; these are organisms obtained after combining sets of chromosomes from species with different chromosome numbers.
- × These hybrids are ordinarily sterile because the total number of chromosomes does not allow full homologous pairing to occur.
- × However if the hybrid has a chromosome number that is a multiple of the original chromosome number, it can produce a new fertile species.

Application; Present day wheat;

- The basic haploid number of wild grasses is seven. A tetraploid with 28 chromosomes (emmer wheat) was accidentally cross fertilized with a wild grass with 14 chromosomes.
- The resultant wheat had 42 chromosomes and the main cultivated wheat today.
- It is fertile because its chromosome number is a multiple of the original haploid number 7.

REASONS WHY POLYLOIDY IS RARE IN ANIMALS

→ It is so because animals' sex determination involves a number of chromosomes; if polyploid occurred it would interfere with this, an animal progeny with multiple sex chromosomes wouldn't be able to reproduce more of its kind unless it can reproduce asexually.

→ In plants however; since reproduction by vegetative propagation is possible polyploids can be produced and as well polyploids is any way are rendered an advantage by the environmental selection pressures as they are more resistant to climatic changes among other .

CHANGES IN CHROMOSOME NUMBER

This occurs when an individual chromosome fails to separate during anaphase

- For example; in humans one of the 23 pairs of homologous chromosomes fails to segregate during meiosis one of the gametes produced will contain 22 chromosomes and the other 24 chromosomes rather than 23 each.
- Such occurs due to non- disjunction.

Terms used;

- ✓ Aneuploidy; this is an abnormal condition where one or more chromosomes of a normal set of chromosomes are missing or present in more than usual numbers.
- ✓ Monoploidy; this is the loss of an entire set of chromosomes.
- ✓ Euploidy; this where an entire set of chromosomes is duplicated once or more times.

Different conditions of aneuploidy;

1. Nullisomy; the loss of both pairs of homologous chromosomes; individuals are called nullisomics and their chromosomal composition is 2N-2
2. Monosomy; the loss of a single chromosome; individuals are called monosomics and their chromosomal composition is 2N-1
3. Trisomy; the gain of an extra copy of a chromosome; the individuals are called trisomics and their chromosomal composition is 2N+1.
4. Tetrasomic; the gain of an extra pair of homologous chromosomes; individuals are called tetrasomics and their chromosomal composition is 2N+2

Conditions that result from non- disjunction

a. Down's syndrome/ mongolism;

In this case the 21st chromosome fails to segregate and the gamete produced possesses 24 chromosomes; fusion results into trisomy.
In this the 21st chromosome is relatively small and the offspring survives; does not cause fetal death. Children produced have a number of disabilities;

Symptoms of Down's syndrome

Mental impairment	Undescended testicles
Stunted growth	Protruding tongue
Increased skin on the back of the neck	Short neck
Flat head	Shortened hands
Flattened nose	Slanted eyes

b. **Klinefelter's syndrome**;

This results from non-disjunction of the sex chromosomes.
This may result into individuals who have the genetic constitution XXY, XXXY or XXXXY. Symptoms;

- ✓ These individuals are phenotypically male
- ✓ Have small testes and no sperm in the ejaculate.
- ✓ Abnormal breast development and body proportions are generally female.
- ✓ Weaker muscles
- ✓ Greater height
- ✓ Less body hair
- ✓ Less interest in sex

c. **Turner's syndrome**;

This also occurs on the sex chromosomes and in this an individual has a missing X chromosome.
Their genetic constitution is therefore due to Monosomy (XO). Individuals with this condition rarely survive at pregnancy.
Those that survive are phenotypically female, but small in stature and sexually immature.

CHANGES IN CHROMOSOME STRUCTURE

- During meiosis; it is normal for homologous chromosomes to form chiasmata.
- The chromatids break at these points and rejoin with the corresponding portion of the chromatid on its homologous partner; in this mistakes that arise result into serious mutations;

1. **Deletion**; in this a portion of a chromosome is lost. As this involves the loss of genes, it is lethal.
2. **Inversion;** in this a portion of chromosomes becomes deleted, but becomes reattached in an inverted position. The sequence of genes is therefore reversed. The overall genotype is not changed but the phenotype maybe altered.
3. **Translocation**; a portion of chromosome becomes deleted and rejoins at a different point on the same chromosome or with a different chromosome.
4. **Duplication**; in this a portion of chromosomes is doubled, resulting into repetition of a gene sequence.


Make illustrations of the above muations

Or Check in undersatnding biology fig 10.10 page 192

SOME OTHER GENETIC DISORDERS

1. PHENYLKETONURIA (PKU)

- This is a genetic condition that results from an amino acid called phenylalanine building up in the body.
- PKU results from a defect in the gene that is responsible for creation of phenylalanine hydroxylase.
- Phenylalanine hydroxylase is an enzyme that catalyses the conversion of phenylalanine to tyrosine which the body uses to create neurotransmitters such as epinephrine, norepinephrine and dopamine.

- Absence of this enzyme means there is no breakdown of phenylalanine and thus it accumulates.

  Symptoms;
  - Seizures; sudden, uncontrolled brain disturbance.
  - Tremors or trembling and shaking
  - Stunted growth
  - Hyperactivity
  - Skin conditions such as eczema
  - A musty odor of the breath, skin or urine.

2. BLUE BABY SYNDROME

- This is a condition in which a baby is born with or has skin characterized by a blue or purple tinge.
- The bluish appearance is most noticeable at parts where the skin is thin e.g the lips, earlobes and nail beds.

Causes;

- ✓ Can occur at birth due to congenital heart defects, it maybe environmental or due to genetic factors

Note;

- ❖ The baby takes on a bluish hue because of poorly oxygenated blood. Normally; blood is pumped by the heart to the lungs where it receives oxygen.
- ❖ When there is a problem with the heart, lungs or blood, blood may not be oxygenated properly. This causes the skin to take on a blue color. This may be due to;
- Heart defects such as having a hole in the wall that separates the left and right ventricles of the heart and a muscle obstructing the flow of blood from the right ventricle into the pulmonary artery.
- From nitrate poisoning, which occurs if babies are fed on nitrate rich foods.
- Since the gastrointestinal tracts are under developed, there are higher chances of them converting nitrate into nitrite.
- As nitrites circulate in the body, it produces an oxygen rich compound methamoglobin which doesn't release oxygen into the blood stream despite of its richness.

3. ERYTHROBLASTOSIS FOETALIS

- ➢ This known as the hemolytic disease of the new born.
- ➢ There are two main causes of Erythroblastosis foetalis; Rhesus incompatibility and ABO incompatibility which are all associated with blood type.
- ➢ Rhesus incompatibility occurs when a rhesus negative mother is impregnated by a rhesus positive father details discussed earlier on page 290

Symptoms;

- ✓ Swollen and pale jaundiced body
- ✓ Anemia or low red blood cell count
- ✓ Fluid accumulation in the abdomen, heart and lungs.

POPULATION GENETICS

- Population genetics is the branch of biology that deals and provides the mathematical structure for the study of micro evolutionary process.

- **Microevolution** refers to the change in one gene pool or the allele frequencies that occur within a population over time. Mainly due to mutations, genetic drift, gene flow, selection (natural and artificial), gene flow for example industrial melanism, microevolution of resistance to antibiotics, pesticides etc.

- **Macroevolution** refers to speciation or evolutionary changes at a level higher than the species level, resulting into formation of a higher taxonomic group such as class or genus.
- Each organism's combination of traits affects its survival and reproductive success compared to other individuals; it's only those individuals that can reproduce successfully before death that contribute to the future species. But the evolutionary impact of natural selection is only apparent in the changes in a population of organisms over time, for this reason; **though individual** organisms are acted upon by natural selection, its populations that evolve but not individuals.
- The population is the smallest unit of evolution. In theory an individual in a population is capable of breeding with any other. Due to this therefore the genes of a population are interchangeable.

TERM USED IN POPULATION GENETICS

1. **A population**: It is group of organisms of the same species occupying a particular area at a given time.
2. **A Species**: It is a group of organisms which share common characteristics that sexually reproducing are capable of interbreeding to produce fertile offspring.
3. **Deme**: Is a small isolated (localized) group of organisms that are capable of interbreeding to produce fertile offspring. It consists of its own distinct gene pool.
4. **A gene pool:** It is the total number of genes and their corresponding alleles present in an actively interbreeding population.
5. **Gene frequency / Allele frequency:** It is the number of a given allele in a population relative to the total number of alleles at the same gene locus.
   OR: It is the ratio of the number of a specified alleles in a population to the total of all alleles at its genetic locus
6. **Genotype frequency**: It is the number of individuals with a given **genotype** relative to the total number of individuals in the population.
7. **Phenotype frequency**: It is the number of individuals that have a specific observable trait (phenotype) relative to the total number of individuals in the population.
8. **Genetic drift:** It is the change in the frequency of a given allele / gene in a small population as a result of chance rather than natural selection. A gene may drift to a lower frequency or higher frequency.
   For example; premature accidental death of an organism in a small population may lead to the loss of the sole possessor of the allele.

9. **Genetic death:** It is the removal / elimination of a gene from a gene pool of population as a result of natural infertility, failure to reproduce or death before sexual maturity of all individuals carrying that gene.
   Presence of infertile males (genotypes) can lead to genetic death, or death in the struggle to mate.

10. **Genetic load:** It is the accumulation of disadvantageous / deleterious alleles within a population due to their existence in heterozygous condition. This offers such alleles a heterozygote advantage and are not exposed to natural selection. For example; the allele that causes ***sickle cell anaemia*** and the ***sickle cell trait***.

The mathematical relationship between the frequencies of alleles and genotypes in populations was developed by Hardy and Weinberg. The relationship is therefore known as the '***Hardy-Weinberg principle***'.

HARDY-WEINBERG PRINCIPLE

This principle was put forward by G. H. Hardy in Britain and W. Weinberg in Germany in 1908.
It states that "The allele and genotype frequencies in a population will remain constant from generation to generation in absence of other disruptive (evolutionary) influences".
OR
"In a large, random-mating population that is not affected by the evolutionary processes of mutation, migration, or selection, both the allele frequencies and the genotype frequencies remain constant from generation to generation**".**
For this principle to hold true, the following must be fulfilled:

- No mutation
- Large size of population
- Random mating
- No migration (No gene flow)
- No selection
- All genotypes equally fertile.
- Generations do not overlap

Disruptive influences include

- Mutation
- Small population size
- Nonrandom mating
- Migration (gene flow)
- Selection
- Infertile genotypes
- Generation overlap

HOW DISRUPTIVE INFLUENCES AFFECT GENETIC EQUILIBRIUM

1. **Mutation:**

✓ It leads to change in DNA structure and introduces new alleles or may lead to loss of some alleles. This results in increase in overall number of alleles and hence a decrease in the frequency of a certain allele.

2. **Small population size:**

- ✓ Small sized population are affected by genetic drift. For example premature accidental death of the sole possessor of an allele can lead to total loss of a given allele or reduction in its frequency.
- ✓ However, a gene may drift to a higher frequency if it is favored by the environment, survive and reproduce and increase in numbers of individuals with it. In a large population, chance events are insignificant.

3. **Nonrandom mating:**

- ✓ It occurs when the **probability** that two individuals in a population will mate is not the same for all possible pairs of individuals.
- ✓ If either the males or the females show strong preferences during the mate-selection and/or the mating process, then only certain genotypes will get to pass on their genes to the next generation. The genotype frequencies will be different in each generation.
- ✓ When the **probability** is the same, then individuals are just as likely to mate with distant relatives as with close relatives -- this is **random mating**.

4. **Natural selection**

- ✓ Natural selection differentially removes certain genotypes from a population and thus increases the frequency of certain alleles in the next generation.

5. **Migration (gene flow)**

- ✓ Through immigration or emigration of individuals into or out of a population, it leads to exchange of genotypes between populations which acts to reduce or increase genetic variety of a population. This causes the frequency of a particular genotype to change.

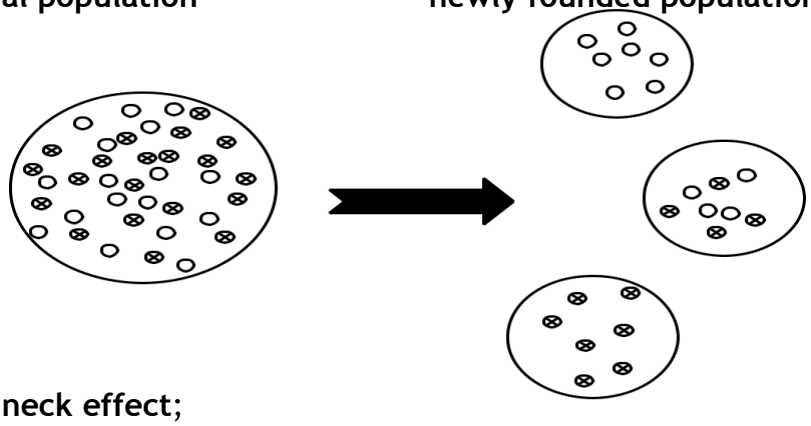
6. **Natural selection:** Natural selection differentially removes certain genotypes from a population and thus increases the frequency of certain alleles in the next generation.
7. **Generation overlap**: In a population with overlapping generations, where adults reproduce over multiple breeding seasons, the changes in genetic variation due to genetic drift have shown to be twice as great as opposed to one with non-overlapping generations. This leads to increased change in frequency of a particular allele or genotype.
8. **Infertile genotypes.** The presence of some infertile individuals within a population prevents some genes from being passed on to the next generation through sexual reproduction. This results in genetic death.
9. 10. **Genetic drift:**

This refers to the change in the gene frequencies within a population as a result of chance rather than by natural selection. Although chance events occur in populations of all sizes, they alter allele frequencies substantially only in small populations.

Founder effect. A small population may become isolated from a large population and it may not be truly representative of the original population in terms of allele and genotype frequencies.

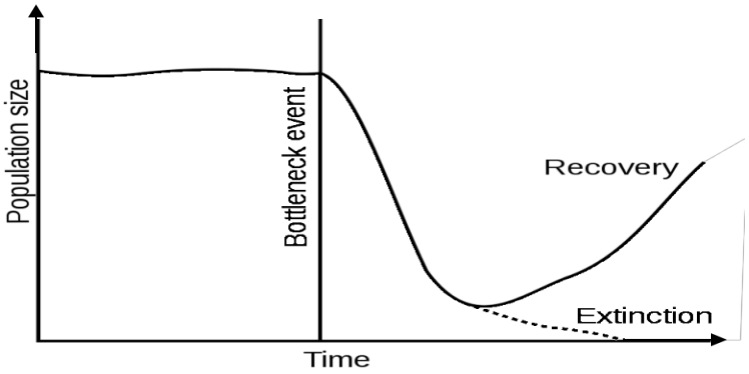
- × Some alleles may be absent while others may be disproportionally represented. Continuous breeding within the pioneer population will produce a gene pool with allele frequencies different from that of the original parent population; this is known as the founder effect.

Original population **newly founded populations**



Bottle neck effect;

- In the same way, a sudden change in the environment, such as a fire or flood may drastically reduce the size of a population, just by chance, certain alleles may be overrepresented among the survivors, others may be underrepresented, and some may be absent altogether.
- Ongoing genetic drift is likely to bring about changes in the allele frequencies of the population and may result into a gene pool that is different from the original population. This is referred to as the ***bottleneck effect***.



Comparison between Founder effects and Bottleneck effects

Similarities:

- Both are followed by genetic drift which results in changes in allele frequencies.
- In both, there is loss in genetic variation / diversity.
- Both involve a small number of individuals breeding with each other.
- In both, the alleles in the new population is not a true representation of the original group.
- Both may involve inbreeding among close relatives.

Founder effects	Bottleneck effects
Founder establishes a subpopulation as a new colony drawn from a larger Population.	Subpopulation caused when a natural disaster reduces the size of an original Large population.
Result of migration.	Result of habitat fragmentation and / or Over exploitation of the species.
Individuals are ecologically separated / Isolated, reducing the choice of mates.	Individuals are killed, reducing the Choice of mates.

NOTE:

- Whereas genetic drift may lead to a reduction in variation within a population it can increase variation within the species as a whole. Small isolated populations may develop characteristics unusual of the main population which may have a selective advantage if the environment changes.
- In this way genetic drift can contribute to the process of speciation.

APPLICATION OF THE HARDY WEINBURG PRINCIPLE

If we want to determine the frequency of a given genotype in a population, we can make use of the Hardy – Weinberg formula / equation.

The Hardy – Weinberg equation

According to this equation:

p = the frequency of the dominant allele (represented here by ***A***)

q = the frequency of the recessive allele (represented here by ***a***)

For a population in genetic equilibrium:

$$p + q = 1.0$$

(The sum of the frequencies of both alleles is 100% or 1.0.)

Individuals in the population will be either homozygous for the dominant allele (**AA**), homozygous recessive (**aa**) or heterozygous (**Aa**).

The frequency of these different genotypes within a population in any given generation will be determined by the way the gametes fuse.

Gametes	**A** p	**a** q
A p	**AA** p^2	**Aa** pq
a q	**Aa** pq	**aa** q^2

Or

$$(p + q)^2 = 1$$

So

$$p^2 + 2pq + q^2 = 1.0$$

The three terms of this binomial expansion indicate the frequencies of the three genotypes:

p^2 = frequency of *AA* (homozygous dominant)
$2pq$ = frequency of *Aa* (heterozygous)
q^2 = frequency of *aa* (homozygous recessive)

Applications;

1. Tongue rolling is caused by a dominant autosomal allele. Suppose that in a certain population, 84% of people can roll their tongue whereas others cannot. Using the Hardy – Weinberg formula, determine how many people are heterozygous for tongue rolling.

SOLUTION;

Frequency of non-rollers = 100% – 84% = 16%

So $q^2 = 0.16$

Therefore $q = \sqrt{0.16}$

$= 0.4$

But $p + q = 1.0$

Therefore $p = 1.0 - 0.4$

$= \mathbf{0.6}$

So $2pq = 2 \times 0.6 \times 0.4$

$= \mathbf{0.48}$

Hence the percentage of heterozygous individuals will be 48%. The percentage of individuals homozygous for the dominant allele = (84% - 48%) = 36%. Or $\mathbf{p^2} = 0.6^2 = 0.36$ or 36%.

2. In a population of 200 plants 128 are homozygous tall, 64 are heterozygous tall and 8 are dwarf.
   i) Using suitable symbols, state the genotype of all the plants
   ii) Calculate the allele frequency of t and T
   iii) Calculate the genotype frequency
3. In a Caucasian population, the frequency of individuals affected by cystic fibrosis is approximately 1 in 2500. This is a recessive disorder and affected individuals are homozygotes. If q represents allele frequency of the disease, find the frequency of the carrier genotype.
4. In a human population the gene responsible for tongue rolling is dominant over the gene for non-tongue rollers. The population of tongue roller is 84% and non-tongue roller is 16%. Find the percentage of individuals, who are,
   i) Homozygous for tongue rolling
   ii) Heterozygous for tongue rolling

5. In maize plant, the gene for tallness is dominant over shortness. If in a population of 800 seedlings, 560 maize seedlings are tall. Determine the
   I. Frequency of the dominant and recessive allele.
   II. Number of seedlings heterozygous for the gene.

6. The beak color of finches has a complete dominance relationship where black beaks are dominant over yellow beaks. There are 210 individuals with the genotype **DD**, 245 individuals with the genotype **Dd** and 45 individuals with the genotype **dd**. Find the frequency of the dominant and recessive alleles and the frequency of individuals with dominant, heterozygous, and recessive traits.

7. 1 person in 100000 is albino

What frequency is heterozygous for albino trait?

EVOLUTION

- This is a gradual developmental process by which a new species is formed from the pre-existing one over a period of time. Therefore evolution is a continuous change from simple to complex organisms.
- Individuals do not evolve/change. A population is the smallest group that evolves.
- But how then did the first primitive organisms arise and from where? A question you are asking yourself! To answer the question, many biologists have tried to put up theories to explain the origin of life.

THEORIES OF ORIGIN OF LIFE

They are uncertain and include;

- Special creation theory
- Spontaneous theory/ abiogenesis
- Cosmozoan theory/ panspermia
- Steady state theory
- Biochemical theory/ biogenesis

Detail;

1. Special creation theory:

- ✓ Suggests that life was created by a super natural being with super natural powers called God at a particular time in the past and this has been greatly supported by religion and civilization.
- ✓ One of the proponents of this theory archbishop Ussher in 1650AD added figures of ages of all the people in the biblical generations from Adam to Jesus and concluded that God had created the earth in October 4004BC.
- ✓ The theory has only one criticism; special creation occurred only once therefore cannot be observed yet all scientific knowledge must be experimentally proven.

2. Steady state theory:

- ✓ Suggests that the earth had no origin, has always been able to support life, has changed remarkably little if at all and all species had no origin. It asserts that earth has always existed, species too never originated, they have always existed and in history of species, the only alternatives are numbers to vary or it to become extinct.
- ✓ Critics of the theory say that it does not believe in paleontologists.

3. Spontaneous generation theory/ abiogenesis.

- ✓ Suggested that life arose from nonliving matter on numerous occasions.
- ✓ Aristotle believed that life arose spontaneously and assumed that certain particles of matter that contained an active principle would produce a living organism when conditions are suitable.
- ✓ From his observations, Aristotle concluded that such are facts, everything comes into being not only from mating but also from decay of the earth. In plants, some developed from seeds while others by spontaneous generation by natural forces.
- ✓ Basing on this principle, Van Helmont described an experiment which gave rise to mice in three weeks. The raw materials were a dirty shirt, human sweat, wheat grain and dark cupboard.

- ✓ The active principle in the experiment was sweat and in 3 weeks, mice were seen in the cupboard thus concluded that mice arose spontaneously from sweat, dirty shirt and wheat grains in the dark cupboard.

Criticisms:

- He omitted a control experiment in which each variable was systematically eliminated therefore, not scientific.
- Francesco Redi in 1685 observed that the little maggots on decaying fish were actually larvae and by a series of experiments, he produced evidence to support the idea that life can only arise from pre-existing life.
- Louis Pasteur showed that bacteria were ubiquitous and living matter would easily become contaminated if it was not adequately sterilized. He assumed that each generation of organisms develop from the previous generation and not spontaneously.

4. Cosmozoan theory/ pans Permian theory:

- ✓ This extends the origin of life to an extra-terrestrial source elsewhere in the universe.
- ✓ Life could have arose from somewhere else and arrived on to the earth by some means.
- ✓ According to this theory, life is distributed throughout the universe in form of spores that can germinate in the right environments.
- ✓ Repeated sighting of **UFOs and aliens** provide evidence for this theory.
- ✓ In addition, research on comets and meteorites has revealed presence of many organic compounds like hydrocyanic acid which might have acted as seeds.

5. Biochemical theory (biogenesis)

This theory states that the origin of the earth is due to the result of slow and gradual process of chemical evolution that occurred probably about 3.8m years ago. This theory was proposed by Alexander Oparin in 1923. According to this theory;

- ✓ Spontaneous generation of life under the present day environmental conditions is not possible.
- ✓ They believe that the state of early earth was different from that of the present earth in that;
- Early earth atmosphere was a reducing one yet present atmosphere is an oxidizing one.
- Early earth was too hot while present earth is cool
- Main source of energy in early earth was solar radiation and lightening
- ✓ As the earth cooled, carbon and less volatile metals condensed and formed the earth's core whose surface was barren and rugged due to volcanic activity and continuous earths movements but contraction on cooling folded and fractured the surface.
- ✓ It is believed that lighter gases like hydrogen, helium, nitrogen oxygen and argon would have escaped because the gravitational field of the partially condensed planet would not contain them but however, simple compounds containing them like water, ammonia, carbon dioxide and methane would have been retained and until the earth had cooled to 700^{o}C, all the water existed in vapour form.
- ✓ Through a series of chemical reactions, simple organic molecules would have been formed due to presence of a reducing atmosphere as recent experiments in the laboratory show and from a collection of such chemical substances through progressive chemical reactions, the first life arose.

- ✓ In 1923, Alexander Oparin suggested that these organic compounds for example hydrocarbons, formed in the water, from simple compounds and energy was supplied by strong solar radiation which surrounded the earth before formation of the ozone layer which now blocks much of it out of the earth.
- ✓ He argued that considering the multitude of simple molecules that were present in oceans, the surface area of the earth, the energy that was available and the time scale, oceans would have gradually accumulated organic molecules to produce a primordial soup in which life could have arisen.

Evidence of biogenesis

- Basing on the above, in 1953, Stanley Miller performed experiments that proposed conditions on the early earth and they successfully synthesized many substances after a few days including, amino acids, proteins and nucleotides. Similar experiments by Miller and other scientists were able to produce amino acids, some proteins, nucleotides, ATP, ADP, and other molecules which are characteristics of living things. The simple molecules are believed to have reacted with themselves to form larger molecules like RNA and proteins.
- The complex organic molecules could have become the building blocks of the first living organism which were just in single cell form (prokaryotes) and their habitat was water.
- Many chemical reactions continued taking place with modifications and development of new features in already existing prokaryotes until complex organisms (multicellular) arose which also underwent modification, adaptations and advancements to form the present complex multicellular terrestrial organisms like man.

MECHANISM OF EVOLUTION

Lamarck and Darwin have tried to explain evolution to reveal the difference in the existing life forms.

LAMARCK'S THEORY OF EVOLUTION

It's also known as the use and dis use theory.

The theory was based on two conditions that is;

- ✓ use and dis use of structures and
- ✓ The inheritance of acquired characteristics.

- According to Lamarck, in the life of an organism, a change in environment would bring about a change in structures of the organism in order to allow efficient functioning.
- Structures which are often used become bigger and structures which are not used would become reduced. Therefore, throughout life, changes on the organism could accumulate and those characteristics would be passed onto the next generation.
- After many generations with continued accumulation of changes, the overall structure of the organism would be different from that of the earlier organism and thus since different organisms lived in different environments, the changes accumulated would be different depending on the different environmental conditions.
- For example, according to Lamarck, the present day long necked giraffes obtained their long necks from their short necked ancestors through the same process. As the short necked giraffes stretched to reach leaves on tall trees, it created a small elongation of the neck and that was passed on to the next

generation and with further stretching of the neck to feed on tall trees, the neck became longer in the proceeding generations.

- Therefore, Lamarck's theory states that the characteristics organisms acquire during their life time are transmitted to the off spring.

LAMARCK'S CONTRIBUTION TO EVOLUTION

- He recognized the effect of the environment in evolution i.e. creating needs for which adaptations are made.
- He recognized that the inheritance of characters from one generation to another was important in evolution.

CRITICISM'S TO LAMARCKISM

- Acquired characters are brought about by the environment and development but not the genes and therefore cannot be inherited.
- The use and disuse of somatic cells does not influence the reproductive cells therefore cannot play a role in inheritance and evolution.
- The formation of gametes have nothing to do with what it does and in females, gametes are formed before birth in ovaries.

DARWIN'S THEORY OF EVOLUTION / NATURAL SELECTION THEORY

- Charles Darwin visited Galapagos Archipelago islands and studied the finches which inhabited each of the island. While they all had general resemblances to those of the main land to the equator. They however differed in certain aspects e.g. the shape of the beaks.
- He urged that the finches of Galapagos resemble with those of the main land in South America because they descended from a common ancestor. They differed from one another e.g. shape of beaks because each is adapted to its own mode of life and in some instances restricted to its own particular island.
- He noted that a few finches had crossed from the main land to those volcanic islands shortly after formation. They encountered a range of different foods and each type of finch developed a beak which was adopted to suit its diet.
- All along his voyage, Darwin was trying to find out the mechanism by which changes occurred.
- Independent of Darwin, Alfred Wallace had drawn his own conclusions on the mechanism of evolution. Wallace sent Darwin a copy of his theory and Darwin realized that they were the same as his. As a result, they joined to present their findings to the scientific society. A year later, Darwin published his book on the origin of species by means of natural selection and the preservation of the favored races in the struggle for existence.

Important aspects of Darwin's' theory

1. **Over production of offsprings.** He believed that all organisms produced a large number of offsprings which if they survived, would lead to an increase in the size of the population.
2. **Constancy of numbers.** Despite the tendency of organisms to increase in number due to over production of species, most populations maintained relatively constant numbers. The majority of offsprings die before they are able to reproduce.
3. **Struggle for existence**. He concluded on the basis of the above two that members of the species were constantly competing with each other with effort to survive. In this struggle for existence only few would live for long enough to breed.

4. **Variation among offsprings**. They sexually produced offsprings of any species to show individual variation that no two offsprings are identical. As seen earlier.
5. **Survival for the fittest by natural selection.** Among the variety of offsprings, some are better adapted to withstand the prevailing conditions than others. I.e. some will be able to survive in the struggle for existence. Such types are more likely to survive long enough to breed.
6. **Like produce like.** Those that survived to breed are likely to produce offsprings similar to themselves. The advantageous characteristics which gave them a win in the struggle for existence are likely to be passed on in the next generation.
7. **Formation of new species.** Individuals lacking favourable characteristics are less likely to survive long enough to breed and over many generations, their numbers decline. The individuals with favourable characteristics breed with consequent increase in their number. The inheritance of one small variation may not by itself produce new species however, the development of a number of variations in a particular direction over many generations gradually leads to variation of a new species.

Limitations of Darwin's theory

- ❖ Darwin made no attempt to describe how life originated on earth. He only explains how new species arise from pre-existing one
- ❖ The theory 'struggle for existence' was popularized by the coiling of unfortunate terms such as 'survival of the fittest' and 'elimination of the unfit'.
- ❖ A misconception that human beings descended from apes which was perceived as offensive by both religious and secular communities.
- ❖ Contradiction with the Genesis six-day creation and that of a progressive origin for species.
- ❖ The theory fails to account for the extinction of dinosaurs and the giant ferns

DARWIN'S LAW OF NATURAL SELECTION

- ✓ It states that in a highly reproducing population, there is variation among individuals and some characters are inherited such that those possessing them survive to reproduction stage, while those ones which are not favoured by their environment die before they reproduce i.e. favoured characters are selected for while the unfavoured ones are selected against.

How Darwin explained the development of the long necked giraffes

- ➢ Initially both short and long necked giraffe varieties existed.
- ➢ Due to exhaustion of food at the ground level, the short ones could not reach the tree branches and hence starved and died of hunger.
- ➢ The long necked giraffes survived and were able to produce the long necked giraffes in the next generation.

MODERN THEORY OF EVOLUTION (THEORY OF ORGANIC EVOLUTION)

- With the contemporary evidence from research in genetics and molecular biology, the theory of evolution as started by Darwin and Wallace was modified into what currently is known as Neo-Darwinism**.**
- Neo- Darwinism; "this is the theory of organic evolution by natural selection of genetically acquired characteristics."

Or ***"the theory of organic evolution by natural selection of inherited characteristics"***

- This should not be confused with chemical evolution which describes the process of formation of organic molecules from simple inorganic molecules which gave rise to the first life forms in the primitive earth. Organic evolution focuses on the gradual modification of organisms from the first primitive forms of the time to the current forms.
- For Neo-Darwinism theory to be accepted, it is necessary to:

⌦ Establish the fact that evolution has taken place in the past (past evolution)
⌦ Demonstrate a mechanism which result in evolution (natural selection of genes)
⌦ Observe evolution happening today (evolution in action).

- Evidence for evolution comes from many sources based on geology e.g. fossils and stratigraphy. It is found in the experimental and observable data of the natural selection of characteristics that are inherited such as the selection of shell colour in the snail and the mechanism of inheritance demonstrated by Mendelian genetics as in Mendel's work on peas.

Natural selection;

× This is the process by which organisms that are better adapted to their environment survive to breed while those less adapted fail to do so and die in the process. The better adapted ones are likely to pass their characteristics to the succeeding generations. Therefore selection determines the spread of any allele within a gene pool.
× The environment exerts a **selection pressure**; this is abiotic or biotic factor that alters the behaviour and fitness of living organisms within a given environment. Thus it is the driving force of evolution and natural selection.

HOW NATURAL SELECTION OCCURS

- During periods of population increase, some resources become limiting and competition sets in for such resources.
- This creates a struggle for existence in which individuals that are physically, physiologically or behaviorally better adapted to the environment have *a* selective advantage and are selected for by the environment. These reproduce and pass their traits to the next generations, and their numbers increase over time.
- Those that are less adapted are said to have a selective disadvantage and are selected against, fail to reproduce or survive and their numbers decline significantly. Gradual accumulation of the favorable traits in one direction over a long period of time may result into the two groups evolving into different
- species.
- Selection acts by weeding out those individuals, whose characteristics confer a
- selective disadvantage; unfit in favor of the fit individuals.

TYPES OF NATURAL SELECTION

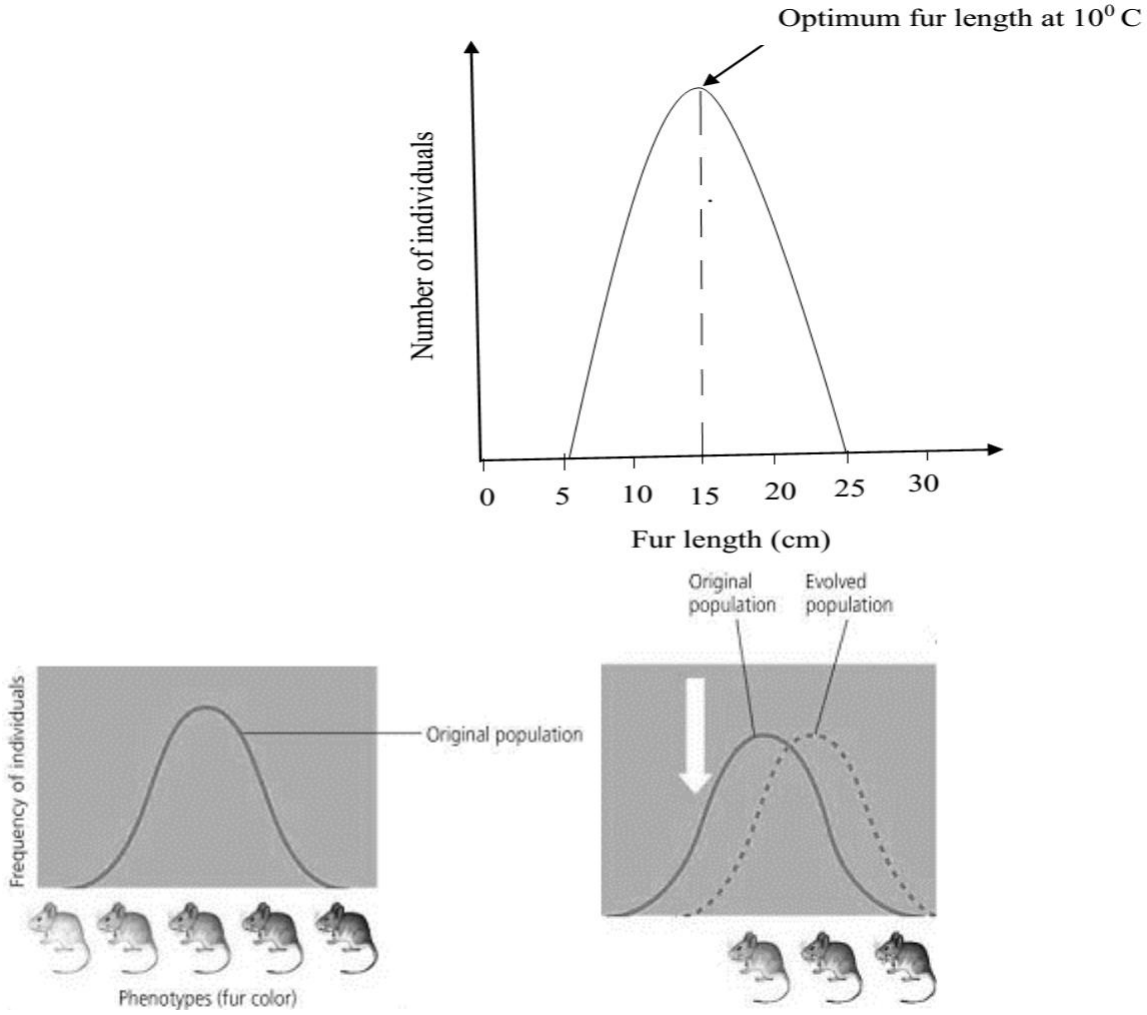
They are directional selection, stabilizing selection and disruptive selection.

1. **Directional selection**

☑ When environmental changes favours a new phenotype, then the individuals of this phenotype are likely to become numerous in the population at the expense of those not favoured hence the mean shifts to a new one and the composition of the population changes accordingly. This is known as progressive selection.
☑ Within the population, there is a range of individuals in respect to a particular character. The continuous variation among individuals forms a normal

distribution curve with a mean representing the optimum for existing conditions.

- ☑ When these conditions change, there is a selection pressure on the species causing them to adapt to new conditions. As the conditions change, also the optimum necessary conditions for survival will change. In this case, only a few individuals will possess the new optimum requirements and by selection, they will dominate the environment. This means that the mean for this particular character will have shifted e.g. the different fur Lengths suits different temperature conditions.
- ☑ Directional selection favours change in allele frequencies and may lead to evolutionally change and forms the basis for the artificial selection of plants and animals and day to day observations of natural selection. Probably when food was in short supply, only the tallest giraffes could reach enough food for survival and only these reproduced to pass their traits, hence gradual development of long necks. Industrial melanism, resistance to antibiotics and selective breeding are examples of the operation of directional selection.



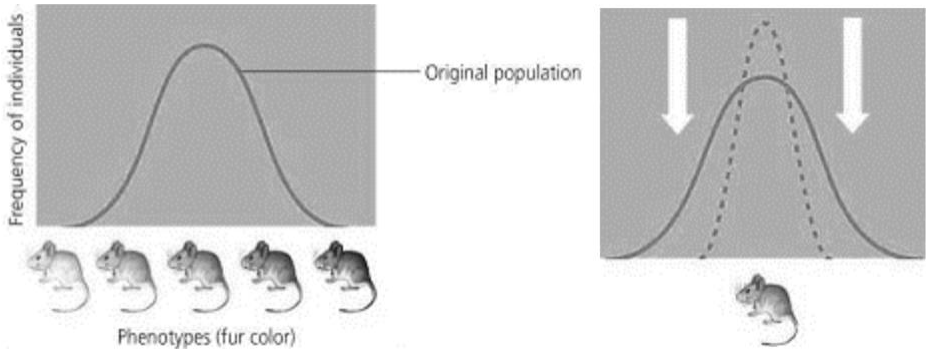
Or check illustration in understanding biology page 202 fig.11.1

2. STABILIZING SELECTION

- × When natural selection favours individuals near the mean, and in distribution it selects against individuals at the extremes, it brings about constancy in the population and does not favour evolution. It ensures that most individuals surviving are then adapted to the environmental conditions.

- Stabilizing selection occurs in all population and eliminates extremes hence reducing variation in the population, thus no opportunity for evolutionary checkup.

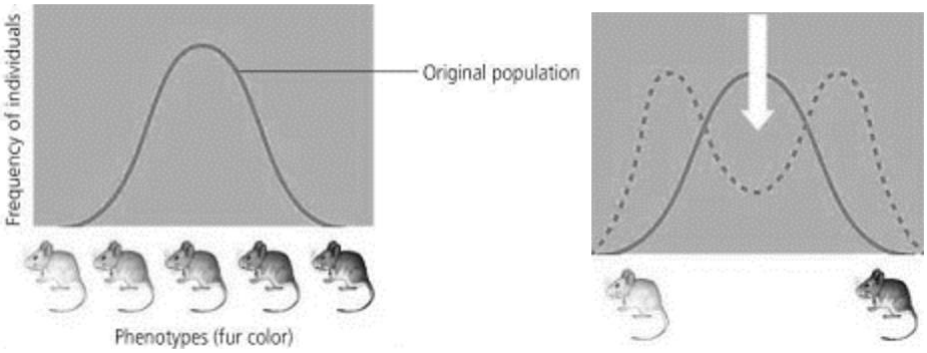
- E.g. in the earlier example, it was seen that at 10^0C there was an optimum fur length of 1.5cm. Individuals within a population however had a range of fur length ranging from 0.5cm to 2.5cm under normal climatic circumstances, the average temperature varies from 1 year to the next.
- In a warm year with an average temperature of 15^0C, the individuals with short fur may be at an advantage as they lose heat more quickly. In such years, the numbers reduce because individuals with short fur die and reduce in number. The periodic fluctuation in environmental temperature therefore help to maintain individuals with relatively long and short fur and tries to eliminate those with longest and shortest fur thus reducing variation.
- Its average environmental temperature was 10^0C every year and there were no fluctuations without the warmer years to give them an advantage in competition with others in the population, the individuals with short hair would decline in number.
- Likewise, the absence of colder years would reduce the number of long haired individuals. The mean fur length would remain at 1.5cm but the distribution curve would show a much narrow range of length. When the environmental temperature constantly remains the same (10^0C), individuals with the longest and shortest fur are eliminated from the population over a number of generations. The inheritance of sickle cell anemia confirms to this type of natural selection since the individuals at the extreme die of their sickle cell disease or malaria while the majority of heterozygous survive.



3. DISRUPTIVE SELECTION

- When natural selection favours the phenotype towards the extremes and selects against those near the mean, it is the reverse of stabilizing selection and may lead to splitting of a single gene pool into two hence two different species may arise (speciation) hence it is one of the agents of quick speciation.
- Speciation is the process of forming new species of organisms. Disruptive selection is less common but important in evolutionary change. It can occur when an environmental factor takes a number of disruptive forms e.g. suppose the environmental temperature alternated between 5^0C in winter and 15^0C in summer with no intermediate temperature occurring. These conditions would favour the development of two distinctive phenotypes within the population: one with a fur length of 2.0cm at an environmental temperature of 5^0C while the other of 10cm optimum length at 15^0C.

- ❖ It's possible that the group with 2.0 cm fur length would aestivate or migrate in summer to avoid the problem of over-heating. The other group might hibernate or migrate in winter to avoid the problem of heat loss. In this way, reproduction between the two groups may be interrupted and the flow of genes between them prevented. Each population might then become a separate species.
- ❖ During the evolution of the Galapagos finches, birds with short beaks had an exclusive use of nuts for food while those with long slender beaks had an almost exclusive use of insects. Members with intermediate beaks were probably out competed



NOTE:

Disruptive selection may result into a population expressing two distinct phenotypes; this is referred to as polymorphism;

a. **Polymorphism** refers to the existence of two or more distinct forms of the same species in the same population. Such phenotypes are referred to as **morphs**

   The best example is the existence of two forms of peppered moths, the Melanic and the normal forms.

   There are two types of polymorphism; balanced/stable and transient polymorphism

b. **Balanced polymorphism:** this occurs when different forms co-exist in the same population in a stable environment. The best example is the existence of two sexes in plants and animals, ABO blood groups in man, red-green colour blindness and the existence of workers, drones and queen bees. In such cases, the genotypic frequencies of the various forms exhibit equilibrium because they have a selective advantage of equal intensity. Whilst the genotypic frequencies may vary within the population, they tend to remain constant from generation to generation.

c. **Transient polymorphism:** this arises when different forms or morphs exist in a population undergoing a strong selection pressure, the frequency of the morphs being dependent on the intensity of the selection pressure. It usually applies in situations where one form is gradually being replaced by another for example in the Melanic and non-Melanic forms of peppered moths

NATURAL SELECTION IN ACTION

This refers to the day to day observations of natural selection or examples of natural selection applications

Examples include the following.

- Insects resistance to insecticides, like flies and mosquitoes to (DDT)
- Pests resistance to pesticides
- Heavy metal tolerance in grass and other plants
- Antibiotic resistance by pathogens e.g. bacteria to penicillin
- Resistance to antimalarial drugs

HOW RESISTANCE ARISES

- Resistance usually occurs due to continuous exposure of organisms to such chemicals which induce random mutations. This causes synthesis of an Oxido-reductase enzyme which either reduces or oxidizes the chemical into a harmless substance making them resistant.
- In such populations, the chemical acts a directional selection pressure that tends to eliminate the non-resistant forms in favour of the resistant ones. The latter have a selective advantage hence a higher reproductive potential, reproduce more rapidly and their numbers increase as resistance is passed to next generations. The non-resistant forms are eliminated and sooner than later, the whole population becomes resistant to the chemical
- In the same way; soils near mines are usually devoid of vegetation. This is because such soils contain high concentrations of heavy metals like mercury, lead, zinc and copper which are highly toxic to plant growth. However a few plants like the horsetails are found scattered in such soils which have developed tolerance to such metals. In such plants, mutations occur rendering them ability to trap these metals into their cell walls, confine them in vacuoles or excrete them. Tolerance is passed to next generations enabling the plants to flourish in polluted areas as their non-tolerant competitors are killed by heavy metals, while in unpolluted areas they have a competitive disadvantage, less competitive and rarely survive

RESISTANCE IN BACTERIA POPULATIONS

Bacterial populations can easily become resistant because of the same following reasons:

- ✓ They have a haploid DNA such that in case of a mutation, the resistant allele is instantly expressed phenotypically due to absence of the non-resistant copy
- ✓ They reproduce rapidly by binary fission hence the number of resistant individuals' increases so rapidly that soon the whole population becomes resistant.
- ✓ Ability of individual bacteria to exchange resistant alleles. This is called **plasmid exchange** leading to a rapid spread of resistance in a population

INDUSTRIAL MELANISM

- **Industrial melanism** is the process that led to the appearance of higher frequencies of melanic forms of peppered moths than non-melanic forms as a result of air pollution that followed the industrial revolution.
- Peppered moths (*Biston betularia)* are known to occur in two phenotypic forms (polymorphic) namely; *Biston betularia typica* and *Biston betularia carbonaria***.** The former are speckled white in colour and are the normal non melanic forms while the latter are melanic mutants and appear darker (almost black). This phenotype is thought to have arisen due to a spontaneous mutation
- The peppered moths are known to fly at night and during day they are resting on tree trunks and walls of buildings.
- They depend on cryptic colouration to camouflage with their backgrounds in effort to prevent predation by birds.

Explanation

- × Originally; before the industrial revolution due to low pollution levels, the tree barks had a pale appearance due to lichen growth.

- The light forms could unlike the dark forms camouflage beautifully as their body colour emerged properly with their back grounds, that predators could not easily spot them.
- These had a selective advantage which rendered them a higher reproductive potential and their numbers increased much more than those of the dark forms which could not emerge well with a pale background. Predators could easily spot them for food which kept their numbers very low.
- Following the industrial revolution, the air pollution resulted into killing of the lichens and backgrounds were further darkened by smoke. In such conditions, the dark forms could more easily camouflage than the light forms and could not easily be spotted by predators.
- These there
- It is also a good illustration of transient polymorphism. The two forms can still interbreed successfully and are therefore of the same species.

ARTIFICIAL SELECTION

- ✓ Man has been cultivating plants and keeping animals for about 10,000 years. Over this time, he tried breeding them selectively.
- ✓ There are two basic methods of selective breeding i.e. inbreeding and outbreeding.

INBREEDING

- ✓ When by chance a variety of plants and animals arose which possessed some useful characters, it was bred with its close relatives in hope of retaining the characters for future generations.
- ✓ The problem with inbreeding is that it increases the danger of the harmful recessive gene exposing itself because there is a greater risk of a double recessive individual appearing.

OUTBREEDING

- This is done to improve the existing varieties where two individuals of the same species each having the beneficial feature are combined during outbreeding to produce a better feature. Outbreeding frequency produce stronger individuals with a better chance of survival.
- Extreme examples of outbreeding occur when individuals of different species are mated. It's only in rare cases where it succeeds. Where it succeeds, the resulting offsprings are normally sterile. A cross between a horse and a donkey produces a mule which is stronger than either parents thus showing hybrid vigor.
- The improvement of human race by the selective or elimination of specific characters is called eugenics but its success is minimal.
- The disadvantage with outbreeding is that it makes consistent qualities harder to achieve but the advantage remains that it results in healthier and stronger offsprings.

EVIDENCES OF EVOLUTION

1. PALEONTOLOGY

- ⌦ This is the study of fossils. A fossil is any form of preserved remains thought to have been derived from a living organism and it includes the entire organism, hard skeletal structures, mould and casts, petrification, impressions, imprints, and fecal pellets.
- ⌦ The fossil evidence doesn't prove that evolution occurred but it shows the progressive increase in complexity of organisms because in old fossil bearing

rocks there are a few types of simple structured fossilized organisms while in younger rocks, there is a great variety of complex structured fossilized organisms.

- ⌦ Throughout the fossil record, many species will appear at early stratigraphic level but disappear at the later level. This shows the period of origin and extinction of that species and in evidence, these organisms might have appeared increased in complexity or have become extinct due to changes in geographical regions and climatic conductor. For example, plants appeared before animals and insects appeared before insect pollinated flowers.
- ⌦ The best example for the study of fossil was the horse which underwent various gradual but progressive modifications in feeding and locomotion structures, from the ancient hyacottherium to the recent advanced equus horse.

Weakness of paleontology

- ✓ The records are less significant if the fossil record is not continuous that is to say it has missing links in the fossil record such that ancient organisms can't be linked to the present ones.

Explanation for gaps or incompetence's of fossil record

Paleontologists have the following explanations to account for missing links in the fossil record;

- Some dead organisms decompose readily and leave no fossils.
- Some dead organisms might be eaten by scavengers.
- Some organisms are soft bodied therefore not fossilized easily.
- During favourable conditions for fossilization, only a small fraction of living organisms might die.
- Only a fraction of fossils have been discovered.

2. CLASSIFICATION

- Before Darwin put forward his theory of evolution, some organisms had led some scientists to propose a system of classification between organisms. This forms a neutral series of phyla, classes, orders, families, genera and species. This was possible because organisms were related by descent.

3. COMPARATIVE EMBRYOLOGY

- Adaptive embryology refers to the study of embryonic stages of organisms. Embryological studies on vertebrates reveal striking structural similarities among embryos of all vertebrate groups especially in early fetal stages of cleavage and gastrulation as well as in early embryonic stages.
- This has been summarized as the recapitulation principle which States that **"Ontogeny recapitulates phylogeny".**
- This literally means that all vertebrates during their embryonic development repeat the evolutionally trends of their proposed ancestors and indicates a common ancestry for all vertebrates.
- However the recapitulation principle does not apply universally as no organism shows all the stages of its proposed ancestor
- At comparable stages of vertebrates, their embryos possess the following features
  - External branchial grooves (gill pouches) in the pharyngeal region. These in fish form the gill slits involved in gaseous exchange while in other vertebrates form the Eustachian tube and the auditory canal involved in hearing

- Segmental myotomes. These are the muscle blocks that are evident in the tail-like structure that is completely retained in certain species only.
- A single circulatory system which includes a two-chambered heart. This is fully retained in the fishes only

4. COMPARATIVE ANATOMY (comparing structures)

- The detailed study of unrelated organisms reveal many structures which are similar. These similarities indicate such individuals have a common ancestor.
- The pentadactyl limb is common to all vertebrates except fish, but during evolution, it has become modified for a number of functions.
- In birds, it forms the wings for flight, in primates it forms the hands for grasping whereas in whales it is modified for swimming.

- **Homologous structures;** are structures from the common ancestral origin that serve different functions e.g. the pentadactyl limb composed of five digits like in the horse for running, monkeys for grasping, human beings for handling and bats for flying.
- This type of evolution is called ***divergent evolution*** which is the type of evolution where by organisms with common ancestors have developed structures that perform different functions because of change in the environment they live in.
- **Divergent evolution** therefore refers to the gradual development of dissimilar structures among phylogenetically related organisms due to adaptive radiation of organisms to different modes of life. E.g. the Darwin's finches
- When structures are further compared, it is observed that some of them differ but serve the same functions. Such structures are known as ***analogous structures***.
- Thus analogous structures are structures from different ancestral origin but serve the same functions. Such evolution is called convergent evolution which is a type of evolution where by different organs with different ancestral origins perform the same function. This is because of the similar environments they live in e.g. wings of birds and wings of insects.

5. COMPARATIVE BIOCHEMISTRY

- In the same way, the similar structures like pentadactyl limb indicates a common ancestral origin. Simple chemicals such as water, glucose, proteins, lipids, nucleic acid, etc. are common to organisms. Cytochromes, haemoglobin and ribosomal RNA are also used in the search for evolutionary affinities (closeness).
- The theory of biochemical homology among organisms emerges from biochemical studies like serological tests, x-ray analysis and protein sequence analysis. The ubiquitous occurrence of similar biochemical molecules and metabolic process in a wide range of organisms suggests a common ancestry. The slight differences like amino acid sequence in proteins and differences in DNA base sequence reflect changes due to adaptive radiation.
- **Examples** of biochemical homology include
  - Proteins like cytochromes, haemoglobin, myoglobin and nucleic acids occur in almost all living organisms
  - The occurrence of similar hormones like prolactin, adrenaline and thyroxin

among all vertebrates Comparative serology has been often used to establish the level of biochemical affinity (closeness) among organisms.

- When foreign protein molecules present in the serum are injected into the blood stream of an animal, they act as antigens that stimulate its immune system to synthesize anti bodies against them.
- If after some time the same sample of serum is added, antibody/antigen interaction occurs resulting into a precipitate which settles and can be measured. If for the second time, serum samples from a variety of animals are added to the sensitized blood stream, the degree of precipitation reveals the level of biochemical similarity between these animals to the first one.
- The higher the level of precipitation is the closer the animal is related to the first animal.

6. GEOGRAPHICAL DISTRIBUTION

- Plants and animals species are not evenly distributed throughout the world. Some zones have their own characteristic fauna and flora.
- It is expected that where identical conditions occur in different parts of the world, the same organisms will be found, but this is not the case. E.g. elephants are found in Africa and India together with South Africa, but the habits are different.
- Britain and New Zealand have similar flora and fauna but having different organisms proves that evolution took place.
- This discontinuous distribution of species can be explained as follows:

a) A species originates in a particular area.
b) Individuals continuously disperse to avoid over-crowding.
c) As they encounter new environments as a result of dispersal, they adapt to meet the new conditions which is termed as adaptive radiation.
d) Climatic topographical and other changes create barriers between the new varieties and their ancestors.
e) This genetic isolation leads to separate gene production and new species.

- ✓ It is thought that in this way, individual species become restricted to specific areas. These barriers are formed by continental drift. It is thought that continents of the earth were formed from a single mass that broke up at the South Pole.
- ✓ This land mass broke up into sections which floated on the earths' molten mantle and drifted apart. Land bridges remain between individual sections and members of the species would freely interbreed.
- ✓ Where these bridges were submerged by changes in sea level, groups became genetically isolated and new species arose.
- ✓ By the time land bridges were reformed due to the fall of sea level, interbreeding between the original groups was impossible, hence the discontinuity of distribution of organisms which used to be of the same species.

SPECIATION

- This is the process by which new species may arise from pre-existing species.
- *Intraspecific speciation* is when a single species gives rise to new species.
- If this occurs when the whole population is occupying the same geographical area, it's referred to as sympatric speciation whilst allopatric speciation occurs when the populations are occupying geographical isolated habitats.
- In some cases, commonly in flowering plants, two species may give rise to a new species; this is known as *interspecific hybridization*.

ALLOPATRIC SPECIATION

- This is the type of intraspecific speciation which occurs as a result of spatial separation of a population into two subpopulations, usually due to geographical barriers like mountain ranges, seas, rivers or differences in habitat preferences.
- This prevents interbreeding among the individuals of the two subpopulations leading to reproductive isolation and interrupts gene flow. Due to continuous selection, mutations and random genetic drift result into changes in the allele and genotype frequencies of the two populations, making their gene pools to diverge more from that of the original population.
- Prolonged separation results into the populations becoming genetically isolated such that the individuals can no longer interbreed successfully, the two are now different species and speciation is said to have occurred. E.g. the Galapagos finches

SYMPATRIC SPECIATION

- ✓ This is the type of sympatric speciation that occurs when all members of the population are occupying the same geographical area.
- ✓ It usually occurs following a short term period of allopatric/geographical isolation which results into accumulation of reproductively isolating traits among the individuals.
- ✓ This interrupts gene flow leading to genetic isolation of the two groups coexisting in the same area. The overall result is independent change in the allele and genotype frequencies of the two subpopulations due to n/s; leading to formation of races and subspecies. If genetic isolation persists over a long period of time, these may gradually evolve into different species, this is referred to as sympatric speciation.

Interspecific hybridization:

- ✓ This is a form of sympatric speciation which occurs when a new species is produced by the crossing of individuals from two unrelated species.
- ✓ It is common in plant breeding and most hybrids are infertile but can reproduce asexually, though Allopolyploidy* may result into production of fertile off springs due to non-disjunction.

ISOLATING MECHANISMS

An isolating mechanism is a means of producing and maintaining reproductive isolation within a population. They are often called reproductive isolation mechanisms

Reproductive isolation:

- *R*efers to the existence of biological factors (barriers) that impede members of the same or different species from interbreeding successfully
- Within a population there are *deme*. Although individuals within a deme breed amongst each other, most of the time it is still possible for them to breed with other individuals from other demes.
- Therefore it remains a single gene pool but if demes become separated in any way, the flow of genes between them may cease.
- Each deme may then develop a long a separate line. The two demes may become so different that even if reunited, they will be incapable of successful breeding with each other. They would thus become separate species each with its gene pools.

Geographical isolation:

- Any physical barrier which prevents two groups of the same species from mating must prevent them from interbreeding.
- Such barriers include mountains, deserts, rivers, oceans, etc.
- The environmental conditions on either side of the barrier frequently differ. This leads to a group on either side adapting to suit its own environments. The process is known as adaptive radiation.

Check understanding biology page 208 fig 11.4

Ecological isolation:

- Occur when two species inhabit similar regions but have different habitat preferences within that same area. Such species can meet only very rarely if at all.

Behavioral mechanism:

⌦ This occurs where animals exhibit courtship patterns. Mating only results if the courtship behavior displayed by one sex is accepted or interpreted by another. Colour and marking on members of the opposite sex E.g. Darwin's finches.

Seasonal isolation:

- Occurs when two species mate or flower at different times of the year. Eg *Pinus radiata*in February and *Pinus attenuata*in April
- The timing of courtship behaviour and gamete production is also important in that if the breeding season of the two demes does not coincide, they can't breed. On the other hand, different flowering times of plants mainly at cross pollination is impossible.

Physiological isolation:

This is where two groups of individuals cannot breed due to a number of reasons connected to their physiological nature.

i) The genitalia of the groups may be incompatible; *mechanical isolation*. It may be physiologically impossible for the penis of the male to enter a female's vagina.
ii) The gametes may be prevented from meeting e.g. in animals, the sperms may not survive in the female reproductive parts or in plants, the pollen tube may fail to grow.
iii) Fusion of gametes may not take place despite the sperm reaching the ovum or the pollen tube entering the micropyle thus in this case, the gametes are incompatible so do not fuse; *Gametic isolation*.
iv) Development of the embryo may not occur despite fertilization taking place, further development may not occur or fetal abnormalities may arise during early growth; *hybrid isolation*
v) The hybrid may be sterile (hybrid sterility). E.g. a mule; *hybrid isolation*.
vi) Hybrid inviability; this is when the produced hybrids are unable to survive to reproductive maturity. The genes of different parent species may interact in ways that impair the hybrid's development or survival in its environment. Sometimes development of embryo may not occur after fertilization.
vii) Hybrid sterility: This is when hybrids are viable but fail to produce functional gametes and are therefore infertile. This is because the chromosomes of the two parent species differ in number or structure, that they cannot allow for complete pairing of chromosomes during meiosis e.g. the mule (2n =63) results from a horse 2n=60 and donkey (2n=66).
viii) Hybrid breakdown: The F1 hybrids are fertile but the F2 hybrids and their back crosses are infertile.

CLASSIFICATION OF ISOLATING MECHANISMS

Isolating mechanisms are classified as;

1. **Prezygotic** mechanisms; which are barriers that may lead to formation of hybrids.
2. **Post zygotic** mechanisms; barriers that prevent hybrids from reproducing.
3. **Post zygotic mechanisms;** barriers that occur after fertilization.

The above mentioned isolating mechanisms all fall under these three.

I thank you for the work done in understanding this topic. We looked at a variety of aspects starting from the genetic code, through genetics, variation, population genetics, Origin of life, evolution, selection and speciation. We have had questions at the end of every sub topic which am aware you have tried out without leaving anything.
Now try out these final questions

1. a. Explain what is meant by the term mutation.
   b. State the main features of mutations
   c. explain how mutation contributes to variation.
2. a. define the term variation
   b. distinguish between continuous and discontinuous variation.
   c. explain the effect of the environment on genetic variations.
3. a. what is meant by the term polyploidy?
   b. describe the different forms of polyploidy
   c. explain why polyploidy is
      i. more common in plants than in animals.
      ii. Associated with increased size of the organism.
4. a. with examples, explain the term discontinuous variation
   b. explain how sexual reproduction causes variation in populations
5. a. what do you understand by the term evolution
   b. explain how the following provide evidence for evolution
      i. fossils
      ii. Distribution of camels
6. a. what is meant by the term selection as used in evolution.
   b. explain the role of the following forms of selection
      i. stabilizing selection
      ii. Disruptive selection
      iii. directional selection
7. state Darwin's theory of natural selection
   b. state three observations and two conclusions from which Darwin derived his theory
   c. how does the modern view of evolution differ from Darwin's
8. a. explain the role of the following in natural selection
      i. environment
      ii. Increased selection pressure
      iv. reduced selection pressure
9. a. Explain the role of heterozygosis in variation
   b. explain the low frequency of recessive alleles within the population.
   c. explain the conditions under which the frequency of a recessive population may increase.

7. TRANSPORT

REASON WHY ORGANISMS NEED SPECIALIZED TRANSPORT SYSTEMS

- All organisms need to exchange materials between themselves and their environment. Respiratory gases and raw materials for growth must pass into an organism and waste products must be removed.
- This exchange is carried out passively by diffusion and osmosis and actively by active transport, pinocytosis and phagocytosis.
- To be efficient, exchange mechanisms require the surface area over which transfer occurs to be large when compared to the size of the organism.
- In small organisms, externally, they have a large surface area to volume ratio which means diffusion alone is enough to meet their metabolic demands and exchange of materials all over the body surface for example;
- Unicellular organisms like amoeba are very small, flat worms or the Platyhelminthes have flattened bodies, hydra are hollow, bryophytes are small and lack cuticle whereas internally, the distance the materials have to travel in such organisms is small and thus diffusion can meet it or cytoplasmic streaming.
- Some organisms are not very active and this have low metabolic rates thus metabolic wastes accumulated can be removed by diffusion alone.
- Such organism will not require a specialized transport system however;
- Some organisms are large in size that means they have a small surface area to volume ratio; hence diffusion alone cannot occur fast enough to meet the body demands due to metabolism.
- Such organism internally materials have to travel a longer distance, as well they are physically active and need metabolites delivered to and waste products removed as fast as they are made which diffusion cannot meet.
- Some organisms have body covered with impervious layers that prevents direct exchange of materials by diffusion.
- Due to such instances survival of organisms will be dependent on an efficient transport system and thus the need for it.
- In higher organisms, both plants and animal tissues are bulky and the body is complex. Such organisms involve a highly vascularized conducting muscular tissue to enable movement of important materials through the body.

Key components of a transport system

- ✓ Tubular tissue in which substances move.
- ✓ Fluid that dissolves the substance.
- ✓ Pumping organ for circulatory of materials.

Importance of transport system

- ➢ Transport of materials from one part of the body to another.
- ➢ Transport of waste products.
- ➢ Movement of important substances i.e. water, hormones, enzymes, etc.
- ➢ Movement of respiratory gases.

WATER AS MEDIUM IN PLANTS AND ANIMALS

- Organisms can obtain their gases from the air or from water.
- Water is characterized varying oxygen concentrations in fresh waters, therefore an aquatic organism must pass a greater volume of the medium over its respiratory surface in order to obtain enough oxygen.
- Water contains far less oxygen per unit volume than air and it is further reduced if the temperature increases, the concentration of dissolved salts increased or if water is slow moving or contains high levels of decomposing material.
- Fresh water invertebrates show various adaptations to enable them to obtain as much of this dissolved oxygen as possible;
- Have respiratory pigment with a high affinity for oxygen e.g Tubifex
- Direct exposure to air for example great diving beetle.
- Some have external gills for example the nymph of small mayfly.

Water and air as respiratory media

Property	Water	Air
Oxygen content	Less than 1%	21%
Oxygen diffusion rate	low	High
Density	Relative density of water about 1000 times greater than that of air at the same	
viscosity	Water much greater, about 1000 times that of air	

TRANSPORT IN ANIMALS

- Many materials including oxygen, carbon dioxide, soluble food substances, hormones, urea etc. need to be transported from one point to another using a transport network and medium.
- The transport system in animals is mainly made up of blood vessels consisting of blood as the medium circulating through them to the various body tissues. The transport system is also made up of the pump i.e. the heart which brings about circulation of blood throughout the body, by pumping it. The transport system is also composed of the lymph vessels containing the lymph fluid.
- The larger, compact and more active an organism is, the more the need for a transport system.

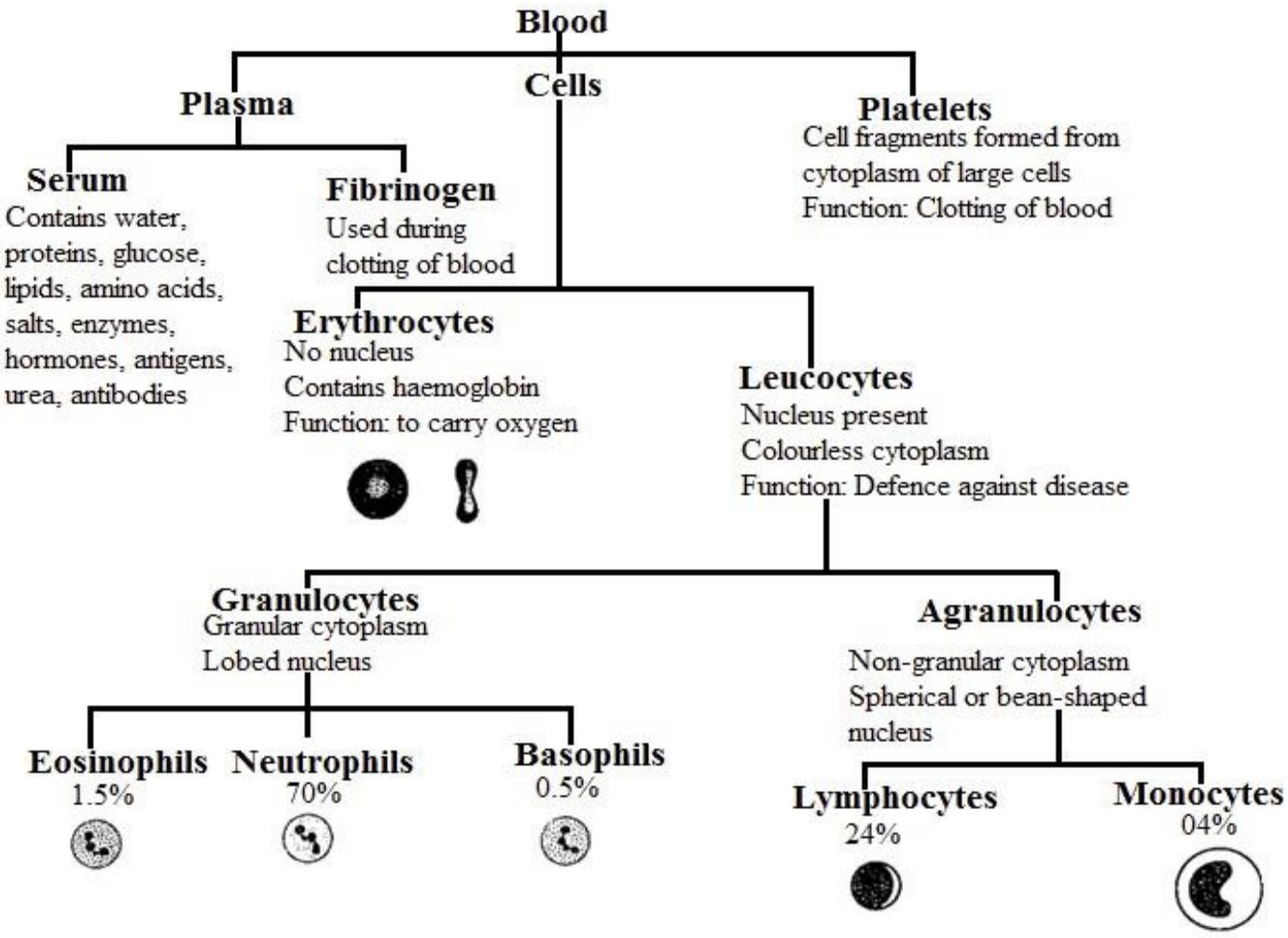
BLOOD

This is a highly specialized fluid tissue which consists of different types of cells suspended in a pale yellow fluid known as the blood plasma.

FUNCTIONS OF BLOOD

1. **Tissue respiration.** It enhances the formation of energy in the tissues by transporting oxygen and soluble food substances to the tissues to be used as raw materials for respiration. Carbon dioxide is also transported away from the tissues mainly in the form of bicarbonate ions (HCO_3^-) as a by-product of respiration and then taken to the lungs for its removal from the body. Oxygen is transported in the form of oxyhaemoglobin from the respiratory surfaces to the tissues.
2. **Hydration.** Blood transports water from the gut to all tissues.
3. **Nutrition.** Blood transports the soluble well digested food materials from the gut to the body tissues.

4. **Excretion.** Blood transports metabolic waste products from the tissues to the excretory organs for their removal from the body e.g. blood transports urea from the liver to the kidney in order for it to be removed from the body.
5. **Temperature regulation.** Blood distributes heat from the organs where it is mainly generated e.g. the liver and the muscles, uniformly throughout the body.
6. **Maintenance of constant pH.** Blood maintains a constant pH through the maintenance of circulation of the plasma proteins manufactured by the liver which act as buffers to maintain the pH of the body fluids constant. This enables enzymes to function efficiently as charges will denature the enzyme.
7. **Growth, development and co-ordination.** Blood transport different metabolites such as glucose, amino acids and hormones needed for the growth and development of the body.
8. **Defence.** Blood defends the body against diseases through the following ways;
   a. By using some white blood cells; leucocytes which phagocytotically ingest and destroy pathogens that cause diseases.
   b. By formation of a blood clot around the wound so as to prevent entry of microbes or pathogens into the body.
   c. By use of the immune response mechanism towards infection e.g. by use of the different types of antibodies to destroy the microbes.



BLOOD PLASMA

- This is a pale yellow fluid component of blood composed of the plasma proteins and blood serum where the blood cells are suspended. Blood plasma carries the biggest percentage of blood and consists of a colourless fluid known as serum and also plasma proteins.
- It is the blood serum that all the different soluble materials are dissolved e.g. urea, hormones, soluble food substances, bicarbonate ions etc.

RED BLOOD CELLS/ ERYTHROCYTES

Importance of Red Blood Cells

- They transport oxygen from gaseous exchange surfaces to the tissues
- They transport carbon dioxide from tissues to the gaseous exchange surfaces.

Adaptation of Red Blood Cells to carry out their function

- They are biconcave in shape so as to avail a large surface area to volume ratio for absorption of oxygen.
- They have haemoglobin molecules that bind to oxygen and transport it from the lungs to the tissues.
- They have a thin membrane which reduces the diffusion distance for the respiratory gases in and out of the cells.
- They lack nuclei which provides enough space for packaging of haemoglobin
- They lack mitochondria and generate their ATP exclusively by anaerobic respiration to prevent them from using the oxygen they are carrying.
- They have an enzyme, carbonic anhydrase which plays a role in carbon dioxide transport.
- They are numerous to increase surface area for transportation of oxygen.
- They have flexible membranes which make them able to squeeze through capillary networks as they exchange materials they transport with the surrounding tissues.

NOTE:

1. The concentration of red blood cells increases as one climbs up a mountain because the concentration of oxygen in the air reduces with increase in height above sea level.
2. So the body adopts by producing more red cells to increase the available total surface area to bind and carry oxygen to the tissues regardless the reducing oxygen partial pressure.
3. Red blood cells have a lifespan of 120 days

WHITE BLOOD CELLS (LEUCOCYTES)

- ✓ They have nuclei
- ✓ They have an irregular shape and change their shape/ amoeboid
- ✓ They are manufactured in the bone marrow, spleen and lymph nodes.

TYPES OF LEUCOCYTES

1. **Granulocytes:**
   - × These are WBC that possess granules in their cytoplasm and can easily be stained. Such leucocytes have an amoeboid shape and irregular.
   - × They also possess a lobed nucleus.
   - × They are mainly involved in engulfing germs.
   - × Granulocytes involve the following:

i) **Neutrophil:** These constitute about 70% of all the WBC. They defend the body by engulfing foreign bodies or destroying old worn out cells.

ii) **Eosinophil:** These constitute 15% of all WBC in the body, their major function is detoxification of toxins produced by foreign bodies.

iii) **Basophil:** These constitute 0.5% of all WBC in the body. It produces heparin, an anticlotting protein and histamine, a chemical found in damaged tissues which is involved in inflammation.

2. **Agranulocytes:**
   - These are WBC that don't contain any granules in their cytoplasm and can't be stained. They possess large rounded nucleus.
   - These cells originate in the bone marrow and lymph nodes they are either monocytes or lymphocytes.
   - **Monocytes**; are leucocytes which enter the tissues from which they develop into macrophages which carryout phagocytosis to defend the body against pathogens.
   - They have bean shaped nucleus.
   - **Lymphocytes**; they are produced in the thymus gland and lymph nodes. The precursor cells of lymphocytes in the bone marrow form a tissue which is called the lymphoid tissue.
   - Lymphocytes; are usually round and they possess a small quantity of the cytoplasm.
   - Lymphocytes produce antibodies, agglutins, lysins, opsonins, and antitoxins

Function of White Blood Cells

- They defend the body against disease causing organisms (antigens) by producing antibodies. The antibodies defend the body by:
  The antibodies defend the body by.

i. **Agglutination:**
   - Some antibodies have many binding sites and can join the antigens of many different pathogens. In this way, the pathogens can be joined together in clumps making them vulnerable to attack from other types of antibody.

ii. **Precipitation:**
   - Some antibodies bind together soluble antigens into large units which are thus precipitated out of solution. As such, they are more easily ingested by phagocytes.

iii. **Neutralization:**
   - Certain antibodies bind toxic molecules produced by pathogens and in doing neutralize their harmful effects.

iv. **Opsonisation:**
   - Antibodies bind cell surface antigens on bacteria cells and make them more susceptible to being digested by phagocytes.

v. **Lysis:**
   - Some breakdown pathogens' membranes and cell walls if they have them leading to water getting into it by pinocytosis. The pathogens swell and burst in the process called lysis.
   - They also defend the body by engulfing foreign materials (phagocytosis/endocytosis).

NB: The number of white blood cells increases during infection because the body manufactures more white blood cells to attack the disease causing organisms and prevent the infection from proceeding.

⌦ They have a lifespan of 21 days.

Adaptations of the white blood cells

- ➢ They do not have fixed shape and hence the amoebic movements used to engulf pathogens.
- ➢ They are larger than the pathogens.
- ➢ They are numerous
- ➢ Some lymphocytes produce antibodies which attack pathogens.

- They have an irregular shaped nucleus which allows them to squeeze through the narrow capillaries.
- They have a sensitive cell surface membrane that detects micro-organisms.
- They have enzymes in their cytoplasm to digest the engulfed micro-organisms.
- They have a large nucleus which contains many genes for the control of the antibody production.

PLATELETS/ THROMBOCYTES

- They are cell fragments
- They lack nuclei

Functions

- They play a role in blood clotting which protects the body against excessive loss of blood and entry of pathogens through the injured part.

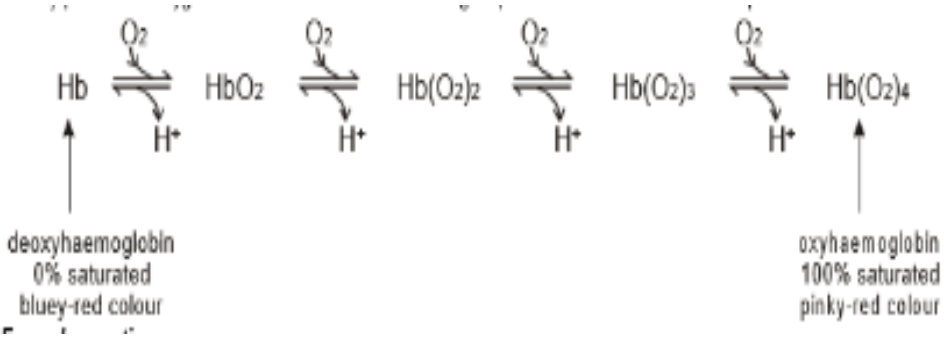
TRANSPORT OF OXYGEN

Oxygen is carried in red blood cells bound to the protein haemoglobin.

HAEMOGLOBIN

- Haemoglobin is a large and complex molecule that is composed of four polypeptide chains therefore it has a quaternary structure arranged around four haem groups.
- Two of the polypeptide chains are coiled to form α-helix, and this in turn is folded on itself into a roughly spherical shape, the other two chains are called ß-chains due to unique primary structures in both types of chains.
- Various kinds of chemical bonds, together with electrostatic attraction, keep the folds of the chain together and maintain the shape of the molecule.
- Haemoglobin is an example of a conjugated protein: attached to the hydrophobic crevice of the polypeptide chain is a flat group of atoms, the prosthetic group, consisting of a central iron atom held by rings of nitrogen atoms, which are part of a large structure known as porphyrin rings.
- The prosthetic group is haem and it is to the iron atom in the middle of it that the oxygen molecule becomes attached. The presence of four haem groups means that a single molecule of haemoglobin can carry four molecules of oxygen.
- Haem belongs to a class of organic compounds known as the porphyrins.
- One haemoglobin molecule can bind up to four oxygen molecules. When this happens, a conformational change occurs that exposes the next haem group for binding with oxygen.
- Thus, oxygen easily binds to a haemoglobin molecule that already possesses oxygen. This means there are 4 binding steps as shown in this chemical equation:

Check diagram in understanding biology page 414 fig. 21.2



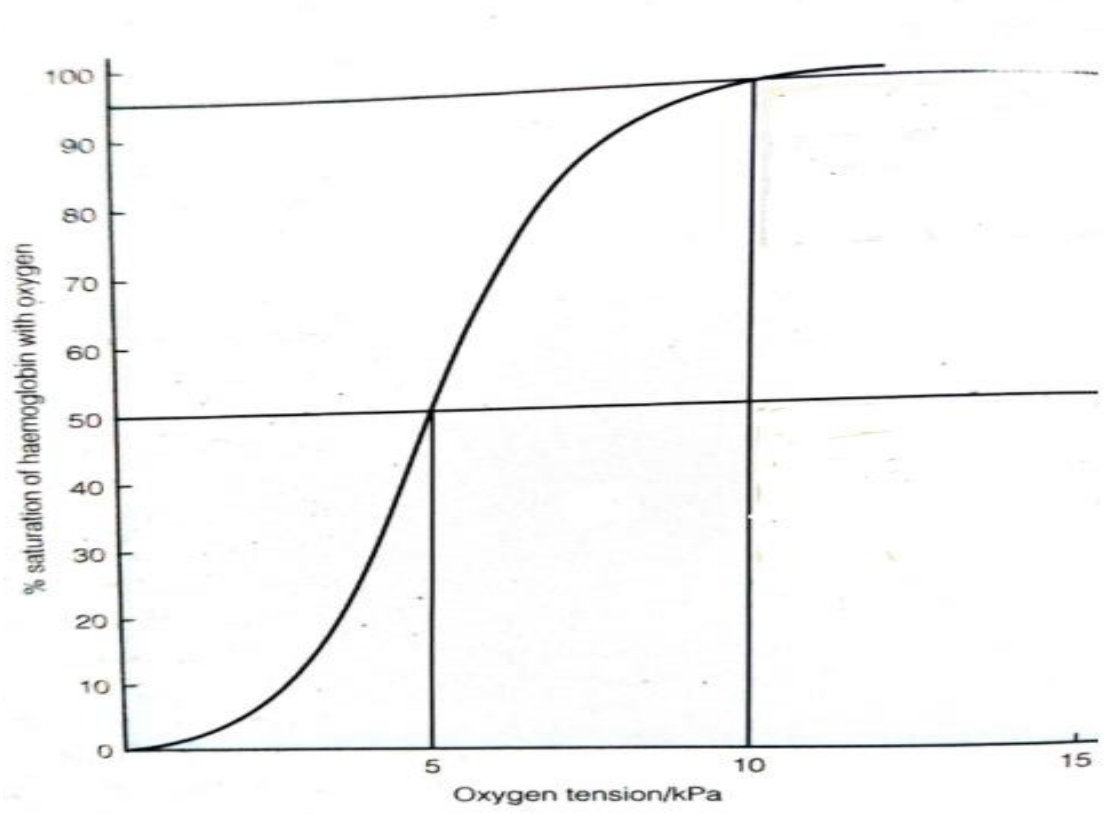
OXYGEN TENSION AND OXY-HAEMOGLOBIN FORMATION

- ✓ The ability of erythrocytes to carry oxygen to the tissues is due to haemoglobin having a high affinity for oxygen i.e. it can readily combine with oxygen and becomes fully saturated with it at relatively low partial pressures of the gas.
- ✓ Partial pressure of a gas is the measure of the concentration of a gas expressed in Kilo Pascals (KPa) or millimeters of mercury (mmHg); **oxygen tension**
- ✓ The high affinity of haemoglobin for oxygen is measured experimentally by determining the percentage saturation of haemoglobin with oxygen. When the percentage saturation of blood with oxygen is plotted against the partial pressure of oxygen an S-shaped curve or sigmoid curve is obtained and this curve is called the oxygen dissociation curve.

OXYGEN DISSOCIATION CURVE

- This is a graph illustrating the relationship between the partial pressure of oxygen and the percentage saturation of haemoglobin with oxygen.

A sample ODC



OR check fig.21.3 in understanding biology page 414
Or advanced biology by Micheal kent page 129 fig.3

- The curve indicates that a slight increase in the partial pressure of oxygen leads to a relatively sharp/ steep increase in the percentage saturation of haemoglobin with oxygen.
- This indicates that haemoglobin has a high affinity for oxygen in that it readily combines with it and become saturated with it at even low partial pressures of oxygen.

- The S-shaped curve is due to the way in which haemoglobin binds to oxygen. The first molecule of oxygen combines with a haem group with difficulty and distorts the shape of the haemoglobin molecule during the process.
- The remaining three haem groups bind with three oxygen molecules more quickly than the first one which increases rapidly the percentage saturation of haemoglobin with oxygen.
- When oxyhaemoglobin is exposed to regions where the partial pressure of oxygen is low, e.g. in the respiring tissues, the first oxygen molecule is released easily and faster but the last one is released less readily with a lot of difficulty and least readily.
- The steep part of the curve corresponds to the range of oxygen partial pressures found in the tissues.
- Beyond this part of the curve, any small drop in oxygen partial pressure results into a relatively large decrease in the percentage saturation of blood due to the dissociation of oxyhaemoglobin to release oxygen to the tissues.
- In conclusion, the curve indicates that haemoglobin has a high affinity for oxygen where the oxygen tension is high e.g. in the alveolar capillary of the lungs. However, the affinity of haemoglobin for oxygen is lower where the oxygen tension is low and instead it dissociates to release oxygen e.g. in the blood capillaries serving blood to respiring tissues.

Note;

1. Animals which burrow into oxygen-deficient mud have haemoglobin which has a high affinity for oxygen. The oxygen dissociation curve for the lugworm is therefore situated to the left of human blood.
2. The oxygen supply can be according to the requirements of different times, with skeletal muscles getting more during exercise or the intestinal tract more during digestion. Of particular importance is the constant flow of blood to the brain.
3. Unloading tension id measured at 50% and loading tension at95%
4. Haemoglobin can never be 100% saturated because of the continual use of part of oxygen it carries for the body functioning.
5. The more the ODC of a pigment is to the left the more it readily picks up oxygen and the less it releases it.
6. The more the ODC of a pigment is to displaced to the left, the less it readily picks up oxygen, but the more it releases it.

EFFECT OF CARBON DIOXIDE ON THE OXYGEN DISSOCIATION CURVE

- Increase in carbon dioxide concentration decreases the affinity of haemoglobin for oxygen, by making the pH of the surrounding medium more acidic; low, thereby shifting the oxygen dissociation curve to the right. This shifting of the curve to the right is known as **Bohr's effect.**

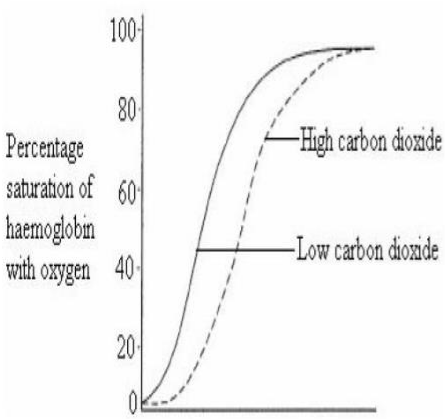
BOHR'S EFFECT

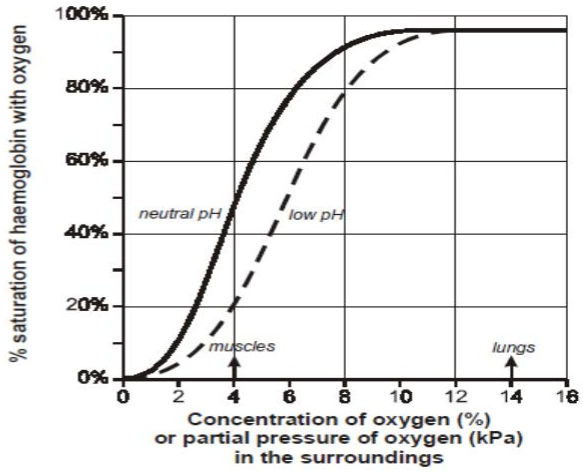
☑ This is shifting of the oxygen dissociation curve to the right due to the increase in partial pressures of carbon dioxide which results into haemoglobin having a low affinity for oxygen and a high affinity for carbon dioxide.

Definition;

✓ **Bohr's effect** may be defined as the rightward and downward shift of the oxygen dissociation curve of haemoglobin due to high carbon dioxide concentration or a fall in pH.; how it occurs

- ✓ CO_2 dissolves to form a weak acid which dissociates to release hydrogen ions. The hydrogen ions released combine with haemoglobin (Hb) and make it less able to carry O_2; it reduces haemoglobin affinity for O_2.
- ☑ From the dissociation curves below, shifting the oxygen dissociation curve to the left means that haemoglobin has a higher affinity for oxygen and therefore becomes fully saturated with oxygen it at very low partial pressures of oxygen. It also means that haemoglobin has a low rate of dissociation to release oxygen to the tissues but a high rate of combining with oxygen.
- ☑ Shifting of the oxygen dissociation curve to the right means that haemoglobin has a lower affinity for oxygen and a higher rate of dissociation to release oxygen to the tissues rapidly to support tissue respiration





From graph 2

- ❖ In tissues, like muscle, liver or brain, oxygen is used by respiration, so is low, typically about 4 KPa. At this PO_2 the haemoglobin is only 50% saturated, so it unloads about half its oxygen (i.e. from about 100% saturated to about 50% saturated) to the cells, which use it for respiration.
- ❖ In tissues that are respiring quickly, such as contracting muscle cells, the PO_2 drops even lower, to about 2 KPa, so the haemoglobin saturation drops to about 10%, so almost 90% of the oxygen is unloaded, providing more oxygen for the muscle cells.
- ❖ Actively-respiring tissues also produce a lot of CO_2, which dissolves in tissue fluid to make carbonic acid and so lowers the pH, so low pH reduces the % saturation of haemoglobin at any PO_2. This is shown on the graph by the dotted line, which is lower than the normal dissociation curve. So at a PO_2 of 2%, the actual saturation is nearer 5%, so almost all the oxygen loaded in the lungs is unloaded in respiring tissues.



Hope you can now understand that oxygen is supplied depending on the need!

EFFECT OF CARBON MONOXIDE ON THE OXYGEN TRANSPORT

- × There's a loose and reversible reaction between oxygen molecules and iron (II) atoms of haem groups of haemoglobin to from oxyhaemoglobin. This means that iron (II) is not oxidized to iron (III) as haemoglobin combines with oxygen.
- × In the presence of carbon monoxide and oxygen, haemoglobin readily combines with carbon monoxide to form a permanent compound carboxy haemoglobin rather than combining with oxygen.

- This is so because carbon monoxide oxidizes iron (II) to iron (III). This reduces the free haemoglobin molecules available for transport of oxygen to the tissues that may result into anoxia; total lack of oxygen by the tissues.
- This is why it is referred to as a respiratory poison as it readily combines with haemoglobin faster than oxygen does and carboxy haemoglobin formed does not easily dissociate.

OTHER BLOOD PIGMENTS

MYOGLOBIN

- Myoglobin is a respiratory pigment which also contains iron containing haem groups mostly found in the muscles where it remains fully saturated at partial pressures below that required for haemoglobin to give up its oxygen.
- Myoglobin has a higher affinity for oxygen than haemoglobin in a way that it combines readily with haemoglobin and it becomes fully saturated with oxygen at a lower partial pressure of oxygen.
- Myoglobin acts as a store of oxygen in resting muscles in form of oxymyoglobin and only releases the oxygen it stores only when oxyhaemoglobin has been exhausted i.e. many vigorous activities because myoglobin has a higher affinity for oxygen than haemoglobin.
- The oxygen dissociation curves for myoglobin lies to the left of that of haemoglobin.

  ☺ **Sketch this please and check fig 21.8 in understanding biology page 417 or Micheal kent page 131 fig.3**

Other pigments

pigment	Atom present	Organisms that use it
Haemocyanin	copper	Molluscs, crustaceans and arachnids
Haemoerythrin	iron	Annelids
Chlorocruorin	iron	annelids

SOME CASE STUDIES OF OXYGEN DISSOCIATION CURVES

a. Lug worm

Check understanding biology page 416 fig. 21.5

- ✓ The oxygen dissociation curve of the lugworm's haemoglobin lies on the left of that of man's haemoglobin.
- ✓ This indicates that the haemoglobin of the lugworm has a higher affinity for oxygen than that of man. This is because the lugworm lives in oxygen deficient mud and so in order to extract enough oxygen from that environment of low oxygen tension, the haemoglobin of the lugworm must have a higher affinity for oxygen than that of man thriving in a well-supplied environment with oxygen.
- ✓ This implies that the lugworm's haemoglobin dissociates slowly to release oxygen to its tissues compared to that of man which makes the lugworm less active than man, who releases much oxygen rapidly to the tissues

b. Fetal haemoglobin

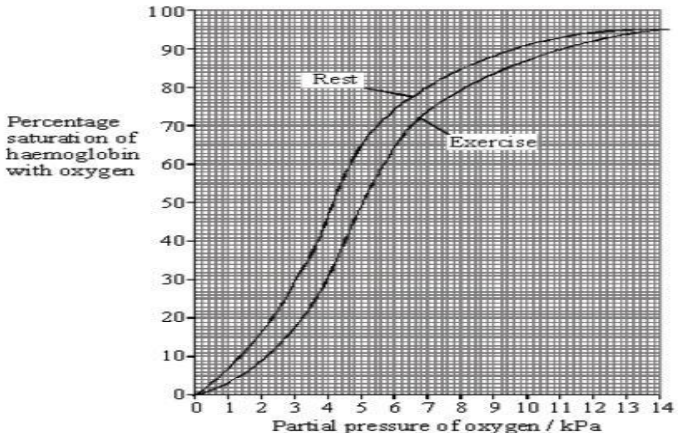
Check understanding biology page 416 fig. 21.7

- ✓ The oxygen dissociation curve of foetal haemoglobin lies to the left of maternal haemoglobin
- ✓ This indicates that the foetal hemoglobin has a higher affinity for oxygen than that of the mother. This enables the foetal haemoglobin to pick sufficient oxygen from

the mother via the placenta and also increases on the oxygen carrying capacity to the tissues, especially when the foetus needs a lot of energy.

✓ It also increases on the oxygen carrying capacity to the tissues of the foetus in the situation whereby deoxygenated and oxygenated blood are mixed due to the bypasses of ductus arteriosus and foramen ovale in the foetus.

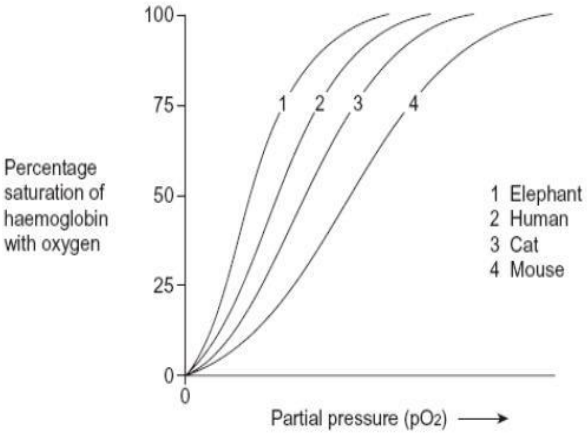
c. At rest and exercise;



➢ During exercise; oxyhaemoglobin releases oxygen more readily hence the oxygen dissociation curve during exercise is to the right of that when the individual is at the right of the curve when at rest.

➢ This is so because the person at exercise has a high metabolic activity that requires sufficient oxygen supply which must be met by haemoglobin

d. Size of different organisms.



× Small animals have higher metabolic rates and so need more oxygen per gram of tissue than larger animals. Therefore they have blood that gives up oxygen more readily i.e. their dissociation curves are on the right of the larger animals in order to meet this demand.

EFFECT OF CHANGE IN ALTITUDE ON OXYGEN CARRIAGE

- <u>The amount of oxygen in the atmosphere is the same at high altitudes as it is at sea level namely 21%. The respiratory problems associated with living at higher altitudes are due to reduced atmospheric pressure.</u>
- There is a decrease in the partial pressure of oxygen in the atmosphere with increase in altitude from sea level. Therefore the volume of oxygen fixed is less at high altitudes than at sea level.
- When an organism moves from the sea level to high altitudes, very fast, such an organism tends to develop symptoms of anoxia which include headache, fatigue, nausea, and becoming unconscious.
- However, when an organism moves slowly from sea level to high altitudes like the mountain climbers, such an organism can at first develop symptoms of anoxia but later on such symptoms disappear due to adjustments in the respiratory and circulatory systems in response to insufficient oxygen reaching the tissues from the surrounding;
- The amount of haemoglobin and the red blood cell count increases together with the rate of breathing and the heartbeat.

- More red blood cell formation occurs in the bone marrow under the control of the hormone called *erythropoietin* secreted by the kidney.
- Secretion of erythropoietin is stimulated by lower oxygen tension in the tissues.
- In order for the person to overcome such challenges acclimatization occurs;

Acclimatization; is therefore a condition whereby an organism carries out a series of physiological adjustments in moving from a low altitude area to a high one to avoid symptoms of anoxia so that such an organism can survive in an environment of low oxygen content.

Adjustments involved in acclimatization

1. Adjustments in pH; the reduced loading of haemoglobin leads to deeper breathing/ hyperventilation, this leads to excessive removal of carbon dioxide caused a raised pH.
2. Increased oxygen uptake
3. Improved transport of oxygen to tissues i.e increased red blood cell and haemoglobin concentration
4. Changes in haemoglobin affinity
5. Increased myoglobin levels in muscles.

Note;

- ✓ The mammals that live in regions of the world beyond the sea level e.g. mountains solve the problem of lack of enough oxygen in the atmosphere by possessing haemoglobin with a higher affinity for oxygen than that of mammals at sea level. This enables the high altitude mammals to obtain enough oxygen through the oxygen deficient environment.

DIVING ANIMALS

Diving mammals e.g. seals, dolphins and whales.

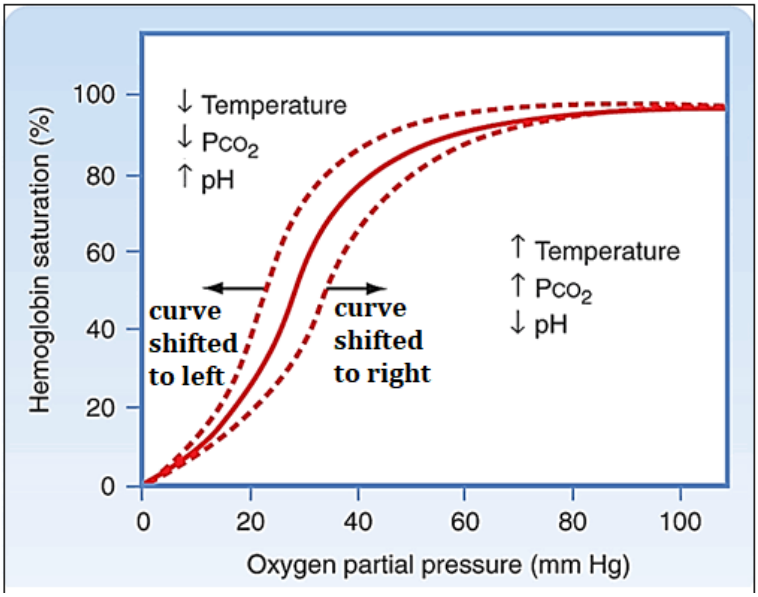
a. They have a large spleen which can store large volumes of blood e.g. the seals spleen stores 24l of blood after the dive has begun, the spleen contracts and supplies the blood in circulation with additional erythrocytes that are highly leached with oxygen.
b. Have high concentration of myoglobin in their muscles. Myoglobin is an oxygen storing protein.
c. Mammals during the diving reflex slow down the pulse as the heart beat is also slowed down in order to effect an overall reduction on oxygen consumption since there is reduced cardiac output to the tissues.
d. Store oxygen in their blood as oxyhaemoglobin and this they achieve by having concentration of haemoglobin.
e. Blood supply to muscles is restricted and completely cut off during the longest dives hence encouraging anaerobic instead of aerobic respiration.
f. In this way, the muscles use sparingly oxygen stored in their myoglobin.

Mammals living at high altitudes

a. These possess an improved capillary network in the lungs which coupled with their deeper breathing (hyperventilation) insures increased oxygen uptake.
b. They have an increased red blood cell which increases the amount of oxygen transported by blood.
c. Increased haemoglobin concentration in the red blood cells which improves the amount of oxygen transported by the blood.

d. Changes in haemoglobin affinity for oxygen. Here the oxygen dissociation curve is shifted to the right to facilitate release of oxygen to the tissues. This particularly occurs at relatively lower altitudes.
e. Mammals living at altitudes about 3500m have their oxygen dissociation curves shifted to the left this favours their survival by promoting an increased affinity for oxygen by haemoglobin.
f. Increased myoglobin levels in muscles myoglobin has a higher affinity for oxygen than haemoglobin. This facilitates the exchange of oxygen from the blood to the tissues making oxygen available to the tissues

EFFECT OF TEMPERATURE ON OXYGEN TRANSPORT



- A rise in temperature lowers the affinity of haemoglobin for oxygen thus causing unloading from the pigment i.e. a rise in temperature increases the rate of dissociation of oxyhaemoglobin to release oxygen to the tissues.
- Increased tissue respiration which occurs in the skeletal muscles during exercise generates heat. The subsequent rise in temperature causes the release of extra oxygen from the blood to the tissues. <u>This is so because increase in temperature makes the bonds (oxy-haemoglobin) which combine haemoglobin with oxygen to break, resulting into the dissociation of oxyhaemoglobin.</u>

CARBON DIOXIDE TRANSPORT

Carbon dioxide is more soluble than oxygen in water, but its transport in solution is still inadequate to meet the needs in most animals.

There are three methods of carrying oxygen from the tissues to the respiratory surface;

1. As dissolved gas in blood plasma (5%); Very little travels this way as CO_2 is not very soluble in water (about 0.02%)
2. As Carbamino Haemoglobin (10%); Carbon dioxide can bind to amino groups in haemoglobin molecules forming Carbamate ions
   Since there are so many haemoglobin molecules in red blood cells, and each one has many amino groups, quite a lot of CO_2 can be carried this way
3. As Hydrogen carbonate ions (85%)

DETAILS OF CARBON DIOXIDE TRANSPORT IN FORM OF HYDROGEN CARBONATE

- When carbon dioxide is formed during respiration, it diffuses from the tissues into the erythrocytes, via their thin and permeable membrane. Inside the erythrocytes, carbon dioxide reacts with water in the presence of carbonic anhydrase enzyme to form carbonic acid as shown below;

$$H_2O\ (l) + CO_2\ (g) \xrightarrow[\text{Carbonic anhydrase}]{} H_2CO_3\ (aq)$$

- The formed carbonic acid then dissociates into hydrogen ions and bicarbonate ions as shown below

$$H_2CO_3\ (aq) \rightleftharpoons H^+\ (aq) + HCO_3^-\ (aq)$$

- The formed hydrogen ions decrease the pH in erythrocytes which results into the dissociation of oxyhaemoglobin being carried from the lungs to the tissues into the free haemoglobin molecules as free oxygen molecules.
- The free oxygen molecules diffuse into tissues to be used in respiration. The free haemoglobin molecules buffer the hydrogen ions inside the red blood cells into a weak haemoglobinic acid.

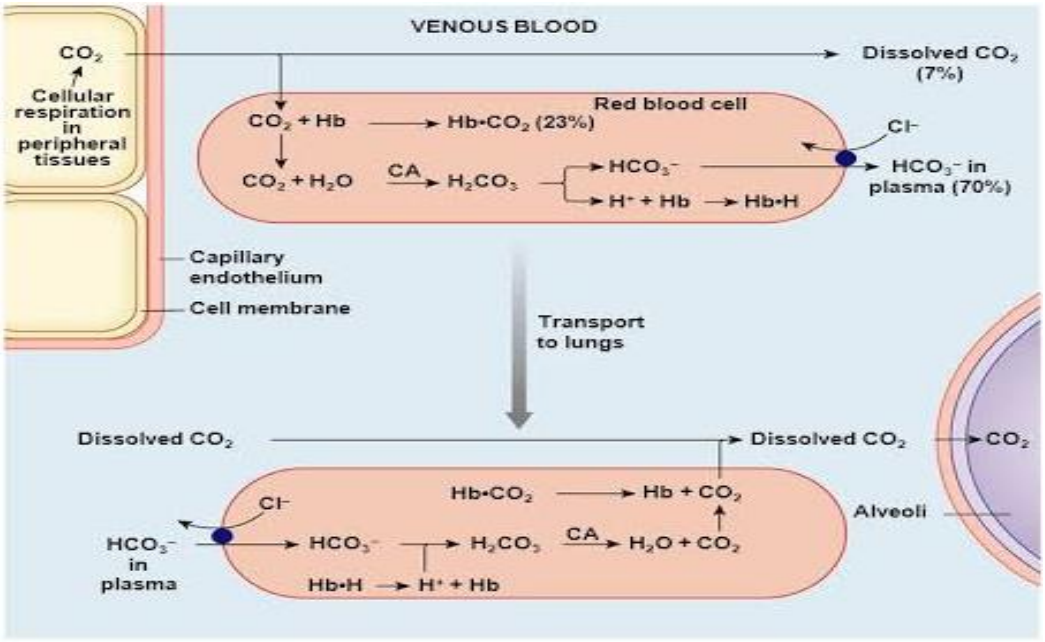
$$H^+ + Hb \longrightarrow HHb$$

- The formed hydrogen carbonate ions within the erythrocytes diffuse out into the plasma along the concentration gradient and combine with sodium to form sodium hydrogen carbonate which is then taken to the lungs.
- The outward movement of bicarbonate ions from the erythrocytes into the plasma results into an imbalance of positively charged and negatively charged ions within the cytoplasm. In order to maintain electrochemical neutrality, to remove this imbalance in the red blood cells, chloride ions diffuse from the plasma into the red blood cells, a phenomenon known as the **chloride shift.**

Chloride shift; <u>the movement of chloride ions into the red blood cells as hydrogen carbonate ions leave during the picking up of carbon dioxide by blood in order to restore electro-neutrality of the cell.</u>

- When the bicarbonate ions reach the lungs, they react with H^+ to form carbonic acid which eventually dissociates into carbon dioxide and water.
- The carbon dioxide and water formed from the dissociation of carbonic acid in the lung capillaries are then expelled out by the lungs during exhalation so as to maintain the blood pH constant

Illustration of carbon dioxide transport



CIRCULATORY SYSTEMS IN ANIMALS

Every circulatory system in animals is modified in one way or the other to ensure proper functioning. However it must have the following;

- ✓ It has a circulating fluid e.g. blood or lymph
- ✓ It has a pumping device inform of a modified blood vessel or a heart.
- ✓ It has tubes through which the fluid can circulate e.g. blood vessels.

There are two types of circulatory systems viz;

- Water circulatory system
- Blood circulatory system

WATER CIRCULATORY SYSTEM

It exists in lower animals like sponges and hydra where water from the surrounding medium acts as a circulatory fluid. They include;

i) Canal system:

- × It exists in poriferans like sponges. They have a system of tubes called canal system which could be simple or complex depending on the organization of the sponge.
- × All canals ultimately communicate to the exterior through the numerous pores called Ostia. The body of the sponge is in form of a cylinder enclosing a cavity called spongocoel with a large opening called osculum.
- × The beating of flagella lining the canals causes the current of water to enter through Ostia which are like inhalant siphon.
- × The current of water bring in food and oxygen for the sponge. As the water moves through the various canals, food is taken in and wastes are given out and finally the water leaves the sponge through the osculum i.e. exhalent siphon.

ii) **Coelenterons water filled cavity**:

- × All coelenterates possess a single large cavity called coelenteron lined by endodermal cells. This cavity has a single opening through which water enters and leaves the animal.
- × The water carrying food and oxygen passes in through the mouth and circulates through the coelenteron. After collecting the wastes and carbon dioxide the water leaves the coelenteron through the same mouth opening.
- × The flagellated cells of the endoderm direct the movement of water.

BLOOD VASCULAR SYSTEM/ CIRCULATORY SYSTEM

- ⊠ It exists in all higher animals where the heart and blood vessels together with the circulatory fluid; blood constitutes a blood vascular system.
- ⊠ The heart Pumps and conducts the circulatory fluid to various tissues.
- ⊠ Arteries take blood away from the heart and veins bring blood back to the heart.
- ⊠ The higher invertebrates and vertebrates have two types of circulatory systems

i) Open circulatory system and
ii) Closed circulatory system

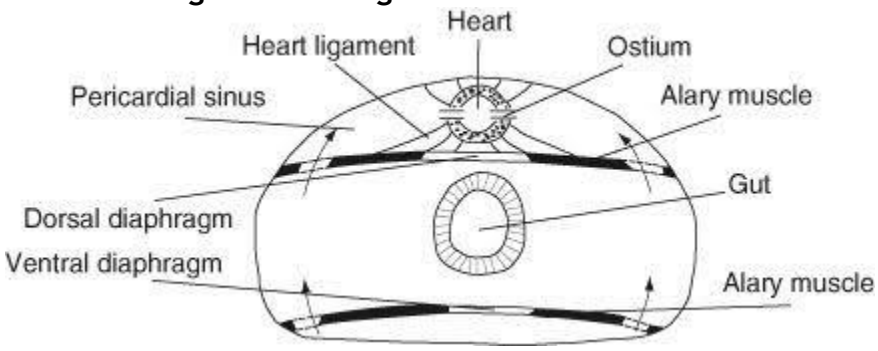
OPEN VASCULAR SYSTEM

- ✓ Open circulation is the flow of blood through the body cavities called Haemocoel instead of flowing in blood vessels. This exists in most arthropods, molluscs and tunicates.
- ✓ In this system, blood is pumped by an aorta which branches into a number of arteries which open into the haemocoel. From the haemocoel, blood under low

pressure moves slowly to the tissues where there's exchange of materials e.g. gases, nutrients etc. from the haemocoel blood percolates back into the heart via the open ended veins.

- ✓ In insects the haemocoel is divided into two parts by a transverse pericardial membrane forming a pericardial cavity dorsally and a perivisceral cavity ventrally.
- ✓ In the body of the insects there are no blood vessels except the tubular heart which is suspended in the pericardial cavity by slender ligaments and extends through the thorax and abdomen.
- ✓ The heart is expanded in each segment to form a total of 13 small chambers which are pierced by a pair of tiny tubes called Ostia.
- ✓ The Ostia allow blood to flow from one segment of the chamber to another.
- ✓ Alary muscles are located at each chamber of the heart.

Diagram showing the heart of the insect



Mechanism of open vascular system

- Blood flows through the heart from the posterior end to the anterior end by waves of contractions which begin from the posterior end and proceed to the anterior end. These waves of contractions enable blood to flow through the heart and then enter the perivisceral cavity.
- During systole, the heart ligaments are stretched with a result that during diastole they pull the heart walls outwards, thereby decreasing the pressure in the heart and increasing its volume.
- This results into sucking of blood into the heart via the Ostia from the perivisceral cavity which has a higher pressure than the pericardial cavity. The back flow of blood is prevented by the valves found between the ostium.
- During diastole, the alary muscles contract which increases the volume of the heart and reduces the pressure at the same time.
- The drop in pressure leads to movement of blood from the haemocoel through the Ostia into the heart. Contraction of the alary muscles also has the effect of pulling the pericardial membrane downwards, thereby raising the blood pressure in the perivisceral cavity and decreasing it in the pericardial cavity, hence blood flows into the pericardial cavity. And the cycle continues.

CLOSED VASCULAR SYSTEM

- A closed circulatory system is one where blood is confined to blood vessels throughout its course of circulation in the body.
- This is present in all vertebrates and higher invertebrates like annelids,
- There are two types of closed circulatory systems;

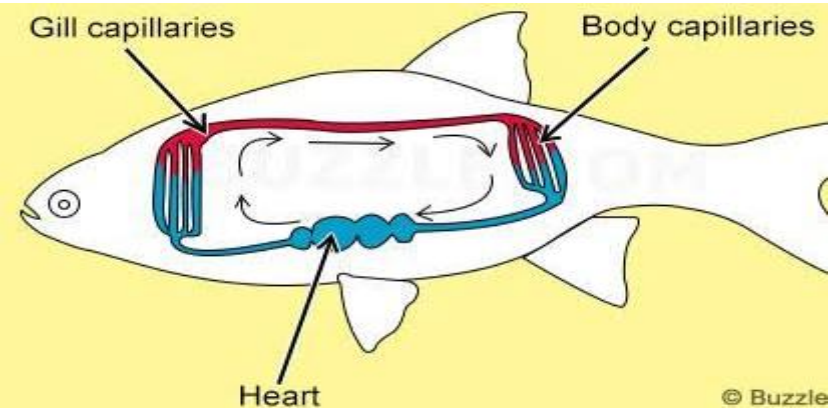
1. The single circulatory system: in this case the blood flows through the heart once in each complete circulation.
2. The double circulatory system. In this case the blood flows through the heart twice in each complete circulation.

SINGLE CIRCULATORY SYSTEM

- Single circulation is the flow of blood through the heart once for every complete circulation around the body.

a. Single circulation in fish

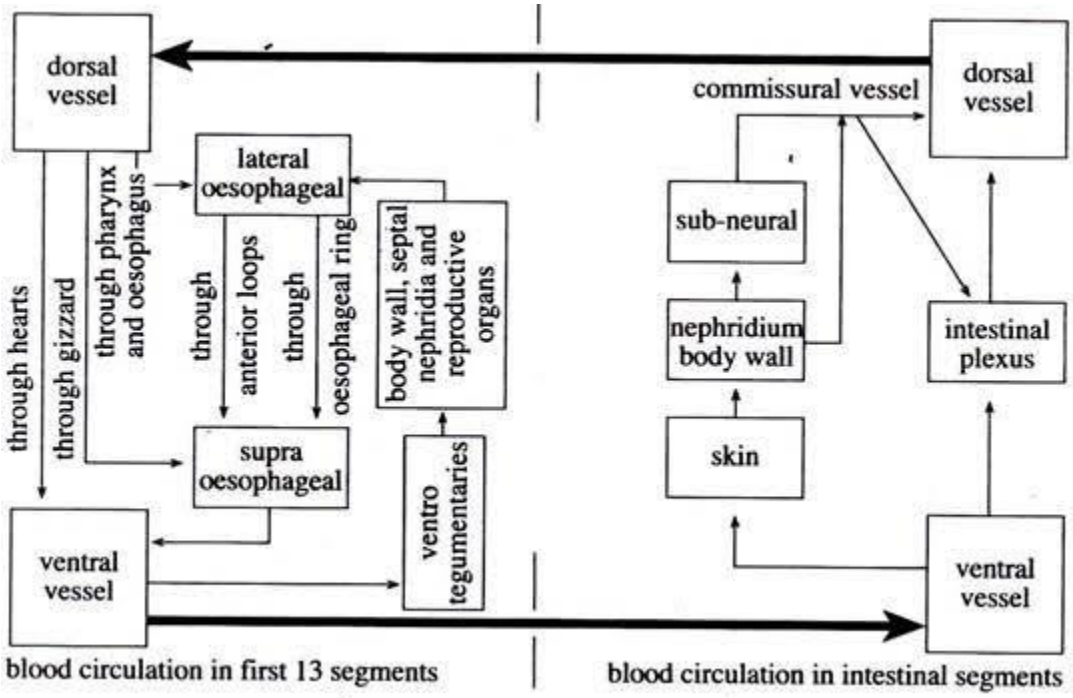
- The deoxygenated blood from the body tissues is pumped by the heart to the gills from where it flows back to the body tissues and eventually returns to the heart.



b. Single circulation in earthworms

- In the earthworm the circulatory fluid blood consists mainly of water in which are dissolved gases, sugars, amino acids, salts and many other molecules and ions taking part in metabolism.
- The blood also has haemoglobin and this makes it able to carry oxygen. However this haemoglobin is not confined in blood cells but is dispersed in the blood.
- The circulatory system here consists of a system of large longitudinal blood vessels on both the dorsal and ventral parts of the body which end in capillaries where exchange of materials between the blood and organs like the skin, intestines, nephridia and other tissues takes place. In addition to these blood vessels there is a “heart” which in essence consists of five pairs of aortic loops whose walls are capable of muscular contraction.
- Blood is propelled from the aortic loops when muscles contract. Blood flows through vessels to organs and tissues where they terminate into capillaries. Once through the capillaries the blood is collected by a branching network of blood vessels leading into the dorsal blood vessel.
- This vessel contracts rhythmically forcing blood to flow forward to the anterior of the animal until it reaches the aortic loops and the cycle is repeated.

Illustration of blood flow in parts of an earthworm



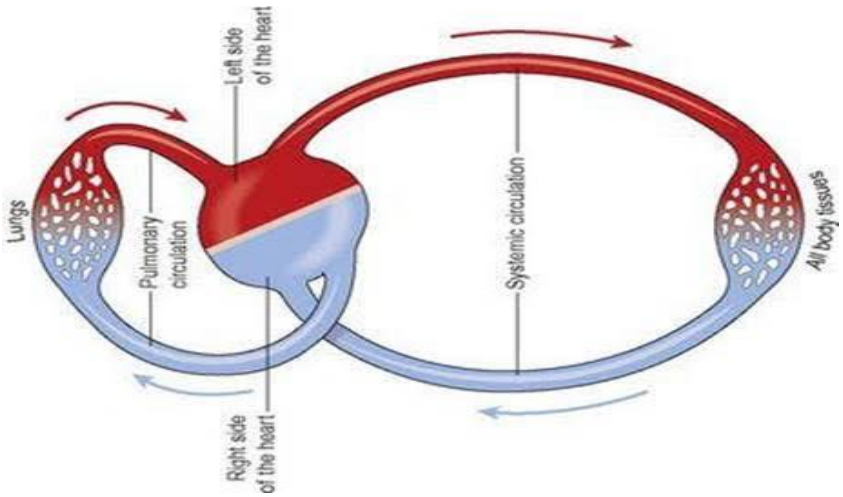
Functions of blood circulation in earthworm

- Transport of; nutritive molecules, respiratory gases and nitrogenous wastes
- Defense against diseases. The blood has amoebocytes which engulf any disease causing organisms in the blood.

N.B in all organisms almost the general functions of blood are important

DOUBLE CIRCULATORY SYSTEM

- This is one where blood passes through the heart twice in one complete circulation. This is a characteristic of all members of the vertebrata with the exception of the fish.
- Blood entering the heart first flows to the lungs and back to the heart which is known as pulmonary circulation after which it is then pumped to the rest of the body. This is known as systemic circulation. For this reason higher blood pressure can be attained than in single circulation.

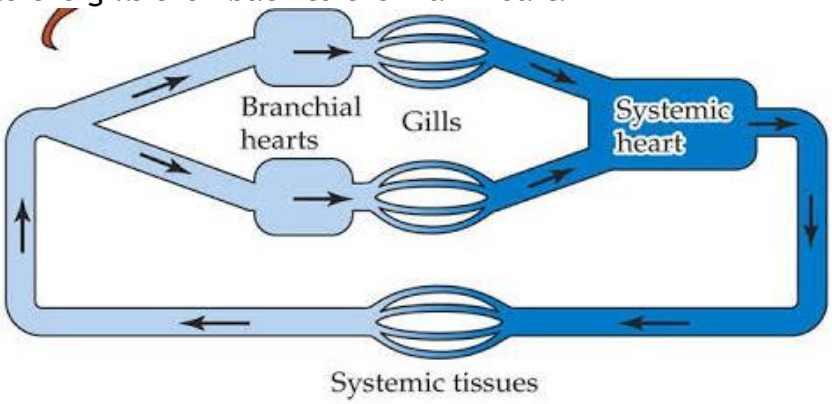


a. Double blood circulation in amphibians

- The heart is three chambered with two atria and a single ventricle.
- Both deoxygenated and oxygenated blood in the frog flow through the same ventricle and conus arteriosus at the same time without mixing
- The mixing of blood which would otherwise have occurred in the ventricle is prevented by the presence of spiral valve in the conus arteriosus.
- The extensive blood supply to the lungs and the skin via pulmo-cutaneous blood vessels greatly increases the efficiency in transporting gases in addition to the presence of haemoglobin in the RBC.
- Again this is greatly enhanced by the structural arrangement of the circulatory system which ensures that blood is pumped to the skin and lungs where gas exchange occurs from the ventricles at the same pressure with that to the rest of the body.

b. Double circulation in Octopus

- High blood pressure is maintained by branchial hearts. The blood is pumped at a high pressure by the main heart to the body, then taken up by the branchial heart, to the gills then back to the main heart.



Advantages of a closed circulatory system over open one

- Relatively high pressure required for fast flow of blood is acquired than in open circulation.
- Since the blood is returned rapidly to the heart for pumping, more rapid circulation can be attained.
- The separation of oxygenated and deoxygenated blood in it improves efficiency of oxygen distribution and therefore sustain the high metabolic rate required by such animals.
- The blood is piped directly to where it is needed.
- The amount flowing to certain organs can be regulated by changing the diameter of the blood vessels.
- Blood cells and large molecules remain within vessels
- Can support higher levels of metabolic activity

Differences between open and closed circulatory system

Open circulatory system	Closed circulatory system
Blood flows through large open spaces and channels called lacunae and sinuses among tissues.	Blood flows through a system of closed chambers and tubes called the heart and blood vessels.
Tissues are in direct contact with the blood.	there is no direct communication with any tissue, open body cavity or space
blood flows under very low pressure and moves slowly through the tissues	By strong pumping action of the heart blood flows with great pressure in the arteries
Heart pumps oxygenated blood into an	Heart pumps oxygenated blood to aorta

aorta which branches into number of arteries, which open into series of blood spaces and lacunae collectively known as haemocoel	which branches into a number of arteries, then to arterioles and finally to a network of capillaries all over the body
Blood takes comparatively longer time to circulate through the whole body	Blood takes a much shorter time to circulate through the body
Exchange of gases takes place directly between blood and tissues	Nutrients and gases pass through the capillary wall to the tissues
Volume of blood flowing through a tissue cannot be controlled as blood flows out in open spaces	Volume of blood flowing through a tissue or organ can be regulated by contraction and relaxation of the smooth muscles of arteries
It is present in higher invertebrates like most arthropods, prawns, insects etc	It is present in echinoderms, some mollusks, annelids and all vertebrates

DOUBLE CIRCULATION IN MAMMALS

- Mammals have a complete double circulation. The heart is divided into a left and right section there by ensuring complete separation of deoxygenated and oxygenated blood.
- The heart is therefore two pumps in one and this is why it is able to send out different volumes of blood to different organs at different pressure. Both these pumps work simultaneously.
- The mammalian blood circulation is mainly based on the heart and blood vessels.

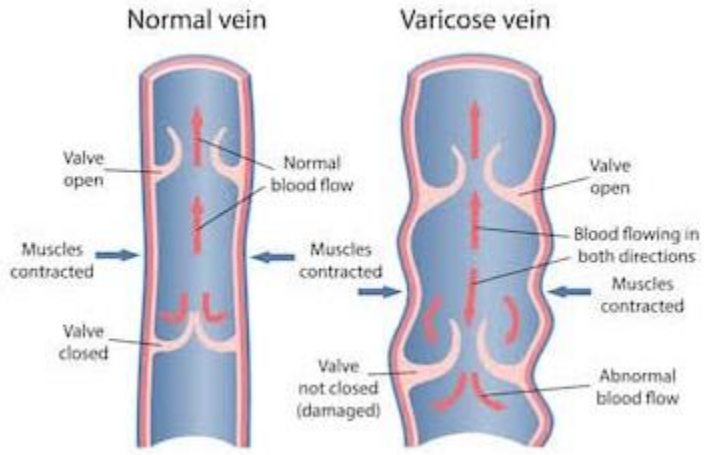
BLOOD VESSELS

In a closed circulatory system there are three types of vessels;

1. Arteries; carry blood away from the heart.
2. Veins; carry blood to the heart.
3. Capillaries; these link veins and arteries.

VEINS

- The blood has lost almost all its pressure in the capillaries, so it is at low pressure inside veins and moving slowly.
- Veins therefore don't need thick walls and they have a larger lumen than arteries, to reduce the resistance to flow.



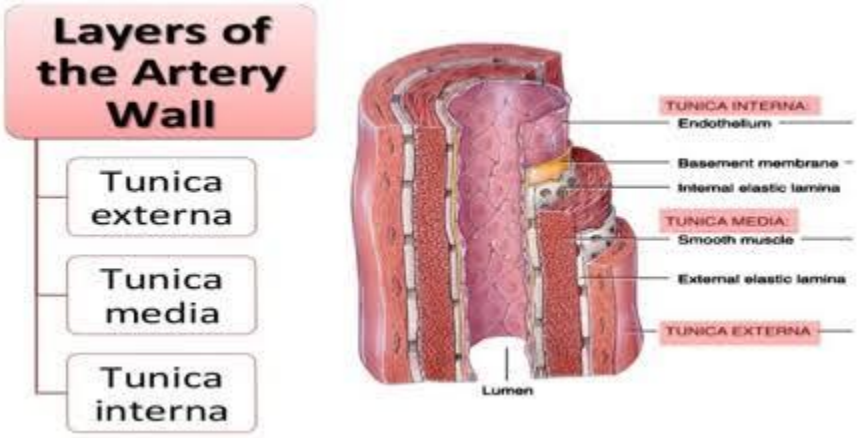
- They also have semi-lunar valves to stop the blood flowing backwards. It is particularly difficult for blood to flow upwards through the legs to heart, and the flow is helped by contractions of the leg and abdominal muscles:

Note:

× The body relies on constant contraction of these muscles to get the blood back to the heart, and this explains why soldiers standing still on parade for long periods can faint, and why sitting still on a long flight can cause swelling of the ankles.

ARTERIES

- ✓ Arteries carry blood from the heart to every tissue in the body. They have thick, elastic walls to withstand the high pressure of blood from the heart.
- ✓ The arteries close to the heart are particularly elastic and expand during systole and recoil again during diastole, helping to even out the pulsating blood flow.



- ✓ The smaller arteries and arterioles are more muscular and can contract; vaso constriction to close off the capillary beds to which they lead; or relax; vasodilation to open up the capillary bed.
- ✓ These changes are happening constantly under the involuntary control of the medulla in the brain, and are most obvious in the capillary beds of the skin, causing the skin to change colour from pink; skin arterioles dilated to blue; skin arterioles constricted.

WALLS OF ARTERIES AND VEINS

The walls of arteries and veins are made of three layers;

- **Tunica externa,** this is the outermost layer which is tough and made up of thick collagen fibres which provide strength and prevents extensive stretching.
- **Tunica media;** is the middle layer which consists of smooth muscles, collagen and elastic fibres. The structural proteins allow for the stretching of the walls of blood vessels during vaso-dilation. The smooth muscles allow for the distension and constriction of the walls of the blood vessels.
- **Tunica interna;** is the innermost layer composed of a single layer of squamous endothelium. It is found in all walls of blood vessels. Capillaries have only the tunica interna.

DIFFERENCES BETWEEN ARTERIES AND VEINS

→ Both tunica media and tunica externa are more developed in arteries than veins and therefore arteries have thicker walls than those of veins.

NOTE:

Arteries have thicker walls than veins because blood flows through them at a higher pressure than in the veins, due to the pumping action of blood by the heart. Arteries therefore have thicker walls to counteract the pressure by which blood moves through them.

→ The walls of the arteries are more elastic than those of veins, in order to overcome the pressure by which blood flows through them by rapidly stretching without bursting.

→ Also arteries have a narrower rumen than veins, which increases the pressure of the blood flowing through them.

→ Arteries also lack valves while veins haves valves which prevent the backflow of blood in veins.

NOTE:
However, arteries do not need valves since they transport blood under high pressure, which pressure ensures that blood flows forward.

→ Blood in arteries moves inform of pulses while in veins is flows smoothly without any pulse.

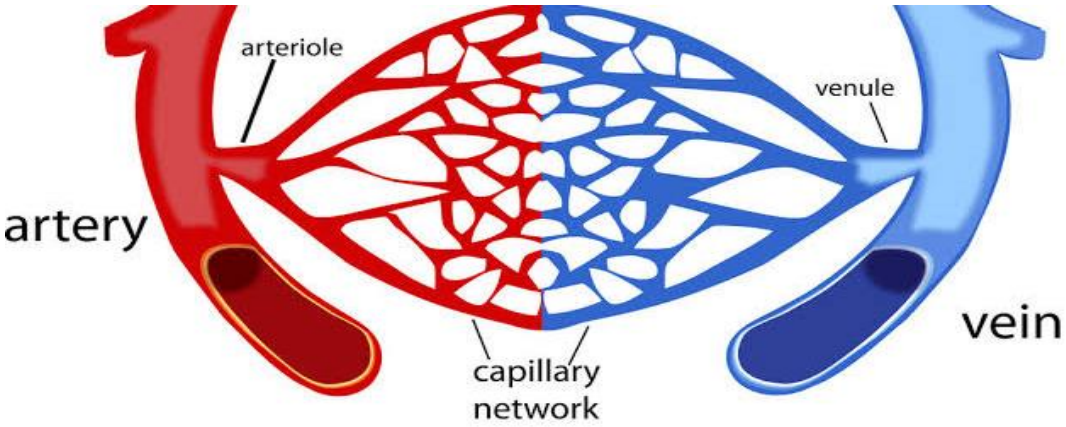
NOTE:
A pulse is a series of waves of dilation that pass along the arteries caused by the pressure of the blood pumped from the heart through contractions of the left ventricle.

→ Arteries transport oxygenated blood from the heart to the tissues except the pulmonary artery which transports deoxygenated blood from the heart to the lungs while veins transport deoxygenated blood from tissues to the heart except the pulmonary vein which transports oxygenated blood from the lungs to the heart.

CAPILLARIES

- Capillaries are where the transported substances actually enter and leave the blood. No exchange of materials takes place in the arteries and veins, whose walls are too thick and impermeable.
- Capillaries are very narrow and thin-walled, but there are a vast number of them, so they have a huge surface area to volume ratio, helping rapid diffusion of substances between blood and cells.
- Capillaries are arranged in networks called capillary beds feeding a group of cells, and no cell in the body is more than 2 cells away from a capillary.

Relationship between arteries, veins and capillaries



Adaptations of capillaries to their function;

- ✓ Blood capillaries are the smallest blood vessels found in close contact with tissues in form of a dense network which allows a high rate of diffusion of materials during their exchange between the blood circulatory system and the tissues.

- ✓ They are numerous in number to provide a large surface area which increases the rate of diffusion and allows rapid exchange of materials between blood and the tissue fluid.
- ✓ They have a thin and permeable membrane which is made up of thin flattened pavement cells which allow rapid diffusion and exchange of materials between blood and tissues with minimum resistance.
- ✓ They possess the capillary sphincter muscles which contract and relax so as to regulate the amount of blood entering into the capillary network.
- ✓ Some capillaries have a bypass arterio-venous shunt vessel which links the arterioles and venules directly so as to regulate the amount of blood which flows through the capillary network e.g. in the capillaries of the feet, hands, stomach etc.
- ✓ The capillary network offers maximum resistance to blood flowing through them hence decreasing the speed of blood flow which allows the maximum diffusion and exchange of materials between blood and the tissues.

Note;

The flow of blood is maintained by the following;

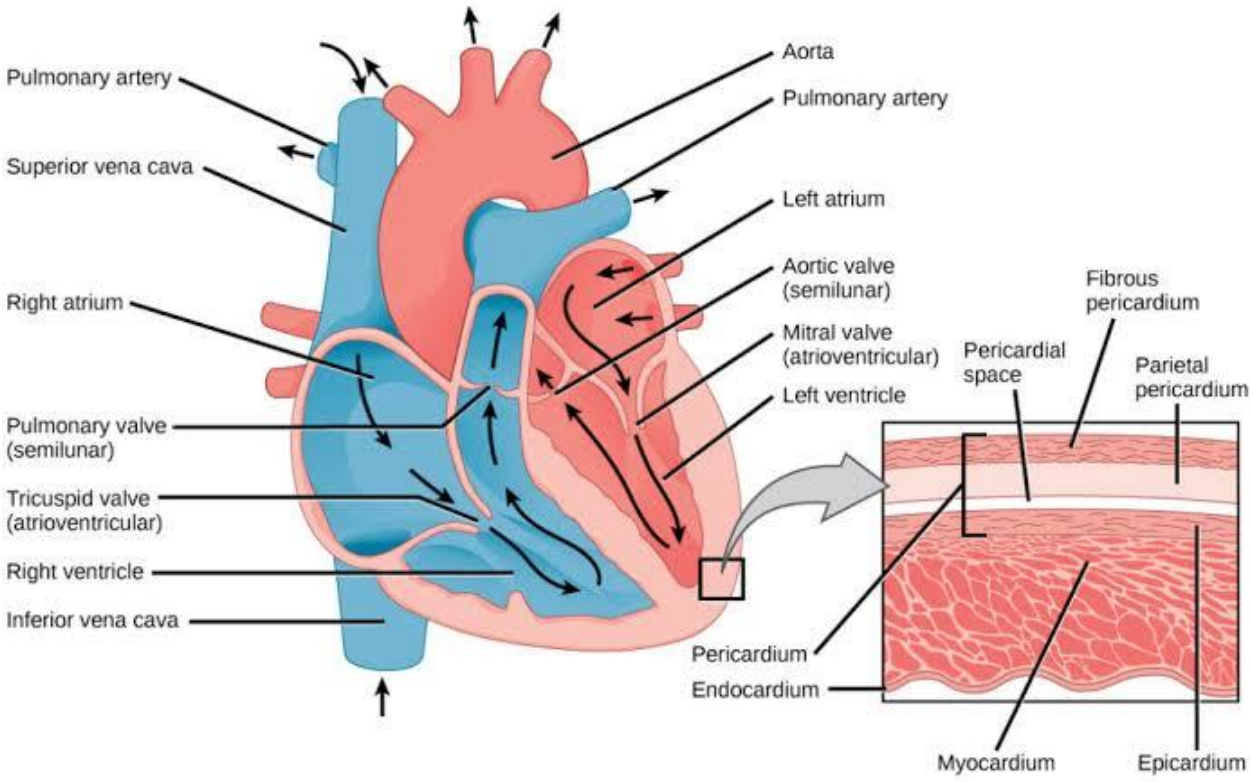
1. The pumping action of the heart; this forces blood through arteries into capillaries
2. Contraction of skeletal muscles; this squeezes the thin walled veins increasing pressure of blood within them.
3. Inspiratory movements; breathing in, reduces pressure in the thorax which enhances blood drawing towards the heart within the thorax

THE MAMMALIAN HEART

- The internal structure of the heart shows that the heart has two sides, the left side and right side. These are separated by a muscular wall known as septum.
- The heart has the atria which collects blood from the body and pumps it to the lower chambers known as ventricles.
- The ventricles pump blood to the arteries and this is the reason why they have thick walls.
- The left ventricle which pumps blood to the rest of the body has a thicker and stronger wall than the right ventricle which pumps blood to the lungs which are a shorter distance away.
- The atria and ventricles are separated by valves. The valve on left side consists of two flaps and is known as bicuspid valve; mitral valve while that on the right is known as tricuspid but collectively both are known as atrio ventricular valves.
- These valves are supported by strands of strong inelastic tissues known as tenderone chords or chordate tendinae. These prevent the valves from being turned inside out by the high pressure generated when ventricles contract
- The bases of the arteries in the heart also have valves shaped like crescents and are commonly known as the semi lunar valves.
- However to be more specific the valves at the base of the aorta are known as aortic valves while those at the base of the pulmonary artery are known as pulmonary valves. All valves serve to prevent blood flowing in the wrong direction.

- The heart is further composed of cardiac muscles within its walls which are myogenic in nature (the initiation of their contraction is not under the control of the central nervous system but within the muscles themselves.)
- The heart has a connection of four great vessels; the venacava which transports deoxygenated blood from body tissues through the right atrium of the heart; the pulmonary artery which transports deoxygenated blood from the right ventricle of the heart to the lungs; the pulmonary vein which transports oxygenated blood from the lungs into the left atrium of the heart; the aorta which is the biggest vessel and it transports oxygenated blood from the left ventricle of the heart to the body tissues.

Diagram of the mammalian heart



INITIATION OF HEART BEAT

- The cardiac muscle within the heart walls is myogenic in that the initiation of the contraction is within the heart itself, but not under the control of the central nervous system. This enables the muscles to contract rhythmically and continuously without fatigue to enable the heart to beat continuously and rhythmically without stopping.
- The rhythmic contraction of the cardiac muscle is initiated by specialized network of fine cardiac muscles found inside the wall of the right atrium close to the entrance of blood from the venacava into the right atrium.
- This network of fine fibres is called Sino Atrial Node (SAN) and it serves as the pace maker by giving off a wave of electrical excitations similar to impulses, which spread out very rapidly over both the atria causing them to contract and force blood to ventricles via the open atria ventricular valve.
- When the electrical excitations reach the junction at the boundary of the atria, they excite another specialized plexus of other cardiac muscle chambers known as Atrio Ventricular Node (AVN)

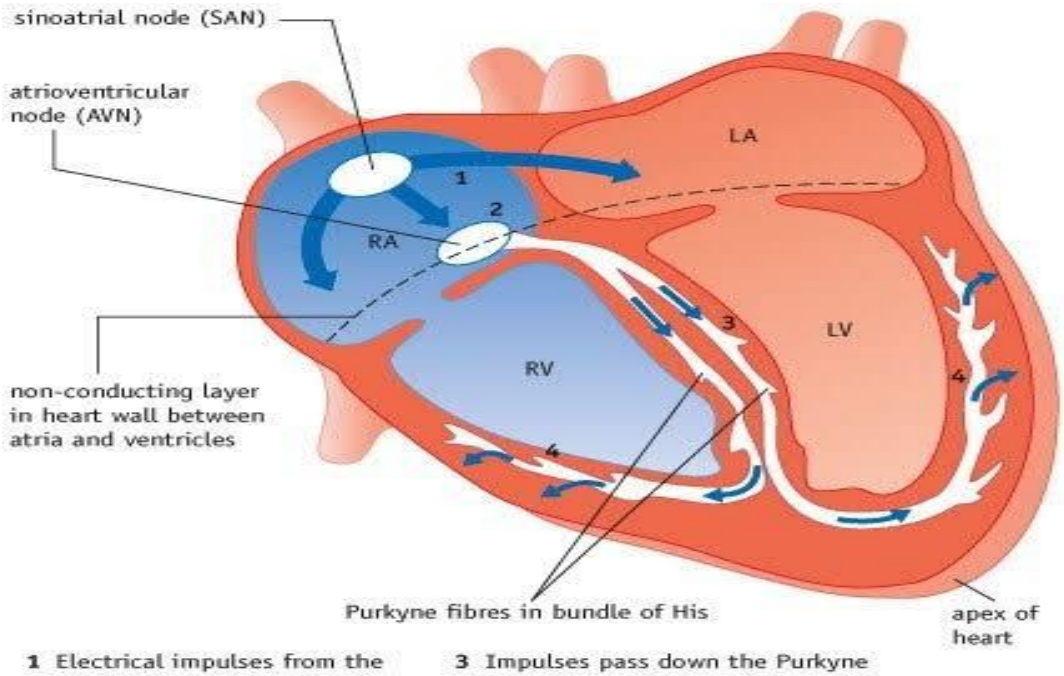
- When excited, the AVN sends waves of excitations down to another bundle of cardiac muscle fibres found along the inter-ventricular septum known as the purkinje/ purkyne tissue or bundle of His to the apex of the heart.
- This conducts and spreads the excitement through radiating them upwards to both ventricles which eventually contract to pump blood into the arteries.

NOTE:

a. The closing of the atrio ventricular valves during ventricular systole produces the first heart sound, described as lub.

b. The closing of the semi lunar valves causes the second heart sound, described as dub.

Illustration of initiation of heart beat



1 Electrical impulses from the SAN spread across the atria walls, causing contraction.

2 Impulses pass to the ventricles via the AVN.

3 Impulses pass down the Purkyne fibres to the heart apex.

4 The impulses spread up through the ventricle walls causing contraction from the apex upwards. Blood is squeezed into the arteries.

INTRINSIC CONTROL OF HEART BEAT

- ✓ The cardiac muscle in the heart is myogenic. It contracts and relaxes automatically and does not depend on stimulation by nerves. The initial stimulus originates from the sino-atrial node (SAN), often called the pacemaker.
- ✓ The pacemaker is found in the right atrium wall at the entrance of the superior venacava. The membranes of the cells of the SAN are permeable to sodium ions. Sodium ions enter into these cells and the cell membranes are depolarized.
- ✓ An excitatory wave of depolarization is generated which spreads rapidly from the SA node across the two atria causing them to contract simultaneously. A slowing down occurs as depolarization of the atrio-ventricular node (AVN) is delayed for about 0.1s to allow the atria to complete their contraction and empty the blood into the ventricles.

- ✓ Impulses from the AV node are conducted by specialized muscle fibres called bundle of His in the inter-ventricular septum towards the heart apex. Impulses are conducted by Purkinje fibres throughout the ventricular walls.
- ✓ This causes the contraction of both ventricles forcing blood into the pulmonary arteries and the aorta.

THE CARDIAC CYCLE

- This is the sequence of events of heart beat by which blood is pumped around the body.
- On average heart beats 72 times per minute. Heart pumps about 5 liters of blood per minute. Both auricles contract simultaneously and the blood flows into the ventricles and both ventricles contract together forcing the blood into pulmonary artery and aorta.

The cardiac cycle involves the following events;

1. Systole: Refers to the contraction of the cardiac chambers and as a result the
2. heart contracts forcing the blood into the pulmonary artery and the aorta.
2. Diastole: This refers to the relaxation of the cardiac chambers hence enabling the heart to refill.
3. Joint diastole: This refers to the relaxed state of both atria and ventricles.

Detail for one complete cardiac cycle;

Atrial filling and joint diastole:

- Filling of right atrium (RA) with deoxygenated blood from the great veins and left atrium (LA) with oxygenated blood from pulmonary vein.
- As the pressure increases in the atria, the bicuspid and tricuspid valves open and blood flows into the respective relaxed ventricles.
- The semilunar valves remain closed because of the low pressure and blood does not flow out of the ventricles.

Atrial systole and ventricular diastole:

- At the end of joint diastole, next heart beat begins. The two atria contract, forcing most of the blood into the ventricles.
- Simultaneous closing of great vein roots; superior and inferior vena cava by compression occurs.
- Bicuspid and tricuspid valves are open.

Ventricular systole (VS) and atrial diastole (AD):

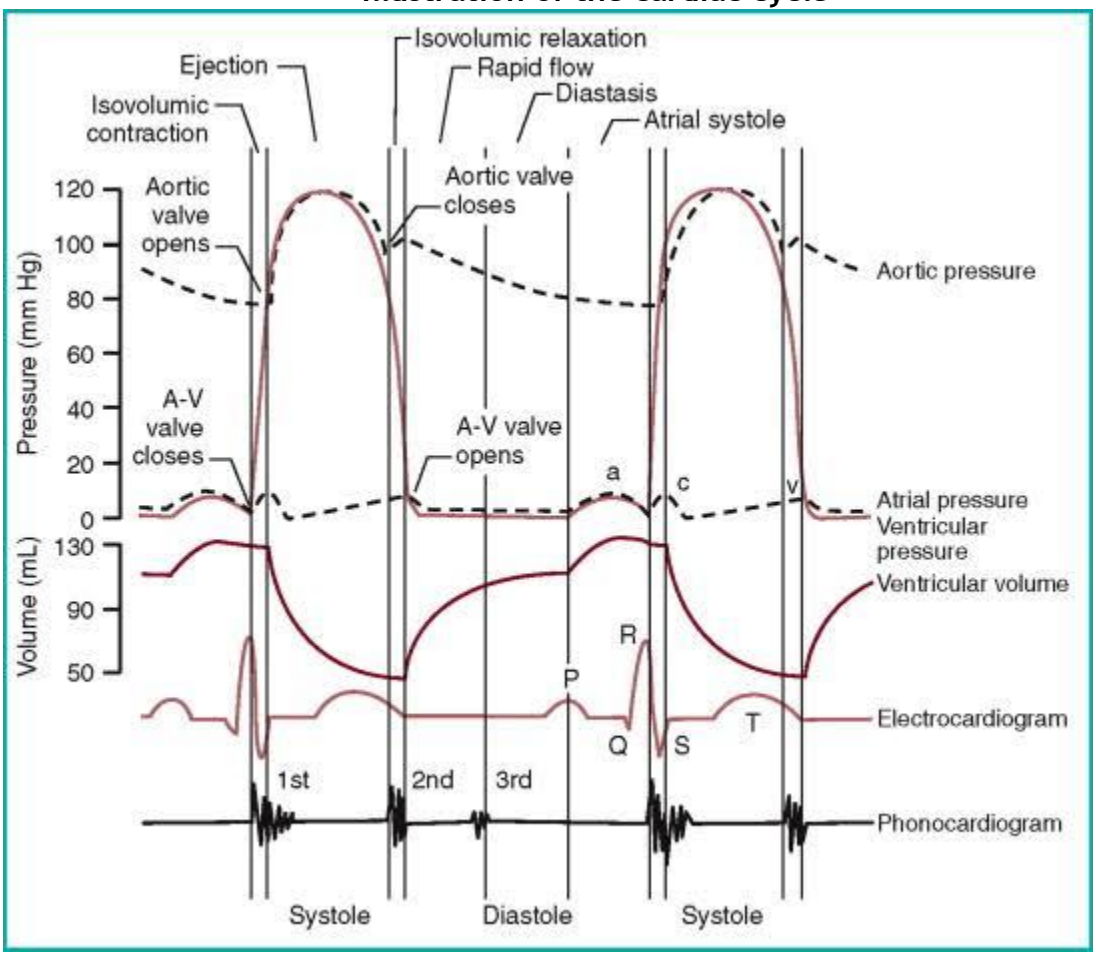
- Ventricles contract while atria relax. This forces the atrio ventricular valves to close producing the first heart sound 'lub'. This prevents the back flow of blood into the auricles.
- As the chambers contract, then the ventricular pressure exceeds the pressure in the pulmonary artery and aorta forcing the opening of the semi lunar valves. Blood flows from ventricles to great arteries.
- It lasts for about 0.25 seconds.

Ventricular diastole and atrial diastole (beginning of joint diastole):

- Ventricles relax and the pressure falls below that in the great arteries. This causes the closing of the semilunar valves in the pulmonary artery and aorta to produce the second heart sound 'dub'.
- This prevents backflow of blood into ventricles. As the low ventricular pressure is still greater than the atrial pressure, the AV valves remain closed.
- Continued ventricular diastole decreases the pressure tremendously and now both atria and ventricles are in joint diastole.
- This lasts for about 0.4 seconds.

- One complete systole and diastole forms a cardiac cycle which takes about 0.8 seconds.

Illustration of the cardiac cycle



THE PHONOCARDIOGRAM

- ✓ The PCG (phonocardiogram) is a recording of the sound the heart makes.
- ✓ The cardiac muscle itself is silent and the sounds are made by the valves when closing. The first sound (lub) is the atrio ventricular valves closing and the second sound (dub) it is the semi lunar valves closing.

THE ELECTROCARDIOGRAM

- ✓ The ECG (electrocardiogram) is a recording of the electrical activity of the heart. It shows characteristic waves of excitations as the excitation spreads through the heart.
- ✓ **P-wave;** shows atrial depolarization over the atrial muscle and spread of excitation from the SAN during atrial systole.
- ✓ **QRS- wave**; shows spreading of a wave of excitation through the ventricles during ventricular systole.
- ✓ **T- Wave;** shoes recovery or the beginning of ventricular diastole.

HEART RATE, ARTERIAL PULSE AND BLOOD PRESSURE

HEART RATE:

- × It refers to the number of times the heart beats per minute. Heart rate of humans is 68-72 times/min at rest, Heart rate of elephant is 25 times/min and Heart rate of rat 300 times/min.

- As it is clear from the figures given above, heart rate varies in animals. The smaller animals have high metabolic rates and hence need greater action of heart to pump more oxygen and nutrients to tissues.
- This is the reason why smaller animals have much higher heart beat rate than the larger animals.

Abnormalities in heart rate

1. **Tachycardia**: It refers to the abnormal increase in heart beat rate. It could be due to many factors like emotional stress, anxiety, anger, excitement, etc. It can also be due to over activity of thyroid gland.
2. **Bradycardia**: It refers to the abnormal decrease in heart beat rate. Athletes who generally have a high heart rate may suffer low heart rates during rest. It can also be due to under activity of thyroid gland.

CONTROL OF HEART BEAT

The rate at which the heart beats to pump blood from itself is under the control of the autonomic nervous system

- The heart is innervated by the sympathetic nerve from the sympathetic autonomic nervous system and by the vagus nerve a branch of a parasympathetic autonomic nervous system.
- The nerves modify the rate at which the pace maker gives waves of electrical excitations hence controlling the speeding up or slowing down of the rate of the rate of heart beat.
- When the rate of heart beat increases beyond the normal rate, the vagus nerve (parasympathetic nerve) is stimulated such that it lowers back to normal the rate of heart beat. If however, the rate of the heart beat lowers below the normal rate or if there's need for higher rate of heart beat the sympathetic nerve is stimulated to bring back or increase to the cardiac frequency usually to the normal rate. Therefore the sympathetic and vagus nerves are antagonistic, functionally.

Other factors the affect heart beat;

- ✓ Body temperature
- ✓ Blood pH
- ✓ Carbon dioxide concentration
- ✓ Partial pressure of oxygen
- ✓ Hormonal balance
- ✓ Salt balance
- ✓ Blood pressure
- ✓ Emotional situations
- ✓ Impulses from the venacava and aorta

ARTERIAL PULSE OR PULSE WAVE:

- It is a wave of distension followed by constriction experienced in the arteries as a result of ventricular systole and diastole.
- Pulse rate per minute = Heart beat rate/minute.
- As the ventricles contract, blood is pumped out into arteries with force. It causes distension of the elastic wall of arteries and is felt as a pulse when a finger is placed on an artery near the wrist.
- This pulse becomes fainter and fainter as the blood moves further away and becomes so low in capillaries that it cannot be felt.
- As the ventricles relax, there is a drop in the pressure in the arteries and the distended portion comes back to normal.

BLOOD PRESSURE:

- ✓ It is the pressure or the force exerted by the blood against the walls of the arteries.
- ✓ As the arteries already contain blood, the pressure in them increases due to sudden flow of blood during ventricular systole and falls slightly as the ventricles relax.
- ✓ The blood pressure is measured as two values, for example for a normal healthy man, it is equal to 120 by 80 mmHg. It means that the person has a systolic pressure of 120 mmHg and diastolic pressure of 80 mmHg.

I. **Systolic pressure:** It is the pressure experienced in the arteries as a result of contractions in the ventricles. It is equal to 120 mmHg for a normal healthy person.

II. **Diastolic pressure**: It is the pressure in the arteries when the ventricles relax. It is equivalent to 90 mmHg for a normal healthy person.

- ✓ The values of blood pressure change with age, sex or health of a person.
- ✓ The blood pressure can also be affected by other conditions like arteriosclerosis where due to hardening of arteries, their lumens become narrower and so the blood pressure increases.

CONTROL OF BLOOD PRESSURE

- ❖ Via the cardiovascular regulatory center in the medulla oblongata, the nervous system can regulate blood pressure by varying the activities of SAN via the vagus nerve which decelerates the heart beat and via the sympathetic nerve
- ❖ which accelerates the activities of the SAN.
- ❖ At the back of the aorta, there are sensory cells sensitive to stretching and concentration of CO_2. These are carotid and aortic bodies. When they are stimulated, they send impulses to the cardiac regulatory center which in turn affects the SAN e.g. when blood pressure is low or when CO_2 is high, the carotid bodies are stimulated, send impulses to cardiac accelerating center which responds by sending impulses via the sympathetic nerve to the SAN. This
- ❖ causes an increase in the cardiac output hence blood pressure.
- ❖ Within the cells of the arteries, there are bare receptors, those are sensitive to pressure changes in the arteries. When the blood pressure in the arteries reduces, they are stimulated and they send impulses to the vasomotor center in the medulla. This responds by sending impulses through the sympathetic nerve to the smooth muscles of arteries which contract to increase the blood pressure.

DEFENCE AGAINST DISEASES

Mammals have ways of protecting their bodies from microbe entry or withstand pathogen attacks. These are the ways it does so;

1. Blood clotting
2. Phagocytosis
3. Immune system

BLOOD CLOTTING

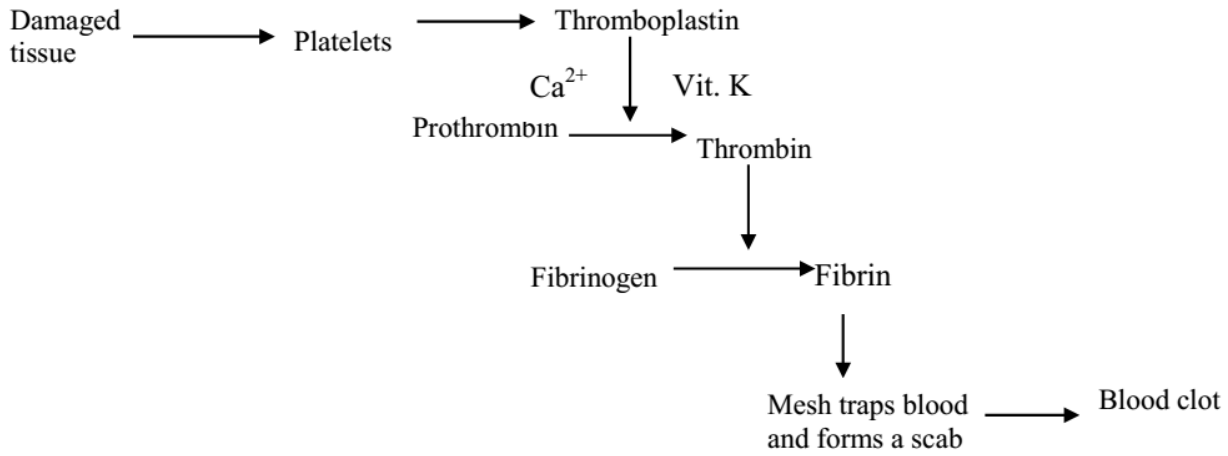
Blood clotting is brought about by a soluble plasma protein called fibrinogen when it is converted to an insoluble form called fibrin. How it occurs;

- ⌧ When blood platelets and damaged tissues are exposed to air, the platelets disintegrate and release an enzyme called thromboplastin or thrombokinase, which in the presence of plasma proteins and calcium ions catalyses the

conversion of a plasma protein derived from vitamin K called Prothrombin into thrombin enzymes.

- ⌦ Thrombin is a proteolytic enzyme that hydrolyses a plasma protein called fibrinogen into an insoluble protein called fibrin.
- ⌦ Fibrin forms fibres at the wounded area. Within the fibrous network of fibrin blood cells become trapped, thereby forming a fibrin clot or a blood clot.
- ⌦ The clot not only prevents further blood loss, but also prevents the entry of bacteria and other microbes which might otherwise cause infection.

Illustration of the blood clotting process



N.B. Blood cannot clot inside vessels because; Connective tissue plus the liver produce chemical, **heparin**, which prevents the conversion of prothrombin to thrombin, and fibrinogen to fibrin.

IMMUNE SYSTEM

Immunity is defined as the capacity to recognize the entry of foreign materials in the body and to mobilize cells to help and remove the foreign particles immediately it enters the body or before they enter the body.

TERMS USED

1. **Antigen:**
   Molecule that stimulates an immune response. Usually proteins (polysaccharides, nucleic acid, lipids can also act as antigens) and other inorganic molecules important for self-recognition.
2. **Self-antigen**: Only found on the host's own cells and does **not** trigger an immune response. There is only 1:4 change that siblings will possess an identical antigen.
3. **Non-self-antigen:** Found on cells entering the body (e.g. bacteria, viruses, and another person's cell) and can cause an immune response.

4. **Antibody (immunoglobin protein):**
   Secreted by B-lymphocytes and produced in response to a specific (foreign) non-self-antigen. B-lymphocyte's receptor site matches the non-self-antigen. Each antibody is produced by one type of B-lymphocyte for only one type of antigen

TYPES OF IMMUNE RESPONSE

- × Specific response
- × Non- specific response

NON-SPECIFIC WAY

This gives innate defence. It acts in the following ways;

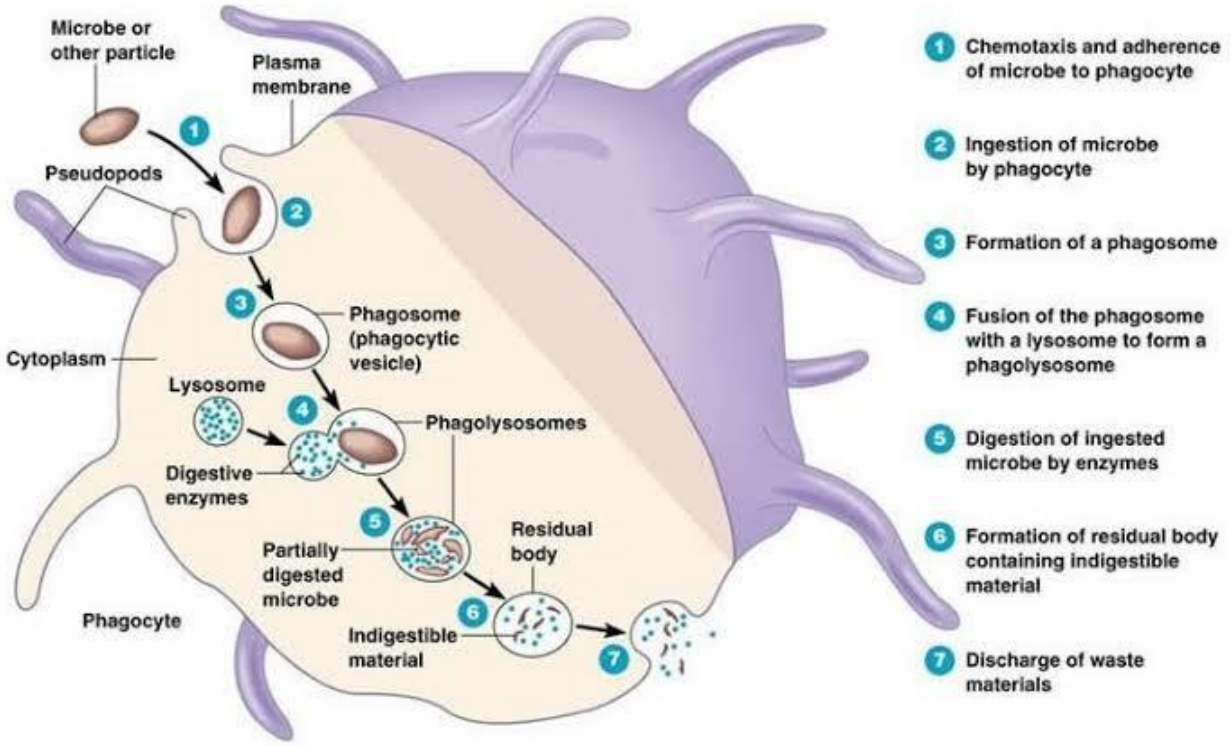
- ✓ Phagocytosis
- ✓ Physical barriers
- ✓ Natural killer cells
- ✓ Fever
- ✓ Anti-microbial proteins
- ✓ Inflammation

PHYSICAL BARRIERS

- The intact skin is a barrier that cannot be penetrated by bacteria or viruses, although minute abrasions allow their passage.
- In the same way, the mucus membranes which line the digestive, reparatory and urinal genital tracts prevent the entry of potentially harmful microbes.
- Apart from their role as physical barriers, the skin and mucus membranes produce secretion that counter pathogens e.g. in humans, secretions from the oil and sweat gland give the skin a pH ranging from 3-5 which is acidic enough to discourage micro-organism from colonizing their bacteria that make the normal flora of the skin are adapted to its acidic relatively dry environment.
- Saliva, tears and mucus secretions that bathe the surface of the exposed epithelia wash away many potential invaders and in addition to these secretions contain various antimicrobial proteins.
- **E.g.** the enzyme cysotyme which digests the cell walls of many bacteria, destroys many microbes entering the upper respiratory system and openings around the eyes.
- Microbes present in food or those trapped in swallowed mucus from the upper respiratory system pass through the highly acidic food gastric juice produced by the stomach lining which destroys them before they enter the intestines.

PHAGOCYTOSIS/ ACTION OF WHITE BLOOD CELLS

- Certain white blood cells particularly neutrophils and monocytes are attracted by chemicals released by body cells which have been damaged by invading pathogens.
- These white blood cells show amoeboid movements which engulf, ingest and destroy pathogens.
- Neutrophils can squeeze through blood capillary walls a process called diapedesis and move about in tissue spaces. The monocytes migrate out of blood stream then become larger white blood cells (leucocytes) called macrophages.
- Some macrophages are permanently located in tissues and organs such as the liver, spleen, kidney and lymph nodes while other circulate throughout the body.
- The macrophages are long lived phagocytes which even engulf much larger particles like old red blood cells and protozoan parasites.
- The eosinophils have low phagocytic activity but are critical to defence against multicellular parasitic invaders such as the blood fluke they rarely engulf such a large parasite but position themselves against the parasites body and though discharged destructive enzymes which damage the invader.
- The action of the white blood cells is fully related to phagocytosis that was earlier covered in movement in and out of the cell.



INFLAMMATION

- This is a localized non-specific response initiated by the defence system of the body, in which the part of the body infected by a micro –organism has its blood vessels dilated, more permeable to blood components, having increased blood flow swells up, becomes warm and red as the phagocytes destroy the invading pathogens.

- An inflammation is usually by physical damage to the skin or mucus membranes by bacteria
- This physical damage causes release of chemical signals such as histamine and prostaglandins. The chemical signals induce increased permeability of the blood capillaries and the flow of blood to the affected area respectively.
- They also attract phagocytic cells and lymphocytes which on arrival at the site of injury, the phagocytes consume pathogen and the cells debris and consequently the tissue heals.
-
- The histamine cause vasodilatation i.e. the capillaries dilate and the walls become leaky. As more fluid collects around the wound, the site becomes red, swollen and warm. The localized swelling is called oedema.
- The prostaglandins are the ones that promote blood flow to the site of injury and increase the sensation of pain.

ANTI MICROBIAL PROTEINS

- These are proteins that function in the mechanisms by attacking microbes directly of by impeding the production e.g. lysozyme.
- Other antimicrobial proteins include about 30 serum proteins that make up the complement system proteins through a sequence of stops, leading to lysis (bursting) of invading cells.

- Some complement proteins initiate inflammation and also play a role in acquired defence.

FEVER

- ✓ Fever refers to increase in body temperature.
- ✓ It is triggered if microbes infect larger areas of the body in response to infection, certain leucocytes releases pyrogens which are also anti-microbial protein of the complement system.
- ✓ The pyrogen stimulate the hypothalamus to rise the body temperature set point from its normal value about 39^0C hence casing a fever. The fever has several beneficial effects;
- ✓ It increases the activity of phagocytes which then attack the invading microbes more efficiently.
- ✓ It increases the production of interferon in virus infected cells. Interferons are proteins which inhibit viral replication, activate natural killer and stimulate macrophages to destroy tumor cells and virus infected cells.

NATURAL KILLER CELLS

- This is a class of white blood cells which attack virus injected body cells and abnormal cells that could form tumors.
- The virus infected cells have viral proteins displayed on their surfaces and these are recognized by the natural killer cells contains perforin – filled vesicle.
- When an N.K encounters a virus infected cell, perforin molecules are released by exocytosis. Perforin molecules make large holes of pores in the turgid cells plasma membrane, causing leakage of the cytoplasmic contents. This results into cell death. The membrane of NK cell is not affected by these membranes dissolving molecules.

SPECIFIC IMMUNE RESPONSE

- The specific immune response confers immunity against specific microbes it involves immune system whose response result from the interaction among several types of lymphocytes, the molecules they produce; antibodies and the foreign material introduced by microbes; antigens.

CELLS OF THE IMMUNE SYSTEM

1. **B-CELLS; B-lymphocytes**

- These are lymphocytes that produce antibodies when stimulated. They are produced and mature in the bone marrow from the stem cells.
- They have glycoprotein receptors on their cell surface membranes which bind specific antigens.
- Mature B-cells become plasma cells and memory cells produce much more antibodies in terms of quantity and effectiveness than plasma cells.

2. **T-CELLS; T-lymphocytes**

- The T-lymphocytes regulate the immune response or kill certain types of cells the T cells are produced in the bone marrow but mature in the thymus gland where they develop specific receptors which recognize specific antigens. These are two main categories of T cell namely;

They are divided into;

a. **Killer T-cells/ cytotoxic cells;** These are cells which attach to invading cells and secrete a number of cellular toxic substances called lymphokines which kill the invading cells called microbes.
b. **Suppressor T-cells;** These suppress the activity of the killer T-cells and B-cells after the microbes have been cleared out of the body to prevent these cells from attacking and destroying the body cells. Suppressor T-cells therefore regulate the immune response and prevents antibodies from being produced by the B-cells.
c. **Helper- T cells**; these are cells that recognize a specific antigen on an antigen presenting cell and binds to it, then assists a B-cell binding the same antigen to proliferate into specific antibody secreting cells.

Memory cells; these are derived from B cells and T-cells. They are long lived and confer future immunity against subsequent infections by the same antigen i.e. they are the ones responsible for causing the secondary immune response.

× **Characteristics of an immune system**

× The immune system develops specific response against each type of foreign microbes, toxin or transplanted tissues. The immune system has 4 features i.e.

1. **Specificity**

- The immune system has the ability to recognize and eliminate particular microorganism, and foreign molecules.
- The immune system responds to an antigen by activating specialized lymphocytes and producing specific proteins called antibodies.
- Antigens that trigger an immune response include molecules belonging to viruses, bacteria, fungi, protozoa and parasitic worms.
- Anti-bodes recognize antigens using epitopes which are antigenic determinants on the surfaces of the antigens. If an antigen has several epitopes, it stimulates several different B cells which secrete specific distinct antibodies against it.
- Therefore each antigen has a unique molecular shape and stimulate the production of the very type of antibody that defends against that specific defenses, each response the immune system targets a specific invader distinguishing it from other foreign molecules that may be very similar.

2. **Diversity**

- The immune system has the ability to respond to very many kinds of invaders each recognized by its antigenic markers.
- This diversity of response is possible because the immune system is equipped with an enormous variety of lymphocyte population among the antibody producing lymphocytes (B-lymphocytes)
- Each population is stimulated by a specific antigen and response synthesizing and secreting the appropriate type of antibody.

3. **Memory**

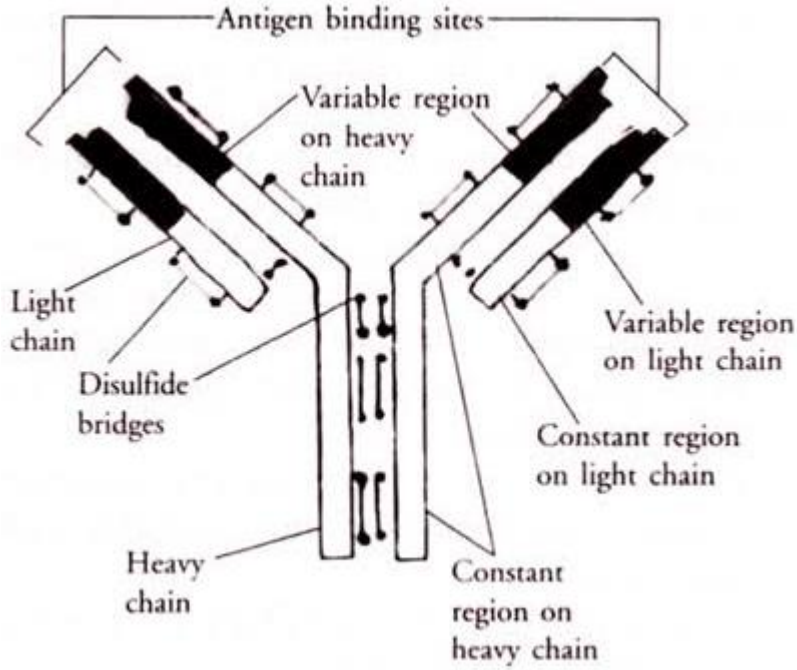
- The immune system has the ability to “remember” antigen encountered and react more promptly and effectively on the subsequent exposures. This characteristics also known as acquired immunity.

4. **Self/non self-recognition**

- The immune system distinguishes the body’s own molecules from foreign molecules (antigens). Failure of self/non self-recognition leads to anti immune disorders in which the immune system destroys the body’s own tissues

ANTIBODIES

❖ Antibodies constitute a class of proteins called immunoglobulins. Every antibody molecule has at least two identical sites that bind to the epitope that provide its production.



❖ The typical structure of an antibody molecule is composed four polypeptide chains one of the pair is long and made of heavy linked together by disulphide bridges (s-s) and the other is shorter and made of light chains and has got a Y shaped molecule.

❖ It has two sites called antigen binding sites which fix exactly into the antigen

❖ It is made of a constant region which is made by the heavy chains and is common to all antibodies and the variable chain that region that i made of light chains and is different for all antibodies.

Or check illustration in understanding biology page 423 fig.21.12

- An antibody does not directly destroy an antigenic invader.
- However antibodies bind to antigens to form an antigen antibody complex which is the basis for several effector mechanisms which make macrophages recognize the antigens and destroy them.
- The binding of antibodies to antigens takes various forms, some of which include the following;

Neutralization

- Here the antibody blocks certain sites on an antigen or toxins making it ineffective. Antibodies neutralize a virus by attacking to the sites the virus uses to bind to its host cell. Also bacterial toxins become coated with antibodies hence getting neutralized, eventually, phagocytic cells (macrophages) destroy these antigen-antibody complexes.

Agglutination (clumping)

- This is when antibodies cross link adjacent antigens/ clumps them together. This is made possible because certain antibodies possess at least two antigen binding sites.
- The clumping of antigens e.g. bacteria makes it possible to be recognized by macrophages and other phagocytes which destroy the antibody-antigen complex

Precipitation

- This is similar mechanism to agglutinations except that here the antibody-antigen complexes are formed when soluble antigen molecules rather than

cells are linked to form immobile precipitates which are captured by phagocytes and macrophages that destroy them.

Opsonisation

- Here, the antibody molecule coats the surface of a microbe making it easier for phagocytic leucocytes to engulf it.

Complement fixation

- Here, the antibodies activate the complement proteins which then leads to lysis of foreign cells.

IMMUNE RESPONSES

The immune system mounts two different types of responses to antigens namely;

- Cell-mediated response.
- Humoral response.

HUMORAL RESPONSE

This is also known as antibody mediated immunity

- ✓ The Humoral immunity results in the production of antibodies which are secreted by B-cells, the antibodies circulate as soluble proteins in blood plasma and lymph.
- ✓ Each B-lymphocyte recognizes only one specific antigen or need T-helper cell to be activated.
- ✓ Mature B-cells develop to give many different variants of specific immune system responding to any type of pathogen entering the body.

CELL MEDIATED RESPONSE

- This is an immune response produced when sensitized T cells attack foreign antigens and secrete lymphokinase that initiates the body's humoral immune response
- When a macrophage ingests a microbe, most of the microbe antigens are digested by its enzymes, however some fragment of the foreign antigens combines with the major histocompatibility (MHC) proteins which are found in the macrophages cell membrane.
- In this way the macrophage becomes an antigen presenting cell (APC), this so because it has become marked by MHC.
- The APC interacts with helper-T cells especially the killer cells. The killer cells hold the APC and the T helper cells which activates them.
- This stimulates the APC to divide to produce several interleukins which activates the t-killer cells to start dividing and also stimulate the t-helper cells to divide more rapidly. If the cells are infected by a microbe, its fragments are displayed on the membrane with the aid of MHC.
- The T-cell becomes activated when in contact with the MHC antigen complex on the affected cell.
- The stimulated T- killer cell release perforins; a protein that forms pores in the infected cell membrane. This results into lysis of the infected cell. This exposes the pathogen to destruction by the circulating antibodies.

PRIMARY RESPONSE

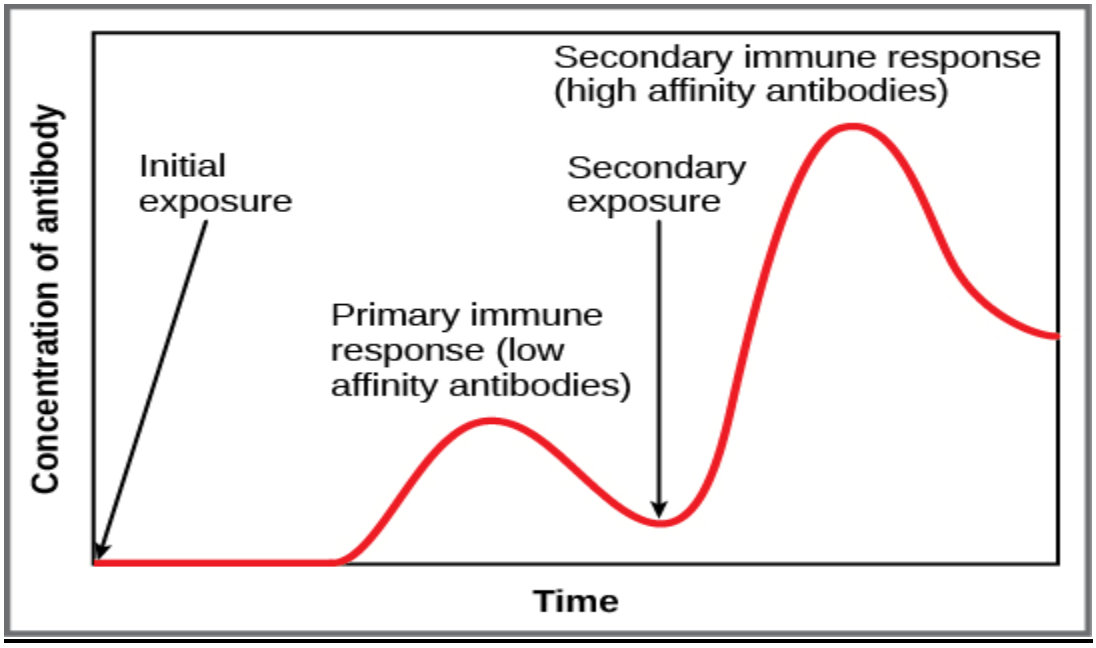
- Pathogen is ingested by macrophages /macrophage displays the pathogens surface non-self-antigen on its surface (antigen presentation).
- It then joins with specific T-helper cells and B lymphocytes that have membrane receptors and are complementary in shape to the non-self-antigen.

- In primary immune response there is selective proliferation (multiplication) of lymphocytes to form clones of effector cell upon the first exposure to an antigen. Here there is a lag period between initial exposure to an antigen and maximum production of effector cells.
- During the lag period, the lymphocytes secreted by the antigen differentiates into effector T-cells (T-helper and T-killer) and antibody producing plasma cells
- T-helper cells will release cytokines to activate selected B-cell/lymphocyte:
    - Secretes antibodies of the same type into the blood
    - Divided by mitosis to produce a clone
    - Cells grow to form plasma cells producing masses of free antibodies.

SECONDARY RESPONSE

- This occurs if an individual is exposed again to the same antigen. There is immediate recognition and distraction - faster, larger response usually prevents harm.
- Response is the rapid response that results in faster production of effector T-cells and antibody molecules when the body is exposed to subsequent infection of the same antigen that has ever invaded the body. Antibodies produced during the secondary immune response are more effective in binding to the antigen than those produced during the primary immune response.
- The immune systems' ability to recognize an antigen as previously encountered is called immunological memory. The ability is based on long lived effector cells of the immune response, memory cells are not active; memory cells survive for long periods and proliferate rapidly when expose to the same antigen that caused their formation secondary immune gives rise to new clone to memory cells as well as effector cells.

Graph illustrating antibody concentration in primary and secondary response



TYPES OF IMMUNITY

1. Active acquired immunity; depends on the response of a person's own immune system.

- Here the individual organism produces antibodies using the B-lymphocytes against the infectious agent.
- Active immunity is naturally acquired but it can also be artificially acquired by vaccination.

2. **Passive immunity**; antibodies are transferred from one individual to another as in the case that occurs naturally when a pregnant woman's body passes some of her antibodies across the placenta to the fetus.

- The new born's immune system is not fully operative and depends on the mothers immune system.
- Certain antibodies are also passed from the mother to her nursing infant in breasts milk especially in her colostrum or fast secretions.
- Passive immunity can also be transferred artificially by introducing antibodies from an animal or human who is already immune to the disease e.g. rabies is treated in humans by injecting antibodies from people who have been vaccinated against rabies.
- This produces an immediate immunity which is important because rabies progress rapidly and the response to vaccination would take too long.

TYPES OF NATURAL IMMUNITY

1. **Natural passive immunity**
   - This involves passing antibodies in the body of an organism into the body of another organism of the same species e.g. from the mother to the foetus via to the placenta to defend the body against disease and also via the first milk called colostrum to the child.
   - This type of immunity is temporary.
2. **Natural active immunity**
   - This is the immunity that involves formation of antibodies by the body of an organism in the presence of certain antigens.
   - This type of immunity is permanent because during the immune response, memory B-cells are produced which recognize the microbes on reinfection; second infection and then stimulate the rapid production of large amounts of antibodies to curb down the microbes before causing significant damage.
   - Memory B-cells stay for long in blood.

AUTO IMMUNITY

- ❖ This is a kind of immunity the body imposes on its own components.
- ❖ The immune system goes away and usually turns against component of the body. Leading to auto immune diseases.
- ❖ In insulin dependent diabetes, an auto immune reaction causes the destruction of insulin producing cells of the pancrease.
- ❖ In Rheumatoid arthritis is a crippling auto immune disease in which inflammation damages the cartilage and bone of joints.

- ❖ Rheumatic fever is an auto immune condition in young adults where antibodies produced in response to streptococcal pathogens in the throat.
- ❖ Multiple sclerosis; this is where the immune system destroys all the protective covering of the nerves.
- ❖ AIDS

Other conditions due to immune system failure are allergy and immune deficiency in some conditions.

VACCINES

- Vaccines are toxic chemicals or killed or attenuated; weakened microbes introduced into the body of an organism to make it produce very many antibodies against a certain pathogen.
- The killed microbes are usually viruses and bacteria.
- The attenuated microbes are living microbes which are inactivated and they lack powers to infect the body due to the chemical or temperature treatment given to them.
- Toxins are toxic chemicals produced by microbes and therefore can work as antigens

TYPES OF VACCINE

1. Vaccine containing dead pathogens. Antigen is still recognize and an immune response made;
   - ✓ Salk polio vaccine (Polio vaccine is injected)
   - ✓ Influenza
   - ✓ Whooping cough
2. Vaccine containing a toxin
   - o Diphtheria
   - o Tetanus
2. Vaccine containing an attenuated (modified or weakened) organism which is alive but has been modified so that it is not harmful Sabin polio vaccine (Taken orally, often sugar pumps)
3. Purified antigen - genetically engineered vaccine.
   - ❖ Hepatitis B (A gene coding for a surface protein of the hepatitis B virus has been inserted into yeast cells which produce the protein when grown in fermenters)

TRANSPLANTATION

- ✓ This is the replacement of diseased tissue or organs by healthy ones through a surgery.
- ✓ It's less successful than blood transfusion because the organ contains more antigens than blood so they are likely to be rejected by the body's immune system. Tissue rejection has been perfectly overcome by:
- × Careful tissue typing i.e. using tissue which meets the donor and recipient antigens as exactly as possible.
- × Use of immune suppressive drugs which suppress the recipient's immunity in order to increase the chances of transplant success.

Types of transplants

- **Auto-graft**; the tissue is grafted from one area to another on the same individual. E.g. skin. Rejection is not a problem.
- **Iso-graft**; a graft between two genetically identical individuals' e.g. identical twins. Rejection is not a problem.

- **Allo-graft**; a tissue from individual to individual but the two must be closely attached or related though of different genetic constitution. In case of rejection, immune suppressive drugs can be used.
- **Xeno-graft**; a graft between individuals of different species such as from sheep to human.

BLOOD TRANSFUSION

- ✓ Blood transfusion is the blood transfer process from the donor to the receiver.
- ✓ There are basically two blood group systems; ABO system and the Rhesus factor system. Both systems have to be considered during blood transfusion

ABO system

- ✓ Under this system, there are four blood groups:
  i) Blood group A
  ii) Blood Group B
  iii) Blood Group AB
  iv) Blood Group O
- ✓ A person's type of blood is determined by carbohydrate or protein structures located on the extracellular surface of the Red blood cell membrane.
- ✓ These structures are called **antigens.** So if a person is of;

- Blood group A, he or she has the **A type antigens**
- Blood group B, he or she has the **B type antigens**
- Blood group AB, he or she has the **A and B types of antigens**
- Blood group O, he or she **lacks antigens** on his or her red blood cells.

- ✓ The antigens of an individual's red blood cells have corresponding antibodies in the plasma of blood which are different from the antigens in that;

- A person of blood group A has **antibodies of type b**.
- A person of blood group B, has **antibodies of type a**.
- A person of blood group AB, has no antibodies to any ABO blood group antigens.
- A person of blood group O has **antibodies of type b** and **a.**

NOTE:

- ✓ During blood transfusion, the blood of the recipient should not have antibodies against antigens of blood donated by the donor otherwise *agglutination* will occur.
- ✓ Agglutination is the formation of a blood clot due to a reaction between the antigens in the donor's blood and antibodies in the recipient's blood.
- ✓ After agglutination there are higher chances of haemolysis.
- ✓ Despite the knowledge and careful matching of blood groups, there continues to be a failure of blood transfusion if the rhesus system is not considered.
- ✓ Refer to genetics for the effect of Rhesus factor.
- ✓ In blood transfusion its always represented as either "+" or "-" on the blood group

NOTE:

- **A person with blood group O is universal donor because** he/ she lacks antigens A and B on the surface of his or her blood cells and his or her blood can be donated to any other person having any blood group without agglutination occurring.
- **A** person of blood group AB is a universal recipient because he/ she lacks antibodies b and a in the plasma of his or her blood and can be transfused with blood of a donor having any blood group without agglutination occurring.

Take a clear look at the table of compatibility in the ABO and Rhesus system below
Or check table on page 428 in understanding biology

	Donor							
Recipient	O-	O+	A-	A+	B-	B+	AB-	AB+
O-	√							
O+	√	√						
A-	√		√					
A+	√	√	√	√				
B-	√				√			
B+	√	√			√	√		
AB-	√		√		√		√	
AB+	√	√	√	√	√	√	√	√

THE LYMPHATIC SYSTEM

- The lymphatic system returns tissue fluid to the blood and also plays a role in the body defence. As blood passes through the capillaries, there is accumulative loss of fluid which is effected by ultra-filtration of blood and this forms tissues fluid that bathes cells.
- The lost fluid is similar to blood in composition except that of lacks blood plasma proteins and cells. The lost fluid returns to blood via the lymphatic system. It enters the system by diffusion into tiny lymph capillaries which are intermingled among the capillaries of the cardio vascular system.
- Once inside the lymphatic system, the fluid is called lymph. The lymphatic system drains into the circulator system near the shoulders where it pours its contents on the sub clavian vein that leads to the anterior vena cava.
- Along the lymph vessels are specialized swellings called lymph nodes. These filter the lymph and attack bacteria, virus infected cells and other antigens using the lymphocytes in them.
- When the body is infected by an antigen the cells in the lymph nodes multiply rapidly and the lymph nodes become swollen and tender. Like the veins of the cardio vascular system lymph vessels have valves which prevent back flow of fluids towards the capillaries. In the same way, lymph vessels depend on the movement of skeletal muscles to squeeze the fluid along the vessel

Check diagram in understanding biology page 441 fig 21.23

Functions of the lymphatic system

- Defend the body against infection
- Maintains the level of the interstial fluid/ tissue fluid
- Transports fats from the digestive tract to the circulatory system.

Movement of lymph through the lymphatic system is achieved through; Lymph; this is a milky fluid obtained from tissue fluid.

1. **Hydrostatic pressure;** the pressure of tissue fluid leaving the arterioles helps push the lymph along the lymph system
2. **Muscle contraction**; this compresses the lymph vessels, exerting a pressure on the lymph within them.
3. **Inspiratory movements**; on breathing, pressure in the thorax is decreased, this helps to draw lymph towards the vessels in the thorax.

VASCULAR SYSTEM OF FLOWERING PLANTS

- ✓ Plants require adequate supply of CO2, O2, mineral salts and water for normal growth.
- ✓ Lower plants like algae move materials in and out of their bodies by diffusion and active transport because they have a large surface area to volume ratio.
- ✓ Higher plants have a vascular system which helps in translocation. The vascular tissues have several adaptations to perform their functions.

The vascular system is made of the xylem and the phloem

XYLEM

Structure on page 74

Adaptations of the xylem tissue

- Has long cells joined end to end in order to form a continuous column for the flow of water.
- End walls break down to form an uninterrupted structure to ensure smooth flow of water from vessels to leaves in tracheid. Where end walls are not present, large pits are formed to reduce the resistance to flow.
- There are pits at particular places where lignin is deposited. These pits allow natural flow of water where this is necessary to prevent air bubbles from blocking the vessels.
- Deposition of cellulose walls with lignin increases the adhesive forces between water molecules and the tissue wall and it enables water to raise up by capillarity.
- The xylem tissue especially the vessels have very narrow lumen of about 0.01-0.02mm in diameter. This increases capillarity forces for the uptake of water.
- Each xylem element has a wall made up cellulose and lignin. Lignin is water proof and a very strong material which helps in maintaining water inside the xylem element.

PHLOEM

Structure on page 77

Adaptations of the phloem to its function

The phloem has tissues that are well adapted to movement of materials in the following ways:

- ✓ Possess cytoplasmic strands over which materials can flow.
- ✓ Possess end walls called sieve plates which are perforated by numerous pores to allow passage of substances from one sieve element to the next.
- ✓ The cytoplasm of the sieve elements is structurally simple with no or few organelles like endoplasmic reticulum. This provides large space for the movement of materials.
- ✓ Besides each sieve element is a companion cell which possesses nucleus, mitochondria, endoplasmic reticulum, etc., which is a site for intense metabolism. The mitochondria provides the energy required.
- ✓ Cells have plasmodesmata pits that allow movement of materials between sieve elements.
- ✓ The phloem tissue in leaves have transfer cells responsible for moving products of photosynthesis from the mesophyll cells to the sieve tubes.

NOTE:

- Water and mineral salts are necessary for photosynthetic reactions and other metabolic processes; hence they must be absorbed in sufficient quantities by using the root system and transporting them through the xylem to the mesophyll cells of leaves where photosynthesis takes place.

- Water however can be lost from the mesophyll cells into sub-stomatal air chambers and then eventually lost into the atmosphere of water vapour through tiny pores called "stomata" by a process known as transpiration.

TRANSPIRATION

This is the process of water loss inform of water vapour to the atmosphere from the plant mainly through the stomata pores. Transpiration takes place at three major sites hence the types;

Stomatal transpiration;

- This is the loss of water vapour to the atmosphere through the stomatal pores of the leaves.
- This contributes 90% of the total water loss from a leafy shoot. This is because leaves contain a large number of stomata for gaseous exchange where this water vapour can pass and also there's little resistance to the movement of water vapour through the stomatal pores.
- In addition, leaves also have a large surface area over which water vapour can evaporate rapidly to the atmosphere.

Cuticular transpiration;

- This is the loss of water vapour to the atmosphere directly through the epidermis coated with a cuticle layer.
- It contributes 10% to the total water loss from the leafy shoot. This is because the cuticle is hard, waxy and less permeable to most diffusing molecules including water vapour molecules.

Lenticular transpiration;

- This is the loss of water vapour through a mass of loosely packed cells known as lenticels found scattered on the stems.
- It also contributes 5% of the total water loss to the atmosphere in a leafy shoot. It is because the lenticels are usually few in number and not directly exposed to environmental conditions.
- Lenticular transpiration is the main source of water loss from deciduous plants after shading off their leaves. Because there are more stomata on the leaves than elsewhere in the shoot system, it is evidence that most of the water vapour is lost from the leaves.

NOTE:

1. Transpiration would appear to be inevitable, if undesirable, consequence of having leaves punctured with stomata this is because the stomata are needed for photosynthesis. This means that any opening in the leaf will inevitably allow water out.
2. In conclusion transpiration is a necessary evil.

How to know that transpiration really occurs

- In order to establish that transpiration occurs mostly in the leaves, an experiment using absorptive paper, dipped Cobalt II Chloride solution or Cobalt II thiocynate solution is carried out.
- The paper is covered on the surface of both sides of the leaves and then clamped with glass slides. After some time, the blue cobalt thiocynate paper changes to pink, indicating the evaporation of water molecules from the leaf by transpiration.

- The rate of change from blue to pink is higher at the lower epidermis than the upper epidermis. This is because structurally there are more stomata on the lower epidermis to prevent excessive loss of water by transpiration due to direct solar radiation.

DETERMINING THE RATE OF TRANSPIRATION

- The rate of transpiration can be measured by either determining the rate of transpiration at which the plant loses mass due to water loss
- Or determining the rate at which the plant takes in water; this possible because it is almost as the rate of transpiration because a little water taken up by the plant is used for photosynthesis and other metabolic processes, but a lot is transpired.
- It is done using instrument called a potometer.

THE WEIGHING METHOD

- ✓ The rate of mass loss by the plant can be determined by using the potted plant placed on an automatic weighing balance whereby the change in mass is noted over a given period of time.
- ✓ Using this method, it is assumed that the mass loss is only due to water loss by transpiration. However, the whole pot must be enclosed in a polythene bag to prevent water from evaporating from the soil.
- ✓ In addition, the soil must be well watered before the beginning of the experiment so that the plant has enough water throughout the experiment. The rate of transpiration is then expressed in terms of mass lost per unit time.

USING A POTOMETER

Principle of operation

- × The potometer is used to measure the rate of water uptake by the shoot of the leafy plant.
- × However, since most of the water taken up is lost by transpiration, it is assumed that water uptake ≈ water loss. The leafy shoot is cut under water to prevent the air bubbles from entering and blocking the xylem vessels.
- × The cut leafy shoot is immediately fixed in the sealed vessel of connected to the capillary tube. The rate of water uptake is then measured by introducing an air bubble at the end of the graduated capillary tube and the distance moved by the air bubble per unit time is noted.
- × To drive the air bubble back to the original position, water is introduced into the capillary tube from the reservoir by opening the tap on the reservoir.
- × The leafy area is also established by tracing the outline of the leaves on a squared graph paper and then counting the number of complete and incomplete squares enclosed in the outline

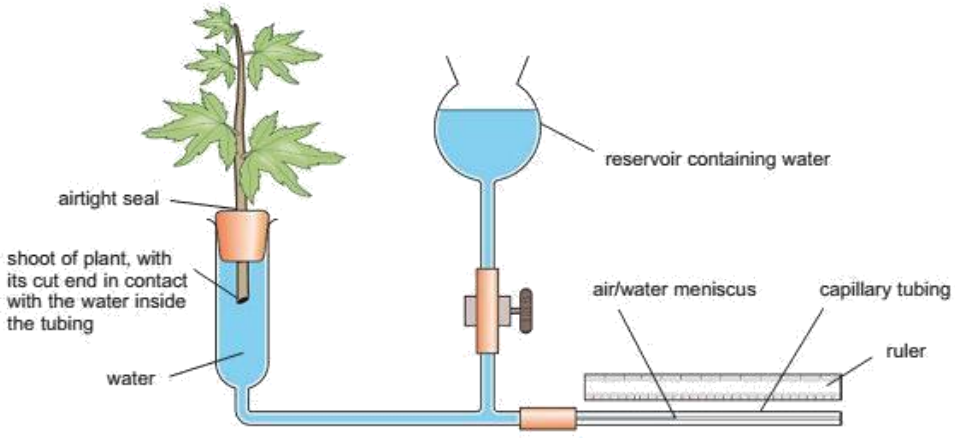
How to use a potometer

- The leafy shoot is cut under water to prevent air bubbles from entering and blocking the xylem vessels. The cut leafy shoot is immediately fixed in the sealed vessel of water connected to a capillary tube. Allow time (5 minutes) for the apparatus to equilibrate. The rate of water uptake is measured by introducing the air bubble at the end of the graduated capillary tube and the distance moved by the air bubble per unit time is noted.
- To drive the air bubble back to the original point, water is introduced into the capillary tube from the reservoir by opening the tap.

Precautions when using a potometer

→ The leafy shoot used should have a significant water loss by having very many leaves
→ The stem of the leaf shoot must be cut under water to prevent air from entering and blocking the xylem vessels
→ The setup must have plenty of water
→ Ensure that only one bubble is present in the capillary tube
→ A well graduated scale must be used e.g. a ruler, so that clear readings are taken
→ The air bubble should always be reset to zero mark before the potometer is used again under different conditions
→ The water reservoir should be filled with water when setting the air bubble at the zero mark.
→ The cut leafy shoot must be in contact with water in the sealed vessel

Diagram of a potometer



Or check fig 22.12 in understanding biology page 457.
Or Micheal kent fig 2 page 276.

Advantages of transpiration

- It allows the uptake of water from the roots to leaves in form of transpiration stream. This is due to transpiration pull created in the leaves.
- It facilitates the uptake of the absorbed mineral salts within the xylem vessels from roots to leaves.
- It brings about the cooling of the plant since as water evaporates to the atmosphere in this excessive heat is lost as heat of vaporization.

- ❖ It brings about mechanical supporting non-woody or herbaceous plants, due to water uptake which provides turgidity to parenchyma cells of the stem and leaves.
- ❖ It is important for cloud formation via evapotranspiration hence resulting into rainfall.

Disadvantages of transpiration;

- ☑ It causes wilting of plants in case of excessive transpiration
- ☑ It may eventually cause death of the plant, when the plant loses water excessively due to excessive transpiration

FACTORS AFFECTING THE RATE OF TRANSPIRATION

There are various factors that affect the rate of transpiration. For convenience these factors have been divided into external factors and internal factors.

External factors affecting the rate of transpiration

Humidity;

- The humidity of the atmosphere affects the gradient of water vapour between the sub-stomatal air chamber and the atmosphere around the leaf i.e. it affects the rate of diffusion of water vapour.
- Low humidity (low water vapour pressure) outside the leaf increases the rate of transpiration because it makes the diffusion gradient of water vapour from the moist sub-stomatal air chamber to external atmosphere steeper.
- When humidity is high in the atmosphere, the diffusion gradient or the water vapour pressure gradient is greatly reduced between the sub-stomatal air chamber and the atmosphere which results into reduction in the rate of transpiration.

Temperature;

- ⌦ Increase in temperature increases the rate of water loss by the leaves via transpiration. A decrease in temperature lowers the rate of water loss by the plant leaves via transpiration.
- ⌦ This is because increase in temperature increases the kinetic energy and movement of water molecules hence the water molecules evaporate rapidly to the sub-stomatal chambers and eventually to the atmosphere via the stomata.
- ⌦ Increase in temperature also lowers humidity outside the leaf which further increases the rate of transpiration. In extremely hot conditions, the stomata of some plants close, an adaptation to prevent water loss by transpiration.

Wind speed/ air currents;

- In still air; no wind, layers of highly saturated vapour build up around the stomatal pores of the leaf and reduces diffusion gradient between the stomatal air chamber and the external atmosphere, thereby reducing the rate of diffusion of water vapour from the leaf. The layers of highly saturated water vapour which build up around the stomatal pores of the leaf are called diffusion shells.
- Windy conditions result in increased transpiration rates because the wind sweeps away the diffusion shells around the leaf, thereby maintaining a steep diffusion gradient which keeps the rate of transpiration high.

Light;

- It affects transpiration indirectly by affecting the closure and opening of the stomata, which usually opens in bright sunlight to allow evaporation of water to the atmosphere. Therefore sunlight increases the rate of transpiration.
- At night and in darkness, the stomata close and therefore there is no evaporation of water from the sub-stomatal air spaces to the atmosphere. This greatly lowers the rate of transpiration in the plant

Atmospheric pressure;

- Water vapour and atmospheric pressure decreases with increasing altitude.
- The lower the atmospheric pressure the greater the rate of evaporation of water from the sub-stomatal air chamber. This implies that plants growing on a mountain have a higher rate of transpiration than those growing in low land areas.
- However, when the atmospheric pressure is high e.g. in the lowland areas, the evaporation of water vapour from the sub-stomatal air chamber to the atmosphere decreases, thereby increasing the rate of transpiration.

Water availability;

- ✓ For water vapour to diffuse out of the sub-stomatal air chamber to the atmosphere, the mesophyll cells must be thoroughly wet. Shortage of water in the soil or any mechanism which hinders the uptake of water by the plant leads to wilting of the plant hence the closure of the stomata.
- ✓ When water is supplied in large amounts, too much water evaporates to the atmosphere and therefore a high rate of transpiration. However, when the water supply to the mesophyll cells is low, less water evaporates from the sub-stomatal to the atmosphere, hence a low rate of evaporation.

Internal factors that affect the rate of transpiration

Leaf area;

- × The larger the leaf surface on a plant, the higher the rate of water loss by transpiration. This is because the broad leaves provide a large surface area over which water vapour evaporates to the atmosphere in comparison to the narrow leaves

Cuticle;

- × The cuticle is the waxy covering over the leaf surface which reduces water loss. The thinner the cuticle; the higher the rate of water loss by transpiration and the thinner the cuticle the lower the rate of water loss by transpiration.

Density of stomata;

- × The greater the number of the stomata for a given leaf area, the higher the rate of transpiration.

Distribution of stomata;

- × The relative numbers of stomata on the upper and lower leaf surfaces affect the rate of transpiration this is because they affect the surface area available for transpiration to occur. The higher the number of stomata on the upper surface the greater the rate of respiration and vice versa.

GUTTATION

- ✓ Most water is lost as vapour by plants however some water maybe exuded in liquid form by a process known as guttation.
- ✓ Guttation is the process of water loss/ exudation in form of liquid droplets from the leaf margins and tips of a plant
- ✓ The appearance of water drops is due to exudation through the special glands known as **hydathodes.**

Hydathodes;

- A hydathodes is an opening or pore in the leaf epidermis around which several thin walled parenchyma cells are situated. The pore is like an incomplete stoma that lost ability to close or open.

There are two types of hydathodes; the epithem hydathodes and the active hydathodes.

1. Epithem hydathodes; these function due to excessive root pressure.
2. The active hydathodes; these exude water due to the force created within the cells themselves.

N.B

i. Guttation only occurs in plants growing in warm and humid climate and at night or early morning.
ii. Factors affecting transpiration are the very factors that affect guttation.
iii. It is mainly due to root pressure

Differences between stomata and hydathodes

stomata	hydathodes
Can open and close	Always open
Occurs in the epidermis and stems of young plants	Occurs at the tip or margin of leaves
Stomatal aperture is guarded by two guard cells	Aperture of hydathodes are surrounded by a ring of cuticularised cells
Involved in transpiration	Involved in guttation

Differences between guttation and transpiration

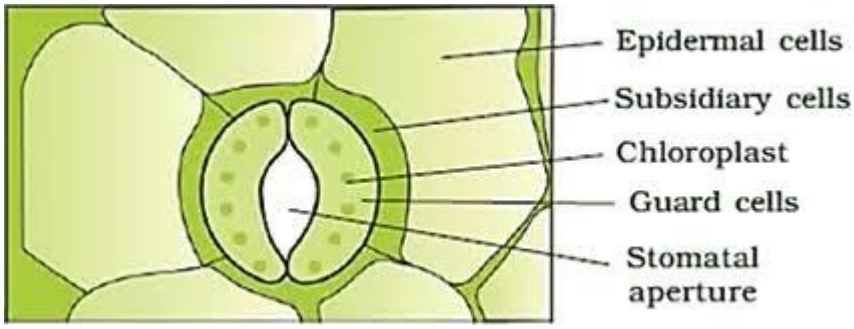
Transpiration	Guttation
Loss of water in form of water vapour	Loss of water in form of liquid droplets.
The transpired water is pure	Guttated water is a dilute solution of organic and inorganic substances.
Occurs through general surface of the leaves	Occurs at the margins and tips of the leaves.
It does not leave anything of the leaf surface	An incrustation of salts id formed on the surface.
Occurs during hotter periods of the day	Occurs mostly during the night and early morning hours.
Occurs through the stomata, lenticels and cuticles	Only occurs through water pores.
Stomata can be opened or closed	The water pore is always open.
Occurs most during dry periods	Does not occur in conditions of water deficiency
Occurs through stomata	Occurs through hydathodes

THE STOMATA

- In terrestrial plants, gaseous exchange takes place predominantly in the leaves. The epidermis of the leaves contains small pores called stomata (singular. stoma). Through stomata, gaseous exchange between the inside of the leaf and the outside air takes place by diffusion.
- The broad leafed shape of the leaf offers a large surface for diffusion of gases, its thinness reduces the distances over which diffusion of gases from the atmosphere to the inner most cells.
- In most terrestrial plants, stomata are more abundant on the lower side than the upper surface of the leaf. This reduces water loss through transpiration since the upper surface is exposed to direct sunlight.
- The number of stomata in leaves vary from one plant species to another. They are normally absent in submerged leaves of water plants.

THE STRUCTURE OF THE STOMA

- Each stoma consists of a stomatal pore bordered by a pair of crescent or bean-shaped cells called guard cells. Unlike epidermal cells, guard cells contain chlorophyll.
- The outer wall are thin and more elastic whereas the inner cell wall of guard cells is thicker and less elastic.
- Microfibrils are radially orientated in the cell wall and the guard cells are joined at the ends.
- The epidermal cells surrounding the guard cells are subsidiary cells.



Or check understanding biology page 452 fig.22.7

STOMATAL OPENING AND CLOSURE

- The opening and closing of stomata occurs as a result of changes in the shape of the guard cells.
- When guard cells take in water by osmosis, they expand and become turgid. However, they do not expand uniformly in all directions. The thick inelastic inner wall makes the guard cells to curve away from each other, opening the stoma. When the guard cells lose water, they become flaccid and collapse, closing the stomata.
- The closing and opening is controlled mainly by the intensity of light. They are normally open during daylight and closed during the night.

THEORIES OF STOMATAL OPENING AND CLOSURE

PHOTOSYNTHETIC THEORY;

- Guard cells have chloroplast. During day light, they carry out photosynthesis producing sugar.
- The sugar increases the osmotic pressure of the cell sap, this causes water to move into the guard cells by osmosis from the neighbouring epidermal cells by osmosis.
- The result is expansion of the stomata causing them to open.
- In darkness, photosynthesis stops and the sugar in the guard cells is converted to starch. This lowers the osmotic pressure of guard cells causing them to lose water to the neighbouring cells by osmosis. The guard cells thereafter become flaccid and the stomata close.
- Limitations of the theory
- It does not account for the rapid opening of the stoma depending on the rate of glucose production.

POTASSIUM ION MECHANISM;

- ✓ Guard cells have chloroplast hence manufacture ATP. When exposed to light during day which activates the ATPase enzyme, it catalyzes the conversion of ADP to ATP this provides energy to the hydrogen pump to pump out hydrogen ions from the guard cells to the epidermal cells and as well the ATP formed drives a potassium ion pump on the cell membrane of the guard cells.
- ✓ This causes the active uptake of potassium ions in the guard cells from the surrounding epidermal cells the potassium ions enter the guard cells with chloride ions.
- ✓ Accumulation of potassium ions and chloride ions in the guard cells increases the osmotic pressure of their cell sap/ causes the water potential in the guard cells to become more negative. This causes water to move from the neighbouring epidermal cells into the guard cells by osmosis. The result the expansion and increase in turgidity of the guard cells that causes the opening of the stomata.
- ✓ This so because they become turgid and since the walls of the guard cells do not expand uniformly due to the difference in elasticity, makes the guard cell walls to curve away from each other thereby opening the stoma.
- ✓ At the onset of darkness, ATP concentration in the guard cells falls rapidly stopping of the hydrogen pump and the potassium ion pump.
- ✓ Potassium ions migrates from the guard cells to the neighbouring epidermal cells by diffusion. This lowers the osmotic pressure of the guard cells causing them to lose water to the neighbouring cells by osmosis. This causes the closing of the stomata.

Note;

- ✓ The above theory is the most widely accepted theory today. It is supported by the fact that the opening of stomata is prevented by metabolic poisons which inhibit active transport.

Check illustration in understanding biology page 452 fig.22.8
Or Micheal kent fig 3 on page 281

From the two theories we can have the stomatal opening and closure mechanism

MECHANISM OD STOMATAL OPENING AND CLOSURE

a. Opening;

- Stomata opening is promoted by high light intensity and low mesophyll carbon dioxide levels. Guard cells generate ATP by photophosphorylation during photosynthesis. .
- Blue light is absorbed by blue-light photoreceptors which activate a proton-pump (H^+-ATPase) in the cell membrane of the guard cell
- ATPs generated by the light-dependent reaction of photosynthesis are hydrolysed to provide energy to drive the proton-pump. As protons (H^+) are pumped out of the guard cells, the cells become increasingly negatively charged. Potassium channels are activated and K^+ ions diffuse from subsidiary cells through the channels down this electrochemical gradient into guard cells. Chloride ions (Cl^-) then enter to balance the charge.
- In some plants the starch is converted to malate.
- The accumulation of K^+ (and malate ions) causes the water potential in the guard cells to become more negative. Water enters by osmosis from the neighbouring subsidiary cells into the guard cells. The guard cells become turgid.
- The outer wall of the guard cells is thinner and more elastic than the thicker inner wall. There are cellulose micro fibrils which are radially arranged around the cell wall and the ends of the two guard cells are joined
- The increased turgor pressure therefore causes the guard cells to curve outward and the stoma opens

b. Closure;

- Stomata closure can be triggered by water stress, high temperature, increasing carbon dioxide levels in the leaf mesophyll and low light intensity (night time)
- The hormone Abscissic acid (ABA) is secreted by plant cells when transpiration rate is high and soil water is low.
- ABA binds to receptors at the cell membrane of the guard cells. This increase the permeability of calcium channels in the cell membrane. Calcium ions (Ca^+) enter into the guard cell. The influx of calcium ions also triggers the release of Ca^+ from the cell vacuole into the cytosol.
- Potassium ions (K^+) move out of the guard cells into the subsidiary cells
- In some plants (Cl^-) and certain organic ions e.g. malate ions also move out of the guard cells
- The water potential in the guard cells increase. Water diffuses out to neighbouring subsidiary cells by osmosis. The turgor pressure in the guard cells decreases, the cells become flaccid and the stoma closes.
- At night the chloroplasts in the guard cells do not photosynthesize, less ATP is produced and there's no active uptake of K^+ ions. Instead, the K^+ ions diffuse out of the guard cells. The cells become flaccid and the stoma closes.

MOVEMENT OF WATER ACROSS THE LEAF

Provided there is some air movement around the stomata. The water lost from the substomatal air spaces is replaces by more evaporating from the spongy mesophyll cells surrounding the space. The water is brought to the spongy mesophyll cells from the xylem in the leaf in three ways;

1. **The apoplast pathway**;
- ❖ Most water travels from cell to cell via the cell wall, which is made up of cellulose fibres, between which are water filled spaces. As water moves from the sub stomatal air spaces from the wall of one cell, it creates a tension which pulls in water from the spaces in the walls of the surrounding cells.

2. **The symplast pathway**;
- ❖ Some water is lost to the sub stomatal air space from the cytoplasm of cells surrounding it. The water potential of the cytoplasm of this cell is therefore made more negative.
- ❖ Between adjacent cells are tiny strands of cytoplasm known as plasmodesmata, which link the cytoplasm of one cell to that of the next. Water may pass along these plasmodesmata from adjacent cells with less negative water potential.

3. **The vacuolar pathway**;
- ❖ A little water passes by osmosis from the vacuole one cell to the next, through the cell wall, membranes and cytoplasm of adjacent cells. In the same way as the symplast pathway, a water potential gradient between the xylem and the sub stomatal air space exists. It's along this gradient that water passes.

THE UPTAKE OF WATER:

ABSORPTION

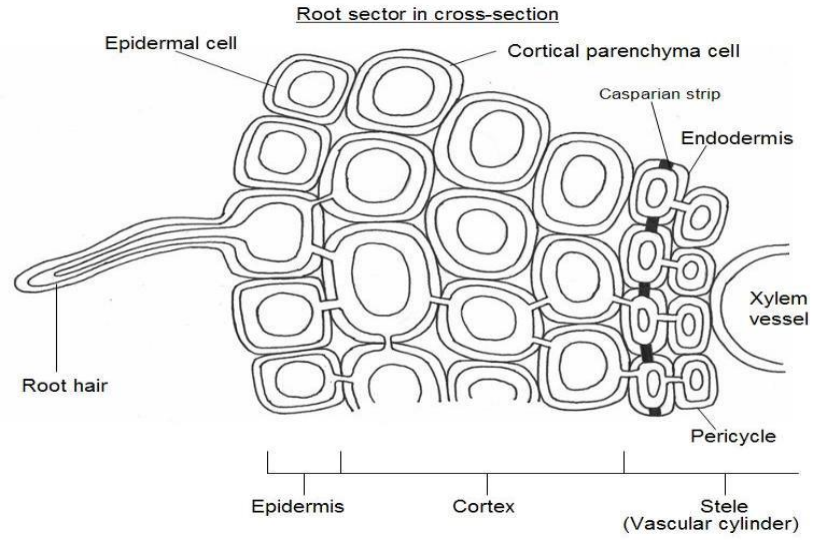
The uptake of water by the roots is mainly done by the root hairs which are extensions of epidermal cells in the piliferous region of the root. Here the epidermis is freely permeable to water but selectively permeable to inorganic ions.

ROOT STRUCTURE

- The root consists of various tissues which occur in concentric layers. The cells at the surface of the young root forming the peliferous layer are so called because it is by the root hairs. As the roots get older, they increase in girth; thickness or diameter and the peliferous layer; breaks raptures and peels off leaving the outer most layer of cells known as epiblem, to become the functional outer layer.
- Next to the epiblem is the thicker layer of loosely packed parenchyma cells, known as cortex. Adjacent to the cortex is a layer of cells known as endodermis.
- The endodermal cells have their radial and horizontal walls coated with a corky band called casparian strip. This strip is made up of a substance called suberin. The Casparian strip is impermeable to water and solutes due to the suberin that it contains and therefore prevents water and solutes to pass through the cell walls to the endodermis. The endodermis also contains starch grains.
- Next to the endodermis is another layer of cells known as **pericycle** from which lateral roots develop. The pericycle, that is made up of parenchyma cells which encloses the vascular bundles; xylem and phloem in the centre of the root.

Or Check understanding biology page 462 fig 22.13 a and b

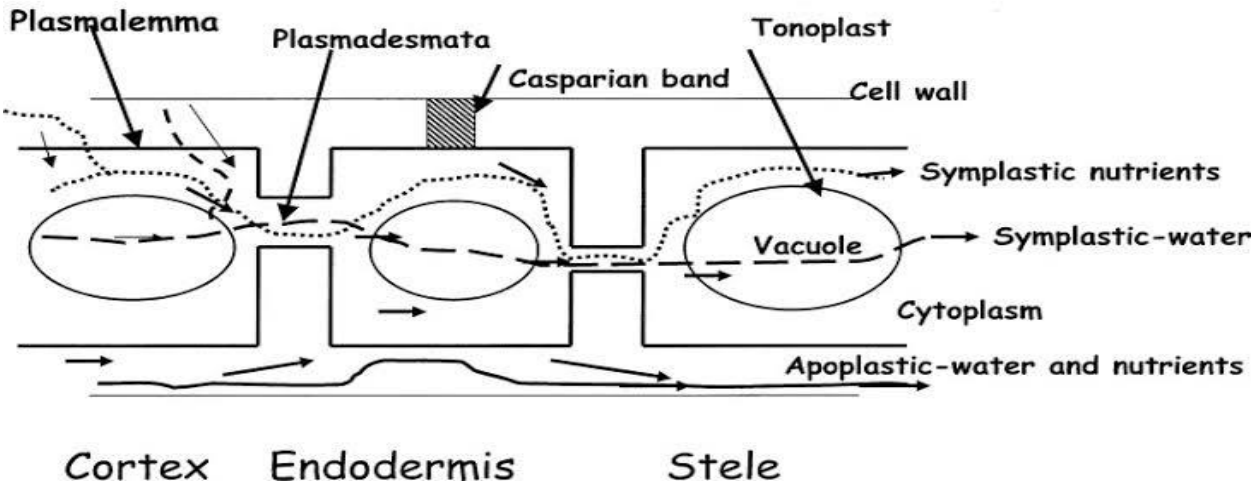
Longitudinal section through the root



MOVEMENT OF WATER AND DISSOLVED SALTS ACROSS THE ROOT:

This takes place via three different routes:-

1. **The Symplast:** i.e. from cytoplasm to cytoplasm through the plasmodesmata. The term symplast is used to refer to the continuous large fluid compartment consisting of the cytoplasm of adjacent cells and the plasmodesmata connecting them with no intervening cell surface membranes. Water enters the symplast by osmosis.
2. **The Apoplast:** i.e. from cell wall to cell wall. The cellulose fibres which make up these cell walls leave many spaces between them which are filled with water just as are the intracellular spaces. Since these are freely permeable water moves across them by diffusion. It is this continuous fluid system in the cell walls that is known as the apoplast.
3. **The vacuolar pathway**: i.e. from vacuole to vacuole. Since water is one of the components of the vacuole sap.



Or check illustration in understanding biology page 465 fig. 22.15

Or Functional approach page 184 fig 12.5 B and C

Note;

- The most used route for water movement across the root is the apoplast because it offers relatively least resistance to water flow for it does not need to go through any impeding membranes. Compare this with the vacuolar in route where- to pass from cell to cell the water must move by osmosis through the tonoplast, and through the cell membranes and cell walls. This certainly offers great resistance and slows down its movement.
- Water moves along a water potential gradient by either of the above three routes from the piliferous layer to the epiblem, cortex, endodermis, pericycle and finally the xylem,
- At the endodermis due to the presence of the casparian strip water is forced to move only along the symplast.

The role of the endodermis and its casparian strip in water uptake and transport stems from the fact that:

- ✓ The endodermis secretes salts actively into the vascular tissues and the low water potential thus created there forces water to enter by osmosis.
- ✓ The casparian strip prevents the outward leakage of salts from the vascular tissues hence maintaining this status quo of a low water potential.

Adaptations of the root hairs to water absorption

- They are numerous in number so as to provide a large surface area for the maximum absorption of water by osmosis.
- They are slender and flexible for easy penetration between the soil particles so as to absorb water.
- The lack a cuticle and this enhances the passive osmotic absorption of water without any resistance
- They have a thin and permeable membrane which allows the absorption of water by osmosis.
- They have a water potential lower than that of the soil solution which facilitates a net osmotic flow of water from the

MOVEMENT OF WATER WITHIN THE XYLEM / UP THE PLANT

Three theories have been suggested to explain the movement of water in the xylem up the plant.

These are;

1. **Capillarity theory;**

- ➢ Capillarity is the rise of liquids in narrow tubes and among other things depends on the adhesion of water molecules to the walls of the tubes. As a result of this, water tends to rise highest in the narrowest tubes because they present the largest relative surface area of the wall in contact with adhering water molecules.
- ➢ Now since the xylem vessels are also tubes of very fine bore water adheres to the vessel walls and since they are stacked end to end they form long capillary tubes from roots to leaves.
- ➢ Consequently water will rise up the xylem from the root by capillarity. However this process must be playing a minor role in the upward movement of water in a plant for even in the finest vessels it would only rise about 1metre which is not far enough to reach the leaves of even a small tree. Therefore other mechanisms must be involved.

2. **The Root pressure theory**

- This has been suggested as a result of the common observation that water tends to exude from a cut stem indicating that some pressure in the root is actually pushing it up.
- The origins of root pressure are in the endodermis where the active transfer of ions from the cortex into the xylem occurs which are subsequently prevented from leaking out by the casparian strip and result in a water potential gradient forcing water into the xylem via the symplast of the endodermal cells which results in a hydrostatic pressure which can only be relieved by water moving up the xylem.
- Root pressure is an active process and is confirmed by the facts that:-

✓ It occurs only in living plants

✓ It is affected by the same factors affecting respiration in cells like oxygen supply, temperature, carbohydrate supply and the presence of respiratory poisons like cyanide.

✓ There are numerous starch grains in endodermal cells which could act as an energy source for active transport.

- Like capillarity, root pressure is not sufficient on its own to push water to leaves at the top of tall trees.

3. The transpiration theory:

- This theory suggests that water is not pushed up the stem but pulled up as a result of tensions; negative pressure created in the leaves due to the loss of water in them by evaporation in the process of transpiration.
- Thus the cells of the leaf mesophyll in order to replace the lost water exert a pull by which they draw water from the xylem vessels known as the transpiration pull.
- The resulting movement of water in the xylem in continuous column is called the transpiration stream and this is possible because water molecules being polar, i.e. have a property of attracting one another; cohesion and other molecules as well like the walls of the vessels (adhesion).
- For this reason great tension can be maintained in the xylem without the columns of water breaking. By combination of the three forces transpiration, cohesion and tension the water column can be pulled to the top of the tallest trees.

Evidence of transpiration pull

- The diameter of most tall trees has been found to decrease during periods of maximum transpiration e.g. around mid-day. This is explained by the fact that columns of water molecules now draw this by the tension exerted by the transpiration pull still continue to adhere to the xylem vessel walls and pull them inwards.

Limitation of transpiration pull theory

- However the theory does not explain why it is not possible to block the xylem vessels with air bubbles e.g. when branches on a tree breaks off.

UPTAKE AND TRANSLOCATION OF MINERALS

All plants require a supply of minerals like we saw in chemicals of life. These minerals are largely absorbed by roots through the root hairs, although leaves can also absorb them if sprayed with a suitable solution.

Mechanisms of mineral uptake

Minerals maybe absorbed either passively or actively.

1. **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.

2. **Active absorption;**

- If the concentration of the mineral in the soil solution is less than that in the root hair cell it may be absorbed by active transport (refer to movement in and out of the cell)
- Most minerals are absorbed in this way. The process is selective. Because the active absorption requires energy, it is dependent upon respiration.
- Minerals are transported by either 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 may 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.
- 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 tissues.

EVIDENCE OF ACTIVE TRANSLOCATION OF MINERAL IONS

- When salts are added to plants growing in water, the respiration rate increases presumably to provide the energy required for the mineral absorption.
- However addition of a respiratory inhibitor such as potassium cyanide, the rate of respiration decreases this directly affects the active uptake of mineral ions which as well decreases and thus mineral uptake under such a situation can only occur by passive means which may not meet the demand of the plant and eventually it becomes stunted.
- Increase in temperature around the plant increases the rate of mineral ion uptake from the soil as it increases respiration that can provide energy for active transport
- Depriving the root hairs of oxygen prevents active uptake of minerals by the roots and as a result very few ions enter the plant by diffusion.

***Check in understanding biology page 466& 465 fig 22.16& 22.17**

EVIDENCE FOR SUPPORTING THE ROLE OF THE XYLEM IN TRANSPORTING MINERALS

- The presence of mineral ions in the xylem sap i.e. many mineral ions have been found to be present in the xylem sap.

- There's a similarity between the rate of mineral ion transport and the rate of transpiration i.e. if there's no transpiration, then there's no mineral ion transport and if transpiration increases, the rate of mineral ion transport also increases.
- There's evidence that other solutes e.g. the dye, eosin, when applied to the plant roots, it is carried in the xylem vessels
- By using radioactive tracers e.g. phosphorous-32. When a plant is grown into a culture solution containing radioactive phosphorous-32, phosphorous -32 is found to have reached all the xylem vessels but not the phloem tubes; where lateral transfer of minerals can take place minerals pass from the xylem to the phloem and where lateral transfer is prevented, the transport of minerals takes place in the xylem.

TRANSLOCATION OF ORGANIC MOLECULES

- The organic materials produced as a result of photosynthesis need to be transported to other regions of the plant where they are used for growth or storage.
- This movement takes place in the phloem tissue particularly in the sieve tubes.

Evidence for transport of organic material in the phloem

- When the phloem is cut, the sap which exudes out of it is rich in organic food materials especially sucrose and amino acids.
- The sugar content of the phloem varies in relation to environmental conditions. When the conditions favor photosynthesis, the concentration of the sugar in the phloem increases and when they not favor photosynthesis and concentration of the sugar in the phloem reduces.
- Removal of a complete ring of phloem around the phloem causes an accumulation of sugar around the ring, which results into the swelling of the stem above the ring. This indicates that the downward movement of the sugars has been interrupted and results into the part below the ring failing to grow and may dry out. This is called the ringing experiment.
- The use of radioactive tracers. If radioactive carbon dioxide-14 is given to plants as a photosynthetic substrate, the sugars later found in the phloem contain carbon-14. When the phloem and the xylem are separated by waxed paper, the carbon-14 is found to be almost entirely in the phloem.
- Aphids have needle like proboscis with which they penetrate the phloem so as to suck the sugars. If a feeding aphid is anaesthetized using carbon dioxide or any other chemical e.g. chloroform and then its mouth parts cut from the main body, some tiny tubes called the proboscis remain fixed within the phloem sieve tubes from which samples of the phloem contents exude.
- When the contents of the phloem are analyzed, they are confirmed to be containing carbohydrates, amino acids, vitamins etc. which further confirms that the phloem transports manufactured foods.
- When small sections of the pierced stems are cut following the proboscis penetration, the tips of the proboscis are found within the phloem sieve tubes.

MECHANISM OF TRANSLOCATION IN THE PHLOEM

It has been found out that materials in the phloem are not translocated by diffusion because the rate of flow of materials in the phloem is much fast for diffusion to cause.

The following theories have been put forward to explain this movement;

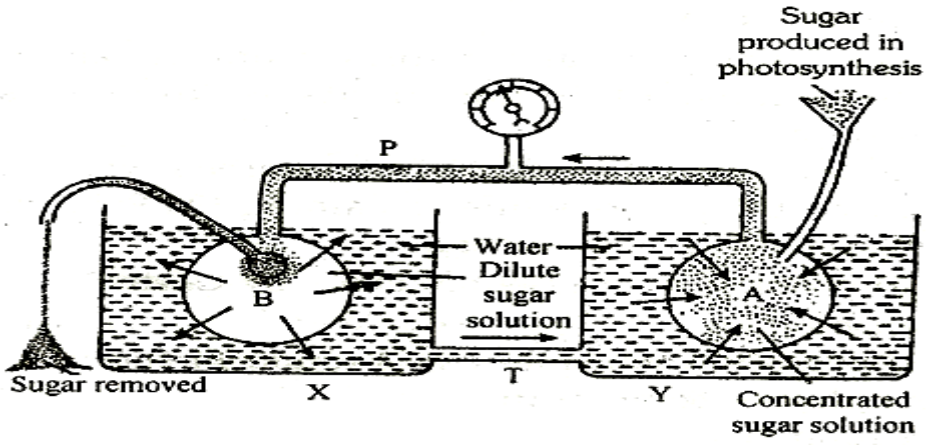
1. Mass flow hypothesis
2. Electro-osmosis
3. Cytoplasmic streaming

MASS FLOW HYPOTHESIS/ MUNCH'S HYPOTHESIS/ PRESSURE FLOW

Mass flow; this is the bulk movement of materials from one point of an organism to another due to turgor differences that occurs between these two points.

- According to this theory, photosynthesis forms soluble carbohydrates like sucrose in the leaves. The photosynthesizing cells in the leaf therefore have their water potential lowered due to the accumulation of this sucrose.
- Sucrose is actively pumped into the phloem sieve cells of the leaf. As a result, water which has been transported up to the stem xylem enters these mesophyll cells by osmosis due to the accumulation of sucrose.
- This causes an increase in the pressure potential of the leaf cells including the leaf sieve tube elements more than that in the cells in the sink i.e. the mesophyll cells where the sugars are manufactured are referred to as **the source** while the other parts of the plant such as the roots and other tissues where food is utilized are referred to as **the sink**.
- The two; sink and source are linked by the phloem and as a result, the food solution in the sieve tubes then moves from a region of higher pressure potential in the leaves to that of lower pressure potential in the sink such as roots following a hydrostatic pressure gradient.
- At the other parts of the plant which form the sink e.g. the roots, sucrose is either being utilized as a respiratory substrate or it is being converted into insoluble starch for storage, after being actively removed from the sieve tubes and channeled into the tissues where they are required.
- The soluble content of the sink cells therefore is low and this gives them a higher water potential and consequently lower pressure potential exists between the source (leaves) and the sink such as roots and other tissues.

Physical model of mass flow hypothesis



Or check fig 22.23 on page 470 of understanding biology
Or functional approach page 195 fig 12.17

Evidence supporting mass flow hypothesis

- When the phloem is cut, the sap exudes out of it by mass flow
- There's rapid and confirmed exudation of the phloem's sap from the cut mouth parts of the aphids which shows that the content of the sieve tubes move out at high pressure.
- Most researchers have observed mass flow in microscopic sections of the sieve tube elements.
- There's some evidence of concentration gradient of sucrose and other materials with high concentration in the leaves and lower concentration in the roots.
- Any process that can reduce the rate of photosynthesis indirectly reduces the rate of translocation of food.
- Certain viruses are removed from the phloem in the phloem translocation stream indicating that mass flow rather than diffusion, since the virus is incapable of locomotion

Criticisms to mass flow hypothesis

- × By this method all organic solutes would be expected to move in the same direction and at the same speed. It was however observed that the organic solutes move in different directions and at different speeds.
- × The phloem has a relatively high rate of oxygen consumption which this theory does not explain.
- × When a metabolic poison such as potassium cyanide enters the phloem, the rate of translocation is greatly reduced, implying that translocation is not a passive process, but an active one.
- × The mass flow hypothesis does not mention any translocation of solutes with influence of transfer cells and Indole Acetic Acid hormone that loads the sugars or solutes into the sieve tubes and also unload it into the cells of the sink.
- × The sieve plates offer a resistance which is greater than what could be overcome by the pressure potential of the phloem sap. This implies that the pressure would sweep away the sieve plates during this transport.
- × Higher pressure potential is required to squeeze the sap through the partially blocked pores in the sieve plates than the pressure which has been found in the sieve tubes

ELECTRO- OSMOSIS HYPOTHESIS

This is the movement of ions in an electrical field through a fixed porous electrically charged surface.

- It follows observations that:-
- Ions move in an electrical field to the pole with a charge opposite to their own i.e. + to – and vice versa
- Ions with a like charge repel each other.
- Ions in aqueous solution are surrounded by a shell of water i.e. they are hydrated.
- Water and its dissolved solutes e.g. sucrose which surrounds the hydrated ions is bound to the hydration shell by hydrogen bonds.

- When hydrated ions move in an electric field water and dissolved solutes will follow such ions.
- The sieve plates and phloem proteins are normally negatively charged thus forming the required fixed and charged porous surface.

✓ Thus it is argued that when mass flow occurs downwards through the phloem the anions being repulsed accumulate above the sieve plate so that the cell above the sieve plate becomes negative with respect to that below.

✓ A potential difference builds up on the sieve plate and when it reaches a critical value (the threshold) protons (H^+) surge from the wall of the upper cell into its cytoplasm lowering its pH and making the cytoplasm above the sieve plate positively charged.

✓ This pushes other positive ions (cations) mainly K^+ by electrical repulsion through the sieve plate from the upper to the lower cell (i.e electro-osmosis occurs).

✓ This surge of hydrated potassium ions carries water molecules and dissolved solutes like sucrose across the sieve plate. Later on using ATP from the mitochondria in the companion cell, proton pumps in the surface membrane of the sieve tube cell quickly pump protons out of its cytoplasm and back into its cell wall.

✓ The cell therefore reverts to its original state and the process begins all over again

NOTE:

☑ This theory does not object Munch's mass flow hypothesis but modifies it to explain among other things:-

☑ The great velocity of translocation in the phloem, the great energy demands and the fact that presence of sieve pores does not necessarily increase resistance to flow.

☑ It therefore accounts for the need for companion cells and sieve plates in the phloem and this is compatible with Munch's hypothesis by suggesting that solutes move in the phloem by mass flow but the flow is boosted at intervals; at the sieve plates by electro-osmosis

Evidence of electro-osmosis

- K^+ ions stimulate the loading of the phloem in the leaves with sugars during photosynthesis.
- Numerous mitochondria produce a lot of energy for translocation, an indicator that translocation is an active process. If however, the phloem tissues are treated with a metabolic poison, the rate of translocation reduces.

CYTOPLASMIC STREAMING/ TRANSCELLULAR STRAND HYPOTHESIS

- Within the phloem tissue, there are cytoplasmic strands or filaments which are proteins in nature and they are continuous from one sieve element to another via the pores.
- Food substances are able to move along these strands due to wave-like contractions/ peristaltic contractions generated by the filaments. The sieve elements use energy provided by the companion cells to carry out such contractions.
- Cytoplasmic streaming enables some food substances to move upwards while others downwards. It therefore accounts for the bi-directional flow of substances observed in the phloem tissue

Evidence of cytoplasmic streaming

- ⌦ It has been found that the solute materials move in both directions in the phloem tissue
- ⌦ The theory explains the existence of the trans-cellular strands in the phloem tissue as well as many mitochondria in the companion cells
- ⌦ Presence of a sieve plate where a potential difference can be developed across the plate

Criticisms of cytoplasmic streaming

- ✓ Cytoplasmic streaming has not been reported in mature sieve tube elements but only in young sieve tubes.
- ✓ The rate at which the protoplasm streams is far slower than the rate of translocation.
- ✓ Plants would require a lot of energy to transport the observed food units of food substances.

END OF TOPIC TRANSPORT

I thank you for you have been able to complete this topic hope it has been interesting. I guess yes anyway we have looked at the necessity of transport in both plant and animals, blood and its functions, the immune system in detail, the circulatory systems, heart structure and its initiation and action, lymphatic system, importance of water in transport in plants, xylem and phloem functioning, transpiration and guttation, uptake of water by roots, water flow in the leaves, uptake and translocation of mineral ions and finally translocation of organic molecules.
Am grateful all has been well mastered so you can now answer the questions below.

1. a) Describe the Cohesion-tension theory water movement in the xylem
   b) State the importance of transpiration to plants.
   c) Briefly describe how xylem is formed from a meristematic cell
   d) How is the rate of transpiration controlled in plants
   e) Explain why certain plants may fail to absorb water in water logged soils

2. a. differentiate between natural active immunity and artificial active immunity
   b. state the different ways in which the mammalian body naturally prevents pathogens from accepting its internal environment.
   c. what is the significance of high body temperature experienced when the mammalian body is attacked by plasmodium species?

3. a. state any two theories which have been put forward to explain the stomatal movements.
b. describe the mechanism of stomatal movement based on each of the theories stated above,
c. state any weaknesses for the two theories stated.
4. a. describe the structure of the phloem tissue.
b. describe the mass flow theory of food transport in plants.
5. explain how water moves from;

a. soil into the xylem
b. stem to the leaf
6. a. what is meant by the term chloride shift?
b. account for the relative position of the oxygen dissociation curve of human and rat haemoglobin.
C. explain the rapid dissociation of oxyhaemoglobin of a rat during vigorous exercise.
7. a. describe the events which occur during the heart beat.
b. outline the features which ensure efficient flow of blood within the mammalian body.
8. a. describe the mechanism of stomatal movement based on osmotic pressure.
9. Explain how each of the following affect the rate of transpiration
i. temperature
ii. Sunken stomata.
10. a. what is the physiological significance of the Bohr's effect in animals?
b. discuss the factors that may alter the rate of heart beat in mammals.
11. Briefly explain the significance of existence of the casparian strip within the endodermal cells in roots.
12. a. describe the distribution of vascular and parenchyma tissues in plants.
b. discuss the theories of food transport in plants.
13. a. distinguish between auto immunity and immunity
b. suggest three key roles played by the body' immune system
c. state three ways body openings are protected from entry of pathogens.
d. state two immune diseases resulting from auto immune disorders.
14. a. explain why simple organisms do not have a specialised transport system
b. state three differences between vascular systems in higher plants and circulatory systems in animals.
c. describe what happens in the following pathways during transport in plants
i. the apoplast
ii. The symplast
15. a. what is meant by the term Bohr's effect?
b. briefly explain the following observations; the oxygen dissociation curve of;
i. man shifts to the right during exercise.
ii. The elephant is on the left of that of a mouse
iv. the lugworm is on the left of that of man

8. NUTRITION

AUTOTROPHIC NUTRITION

This is derived from '*auto*' which and '*self*' and '*trophic*' which means '*feeding*'; organisms use an inorganic form of carbon, such as carbon dioxide to make up complex organic compounds.
These organic compounds are more ordered and possess energy.
There are two types of autotrophs;

- Phototrophs - organisms which synthesize organic compounds using light energy. E.g. all green plants, algae, cyanobacteria, blue-green bacteria, green sulphur bacteria, purple sulphur bacteria, colourless sulphur bacteria.
- Chemotrophs - organisms which synthesize organic compounds using energy extracted from oxidation of inorganic most bacteria such as Nitrosomonas and Nitrobacter

CHEMOSYNTHESIS

This is a chemical process in which inorganic chemicals are oxidized to provide energy to living organisms for the synthesis of organic compounds.
The chemosynthetic bacteria utilize the energy from the chemical oxidation of inorganic chemicals to synthesize organic compounds (carbohydrates), some of which are subsequently oxidized in respiration to yield energy for metabolism.

$$6CO_2 + 12H_2S \longrightarrow C_6H_{12}O_6 + 6H_2O + 12S$$

These include;

a. Nitrosomonas; this found in soils and serves to oxidize ammonium compounds into nitrites with release of 79 to 81 Kcals of energy
b. Nitrobacter; this is found in soil and serves to oxidize nitrites into nitrates. This reaction releases 22 to 24 Kcals of energy.
c. Thiobacillus; this is found in decaying organic matter; plants and animals and serves to oxidize sulphur (energy source) in form of hydrogen sulphide into sulphates. This reaction too releases lots of energy
d. Iron bacteria/ Ferro bacillus; this is found in streams flowing over iron rocks and oxidizes iron (II) containing compounds(energy source) to iron (III) compounds; with release of energy
e. Hydrogen bacteria; this found in soils and converts hydrogen(energy source) to water and releases energy

N.B the major importance of chemosynthetic bacteria is in nutrient recycling such as in the sulphur and nitrogen cycles.

PHOTOSYNTHETIC BACTERIA

1. **Green sulphur bacteria**; these are photo auto trophic bacteria, they are obligate anaerobes, they use sulphide ions as electron donors. They contain bacteriophylls a, c, d and e which are located in the plasma membranes. They are common in extremely anoxic environments. Use H2S and S
2. **Purple sulphur bacteria**; these are photosynthetic bacteria. They are anaerobic found in hot springs, stagnant water. These do not produce oxygen because they do not use water as their reducing agents. They use sulphur inform of sulphide or thiosulphate as the electron donor in their photosynthetic pathways.
3. **Cyano bacteria**; these are free living photosynthetic bacteria. They commonly obtain their through oxygenic photosynthesis they are found in freshwater and terrestrial environments. They use chlorophyll

PHOTOSYNTHESIS

It is the formation of complex organic substances inside the cell containing chlorophyll from carbon dioxide and water using sunlight energy.

It is principally important because;

- It is the means by which the sun's energy is captured by plants for use by all organisms.
- It provides a source of complex organic molecules for heterotrophic organisms.
- It releases oxygen for use by aerobic organisms.
- It reduces on gaseous carbon dioxide, which would accumulate in the atmosphere to cause greenhouse effect.

LEAF STRUCTURE

The leaf is the main photosynthetic structure of a plant, although other parts such as stems, sepals and other parts may also photosynthesize.

The leaf is adapted to bring together the three raw materials for photosynthesis water, carbon dioxide and light.

Adaptations of the leaves to obtaining energy/ sunlight

- Phototropism causes shoots to grow towards light in order to obtain energy.
- Etiolation causes rapid elongation of shaded shoots to enable access to light.
- The mosaic leaf arrangement minimizes leaf overlap and reduces leaves shading each other.
- Leaf large surface area enables capturing maximum sunlight.
- Thinness of leaves enables maximum light penetration.
- The transparence of leaf cuticle and epidermis allow light penetration into the photosynthetic mesophyll.
- The palisade mesophyll cells are densely packed with chloroplasts to trap much light.
- Movement of chloroplasts within the mesophyll cells; cyclosis allows re-positioning in the direction of light.
- The chloroplasts hold chlorophyll in an ordered 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.
- Multiple cell layers in the palisade mesophyll of sun plants increases photosynthetic efficiency.
- The leaves are thin this makes almost all the light received to be utilized directly for photosynthesis and not the leaf itself filtering it out.

Adaptations of the leaves to obtaining and removing gases

- Numerous stomata are present in the epidermis to enable entry and exit of gases
- The guard cells surrounding the stoma cause the opening and closing of the stoma thus regulating the uptake of carbon dioxide.
- Spongy mesophyll possesses many air spaces to enable faster and uninterrupted diffusion of gases between the atmosphere and the palisade mesophyll which would be much slower if the gases were to diffuse through the cells themselves.

Adaptations of leaves for obtaining and removing liquids

- They have a large central midrib which contains a large vascular bundle comprising of the xylem and phloem tissue. They xylem allows water and mineral salts to enter the leaf and the phloem carries away the sugar solution usually inform of sucrose.

- A network of small veins is present, these ensure that no cell is ever far from the xylem or phloem sieve tube thus cells have a constant water supply for photosynthesis and a means of removing sugars they produce.

As a matter of fact we can say conditions required for photosynthesis are three i.e carbon dioxide water and light.

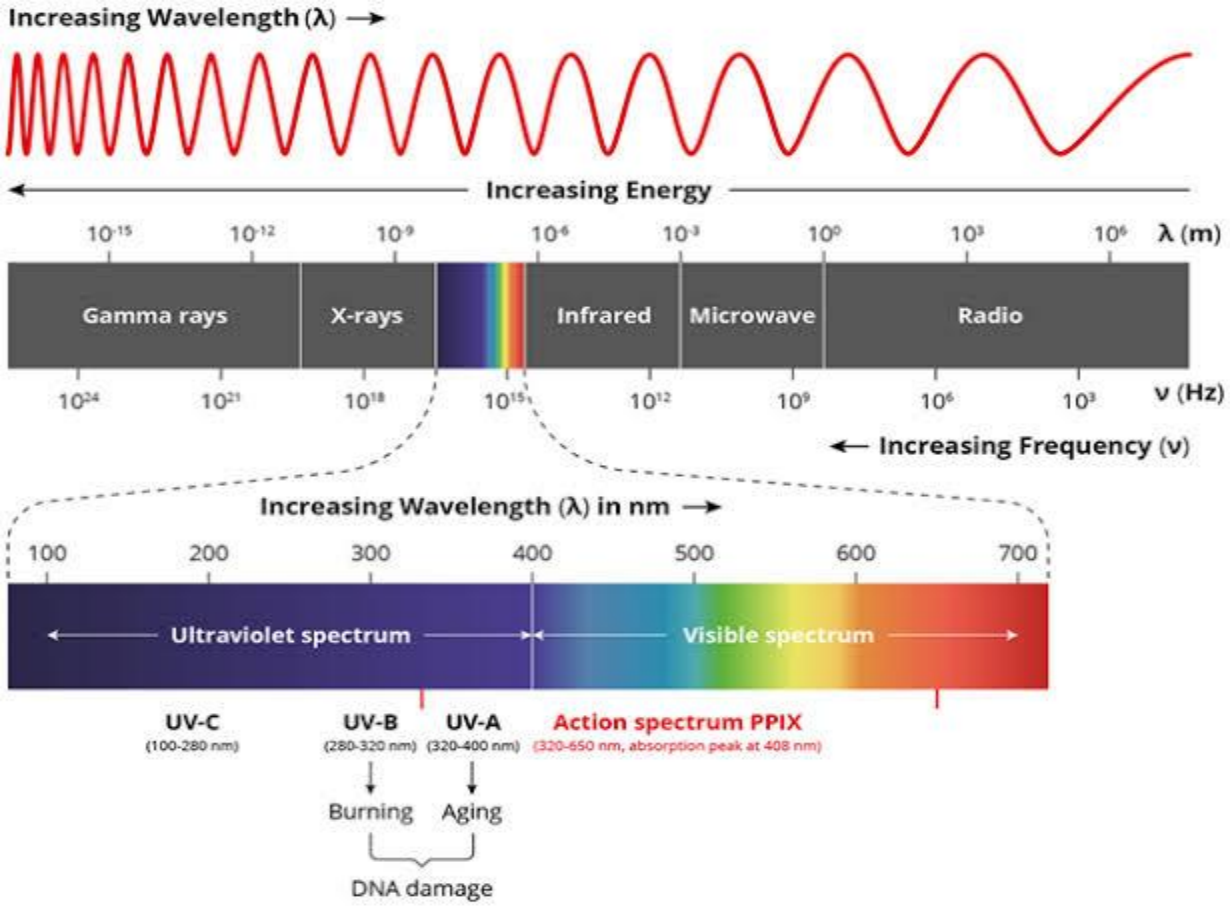
1. **Carbon dioxide**; this is obtained via diffusion through the stomata on the leaf and as well absorption in form of bicarbonates or carbonates through the leaves. The concentration of carbon dioxide in water and air vary with little in water and much(0.04%) in air
   So most aquatic plants have adapted to acquiring carbon dioxide in various ways;
   - ✓ Having many stomata on the upper surface with little or no stomata on the water surface such as in the water lily.
   - ✓ Having broad leaf surfaces these provide a large surface area for stomata circulation.
   - ✓ Absorbing bicarbonates and converting them to carbon dioxide.
   - ✓ Having all the stomata opened during day(stomatal rhythm)
2. Water is an electron and proton donor for the reduction of carbon dioxide.
3. **Light**;

There are three features of light that make it biologically important
Quality; colour, intensity; brightness and duration; day length.

LIGHT

Light is an electromagnetic energy propagated in photons or quanta.
Quanta are particles found in light and a single quantum is called a photon
Light has a wave nature and thus forms part of the electromagnetic spectrum.

Electromagnetic spectrum



- Visible light represents that part of the spectrum from violet (400nm) to red (700nm).
- It can be observed that the shorter the wavelength, the greater the frequency.
- Light with a short wavelength has more energy than light with longer wavelength e.g. Blue light (wavelength 400nm) has more energy than a photon of red light (wavelength 700nm

How to obtain light for photosynthesis;

❖ Incandescence: The emission of light from hot matter e.g. the sun. The hotter the material, the shorter the wavelengths of emitted light, the more the energy.

❖ Luminescence: The emission of light when 'excited' electrons fall to a lower energy, emitting a photon e.g. the light-emitting diode bulbs in school labs, fluorescent lights, light from leaf extracts, etc.

NOTE: when light reaches the leaves, it, maybe;

- ✓ Simply rebound off the leaf surface and hence never utilized in leaf photosynthesis; reflection
- ✓ Transmitted through the leaf, exiting from the underside. Transmission depends on the thickness of the leaf; thin leaves transmit more light than thick leaves
- ✓ Absorbed by the leaf, in which case the light might be used in photosynthesis.
- ✓ Of the absorbed visible radiation, 70%, is used in photosynthesis while 30% is transmitted through the leaf. Blue and red are the most absorbed wavelengths, and green and far infrared wavelengths pass through.

SHADY AND OPEN PLANTS

- × Shady plants have shade leaves; shade leaves grow on branches exposed to light that has passed through leaves.
- × Open plants/ sun plants have Sun leaves; are those that grow on branches exposed to direct sunlight while
- × In low light, plants need to maximize light absorption for photosynthesis to exceed respiration if they are to survive. In high light environment, plants maximize their capacity for utilizing abundant light energy, while at the same time dealing with excess sunlight which can bleach chlorophyll.

Leaves have become adapted to maximum light absorption with respect to their environments in a number of ways as follows

Comparison between Sun and Shade plants

Shade plant	Sun plant
1. Abundant chlorophyll b (low chlorophyll a to chlorophyll b ratio) which gives leaves dark green colour to increase light absorption in the dark; 2. Palisade/ spongy mesophyll ratio low to allow maximum light penetration; 3. Mesophyll cell surface / leaf area ratio low to maximize light trapping; 4. Leaf orientation horizontal to maximize light trapping; 5. Reddish leaf undersides to enhance reflectance back up through the photosynthetic tissue; giving the plant a second chance to utilize the light.	1. Abundant chlorophyll a (high chlorophyll a to chlorophyll b ratio) to increase light absorption; 2. Palisade/ spongy mesophyll ratio high to minimize light penetration; 3. Mesophyll cell surface / leaf area ratio high to minimize excessive light and transpiration; 4. Leaf orientation erect to minimize light trapping; 5. Stomatal density high to avoid over heating;

6. Stomatal density low to avoid over cooling; 7. Thin leaves to maximize light penetration; 8. Stomatal size large to allow loss of excess water; 9. Elongated internodes for increased access to light;	6. Much carotenoids to prevent damage to chlorophyll from very bright light. 7. Thick leaves to minimize light penetration; 8. Stomatal size small to minimize water loss; Other features (i) Rubisco and soluble protein content /mass higher (ii) Chlorophyll / soluble protein ratio high (iii) Chloroplast size small

Comparison of open and shade photosynthetic pigments

- The ratio of chlorophyll a: chlorophyll b is bigger in sun leaves than shade leaves (Sun leaves contain more chlorophyll a than shade leaves) because chlorophyll a is more effective at absorbing the light wavelengths available to sun leaves e.g. about 450 nm.
- Shade leaves contain more chlorophyll b than sun leaves because in shade plants chlorophyll b improves light-capturing capability of the chloroplast.
- Sun leaves contain more carotenoids than shade leaves because carotenoids are accessory pigments that shield chlorophylls from destruction by excessive sunlight.

PLANTS UNDER THE CANOPY

The cover made by branches and leaves that spread out in the forest is what is called a canopy. It will always look like an umbrella in a forest

Plants under canopy of forest trees are in a light shadow and usually live in water logged soils of the forest which have less aeration. The following make these plants to survive successfully;

- Some have adopted a parasitic mode of life and are found developing from the stems of tall forest trees as epiphytic feeders.
- Some have climbing stems. This makes them capable of reaching out to light by growing their leaves beyond the forest canopy.
- Some have breathing roots that grow up from the water logged soils to allow for proper gaseous exchange.
- Some plants such as the ferns have tissues that are well adapted to live in the water logged soils of the forest.
- Some plants are well adapted to photosynthesize at low light intensities below the forest canopy.
- Some plants form symbiotic relationships with the forest trees and other saprophytic organisms (such as fungi) in order to obtain enough nourishment.
- Some have adopted C4 photosynthetic pathway, making them more efficient at photosynthesis.
- Most plants have a higher chloroplast density in their leaves compared to the tall forest tress. This makes them efficient at trapping the low light that reaches them below the forest canopy.
- Some plants are more efficient at trapping and utilizing light of different wavelength from that trapped by the tall trees. Thus, they can still be able to receive this after the tall trees have trapped the rest from the light spectrum.
- Some of the plants such as the insectivorous plants are heterotrophic feeders and so require a minimum amount of light which they can sufficiently receive even below the forest canopy.

- Most plants possess an extensive surface root system in order to obtain enough aeration in the water logged forest soils.
- Most plants are seasonal, growing only when conditions are favorable

N.B in the above question emphasis is put on how they are able to obtain light, water and carbon dioxide.

PHOTOSYNTHETIC PIGMENTS

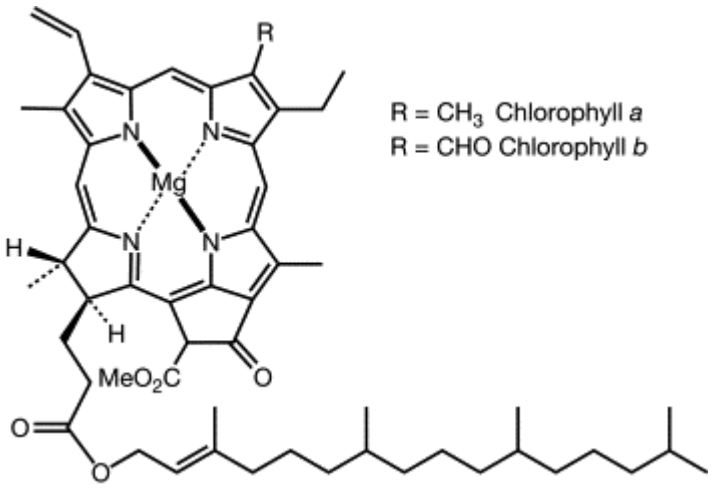
1. A variety of pigments are involved in photosynthesis of which chlorophyll is by far the most important.

There are a number of different chlorophylls;

- **Chlorophyll a** is in most photosynthetic plants and by far the most abundant. It absorbs moat energy from wavelength of violet blue and orange red. It reflects green yellow light and as such contributes to the observed green colour in most plants.
- **Chlorophyll b** is common in higher plants. It is more soluble in polar solvents than chlorophyll a because of its carbonyl group. Its colour is green and primarily absorbs blue light.

GENERAL STRUCTURE OF CHLOROPHYLL

- Chlorophyll molecule has a tadpole-like structure, with a hydrophilic head called porphyrin and a hydrophobic tail made up of long chain alcohol called phytol. That is always embedded in the thylakoid membrane and anchors and orients the molecule.



- The flattened head is made up of four nitrogen containing pyrrole rings which are linked by methine bridges.
- The skeleton of each pyrrole ring is made up of 5 atoms - four carbon and one nitrogen. The nitrogen lies towards the centre.
- A magnesium atom is held in the centre of porphyrin head by nitrogen atoms of pyrrole rings using 2 covalent and 2 coordinate bonds.
- Chlorophyll b differs from chlorophyll a in having the group (-CHO) instead of a methyl group (-CH3) at position R (carbon 3).

Or check in understanding biology page 274 fig.14.4

2. **Carotenoids**;

These occur in chloroplasts of plants, algae, some bacteria and some fungi
These are divide into;

- ✓ **Xanthophyll**; these are often yellow
- ✓ **Carotenes;** these have various colours depending upon the plant they are in e.g they are responsible for the orange colour of carrots. They absorb ultra violet and blue light and scatter orange, red and yellow light.

3. **Bacteriophylls**, these are used by the photosynthetic bacteria.

Note; Chlorophyll *b* and carotenoids are accessory pigments (help chlorophyll a) i.e. they hand over energy absorbed to chlorophyll *a*.

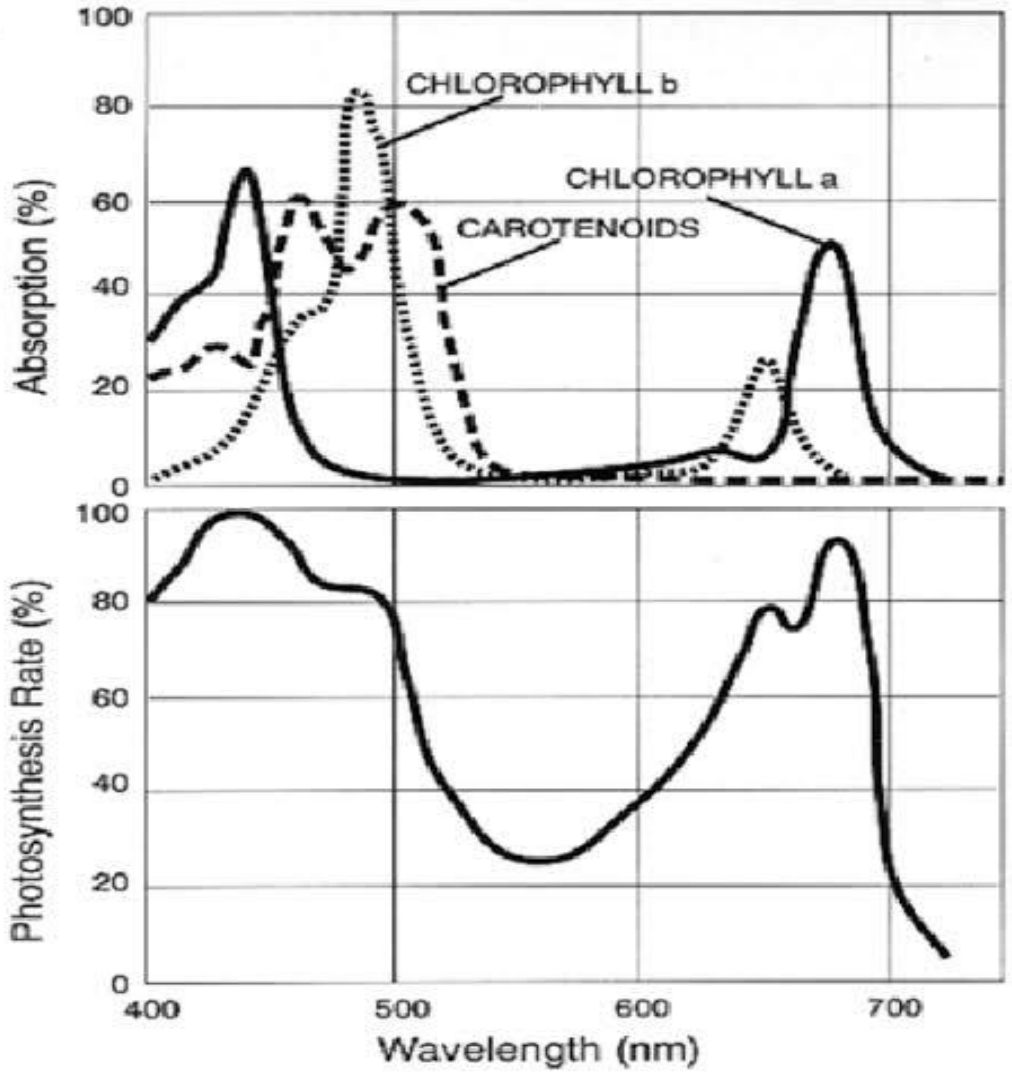
ABSORPTION AND ACTION SPECTRA

If a pigment such as chlorophyll is subjected to different wavelengths of light, it absorbs some more than others, and this is represented graphically;

1. **Absorption spectrum**; It is a graph of the relative absorption of different wavelength of light by a pigments.
2. **Action spectrum**; it is graph of the effectiveness of different wavelengths of light in stimulating the photosynthetic process/ biological effect of different wavelengths of light.

Or check understanding biology page 275 fig 14.6

Absorption and action spectrum of chlorophyll a, b and carotenoids



MECHANISM OF PHOTOSYNTHESIS

Photosynthesis is generally a process of energy transduction. Light energy is first converted into electrical energy and finally into chemical energy. It has two main processes.

3. **The light dependent stage**; it involves Light harvesting; light is captured by the plants using photosynthetic pigments and flow of electrons from the effect of light on chlorophyll causing splitting/photolysis of water into hydrogen ions and oxygen.
4. **The light independent stage/ dark stage**; hydrogen ions are used in the reduction of carbon dioxide and hence the manufacture of sugars

LIGHT DEPENDENT STAGE

Light harvesting stage

- Pigment molecules in thylakoid membrane absorb and collect solar energy and funnels it to special molecules of chlorophyll a known as the reaction centre chlorophyll molecule. On striking this molecule an electron in its orbit is raised to a higher energy level, and picked by electron acceptor.
- There are two kinds of reaction centres in plants called photosystem I (PSI) and photosystem II (PS II) that differ in structure and function.
- PSI absorbs light at 700nm and PSII at 680nm while many chlorophyll molecules are involved in collecting energy, only a few make up the reaction centres.
- The transport of electron through the two centres comprise the second state of photosynthesis.

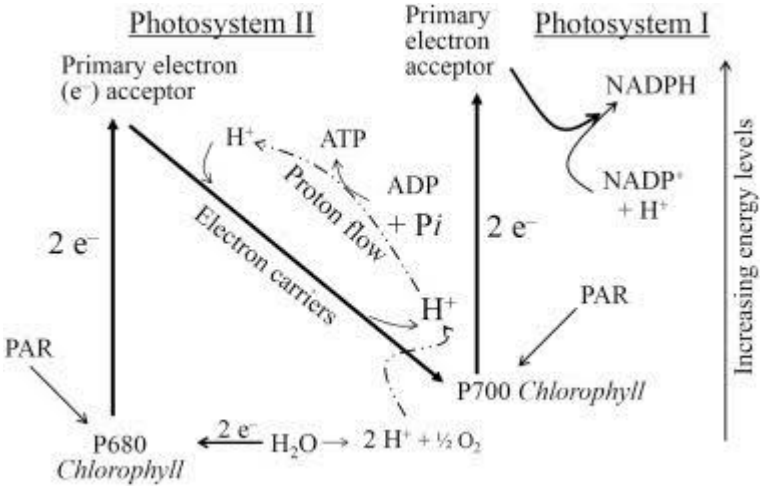
Electron transport

- It takes place within the thylakoid membrane of the chloroplast
- Its reactions are triggered by light energy exciting photosystems I and II inside the thylakoid membrane at the same time, not one after the other.
- In this process there is splitting of water; photolysis of water and as well ADP is converted to ATP.
- This addition of phosphorus is known as phosphorylation and since light is involved it becomes photophosphorylation.

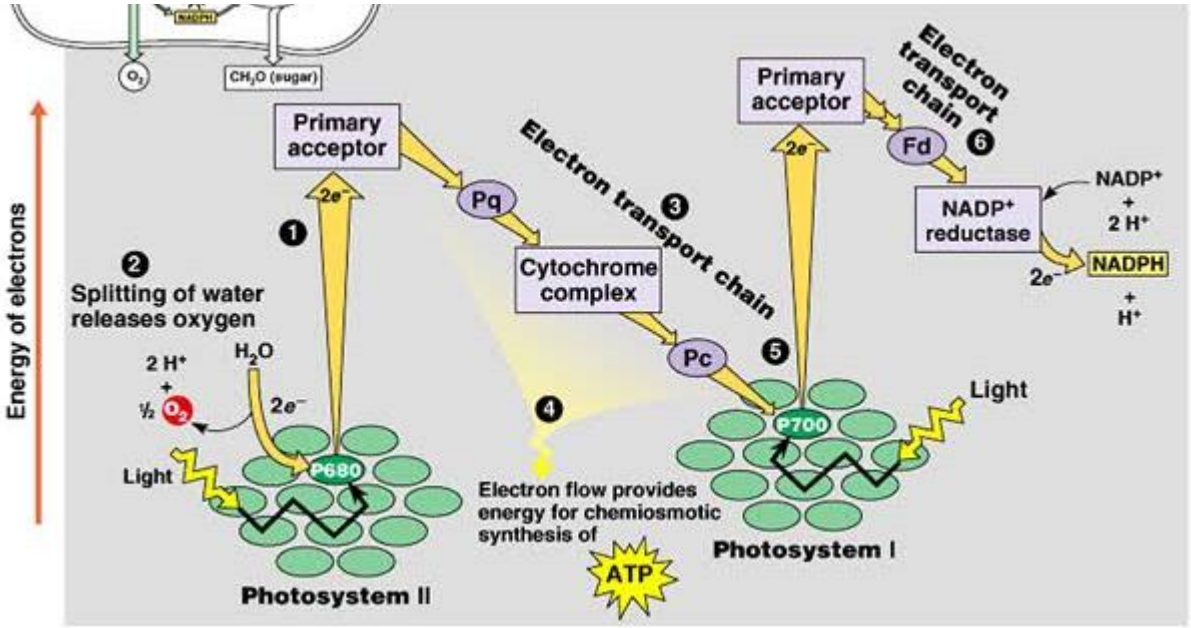
(1) N.B photophosphorylation is the addition of an inorganic phosphate to Adenosine diphosphate (ADP) to form Adenosine triphosphate (ATP) using light energy.

The process in detail

1. Light energy of wavelength 680nm is trapped in photosystem II and boosts electrons to a higher energy level.
2. The electrons are received by an electron acceptor called plastoquinone.
3. The electrons are passed from the acceptor along a series of electron carriers to photosystem I. the energy lost b electrons is captured by converting ADP to ATP. Light energy has thereby been converted to chemical energy.
4. Light energy of wavelength 700nm absorbed by photosystem boosts the electrons to an even higher energy level. The electrons are received by an electron acceptor called ferrodoxin.



5. The electrons which have been removed from photosystem II are replaced by pulling electrons from a water molecule.
6. The electrons lost from the water molecule cause it to dissociate into protons and oxygen gas.
7. The protons from the water molecule combine with the electrons from the second electron acceptor; ferrodoxin and these reduce nicotinamide adenine dinucleotide phosphate.
8. Some electrons from the second electron acceptor may pass back into the chlorophyll molecule by the electron carrier system, yielding ATP as they do so. This process is called cyclic photophosphorylation



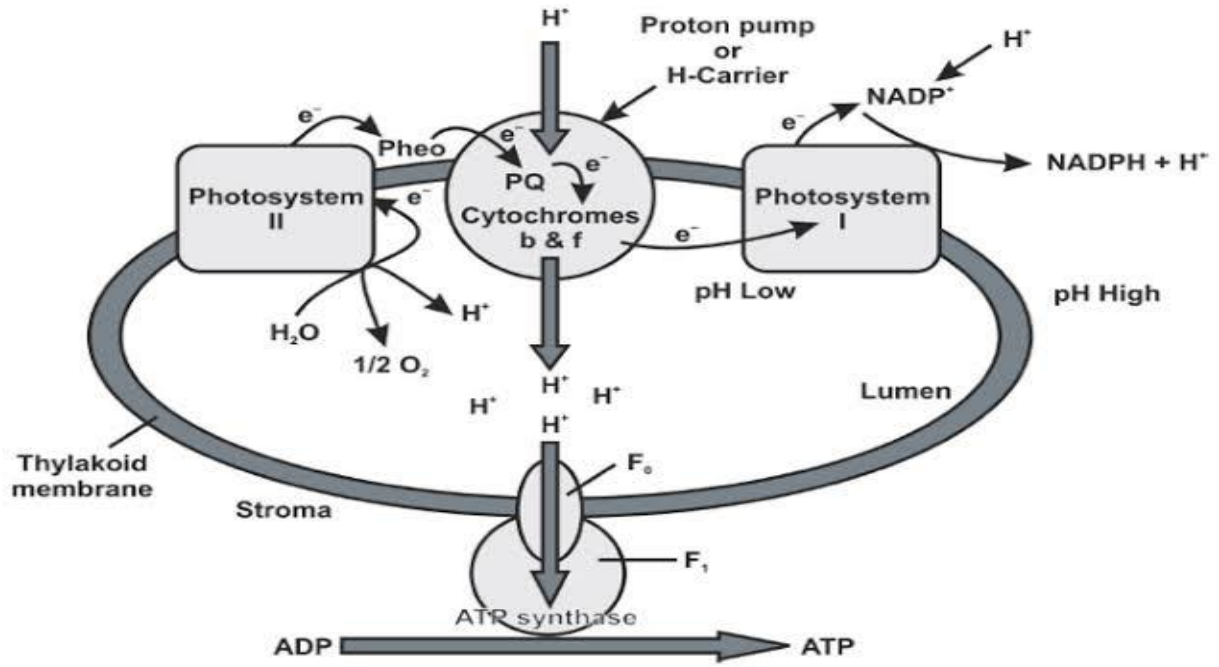
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The formation of ATP is explained by the chemiosmosis by p.mitchell which is discussed below.

Chemiosmosis: It is the movement of ions across a selectively permeable membrane down an electrochemical gradient.

Physiology that occurs in the chloroplast according to p.mitchell

- The hypothesis by Peter Mitchell called chemiosmotic hypothesis explains synthesis of Adenosine triphosphate/ATP from Adenosine diphosphate/ADP and inorganic phosphate using energy formed due to electro-chemical proton gradient which exists across the thylakoid membrane of the chloroplast span by the respiratory chains of electron carriers. In the stroma the hydrogen atoms dissociate into protons and electrons
- The electrons are fed into the respiratory chain of carriers at different energy levels leading to formation of energy used to combine ADP with inorganic phosphate to form ATP.
- Active transport of protons from the stroma into the thylakoid space across the impermeable thylakoid membrane occurs.
- This proton pump is driven by energy released from the excited electrons as they pass down the electron transport system.
- This increases the acidity within the thylakoid space and creates the electrochemical proton gradient across the thylakoid membrane.
- This results into diffusion of some protons back into the stroma via the special channels called chemiosmotic channels down the electrochemical gradient.
- These channels are associated with catalytic knobs on the stroma side and ATPase enzyme/ ATP synthase complex.
- The diffusion of protons through the chemiosmotic channels result into release of energy used to combine ADP with inorganic phosphate to form ATP.



ATP synthesis through chemiosmosis (in noncyclic photophosphorylation)

NOTE:

1. When asked to write about the conversion of light energy to chemical energy, you must incorporate the theory above in your explanation.
2. Non-cyclic photophosphorylation is a form of ATP production in which electrons are not recycled and is normally known as the Z- scheme because of the zig zag route of the electrons in the diagram resembles a Z on its side.
3. Cyclic photophosphorylation is a form of ATP production in which electrons from the pigment system return to chlorophyll directly, via the electron carrier system, harnessing energy and it only involves photosystem I

COMPARISON OF CYCLIC AND NON-CYCLIC PHOTOPHOSPHORYLATION

Similarities; in both;

- there is flow of electrons through several electron carriers
- there are pigment systems which accept and lose electrons
- ATP is formed
- pigment system I is involved
- electron movement is located in the thylakoid membranes
- protons are moved outwards of the thylakoids
- protons (H^+) are actively pumped from stroma into thylakoid space
- There is photo-excitation of electrons in the pigment systems.

Differences;

non-cyclic photophosphorylation	cyclic photophosphorylation
Electrons flow non-cyclically	Electrons flow cyclically
First electron donor; source of electrons is 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 STAGE/DARK STAGE OF PHOTOSYSNTHESIS

- It's called dark reaction because does not require light, it can take place whether light is present or not. It occurs in the stroma of chloroplasts.
- The details were analyzed by Melvin Calvin and his co-workers and thus the Calvin cycle for C_3 plants.

NOTE:

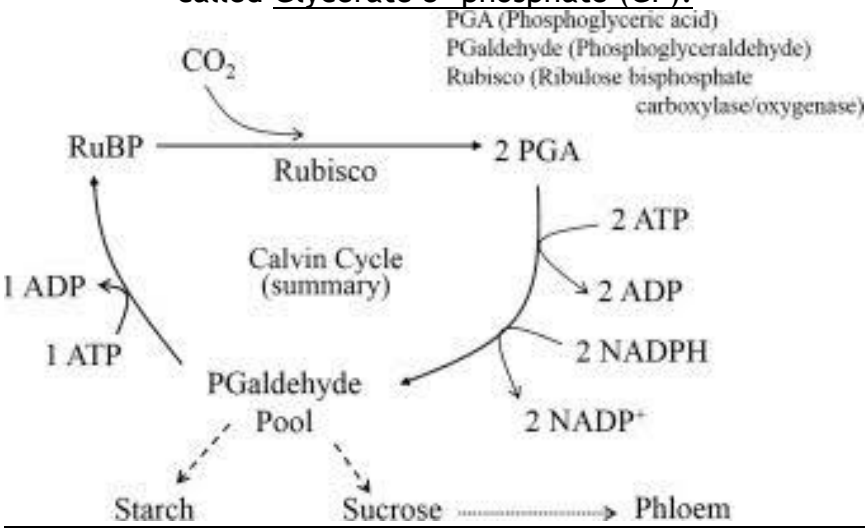
1. This process is basically the reduction of carbon dioxide using the reduced nicotinamide adenine dinucleotide phosphate ($NADPH + H^+$) and ATP from the light dependent stage.
2. The dark reactions in C_4 plants were studied by Hatch-slack hence the Hatch slack pathway.

DARK STAGE IN C3 PLANTS

It occurs mainly in three stages;

1. Carboxylation.
2. Reduction and phosphorylation
3. Regeneration

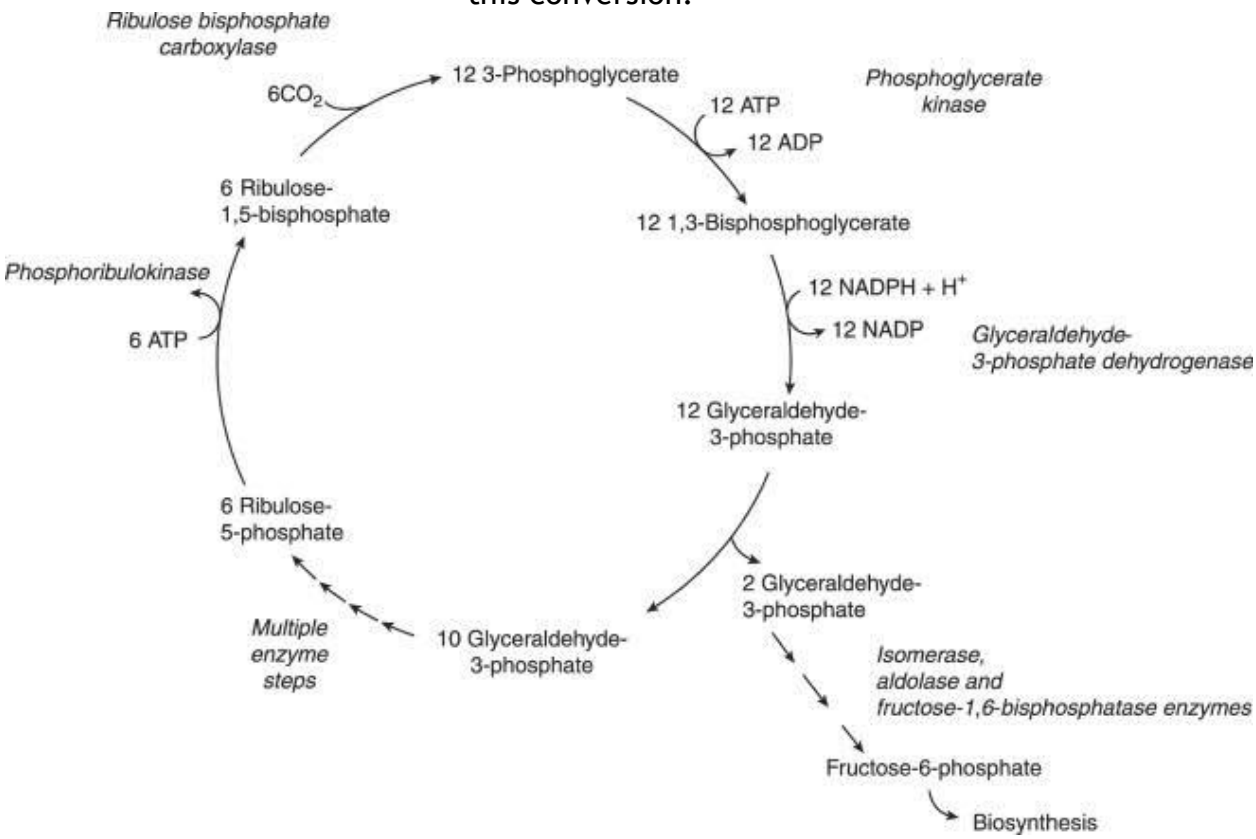
- Carbon dioxide diffuses into the leaf through the stomata and dissolves in the moisture on the walls of the palisade cells. It diffuses through the cell membrane, cytoplasm and chloroplast membrane into the stroma of the chloroplast.
- The carbon dioxide combines with a 5-carbon compound called ribulose bisphosphate (RUBP) under the catalytic activity of ribulose bisphosphate carboxylase (BUBSICO) to form an unstable 6- carbon intermediate.
- The 6- carbon intermediate breaks down into two molecules of the 3- carbon called Glycerate 3- phosphate (GP).



- Some of the ATP produced in the light dependent stage is used to convert G.P into triose phosphate (1, 3 diphosphoglycerate).
- The reduced nicotinamide adenine dinucleotide phosphate ($NADPH + H^+$) from the light dependent stage is necessary for the reduction of 1, 3 diphosphoglycerate into a triose phosphate; 3- phospho-glyceraldehyde (PGAL).
- $NADP^+$ is regenerated and returns to the light stage to accept more hydrogen.
- Pairs of triose phosphate molecules are combined to produce an intermediate hexose sugar.

- The hexose sugar is polymerized to form starch which is stored by the plant.

- Not all the triose phosphate is combined to form starch, a portion of it is used to regenerate the original carbon dioxide acceptor; ribulose bisphosphate.
  - Five molecules of the 3- carbon triose phosphate can regenerate three molecules of the 5- carbon ribulose bisphosphate. More of the ATP is used for this conversion.



A detail of the molecules and enzymes in the Calvin cycle

NOTE: RUBISCO is the most abundant enzyme in plants known and the very inefficient; this true because;

- RUBISCO can add approximately $3CO_2$ to 3 molecules of RuBP each second, which is very slow for an enzyme. To make up for this, plants produce large quantities of RUBISCO, which composes 50% of the protein in a chloroplast.
- RUBISCO is not a very specific enzyme as it sometimes combines RuBP with oxygen rather than CO_2 because of a relatively non-specific active site, causing photorespiration which leads to the formation of a useless oxygenated intermediate that inhibits carbon dioxide fixation.

PHOTORESPIRATION

- Oxygenation of RuBP by RUBP carboxylase at high temperature, low carbon dioxide and high oxygen concentration to form phosphoglycolate which undergoes oxidation in peroxisomes and metabolism in mitochondria to release CO_2.
- When C_3 plants are exposed to low carbon dioxide concentration or high oxygen concentration and when stomata close to reduce water loss, RuBP carboxylase catalyses the reaction between RuBP and oxygen to form a 2-carbon compound; phosphoglycolate, which is oxidized to release carbon dioxide.

- Photorespiration therefore reduces the potential yield of photosynthesis.

FATE OF PHOTOSYNTHETIC PRODUCTS

1. **Synthesis of other carbohydrates;** the triose phosphate of the Calvin cycle can be synthesized into hexose sugars such as glucose and fructose by a reversal of the stages of glycolysis.
- Glucose and fructose maybe combined to give disaccharide sucrose which is transported throughout the plant phloem.
- The glucose maybe on the other hand polymerized into starch for storage or polymerized to cellulose to make plant cell walls.

2. **Synthesis of lipids**; lipids are mostly esters of fatty acids and glycerol. Glycerate 3- phosphate maybe converted to acetyl co enzyme A, which is in turn used to synthesize a variety of fatty acids.
- Triose phosphate is easily converted into glycerol. As well as being important storage substances especially in seeds, lipids are a major constituent of the cell membranes, and their waxy derivatives make up water proofing cuticle.
- Fatty acids provide some flower scents, which are used to attract insects for pollination.

3. **Synthesis of proteins**; conversion of the Glycerate 3- phosphate of the Calvin cycle into acetyl coenzyme A is the starting point for amino acids synthesis.
- The acetyl CoA enters the Krebs cycle and from its intermediates a wide variety of amino acids can be made by transamination reactions.
- The amino acids are polymerized into proteins.
- Proteins are essential for growth and development and make up a major structural component of the cell, especially the cell membrane. All enzymes are proteins are proteins, and they may also be used as storage.

DARK STAGE IN C_4 PLANTS/ HATCH SLACK PATHWAY

☑ C4 photosynthesis is type of photosynthesis in which the first stable product of carbon dioxide fixation is a four carbon compound called oxaloacetate (OAA) inside mesophyll cells, which is later reduced and exported into bundle sheath cells for further metabolism.

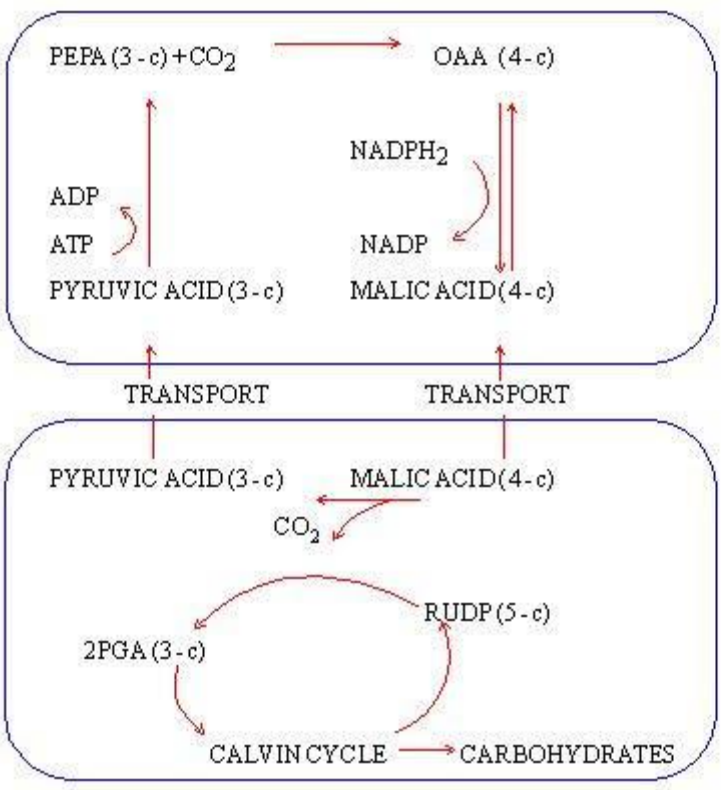
☑ Examples of C4 plants: maize, sorghum, Amaranthus, Sugar cane, paspalum, Bermuda grass, Rhodes grass, nut grass.

☑ C4 plants represent only 3% of the world's vascular plants yet they contribute about 20% to the global primary productivity because of their high productivity.

☑ C4 plants are common in hot / arid / saline tropical habitats. They have a condition in which bundle sheath cells and palisade cells of the mesophyll form two concentric layers (rings) around each vascular bundle of leaves which is known **as the kranz leaf anatomy.**

Process in detail;

a. In the presence of Phosphoenol pyruvic acid carboxylase enzyme (PEPCO), Phosphoenol pyruvic acid (PEP) is carboxylated inside the chloroplasts of mesophyll cells to form oxaloacetic acid.
b. Oxaloacetic acid is reduced by NADPH to malic acid in the presence of malate dehydrogenase enzyme.
c. From chloroplasts of mesophyll cells, malic acid is translocated or shunted to chloroplasts of bundle sheath cells where it is decarboxylated by NADP to form pyruvic acid and carbon dioxide.



d. The pyruvic acid produced returns to mesophyll cells for phosphorylation by ATP to regenerate PEP; the CO_2 acceptor.

e. Now the second carboxylation occurs in the chloroplasts of bundle sheath cells through Calvin cycle.

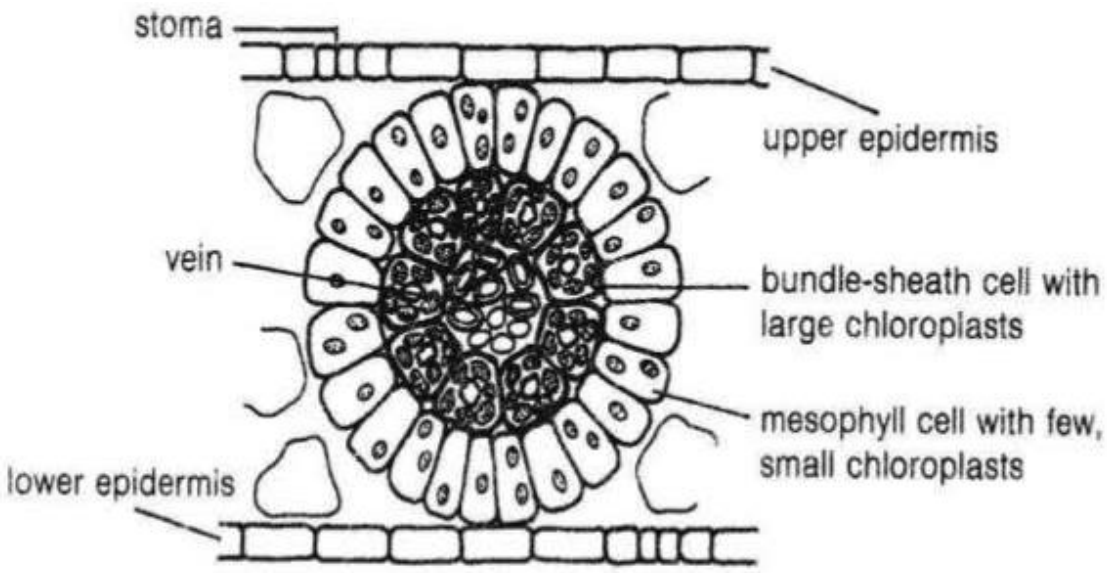
f. RuBP of Calvin cycle is called final or secondary CO_2 acceptor in C4 plants.

g. Ribulose bisphosphate accepts CO_2 to yield 3-phosphoglyceric acid as given in Calvin cycle.

h. Some of the 3-phosphoglyceric acid is utilized in the formation of glucose-6-phosphate and sucrose while rest regenerates ribulose-1, 5 bisphosphate in the system.

i. In the Calvin cycle 3 ATP molecules are required for the C4 plants, 5 ATP molecules are required for the fixation of CO2. For the formation of a glucose molecules, C4 plants require 30 ATP.

KRANZ ANATOMY



N.B when asked to talk about the kranz anatomy, you simply describe the above structure.

ADVANTAGES OF HAVING A HATCH SLACK PATHWAY BY PLANTS

1. C4 plants ably photosynthesize at very low CO_2 concentration (e.g. in dense tropical vegetation) because PEP carboxylase enzyme has a very high affinity for carbon dioxide.

2. Concentric arrangement of mesophyll cell produces a smaller area in relation to volume for better utilization of available water and reduce the intensity of solar radiations.
3. Photorespiration, which inhibits growth in C3 plants is avoided / reduced in C4 because
   (i) the CO_2 fixing enzyme PEP carboxylase does not accept oxygen
   (ii) RuBISCO enzyme inside the bundle sheath cells is shielded from high oxygen concentration by the ring of palisade cells.
4. The CO_2 fixing enzymes in C4 plants are more active at hot temperature and high illumination, therefore photosynthesis occurs rapidly at low altitude, hot and brightly lit tropical conditions than in C3 plants.
5. The productivity of C4 almost four times greater than in C3 because:

(i) of the increased rate of CO_2 uptake caused by
(ii) large internal leaf surface area
(iii) short CO_2 diffusion distance
(iv) CO_2 steep diffusion gradients

6. The bundle sheath cells in which dark reactions occur have
   (i) A large photosynthetic surface area enabled by un-usually large chloroplasts.
   (ii) Lack of grana on which O_2 would be produced, so no photorespiration.
7. The palisade cells in which light reactions occur have large grana to increase the photosynthetic surface area.

Disadvantages of C4 pathway

- The CO_2 fixing enzymes in C4 plants are less active at cool, moist and low illumination conditions, therefore photosynthesis occurs slowly at high altitude with cool temperature and in low light intensity of temperate conditions.

NOTE: C4 plants grow better under hot, dry conditions when plants must close their stomata to conserve water – with stomata closed, CO_2 levels in the interior of the leaf fall, and O_2 levels rise

REASONS WHY MOST PLANTS USE C3 PATHWAY

- ✓ CO2 concentration is a major factor determining the pathway of carbon dioxide fixation.
- ✓ While C4 plants are more productive at low CO2 concentration, C3 plants form the dominant plant life because they are effective at high CO2, whose concentration is high in most environments and steadily increases due to increasing combustion of fossil fuels.
- ✓ Also considering that C4 photosynthesis is more complex i.e. it involves many reactions both in bundle sheath cells and in mesophyll cell, and requires a specialized Kranz anatomy, most plants have simpler structures.
- ✓ Therefore, unless water loss is a significant issue, C3 dominate since C3 photosynthesis is more effective.

COMPARISON BETWEEN C3 AND C4 PLANTS

Similarities;

- Contain RUBISCO enzyme
- Depend on light for their reactions
- Show CO2 fixation
- Have RuBP

- Form several same organic products e.g. PG, PGA, sucrose,
- Have Calvin cycle

Differences;

	C3 pathway	C4 pathway
1	Photosynthesis occurs in mesophyll cells	Photosynthesis occurs in mesophyll cells and bundle sheath cells
2	The CO_2 molecule acceptor is RuBP	The CO_2 acceptor molecule is Phosphoenol pyruvate
3	The first stable product is a 3C compound Called Glycerate-3-phosphate (PGA)	The first stable product is a 4C compound oxaloacetic acid (OAA)
4	Photorespiration rate is high and leads to loss of fixed CO_2. Decrease CO_2 fixation rate	Photorespiration is negligible and is almost absent. Hence high CO_2 fixation rate
5	Optimum temperature is 20 to 25^0C	Optimum temperature is 30 to 45^0C.
6	Photosynthetic rate is low	Photosynthetic rate is high
7.	Examples of C3 plants are rice, wheat and tomato	Examples of C4 plants are maize, sugar cane

CRASSULECEAN ACID METABOLISM PLANTS/ CAM PHOTOSYNTHESIS

- There are C4 plants that live especially in arid environment. Because they are at risk of severe water loss, they have accustomed by opening their stomata at night.
- Thus as opposed to other C4 plants, in CAM plants, the initial fixation of CO_2 by PEP and the conventional Calvin cycle are separated in time.
- The stomata are generally closed during the day so there is little loss of water, the CO_2 is fixed during the night when the stomata are open.

In this;

- CO2 is taken in at night via open stomata, fixed by Phosphoenol pyruvate carboxylase (PEPC) into OAA and stored as organic acid; mainly malate which is later decarboxylated during daytime, re-fixed and CO_2 is assimilated in the Calvin-cycle when stomata are closed.
- Examples of CAM plants: Cacti, sisal, Opuntia, Bryophyllum, Vanilla, pineapples, and Euphorbia milii

Significance of CAM photosynthesis

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

CONCEPT OF LIMITING FACTORS

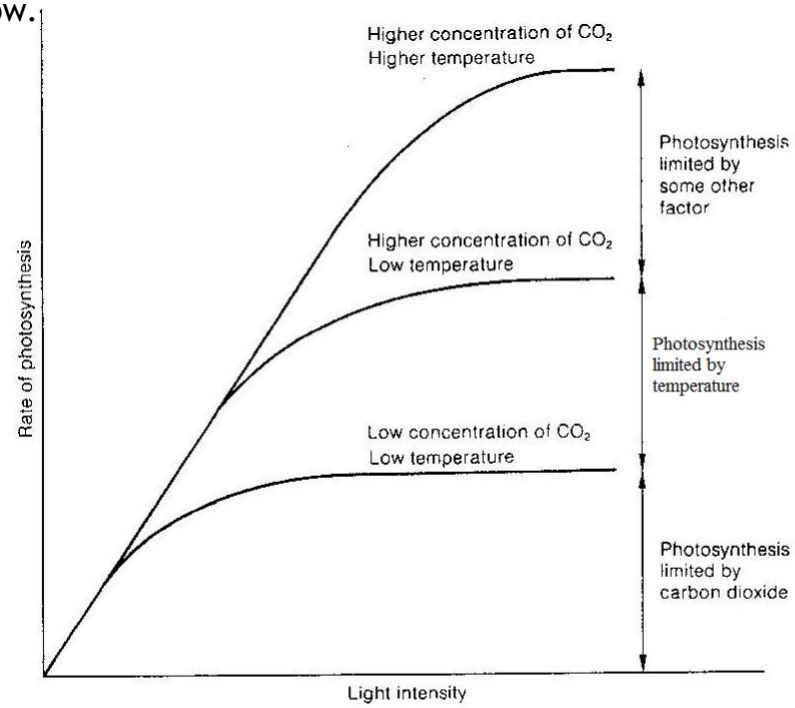
Principle of limiting factors states that; "At any given moment, the rate of a physiological process is limited by the one factor which is nearest its minimum value, and by that factor alone"

In other words it is the factor in the shortest supply which determines the rate of a reaction and any change in the level of this factor will affect the reaction.

For example;

Photosynthesis cannot take place in dark because the absence of light limits the process. The supply of light will alter the rate of photosynthesis meaning that more light, more photosynthesis.

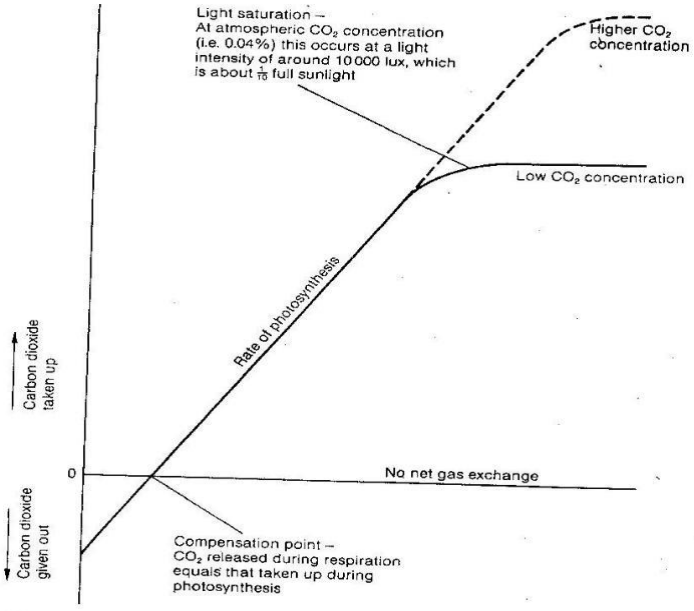
If however more carbon dioxide or temperature is supplied to a plant in the dark, there will be no change in the rate of photosynthesis.
If the amount of light is increased, photosynthesis increases up to a certain point and then tails off. This means that some other factor is affecting the process. Just as illustrated below.



FACTORS AFFECTING THE RATE OF PHOTOSYNTHESIS

There are various factors viz;

- Carbon dioxide concentration
- Light intensity
- Temperature
- Chlorophyll concentration
- Oxygen concentration
- Water and dissolved nutrients
- Enzyme inhibitors e.g. cyanide, dichlorophenyl dimethyl urea.
- Some air pollutants e.g. Sulphur dioxide
- Altitude
- Salinity



Effect of light intensity on the rate of photosynthesis

- The rate of photosynthesis is measured by the amount of carbon dioxide absorbed or oxygen evolved by the plant. But these give relative values.
- Low light intensity lowers the rate of photosynthesis. As the intensity is increased the rate also increases. As light is increased, carbon dioxide from respiration is utilized in photosynthesis and so less is evolved. With continuing increase in light intensity, a point is reached where carbon dioxide is neither evolved nor absorbed. This point is called the compensation point.
- **Compensation point**: The light intensity at which the photosynthetic intake of carbon dioxide is equal to the respiratory

output of carbon dioxide. At this point, the carbon dioxide produced in respiration exactly balances that being used in photosynthesis.

- Further increases in light intensity result in a proportional increase in the rate of photosynthesis until a light **saturation point** is reached. Beyond this point increase in light intensity have no effect on the rate of photosynthesis.
- However very high intensity may, in fact, slow down the rate as it bleaches the chlorophyll.

Effect of carbon dioxide concentration

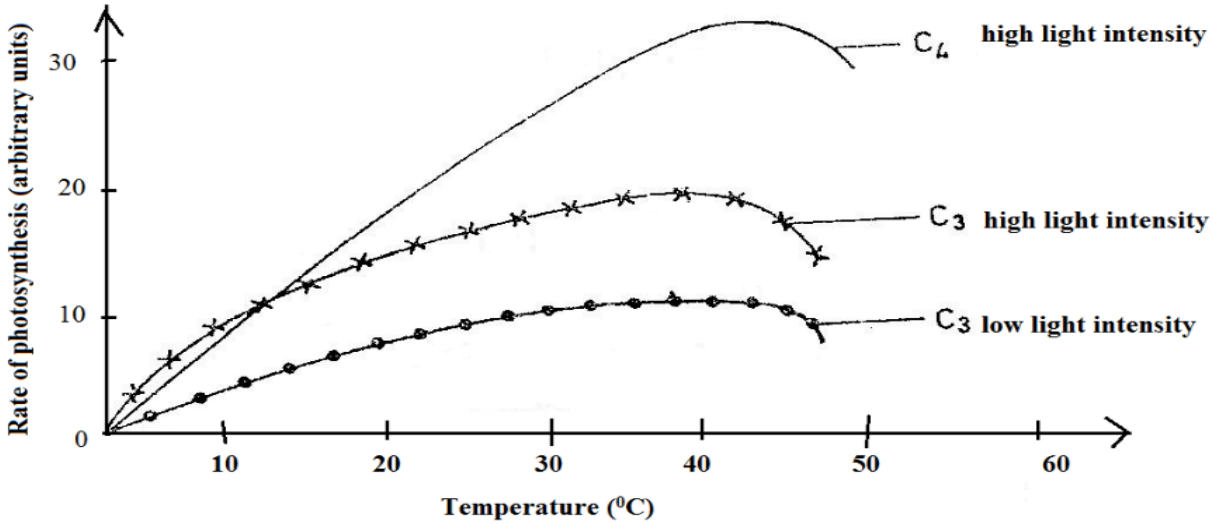
Carbon dioxide is one of the less abundant gases in the atmosphere. It has a normal concentration of 0.04%.

Normally low carbon dioxide concentration is a major limiting factor to the rate of photosynthesis. Increase in carbon dioxide concentration to the optimum increases the rate of photosynthesis.

Effect of temperature on the rate of photosynthesis

Normally; an optimum temperature ranging from 25°C to 35°C is required for maximum rate of photosynthesis. At temperatures around 0°C the enzymes stop working and at very high temperatures the enzymes are denatured.

Temperature has varying effects on C3 and C4 plants as illustrated below



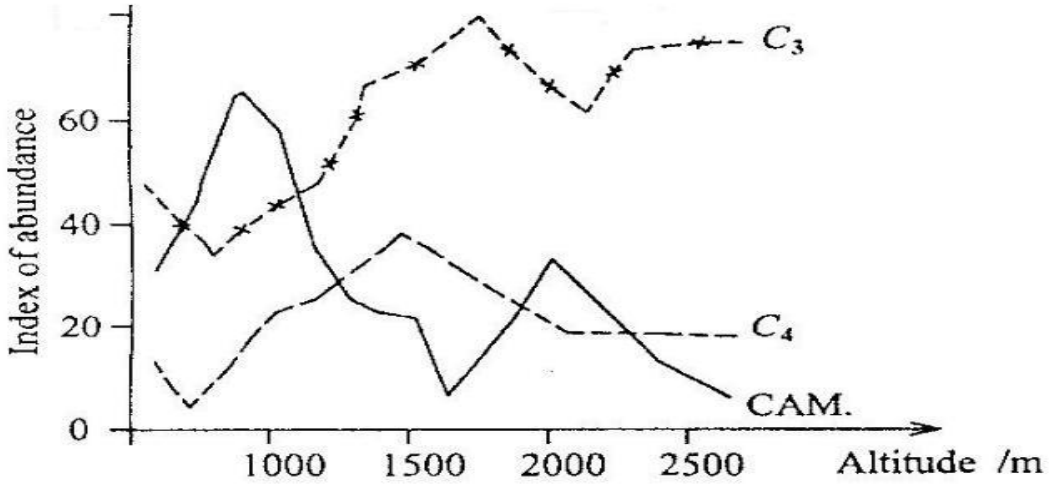
Or check UACE 2008 biology paper 1 number 41

- ✓ Maximum rate of photosynthesis is higher for C_4 plants than C_3 plants.
- ✓ At temperature below 10^0 C, C_3 plants have a higher rate of photosynthesis
- ✓ At temperature above 20^0 C, the rate of photosynthesis in C_3 plants is lower than that in C_4 plants.
- ✓ In C_4 plants, rate of photosynthesis is increase rapidly with temperature up to a maximum at 40^0 C. For C_3 plans, rate of photosynthesis increases gradually at a decreasing rate with temperature, to a maximum about 35^0 C

Give explanations to that description

Effect of altitude on the rate of photosynthesis

Altitude affects photosynthesis in C3, C4 and CAM plants as follows.



Or check UACE 2009 biology paper 1 number 43

C_3 plants; Are more abundant at high altitude. This is so because;

- At high altitude, the partial pressure of oxygen is lower. This reduces competition between carbon dioxide and oxygen for RUBP carboxylase enzyme and enhance carbon dioxide fixation.
- Thus, C3 plants are more abundant at high altitude where they can photosynthesis more efficiently.

C_4 plants; Are more abundant at mid-altitude levels. This so because;

- Since PEP carboxylase is not affect by oxygen concentration, temperature is the major limiting factor of photosynthesis in C_4 plants.
- At low altitudes, temperatures are very high than at high altitude. Only moderate temperature of mid- altitude levels favor efficient photosynthesis in C_4 plant, making them more abundant there.

CAM plants; Are more abundant at low attitudes**.** This is because**;**

- CAM plants adapted to photosynthesizing more efficiently at higher temperatures.
- Such temperature can only be experienced at low altitudes, explaining their more abundance there.

Effect of inorganic ions on the rate of photosynthesis

In absence of certain ions, such as iron, chlorophyll cannot be synthesized.
Other ions like nitrogen and magnesium are integral parts of chlorophyll molecule and their absence likewise prevents its formation.
For more refer to chemicals of life.

Relate other factors to photosynthesis!

END OF AUTOTROPHIC NUTRITION. THANK YOU. QUESTIONS AT THE END OF THE TOPIC

HETEROTROPHIC NUTRITION

- This is the type of nutrition in which organisms take in readymade organic food substances made by autotrophs.
- Heterotrophic organisms consume complex organic food material.

There are a number of forms of heterotrophic nutrition;

1. **Holozoic nutrition**; involves the consumption of complex food which is broken down inside the organism into simple molecules which are then absorbed.
2. **Saprotrophic nutrition/ Saprophytic nutrition/ saprobiontic**; involves the consumption of organic food from the bodies of decaying organisms. The food is either already in soluble form or it is digested externally into simple molecules which then diffuse into the organism.
3. **Parasitism**; involves feeding on complex organic food derived from other living organisms.
4. **Mutualism**; this involves a close relationship between members of two species but on which both organisms benefit from the relationship.
5. **Commensalism**; in this association, one member benefits while the other neither benefits nor it's harmed.

NOTE:
Symbiosis; is used to describe two species which live together in an intimate/ close relationship which includes one living in or on the body of the other.
It is a general term covering mutualism, parasitism and commensalism.

HOLOZOIC NUTRITION

- ✓ This is the type of nutrition in which complex organic food is taken in and broken down inside the body of an organism into simple soluble molecules which are then absorbed and assimilated.
- ✓ This type of nutrition involves the following stages;

a. **Obtaining food**: May involve movements to capture or find new food sources from the environment.
b. **Ingestion**: The intake of food into the body (feeding mechanisms).
c. **Physical digestion**: physical breakdown; by teeth, gizzard, mandibles, radula of large insoluble molecules of food into small soluble molecules.
d. **Chemical digestion**; enzymatic breakdown of food materials.
e. **Absorption**: The uptake of nutrient molecules into the cells of the digestive tract and, from there, into the bloodstream
f. **Assimilation**: The utilization of the absorbed soluble food substances to form energy or materials which are incorporated into the body tissues.
g. **Elimination (Egestion)**: removal of undigested residue from the body.

Holozoic organisms are classified according to the type of food ingested;

1. Herbivores; organisms which feed on living or recently dead plant material.
2. Carnivores; organisms which feed on living or recently dead animals.
3. Omnivores; organism which feed on a diet combining plant and animal material.
4. Liquid feeder; organisms that consume liquid material.
5. Phagotrophs; organisms that take in particles of solid food.
6. Macrophagous feeders; Phagotrophs that take in relatively large particles.
7. Microphagous feeders; Phagotrophs that take in very small particles.

FOOD AND DIET

Food is any substance taken into the body for nourishment and sustenance of life.
Human beings require a constant supply of essential nutrients in balanced proportions to maintain themselves healthy.
An individual's needs will need to vary according to size, age, sex, level of activity, state of health and particular personal circumstances such as pregnancy.

BALANCED DIET

Balanced diet is one which contains the correct proportions and quantity of protein, carbohydrate, lipids, vitamins, mineral salts, water and dietary fibre/roughage required to maintain health.
Mainly, carbohydrates and lipids are for energy production, proteins are for growth and repair, vitamins and mineral salts are for protection of good health, and water is a solvent while roughage stimulates peristalsis to prevent constipation.
N.B water is a vital constituent of the diet for many reasons like we saw in chemicals of life.

ENERGY REQUIREMENTS

The amount of energy in foods is expressed in joules although for practical purposes the kilojoule is a much more convenient unit and sometimes calories and kilocalories.
1 calorie = 4.18 joules.
The total heat generated gives a measure of the food's energy content which is known as its calorific value.
The term which describes the basal metabolic processes needed to keep a human alive is basal metabolism and the rate at which energy is used up in maintaining basal metabolism is termed as basal metabolic rate (BMR)

Importance of energy

- ☑ Maintain the basal metabolic rate (BMR)
- ☑ Sustain body activities like muscle contraction during movement, locomotion
- ☑ Generation of heat to maintain body temperature at about 37^0C

BASAL METABOLIC RATE

Minimum energy a body requires at rest to perform vital functions like beating of the heart, breathing, peristalsis, impulse transmission, synthesis of biological molecules like proteins, etc.

Factors affecting the Basal Metabolic Rate

- ✓ Age
- ✓ Sex
- ✓ Body mass
- ✓ Nature of physical activity engaged in Muscle mass, Diet, and Drugs.
- ✓ Environmental factors e.g. temperature,
- ✓ Hormonal factors e.g. during pregnancy and lactation, Genetics.

Factors in detail;

Variation in BMR with sex

- At about 2.5 years and below, BMR in males is equivalent to BMR in females because infants have basically identical composition of carbohydrates, fats and protein.
- From about 2.5 years throughout life, BMR is slightly higher in males than in females because males usually have more body muscle than females while females usually have more fat than males per unit body mass and surface area.
- The more muscle tissue in the body, the more energy the body needs just to function e.g. to conduct impulses and biosynthesis compared to fat cells that largely store fat, with little biosynthesis.

Variation in BMR with age

- Infants and children have relatively high BMR than old-aged adults because at infancy and childhood much of the energy consumed is used in biosynthesis of cellular components required for growth.
- At adulthood, biosynthesis is greatly reduced since growth has stopped.
- From the age BMR was first determined to about 20 years of age, BMR decreases rapidly, then remains constant up to about 50 years of age and thereafter decreases slowly.
- From infancy to maturity at 20 years of age, biosynthesis of cellular components required for growth decreases rapidly, then remains constant by middle age until 50 years of age and thereafter decreases slowly, partly because of loss of muscle tissue, and also because of hormonal and neurological changes.
- Only repair and replacement of worn out cells occurs at slow rate by adulthood.
- **Muscle mass** (amount of muscle tissue in the body). Muscle requires more energy to function than fat. The more muscle tissue in the body, the more energy the body needs just to exist.
- **Body size:** Larger bodies tend to have a higher BMR because they usually have larger internal organs and fluid volume to maintain.
- Taller people have a larger skin surface, therefore have higher metabolism to maintain a constant temperature.
- **Genetics:** Genotypes and genetic disorders determine the rate of BMR.
- **Physical activity:** Regular exercise increases muscle mass and causes the body to burn kilojoules at a faster rate, even when at rest. ▫**Hormonal factors (e.g. during pregnancy and lactation):** Hormonal imbalances caused by certain conditions, including hypo- and hyperthyroidism, can affect the metabolism. Expectant and lactating mothers require more energy to support foetal and baby growth respectively.
- **Environmental factors (e.g. temperature):** Weather can also have an effect on body metabolism; if it is very cold or very hot, the body works harder to maintain its normal temperature and that increases the metabolic rate.
- **Drug content in the body:** Caffeine and nicotine can increase your metabolic rate, while medications including some antidepressants and anabolic steroids can contribute to weight gain regardless of what you eat.
- **Diet:** Certain aspects of one's diet can also affect metabolism e.g. inadequate intake of iodine for optimal thyroid function can slow down body metabolism.

NOTE:

Measuring the amount the amount of protein in a food is very difficult and for this reason the amount of nitrogen which is obtained from a protein is used as a more convenient measure.

The quality of a protein is measured as its biological value.

$$\text{Biological value of a protein} = \frac{Nitrogen\ retained}{nitrogen\ absorbed} \times 100$$

MALNUTRITION

This maybe over nutrition or under nutrition

Causes;

- If energy output exceeds energy input, carbohydrate reserves; glycogen and fat reserves; adipose tissue are respired and the person's body mass decreases.

- When carbohydrate and fat reserves exhaust, tissue protein is respired and the body wastes away.
- If energy intake exceeds energy usage over a period of time, carbohydrate is turned into fat and the person's body mass increases leading to obesity; overweight.
- starvation

Measuring malnutrition;

$$BMI = \frac{\text{Mass in kg}}{\text{Height}^2}$$

Height is measured in meters. A body mass index of between 20 and 25 represents the least risk. Where BMI exceeds 27.5 an individual is said to obese.

STARVATION

Causes of starvation

- Prolonged fasting
- anorexia
- deprivation
- disease

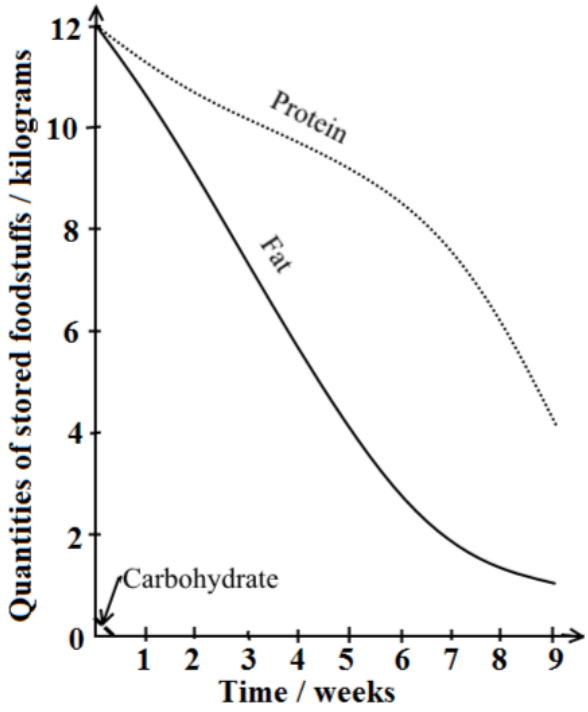
Symptoms of starvation

- Weight loss
- Dehydration
- Increased susceptibility to infectious disease
- discolored hair color
- Flaky skin and massive edema in abdomen and lower limbs causing the abdomen to appear bloated.

Interventions against starvation

- Rehydration and feeding the starving person low-bulk food with much proteins, much energy and fortified with vitamins and minerals.
- Avoid foods high in bulk but low in protein content

Changes in energy reserves



- Glycogen, proteins, and fats are all metabolized during starvation.
- Exhaustion of blood glucose stimulates glucagon secretion and insulin secretion is inhibited.
- Within the first 24 hours, the very low glycogen amount stored in the liver and muscles decreases rapidly to depletion because glycogen is broken down into glucose for oxidation to release energy, while the amounts of fats and protein remain high.
- Anaerobic breakdown of glycogen in skeletal muscle is also stimulated.

Note; during starvation;

✓ Within week 1, a few hours after depletion of carbohydrate/glycogen, the amount of fats decreases rapidly while the amount of protein decreases gradually until about 6 weeks of starvation.

✓ This is because fats are hydrolysed rapidly into fatty acids and glycerol while oxidation of amino acids releases energy.

- ✓ The liver metabolizes fatty acids into ketone bodies that are degraded to release energy.
- ✓ Accumulation of ketones causes ketosis, by condition characterized by blood becoming acidic
- ✓ Fatty acids in skeletal muscles are broken down to release energy, thus decreasing the use of glucose by tissues other than the brain.
- ✓ Glycerol is converted into small amount of glucose, but most of the glucose is formed from the amino acids of proteins.
- ✓ The brain begins to use ketone bodies, as wells as glucose, for energy.
- ✓ Dependency on fats for energy release decreases the demand for glucose, protein breakdown reduces but does not stop.
- ✓ The liver degrades non-essential proteins into glucose for the brain in a process called gluconeogenesis, which involves converting carbon skeletons into pyruvate or Krebs' cycle intermediates and excreting amino groups from the body as urea.
- ✓ From 6 weeks to 8 weeks, amount of fat decreases slowly to very low levels, while amount of protein decreases rapidly. This is because as fat reserves / stores are getting depleted, metabolism of fats to release energy occurs gradually and the body begins to rapidly break down essential proteins, leading to loss of liver and heart function as these organs are broken down for fuel metabolizing proteins as the major energy source.
- ✓ Muscles, the largest source of protein in the body, are rapidly depleted.

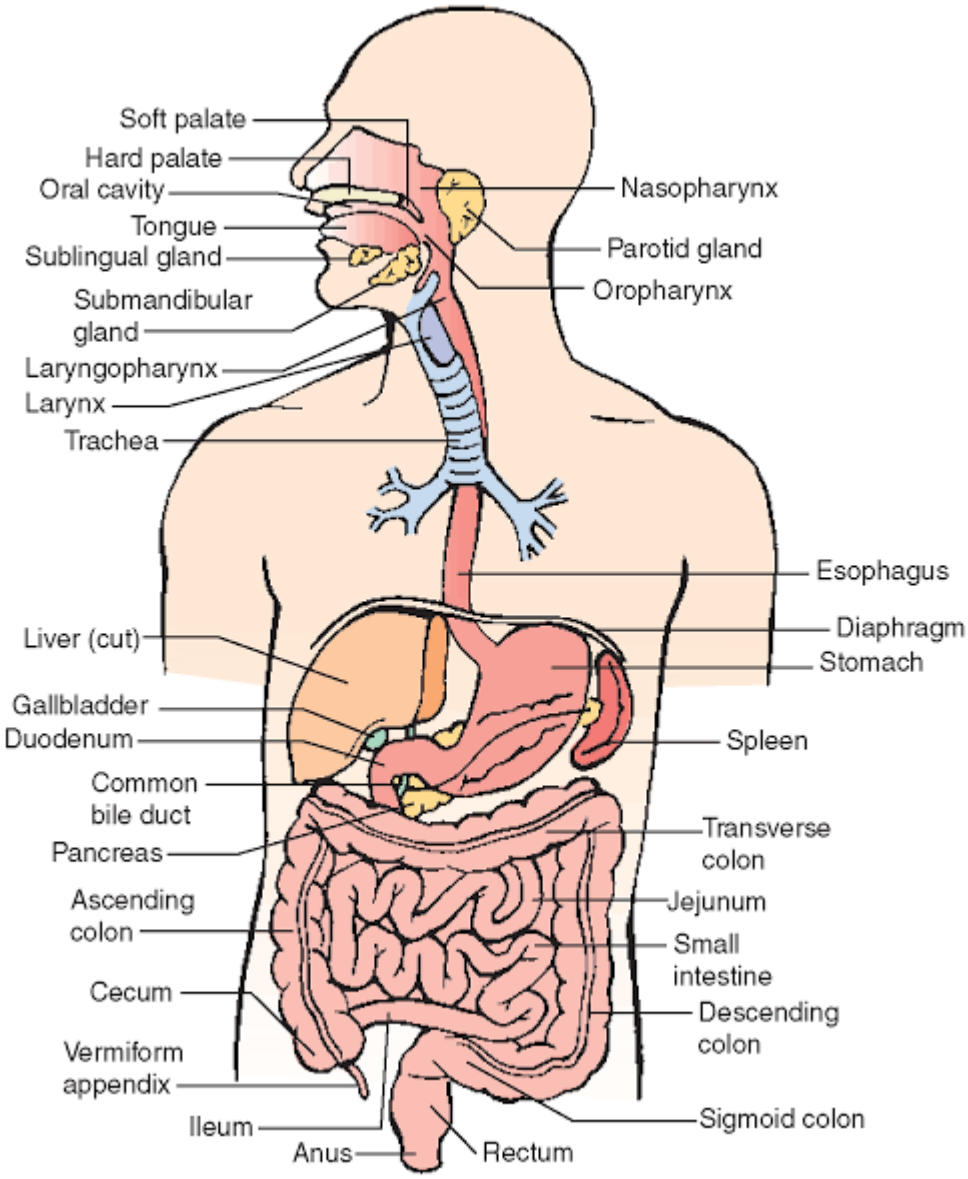
DIGESTION IN HUMANS

- ✓ Digestion is the process by which large food molecules are broken down into small soluble molecules which can be absorbed and assimilated into the tissues of the body.
- ✓ Digestion in humans takes place along a muscular tube which measures around 10m in length in adults. Associated with it are a variety of secretory glands, some of which are embedded in the wall of the alimentary canal, others are separate from it but connected to it by a duct.
- ✓ **Alimentary canal:** Mouth, throat, oesophagus, stomach, small intestine (duodenum, jejunum and ileum), large intestine (colon, caecum and appendix), rectum and anus.
- ✓ **Accessory structures:** Teeth, tongue, salivary glands, liver, gall balder and pancreas. These are organs, glands, and tissues that enable digestive processes, e.g. by secreting fluids /chemicals, but the food does not actually pass through them.

Digestion includes two types of processes:

1. Mechanical/ physical processes**:** which include the chewing and grinding of food by the teeth and also the churning and mixing of the contents of the stomach to expose more surface area to the enzymes that finish the digestive process.
2. Chemical processes**:** which include hydrolysis action of digestive enzymes, bile, acids.

DIAGRAM SHOWING THE HUMAN DIGESTIVE SYSTEM



DIGESTION IN THE MOUTH

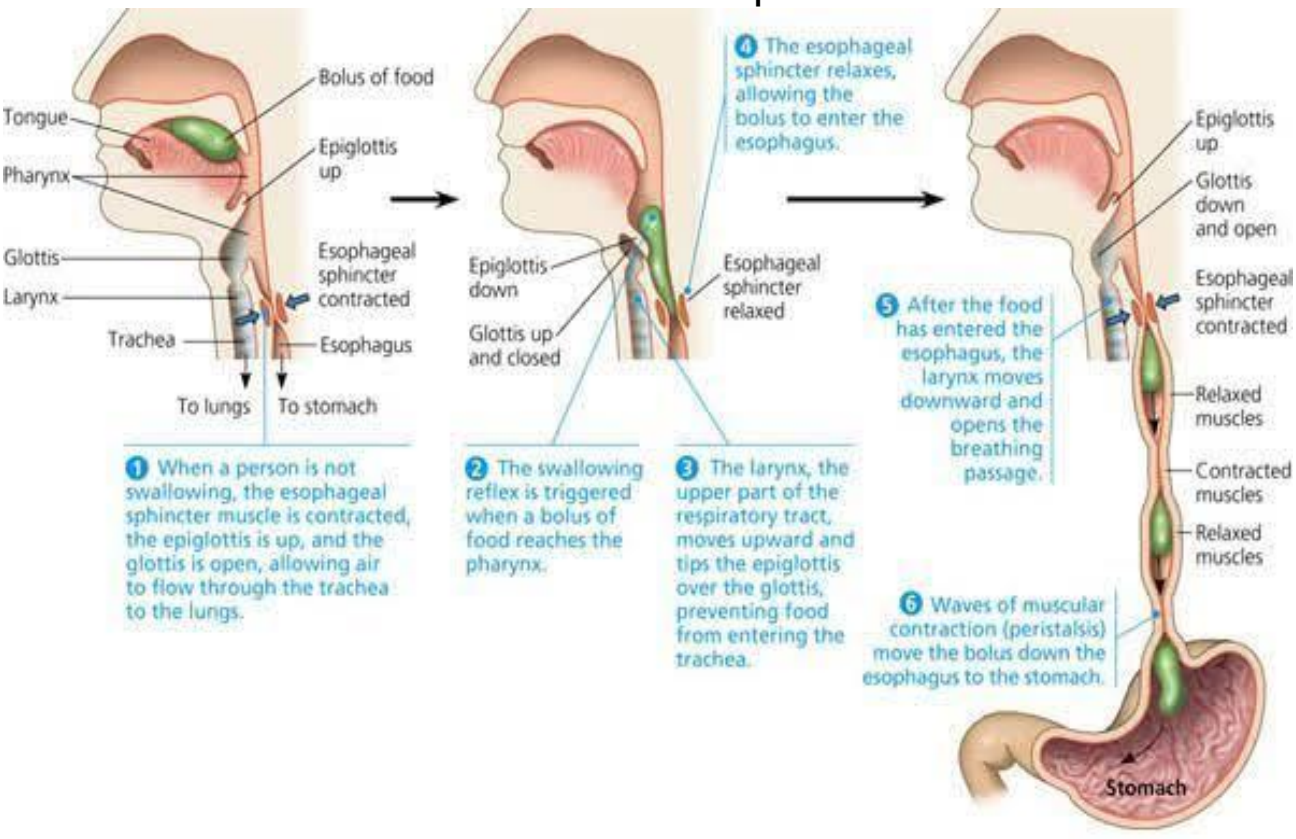
- Mechanical breakdown of food begins in the mouth or buccal cavity.
- It starts with chewing; mastication, which breaks food into pieces small enough to be swallowed and also increases the surface area of food to digestive enzymes.
- The sight, taste, smell and thought of food induces salivary glands to secrete saliva, a watery fluid with PH of 6.8 to 7.0.
- During chewing, saliva mixes with food and the different saliva components perform different functions:
  - Salivary amylase; ptyalin enzyme catalyses the breakdown of amylose of cooked starch into maltose.
  - Water moistens food and binding it together for swallowing
  - Mucin; a sticky material which binds and lubricates food; to enable swallowing.
  - Chloride ions activate salivary amylase
  - Lysozymes kill bacteria in the buccal cavity.

- Taste buds on the tongue allow food to be selected; unpleasant tasting food being rejected.
- The thoroughly chewed food is rolled into a bolus and passed to the back of the mouth into a bolus and passed to the back of the mouth for swallowing.

PROCESS OF SWALLOWING

- ✓ This is a reflex action, which lasts less than 10 seconds.
- ✓ Tongue contracts to push the bolus towards the throat, forcing the soft palate upwards to close the naso-pharynx
- ✓ Larynx (which leads to the trachea) and hyoid bone move anteriorly and upwards.
- ✓ Epiglottis bends downwards to close larynx (trachea entrance) to prevent food from entering the trachea. Any food that enters into trachea is expelled out by coughing reflex.
- ✓ Breathing briefly stops due to closure of glottis.
- ✓ Pharynx shortens.
- ✓ Upper oesophageal sphincter relaxes, to allow the bolus enter into oesophagus
- ✓ In oesophagus the food bolus moves by peristalsis, a sequence of wave-like contractions that squeeze food down the oesophagus.
- ✓ Lower oesophageal sphincter; cardiac sphincter relaxes to allow food into stomach.

Illustration of the process



DIGESTION IN THE STOMACH

- ✓ The stomach is roughly J- shaped, situated below the diaphragm.
- ✓ It is muscular sac with a folded inner layer called gastric mucosa. Embedded in this is a series of gastric pits which are lined with secretory cells (G-cells). These produce gastric juice.

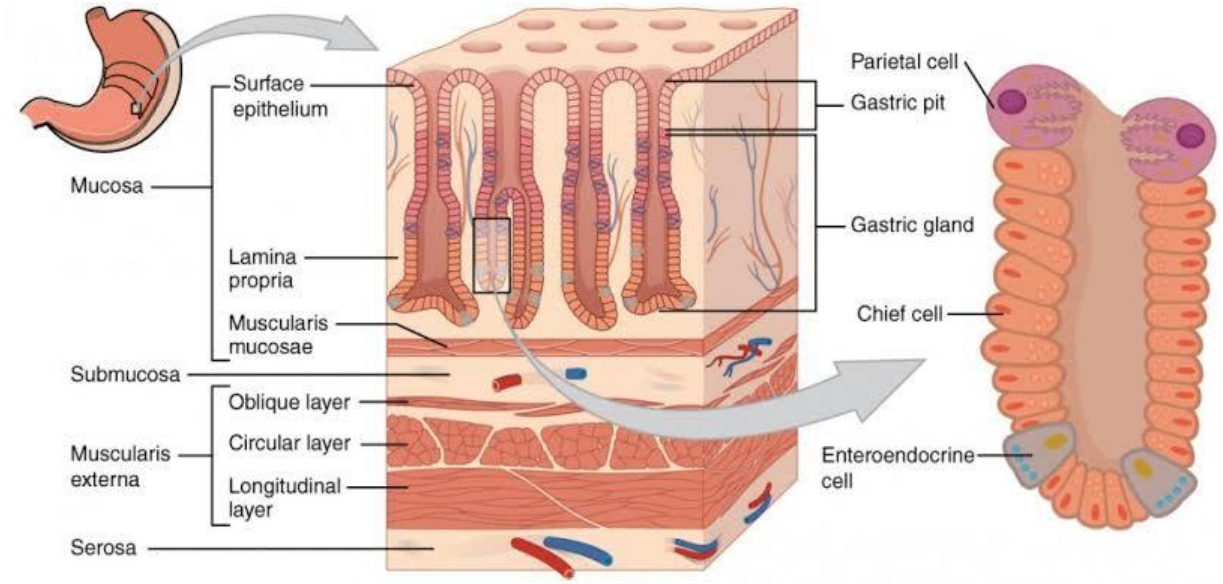
Detail;

- Arrival of food in the stomach stimulates secretion of gastrin hormone from G-cells into the blood stream, which stimulates the gastric glands to secrete gastric juice, whose components include: mucus, pepsinogen, hydrochloric acid and intrinsic factor.
- The components of gastric juice are secreted by different cells and perform different roles as follows:

1. **Water;** the bulk of the secretion is water in which are dissolved the other constituents.
2. **Pepsinogen;** this is produced by the zymogen/ chief/ peptic cells in an active form to prevent it from hydrolyzing the proteins of the cells producing it. Once in the stomach it is activated to pepsin by hydrochloric acid. Pepsin is an endopeptidase which hydrolyses protein into polypeptides.
3. **Gastric lipase**; this is produced by the chief cells and weakly catalyzes the digestion of lipids to fatty acids and glycerol.
4. **Prorennin/ prochymosin**; this is secreted by the chief cells in an inactive form and when in the stomach it is activated by hydrochloric acid to rennin which catalyzes the coagulation of soluble milk protein; caseinogen into insoluble casein.
5. **Intrinsic factor**; this is secreted by the parietal cells and forms a complex which enables the absorption of vitamin B12 that is necessary in red blood cell formation.
6. **Hydrochloric acid**; this is produced by the oxyntic/ parietal cells and with water forms a dilute solution giving gastric juice a pH of 2.0. It's necessary for;

- It kills bacteria brought with in food.
- Activates enzymes pepsinogen and Prorennin.
- It initiates the hydrolysis of sucrose and nucleoproteins.
- Inhibits further activity of salivary amylase.

Illustration of the stomach



Or **check understanding biology page 299**

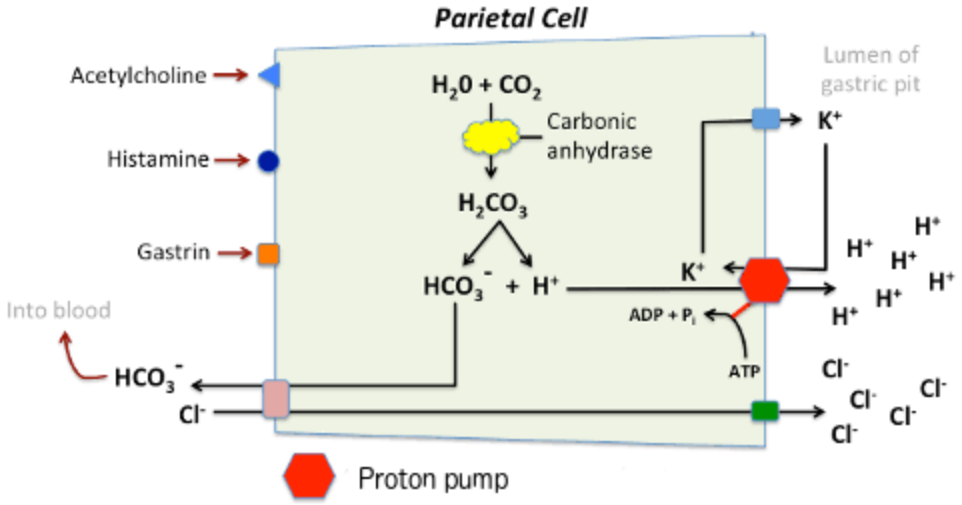
Mucus; this is produced by the goblet cells and forms a protective layer on the stomach wall, thus preventing pepsin and hydrochloric acid from breaking down the gastric mucosa i.e prevents autolysis.

- If the protection is not effective and gastric juice attacks the mucosa, an ulcer results.
- Mucus also lubricates the movement of food within the stomach.

Formation of hydrochloric acid in the parietal cells

- Hydrochloric acid is produced by parietal cells through a complex series of reactions.
- Catalysed by the enzyme carbonic anhydrase, carbon dioxide; which diffused from capillaries reacts with water to form carbonic acid, which dissociates into bicarbonate ion and hydrogen ion.
- Bicarbonate ion is transported into the blood stream by an ion exchange molecule in plasma membrane which exchanges bicarbonate ions exiting parietal cells for chloride ions entering.
- Hydrogen ions are actively pumped into the duct of gastric gland and the negatively charged chloride ions diffuse with the positively charged hydrogen ions.
- Potassium ions are counter pumped into the parietal cell in exchange for hydrogen ions.
- This results in the reaction of hydrogen ions and chloride ions thus producing hydrochloric acid in the parietal cells and its secretion into the gastric gland duct.

Summary of the process



Note;

- ⌦ During its stay in the stomach, food is thoroughly churned and mixed with gastric juice by periodic contractions of the stomach wall.
- ⌦ In this way a creamy fluid called chyme is produced.
- ⌦ Relaxation of the pyloric sphincter and contraction of the stomach allow the chyme to enter duodenum.
- ⌦ The chyme from one meal is released gradually after a period of 3-4 hours.
- ⌦ This enables the small intestine to work on a little material at a time.
- ⌦ To pass through each region food has to be moved along the alimentary canal by **peristalsis.**
- ⌦ In this there is constriction of a part before the food material forces food forward and the process is continuous.

DIGESTION IN THE SMALL INTESTINE

- In humans the small intestine is over 6m in length and it coils over to fill much of the lower abdominal cavity.
- It consist mainly of two parts;
- **The duodenum**; much shorter and its where much digestion occurs.
- **The ileum**; much concerned with absorption.

The digestive juices that operate in the small intestines come mainly from the liver, pancreas and the intestinal wall.

Digestion in the duodenum

- Arrival of partially digested, acid food mixture in the duodenum stimulates endocrine cells in duodenal walls to secrete the hormones: Secretin, Enterogastrone, Cholecystokinin (CCK) formerly Cholecystokinin-Pancreozymin (CCK-PZ), Villikinin and Enterocrinin.
- These hormones coordinate activities of the stomach, pancreas, gall bladder and ileum as follows:

1. **Secretin** is secreted with response to acid chyme in the duodenum; it;

- Stimulates the liver to secrete bile into the gall bladder.
- Stimulates pancreatic juice secretion which contains mineral salts mainly hydrogen carbonate which;
- Neutralizes the acid from the stomach to provide an alkaline PH for pancreatic enzymes.
- Inhibits further secretion of hydrochloric acid by parietal cells as the chyme leaves the stomach.

2. **Enterogastrone**; this secreted in response to fat in the duodenum. It;

✓ Reduces stomach motility
✓ Inhibits oxyntic cells from secreting hydrochloric acid in order to provide an optimum pH for pancreatic enzymes.
✓ Causes the stomach to empty slowly when fat is present, allowing much time for digestion of fat already emptied.

3. **Cholecystokinin**; is secreted in response to protein in the duodenum and partially digested fat; it;

✓ Reduces stomach motility
✓ Stimulates the contraction of the gall bladder to release bile juice into the duodenum.

Bile juice; is a complex green fluid produced by the gall bladder of the liver. It contains no enzymes but possess two substances;

a. Mineral salts i.e sodium hydrogen carbonate
b. Bile salts; sodium and potassium glycocholate; these emulsify lipids breaking them down into minute droplets. This is a physical not a chemical change which provides a greater surface area for pancreatic lipase to work on.

✓ Stimulates the pancreas to secrete **pancreatic enzymes**;

a. Pancreatic amylase; completes the catalytic hydrolysis of starch to maltose which begun in the mouth.
b. Trypsinogen; which when activated by enterokinase from the intestinal wall forms trypsin which catalyzes the hydrolysis of proteins into peptides.
c. Trypsin activates chymotrypsinogen; into chymotrypsin which also catalyzes the hydrolysis of polypeptides; casein into peptides.
d. Carboxy peptidase; which catalyses the conversion of peptides into smaller peptides and some into amino acids.

4. **Villikinin**; this' secreted in response to alkaline pH in the duodenum. It;

- Reduces stomach motility and increases peristalsis in the small intestines and ileum villi movements, in preparation for incoming food.

The churning action of duodenal walls turns the semi-solid Chyme into a thin, milky-looking alkaline fluid called Chyle which enter the ileum.

DIGESTION IN THE ILEUM

☑ The mucus and intestinal juice/ succus entericus are made by coiled Brunner's glands whereas the enzymes are produced by the lysis/ breakdown of cells at the tips of the villi; these are finger-like projections on the walls of small intestines. They contain fibres of smooth muscle and regularly contract and relax

Detail;

- Distention of the small intestine by food; tactile stimulus stimulates the secretion of intestinal juice, Some of the components of Succus entericus include the following enzymes:
- Proteases/ erepsin which includes exopeptidases called aminopeptidases which catalyse hydrolysis of peptides into smaller peptides and amino acids, thereby completing the digestion of proteins.
- Nucleotidases; which catalyse hydrolysis of nucleotides into phosphoric acid, nitrogenous bases and pentose sugars.
- Carbohydrases; these include;
- Maltase; catalyses hydrolysis of maltose into glucose molecules, thereby completing starch digestion.
- Sucrase; invertase; catalyses hydrolysis of sucrose into glucose and fructose molecules.
- Lactase; catalyses hydrolysis of milk sugar lactose into glucose and galactose molecules.
- Intestinal lipase; catalyses hydrolysis of lipids into fatty acids and glycerol thereby completing the digestion of lipids.
- Intestinal amylase; catalyses hydrolysis of the remaining starch into maltose.
- Mucus; this lubricates the intestinal walls and prevents autolysis.
- Enterokinase; a non- digestive enzyme which activates the trypsinogen produced by the pancreas.
- Mineral salts; mainly sodium hydrogen carbonate which neutralizes the acid chyme from the stomach and thus provides a more suitable pH for intestinal enzymes.

Note; somatostatin/ growth inhibiting hormone is found in endocrine cells of the pancreas and intestine inhibits secretion of pancreatic amylase enzyme and its secretion is stimulated by secretin

ABSORPTION AND ASSIMILATION

× It is the process by which soluble food substances are absorbed across the gut epithelium into blood circulatory system or lymphatic system to be carried to all body cells.

- Digestion results into relatively small, soluble molecules which, provided there is a concentration gradient could be absorbed into the body through the intestinal wall by diffusion.
- This however, would be slow and wasteful and in case if the epithelium lining were permeable to molecules such as glucose, it could easily be diffusing out of the body when the concentration in the intestine was too low.
- For these reasons, most substances are absorbed by active transport which only allows inward movement.
- However the following are the processes by which food is absorbed;

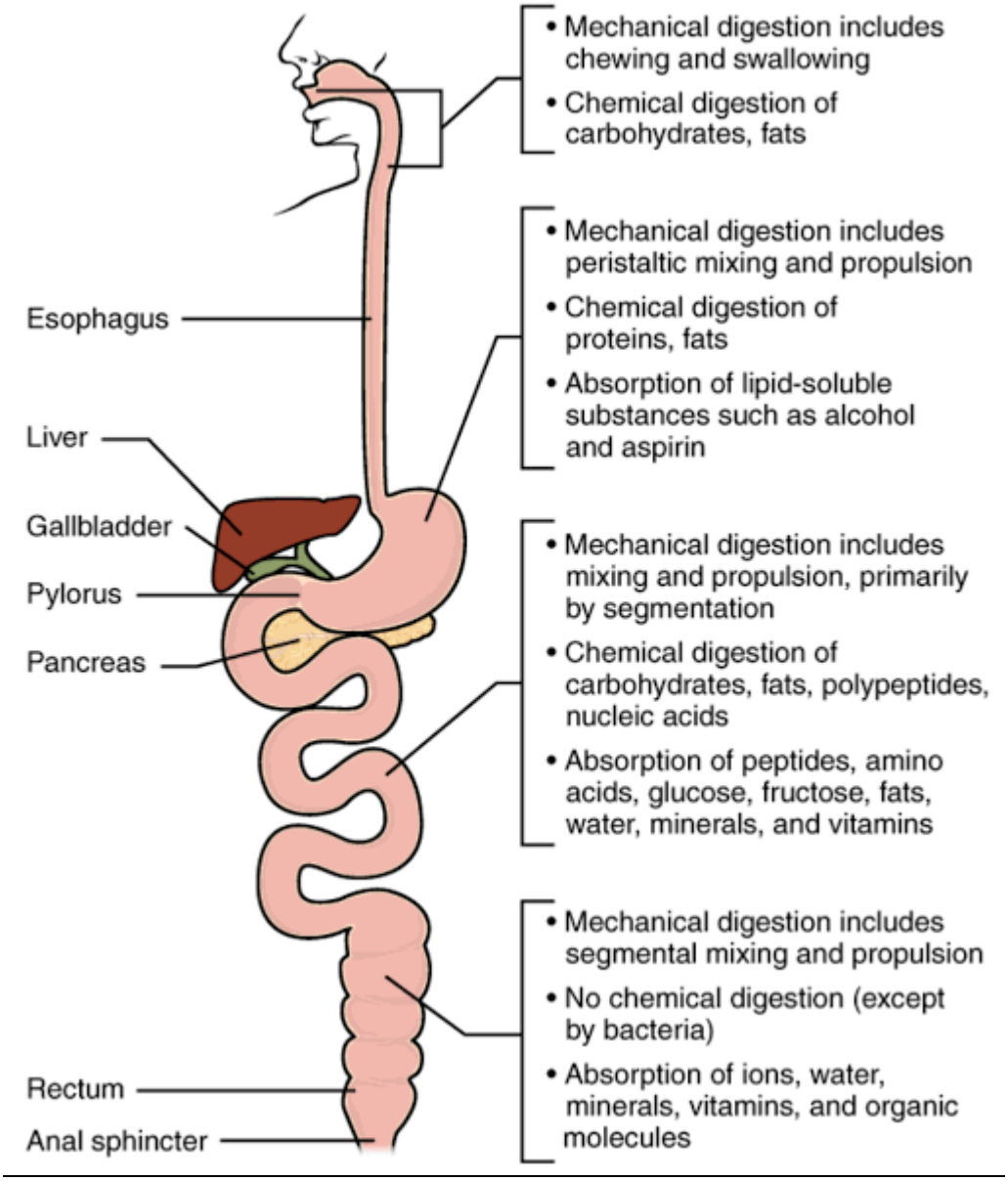
- Simple diffusion, Facilitated diffusion, Active transport, Direct active transport and Secondary active transport

<u>All as handled in movement in and out of the cell earlier</u>

NOTE:

1. Glucose and galactose are absorbed by co-transport with sodium ions.
2. Fructose is absorbed by facilitated diffusion.
3. Amino acids are absorbed by co-transport with sodium ions
4. Peptides are absorbed by co-transport with hydrogen ions.
5. Fatty acids are absorbed by simple diffusion

SUMMARY OF DIGESTION IN MAN



Adaptations of the ileum to its function of food absorption

- Ileum is very long and highly folded for increased surface area in absorption of soluble food substances.
- Ileum has numerous finger-like projections called **villi** which increase the surface area for absorption of soluble food.

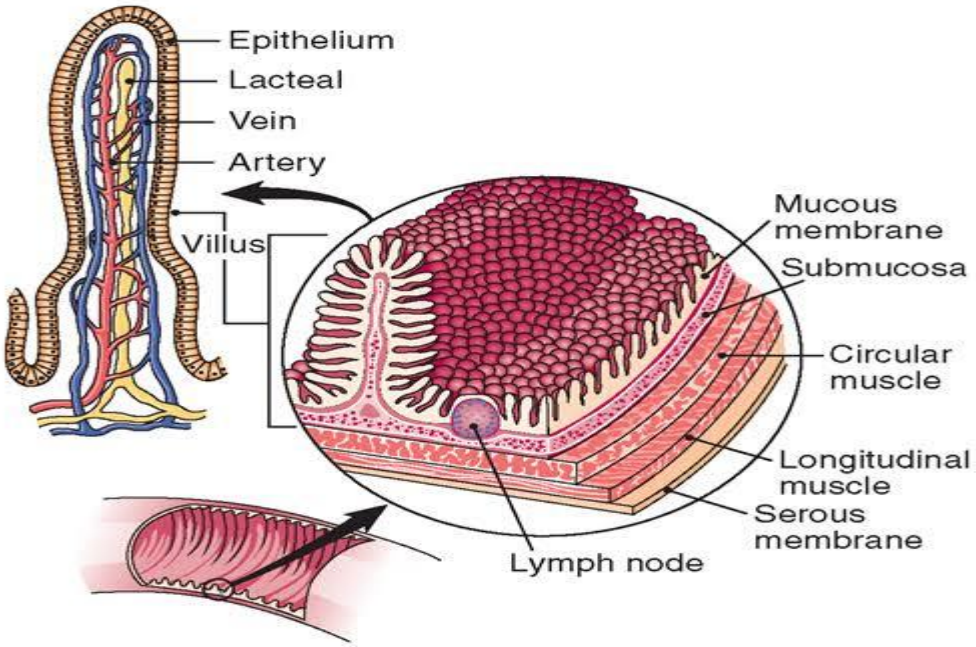
- Ileum epithelial cells have microvilli which further increase the surface area for efficient food absorption.
- Ileum epithelium is thin to reduce diffusion distance for soluble food substances to allow fast rate of diffusion.
- Ileum epithelium is permeable to allow movement of soluble food substances across with minimum resistance.
- Ileum villi have dense network of blood capillaries to rapidly carry away digested food from the absorption area which maintains a steep diffusion gradient.
- Ileum villi have permeable lacteal, a branch of the lymphatic system for carrying away fats
- Ileum epithelial cells have numerous mitochondria to generate ATP energy for active transport of some ions
- Ileum inner surface is lined with a lot of mucus to prevent autolysis (self-digestion) by proteolytic enzymes.

VILLI

- These are small, slender, vascular projections that increase surface area of the membrane on which they are.
- They are most prevalent at the beginning of the small intestine and diminish toward the end of the tract.
- Each villus has a central core compose of one artery and one vein, a strand of muscle, a centrally located lymphatic capillary; lacteal and connective tissue that adds support to the structures.
- The blood vessels transport proteins and carbohydrates absorbed by cells of the villi.
- Lymphatic capillary removes droplets of emulsified fat; chyle.
- The muscle strand allows the villi to contract and expand.
- Covering the core of the villus is the surface mucous-membrane layer; this mainly composed of tall, narrow, columnar cells that absorb the substances passed into the blood stream and lymphatic cells and goblet cells that secrete mucus into intestinal cavity.
- Microvilli collectively form a brush border.

Adaptations of the villi to absorption of food.

- Large surface area by microvilli; protrusion of exposed parts for fast uptake of soluble substances.
- Epithelium only one layer thick to reduce diffusion distance.
- Protein channels allow facilitated diffusion and active transport.
- Blood capillaries close to epithelium or surface to reduce diffusion distance during absorption of glucose and amino acids
- Lacteal is permeable and has large surface area at centre to absorb fatty acids and glycerol.
- Tight junctions between adjacent villi enable controlling absorption of substances



Or check understanding biology page 303 fig 15.4

Note;

- The passage of food from the ileum into the large intestines or colon id controlled by the ileo-caecal valve.
- The caecum in humans is little more than a slight expansion between small and large intestine and the appendix is a small bind ending sac leading from the caecum.
- In humans, they have no digestive role but have them in herbivores.

WATER ABSORPTION IN THE LARGE INTESTINE

✓ In the colon; there is mainly absorption of: Water into the blood capillaries by **osmosis,** Vitamins Biotin and K, which is synthesized by *Escherichia coli* bacteria that live in the colon, Na^+, Cl^- and K^+

Note;

✓ In the rectum, food is stored temporarily to enable osmotic absorption of water into blood capillaries.

ELIMINATION

- The semi-solid faeces consist of a small quantity of indigestible food; fibre but mostly comprise the residual material from bile juice and other secretions, cells sloughed off the intestinal wall, a little water and immense bacteria.
- The wall of the large intestine produces mucus which, in addition to lubricating the movement of faeces binds them together.
- After 24-36 hours of stay in the large intestine the faeces pass to the rectum for temporary storage and allow osmotic absorption of water into the capillaries.
- After which they are removed by defaecation. Control of this removal is controlled by the two sphincters around the anus; the opening of the rectum to the outside.

NERVOUS AND HORMONAL CONTROL OF DIGESTION

- ✓ The productions of digestive secretions must be timed to coincide with the presence of food in the appropriate region of the gut.
- ✓ In mammals the secretion production of digestive secretions is both under nervous and hormonal control.
- ✓ The control maybe inform of stimulation of inhibition
- ✓ Control in the different regions of the tract;

1. Mouth; nervous control

- Sight, smell or mere thought of food stimulate conditioned reflexes involving the cerebral cortex, hypothalamus and medulla oblongata; which stimulate salivary glands to secrete saliva.
- Once in the mouth, contact of food with tongue taste receptors causes nervous impulses to be transmitted to t via sensory neurons to the hypothalamus and medulla oblongata of the brain; the brain sends impulses via relay neurones along motor neurons to stimulate salivary glands to secrete saliva. –
- Salivary amylase in saliva causes hydrolysis of starch to maltose.

2. Stomach;

This occurs in three phases; cephalic phase, gastric phase and intestinal phase;

Cephalic phase; **nervous phase**; it occurs before food enters the stomach;

- Sight, smell or mere thought of food stimulate conditioned and unconditioned reflexes; involving the cerebral cortex, hypothalamus and medulla oblongata; which stimulate the vagus nerve causing the release of acetylcholine; which stimulates the secretion of the gastrin; whose effects are:
- ✓ Stimulates secretion of gastric juice.
- ✓ Increases contractions of gastro-intestinal tract
- ✓ Relaxes the pyloric sphincter to let in bolus of food from the gullet;
- The cephalic phase lasts for about one hour

Gastric phase; hormonal; it occurs after food arrives in the stomach;

- Arrival of food in the stomach bolus stretches the stomach wall which activates stretch receptors to fire impulses to the Meissner's plexus in the stomach wall to cause the following effects:
- Stimulate local secretory reflexes in the stomach wall to activate gastric glands secrete pepsinogen and HCl;
- Stimulate reflexes in the medulla, via the vagus nerve to activate gastric glands wall to secrete pepsinogen and HCl;
- Stimulate G-cells to secrete gastrin hormone; which stimulates secretion of gastric juice;
- Stimulate G- cells/ entero-endocrine cells to secrete histamine; which activates secretion of gastric juice;
- Partially digested proteins especially peptides or decrease in pH activates chemoreceptors, which stimulate G-cells to secrete gastrin hormone; which stimulates secretion of gastric juice.
- Gastrin continues to stimulate the reduction of gastric juice for up to 4 hours.

Intestinal phase; hormonal;

- ☑ Distension of duodenum presence of acid chyme or partially digested food stimulates the secretion of intestinal gastrin hormone; which stimulates secretion of gastric juice in the stomach; and Intestinal hormones:

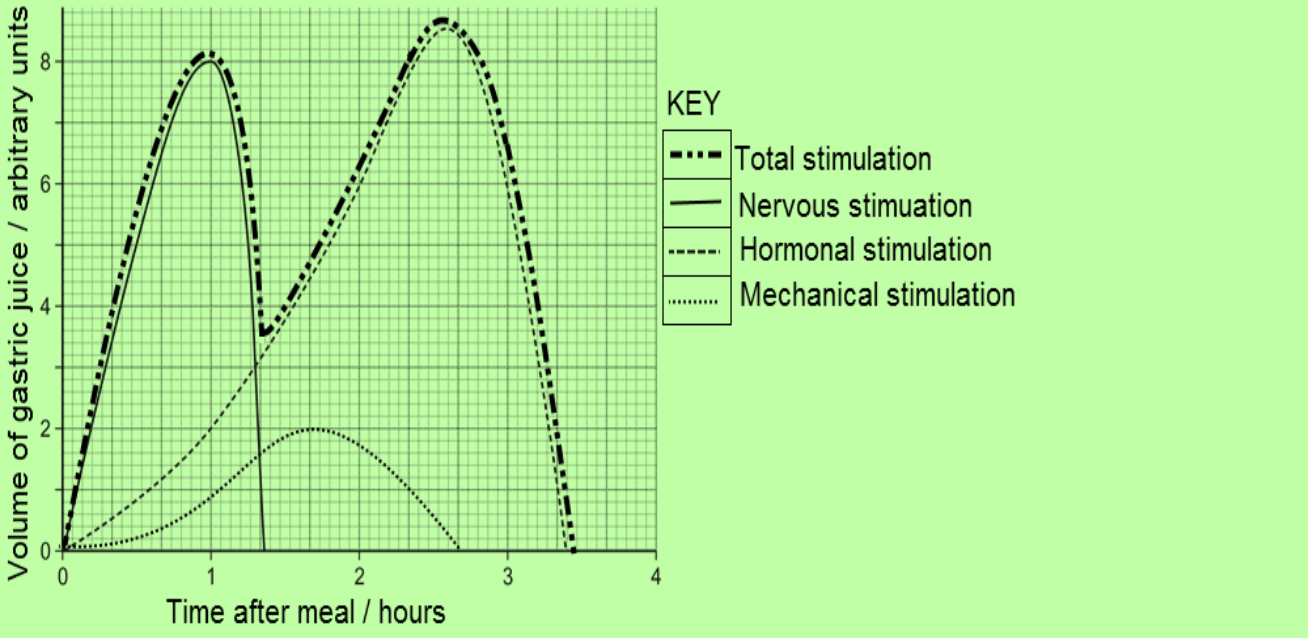
- ☑ When food leaves the stomach and enters the duodenum, it stimulates the production of hormones;
- ☑ Secretin; which stimulates the release of bile from the liver and hydrogen bicarbonate ions in pancreatic juice;
- ☑ Cholecystokinin; which stimulates the pancreas to secrete its enzymes;
- ☑ Enterogastrone; which inhibits/suppresses gastric activity (any further secretion of acid by the stomach);
- ☑ Vasoactive intestinal peptide inhibits gastric acid secretion.
- ☑ Distension of duodenum or fatty acids in the duodenum initiates gastric-inhibitory impulses in the enterogastric reflex causing suppression of gastric activity; and emptying of stomach;
- ☑ Motilin; increases gut emptying.
- ☑ Somatostatin; inhibits secretion and action of many hormones including all the above

3. Ileum;

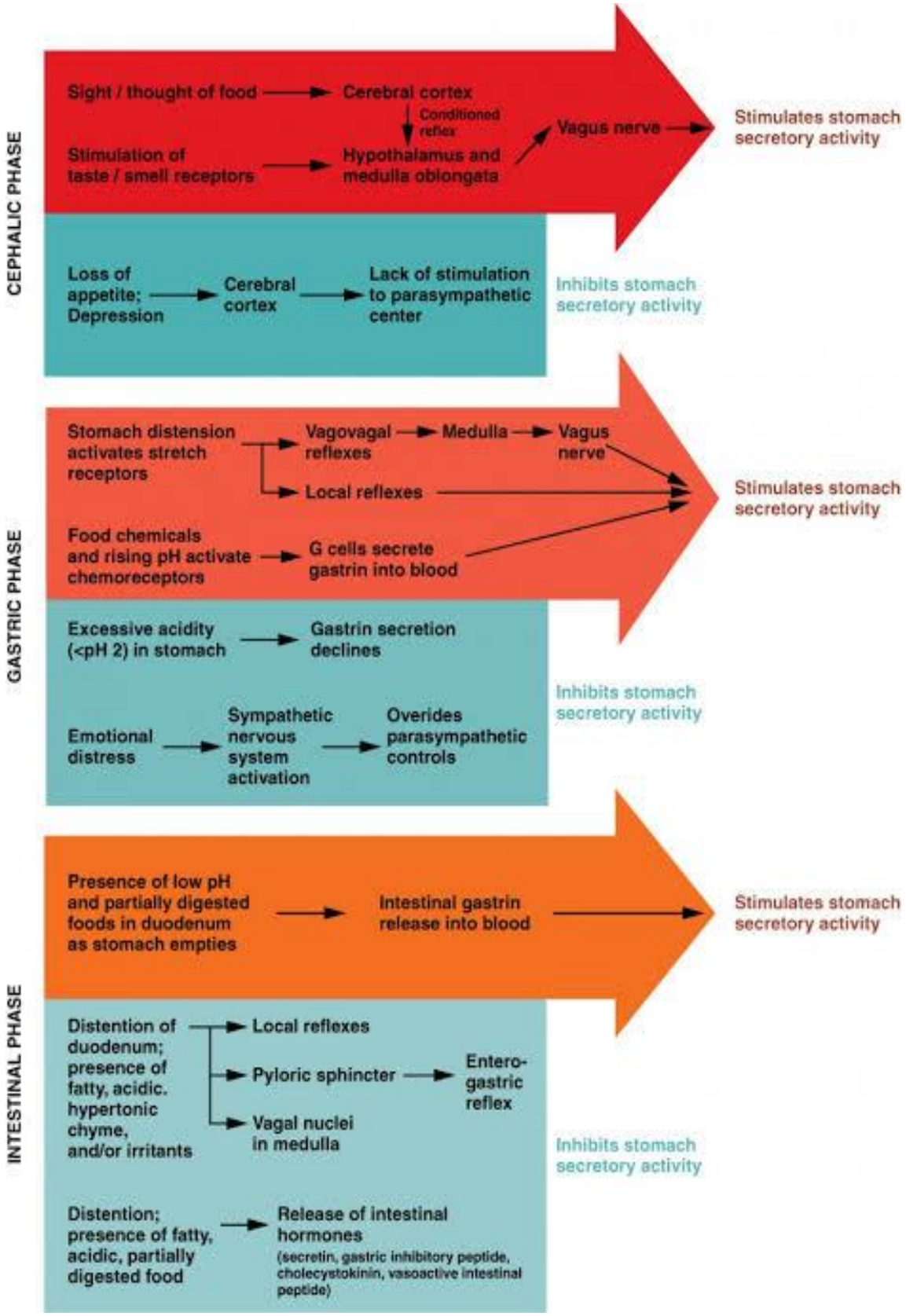
- Contact of food with intestinal lining stimulates the intestinal glands; to secrete intestinal juice composed of enzymes responsible for completion of digestion of food substrates as discussed earlier.

Summary table in understanding biology page 307

Graph illustrating control of digestion



Summary of control of digestion in the stomach


CEPHALIC PHASE
Sight / thought of food
Cerebral cortex
Conditioned reflex
Stimulation of taste / smell receptors
Hypothalamus and medulla oblongata
Vagus nerve
Stimulates stomach secretory activity
Loss of appetite; Depression
Cerebral cortex
Lack of stimulation to parasympathetic center
Inhibits stomach secretory activity
GASTRIC PHASE
Stomach distension activates stretch receptors
Vagovagal reflexes
Medulla
Vagus nerve
Local reflexes
Stimulates stomach secretory activity
Food chemicals and rising pH activate chemoreceptors
G cells secrete gastrin into blood
Excessive acidity (<pH 2) in stomach
Gastrin secretion declines
Inhibits stomach secretory activity
Emotional distress
Sympathetic nervous system activation
Overides parasympathetic controls
INTESTINAL PHASE
Presence of low pH and partially digested foods in duodenum as stomach empties
Intestinal gastrin release into blood
Stimulates stomach secretory activity
Distention of duodenum; presence of fatty, acidic, hypertonic chyme, and/or irritants
Local reflexes
Pyloric sphincter
Entero-gastric reflex
Vagal nuclei in medulla
Inhibits stomach secretory activity
Distention; presence of fatty, acidic, partially digested food
Release of intestinal hormones
(secretin, gastric inhibitory peptide, cholecystokinin, vasoactive intestinal peptide)

NUTRITION IN HERBIVORES AND CARNIVORES

Terms used;

- Carnivorous animals: are either predators or scavengers whose diet consists of mainly flesh obtained from preys.
- Predator: An animal that hunts and kills animals for food.
- Prey: An animal that is hunted and killed for food.
- Scavenger: An animal that eats dead animals, but doesn't kill them.
- Herbivore: An animal whose diet is mainly vegetation
- Grazers: animals that mainly feed on grass
- Browsers: Mainly feed on leaves of shrubs and trees

Adaptations of herbivores to their diet;

Plant material is relatively tough and largely indigestible without the aid of microorganisms.

The first essential of this digestion is to grind up vegetation, so disrupting the tissues and increasing its surface area.

Animals are adapted for Herbivory life in the following ways;

1. Having a horny pad which replaces the upper front teeth.
2. A pronounced gap; diastema, between the incisors and premolars. This provides a space in which newly nibbed food can be kept separate from that being ground down at the back of the mouth.
3. The cheek teeth; molars and premolars; have gripped surfaces which form an effective grinding surface.
4. The jaws easily move from side to side to allow food to be broken down between the ridged teeth.
5. The teeth grow continuously throughout the herbivore's life. This is essential as the grinding action of the teeth wears them away.
6. The alimentary canal is relatively long because digestion of plant material is difficult.
7. The stomach is divided into a number of chambers, some of which produce digestive enzymes to break down the food.
8. The rumen house bacteria and protozoa which produce enzyme cellulase; essential to break down the cellulose which constitutes the bulk of the food ingested.
9. Their tongue is muscular for manipulating food during chewing.
10. Have well developed jaw muscles which provide much grinding power for crushing food.

Adaptations of a carnivore to its diet

Carnivores mainly eat meat which is mainly muscle of another animal. This is rich in nutrients and therefore a much more concentrated source of food than plant material.

Once captured and ingested, the digestion of meat presents little problem;

Adaptations of typical carnivores;

1. The incisor teeth are sharp for nipping and biting.
2. The canines are long and pointed. They are used for piercing and killing the prey and tearing flesh from the body.
3. The molars and premolars have a number of sharp pointed cusps. The last upper premolar and the first lower molar on each side of the mouth are particularly large and are known as carnassial teeth.
4. The teeth of the upper jaw tend to overlap those of the lower jaw. The carnassial teeth therefore slide pat one another, in order to slice the meat into manageable pieces.

5. The muscles of the jaws are well developed and powerful. This enhances grip of the prey firmly during the kill and in the crushing of the bone.
6. There is no lateral jaw movement as in herbivores. Such movement leads to easier dislocation of the jaw, and may cause prey escape.
7. Vertical movement of the jaw is less restricted allowing a wide gape for capturing and killing prey.
8. The alimentary canal is short, reflecting the relative ease with which chemical digestion can take place.

Differences between herbivores and carnivores

Carnivores	Herbivores
Closed pulp cavity in teeth	Open pulp cavity in teeth
Upper jaw incisors present	Upper jaw incisors absent in most herbivores
Canines present and well developed	Canines small or absent to create a diastema
Carnassial teeth present	Carnassial teeth absent
Cheek teeth pointed	Cheek teeth flattened with enamel ridges and dentine grooves
Articulation of lower jaw prevents lateral movement	Articulation of lower jaw permits lateral movement
Relatively short alimentary canal	Relatively long alimentary canal
No cellulose digestion	Cellulose digestion occurs in rumen

PARASITISM

This is an association between two organisms in which one; the parasite, is metabolically dependent on the other; host.
This is invariably a nutritional dependence, the parasite absorbing either host tissues or fluids or the contents of the host's intestine. In so doing the host is harmed.

Note; difference between parasitism and predation;

- In parasitism, the parasite spends significant length of time feeding on the host.
- A host can produce an immune response to a parasite but not a predator.

CATEGORIES OF PARASITES

Parasites may either be;
Endo parasites; which live inside the body of the host
Ecto parasites; which live on the outside of the body.
In both cases, a parasite must be able to maintain its position in or on the host.

Problems to parasites

- ✓ Failure to find the right intermediate host for dispersal to the final host
- ✓ Failure to obtain nutritive molecules from the host.
- ✓ Failure to penetrate the host.
- ✓ Destruction by digestive enzymes and immune responses of the host
- ✓ Fluctuating environment of low oxygen tensions, heat among others.
- ✓ Complete elimination or destruction
- ✓ Failure to cling on the host to avoid being dispositioned.

Adaptations of parasites to their mode of life

Structural adaptations;

- Camouflaging to increase survival chances.
- Possession of nutrient suckers in leeches
- Possession of specialized mouth parts in some ecto parasites to suck hosts e.g sharp stylets in aphids
- Possession of penetrative devices for host entry e.g cutting teeth in hook worms

- Development of digestive resistant outer covering to avoid host's enzymes attack e.g in tapeworm
- Degeneration of non-essential parts e.g no feeding, no locomotory organs in order to reduce body size and fit in intestines and as well reduce energy expenditure on such organs e.g tapeworm.

Physiological adaptations;

- Rapid means of escape which increase survival chances eg in mosquitoes.
- Highly tolerant to fluctuating environment e.g using anaerobic respiration.
- Production of mucus for resisting digestion by host's enzymes.
- Production of enzymes to digest the hosts' tissue during penetration into the host e.g in plasmodium.
- Some endo parasites produce chemicals to protect themselves against the immune responses of the host.
- Production of anticoagulants by blood feeding parasites to avoid blood clotting during feeding e.g in mosquitoes.
- Production of anesthetic chemicals so as to bore the host unaware e.g in leeches.

Reproductive adaptations;

- Production of large number of infective agents such as eggs, cysts and spores which increase survival chances to avoid extinction e.g tapeworm.
- Some are hermaphrodites with the ability to carry out self-fertilization to increase the rate of reproduction e.g in tapeworm.
- Development of reproductive bodies that are highly resistant when out of the host to survive adverse conditions e.g cysts in plasmodium.
- Release of sexually mature forms of the parasites of the parasites as free living organism e.g in some parasitic animals such as horse hair worms.
- Some asexually reproduce for high rate of reproduction for high rate of reproduction to avoid extinction.
- Some use hereditary transmission for increased spreading e.g some parasites infect the ovary of primary host which lays parasite infected eggs.
- Use of intermediates host for their transfer to primary host e.g in plasmodium in female anopheles mosquito to man.

Case studies of some parasites

1. The tapeworm;

- ✓ Humans are the definitive hosts for Taenia solium, eggs or proglottids are passed out in faeces.
- ✓ Cattle and pigs become infected by ingesting vegetation contaminated with eggs or gravid proglottids.
- ✓ In the animals' intestine, the oncospheres hatch, invade the intestinal wall and migrate to striated muscles, where they develop into cysticerci.
- ✓ A cysticercus can survive for several years in the animal.
- ✓ When man eats undercooked meat. The scolex turns inside out and attaches on the gut wall.
- ✓ In the human intestine, the cysticercus develops over 2 months into an adult tapeworm which can survive for years.
- ✓ Adult tapeworms attach and stay in small intestine by their scolex.
- ✓ The adults produce proglottids which mature, become gravid, detach from the tapeworm and migrate to the anus or are passed out in stool.
- ✓ The eggs contained in the gravid proglottids are release after the proglottids are passed with the faeces.

Illustration in understanding biology page 310

2. Round worms/ *Ascaris lumbricoides*

- Adult female in lumen of the ileum lays very many eggs about 150000 daily which are passed out in faeces.
- Fertile eggs embryonate and become infective after about three weeks if the conditions of moisture, warmth are optimum
- On being swallowed by humans, eggs hatch into larvae, which invades the intestinal wall and are carried via the systemic circulation to the lungs.
- Larvae mature further in the lungs in about two weeks, they penetrate alveolar walls and ascend the bronchi to the throat, and are swallowed into the gut.
- Upon reaching the ileum, they develop into adult worms.
- Within a period of three months the ineffective eggs are ingested by the adult worms.

3. **Plasmodium**;

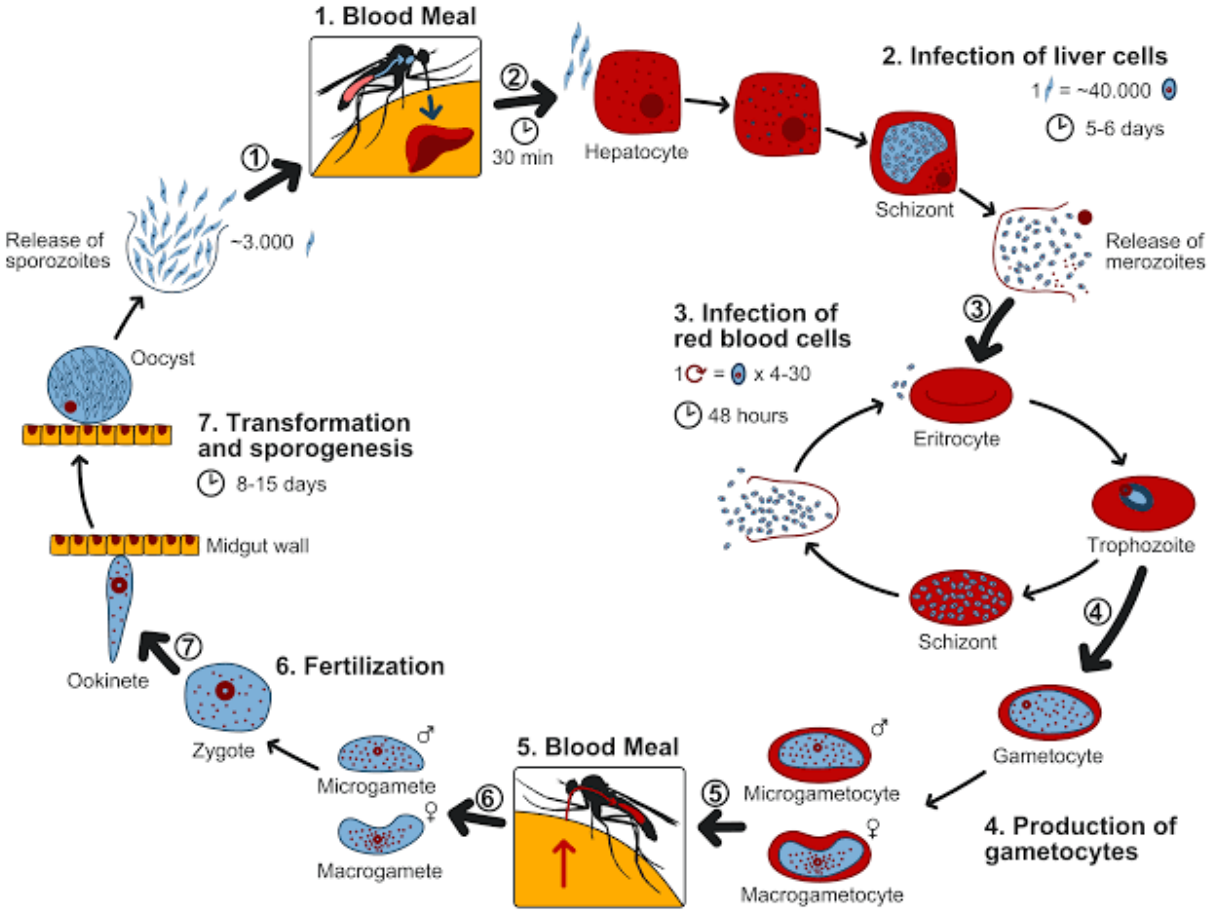
Four species of plasmodium are considered true parasites of humans, as they utilize humans almost exclusively as a natural intermediate host;

- ✓ P. falciparum,
- ✓ P. vivax
- ✓ P. ovale
- ✓ P. malariae.

Lifecycle

- Plasmodium has two different hosts during its lifecycle humans and mosquitoes of the genus anopheles. Humans as intermediate host and adult female anopheles mosquito as definitive host.
- During a blood meal, a malaria-infected female *Anopheles* mosquito releases sporozoites into human blood.
- On reaching the liver, sporozoites infect liver cells and mature into schizonts, which rupture and release merozoites.
- The merozoites invade the red blood cells where they further multiply at the expense of the cell
- After this initial replication in the liver, the parasites undergo asexual multiplication in the erythrocytes.
- Merozoites re-invade and infect red blood cells, the ring stage trophozoites mature into schizonts, which rupture releasing merozoites.
- Some parasites differentiate into gametocytes.
- Blood stage parasites are responsible for the clinical manifestations of the disease and symptoms such as;
- Headache, tiredness, aching, vomiting, shivering, feeling cold which lasts around two hours;
- Sudden rise in body temperature to 40^{o}C or above, leading to faster heart beat and breathing rate, fever lasting for four hours;
- Profuse sweating for between two to four hours as the body temperature returns to normal.
- The gametocytes, male; microgametocytes and female; macro gametocytes, are ingested by an *Anopheles* mosquito during a blood meal.
- While in the mosquito's stomach, the microgametes penetrate the macrogametes forming zygotes.
- Zygotes become motile and elongated; ookinetes, invade the mid-gut wall of the mosquito to develop into oocysts.
- Oocysts grow, rupture, and release sporozoites, which enter the mosquito's salivary glands.
- Inoculation of the sporozoites into a new human host during a blood meal repeats the malaria life cycle.

Illustration of the malaria cycle

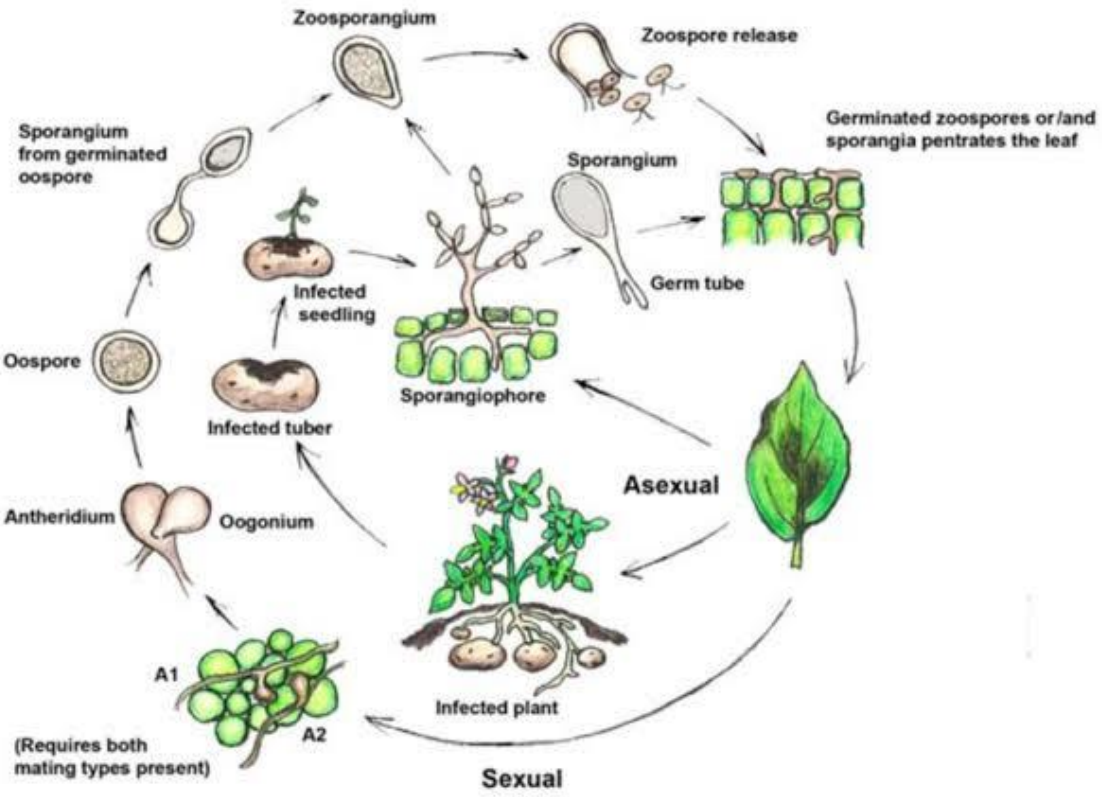


Think about the control measures of malaria!

4. Phytophora infestans

- This is a fungi that has one primary host; the potato and causes potato bright
- *Phytophthora* produce two kinds of spore i.e. diploid oospores, formed sexually from fusion of haploid antheridia and oogonia, and chlamydospores formed asexually.
- Both types of spore have thick cell walls for surviving harsh conditions.
- Under cool wet conditions, *Phytophthora* both the spores germinate to form hyphae or directly produce sporangia.
- Sporangia release free swimming bi-flagellated zoospores, which travel in moisture at the surface of leaves, and in soil.
- On reaching plant root or leaf surface a zoospore forms a cyst.
- The encysted zoospore then germinates to form hyphae on the host surface, which penetrates plant leaf or root tissues to absorb nutrients.
- After *Phytophthora* infects the plant, it produces sporangia and zoospores which further infect other tissues of the same plant or nearby plants.
- Sexual reproduction occurs when positive and negative mating types are present.
- Haploid nuclei of antheridium and oogonium fuse together when the antheridium enters the oogonium to form a diploid oospore, which develops into a sporangium and the cycle will continue as is would asexually.

Illustration of the lifecycle of *Phytophora infestans*



Control of endoparasites

- Avoid eating infected under cooked meat
- Through proper disposal of sewage which prevents these worms from spreading
- Through cooking meat thoroughly for example prolonged heating destroys the tapeworm bladders
- Regular deworming to flush the worm out of the wall of the intestines in faeces.
- Through regular meat inspection before it is consumed by man.
- By prohibition of the discharge of raw sewage into inland waters and seas.

SAPROBIONTISM

Saprobionts are heterotrophic organisms which obtain carbon by absorption from dead organisms or organic wastes.

Saprobionts d not invade living tissues but some parasitic fungi e.g *Ceratocystis ulmi* which causes elm disease are able to feed saprobiontically when they have killed their hosts.

Extracellular digestion by Saprobionts

- The saprobiont such as bacteria or fungi under suitable conditions of moisture, oxygen, pH, temperature, secrete enzymes to the outside of their cells onto the dead organisms/ organic matter.
- These enzymes include amylases, cellulases, lignases and proteases which break down the material on which the saprobiont grows from complex into simple soluble substances;
- Lignases catalyze the breakdown lignin in the cell wall of wood and tree back, proteases catalyze the breakdown proteins into amino acids, cellulases catalyze the

breakdown cellulose into glucose, amylases catalyze the breakdown starch into simple disaccharides such as maltose

- The organism now becomes surrounded by a solution full of nutrients of monosaccharides and amino acids which are then absorbed by either endocytosis, simple diffusion, facilitated diffusion or active transport.
- An example of a saprobiont feeding in this way is the fungus ***Rhizopus*** which secretes enzymes from the tips of the hyphae.

COMPARISON OF SAPROPHYTES AND PARASITES

Similarities;

- Both are heterotrophic
- Both produce large number of offspring.
- Both have sexual and asexual phases in their reproductive cycle.
- Both have digestive enzymes.

Differences;

Saprophytes	Parasites
• Derive energy from decaying organic matter	• Derive energy from living organisms
• Involve a single adult stage and spores in their life cycle	• Involve many stages in their life cycle
• Use a variety of food sources	• Are very specific to their hosts
• Have simple method of nutrition	• Have a complex method of feeding
• Almost totally bacteria and fungi	• Most plant and animal groups have representatives
There are aerobic and anaerobic forms	Most are aerobic

Importance of saprophytism;

- ✓ Recycling of materials by feeding on decaying organic matter, the saprophytes unlock and recycle nutrients which would otherwise have been lost with the dead organisms.
- ✓ Decomposition of sewage or waste; saprophytes aid the decomposition of waste produced by human activities. By this the bulk of the waste is reduced and nutrients made available to crops.
- ✓ Some saprophytes, especially fungi are used as food by man.
- ✓ Physiological processes of saprophytism and as fermentation are useful in brewing and baking.
- ✓ The production of yoghurt and cheese from milk also employs saprophytic mechanisms.
- ✓ Some saprophytes are used in the production of antibiotics.
- ✓ Industrial processes such as leather tanning and production of some vitamins make use of saprophytic organisms.

MUTUALISM

Mutualism is an association between two different organisms in which neither is harmed and both may benefit in some way.

Examples of mutualism include;

1. **Lichen;**

- This is an association between green algae usually *Trebouxia*, and a fungus usually an ascomycete.

- The fungus receives and uses the products of algal photosynthesis; organic compounds and oxygen meanwhile the fungi it absorbs water for use by the algae from the atmosphere, provides protection as it forms an outer covering, mineral salts, anchorage to the algae.

2. **Hydra-chlorella symbiosis**;

- *Chlorella* are unicellular green algae found in the ectoderm of the *cnidarian* Hydra.
- They are able to photosynthesize and supply the *Hydra* with maltose.
- Meanwhile the algae obtains protection and mineral salts. This association is endo symbiosis as one organism lives symbiotically inside the cells of the other.

3. **Mycorrhizas**;

- These are structures formed by the association of plant roots with the fungi.
- They are common in higher plants including pine, oak, beech and birch.
- The fungus is dependent on symbiosis for carbon nutrition; carbohydrates from photosynthesis and higher plants for inorganic nutrients and water.

4. **Termites**;
   - Termite's breakup the wood into tiny pieces using their sharp and strong mandibles which they swallow easily. On reaching the crop, protozoa; *Trychonympha* in the crop ingest the swallowed food by phagocytosis. The secrete cellulase into their food vacuoles, thereby digesting the cellulose in the termites' diet.
   - Some soluble products of digestion such as glucose diffuse out of the protozoa and are absorbed by the termite meanwhile the protozoa obtains shelter.

DIGESTION OF CELLULOSE BY MICROORGANISM

Lacking the ability to produce their own cellulase, herbivores are reliant upon bacteria and protoctista to carry out cellulose breakdown for them.
The herbivore must provide a region of the alimentary canal for these microorganisms to inhabit.
Note;

a. This region must be separate from the main canal in order that food can be kept there long enough for these microorganisms to carry out the breakdown.
b. Also being separate also protects the microorganisms from the mammal's digestive enzymes, and as well provides a suitable pH for the activity of the microorganisms.

<u>In ruminants such as cattle, goats, sheep, etc</u>;

- A complex four chambered stomach is present.
- When food id swallowed, it enters the first two chambers; the rumen and reticulum. And after some hours and usually in the relative safety of some sheltered position, the herbivore regurgitates the food into the mouth where it thoroughly chews it "chewing the cud".
- On being re-swallowed, the food enters the final two chambers of the stomach the Omasum and abomasum where the usual process of digestion takes place.

Detail;
Rumen;

- Bacteria and protozoa in the rumen secrete cellulase enzyme which breaks down cellulose into glucose which undergoes fermentation to form organic acids, carbon dioxide and methane.

- The fermentation process produces heat that keeps ruminants warm. The products of this digestion are either absorbed by the walls of the rumen are absorbed by microorganisms and digested later.
- The waste gases, largely carbon dioxide and methane are expelled via the mouth.

Reticulum;

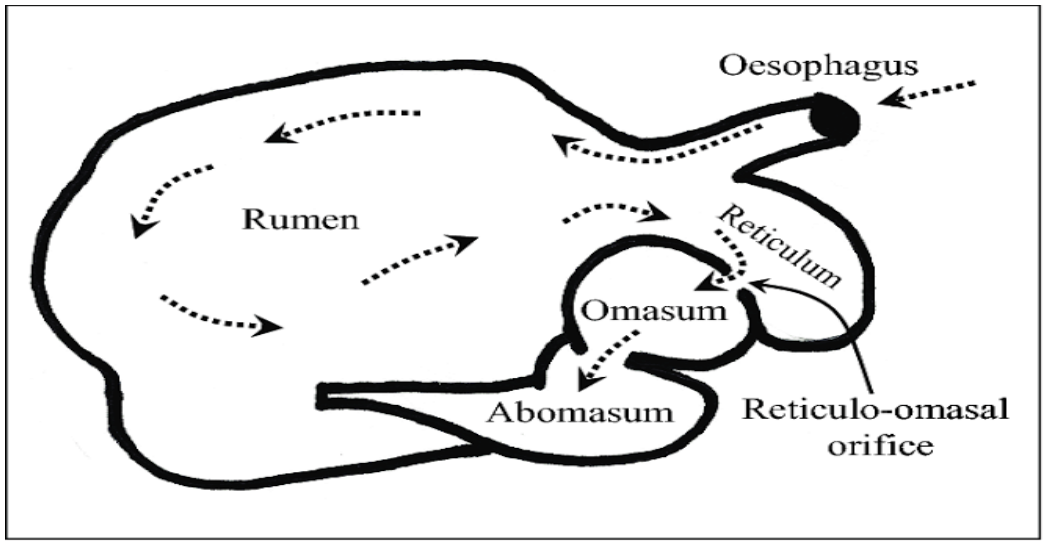
- Here any foreign objects that may have been accidentally swallowed with food settle out in the honeycomb structure of the reticulum's walls.
- And as well some absorption of food takes place here due to presence of villi
- Reticulum is sometimes called "hardware stomach".

Omasum;

- Absorbs water from food and also absorbs more nutrients called volatile fatty acids that supply ruminants with energy.

Abomasum or True stomach;

- Here, the food particles are digested by hydrochloric acid in the same way it occurs in human stomachs. The remaining particles are then passed on to the small intestine where most of the nutrients are absorbed by the body and made available to the ruminant.



Note;

- Also present in the rumen are protein synthesizing bacteria which use ammonia as the source of nitrogen.
- These protein rich bacteria are engulfed by the protoctista which in turn are digested by the ruminant's digestive enzymes availing the protein to the protozoa.

<u>In non-ruminants such as rabbits and horses</u>;

- ✓ The caecum and appendix are much enlarged and accommodate the microorganisms.
- ✓ The caecum and appendix thus contain bacteria that secrete cellulase enzyme for digesting cellulose into glucose. The herbivore gains glucose while the bacteria get shelter.
- ✓ In the process described as <u>coprophagy</u>; the yield is improved by re-swallowing of the materials from the caecum after it has left the anus.
- ✓ For example; rabbits eat own faecal pellets while dung beetles feed on cow dung to enable absorption of glucose at the ileum.

RHIZOBIUM

- Many angiosperms and a few conifers form swellings called nodules on their stems, roots or leaves.
- The nodules contain microorganisms which are capable of nitrogen fixation.
- For example the root nodules of leguminosae such as peas, beans and ground nuts.
- In this case, the nitrogen fixing microorganism is the bacterium *Rhizobium*.
- This association provides the bacteria with a carbon source and the plant with nitrates.
- The development of a nodule is similar to development of a lateral root except that the central cells are filled with bacterial cells enclosed in a membrane.

COMPARISON OF MUTUALISM AND PARASITISM

Similarities;

- Both are close association between two living organisms of different species.
- In both, one organism is smaller and lives in or on the larger organism.
- In both, the smaller organism may be aerobic or anaerobic.

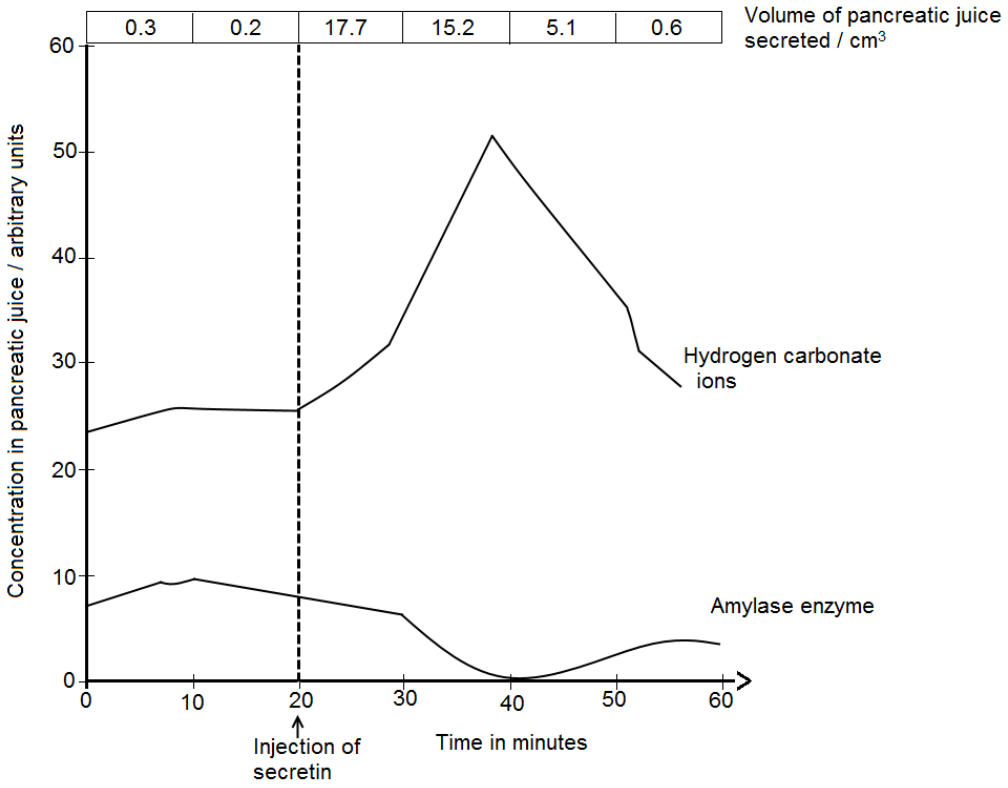
Differences;

Mutualism	**Parasitism**
• Both organisms benefit	• Only one organism (the parasite) benefits
• **No organisms is harmed**	• The host suffers harm form the parasite.
• Produces nutrients important to other organisms in nature	• Does not produce any useful nutrients in the environment
• **Usually important in nutrient recycling in nature**	• No important in nutrient recycling.

END OF TOPIC NUTRITION IN ORGANISM

I thank you very much for you have completed the topic very well and understood the key concepts of it. Due to this is remind you that we started with autotrophic nutrition where we looked at leaf structure and different adaptations to obtaining requirements for photosynthesis, mechanisms of photosynthesis, factors affecting photosynthesis, chemosynthetic bacteria. We further covered heterotrophic nutrition where we looked at in detail holozoic nutrition, balanced diet, human digestion, parasitism, saprobiontism and mutualism. And you have proved to have understood the subject matter.
With that I request you try out the questions below. Thank you

1. What roles do the liver and pancreas play in: (i) food digestion
   (ii) Metabolism of absorbed products
   (b) How can the diet of raw liver prevent the disease pernicious anaemia?
2. a. Describe the process of swallowing food in humans. (10 marks)
   b. Explain the role of gastric juice during food digestion in adult humans (10)



3. The graph aside shows how an injection of secretin affects the secretion of pancreatic juice by the pancreas. Use the graph to explain the effect of secretin on pancreatic secretion.

b. From the graph, comment on the composition of pancreatic juice.

c. State any other digestive secretion stimulated by secretin.

d. Certain types of ulcers are thought of to be made worse by the production of too much acid from the stomach. Medical doctors have used several methods to treat such ulcers.

Suggest how each of the following treatments might reduce the amount of acid secreted by the stomach:

i. Cutting the gastric vagus nerve.

ii. Blocking the action of acetylcholine by giving the patient atropine.

4. a. Explain the effect of light intensity and temperature on the rate of photosynthesis.

b. Explain photophosphorylation in terms of chemiosmosis.

c. Explain the reactions involving the use of light energy that occur in the thylakoids of the chloroplast.

5. (a) Outline the light-independent reactions of photosynthesis.

b. Explain:

(i) why the light-independent reactions of photosynthesis can only continue for a short time in darkness.

ii. how the light-independent reactions of photosynthesis rely on light-dependent reactions.

6. (a) Outline the formation of carbohydrate molecules in photosynthesis starting from the absorption of light energy

(b) Compare the structure of a chloroplast and a mitochondrion in relation to function.

7. (a) Explain how a photosystem increases the light harvesting ability of a chloroplast?

b) Explain the relationship between the action spectrum and the absorption spectrum of photosynthetic pigments in green plants.

8. Explain the concept of limiting factors in photosynthesis, with reference to light intensity, temperature and concentration of carbon dioxide

9. The table below shows effect of temperature on rate of photosynthesis in two grasses, ***Agropyron*** and ***Bouteloua***

Leaf temperature (^{0}C)	Rate of photosynthesis in arbitrary units	
	Agropyron	Bouteloua
10	23	10
15	26	15
20	30	19
25	31	24
30	30	30
35	27	35
40	20	39
45	10	38

a. represent the data above graphically
b. compare the rate of photosynthesis in the two plants
(c) Account for the variation of the rate of photosynthesis in the two plants.
(d)(i) Describe the photosynthetic mechanism which is likely to occur in the cytoplasm of the mesophyll of Bouteloua
e. Explain the physiological significance of the mechanism described in (e) (i) above.
10. Experiments on cultures of a unicellular protist to investigate the effect of light and carbon dioxide on certain metabolites. In the first experiment, the levels of PGA, RuBP and sucrose in the protest were determined at different time intervals in the presence of light. At the 35th minute, light was switched off, suddenly putting the protists in darkness; the results are shown in the table below

Time (minutes)		0	20	35	40	50	60	70
Amount of metabolite	RuBP	35	35	35	30	15	10	10
	PGA	45	45	45	50	65	70	70
	Sucrose	10	54	72	66	52	35	20

a. represent the data provided graphically
b. Using the graph obtained in (a) above, explain the variation in the levels of the metabolites with time
11. Compare photosynthesis and aerobic respiration.
b. explain the effect of low oxygen tensions on;
i. C3 plants
ii. C4 plants
c. explain why C4 plants are more efficient in photosynthesis than C3 plants.
12. Describe the control of digestion in man.
13. Describe what happens when a person takes in a heavy meal of maize, cassava, banana/ matooke, beans some vegetables and accompanies it with mango juice.

9.GASEOUS EXCHANGE

PRINCIPLES OF GASEOUS EXCHANGE SYSTEMS

Gaseous exchange is the uptake of molecular oxygen from the environment and discharge of carbon dioxide to the environment by cells of an organism.
All organisms must obtain regular supplies of oxygen from their environment and return waste gas carbon dioxide to it.
The movement of these gases occurs primarily by diffusion over part or all of the body surface.
Terms used;

1. **Gaseous exchange medium**; the source of oxygen for example air for land organisms and water for aquatic organisms.
2. **Respiratory surface**; the part of the body or the body over which gaseous exchange takes place.
3. **Respiration**; the chemical reactions by which organic compounds are broken down to produce energy as we shall see in detail in the next chapter.
4. **Ventilation**; the movement of air between the gas exchange medium and respiratory system to maintain appropriate concentrations of oxygen and CO2 in body fluids. It involves processes of inspiration and expiration.

RESPIRATORY SURFACE

An efficient respiratory surface should;

- Have a large surface area relative to the volume of the organism to maximize the rate of gas exchange.
- Thin for gases to diffuse across faster.
- Moist to dissolve respiratory gases to ensure faster diffusion
- Permeable to the respiratory gases to enable their diffusion
- Efficient transport system that maintains a high concentration gradient for the diffusion of respiratory gases.

Due to the variation in the oxygen content in water and air as earlier learnt in transport, organisms have developed respiratory surfaces and other mechanisms to enhance maximum and efficient gaseous exchange.

Summary table of respiratory surfaces

Animal/organism	**Respiratory medium**	**Respiratory organ**	**Respiratory surface**
Amoeba	Water	None	Cell surface
Planarian (flat worms)	Water	None	Body surface
Insects	Air	Trachea	Tracheoles
Fish	Water	Gills	Gill plate
Amphibian (tadpole)	Water	Gills	Gill filaments
Amphibian adults	Water	Skin	Epithelial skin surface
	Air	Buccal cavity	Epithelium of buccal cavity
	Air	Lungs	Alveoli
Reptiles, birds and mammals	Air	Lungs	alveoli

ADAPTATION BY DIFFERENT ORGANISMS TO THEIR RESPIRATORY MDEIUM

WATER RESPIRATORY MEDIUM/ AQUATIC ENVIRONMENT

Problems faced by aquatic organisms as far as gaseous exchange is concerned;

- The content of oxygen in the water is low
- The diffusion rate of oxygen in the water is low
- The water viscosity is high
- The water density is high

1. **Cell surface membranes in unicellular organism e.g the amoeba**
   - ✓ In this the cell surface membrane is permeable to respiratory gases.
   - ✓ The cell surface membrane has sufficiently large area to volume ratio that increases efficiency of diffusion of gases.
   - ✓ The cell surface membrane is always moist to dissolve respiratory gases to enhance their diffusion.
2. **Gills in fish; internal**;
   - ✓ Gill filaments are moist to enable dissolution of respiratory gases for easy diffusion.
   - ✓ There is a counter current flow; bony fish which maintains a gaseous concentration gradient for diffusion of gases.
   - ✓ Gill filaments have lamellae that increase the surface area for gaseous exchange.
   - ✓ The gill lamellae have a network of capillaries to carry gases.
   - ✓ Gill filaments are thin walled to minimize the diffusion distance of respiratory gases.
   - ✓ The gill filaments overlap which reduces the speed of water flow over them and creates more time for gaseous exchange to occur.
3. **Entire body e.g in Earthworm**
   - ✓ Skin surface is moist to enable dissolving of respiratory gases for efficient diffusion.
   - ✓ Skin is thin to reduce the diffusion distance such that
   - ✓ There is increased rate of diffusion of respiratory gases.
   - ✓ The epidermal tissue is highly vascular to deliver and carry respiratory gases such that a high concentration gradient for the gases is maintained

AIR RESPIRATORY MEDIUM /LAND ENVIRONMENT

1. **Alveolar surface of lungs in mammals**
   - ✓ The alveolar is moistened to enable dissolution of respiratory gases to increase the rate of diffusion.
   - ✓ There is a high concentration gradient of gases maintained by ventilation and extensive capillary network.
   - ✓ Lungs have numerous alveoli which provide a large surface are for gaseous exchange.
   - ✓ The alveoli and capillary walls are one cell thick to minimize the diffusion distance of respiratory gases.
   - ✓ The epithelial cells of the lungs are flattened to provide a large surface area over which diffusion can occur
   - ✓ Air is warmed as it passes through the nostrils, to increase diffusion rate.
2. **Plasma membrane of leaf, stem and root cells; mesophyll, cortex and lenticels.**
   - ✓ Root hairs lack cuticle and are moist to facilitate rapid diffusion of gases through it.
   - ✓ Root hairs are numerous to increase the surface area for gaseous exchange.
   - ✓ The cortical air spaces are continuous up and down and laterally allowing transport of gases through the stem and root tissues.
   - ✓ The lenticels consist of loosely packed cells at the opening to enable diffusion of respiratory gases.

- ✓ Opening and closing of the stomata allows maintenance of a concentration gradient of carbon dioxide and oxygen enhancing gas exchange.
- ✓ Large intercellular air spaces in the spongy mesophyll are reservoirs for respiratory gases maintaining their concentration gradient high.

3. **Tracheoles in insects;**
   - ✓ Tracheae are highly branched to form tracheoles that reach every cell enhancing efficient ventilation.
   - ✓ Tracheae are impermeable to gases thus maintain a high diffusion gradient in air that reaches the tracheoles.
   - ✓ Tracheae are kept open to enable continual air movements to reach and leave tracheoles.
   - ✓ Tracheoles are moist to enable dissolution of respiratory gases increasing their diffusion.

NOTE:

You should note that the adaptations of all the respiratory surfaces are based on how best it can;

- Transport respiratory gases
- Dissolve respiratory gases
- Obtain respiratory gases
- Exchange respiratory gases.

COMPARISON OF AIR AND WATER AS RESPIRATORY MEDIA

- Air is much richer in oxygen than water, therefore much less volume of air is required to pass over the respiratory surface to satisfy the oxygen demands of the organism, but too much water is required to pass over the respiratory surface to enable the organism to extract oxygen to satisfy the oxygen demands. Therefore, air is suitable for much active animals while water is suitable for less active animals.
- Air has much lower density and is less viscous than water, therefore much less energy is needed to move air through the respiratory system than is required for water.
- Air is suitable for organisms without ventilation mechanisms like plants while water requires an actively operated ventilation mechanism like fish. Air is also suitable for much active animals like insects while water is suitable for less active animals like toads.
- Air has a dehydrating effect on surfaces which slows gaseous diffusion, hence gas exchange surfaces must be folded into the body to reduce water loss. Air is not suitable for organisms whose gaseous exchange surfaces are exposed e.g. skin of frogs, external gills of tadpoles.
- Slight temperature increase causes oxygen to diffuse out of water hence causing anoxic conditions while oxygen in air remains relatively stable.
- Water's high density supports and prevents collapse of respiratory structures like gills lamellae while alveolar sacs collapse in absence of lung surfactants.
- Unidirectional water flow during ventilation in aquatic animals like bony fish is energetically less costly than tidal ventilation in lungs of land animals.
- Countercurrent flow of water with respect to blood flow over gill lamellae in bony fish improves oxygen extraction efficiency compared to non-directional ventilation of toads with air.
- Carbon dioxide is highly soluble in water, therefore it is easier to eliminate Carbon dioxide in water than in air. Oxygen is 30 time less soluble in water than in air, making water dwelling unfavourable for metabolically very active organisms.

MECHANISMS OF GASEOUS EXCHANGE
GASEOUS EXCHANGE IN PLANTS

Like we saw earlier that plants do not have a specialized transport system as diffusion alone could meet their metabolic demands, we are going to appreciate that they still don't have a specialized gaseous exchange system because;

- Each plant part takes care of its own gas exchange needs without dependence on a liquid transport system.
- Roots, stems, and leaves respire at rates much slower than occurs in animals. Only during photosynthesis are large volumes of gases exchanged, and each leaf is well adapted to take care of its own needs.
- The diffusion distance for gases is very short, even in a large plant because each living cell in the plant is located close to the surface. In stems, middle placed cells are dead while the only living cells are organized in thin layers just beneath the bark.
- The loose packing of parenchyma cells in leaves, stems, and roots provides an interconnecting system of air spaces which exposes one surface of most of the living cells in a plant to air.
- Both the cell walls and plasma membranes are permeable to oxygen and carbon dioxide, enabling diffusion of the gases across.

Mechanism;

- In plants gases; carbon dioxide and oxygen enter mainly through the lenticels in the stem; areas of loosely packed bark cells which form pores between the atmosphere and the cambium layer and through the stomata found in the leaves epidermis and in young plant stems. These can open and close to allow gaseous entry and exit.
- Gases diffuse through the stomata and lenticels.
- Within the plant oxygen moves through the intercellular air spaces to the respiring cells.
- Carbon dioxide moves in the reverse direction.

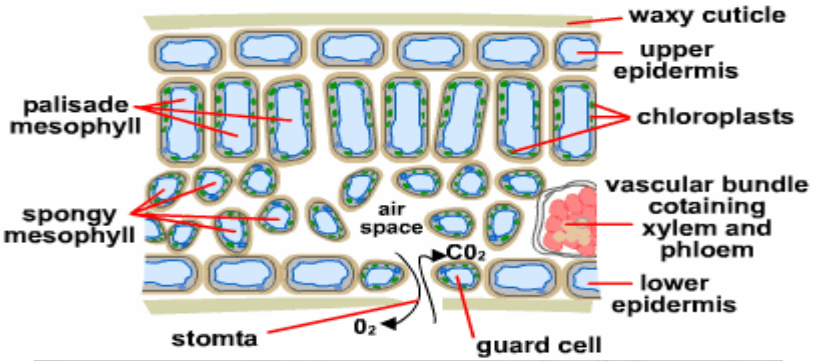
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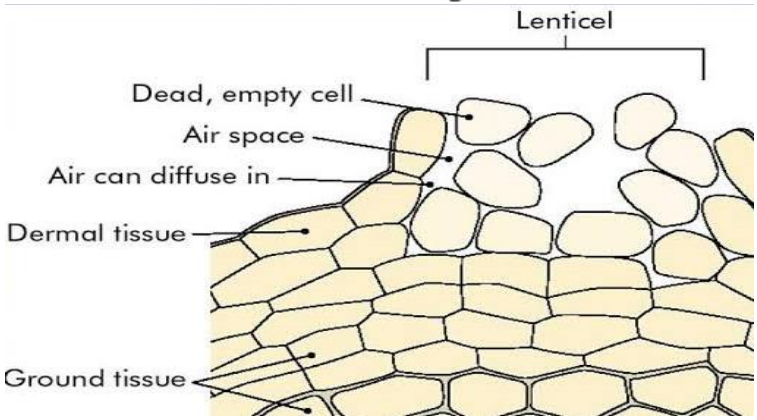
1. Gaseous exchange will occur highly when the stomata are open. It opens and closes according to the following periods.

- Stomatal aperture remains tightly closed from midnight to 3am, after which there is slight opening by 6am. Stomatal aperture then gradually opens up until becoming maximally wide at 9am, narrow by 12 noon, widely open by 3pm, and then progressively decreases through 6pm, 9pm until becoming tightly closed by midnight.

2. Roots;

- Dissolved oxygen from soil air diffuses through the loosely attached dead cork cells where there are pores; lenticels.
- On reaching the inner tissues, oxygen diffuses across the permeable membranes into the protoplasm while carbon dioxide diffuses from respiring cells into the intercellular air spaces through the lenticels and finally into the soil.





Differences between stomata and lenticels

stomata	Lenticels
Open based on plant requirements	Remain open
Have guard cells that determine their size	Lack guard cells
Transpire a lot of water vapour	Transpire less water vapour
Mainly occur in the epidermis of the leaf	Occur in the peridermis of the woody trunk or stem
Occur during primary growth	Occur during secondary growth

Adaptations of plants to gaseous exchange;

1. Internally, stems of hydrophytes have large intercellular / air spaces / aerenchymatous tissue to accommodate much air which increases concentration gradient for faster diffusion of gases.
2. Black Mangroves which live in oxygen deficient mud have pneumatophores (breathing roots projecting up) with air filled spongy tissue connected to lenticels (pits) for faster diffusion of oxygen to all cells.
3. Mangroves which live in oxygen deficient mud water have relatively short roots to remain in close to oxygen rich mud surface to avoid the oxygen deficient deeper layers of mud.
4. Red Mangroves which live in oxygen deficient mud have air-rich pneumatophores in prop roots to supplement the oxygen uptake.
5. Stems of submerged plants have little or no cuticle to reduce the barrier for gas diffusion.
6. Stems of hydrophytes have large air spaces to enable floating to expose leaves above water for access to atmospheric air.
7. Some aquatic plants elongate stems to enable stomata access atmospheric air for gaseous exchange.
8. Spongy mesophyll cells are loosely packed to accommodate much air which increases the concentration gradient of gases to enable faster diffusion.

9. Spongy mesophyll cells are covered by a thin film of water to dissolve respiratory gases to enable faster diffusion.
10. Palisade mesophyll cells are tightly packed with thin walls to reduce diffusion distance.
11. Differences in thickness of guard cell walls enables the thin outer wall to bulge out and force the thicker inner wall into a crescent shape to open stomata when full turgor develops while regaining of shape when guard cells lose turgor causes stomatal aperture to close.
12. Floating leaves e.g. water lilies generally lack stomata in lower epidermis but very many stomata in the upper epidermis to maximize gas exchange with air at the upper surface.
13. Leaves of hydrophytes have very thin or no cuticle to reduce or prevent any barrier to the diffusion of gases into the leaves.
14. In land plants, stomata are spread out over leaves, to increase the rate of diffusion of waste gases produced by the leaf, which stops the build-up of excreted products that would slow gas exchange.
15. Leaves have a very large surface area, which increases diffusion rate of gases.
16. Sunken in stomata and sub stomatal spaces enable leaves to minimize stomatal transpiration while maintaining gaseous exchange.
17. Some plants e.g. water lilies have elongated petioles to enable lamina maintain access to atmospheric air for gaseous exchange.

GASEOUS EXCHANGE IN SMALL ORGANISMS

- Small organisms have a large surface area to volume ratio and do not require specialized structures for gaseous exchange.
- In unicellular organisms such as protozoa e.g. amoeba, the medium of gas exchange is fresh water and the gas exchange surface is the whole body
- Along their concentration gradients, dissolved oxygen diffuses from the water across the permeable plasma membrane into the cytoplasm while dissolved carbon dioxide diffuses into water.
- In filamentous algae, the medium of gas exchange is fresh water and gas exchange occurs across the plasma membrane by diffusion. In the dark no photosynthesis occurs in the chloroplast, no oxygen is made.
- Dissolved oxygen diffuses from the water across the cell membrane into the mitochondria while dissolved carbon dioxide diffuses into water, along their concentration gradients. In the light, photosynthesis in chloroplasts releases oxygen, some of which diffuses into the mitochondria, the excess diffuses out.

GASEOUS EXCHANGE IN EARTHWORMS

- Earthworms exchange oxygen and carbon dioxide with water or air directly through their moist skin.
- Dissolved oxygen diffuses into tiny blood vessels under the skin surface, where it loosely combines with haemoglobin that moves it through bloodstream to tissues. Carbon dioxide released by tissues attaches to haemoglobin then detaches to diffuse out of the skin. This is efficient because;
- Earthworms have low metabolic rate, therefore require relatively low oxygen supply for aerobic respiration.
- Moist surface with dense network of blood capillaries under the skin enable efficient gas exchange between air and blood.

- Earthworm circulatory system contains haemoglobin in blood to increases the oxygen carrying capacity of blood.
- Long, thin body provides large surface area compared to body size, efficient for gas exchange.
- Blood capillaries are very close to the skin surface to reduce the diffusion distance for gases.

GASEOUS EXCHANGE IN ANIMALS

Most animals have a specialised gaseous exchange system because;

- ✓ Animal bodies are large with a small surface area to volume ratio, which limits the efficiency of diffusion alone in supplying oxygen and exit of carbon dioxide.
- ✓ Outermost integuments/ protective layers of most parts on animal bodies are impermeable to respiratory gases.
- ✓ Animal bodies are active therefore depend on fast metabolic rates to supply metabolites, which necessitates fast mechanisms for supplying oxygen and disposal of carbon dioxide.
- ✓ Animal tissues are thickened layers of cells, for which diffusion alone would be ineffective for exchange of gases.

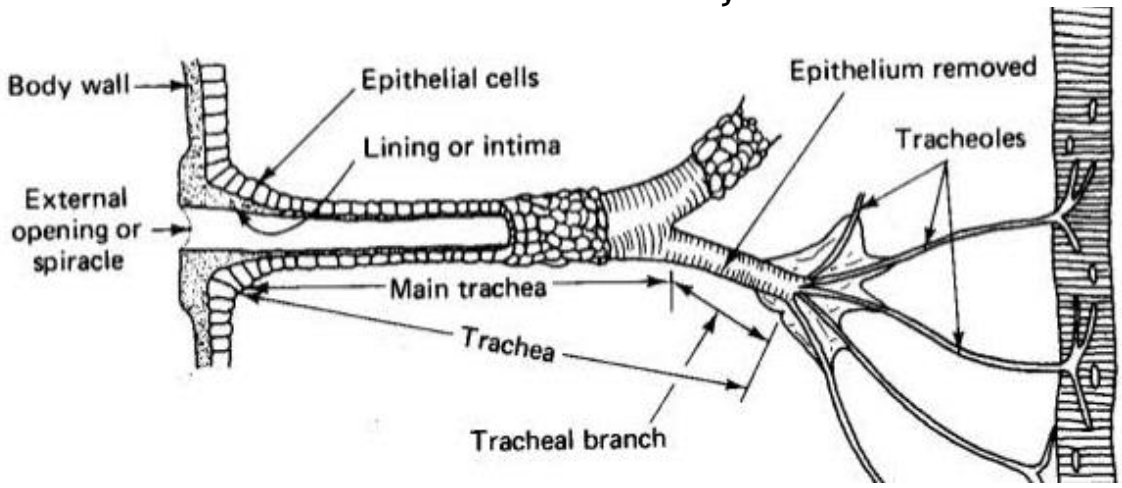
GASEOUS EXCHANGE MECHANISM IN INSECTS

For insects, diffusion of gases over the whole body is not possible. This is because they are predominantly a terrestrial group and need to conserve water.
This they do by having an exo skeleton and waterproof cuticle which are largely impermeable to gases.

Tracheal system of an insect

- Gases enter and leave through pores called spiracles. Spiracles occur in pairs in ten of the body segments located on the lateral sides of the body. Of these, two pairs are thoracic and eight are abdominal.
- Each spiracle is surrounded by fine hairs, which retain water vapour and as well prevent entry of foreign bodies.
- The spiracles are opened and closed by valves operated by tiny muscles.
- The spiracles open into a series of tubes; the tracheae that run throughout the body.
- The tracheae are fine tubes that have a wall of single layered epithelial cells. The trachea are supported by spiral rings of chitin secreted by the epithelial cells these prevent the tracheae from collapsing when the pressure inside the insect falls.
- The tracheae divide to form smaller tracheoles extending into all the tissues.
- The ends of the fine tracheoles are fluid filled and lack cuticular thickening.
- In larger insects such as locusts and grass hoppers the trachea enlarge to form air sacs.

Illustration of the tracheal system



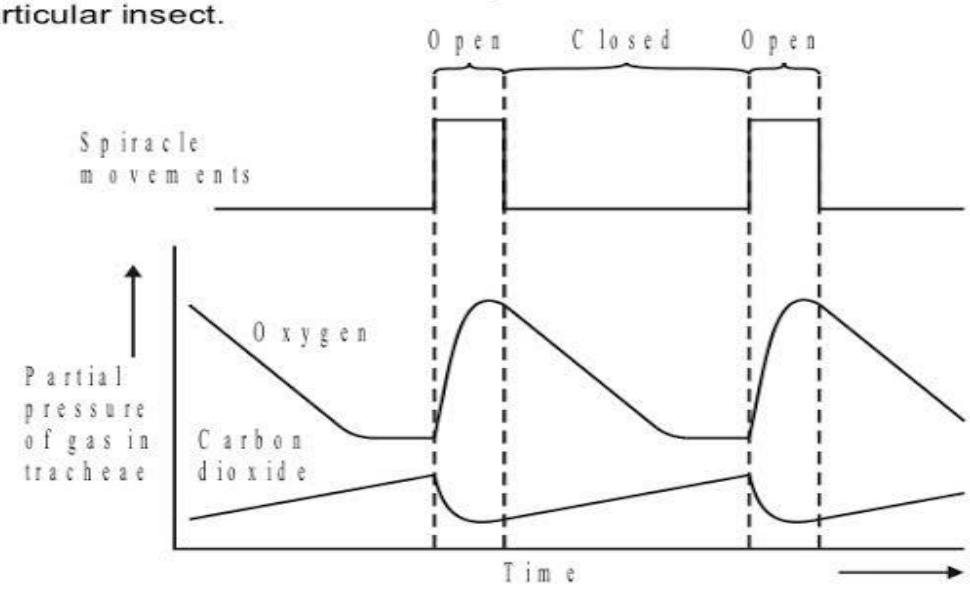
Mechanism of gaseous exchange;

- Increase in carbon dioxide concentration in tissue fluid is detected by the chemoreceptors which cause the relaxation of abdominal muscles increasing the volume and lowering the pressure in the tracheal system
- The spiracle valves open and air rich in oxygen is drawn into the tracheal system.
- Spiracle valves then close and oxygen is forced along the tracheal system into the fluid filled tracheoles which are in direct contact with the tissue fluid. Gaseous exchange occurs along the concentration gradient. Carbon dioxide is expelled out when the muscles contract and flatten the insect body decreasing the tracheal volume.
- Presence of oxygen in the cells this causes the insects to have high metabolic rates.
- As activity increases the muscles respire anaerobically and lactic acid accumulates.
- This raises the solute concentration of the cells above those of that of the fluid in the tracheoles.
- Water therefore moves out of the tracheoles into the muscle cells by osmosis. As water is lost, air is drawn further into the tracheoles, making more oxygen available for cellular respiration.
- When activity lowers or ceases the metabolites are oxidized, solute concentration of the muscle-cells is lowered and water re-enters the tracheoles.
- When water leaves body cells to fill the trachea, it reduces water's effective surface area when asleep or dormant hence reducing chances of evaporation because the spiracle valves will be closed.
- In some insects like grasshopper, there is a one-way flow of air, which increases the efficiency of gas exchange as carbon dioxide enriched air can be expelled without mingling with the incoming flow of fresh air.

OPENING AND CLOSING RHYTHM OF THE SPIRACLE VALVES IN INSECTS

Spiracle valves are opened and closed in a particular order which allows the insect to suck air into the tracheal system at one end of the body and to circulate the air through the system and pass it out at the other end of the body.
However longer spiracle closure period conserves water because water vapour does not diffuse out continually and are thus required by the insect.

Many insects release carbon dioxide in short bursts even though they produce it at a constant rate. The diagram shows how this is achieved in one particular insect.



Description;

- ✓ When spiracles are open the level of oxygen in the tracheae increases rapidly to a maximum this is because opening of spiracles enables rapid entry of oxygen until the tracheae fill up. This is due to relaxation of abdominal muscles which increases abdominal volume while abdominal pressure decreases below atmospheric pressure.
- ✓ While when the spiracles open, the level of carbon dioxide decreases rapidly this is because opening of spiracles enables rapid exit of carbon dioxide from tracheae along a concentration gradient.
- ✓ When spiracles close the level of oxygen immediately decreases rapidly and thereafter remains constant this is because when spiracles close, oxygen rapidly diffuses along a concentration gradient into respiring cells until the gradient can no longer allow any more diffusion into cells hence oxygen level in the tracheae later remains constant.
- ✓ Closing the spiracles causes the level of carbon dioxide to increases gradually this is because when spiracles close carbon dioxide gradually diffuses along a concentration gradient from respiring cells into the closed tracheae.

GASEOUS EXCHANGE IN AMPHIBIANS

Common amphibians are the frogs and toads. In these, gaseous exchange takes place in three main parts of the body:

Lung gaseous exchange;

- Amphibians force air into their lungs by creating a greater than atmospheric pressure in the air outside their lungs. In this;
- Frogs gulp air into the mouth, then close the mouth and nostrils, and raise the floor of the mouth upwards to decrease volume of mouth cavity and increase pressure in the mouth cavity higher than atmospheric pressure.

It is achieved in the following way;

During inhalation;

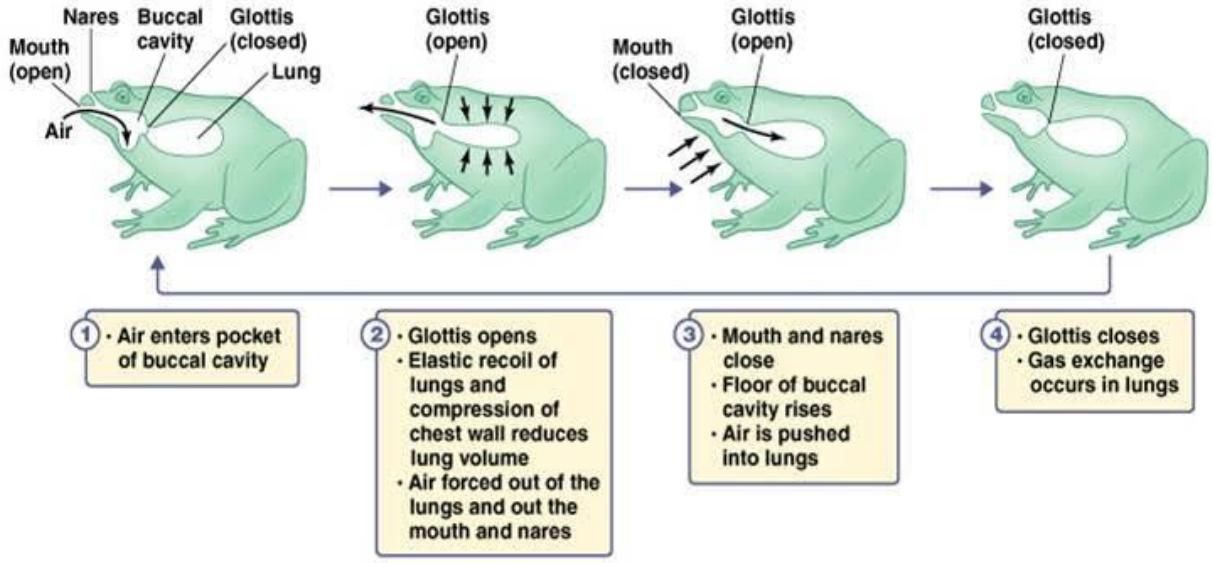
- Mouth and glottis close while nostrils open. The sternohyoid muscles contract while the petrohyoid muscles relax.
- Floor of the buccal cavity lowers to increase the buccal cavity volume and decrease the buccal pressure below that of the atmosphere pressure. This causes air to be drawn into the buccal cavity via the open nostrils.
- Nostrils close, then the floor of the buccal cavity is raised by simultaneous contraction of petrohyoid and relaxation of sternohyoid muscles this decreases the buccal volume and increases the buccal pressure above atmospheric pressure which forces air into the lungs via the open glottis.
- Oxygen then diffuses into lung capillaries along concentration gradient while carbon dioxide diffuses from the lung capillaries into the alveolus.

During exhalation;

- Sternohyoid muscles contract while the petrohyoid muscles relax.
- Floor of the buccal cavity lowers to increase buccal volume and decrease buccal pressure below that of the lung pressure.
- Air rich in carbon dioxide from lungs is forced out into the buccal cavity through the glottis and simultaneously atmospheric pressure enters the buccal cavity via external nostrils.
- In this the buccal cavity receives mixed air which is again pushed into the lungs.

- Due to this inefficiency there is need to supplement with the other mechanisms below

Summary of events above



Cutaneous/ skin gaseous exchange

- Oxygen from atmospheric air dissolves in moisture / mucus at the outer skin surface, then diffuses through the thin skin into the underlying dense capillary network while carbon dioxide diffuses out of the skin.
- This due to the great moisture on the skin

Mouth/ Buccal cavity gaseous exchange

- The muscles of the mouth contract to lower the surface of the mouth hence reducing its pressure than that of the atmosphere.
- Air rich in oxygen is inhaled through the nostrils into the mouth cavity. Oxygen diffuses into the dense capillary network under the buccal cavity lining and is transported by the red blood cells.
- Carbon dioxide diffuses from the blood tissues to the buccal cavity; then exhaled through the nostrils when the mouth floor is raised.

Note; many cases all the above mechanisms may be employed in its habitat however during hibernation they solely depend on the skin gaseous exchange in order to minimize the energy output.

GASEOUS EXCHANGE MECHANISMS IN FISH

There are two categories of fish whose gaseous exchange is to be discusses; bony fish and cartilaginous fish.

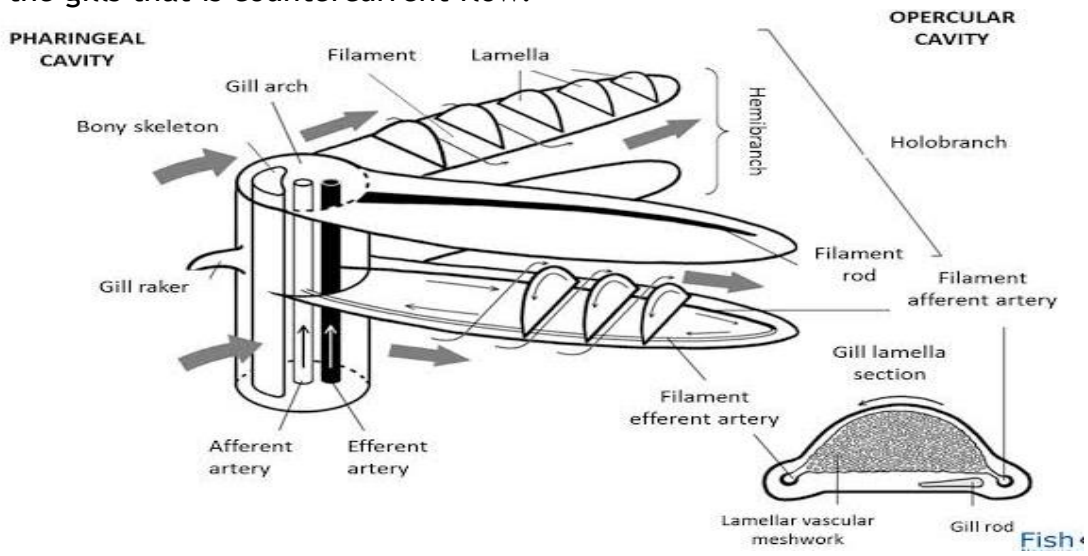
In fish gaseous exchange takes place at the gill lamellae.

BONY FISH

Structure of the gills.

- Bony fish have four pairs of bony branchial arches supporting gill filaments.
- These filaments form a double row arranged in V-shape and bear gill plates at right angles to their surface.
- Each filament; primary lamella is covered with rows of secondary lamellae perpendicular to filament
- Each gill arch contains an afferent and efferent artery.
- Afferent blood vessels carry deoxygenated blood to the capillaries in the secondary lamellae.

- Efferent blood vessels carry oxygenated blood from the capillaries back to the gill arch.
- Secondary lamellae are semicircular, thin-walled and highly vascularized with capillaries.
- Blood flow through capillaries in secondary lamellae is opposite the flow of water through the gills that is countercurrent flow.



Gill slits are covered by a bony flap called operculum.

Mechanism;

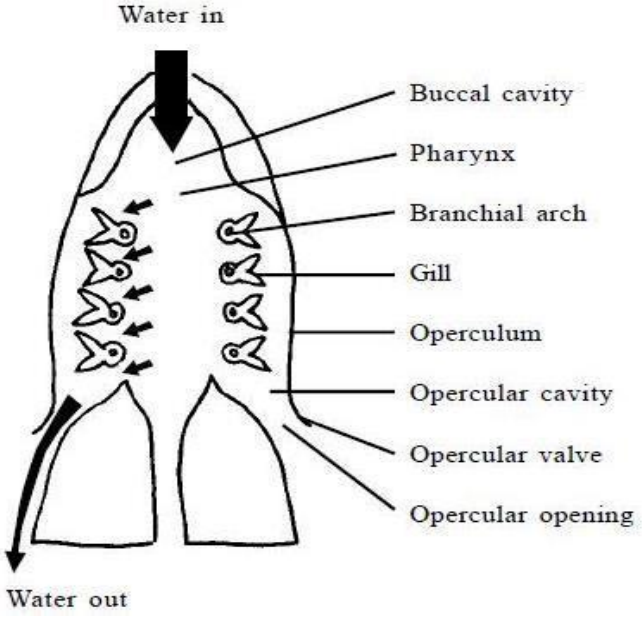
During inhalation;

- Contraction of the mouth muscles lowers the floor of the mouth, increasing buccal cavity volume and pressure decreases buccal pressure below that of the surrounding water.
- Water rushes to fill the buccal cavity, and at the same time, water's pressure outside presses against and closes opercular valves.
- Operculum muscles contract; causing operculum to bulge and increase opercular volume but decreases opercular cavity pressure.
- Mouth muscles contracts to decrease buccal cavity volume while increasing buccal pressure, which forces or sucks water into opercular cavity which is at lower pressure.
- As water flows over gill filaments in opposite direction to flow of blood, oxygen diffuses into blood capillaries to combine with haemoglobin while carbon dioxide diffuse into the flowing water along concentration gradients.

During exhalation

- Mouth muscles are fully contracted with mouth valve tightly closed. This increases the buccal pressure as volume decreases.
- Opercular muscles relax to decrease opercular cavity volume and increase pressure.
- Pressured water in opercular cavity forces opercular valves to open and water exits.

Horizontal section through the gills and pharynx



PRESSURE CHANGES IN BUCCAL AND OPERCULAR CAVITY OF BONY FISH DURING VENTILATION

Fig 1

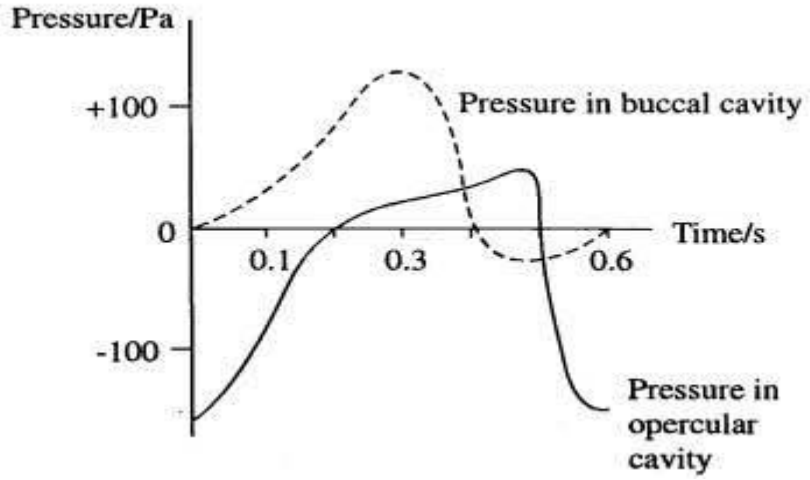
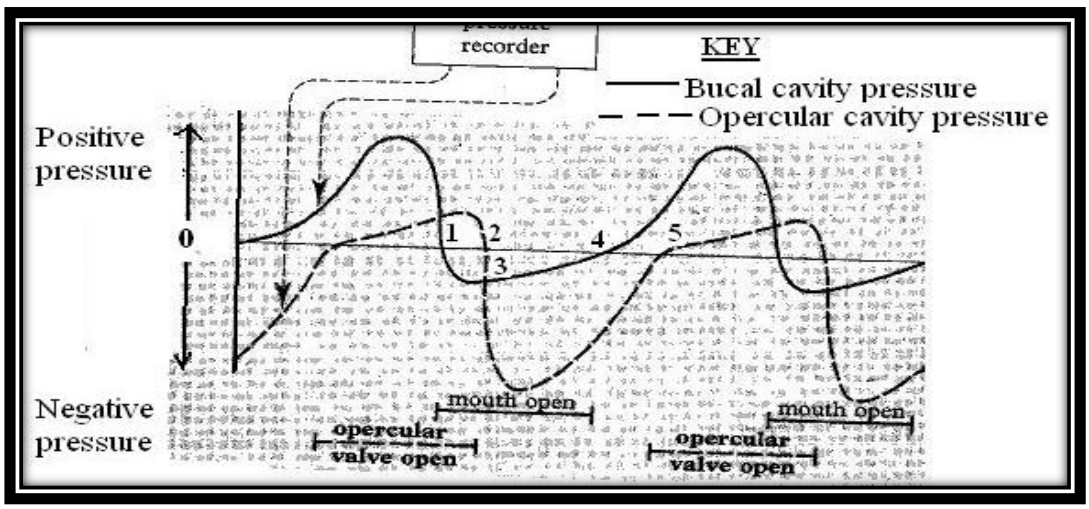


fig2



From fig 1 you can appreciate that water flows in one direction because;

- Throughout the ventilation cycle, except for one short period when the buccal cavity expands, the pressure in the buccal cavity is higher than that in the opercular cavity forcing water to flow from the buccal cavity to the opercular cavity along the pressure gradient. Expansion of buccal cavity lowers the pressure below atmospheric pressure, causing the water to enter the buccal cavity but at the same time the opercular valves close to prevent entry of water.

From fig 2

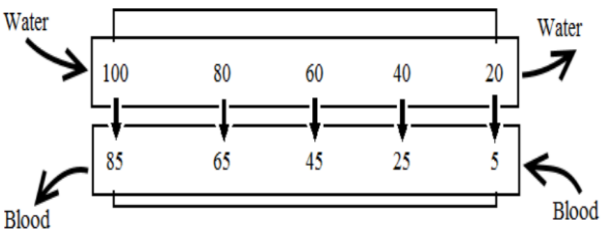
- At 1, the buccal cavity is expanding, the pressure reduces and falls below atmospheric pressure (acquires negative pressure); mouth valve opens and water enters from outside.
- At 2, opercular cavity is expanding, pressure reduces below atmospheric pressure (acquires negative pressure); opercular valve closes.
- At 3, buccal cavity begins to contract, volume gradually decreases as pressure gradually increases while expansion of opercular cavity increases the volume further as pressure decreases further to fall below buccal cavity pressure, resulting in water being sucked into opercular cavity from buccal cavity.
- At 4, buccal cavity pressure increases above atmospheric pressure (acquires positive pressure); mouth valve closes and water flows along the pressure gradient from buccal cavity to opercular cavity.
- At 5, opercular cavity is contracting to decrease the volume as pressure increases above atmospheric pressure (acquires positive pressure); opercular valve opens and water is expelled

Note:

1. Positive pressure; refers to actively creating a positive; increased pressure in the breathing apparatus higher than atmospheric pressure, to establish the air pressure gradient.
2. Negative pressure; refers to actively creating a negative; decreased pressure in the breathing apparatus lower than atmospheric pressure, to establish the air pressure gradient
3. The pressure in the buccal cavity is higher than that in the opercular cavity in order to force water to flow in one direction from the buccal cavity to the opercular cavity along the pressure gradient.
4. Expansion of opercular cavity lowers the pressure below that of buccal cavity, causing the water to flow over gills in the opercular cavity but at the same time the opercular valves close to prevent entry of water.
5. The buccal cavity acts as a force pump while the opercular cavity as a suction pump

COUNTER CURRENT VENTILATION SYSTEM

- This is a system in which water flows across the gill lamellae in an opposite direction to the blood flow, enabling much of the oxygen (80-90%) from the water diffusing into the blood.



- Although dissolved oxygen levels in water drop as the water flows across the gill lamellae, the blood has lower levels; therefore a sustained diffusion gradient is maintained throughout.
- Countercurrent flow maintains high oxygen gradient between water and blood, such that oxygen diffusion into blood occurs even after blood acquires more than 50% of the water's oxygen content

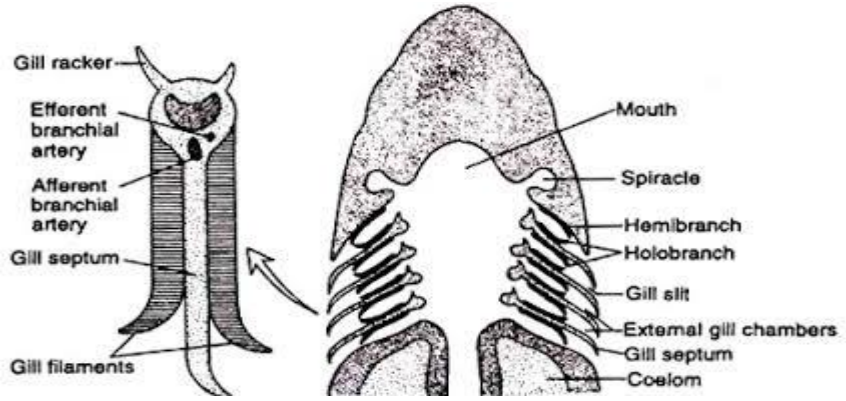
Advantages/ efficiency of counter current system

- Enables blood of the gill lamellae to extract maximum oxygen from the water (80-90%) for the entire period the water flows across the gill filaments.
- Although dissolved oxygen levels in water drop as the water flows across the gill lamellae, the blood has lower levels; therefore a sustained diffusion gradient is maintained throughout. This is because, the gradient is always such that the water has more available oxygen than the blood, and oxygen diffusion continues to take place after the blood has acquired more than 50% of the water's oxygen content.
- Under conditions permitting adequate oxygen uptake, the counter-current fish uses low energy in respiration.

GASEOUS EXCHANGE IN CARTILAGINOUS FISH

- Cartilaginous fish lack the opercular cavities but have parabranchial cavities enclosed by flap like branchial valves.
- The gills are supported by a series of skeletal branchial arches which are separated from one another by gill pouches through which water flows on its way over the respiratory surfaces.
- At the base of each gill, close to gill arch, is an afferent branchial artery which brings deoxygenated blood to the gill from the ventral aorta beneath the floor of the pharynx.
- The base also contains a pair of efferent branchial arteries, each derived from a loop vessel encircling the pouches on either side of the gill.
- An epibranchial artery conveys blood from each efferent loop to the dorsal aorta above the roof of the pharynx.

Diagram of a cartilaginous fish gill



Mechanism;

During inspiration;

- Water with dissolved oxygen is drawn through the open mouth and spiracles into the pharynx which is expanded as a result of contraction of hypobranchial muscles and relaxation of transverse muscles.
- Then it is drawn into parabranchial cavities by out ward movement branchial valves. It flows over gills in a parallel system and gaseous exchange takes place.
- This takes place as blood flows through the capillaries in the gill plates. The barrier between the blood and water is only several cells thick and offer little resistance to diffusion.

During expiration;

- Water containing carbon dioxide is expelled from the gill pouches by raising the floor of the mouth cavity and pharynx.
- This is brought by relaxation of hypobranchial muscles, contraction of transverse muscles and mouth plus spiracles closed.

N.B

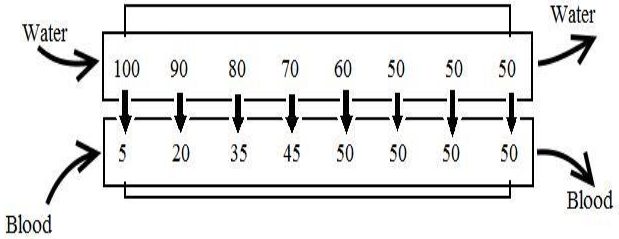
1.

In these fish water and blood flow in the same direction a phenomenon called parallel flow.

2. The vertical septum deflects the water so that it tends to pass over rather than between the gill plates, hence flowing parallel to the lamellae through the gill pouches in so doing counter current flow is prevented.

PARALLEL FLOW SYSTEM

- In this, blood in the gill lamellae flows in the same direction and at the same speed as the water passing it, resulting in only half (50%) of the available oxygen from the water diffusing into blood.
    - The blood and water reach equilibrium in oxygen content and diffusion stops.
    - During parallel flow, initially large amounts of oxygen diffuse but the efficiency reduces when the fluids start to reach equilibrium.
- The concentration of oxygen gained from this system does not meet the physiological needs of the fish.



Comparison between gaseous exchange mechanism in a bony fish and cartilaginous fish

Similarities; in both;

- The respiratory medium is water
- Gills are the gas exchange organs and gas exchange occurs at the gill plates.
- Entry of water during inspiration is via the mouth
- There is a ventilation mechanism ensuring continuous flow of water over the gills.

Differences;

Cartilaginous fish		**Bony fish**
Ventilation is by adjustments in the buccal cavity and pharynx		Ventilation is by adjustment in the buccal pharyngeal and opercular cavities
During inspiration water enters through the spiracles and mouth		Water enters through the mouth only
During expiration exit of water is via gill slits enclosed by the branchial valves		During expiration exit of water is via the opercular valves
They employ a parallel flow mechanism between water and blood		They employ a counter current flow mechanism between water and blood

Note: <u>when fish is removed from water it immediately suffocates may die because;</u>

- ✓ Their gill lamellae collapse and there is not enough surface area for diffusion to take place and the gill lamellae surface dries and oxygen in air fails to dissolve and diffuse into blood.

GASEOUS EXCHANGE IN LUNG FISH

These belong to the order Dipnoi and an example is *Protopterus anthiopiann*. They have two lungs and these organs are used for exchange of gases directly with air when the fish is aestivating during dry season.

These fish can also use gills when there is enough water.

GASEOUS EXCHANGE IN BIRDS

Birds' lungs do not have alveoli and are extensible. They have air sacs some of which extend into the bones. There is no gaseous exchange in the air sacs but their presence improves greatly the rate of ventilation, they also offer lightness to the bird.

During inspiration

- There is lowering of the sternum, expansion of the chest and lungs.
- The lungs diminish in volume and air is expelled from the lungs into the air sacs.

During expiration

- There is raising of the sternum, contraction of abdominal air sacs and then the air is sent into the bronchi and then the capillary bronchioles in the lungs and then outside the body.

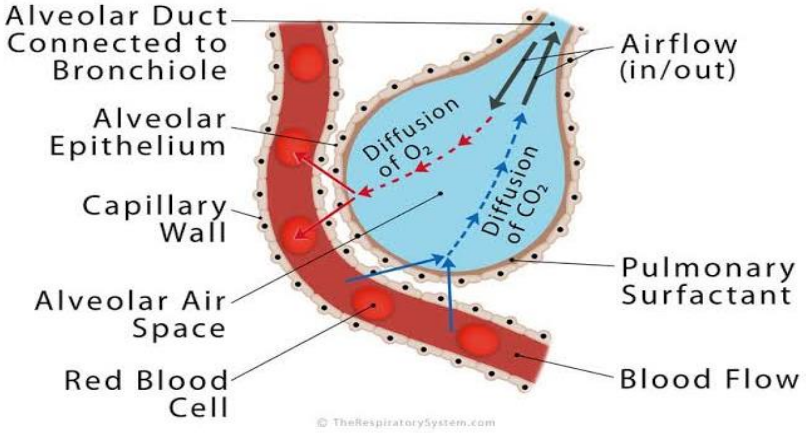
GASEOUS EXCHANGE IN MAMMALS; HUMAN BEINGS

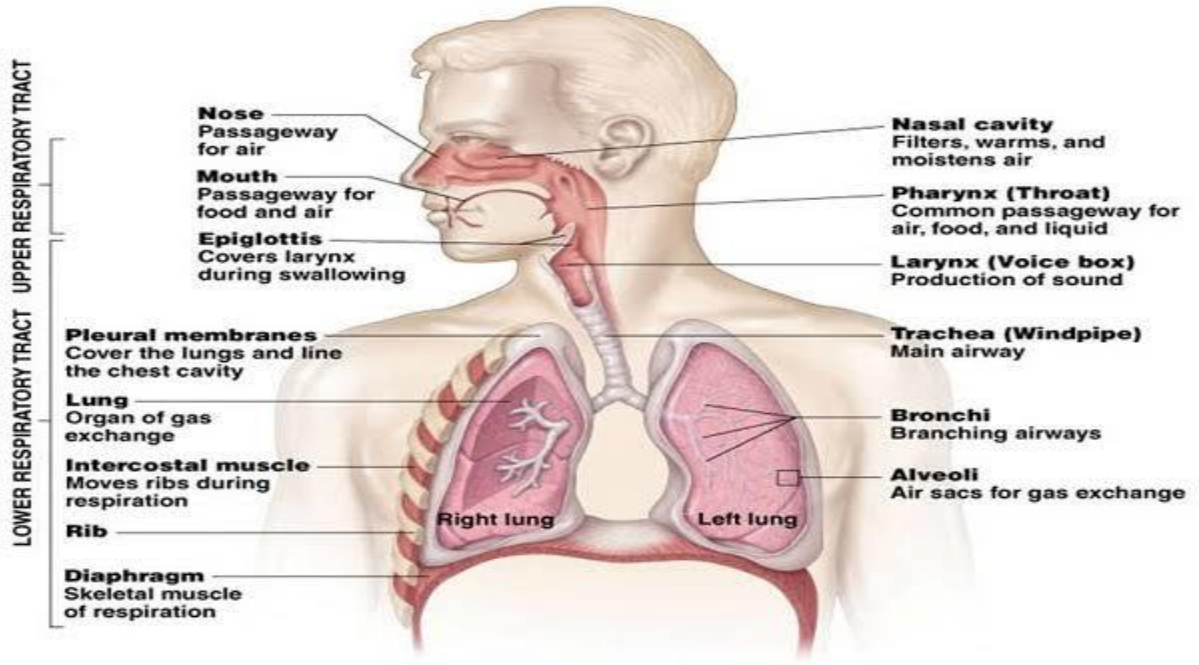
Lungs are the structures of gaseous exchange

RESPIRATORY TRACT

- Air flow in humans is tidal; air entering and leaving along the same route. It enters the nostrils and mouth and passes down the trachea.
- The trachea is also known as the wind pipe and its held open without collapsing by cartilaginous rings. It has inner epithelium that is ciliated, have goblet cells that secrete mucus and has connective tissue made of elastic and collagen fibres.
- From the trachea it enters the lungs via two bronchi which divide into bronchioles and end in air sacs/ alveoli.
- The lungs are found inside the thorax of the body and so efficient ventilation is essential.
- The lungs are delicate structures and together with the heart are enclosed in a protective bony case the rib cage.
- The lungs are a pair of spongy and elastic and thus are capable of expanding and relaxing, they consist of air sacs and alveoli, have blood vessels that are branches of pulmonary artery and vein.
- Each lung is enclosed by two membranes; the outer and the inner pleural membrane. The membranes enclose a space called the pleural cavity that contains fluid that lubricates free lung movement.
- The alveolar ducts and alveoli sacs lack cartilage, are non-ciliated and lack goblet cells. They have a connective tissue with elastic and collagen fibres.
- The alveoli lack cartilage, are non-ciliated and lack goblet cells. They are made of squamous epithelium with liquid surfactant on the inner surface and blood capillaries on the outer surface.

Functioning of the alveoli





For illustration check;
Understanding biology page 400 fig 20.6 and Functional approach page 113
Adaptations of the alveoli

- An average adult has about 600 million alveoli, giving a total surface area of about 100m^2, so the area is large enough.
- The walls of the alveoli are composed of a single layer of flattened epithelial cells, as are the walls of the capillaries, so gases need to diffuse through just two thin cells.
- The alveoli walls are kept moist by water diffusing from the surrounding cells. Oxygen dissolves in this water before diffusing through the cells into the plasma, where it is taken up by haemoglobin in the red blood cells. The water also contains a soapy surfactant which reduces its surface tension and stops the alveoli collapsing.
- The alveoli also contain phagocytes to kill any bacteria that have not been trapped by the mucus.
- The steep concentration gradient across the alveoli wall is maintained by blood flow on one side and by air flow on the other side. This means that oxygen can diffuse down its concentration gradient from the air to the blood, while at the same time carbon dioxide can diffuse down its concentration gradient from the blood to the air.

LUNG SURFACTANT

Lung surfactant is a soapy/ detergent like substance formed by the alveolar cells, which adsorbs to the air-water interface of the alveoli with the hydrophilic head groups in the water and the hydrophobic tails facing towards air.

Functions of the surfactant;

- ✓ It reduces alveolar surface tension thus increasing the ability of the lungs to expand; lung inflation; compliance in this the effort needed to breathe in is reduced.
- ✓ It lowers pressure when the alveoli is small and thus stabilizes it and prevents it from collapsing.
- ✓ It kills bacteria that reach the alveoli.

- ✓ It speeds up the rate of diffusion of gases between the air and the liquid lining of the alveoli.

Mechanism of gaseous exchange;

- The flow of air in and out of the alveoli is called ventilation and has two stages: inspiration or inhalation and expiration or exhalation.
- Lungs are not muscular and cannot ventilate themselves, but instead the whole thorax moves and changes size, due to the action of two sets of muscles: the
- Intercostal muscles and the diaphragm which is a muscular sheet that separates the thorax from the abdomen.

During inspiration; this is an active process;

- In order for air to enter lungs from the exterior, the pressure inside the lungs must be lower than that of the atmosphere and this is brought about due to the following;
- The external intercostal muscles contract while the intercostal muscles relax at the same time causing the rib cage move upwards and outwards.
- The diaphragm muscle contract and flatten.
- These movements increase the volume of the thoracic cavity and lung volume.
- Alveolar lung pressure decreases blow atmospheric pressure causing air to rush into lungs through the nostrils, into nasal passages, pharynx, larynx, trachea, main bronchi, bronchioles, alveolar ducts and into alveoli.
- Air dissolves in the moisture lining the alveolar epithelium, oxygen then diffuses into blood capillaries while carbon dioxide diffuses from capillaries into alveolar air along the concentration gradients.

During expiration; passive process;

- Internal intercostal muscles contract while external intercostal muscles relax causing the rib cage to move downwards and inwards.
- Diaphragm muscles relax to move upwards and assume a dome shape.
- The volume of thoracic cavity and lungs decreases causing lung pressure above atmospheric pressure.
- Carbon dioxide rich air but with low oxygen is then forced out of the lungs.

COMPOSITION OF INSPIRED AND EXPIRED AIR

GAS	PERCENTAGE BY VOLUME		
	Inspired air	**Alveolar air**	**Expired air**
Oxygen	20.95	13.8	16.40
Nitrogen	79.01	80.70	74.60
Carbon dioxide	0.04	5.5	4.0
Water vapour	0.47	No available data	6.20

- ❖ From the table it can be observed that inspired air contains a high volume of oxygen than expired air because inspired is rich in oxygen released by plants during photosynthesis. On entering the alveoli, some of the oxygen of the diffuse into blood capillaries along a diffusion gradient for use in respiration.
- ❖ Exhaled air contains a higher percentage by volume of carbon dioxide than inhaled air because tissue respiration forms carbon dioxide some of which diffuses into alveolar air and expelled during exhalation.
- ❖ The percentage volume of oxygen and carbon dioxide in expired air is intermediate between the inspired and alveolar values this is because some of the oxygen in alveolar air diffuses into blood capillaries while carbon dioxide from blood diffuses into alveolar air. The air that remains in the alveoli mixes with the fresh air in alveolar ducts hence lowering the percentage of oxygen in alveolar air.

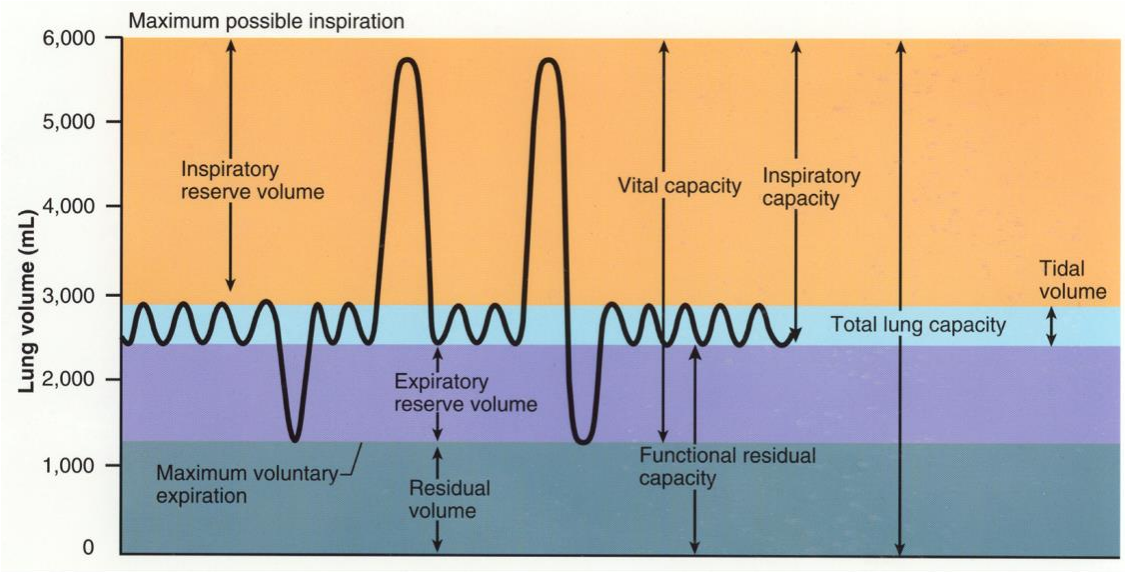
- ❖ The percentage volume of nitrogen in expired air is higher than in inspired air this is because although nitrogen is not used in respiration, its percentage in air during gas exchange changes because of the increased partial pressure of carbon dioxide and water vapour.
- ❖ Exhaled air contains a higher percentage volume of water vapour than inhaled air this is because the tissue respiration forms water some of which diffuses into the alveolar air and is expelled during exhalation.

LUNG VOLUMES AND LUNG CAPACITIES

Lung volumes and lung capacities refer to the volume of air associated with different phases of the respiratory cycle. Lung volumes are directly measured. Lung capacities are determined from lung volumes. They include;

a. **Total lung capacity**; the volume of air contained in the lung at the end of maximum inspiration; the total volume of the lung.
b. **Vital capacity**; the amount air that can be forced out of the lungs after a maximal inspiration. Its normally 3.5l in humans.
c. **Tidal volume**; volume of air normally breathed in when the body is at rest. Its normally 0.45l in humans.
d. **Residual volume**; the amount of air left in the lungs after a maximal exhalation. Its normally 1.5l in humans.

Graph to illustrate lung capacities



e. **Expiratory reserve volume**; the amount of additional air that can be pushed out after the end of normal breathing.
f. **Inspiratory capacity**; the maximal volume that can be inspired following a normal expiration.
g. **Anatomical dead space**; space within the air ways that does not permit gas exchange with blood.
h. **Alveolar dead space**; the volume of inspired air that is not used for gas exchange as a result of reaching alveoli with no blood supply.

Note;

1. Ventilation; Breathing rate: The number of breaths taken in one minute. This is normally 12 – 20 breaths in a healthy adult.
2. Pulmonary ventilation is expressed as dm^3min^{-1}
3. Pulmonary ventilation (dm^3 min^{-1}) = tidal volume (dm^3) x ventilation rate (min^{-1})

CONTROL OF VENTILATION IN HUMANS

- The rate of breathing is controlled by the respiratory centre/ breathing centre, in the medulla oblongata comprising of the inspiratory and expiratory centres.
- Many factors can modify the rate and depth of breathing e.g. low oxygen partial pressure, hormone Adrenaline, but the strongest factors are the levels of carbon dioxide and hydrogen ions (H^+) in arterial blood.
- Central chemoreceptors; cells that respond to chemical stimuli in the medulla oblongata of the brain detect changes in the concentration of carbon dioxide in blood by monitoring the pH of cerebrospinal fluid while peripheral chemoreceptors in the carotid and aortic bodies monitor both carbon dioxide and oxygen concentrations in blood of carotid arteries and aorta respectively.

Nervous control of breathing;

1. Respiring tissues release carbon dioxide from aerobic respiration. Increase in acidity/ increased hydrogen ions stimulates central chemoreceptors in the medulla oblongata while increased blood carbon dioxide stimulates peripheral chemoreceptors in carotid and aortic bodies to send impulses via the glossopharyngeal nerve and vagus nerve respectively to the inspiratory centre in the medulla oblongata.
2. The inspiratory centre sends impulses via the phrenic nerve to the diaphragm and via the intercostal nerve to the intercostal muscles.
3. Diaphragm and external intercostal muscles contract to increase thoracic volume while decreasing the thoracic pressure.
4. Air rushes in to inflate the lungs and cause stretch receptors in their walls to become stimulated and send impulses along the vagus nerve to the expiratory centre in the medulla oblongata.
5. This automatically switches off the inspiratory centre causing the relaxation of the external intercostal muscles and the diaphragm.
6. This causes the thoracic volume to decrease while thoracic pressure increases above atmospheric pressure, forcing lungs to deflate and expel air rich in carbon dioxide.
7. When the stretch receptors are no longer stimulated, the expiratory centre is switched off and inspiratory centre switched on. This causes inspiration to take place again.

EFFECT OF VARIATION OF OXYGEN AND CARBON DIOXIDE PARTIAL PRESSURE

- A deficiency of oxygen; hypoxia deprives the tissue of the vital requirement for metabolism. The consequence is that the sense organs are impaired, unconsciousness occurs suddenly, followed by paralysis and death.
- Breathing pure oxygen; hyperoxia at atmospheric pressure present no problems. However, if breathed at pressures greater than atmospheric as in diving, excess oxygen can be dangerous as the blood's ability to carry way oxygen is exceeded.
- At first, the tissues metabolize very rapidly, to keep pace with the oxygen supply. As the oxygen build up, however, it inhibits certain enzymes involved in the Krebs's cycle, the interfering with respiration.
- As well free oxygen molecules bind to proteins of the lungs interfering with the operation of the central nervous system and also attacking the retina.
- Excessive exposure to above-normal oxygen partial pressure causes, oxidative damage to cell membranes, collapse of the alveoli in the lungs and retinal detachment.
- Cells are more susceptible to changes in the levels of carbon dioxide. An accumulation of this gas increases the acidity of blood and tissue fluids, inhibits enzymes and stops essential metabolic process.

Note; exercise makes the breathing more efficient.

END OF TOPIC GASEOUS EXCHANGE

I thank you very much for this great exercise of understanding this topic am aware now your system is ok. We have covered some details of respiratory surfaces, looked at mechanisms of gaseous exchange in plants, small organisms, earthworms, insects, birds, fish both bony and cartilaginous fish, lung fish, birds and concluded with mammals specifically man in this we looked at the mechanism, control of ventilation, challenges of gases fluctuation, lung capacity among others. So am sure you can try out the questions below.

1. a) Explain the need for special respiratory surface and transport system pigment in higher animals

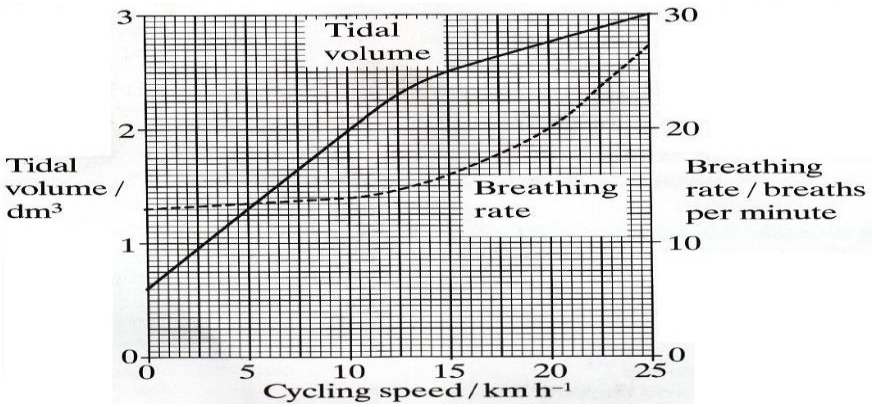
(b) How is gaseous exchange occurring adequately in higher animals?

2. Outline the various kinds of respiratory surfaces in animals.
3. (a) Giving examples in each case, explain how large surface: volume ratio, has been achieved in organisms, for exchange of gaseous and food materials. (12)
   (b) Explain the importance of changes in turgidity to plants (08mark)
4. (a) (i) discuss the factors that affect the rate of diffusion at respiratory surface
   ii. How are the conditions for efficient gaseous exchange fulfilled in mammalian lungs
   (b) the diameter of a capillary is smaller than the diameter of a red blood cell passing through them. How does this relationship help in gaseous exchange in the lungs?
5. Explain

(a) the need for special respiratory surfaces and transport system pigment in higher animals

(b) how gaseous exchange occurs adequately in higher plants without transport system pigments.

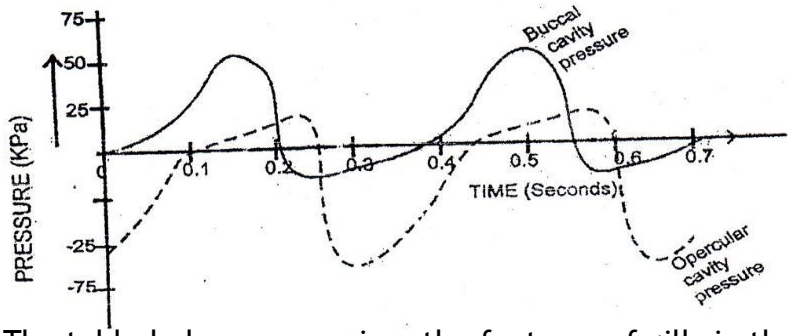
6. (a) What are the qualities of a respiratory surface? (4marks)
   (b) How is each of the following organisms adapted for efficient gaseous exchange?
   (i) an insect (7marks)
   (ii) a terrestrial flowing plant (6marks)
   (iii) An amoeba (3mark)
7. (a) How are gaseous exchange surfaces adapted in terrestrial mammal
   (b) Give an account for the gaseous exchange mechanism in a bony fish such as tilapia.
   (c) How do these mechanisms differ from those of terrestrial mammals?
8. The volume of air breathed in and out of the lungs during each breath is called tidal volume. The breathing rate and tidal volume were measured for a cyclist pedaling at different speeds and the results are given below:
   (a) Describe the changes in:
   (i) Tidal volume (ii) Breathing rate



(c) Calculate the pulmonary ventilation when the cyclist is cycling at 20 kmhr^{-1}. Show your working

9. The figure below shows the pressure changes in the buccal and opercular cavities of a teleost fish obtained by using hypodermic tubing connected to a pressure recorder. Negative pressure indicates expansion while positive

pressures mean contraction of the cavities.



The table below summarizes the features of gills in three species of teleost fish A, B and C.

Fish Species	Thickness of lamellae / µm	Distance between lamellae /µm	Distance between blood and surrounding water / µm
A	35	75	6
B	15	40	3
C	5	20	1

a. Describe the pressure changes in the buccal cavity for the first 0.5 seconds. *(10)*

b. Compare the pressure changes in the buccal cavity and opercular cavity in the first 0.4 seconds. *(06 marks)*

(i) Explain the observed changes in the buccal cavity and opercular cavity from 0.2 seconds to 0.6 seconds. *(06 marks)*

(ii) What is the physiological significance of the differences between the pressure in the buccal and opercular cavities?

(i) Comment on the relationship of the thickness of the lamellae and distance between blood and surrounding water. *(02 marks)*

(ii) Explain the significance of the features of the gills in the table in gas exchange. *(04 marks)*

c. State other structure features of the teleost fish which are important in breathing and gas exchange. *(06 marks)* Blood in the lamellae of the teleost fish flows in opposite direction to that of water. Comment on the efficiency of this mechanism in gas exchange. *(04 marks)*

10. CELLULAR RESPIRATION

It should be noted that organisms require a constant supply of energy to maintain stability of body systems and to ensure their survival.
Whatever form of food the organism takes in must be converted into a carbohydrate normally a hexose sugar; glucose before being respired.
Most respiration is the oxidation of glucose to carbon dioxide and water with release of energy.
Respiration can be into;

1. **Cellular/ internal/ tissue respiration**; which is the metabolic processes within cells that release energy from breakdown of organic compounds.
2. **Gaseous exchange/ external respiration**; the processes involved in obtaining the oxygen for respiration and removal of gaseous waste products.
3. **Aerobic respiration**; which requires oxygen
4. **Anaerobic respiration;** which does not require oxygen

Organic molecules usually carbohydrate are broken down bond by bond, by a series of enzyme controlled reactions. Each bond broken releases a small amount of energy which is converted to **adenosine triphosphate (ATP).**

ADENOSINE TRIPHOSPHATE (ATP)

- ATP is formed from the nucleotide adenosine monophosphate by the addition of two further phosphate molecules.
- ATP is the immediate source of energy for cellular reactions in all organisms and thus it is known to be universal energy carrier.
- ATP is an energy carrier because it stores chemical energy, which is released as free energy on hydrolysis of the covalent phosphate to phosphate bonds.

Importance of ATP

The hydrolysis of ATP to ADP is catalysed by enzyme ATPase and the removal of the terminal phosphate yields 30.6kJmol^{-1} of free energy.
Further hydrolysis of ADP to AMP yields a similar quantity of energy.
However removal of the last phosphate to produce adenosine produces less than half of this quantity of energy.
AMP and ADP maybe reconverted to ATP by addition of phosphate molecules a process known as phosphorylation. This may be;

- Substrate-level Phosphorylation i.e. direct transfer of a phosphate group from high energy phosphorylated compounds to ADP to form ATP. Examples of high energy phosphate compounds e.g Phosphoenol pyruvate, 1, 3- and Bisphosphoglycerate.
- Oxidative Phosphorylation i.e. use of energy supplied by transmembrane proton gradients across the inner mitochondrial membrane during electron transport system to form ATP occurs during cellular respiration in aerobic cells.
- Photophosphorylation i.e. use of energy supplied by transmembrane proton gradients across thylakoid membranes in chloroplasts during photosynthesis to form ATP.

NOTE:

1. The addition of each phosphate molecule requires 30.6kJmol^{-1} of energy. If the energy is less, it cannot be stored and is thus lost as heat.
2. ATP therefore transfers energy from energy rich compounds to cellular reactions requiring it.
3. There are various substances that can transfer energy however, ATP is by far the most abundant because; ATP releases just the right amount of energy for cellular needs when hydrolysed, releases energy at the right time and can be moved to any place when need arises.

Uses of ATP

1. Provide energy to build up macromolecules such as proteins from amino acids, polysaccharides form monosaccharides and DNA synthesis; Anabolic processes.
2. Provide energy for movement of materials such as active transport e.g muscle contraction, ciliary action and spindle action in cell division
3. Provides energy for secretion of materials.
4. Provide energy for muscle contraction, spindle formation in cell division and ciliary action
5. Provide energy for activation of molecules before they are used in the body e.g phosphorylation of glucose at the start of glycolysis.

When glucose is the substrate of respiration, its oxidation can be divided into **three phases;**

a) Glycolysis
b) Krebs or citric acid cycle or TCA, tri-carboxylic acid cycle
c) Electron transport/ hydrogen transport system

Glycolysis is common to anaerobic and aerobic respiration, but the other two phases only occur only in presence of oxygen.

GLYCOLYSIS

- Glycolysis represents a series of reactions in which a glucose molecule is broken down into two molecules of pyruvate.
- Glycolysis occurs in the cytoplasm of cells, not in the mitochondria, and does not require the presence of oxygen.
- The process may be subdivided into two steps, first the conversion of glucose into fructose 1,6 - di-phosphate, and secondly the splitting of fructose -1,6- di-phosphate into 3C sugars which are later converted into pyruvate.
- Two ATP molecules are used up for phosphorylation reaction in the first step. Whilst four ATP molecules are produced in the second step. Four hydrogen atoms are also released. These are oxidized to water by molecular oxygen with accompanying phosphorylation of ADP to ATP molecules during oxidative. Each pair of hydrogen atom is oxidized to form 2 ATP

Table showing ATP molecules generated from glycolysis

Source	Number of ATP
From stages 6 and 7	4ATP
ATP from NADH2	4ATP
Total	8ATP

Giving us a net of 6 ATP molecules; subtract the added two ATP molecules

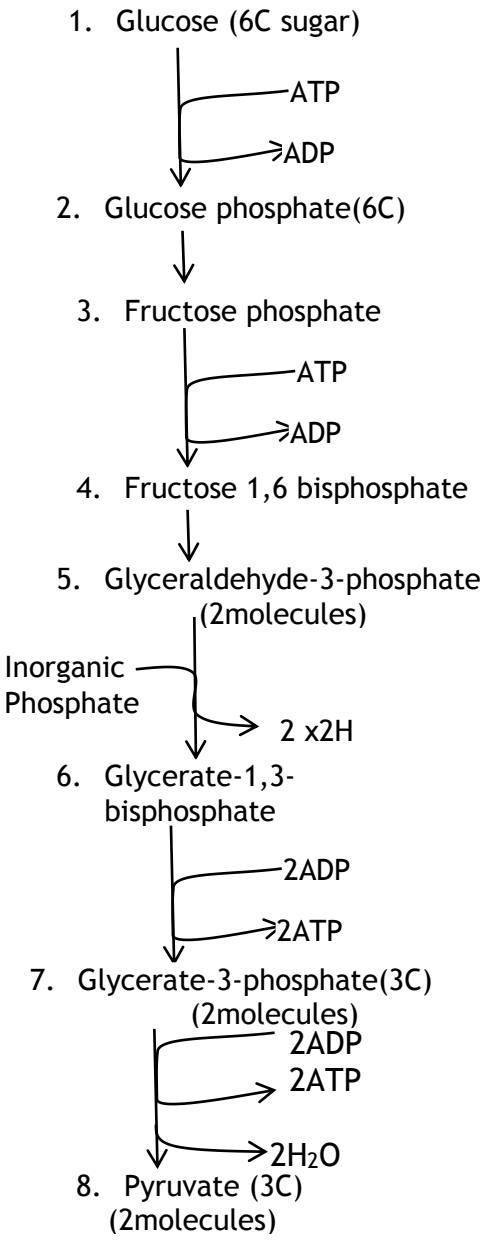
NOTE;

- Glycolysis is important because it yields ATP which is used to power cell activities, NADH and Pyruvate which may be further oxidized to generate additional ATP.

FATE OF PYRUVATE

1. Under aerobic conditions, pyruvate is completely oxidised via the citric acid cycle to carbon dioxide and water.
2. Under anaerobic conditions in the cytoplasm, pyruvate undergoes fermentation.

STAGES OF GLYCOLYSIS



The glucose molecule is phosphorylated to make it more reactive. The phosphate molecule comes from conversion of ATP to ADP

Glucose is reorganized into its isomer fructose phosphate

Further phosphorylation takes place by the addition of another phosphate group from ATP make the sugar more reactive

Sugar splits into two 3 carbon sugars

Further phosphorylation takes place by the addition of another phosphate group from inorganic sources but not ATP. 2pairs of hydrogen removed

A phosphate molecule is lost from each glycerate-1,3-bisphosphate molecule yielding two ATP molecules from two ADP molecules.

A phosphate is removed from the each glycerate-3-phosphate to form a pair of ATP and a water molecule removed

AEROBIC RESPIRATION

- There are two phases involved in aerobic respiration, first, if sufficient oxygen is available, each pyruvate molecule enters a mitochondrion where it is converted into a 2-carbon compound acetyl co-enzyme A (acetyl CoA).
- In this reaction carbon dioxide is given off, and the pyruvate loses a pair of hydrogen atoms which again results in the synthesis of ATP.
- Acetyl CoA is a very important intermediate in respiration because it links glycolysis, oxidation of fats and proteins with the **Krebs cycle.**
- Within the active centre of the enzyme citrate synthetase, CoA transfers the 2-carbon acetyl group to a 4-carbon molecule of oxaloacetate to make a molecule of citrate which enters the Krebs cycle.
- During energy deficiency, amino acids from proteins and fatty acids from lipids can be broken down to provide acetyl CoA for use in respiration.

KREBS/ TRICARBOXYLIC ACID CYCLE

It is a multi-step reaction in the mitochondrial matrix during which an acetyl group is completely oxidized to carbon dioxide with the generation of ATP and reducing hydrogen atoms in the form of NADH and FADH2.
It undergoes the following stages;

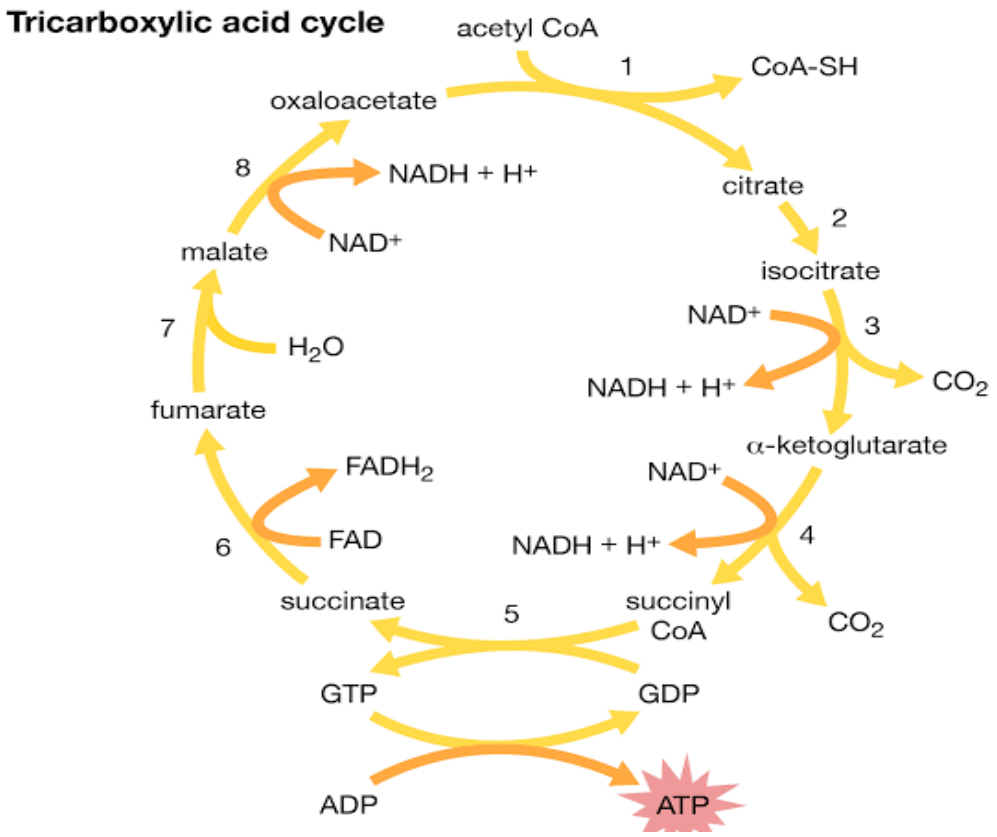
1. Before pyruvate enters the Krebs cycle it combines with a compound called coenzyme A to form Acetyl coenzyme A in the process, a molecule of carbon dioxide and a pair of hydrogen atoms are removed.
2. The 2-carbon acetyl coenzyme A enters the Krebs cycle by combining with a 4-carbon oxaloacetate; oxaloacetic acid to give a 6-carbon citrate; citric acid. This reaction requires energy which is provided at the expense of the energy-rich bond of acetyl group CoA.
3. Citrate isomerizes to a more reactive isocitrate. The isocitrate is decarboxylated and then oxidized to form α-ketoglutarate.
4. The 5-carbon α-ketoglutarate; α-ketoglutaric acid loses a carbon dioxide; is decarboxylated and is oxidised; loses hydrogen to oxidized nicotinamide adenine dinucleotide (NAD^+) to form reduced nicotinamide adenine dinucleotide (NADH) and is attached to coenzyme A to form succinyl-CoA;
5. Succinyl-CoA cause phosphorylation of ADP to ATP and the formation of succinate; succinic acid.
6. The 4-C succinate loses two hydrogen atoms to Flavine adenine dinucleotide (FAD); is dehydrogenated, forming reduced Flavine adenine dinucleotide (FADH2) thus forming a 4-C fumarate.
7. Fumarate is hydrated; a water molecule is added and rearranged to form malate and
8. Malate loses hydrogen to NAD+ to form NADH regenerating oxaloacetate.

Note;

a. For each turn of the cycle, a total of four pairs of hydrogen atoms are also formed.
b. Of these, 3 pairs of hydrogen atoms are combined with hydrogen carrier, nicotinamide adenine dinucleotide (NAD) and yield three ATP for each pair of hydrogen atoms.
c. The remaining pair of hydrogen atoms combine with a different hydrogen carrier, Flavine adenine dinucleotide (FAD). And yield 2 ATP.
d. It must be remembered that all these products are formed from a single pyruvate molecule of which two are produced from each glucose molecule.

Summary table of ATP molecules

Source of ATP	Number of ATP	Total number
3 pairs if H with NAD	9ATP	9ATP x 2
1 pair of H with FAD	2ATP	2ATP x 2
Energy of the cycle	1ATP	1ATP x 2
Glycolysis process	6ATP	8ATP x 1
Pyruvate to Acetyl Co A	3ATP	3ATP x 2
Total		38 ATP



Importance of Krebs cycle

It brings about the degradation of macro molecules.
It provides the reducing power for the electron transport system; it produces pairs of hydrogen atoms which are ultimately the source of metabolic energy for the cell.
It is an interconversion centre; it is a valuable source of intermediate compounds sed in the manufacture of other compounds such as fatty acids and amino acids.

COMPARISON OF GLYCOLYSIS AND KREBS CYCLE

Similarities;

- ✓ NADH forms
- ✓ ATP is generated
- ✓ There is a reduction in number of carbon atoms of organic compounds
- ✓ Pyruvate participates
- ✓ Both occur in living cells

Differences;

glycolysis	Krebs cycle
The electron acceptor FAD isn't involved	The electron acceptor FAD is involved
Occurs in the cytoplasm	Occurs in the mitochondria
Carbon dioxide is not formed	Carbon dioxide is formed
Can occur in absence of oxygen	Occurrence depends on oxygen presence

ELECTRON TRANSPORT SYSTEM

- It occurs in the membranes of the mitochondria. It is the means in by which the energy, in the form of hydrogen atom, from Krebs cycle, is converted to ATP.

- The hydrogen atoms attached to a hydrogen carriers NAD and FAD are transferred to a chain of other carriers at progressively lower energy levels. As the hydrogens pass from one carrier to the next, the energy released is used to produce ATP.
- The series of carrier is called respiration chain. The carriers in the chain include NAD, Flavo protein, coenzyme Q and iron-containing protein called cytochromes. Initially hydrogen atoms are passed along the chain, but latter split into their proton and electron and only the electron pass from carrier to carrier. For this reason, the pathway can be called electron or hydrogen transport system. At the end of the chain the protons and electrons recombine, and the hydrogen atoms create a link with oxygen to form water. The role of oxygen is to act as the final electron acceptor

Note;
This formation of ATP through the oxidation of the hydrogen atoms is called oxidative phosphorylation.

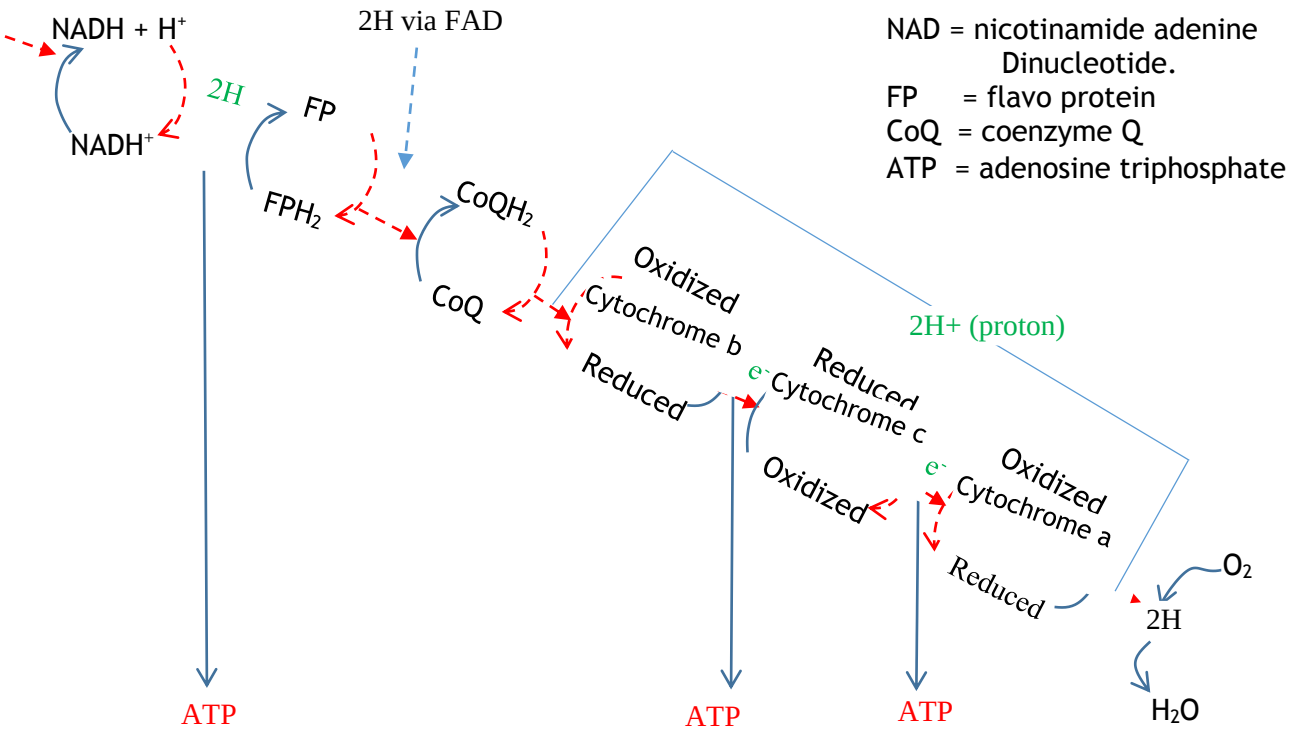
Stages of the respiratory chain

1. **NADH reductase**; NADH donates electrons to the coenzyme Flavin mononucleotide (FMN).which then passes electrons to an iron-sulphur (Fe-S) protein and the electrons lose some energy. NADH is oxidized to NAD^+, while FMN and Fe^{3+} are reduced to FMNH2 and Fe^{2+} respectively. Each electron is transferred with a proton. Electrons from the reduced Fe-S proteins are then passed to Coenzyme Q along with protons. Coenzyme Q is thus reduced while the Fe-S proteins are oxidised back to Fe^{3+} state.
2. **Succinate dehydrogenase**; Electrons from FADH2 are passed on to Fe-S proteins then to Coenzyme Q which transfers them to next stage. FADH2 becomes oxidised to FAD+. During this process, four protons (H^+) are translocated across the inner mitochondrial membrane, from the matrix to the inter membrane space. This creates a proton gradient that will be later used to generate ATP through oxidative phosphorylation.
3. **Reduced coenzyme Q (CoQH2);** transfers electrons to next stage where they pass through several cytochromes and Fe-S proteins and during the process Fe^{3+} is reduced to Fe^{2+}. The electrons lose additional energy and are passed on to cytochrome *c* which passes electrons to cytochrome *c* oxidase, which finally transfers the electrons to reduce molecular oxygen to form water.
   $O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$.
   At the same time, it moves protons (H+) across the membrane into the inter membrane space, producing a proton gradient.
4. Energy lost by electrons in the stages is used to pump protons into the inter membrane space producing a proton gradient.
5. When the protons flow down the concentration gradient through the channels in the stalked particles, ATP synthase enzymes are able to use the energy to generate ATP as explained by the chemiosmotic theory of peter Mitchell.

Note;

i. Oxygen is vital as it drives the entire process. In its absence only the anaerobic glycolysis can continue.
ii. The transfer of hydrogen atoms to oxygen is catalysed by cytochrome oxidase as seen above. It's highly inhibited by cyanide, so preventing the removal of hydrogen atoms at the end of the chain. Hydrogen atoms accumulate and aerobic respiration ceases.

Summary of the electron transport system



NOTE;
Mitochondria are present in all eukaryotic cells where they are main sites for respiratory activity. Highly active cells requiring much energy characteristically have numerous large mitochondria packed with cristae.
These cells include; liver, striated muscle, sperm, nerve, intestinal epithelial cells.

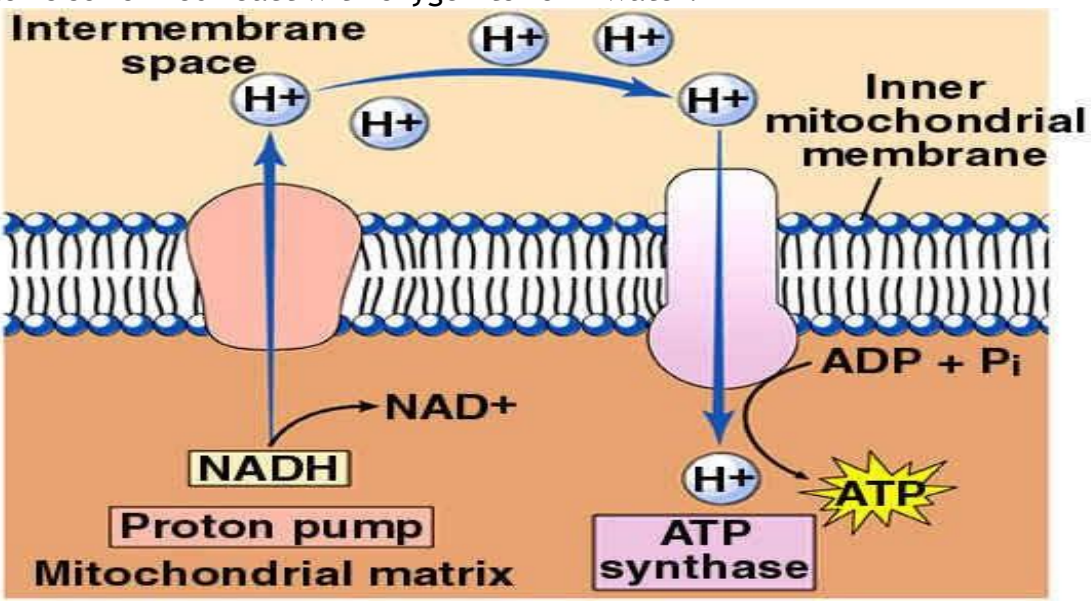
PETER MITCHELL CHEMI-OSMOTIC THEORY

- This is the process by which chemical ions e.g. H^+ move from an area of high concentration to an area of low concentration through transport proteins on the selectively permeable membrane as a result of proton gradient that forms across the membrane that is not readily permeable to ions.
- Mitochondria have an inner membrane which is folded to form cristae in order to increase the surface area. The cristae are lined with staled particles.
- Within the inner mitochondrial membrane there appears to be a mechanism which actively transports protons from the matrix into the inter membrane space.
- Thus creating an electrochemical gradient of hydrogen ions across the inner membrane

Detail;

1. Hydrogen atoms are picked up by NAD in the matrix and are later split into protons and electrons.
2. The protons are actively pumped from the matrix into the inter membrane space; space between the inner and outer membranes by a hydrogen pump.
3. Electrons pass along the cytochromes located within the inner membrane.

4. The protons flow back into the matrix via chemiosmotic channels located in the stalked particles this due to their high concentration in the inter membrane space.
5. This flow is a driving force that combines ADP with an inorganic phosphate under the catalytic activity of ATPase enzyme and so synthesizes ATP.
6. These protons then recombine in the matrix with the electrons and hydrogen atoms so formed react with oxygen to form water.



ANAEROBIC RESPIRATION/ ANAEROBOSIS

- A variety of microorganism employ anaerobic respiration as their major ATP yielding process. Organism that survive only in absence of oxygen are termed obligate anaerobes. Obligate anaerobes find oxygen toxic.
- Other organisms such as yeast and alimentary canal parasites such as tape worms, can exist whether oxygen is available or not. These are called facultative anaerobes.
- Also, some cells that are temporarily deprived of oxygen available to accept the hydrogen such as muscle cells are able to respire anaerobically.
- Pyruvate serves as an electron/hydrogen acceptor in absence of oxygen to accept the hydrogen atoms released during glycolysis; and depending on the metabolic pathways within the organisms' cells, the end-product of anaerobic respiration will either be ethanol and carbon dioxide. This process is known as fermentation.

There are two kinds of fermentation;

- Lactate and alcoholic fermentation.

ALCOHOLIC FERMENTATION

The pyruvate from glycolysis is first converted to ethanal through decarboxylation this reaction being catalyzed by pyruvate decarboxylase

Pyruvate $\xrightarrow{\text{Pyruvate decarboxylase}}$ ethanol + carbon dioxide

Or

$CH_3COCOOH \longrightarrow CH_3CHO + CO_2$

The ethanal is then reduced using the hydrogen from reduced NAD, which was formed during glycolysis, to ethanol. This reaction is catalyzed by the enzyme alcohol dehydrogenase:

$Ethanal + NADH + H^+ \longrightarrow Ethanol + NAD^+$

Overall reaction

$Pyruvate \longrightarrow ethanol + carbon\ dioxide$

Note;

Under anaerobic conditions such as water logging of plant roots, the cells of higher plants may temporarily undergo this form of fermentation.

LACTATE FERMENTATION

In this, pyruvate from glycolysis accepts the hydrogen atoms from reduced NAD under the catalytic activity of lactate dehydrogenase to form lactate.

$$Pyruvate + NADH + H^+ \xrightarrow{\text{Lactate dehydrogenase}} lactate + NAD^+$$

Or

$$CH_3COCOOH + NADH + H^+ \longrightarrow CH_3CHOHCOOH + NAD^+$$

Organisms that experience lactate fermentation.

1. Organisms living in anoxic conditions.
2. Animals living in environments of fluctuating oxygen levels such as pond or river temporary use lactate fermentation.
3. Mammals under strenuous exercise.

EFFECT OF STRENOUS EXERCISE ON THE BODY

- During strenuous exercise in muscles lactate fermentation occurs. This is because during this period the circulatory system is incapable of supplying oxygen to the muscles as per the demand. This causes the accumulation of lactate which causes cramps and ceases muscle operation.
- During this period of lactate accumulation an organism accumulates an oxygen debt.
- This is repaid as soon as possible after activity by continued and deep breathing following the exertion.
- The oxygen absorbed is used to oxidize the lactate to carbon dioxide and water, thereby removing it and at the same time replenishing the depleted stores of ATP and oxygen in the tissues.

Note;

1. In some organisms like parasitic worms, lactate is just excreted.
2. **Oxygen debt** means the amount of oxygen needed to oxidize the lactic acid that accumulates during anaerobic respiration.

COMPARISON OF AEROBIC AND ANAEROBIC RESPIRATION

Similarities;

- ✓ Form ATP
- ✓ Use glycolysis to oxidize glucose to pyruvate
- ✓ Use NAD+ as the oxidizing agent that accepts electrons from food during glycolysis
- ✓ May be carried out by same cells (e.g. muscle cells) or same organisms (e.g. yeasts and bacteria).

Differences;

Aerobic respiration	**Anaerobic respiration**
- Utilizes oxygen	- Does not utilize oxygen
- **Involves complete oxidation of glucose**	- Involves partial oxidation of glucose
- Occurs in both the cytoplasm and mitochondria	- Occurs only in the cytoplasm.
- **Produces more ATP molecules.**	- Produces less ATP molecules.
- **Products are carbon dioxide and water in both animals and plants**	- Products are lactic acid in an animals, ethanol and CO_2 in plants

Note;

1. During aerobic respiration 38 ATP molecules are formed both directly by phosphorylation of ADP and indirectly by oxidative phosphorylation using hydrogen ions generated during glucose breakdown.
2. During anaerobic respiration, glycolysis only occurs and the reduced NAD it yields is not available for oxidative phosphorylation. Therefore the total energy is restricted to two ATP molecules.
3. Of the total 38 ATP molecules produced in aerobic respiration, one ATP molecule is used in transporting some chemicals involved.
4. Each ATP molecule yields 30.6kJ of energy.

ALTERNATIVE RESPIRATORY SUBSTRATES

1. **Respiration of fat/ lipid;**

- In the gut, the enzyme lipase catalyses the hydrolysis of lipids into fatty acids and glycerol which enter the lacteal and finally gain entry into liver cells.
- Glycerol is phosphorylated with ATP, dehydrogenated with NAD and converted to triose phosphate (glyceldehyde-3-phosphate) which is fed into the glycolysis pathway. There is a net yield of 19 molecules of ATP from the oxidation of triose phosphate and of the NADH formed.
- The fatty acid component is progressively broken in the matrix of the mitochondria into fragments of 2 carbons each which are converted to acetyl coenzyme A. This then enters the Krebs cycle with subsequent release of energy.

Note;

i. Fats oxidation produces a large quantity of hydrogen ions. These are transported by hydrogen carriers to the ETS, thus they release energy doubling that produced by carbohydrates.

2. **Respiration of proteins;**

- The body resorts to protein as an energy source only during starvation.
- Protein is first hydrolysed to amino acids which are then individually deaminated i.e. amino groups ($-NH_2$) are removed and converted to ammonia, urea or uric acid for excretion this occurs in the liver.
- The residual carbon compound then enters the respiratory pathway at a number of points depending on their number of carbon atoms:

✓ 5-C amino acids like glutamate are converted to α-ketoglutarate,
✓ 4-C amino acid like aspartate are converted to oxaloacetate.

- Then α-ketoglutarate and oxaloacetate enter Krebs cycle.
- 3-C amino acids like alanine are first converted to pyruvate and then acetyl coenzyme A.

- Amino acids with many carbon atoms are converted by transamination reactions into 3, 4 or 5-carbon amino acids.

3. Respiration of fructose;

- Fructose is present in free form in many fruits and is also formed by hydrolysis of sucrose in the ileum of vertebrates.
- In the muscles and kidney fructose is phosphorylated to fructose-6-phosphate by hexokinase enzyme while in the liver fructokinase enzyme catalyses the phosphorylation of fructose to fructose-1-phosphate which then splits into glyceraldehyde and Dihydroxyacetone phosphate.
- Dihydroxyacetone phosphate converts to glyceraldehyde 3-phosphate while glyceraldehyde is phosphorylated by ATP to glyceraldehyde 3-phosphate. Thus both products of fructose 1-phosphate hydrolysis enter the glycolytic pathway as glyceraldehyde 3-phosphate.

CONTROL OF RESPIRATION

- Because the main function of respiration is to produce ATP, it must be regulated so that ATP is generated only when needed. This occurs in a number of ways:
- At cellular level, the rate at which respiration occurs is regulated mainly by the energy state of the cell the ratio of ATP to ADP, acting via regulatory enzymes.
- High levels of ATP; high energy level of the cell inhibit the enzyme hexokinase that catalyses phosphorylation of glucose at the start of glycolysis while low energy levels; high ADP levels stimulate hexokinase enzyme.

FACTORS AFFECTING THE RESPIRATION RATE

The respiratory rate is majorly influenced by environmental factors such as;

- ☑ **Temperature**; Very low temperature slows down respiration in both homoiotherms and poikilotherms, although it can be observed that homoiotherms need increased respiration rate to generate much heat for maintaining body temperature. In poikilotherms temperature near to that of the body increases the respiration rate.
- ☑ High temperature slows down the respiration rate in homoiotherms. However, excessively high temperatures trigger increased respiration rate and finally stop due to denaturation of respiratory enzymes.
- ☑ **Body size;** Small organisms with a large surface area to volume ratio lose heat faster and therefore respire faster than large organisms.
- ☑ **Level of activity;** Animals engaging in vigorous physical exercise require much energy and so experience faster respiration rate e.g. sprinting, flying, etc
- ☑ **Growth;** Actively growing organism e.g. young animals and germinating seeds respire faster to generate much energy required to drive metabolic processes involved in cell division.
- ☑ **Dormancy during extreme cold and hot seasons;** Respiration rate is always slow to avoid depleting food reserves before the unfavourable season ends.

RESPIRATORY QUOTIENTS

The respiratory quotient (RQ) is the **measure** of the ratio of carbon dioxide evolved by an organism to the oxygen consumed, over a certain period.

- It is always important to determine the RQs because they indicate the kind of substrate being respired by the cell or organism and the kind of respiration whether the respiration is aerobic or anaerobic.

$$RQ = \frac{\text{Amount of Carbon dioxide evolved}}{\text{Amount of oxygen consumed}}$$

Example;

For hexose sugars; glucose

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

Here the RQ is 1.0 dependent on the moles of carbon dioxide and oxygen.

NOTE:

- In fats and proteins, the ratio of carbon dioxide evolved to oxygen consumed is far smaller than in carbohydrates. A fat and proteins, therefore requires more oxygen for its complete oxidation than carbohydrates.
- The respiratory quotient of fats is 0.7 whereas that of proteins is 0.9. Organisms rarely respire one substance at a time, thus the respiratory quotients of an animal is between 0.8 and 0.9.

END OF TOPIC RESPIRATION

I thank you for you have been able to complete the topic very well and have showed clear understanding of this topic. To give you a recap we looked at ATP, glycolysis, Krebs cycle, electron transport system, anaerobic and aerobic respiration and finally respiratory quotient all in clear detail. Am now sure that you can try out the questions below.

1. (a) Differentiate between aerobic and anaerobic respiration.
(b) Describe what happens to the end product of glycolysis in absence of oxygen
(c) Why is it important to produce ATP during cellular respiration?
2. a. Give an account of glycolysis
   b. Explain what happened to the pyruvate under aerobic conditions.
3. a. Distinguish between aerobic respiration and anaerobic respiration
   b. Outline the major steps involved in the process of glycolysis in a cell.
   c. How is energy produced in glycolysis?

11. HOMEOSTASIS

The word homeostasis comes from two Greek words:-**Homoio**- meaning same and **Stasis** – standing.

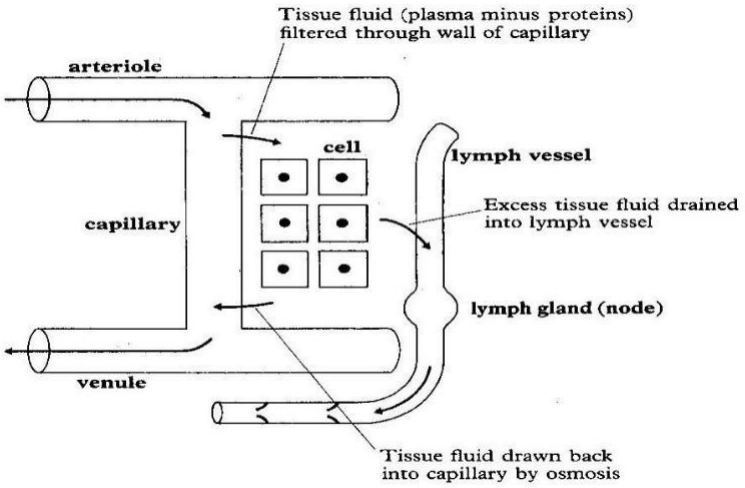
Homeostasis is the maintenance of a constant steady state in the internal environment of the organisms by self-adjusting mechanisms to ensure that the organism as a whole functions efficiently. Due to this we can conclude that; Homeostasis is the maintenance of a constant internal environment.

Internal environment; refers to the immediate surroundings of the cells inside the body.

- In mammalian tissues, the cells are surrounded by tiny channels and spaces filled with a fluid known as inter cellular or interstitial or tissue fluid.
- The internal environment in plants is the cell sap, in insects it's the haemolymph, in echinoderms its water.

FORMATION OF TISSUE FLUID

- Tissue fluid is formed by the process of ultra-filtration which is simply the separation of small molecules due to pressure difference. Generally blood in the arteriole end of the capillary bed is under pressure due to; the pumping action of the heart and the narrow diameter of the capillaries.



- This hydrostatic pressure forces the fluid part of the blood through the walls of the capillaries into the intercellular spaces. The walls of the capillaries act as a filter holding back the protein molecules and the blood cells but allowing everything else to go through thus forming tissue fluid.
- Tissue fluid constitutes all the constituents of blood such as glucose, amino acids, hormones except proteins and cellular components of blood due to their large molecular size.
- Once formed, the tissue fluid circulates among the cells and finally returns to the blood vascular systems. At the venule end, the osmotic pressure of plasma becomes higher than the hydrostatic pressure of blood due to the removal of other constituents. This pressure draws back the fluid by osmosis and it is returned to the general circulation.
- Excess fluid not returned to the general circulation drains to the lymphatic system and eventually back into the veins.
- Intercellular fluid is the medium in which the cells are bathed. Through it respiratory gases diffuse, from it the cells extract all their metabolites, and into it the shed unwanted substances. Since it is formed from blood, it is the blood which must be kept constant.

Or check functional approach page 201 fig 13.2

FACTORS OF THE INTERNAL ENVIRONMENT WHICH MUST BE KEPT CONSTANT

- ✓ Its chemical constituents such as glucose, ions etc.
- ✓ Its temperature; thermoregulation.
- ✓ Level of carbon dioxide and oxygen; respiratory gases.
- ✓ Osmotic pressure which is due to the relative amount of water and salts
- ✓ The pH of blood; acid-base balance.
- ✓ In addition, certain toxic substances must be eliminated from it. They include nitrogenous waste products, salts etc; excretion.

Causes of fluctuation in the above factors

- ❖ Malfunctioning of the body organs such as pancreas and kidney etc.
- ❖ Failure of glands to produce or secrete hormones.
- ❖ To some extend changes in the external environment.

Importance of homeostasis

- ▪ It provides the bodies of organisms with relatively optimal conditions for effective functioning of the cells.
- ▪ Stability of the internal environment provides degree of independence of the external environment.
- ▪ Consequently multicellular organisms can exploit a wide range of external conditions than unicellular organisms.

THE PRINCIPLES OF A HOMEOSTATIC SYSTEM

a) Any homeostatic system should have a self-adjusting system. Here a corrective mechanism is triggered by the variable to be regulated e.g. level of sugars, temperature, water etc.
b) It should have a set point/the norm. This refers to the optimal level of the variable being regulated.
c) Control mechanisms; negative and positive feed backs.

Basic components homeostatic system

1. **Reference point;** the set level at which the system operates.
2. **Receptor or detector**; these monitor the factors being controlled i.e. the detect changes in that factor and send information to the regulator.
3. **The coordinator or regulator or control center**; this initiates appropriate ways of correcting deviations and communicates to the effectors.
4. **Effectors**; these carry out the effective or corrective measures needed to return the system to the reference point.
5. **Feedback loop**; informs the detector of any change in the system as a result of action of the effector.

FEEDBACK MECHANISMS

The efficiency of a control system can be judged by:-

- ✓ Deviation from the reference point; optimum level.
- ✓ The speed with which the level is restored after change.

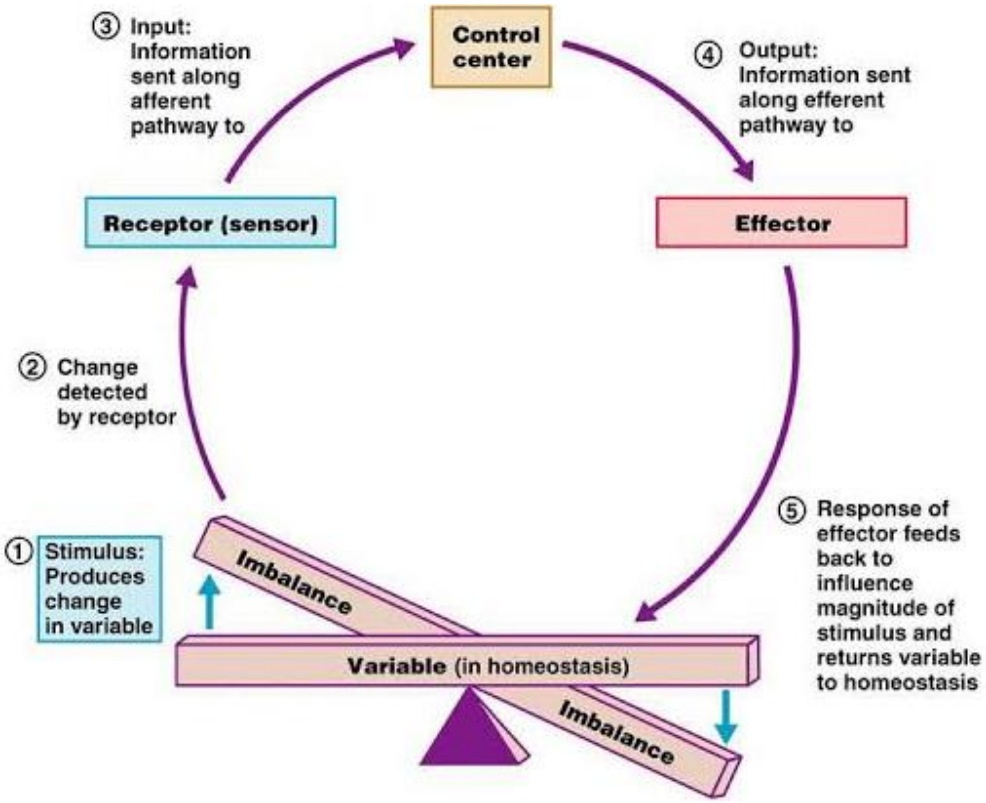
- × Any change from the set point activates the control systems and returns conditions towards their optimum level. As conditions returns to the optimum, the corrective processes can be switched off a process known as **negative feedback**.

NEGATIVE FEEDBACK.

- This is a mechanism of homeostasis in which a change in the quantity of a homeostatically controlled parameter from the norm sets up physiological processes that cause a change in the quantity of the parameter in the opposite direction to return it to normal.
- Negative feedback is associated with increasing the stability of the systems. If the system is disturbed, the disturbance sets in motion a sequence of events which tends to restore the system to its original state. Almost all homeostatic control mechanisms are negative feedback mechanisms.

Examples of biological negative feedback mechanisms include; the control of:

- ✓ Oxygen and carbon dioxide levels in the body by controlling rate and depth of breathing, Heart rate, Blood pressure, Hormone levels, Metabolite levels, Water and ionic balances, The regulation of pH and Body temperatu



POSITIVE FEEDBACK

- Positive feedback is rare in biological systems since it leads to an unstable situation and extreme states.
- In these situations a disturbance leads to events which increase the disturbance even further. The output enhances the original stimulus.

Examples of positive feedback mechanisms include;

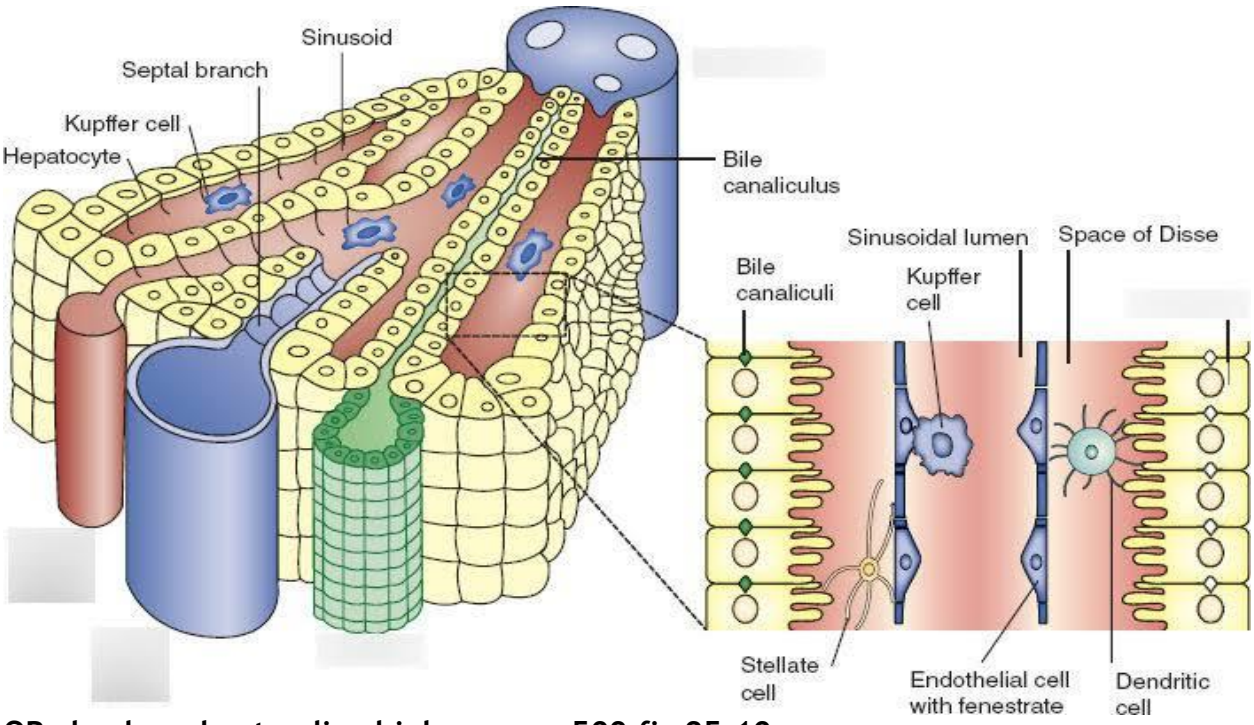
- During the propagation of a nerve impulse, depolarization of the membrane of the neuron produces an increase in its sodium permeability. As sodium ions pass into the axon through the
- The rate at which sodium ions enter therefore increases very rapidly and produces an action potential. In this case positive feedback acts as an amplifier of the response (depolarization).
- During labor, a hormone oxytocin is released which stimulates muscular contractions of the uterus, which in turn stimulates the release of more oxytocin and the cycle goes on until the baby is born.
- During blood clotting to stop bleeding in order to keep blood volume constant, one clotting factor activates another in a cascade form that leads to quick formation of a clot

THE MAMMALIAN LIVER

- It is the largest organ weighing up to 1.5kg, 3-5% of the total body mass.
- It has an excellent blood supply receiving more blood at a time than any other organ. It receives blood through two main routes (vessels) namely the hepatic artery which brings in oxygenated blood and through the hepatic portal vein which brings blood rich in food materials from the gut, then the hepatic vein takes blood from the liver.

Structure

- The liver is composed of structural and functional units called **lobules,** which are cylindrically shaped, numbering over 100,000 and each approximating 1mm in diameter.
- Hepatocytes**;** liver cells closely pack in each lobule in various rows radiating outwards from the centre.
- Hepatocytes are characterized by similarity in structure and function, prominent nuclei, Golgi complex and peroxisomes, numerous mitochondria, lysosomes, glycogen granules and fat droplets. Peroxisomes contain catalase and other oxidative enzymes responsible for detoxification. Hepatocytes which are in contact with blood vessels bear microvilli
- Located between lobules are triads consisting of a branch of hepatic artery which brings oxygenated blood to the liver, a branch of hepatic portal vein which brings nutrients from the gut and bile duct that drains bile from the liver.
- A central vein; branch of hepatic vein runs longitudinally midway each lobule and is linked by sinusoids to the interlobular vessels; hepatic artery and hepatic portal vein. Sinusoids radiate from the centre to the periphery of the lobule and their endothelial lining is perforated.
- Sinusoids alternate with bile canaliculi, small canals which carry bile. Attached to the walls of sinusoids are macrophagous cells called Kupffer cells.



OR check understanding biology page 509 fig 25.10
Or biological science page 667

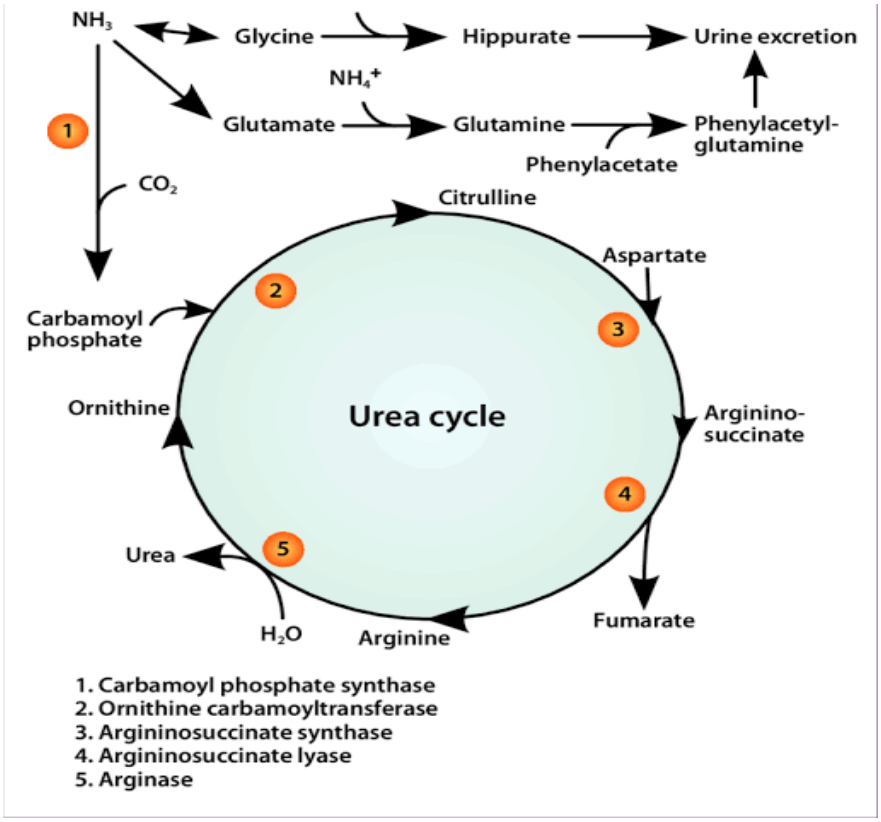
FUNCTIONS OF THE LIVER

The homeostatic functions of the liver include;

1. **Regulation of blood glucose**. Through the intermediary of insulin, the liver removes glucose from, or adds glucose to, the blood depending on the circumstances. Inside the liver cells, the glucose is either built up into glycogen for storage or broken down into carbon dioxide and water with the release of energy. If in considerable excess, it is converted into lipids.
2. **Regulation of amino acids and hence proteins**. The body is unable to store the proteins or amino acids, and any surplus is destroyed in the liver.
   - Excess amino acids brought to the liver in the hepatic portal vein are deaminated by the liver cells. In this process the amino group is removed from the amino acid, with formation of ammonia.
   - The amino acid residue is then fed into carbohydrate metabolism and oxidised with the release of energy. Meanwhile the ammonia must not be allowed to accumulate for its highly toxic even in small quantities.
   - Under the influence of specific enzymes in the liver cells, the ammonia enters a cyclical series of reactions; the ornithine cycle in which it reacts with carbon dioxide to form the less toxic nitrogenous compound, urea.
   - The urea is then shed from the liver cells into the blood stream, and taken to the kidney which eliminates it from the body.

ORNITHINE CYCLE

- ✓ The amino group of an amino acid is removed and reacts with hydrogen to form ammonia.
- ✓ Ammonia reacts with carbon dioxide to form carbamoyl phosphate using energy from hydrolysis of ATP.



- ✓ The carbamoyl phosphate reacts with ornithine to form citrulline all occurring in the mitochondrial matrix.
- ✓ Citrulline diffuses into the cytoplasm of liver cells and reacts with aspartate to form arginino-succinate.
- ✓ Arginino-succinate splits into arginine and fumarate. Fumarate enters the Krebs cycle whereas arginine is hydrolysed to form urea and ornithine.

3. **Regulation of lipids**. The liver cells remove lipids from blood, and either break them down or modify them and send them to the fat deposits.
4. **Detoxification**. In converting ammonia into less toxic compound urea, the liver is functioning as a detoxifying organ. The liver cells detoxify many other poisonous substances, including some drugs, by absorbing them and then changing them chemically. E.g. hydrogen peroxide a highly toxic by-product of certain metabolic pathways, is rapidly split into water and oxygen by the enzyme catalase found in the liver. Foreign particles in the blood stream are removed by phagocytic cells (macrophages) lining blood vessels in the liver.
5. **Production of heat**. The liver is involved in temperature regulation. Its consistently high metabolic rate, coupled with its large size and excellent blood supply, makes it ideal for the steady production and distribution of heat.
6. **Production of bile**. Bile is synthesized by the liver cells and stored in the gall bladder. From the later, it passes the bile duct to the duodenum. The bile salts play an important part in digestion by emulsifying fats in the small intestines. Bile also contains several excretory products.
7. **The Formation of cholesterol**. This is a lipid like substance, some of which is required as an important constituent of the cell membranes, especially of the nerve cells. Excess cholesterol is excreted in the bile. If it is in excess, it may precipitate in the gall bladder or bile duct as gall stones leading to blocking of the bile duct and thus obstructive jaundice in which the skin acquires a characteristic yellow appearance due to retention of bilirubin in the blood. If there is considerable excess in the blood, it may block the arteries leading to coronary thrombosis or heart attack.

8. **Elimination of sex hormones** after they have performed their functions. Some are modified chemically by the liver cells, some are sent to the kidney for renal excretion, and others are excreted in bile.
9. **Formation of red blood cells.** In the foetus, the liver is responsible for4 the formation of red blood cells, but gradually this function is taken over by the bone marrow. However, the adult liver still plays an important role in the production of red blood cells for it stores vitamin B_{12} a porphyrin with cobalt in the centre which is required for the formation of red blood cells in the bone marrow. If this vitamin is lacking, the result is pernicious anaemia, a fatal condition characterized by a drastic reduction in the number of red blood cells and therefore in the amount of haemoglobin in blood.
10. **Elimination of haemoglobin** from used red blood cells. The haemoglobin is broken down by the liver cells into the green pigments biliverdin, which is then reduced to the brown pigment bilirubin, high levels of bilirubin cause a disease Jaundice characterized by a yellowish tint to the white of eyes, lightly pigmented skin .Thus it is eliminated in the liver giving it a characteristic colour.
11. **Storage of blood.** The veins in the liver have great powers of expansion and contraction, to such an extent that the total volume of blood in the human liver can vary from 300cm^3 to 1500cm^3. This enables the liver to serve as a blood reservoir. Along with the spleen, it can regulate the amount of blood in the general circulation.
12. **Synthesis of plasma protein.** They include fibrinogen, the protein responsible for the clotting of blood. The other two plasma proteins, albumen and globulin have a number of functions connected with homeostasis.
13. **Storage of vitamins.** Including A, D and B_{12}, and a number of minerals such as potassium, iron and copper.

HOW THE LIVER IS ADAPTED TO ITS FUNCTIONS

- Kupffer cells ingest worn out red blood cells, bacteria and foreign particles from the blood flowing through the liver.
- Closeness of hepatocytes with sinusoids and canaliculi enables them to receive nutrients and expel waste substances.
- The excellent blood supply provides nutrients to the cells and enables wastes to be carried away.
- Hepatocytes bear numerous mitochondria for ATP production required in providing energy that facilitates some of the metabolic reactions.
- Hepatocytes, which are in contact with blood vessels, bear microvilli to increase the surface area for exchange of substances.
- The liver is large, providing large surface area for metabolic reactions to occur.
- Hepatocytes bear numerous peroxisomes containing catalase and other oxidative enzymes responsible for detoxification of poisonous substances in the liver.
- Its tissue is elastic, enabling expansion to store large volume of blood
- Hepatocytes are similar in structure; undifferentiated enabling them to perform various metabolic functions

CONTROL OF BLOOD SUGAR

The normal concentration of glucose in humans is 90mg/100cm^3 of blood but normally varies between 70-120mg/100cm^3 of blood. After absorption from the small intestines, glucose is carried to the liver where:-

- ✓ It may be broken down to carbon dioxide and water to release energy; cell respiration
- ✓ It may be converted to glycogen and stored, a process known as glycogenesis.
- ✓ It may be converted into fats and sent to the body's fat deposit for storage.
- ✓ Instead of being stored, glucose may be passed to the general circulation from the liver.

The level of glucose in blood and tissue fluids is controlled by self-adjusting mechanisms.

If there is too much glucose in blood, the liver metabolizes some and stores the rest as glycogen. If there is a deficiency of glucose the same liver rises the glucose level in the blood. It adds the glucose to the blood in two ways:

a. Glycogenolysis; this is the breakdown of glycogen to glucose.
b. Gluconeogenesis; this is the conversion of proteins into glucose.

Mechanism of regulation;

These inter conversions of glucose and glycogen are under the hormones produced by the pancreas.

The cells; islets of Langerhans in the pancreas consisting of alpha cells which secrete glucagon and beta cells that secrete insulin.

- ☑ When the glucose level rises above the normal, the beta cells of the islets of Langerhans secrete the hormone insulin directly into the blood stream and conveyed to the liver. On reaching the liver, insulin exerts its effects by:
- Increasing the conversion of glucose to glycogen and fats; glycogenesis
- Inhibiting the formation of glucose from glycogen and other sources; inhibiting gluconeogenesis.
- Increasing the breakdown of glucose in the liver and other cells; cell respiration.
- Insulin thus lowers the amount of glucose in blood restoring the normal level.

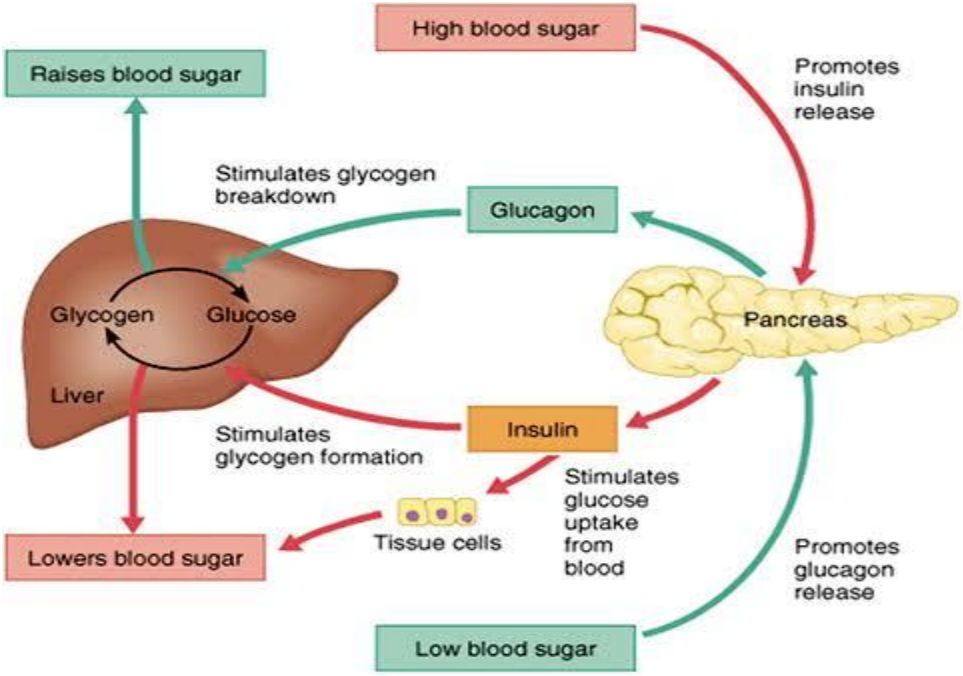
- ☑ When the blood glucose level falls below the normal, the alpha cells of the islets of Langerhans secrete another hormone, glucagon which is transported to the liver and other cells and causes the Conversion of glycogen to glucose; **Glycogenolysis**.
- ☑ The adrenal glands also secretes adrenaline which increases the breakdown of glycogen to glucose and glucocorticoids e.g. cortisol which causes the conversion of amino acids and glycerol to glucose. The overall effect is to raise the normal glucose level.
- ☑ The thyroid glands also secrete thyroxine which stimulates the conversion of amino acids and glycerol to glucose; **gluconeogenesis**.

NOTE:

1. It is the amount of glucose in the body which affects the secretion of the insulin and glucagon. If the blood glucose is abnormally high, it stimulates the beta cells to secrete more insulin. If the glucose level falls, the alpha cells secrete more glucagon.
2. In other words it's the glucose itself which switches on the mechanism by which it is regulated, thus setting into motion the physiological process which returns it to the normal value.
3. In conditions of stress, adrenaline is released from the adrenal glands which causes the breakdown of glycogen in the liver and rises the blood sugar level.

4. In absence of insulin blood glucose goes beyond the normal level, a condition known as **hyperglycemia**. When it reaches a particular level, glucose starts to be excreted in urine a condition known as **glycosuria**.
5. The same happens to people whose pancreas is damaged. This leads to a condition known as **Diabetes mellitus**. This condition can be reversed if insulin is injected regularly into the blood. The hormone can't be taken orally for it can be digested by the gut enzymes.
6. Insulin dependent diabetes is caused by insufficient secretion of insulin while insulin independent diabetes results from insensitivity of cells to insulin.

Note; check Biological science 3rd edition pg650 and Figure 15.6



CONTROL OF RESPIRATORY GASES.

- The amount of carbon dioxide and oxygen is determined by breathing, circulation system and vasodilatation. All cells require continuous supply of oxygen sufficiently for respiratory needs.
- The homeostatic control of both oxygen and carbon dioxide levels in the blood is carried out by the breathing centers in the medulla oblongata of the brain; hind brain. The ventral portion of the breathing centre controls inspiration and the remaining controls expiratory.
- These depend on the chemical receptors which are sensitive to changes in the carbon dioxide concentration in blood.
- When the carbon dioxide level is high, increased ventilation of the respiratory surface is required and the nerves from the chemoreceptor stimulates the respiratory centre in the medulla therefore inspiration takes place in the lungs and vice versa.
- The breathing centre may also be stimulated by the impulse from the fore brain resulting into increase or decrease breathing rate.

CONTROL OF BLOOD PRESSURE

- This is achieved by controlling the rate at which the heart pumps blood and by vessel constriction or vessel dilation of the blood vessels.
- The changes in the heart beat alter the blood pressure thus maintain a high level to allow blood to reach all the tissues requiring it.
- Blood pressure is controlled by the diameter of blood vessels. Vessel constriction results in blood vessels narrowing thus increasing blood pressure while vasodilation results when blood vessels widen thus lowering blood pressure. These two are also controlled by the medulla oblongata; vasomotor centre.
- The pressure receptors; baroreceptors detect pressure changes and send the impulses to the vasomotor which in turn sends a message to the arterioles to dilate and so reduce blood pressure if it was high.
- The increase in blood carbon dioxide also causes a rise in blood pressure. It increases the speed with which blood is pumped to the lungs thus aiding removing of carbon dioxide more quickly.
- Hormones like adrenaline increase the blood pressure of an animal. This hormone prepares the body for action. It therefore links the nervous and the endocrine system thus affecting heart beat.

TEMPERATURE REGULATION

- This is also referred to as thermoregulation. Temperature of environments inhabited by living organism ranges from 90^0C in hot springs to -40^0C. Most organisms ranges from 10 to 30^0C but they are able to exert some control over their body temperature.
- In all organisms heat is gained in two main two ways:

1. Metabolism of food.
2. Absorption of solar energy. This may be absorbed directly or indirectly from heat influenced from the object. Heat from warm grounds (convections) and heat conducted from the grounds.

Heat is also lost in four main ways;

1. Evaporation of water during sweating
2. Radiation from the body to air, water or grounds
3. Convection from the body to air or water
4. Conduction from the body to the ground or other objects.

Importance of temperature regulation

- Most body enzymes act efficiently within a narrow temperature range of 35 – 38^0C. Excessive temperature exceeding 45^0C denatures enzymes and other proteins and below that range inactivates enzymes, both of which are fatal.
- Excessively high or too low temperature disorganizes the structure and functioning of cell surface membranes, and consequently affects entry and exit of substances resulting into death of the organism.

According to heat; temperature regulation there are two groups of animals, endothermic and ectothermic animals.

ENDOTHERMS /HOMOIOTHERMS

- These are animals which maintain a constant body temperature irrespective of the environment temperature changes.
- Their heat is maintained internally by metabolic activities e.g. mammals and birds. Their body temperature ranges from 35 to 44^{0}C.

Advantages of endothermy

- Animals are able to exploit various environments regardless of existing temperatures.
- Enzyme controlled reactions proceed without much interruption most of the time.
- Due to maintenance of high metabolic reactions all the time, plenty of energy is availed to support body processes.

Disadvantages of endothermy

- There is high food intake during low environmental temperature to support the metabolic reactions that liberate heat.
- Enzyme controlled reactions are slowed down during low temperature because enzymes are inactivated.
- It requires efficient cooling mechanisms during hot temperatures to avoid overheating of the body and efficient insulation when the external temperature is too low.

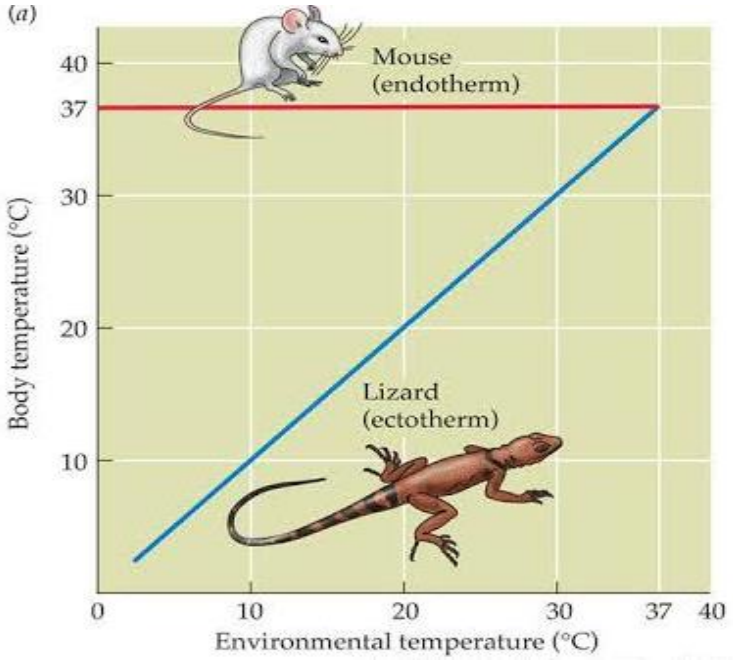
ECTOTHERMIC/POIKILOTHERMIC ANIMALS.

- ✓ These are animals which obtain most of their heat from sources around the body. Their temperature changes according to the environment but never becomes equal to that of the environment e.g. during exercise the metabolic heat produced may rise the temperature above that of the environment.
- ✓ Most ectotherms regulate their body temperature within limits e.g. reptiles, fish, amphibians and invertebrates.

Advantage of ectothermy;

- There is low food intake since regulation of temperature is by behavioural means and from the environment.

If a lizard (an ectotherm) and a mouse (an endotherm) are placed in a closed chamber in which the temperature is gradually raised, the body temperature of the lizard will equilibriate with that of the chamber, whereas the body temperature of the mouse will remain constant.



Disadvantages of ectothermy;

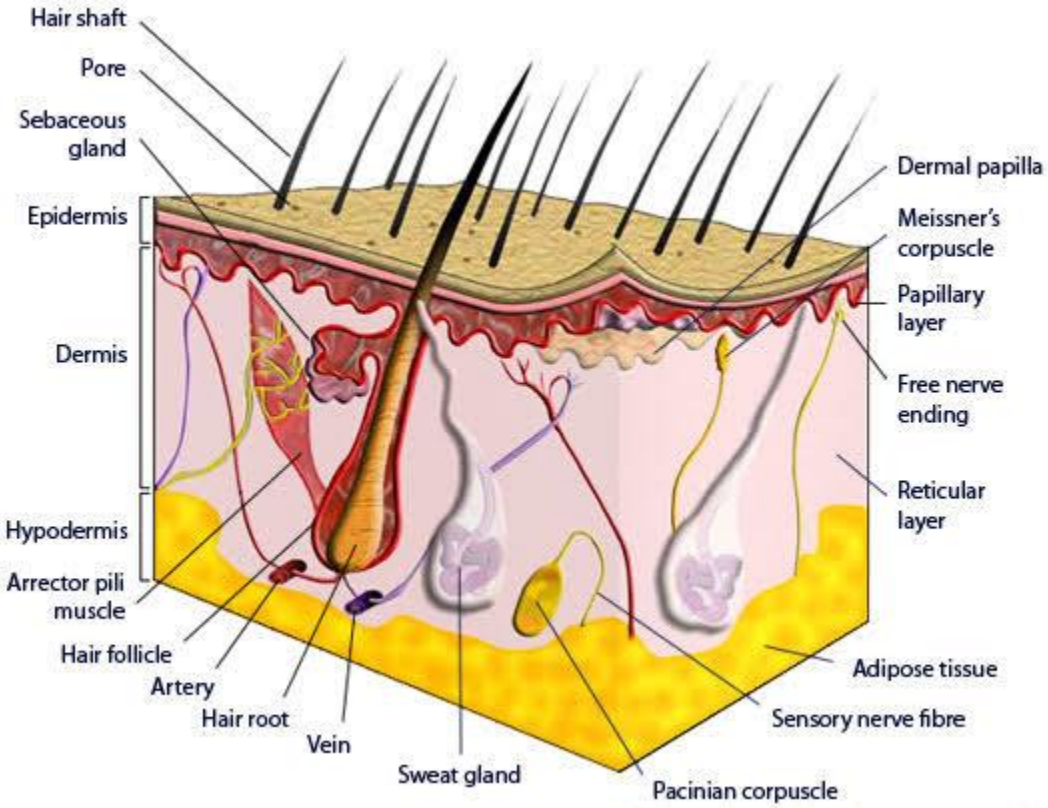
- Animals limited environments to exploit depending on the existing external temperatures
- Their activities are limited during instances of extreme temperatures.
- There is sluggishness and very low response to stimulus in very low temperatures.

THE STRUCTURE OF THE SKIN

The skin plays the most important role in thermoregulation. It has two main layers, the epidermis (outer) and dermis (inner). The epidermis comprises of three regions; the Malpighian layer, granular layer and the Cornified layer. The dermis possess the connective tissue containing hair follicles, blood capillaries, sebaceous gland, subcutaneous part and the sensory nerve ending.

1. **The Cornified layer/ stratum corneum.** This is a surface layer of the skin consisting of dead cells impregnated with keratin. It is tough, resistant and water proof. It is thickest where there is greatest wear i.e. palms of hands and sole of feet.
2. **The granular layer/ stratum granulosum.** This is made of living cells produced by Malpighian layer. As they are pushed towards the skin surface by new cells produced beneath, they accumulate keratin; fibrous protein and lose their nuclei and die
3. **The Malpighian layer/ germinative layer.** This is the deepest layer made up of actively dividing cells. It produces a pigment melanin which determines the skin colour. Melanin absorbs ultra violet light and so protects the tissues beneath from its damaging effects. The Malpighian layer has numerous infoldings that extend into the dermis forming the sweat glands, sebaceous glands and hair follicle. There are no blood vessels in the epidermis and so the cells of this layer obtain food and oxygen by diffusion and active transport from capillaries in the dermis.
4. **Nerves.** These are different sensory cells concerned with providing information on the external environment e.g. touch receptors, pain, temperature and pressure receptors.
5. **Hair follicles.** These result from in pushing of the Malpighian layer. The cells at the base multiply to produce a long cylindrical hair, the cells of which become impregnated with keratin and die. The more melanin in the hair, the darker its colour. The hair is attached to smooth muscles which contract causing the hair to erect.
6. **Subcutaneous gland.** These are found at the side of the hair follicle these produce sebum; oil secretions which waterproofs the hair and epidermis and also protects it against bacteria.
7. **Blood vessels.** This supply both to the epidermis and the dermis with food. The sweat glands and hair follicles are supplied with special network. They play a role in thermoregulation.
8. **Sweat glands.** These are made up of cells which absorb fluids from surrounding blood capillaries and secrete it into sweat ducts. Evaporation of sweat from the skin surface helps to cool the body. Sweat has a variable composition, consisting of mainly water in which mineral salts and urea are dissolved.

9. **Subcutaneous fat layer.** This is a layer of fat tissue; adipose tissue. This acts both as a long term food reserve and as an insulating layer.
   Or check understanding biology page 502



Functions of the skin;

- It is the major organ involved in temperature regulation in the body.
- It provides protection against mechanical damage, ultra violet radiation from the sun, microorganism invasion and water loss of underlying tissues.
- It is a sense organ, containing sensory nerve endings for detecting temperature, touch, pressure and pain.
- It is an excretory organ of urea, salt and excess water.
- It manufactures vitamin D when exposed to sun light. The dermis contains lipids called sterols which are converted by ultraviolet light into vitamin D

RESPONSE OF ENDOTHERMIC ANIMALS TO WARM ENVIRONMENT

a. **Structural adaptations**

- The erector Pilli muscles relax and lie flat on the body. No air is trapped and therefore insulation is reduced hence heat loss is encouraged.
- Animals living in hot climates have relatively little subcutaneous fat. The fat deposits are localized so that heat loss is facilitated e.g. buffalos have fats located on top of the neck, camel has fats stored in the hump.
- Vasodilation. The superficial arterioles dilate to bring more blood near the surface and heat is lost rapidly by conduction from the skin surface.
- Large surface area to volume ratio. Animals in worm environment have large extremities eg the ears compared to cold living animals. Their ears are supplied with blood vessels and short hair making them good radiators of heat.

- Sweating. Evaporation of sweat causes cooling of the skin and blood flowing in it. Sweat glands are common in areas of the skin where fats are absent e.g. pads of feet in dogs.
- Panting and licking. Animals with few or no sweat glands, cooling by evaporation of water takes place through the mouth and nose e.g. dogs, goats, chicken etc. panting in dogs result in the increased breathing rate.

b. **Physiological adaptations**
- The metabolic rate falls so that less heat is generated in the body. This is why animals are less active on hot days.
- Temperature tolerance. The tissue of some animals e.g. camels can function at a wide range of body temperatures. A camel saves water by not sweating. However its body temperature rises to 40^0C and at night, its body temperature falls to 34^0C. This low initial temperature in the morning prevents its body temperature from reaching a lethal temperature by evening.

c. **Behavioral adaptations.**
- Hibernating during very hot periods to avoid great heat loss. E.g. by staying in deep burrows where temperatures are tolerable.
- Being nocturnal e.g. the kangaroo rats resorts to nocturnal life.
- Aestivation; a response to very dry conditions where an organism burrows and hides in mud. The metabolic rate falls to basal metabolism e.g. lung fish.
- Swimming
- Taking cold drinks.
- Putting on light clothing
- Moving to shady places.

RESPONSE OF ENDOTHERMIC ANIMALS TO COLD ENVIRONMENT

a. Structural adaptation.
- Vasoconstriction. The superficial arterioles contract reducing the volume of blood reaching the skin surface. Most of the blood passes beneath the subcutaneous fat thus little heat is lost to the surrounding.
- Insulation. This reduces heat loss from the body by having an external covering of fur or feathers or an internal layer of subcutaneous fat. The thickness of fur is related to the environmental temperature, with animals in cold environments having denser and thicker fur.

Mechanism;
- Rising of the hair by contraction of the erector Pilli muscles resulting in the air being trapped between the hairs. The air being a poor conductor of heat serves as an insulator layer preventing heat loss.
- Aquatic animals have blubbers which are layers of thick subcutaneous fat to increase insulation.
- Small surface area to volume ratio. Under cold conditions, the animals have smaller extremities compared to those in warm areas and thus heat loss is reduced.

b. Physiological adaptations.
- Shivering. Under cold conditions, the muscle undergoes involuntary rhythmical contractions which produce metabolic heat. Shivering results into increased metabolic rate in both the liver and the muscles. This generates an extra heat.

- Increased metabolic rate. In addition to heat produced by muscle contraction during shivering, the liver also increases its metabolic rate. The activities of the thyroid, adrenaline and the pituitary gland are induced by low temperature. These glands produce hormones that increase the body's metabolic rate.
- Variation of superficial and core temperatures. The extremities of animals in cold conditions are maintained at a lower temperature than the body temperature thus reducing the temperature gradient between them and the environment. The reduction of heat from extremities like feet, ears etc is achieved by the counter current heat exchangers found in the limbs of certain birds and animals.

Mechanism;
Blood in veins returning from the limbs pass alongside blood in arteries which is warm and therefore there is exchange of heat. The limb is kept at lower temperatures and the cold blood is prevented from entering the core of the body.

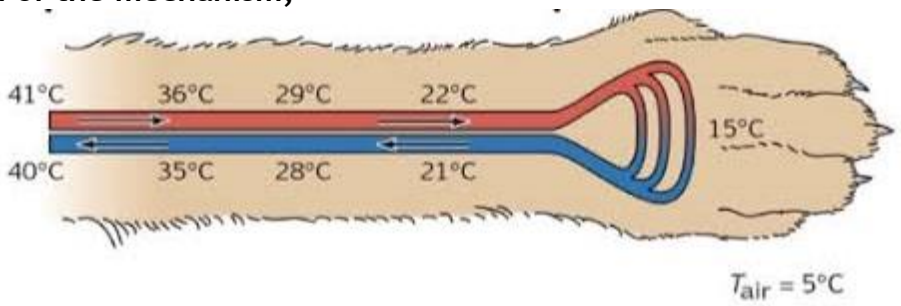
c. Behavioral adaptations.

- Hibernation. This is when animals in cold conditions undergo a period of long sleep when the metabolic rate is reduced below that of the normal with consequent reduction of food and oxygen consumption. This may last for months.
- In cold regions animals are usually active during day time and resting at night i.e. diurnal.
- Huddling together in groups to minimize heat loss.

THE COUNTER CURRENT HEAT EXCHANGER SYSTEM.

- ✓ This system reduces the rate at which heat is lost from limbs of the organism; in the limbs, arterial and venous are in very close proximity. The warm arterial blood flowing towards the tip of the limb loses its heat to the cold venous blood which flows towards the heart; this ensures that the arterial blood reaching tip of the limb is cooled in order to reduce heat/ temperature gradient between the body and its surrounding; thus reducing heat loss;
- ✓ The arterial and venous blood flow in opposite directions hence counter current; it is heat exchanger because arterial blood loses its heat to the venous blood such that blood reaching the heart is warm ; this is found in whales, flukes of seals, wings and legs of birds, and testes of male mammals.

Illustration of the mechanism;



Or check F.A page 239 fig. 15.8

ROLE OF THE BRAIN/ HYPTHALAMUS IN TEMPERATURE REGULATION.

Physiological responses to temperature changes are controlled by the thermoregulatory centre in the hypothalamus of the brain.

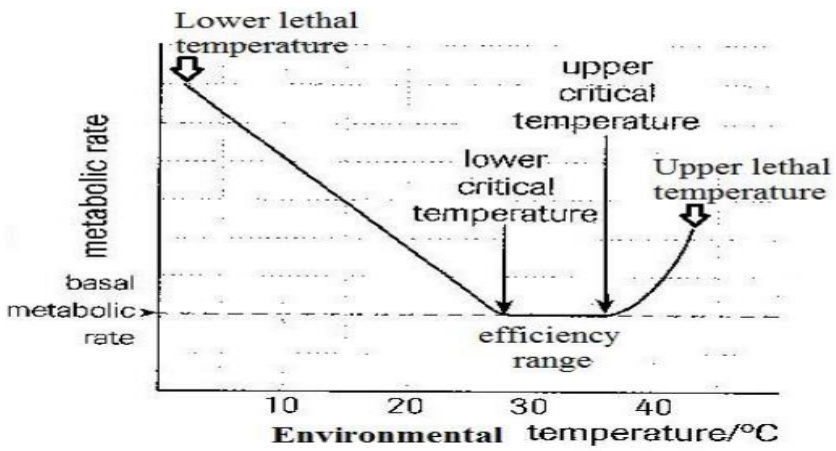
- Variation in body temperature is directly monitored by heat receptors in the hypothalamus and indirectly by receptors in the skin. Receptors in the skin monitor variation of external temperature.
- If the temperature of blood flowing through the hypothalamus drops extremely (hypothermia), the heat gain centre is stimulated to send impulses to the liver and muscles to raise metabolic rate so as to generate heat, and to the skin to cause vasoconstriction to reduce heat loss at the skin surface, reduction in sweat production, contraction of erector pili muscle and shivering. The overall result is increased body temperature to normal.
- If the temperature of blood flowing through the hypothalamus rises extremely (hyperthermia), the heat loss centre is stimulated to send impulses to the skin to cause vasodilation to enable more heat loss at the skin surface, increased sweat production to enable more evaporation, relaxation of erector pili muscles to lower the hairs to avoid air insulation, and to inhibit shivering to minimize heat production by metabolic reactions. All these enable lowering of temperature to normal.
- Variation in external temperature stimulates receptors in the skin to send impulses to the brain and the animal's behaviour is modified accordingly e.g. if the skin heats up, the animal may move to the shade, while cooling of the skin surface may give rise to increased metabolic activity.

CONTROL OF BODY TEMPERATURE THROUGH NEGATIVE FEEDBACK.

When the body temperature rises above the optimum (norm), the thermoregulatory centre activates corrective mechanisms that increase heat loss and reduce heat production. This reduces body temperature back to norm.
When body temperature falls below the optimum level (norm), the thermoregulatory centre activates corrective mechanism that decrease heat loss and increase heat production. This increases body temperature.
Check page. 237 fig 15.5 functional approach for the illustration.

EFFECT OF CHANGING ENVIRONMENTAL TEMPERATURE.

The effect of environmental temperature on the metabolic rate of a human.



Terms relating to temperature regulation.

1. Low critical temperature:

This is low environmental temperature at which physical mechanisms like vasoconstriction and erection of hair fail to maintain body temperature constant, triggering a rise in metabolic rate to generate heat to maintain body temperature constant.

2. Lower lethal temperature:

This is extremely low environmental temperature at which increased metabolic rate fails to generate enough heat to maintain body temperature constant, resulting into death of the organism.

Hypothermia is the condition that results when heat loss greatly exceeds heat gain from metabolism due to prolonged exposure to cold, resulting into great reduction in core body temperature of the organism.

3. High critical temperature:

This is high environmental temperature at which physical mechanisms like sweating and vasodilation fail to maintain body temperature constant, triggering a rise in metabolic rate and body temperature as environmental temperature rises.

4. Upper lethal temperature:

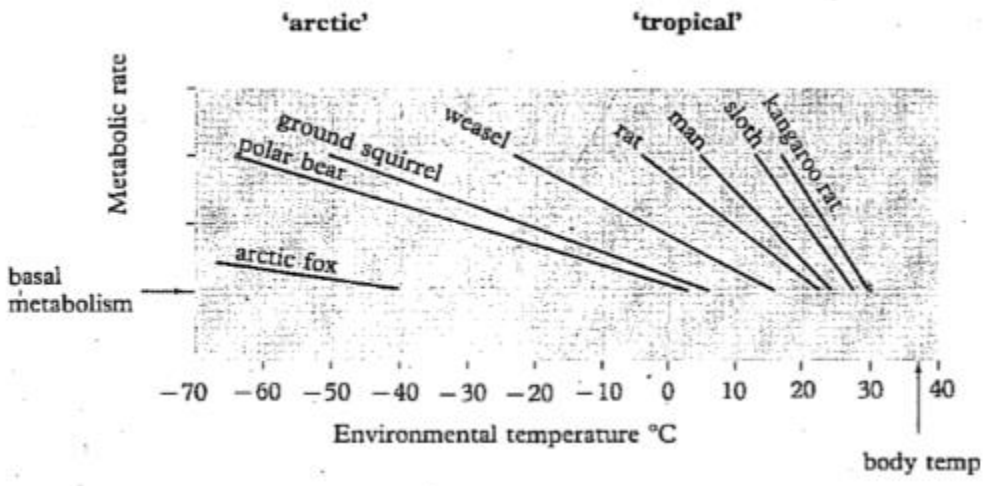
This is an extremely high environmental temperature at which increased metabolic rate generates excessive heat which denatures enzymes and other structures, resulting into death of the organism.

5. Efficiency range (Range of thermo neutrality):

This is external temperature range at which the body's physical mechanisms are capable of maintaining temperature constant. In man this is 27 – 31^{0}C.

Efficiency range varies according to the environmental temperature in which the animal inhabits. This is because animals have the ability to acclimatize. If the environmental temperature is high, acclimatization is by raising the upper critical temperature and if low, acclimatization is by lowering lower critical temperature.

NOTE: Below the lower critical temperature, the graph of metabolic rate and environmental temperature is much less steep for cold dwellers than for warm dwellers because animals in colder conditions have better insulating mechanisms than those in warmer places.



EXPLANATION OF VARYING ENVIRONMENTAL TEMPERATURE

- When the environmental temperature is lowered below the normal environmental temperature (29^{o}C) up to freezing point. The individual will begin to maintain his/ her body temperature by purely physical means. Until a point is reached when the physical mechanism breaks down and can no longer maintain a constant body temperature, the environmental temperature (27^{0}C) at which the physical system breaks down I called low critical temperatures. And is the lowest temperature at which the mechanism the physical mechanism alone can regulate the temperature.
- And if the temperature is lowered further, the temperature is now maintained constant by the chemical means and the metabolic rate continues to increase until the chemical mechanism breaks down. The temperature at which it breaks down is called the lower lethal temperature and the organism dies.
- And if the temperature is gradually increased from normal, at first the body all the various mechanisms promoting heat loss operate to keep the body temperature constant. But a point is reached when the ability of the body to regulate its temperature breaks down. The temperature at which this occurs is called the high critical temperature and it may vary according to the humidity. At this point the metabolic of the body begins to rise with increase in the environmental temperature.
- For every 10^{o}C temperature rises, the metabolic rate doubles. The body's mechanism regulating the temperature fails and at this point the metabolic rate rises even if the temperature of the environment remains constant. This is because every time the metabolic rate rises, it generates more heat which raises the metabolic rate bit more. This is an example of a positive feedback. As the body temperature continues to rise, heat exhaustion occurs which is characterized by cramps and dizziness. This is followed by death. The environmental temperature (about 42^{O}C) at which this occurs is called upper lethal temperature.

OR Check Graphs in fig 15.7, page 239, functional approach
Other special adaptations include;

- ✓ Closely related organisms tend to be larger in cold regions than in warm regions. They have large surface area to volume ratio hence less heat loss and vice versa.
- ✓ Extremities such as ears are smaller in cold dwellers; to minimize heat loss while in warm dwellers, extremities are large with a rich blood supply to promote heat loss.
- ✓ In the flippers of dolphins, whales and in the legs of ducks, the arteries and veins are very close to each other. This ensures that as warm blood flows down the arteries, heat is conducted into the cold blood flowing in the opposite direction in the vein. This achieves two things.
- ✓ Temperature tolerance. This is well adapted to very hot dry conditions by; having tolerant tissues to high temperatures (between 34^{0}c and 41^{0}c) and having tolerant tissues to dehydration.

CONTROL OF BODY TEMPERATURE IN ECTOTHERMS

In these, the temperature regulation is almost entirely by behavioral means which include the following:-

1. Migration. Animals can regulate their body temperature by moving from either warm to cold or vice versa e.g. lizards, fish, insects.
2. Thermo gaping. Here the animal opens its mouth wide open and evaporation of water from the buccal cavity causes a cooling effect e.g. in alligators and crocodiles. Some improve this by protruding their tongue and breathing rapidly.
3. Salivation. Some animals salivate over their necks and front legs so that when saliva evaporates, it produces a cooling effect e.g. tortoise.
4. Burrowing. At night, desert lizards may burrow under rocks and crevices in which they build up a warm atmosphere from heat generated by their metabolism.
5. Basking. Some reptiles e.g. lizards lie on the surface of rocks where they can gain or lose heat by conduction, radiation, convection or reflection.
6. Hibernation. This is a behavioral response to cold condition where by an animal goes to deep sleep. The metabolic rate falls to basal, the body temperature falls and is maintained at a lower minimum than normal. Hibernation is very important especially in very small animals which cannot cope with high metabolic rate required to maintain body temperature.
7. Aestivation. It is a behavioral response to very dry or drought condition whereby an animal goes into dormancy.
8. Thermo-dancing. E.g. lifting opposite pairs of feet alternatively so that they cool in air during hot weather.

THERMOREGULATION IN PLANTS

- Plants lose and gain heat by the same physical processes as animals – radiation, evaporation, conduction, and convection.
- Plant tissues can tolerate wide fluctuation in temperature and are adapted to live in a variety of habitats, but still they must regulate temperature to avoid overheating which would denature enzymes, and freezing of tissues which would slow down metabolic processes.

Plants avoid overheating by:

- Transpiration – as the water evaporates into the atmosphere, plant bodies cool down.
- Wilting – parenchyma cells lose turgidity and drop to reduce the surface area of leaves and stems exposed to the sun, hence avoiding much heat gain.
- Possession of shiny cuticle on leaves to reflect heat (sun's radiation) and avoid overheating.
- Possession of small needle-like leaves in some plants also reduces excessive heat gain from the sun's rays.

Plants avoid overcooling by:

- Producing spores or seeds, which are very temperature resistant.
- Losing the easily damaged leaves when external temperature is low e.g. during winter in temperate plants.
- Orientating leaves to take maximum advantage of light at any one time so that they do not shade each other

EXCRETION AND OSMOREGULATION

- Excretion and osmoregulation are two important processes occurring in living organisms helping them to maintain a constant internal environment.
- **Excretion** is the removal from the body of waste products of metabolism. Products of metabolism mean that the waste products have been made by the body itself.

Note;

1. It differs from egestion which is the removal of undigested food and other substances not involved in metabolism. The only excretory products in faeces are bile pigment. These are breakdown products of the haem of heamoglobin.
2. It also differs from secretion which is the production of useful substances such as hormones, digestive juices by the body.

- **Osmoregulation** is a process by which the osmotic pressure of blood and tissue fluid is kept constant. It involves regulation of the water content and solute concentration of body fluids, particularly of sodium, potassium and chloride ions.
- Body fluids include cell contents as well as fluids outside cells such as blood plasma, tissue fluid and lymph.
- It is vital that the composition of these fluids should remain constant in order for cells to work efficiently.

Significance of excretion and osmoregulation.

- Removal of unwanted products of metabolic pathways in order to prevent imbalancing of chemical equilibrium of reactions.
- Removal of toxic wastes which when accumulated would affect the metabolic activity of the organism. Many toxic substances are inhibitors of enzymes involved in metabolic pathways.
- Regulation of ionic concentration of body fluids. Salts dissociate into ions in the aqueous conditions inside living organisms. E.g. NaCl dissociate into Na^+ and Cl^-. If the balance of these and other ions is not carefully regulated within narrow limits, the efficiency of many cell activities is reduced. E.g. the reduction in Na^+ concentration leads to a decrease in nervous coordination.
- Regulation of water content of body fluids. This is one of the major problems affecting living organisms. As it is crucial for survival.
- Regulation of pH. The pH of urine may vary between 4.5 and 8 in order to maintain the pH of the body fluids at a fairly constant level.

EXCRETORY PRODUCTS

They are of two types i.e. **Nitrogenous** and **non-nitrogenous** waste products.

The nitrogenous waste products include;

- ✓ Urea,
- ✓ Ammonia,
- ✓ Uric acid,
- ✓ Trimethylamine oxide (TMO)
- ✓ Creatinine.
- ✓ Guanine.

They come from the breakdown of proteins, nucleic acids or excess amino acids.
The non-nitrogenous wastes include;

- Water produced by aerobic respiration and condensation reactions and also taken in by nutrition.
- Carbon dioxide from cell respiration. In autotrophic organisms, this may be used as a source of carbon.
- Bile pigments such as bilirubin and biliverdin from breakdown of haem in the liver.
- Oxygen from photosynthesis in plants, algae and some bacteria. Some of this may be used in respiration.

EXCRETORY STRUCTURES.

- The cell surface membrane of unicellular organisms.
- The Malpighian tubules and trachea of arthropods.
- The kidneys, liver, gills, and skin of amphibian and fish.
- The kidneys, liver, lungs and skin of vertebrates.

EXCRETION IN MAMMALS.

1. The main excretory organs are the kidneys, lungs, liver and the skin. Roles of each include;
2. **Skin.** Water, Urea, and salts are actively secreted from capillaries in the skin by the tubules of the sweat glands. Sweat is secreted onto the skin where the water evaporates. In this way heat is lost from the body and this helps to regulate body temperature.
3. **Lungs.** Carbon dioxide and water vapor diffuse from the moist surfaces of the lungs, which in animals are the only excretory organs for carbon dioxide. Some of the water released at the lung surface is metabolic, i.e. produced as a waste product of respiration but its exact origin is not really important in view of the volume of water contained within the body.
4. **Liver**. Bile pigments are the excretory products from the breakdown of the haemoglobin of old red blood cells. They pass to the duodenum in the bile for removal from the body along with the faeces for whose colour they are partly responsible. The most important excretory role of the liver is formation of urea from excess amino acids during deamination.

THE MAMMALIAN KIDNEY

There are two kidneys one on each side of the abdomen and each contains between one and two million nephron, loosely embedded in the connective tissue and amply supplied with blood. The nephron can be regarded as a functional unit of the kidney performing both osmoregulation and excretion.

Structure of the nephron.

- ✓ At the end of the nephron is a spherical structure called Malpighian body.
- ✓ It is about 200ɥm in diameter, and is located in the outer region; cortex of the kidney.
- ✓ The Malpighian body consists of a cup shaped bow man's capsule which is like a ball that has been pressed in on one side. It has the inner layer made up of

podocytes. The invagination contains a dense network of capillaries called the glomerulus.

- ✓ Between the inner and outer lining of the capsule is a cavity, the capsular space whose inner and outer lining is closely attached to the walls of the glomerular capillaries.
- ✓ The barrier between the capsular space and the lumen of the capillaries is composed of only two layers of cells, the epithelium of the capsule and the endothelium of the capillaries.
- ✓ Leading from the bowman's' capsule is a tubule about 60ɥm in outer diameter whose lumen is continuous with the capsular space.
- ✓ The first part of the tubule is known as the proximal convoluted tubule which is contained in the cortex and highly coiled. It leads to a U shaped loop of Henle which plunges down into the deeper part of the kidney; the medulla where it does a hair pin bend and returns to the cortex.
- ✓ Here it leads on to another coiled section, the distal convoluted tubule which opens into a collecting duct along with several other nephrons. The ducts converge at the pelvis of the kidney, shedding their contents into the ureter which conveys the urine to the bladder for temporary storage.

NOTE:

- The essential role of the kidney is to purify the blood which flows through it, extracting and eliminating harmful substances and ensuring that it has the correct composition.
- Blood is conveyed to each glomerulus by an efferent vessel, a branch of the renal artery. Blood leaves the glomerulus by an efferent vessel which breaks up into capillaries enveloping the whole tubule system. Blood is drained from these capillaries surrounding the tubules before leaving the kidney.
  Check understanding biology page 480 fig.23.5 or FA, page 211, fig 14.1 A, B and C.

PRESSURE/ ULTRAFILTRATION IN BOWMAN'S CAPSULE

- × The capsular fluid in the capsular space is formed by the process of ultra-filtration from the glomerular capillaries and consists of exactly the same composition as blood plasma except for the plasma proteins and the blood cells. I.e. those components of blood which are too large to pass through the barrier between the glomerular capillaries and the capsular space.
- × This is the first stage of urine formation at the glomerular capillary wall of kidney nephrons during which hydrostatic pressure forces small molecules in blood of glomerular capillaries to pass across the basement membrane into the capsular space but large molecules are held back.
- × The substances that are forced by pressure to pass passively across the fine basement membrane filter include small molecules like water, glucose, amino acids, vitamins, urea, uric acid, ions, creatine, and some hormones while the large substances retained in blood include red blood cells, platelets, white blood cells and large sized plasma proteins.
- × Although filtration occurs through three layers of glomerular capillary, the endothelium is a coarse screen retaining only blood cells, the negatively charged basement membrane retains negatively charged large sized protein, while the selective filtration occurs at the diaphragms of slit pores formed by foot-like projections of supporting cells called podocytes

- The high hydrostatic pressure of blood in the glomerulus which facilitates ultrafiltration results from the afferent arteriole having a larger diameter than the efferent arteriole.
- Ultrafiltration is a passive process and selection of substances passing from the blood into glomerular filtrate is made entirely according to relative molecular mass.
- Because particle size rather than their importance determines the substances to pass through the basement membrane during ultra-filtration, useful substances such as glucose enter the capsular space to form glomerular filtrate and have to be reabsorbed later.

SELECTIVE REABSORPTION

After the glomerular filtrate has been formed, it flows along the tubules and eventually emerges in the collecting duct as urine. This occurs in the proximal convoluted tubule

The % concentration of a selection of substances in the glomerular filtrate and urine of mammal.

Substance	Glomerular filtrate	Urine
Water	90	95
Proteins	0	0
Sodium ions	0.3	0.35
Chloride ions	0.37	0.6
Glucose	0.1	0.0
Urea	0.03	2.0

From the table above it is shown that the concentration of urine is very different from that of the glomerular filtrate and this is clear that the fluid is modified as it flows along the tubule.

The proximal convoluted tubule is the longest and widest part of the nephron. Its cells are adapted for reabsorption as follows;

- Presence of numerous microvilli (brush border) and basal channels (infoldings of the cell surface membrane) which increases the surface area of the cells. For absorption of glucose, amino acids, vitamins, water among others.
- Numerous mitochondria to provide energy for active transport of substances such as glucose, amino acids, sodium ions, diphosphate ions and bicarbonate ions into the blood capillaries. The surface area of the capillary side of the tubule cells is increased further by the infoldings of the cell membrane.
- Closeness to the blood capillary which transport away the reabsorbed substances.
- The cell surface membrane is indented to form a large area of intercellular spaces bathed with fluid.
- Contain numerous pinocytic vesicles, which enable the digestion of small protein molecules from the renal filtrate.
- Form a thin thickness of one cell layer to ease reabsorption of substances.

NOTE. Over 80% of the glomerular filtrate is reabsorbed in the proximal convoluted tubule which include glucose, vitamins, amino acids, hormones and about 80% of NaCl and water.

MECHANISM OF REABSORPTION

- Glucose, amino acids and ions; Na^+ and Cl^- are reabsorbed by active transport i.e. diffuse into the cells of proximal convoluted tubule and then diffuse into the very permeable blood capillaries.
- The active transport of sodium ions followed by chloride ions into the blood capillaries rises the osmotic pressure and then water enters by osmosis.
- About 50-40% of urea in the glomerular filtrate is reabsorbed by diffusion into the blood capillaries but the remainder is excreted.
- Finally active secretion of some wastes e.g. creatinine and urea from blood into the tubule occurs.

THE LOOP OF HENLE.

- The function of this loop is to conserve water and it does do by reabsorbing water. It concentrates sodium and chloride in the medulla of the kidney resulting into osmotic movement of water from the collecting ducts.
- The descending limb of the loop of Henle is highly permeable to water, some solutes while the ascending limb is thicker and impermeable to water.
- Therefore the U-shaped loop acts as a hair pin counter current multiplier. The term counter current multiplier refers to the fact that the fluid flows in opposite directions in two sides of the loop, down one side and up the other.
- As the renal fluid flows down the descending limb, it becomes more and more concentrated due to the osmotic removal of water. As the glomerular filtrate flows up the ascending limb. Salts e.g. Na^+, K^+, and Cl^- ions are actively pumped out into the tissue fluid of the medulla and they can diffuse into the descending limb.

Adaptations of the loop of Henle to its function;

- The loop of Henle is U-shaped with parallel, opposite flows of tubular fluid in its limbs to provide a multiplier effect that create a concentration gradient, which enables increased water reabsorption.
- The capillaries of vasa recta form loops that accompany the loops of Henle resulting into countercurrent exchange of solute and water between ascending and descending blood.
- The capillaries of vasa recta are in close proximity with tubules to increase the reabsorption of useful substances from the filtrate.

THE DISTAL CONVOLUTED TUBULE AND THE COLLECTING DUCT.

- The cells of the distal convoluted tubule are similar to those of the proximal convoluted tubule. Water and salts are reabsorbed.
- As the fluid moves down the collecting duct which is permeable, the high salty concentration in the medullary tissue cause the osmotic movement of water from the duct into the tissue fluid and into the blood capillaries.
- The distal convoluted tubule also controls the pH of blood maintaining it at 7.4

Adaptations of the distal convoluted tubule to its functions;

- ✓ The distal convoluted tubule is long and coiled to increase the surface area for reabsorption of water and mineral salts.

✓ The distal and proximal convoluted tubules are coiled to slow down the movement of renal filtrate to allow more time for efficient reabsorption of substances like water, mineral salts.

HAIR PIN /COUNTER CURRENT MULTIPLIER SYSTEM

- A system of parallel and opposite flow of renal fluid in the descending and ascending limbs of the loop of Henle in the kidney with active salt concentration in the medullary interstitial tissue, an increase in salt concentration in the renal fluid of the descending limb and a decrease in salt concentration in the ascending limb to cause production of hypertonic urine
- The loop of Henle is the counter current multiplier and the vasa recta is the counter current exchanger.
- If the vasa recta did not exist, the high concentration of solutes in the medullary interstitium would be washed out.
- The ascending limb of the loop of Henle is relatively impermeable to water while the descending limb is freely permeable to water but relatively impermeable to salt and urea.
- Sodium and chloride ions are actively pumped out of the upper part of the ascending limb but diffuse from the lower part raising the solute concentration in the interstitial region and lowering the solute concentration in the ascending limb.
- Water is osmotically drawn from the descending limb and collecting duct and carried away by blood in the vasa recta, resulting into a slightly higher solute concentration in the descending limb than the adjacent ascending limb
- resulting into formation of hypertonic urine.
- The concentrating effect is multiplied such that the fluid in and around the loop of Henle becomes saltier with the saltiest region being the hairpin bend. The glomerular filtrate becomes less salty as it goes up the ascending limb.

PROCESS OF URINE FORMATION

✓ The afferent vessels which bring blood into glomerular in the bowman capsule is wider than the efferent vessels which take blood away. When blood flows from the afferent vessel into the glomerulus, a high pressure develop in the glomerular capillaries. This forces constituents of blood plasma with smaller molecules such as glucose, amino acids, hormones, urea, water and salts to pass into the capsular space but plasma protein and blood cells which have large molecules are prevented.

✓ The endothelium lining in the glomerular are very thin; one cell thick this permits easy passage of smaller molecules.

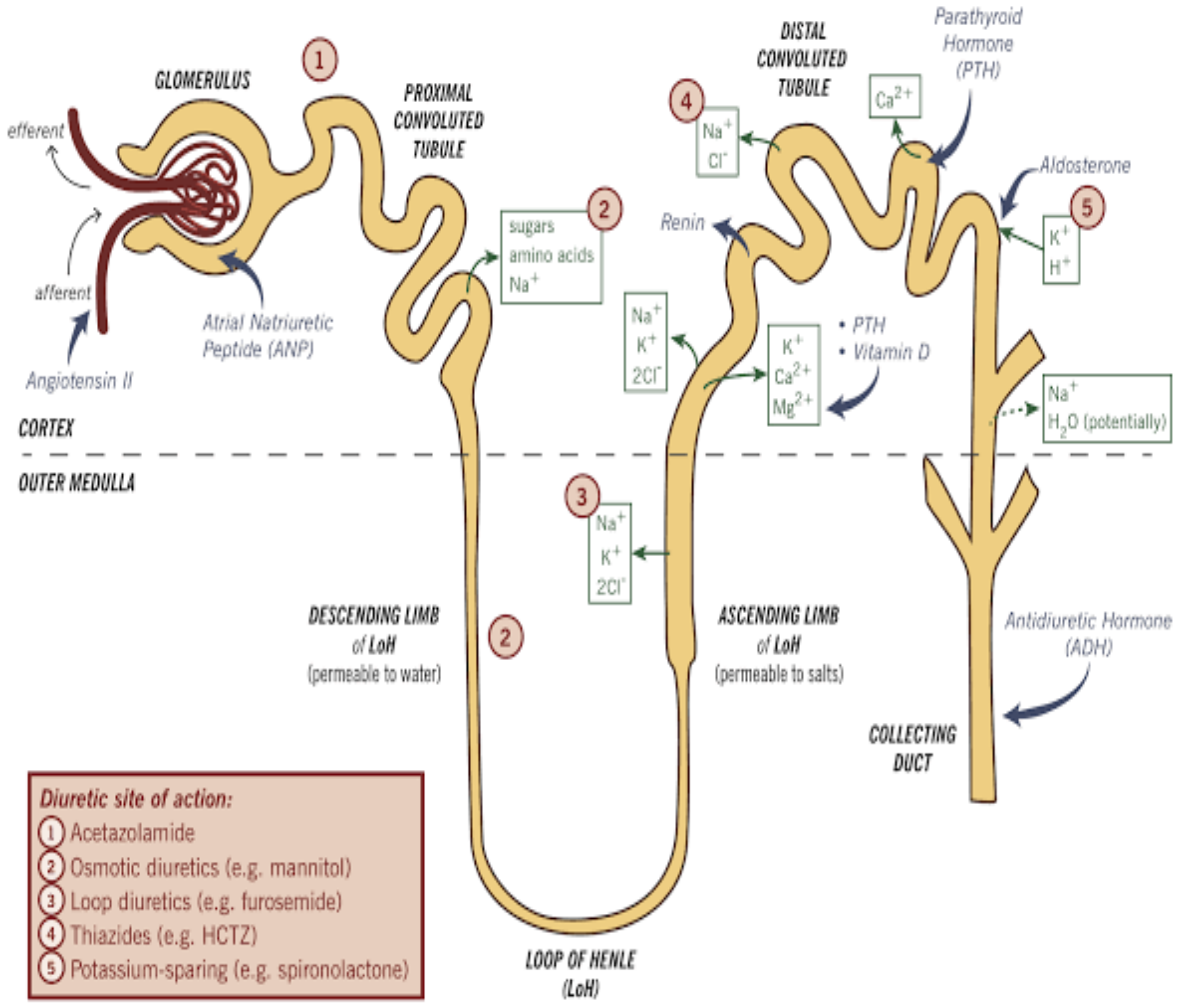
✓ In addition, the basement membrane and the endothelium lining in the glomerulus and the capsular space are pierced by numerous pores which allows only some substances with smaller molecular masses to be filtered out of the glomerular under high pressure a phenomenon called ultra-filtration; pressure filtration and the fluid that collects in the in the capsular space is called the glomerular filtrate. This is passed into the proximal convoluted tubule where there are glucose, amino acids, hormones, urea, and vitamins. Some water and salts are re-absorbed back into blood stream. Water is passively reabsorbed by osmosis, glucose and sodium ions are actively transported out of the proximal convoluted tubules. The energy for this process is provided by the numerous mitochondria present in the cells lining in the proximal convoluted tubules. As the renal fluid passes down the descending loop of

Henle, more water is re absorbed than the sodium chloride is passed out of the tubule; this increases the renal concentration of the fluid down the descending limb of the loop of Henle. While more sodium chlorides is passed out than water the renal fluid moves up the ascending loop Henle, this decreases the renal fluid concentration as it flow up the ascending limb of the loop of Henle.

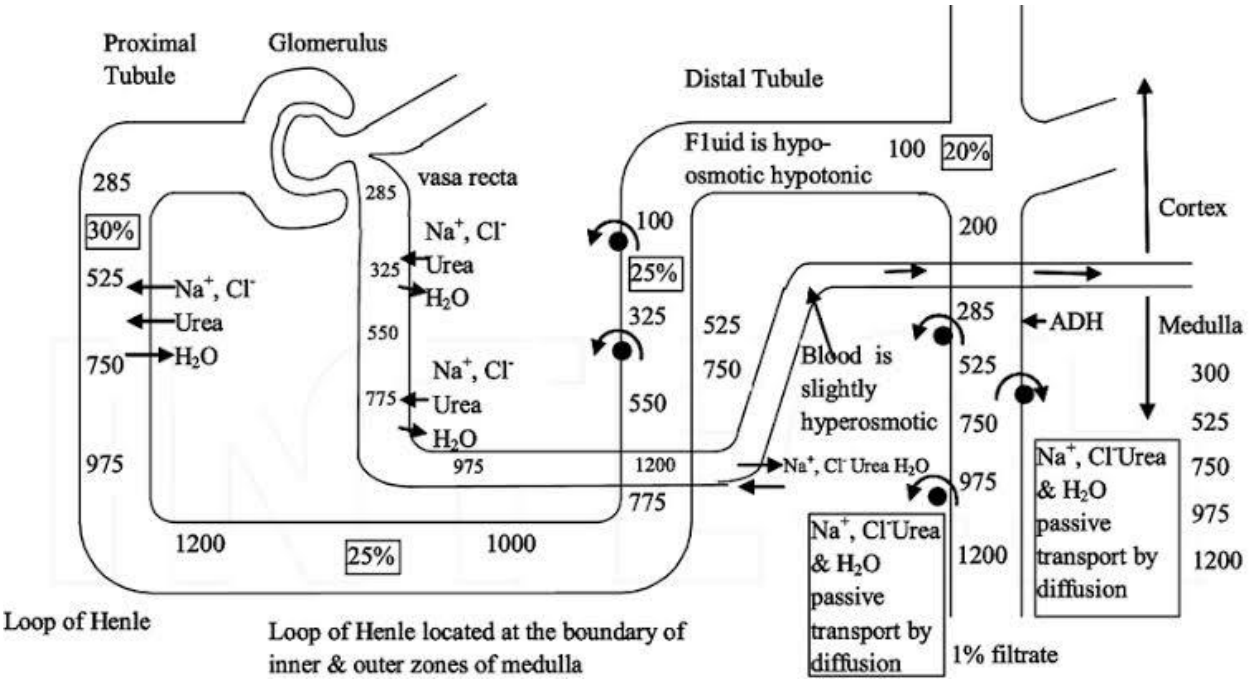
- ✓ When the osmotic pressure of blood is high water loss from the body, the hormone ADH is secreted. This causes the cells of the distal convoluted tubule and the collecting ducts to become permeable to water and more water is reabsorbed making the urine produced hypertonic.
- ✓ When the osmotic pressure in the blood is low, after much in-take of water or fluids, no ADH is released, cells of the distal convoluted tubules and the collecting ducts remain less permeable, little or no water is reabsorbed into the blood stream. Resulting in production of very hypotonic urine which is passed into the bladder for temporary storage before being excreted through the urethra.

NOTE: urine formation almost stops after serious bleeding;

- This is so because the amount of urine produced is proportional to the amount of blood flowing through the kidneys. The total blood volume in the body reduces if serious bleeding occurs, resulting into diversion of blood from other tissues; including the kidneys to the brain to maintain life. Therefore the



volume of blood flowing through the kidneys reduces greatly to the extent that less ultrafiltration and hence formation urine occurs.



GENERAL ADAPTATIONS OF THE KIDNEY TO ITS FUNCTIONS

- Numerous nephrons increase the efficiency for ultra-filtration, selective reabsorption, and secretion. This makes the kidney an excellent organ for excretion and osmo regulation
- The highly coiled tubules offer large surface area for reabsorption of materials. This is both longitudinally and transversely through the microvillus.
- The afferent and efferent arteriole has different sizes of the lumens which creates a pressure difference I the glomerular when blood flow from afferent to efferent arterioles. This is important in ultra-filtration.
- The thin layer of the and presence of small pores on the basement membrane of the Bowman's capsule allow easy passage of substances of smaller molecules from glomerulus to capsular spaces.
- Thin walls of the glomerular capillaries which allow easy passage of constituents of blood with smaller molecules sizes is out of the glomerulus.
- Close proximity of blood capillaries or vasa recta with the ascending and the descending loop of Henle makes it easy for the return and absorption of the essential substances into blood stream.
- The high concentration of the salts in one interstitial tissue, through which collecting ducts passes, this maximizes reabsorption of water back into blood and hence its conservation
- The tightly coiled glomerulus presents a large surface area for ultra-filtration of materials.
- The capsular space has a cavity or space which is cup shaped and conveniently contains the glomerular filtrate.
- Sensitivity of the cells of the collecting ducts to ADH encourages high re absorption of water to produce hypotonic urine this conserves water

- The epithelial cells of the proximal tubules contain numerous mitochondria for provision of energy to enable active transport of materials ie amino acids, glucose, from the kidney tubules.
- Special cells the podocytes at the proximal convoluted tubules at the proximal region enhance movement of fluids.

OSMOREGULATION IN MAMMALS

In mammals osmoregulation is achieved in two best ways i.e.

- Controlling the amount of water regulation
- Controlling the amount of salts gained and lost by the body.

REGULATION OF WATER

- The body maintains the solute potential of the blood at approximately steady state by balancing water uptake from the diet with water lost in evaporation, sweating, egestion and urine. The precise control of solute potential is achieved primarily by the effect of a hormone called antidiuretic hormone (ADH).
- Diuresis is the production of large amounts of dilute urine and anti-diuresis is therefore the opposite.
- ADH is antidiuretic in its effects so it has the effects of making urine more concentrated. ADH is a peptide hormone and is sometimes known as vasopressin.
- ADH is made in the hypothalamus and passes the shortest distance to the posterior pituitary gland by a process called neurosecretion.

Control mechanism;

- When blood becomes more concentrated; solute potential more negative in a situation where too little water has been drunk, excessive sweating has occurred or large amounts of salt has been ingested, osmo-receptors in the hypothalamus detect a fall in blood solute potential. This results in nerve impulses which pass to the posterior pituitary gland which releases ADH.
- ADH travels in blood to the kidney where it increases the permeability of the distal convoluted tubule and collecting duct to water. It does this by bringing about an increase in the number of water channels in the membranes lining the tubules.
- When ADH binds to its specific receptors in the cell surface membrane, it acts via cyclic AMP messenger system to stimulate the fusion of these vesicles to the cell surface membrane. When ADH secretion is stopped, the process is reversed and by a process of endocytosis, the vesicles are taken back into the cell ready for recycling next time ADH is secreted.
- In presence of ADH, the increased number of water channels allows water to move from the glomerular filtrate into the cortex and medulla by osmosis, reducing the volume of urine and making it more concentrated. The water is carried away by blood.
- ADH also increases the permeability of the collecting duct to urea, which diffuses out of the urine into the tissue fluid of the medulla. Here it increases the osmotic concentration resulting in the removal of an increased volume of water from the thin descending limb.
- The opposite occurs when there is a high intake of water. The solute potential of blood begins to get less negative, ADH release is inhibited, the walls of the

distal convoluted tubule and the collecting ducts becomes impermeable to water less water is reabsorbed as the filtrate passes through the medulla and a large volume of dilute urine is excreted.

- The hypothalamus also contains a thirst centre. When blood solute potential is very negative, the thirst centre stimulates the sensation of thirst.

Note;

1. Failure to release sufficient ADH leads to a condition known as **diabetes insipidus** in which large quantities of dilute urine are produced; diuresis. This leads to excessive/ frequent copious urination.
2. Aldosterone is responsible for maintaining a more or less constant sodium level in the plasma which has a secondary effect on water re-absorption. Any loss of sodium cause a decrease in blood volume and aldosterone causes sodium ions to be actively taken up from the glomerular filtrate into the capillaries which surround the tubule.

REGULATION OF SALTS; SODIUM IONS

- This is under the control of a steroid hormone aldosterone secreted by the adrenal cortex. It also influences water reabsorption.
- A decrease in blood sodium ions leads to a decrease in blood volume i.e. less water enters the blood which in turn reduces blood pressure and this is detected by the hypothalamus, which stimulates the anterior pituitary gland to secrete the hormone adrenocorticotropic hormone (ACTH), which stimulates a group of secretory cells; juxtaglomerular complex lying between the afferent arteriole and distal convoluted tubule to release an enzyme renin into the blood stream.
- Renin catalyzes the conversion of angiotensinogen; a plasma globulin produced by the liver into hormone angiotensin which then stimulates the adrenal cortex to release hormone aldosterone which has the following effects;

- Stimulates the Na-K pump in the cells of the distal convoluted tubule resulting in active reabsorption of sodium ions from the glomerular filtrate accompanied by reabsorption of water by osmosis.
- Increases the uptake of sodium ions in the gut and decreases loss of sodium ions in sweat. This effect raises sodium ion levels in blood, more water enters by osmosis raising blood volume and pressure.

NOTE: Elimination of potassium ion also accompanies the process therefore the overall effect of aldosterone is to raise the amount of sodium ions and lower that of potassium ions.

- A rise in sodium ions concentration in the blood above the norm, results into less secretion of aldosterone from the adrenal cortex. This decreases sodium ion reabsorption in the kidneys and its uptake in the gut. These reduces the concentration of sodium ion in the blood which in turn promotes water loss through urine, decreasing blood volume and blood pressure returns to the norm.

REGULATION OF CALCIUM IONS

The regulation of Calcium and phosphate ions is by a hormone called **parathormone** secreted by the parathyroid glands.

Control mechanism;

Low blood calcium level stimulates the parathyroid glands; surrounding the thyroid gland to secrete the parathormone; parathyroid hormone which increases the calcium level and decreases the hydrogen phosphate (HPO_4^{2-}) level through;

- ✓ Increasing the uptake of calcium ions in the gut.
- ✓ Increasing the reabsorption of calcium ions in the kidneys.
- ✓ Encourages the release of calcium and phosphate ions from the bones into the blood stream.
- ✓ Increases the elimination of phosphate by the kidneys.

The overall effect of parathormone is to raise the concentration of calcium ions relative to phosphate ions. Its production is controlled by calcium ions in the blood stream, an excess of calcium ions inhibiting the secretion of the hormone.

High blood calcium level stimulates the **thyroid gland** to secrete **calcitonin hormone**, which increases bone buildup by osteoblasts so as to reduce calcium level.

Note;

Vitamin D has the same effect as parathormone

ACID BASE/ PH BALANCE

The blood and tissue fluids are normally kept at a pH of around 7.4. This is achieved by controlling the relative concentration of acid and base in three main ways;

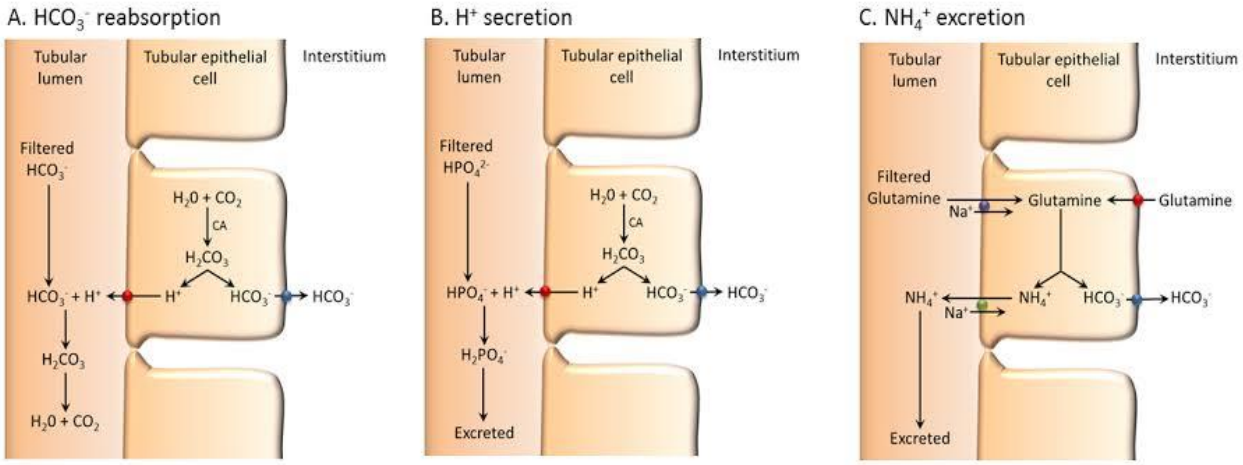
1. Expulsion of carbon dioxide by the lungs.
2. The buffering mechanisms in blood suppresses the hydrogen ions concentration. E.g. haemoglobin buffer mechanism and amino acids
3. The kidneys get rid of hydrogen ions and retain bicarbonate ions

Note;

- If the blood becomes more acidic, H^+ are secreted into the tubules (excreted) lowering the acidity.
- A fall in pH also stimulates the kidney cells to produce ammonia (NH_3) which combines with acids [H^+] and excreted as ammonium salts (NH_4^+).

Control mechanism; kidney;

- When the blood pH starts to lower due to hydrogen ions from dissolution of carbon dioxide in plasma or from metabolic wastes such as lactic acid.
- The cells of the distal convoluted tubule combine water and carbon dioxide to form carbonic acid under the catalytic activity of carbonic anhydrase. This then dissociates into hydrogen ions and hydrogen carbonate ions.
- The hydrogen carbonate ions are absorbed by blood which raises the pH to compensate for the lowering which results from production of hydrogen ions during metabolic processes.
- The hydrogen ions are actively secreted into the lumen of the distal convoluted tubule and collecting ducts by an ATP-dependent Na^+/H^+ exchanger.
- In the tubules, the H^+ ions are buffered by sodium hydrogen phosphate (HPO_4^{2-}) which takes up H^+ ions to form sodium dihydrogen phosphate ($H_2PO_4^-$) which is excreted in urine.
- When the acidity of renal fluid is exceptionally high, the cells of the distal convoluted tubules produce ammonia from glutamic amino acids.
- The ammonia then combines with the excess hydrogen ions to form ammonium ions which are excreted in urine



Or Check illustration in understanding biology page 486 fig 23.10

NITROGENOUS EXCRETORY PRODUCTS AND THE ENVIRONMENT.

Nitrogenous waste products are produced by the breakdown of proteins, nucleic acids and excess amino acids. The first product of the breakdown of excess amino acids is ammonia. It is formed by removal of amino groups from amino acids, a process called deamination like we saw earlier in ornithine cycle.

Factors that influence the type of nitrogenous waste excreted by animals.

1. **Toxicity of the waste product**. Animals excrete nitrogenous wastes with toxicity that either can withstand by their tissues or that can easily be detoxified in the body. In most terrestrial animals, ammonia is very toxic. It is first converted to urea in the body by combining it with carbon dioxide. Urea is less toxic and can safely be excreted from the body without harming the body tissues. Fresh water animals however, excrete the toxic ammonia because they have enough water available for its dilution before excretion. Insects excrete uric acid which is less toxic.
2. **Availability of water**. Animals in fresh water bodies have enough water available for dissolving any waste products. They are able to dilute and excrete ammonia. Terrestrial animals that are able to drink water excrete urea while those unable to drink excrete uric acid.
3. **Solubility of nitrogenous wastes**. Aquatic animals excrete more water soluble ammonia while those in terrestrial habitat excrete less soluble urea and uric acid depending on the amount of water available to them. Terrestrial animals that are able to drink water excrete urea while those that depend on metabolic water such as insects excrete the insoluble uric acid.
4. **Animal body size**. All organisms with big surface area to volume ratio excrete nitrogenous wastes that are more soluble in water and therefore can easily diffuse out through the body surface. For example, amoeba and other unicellular animals excrete ammonia. For large organisms, with small surface area to volume ratio, the other factors determine the nature of nitrogenous wastes excreted

Summary table of common nitrogenous wastes

Nitrogenous product	Habitat	Examples of organisms
Ammonia	Aquatic	Fresh water fish
Uric acid	Terrestrial	Birds, reptiles, insects
Urea	Terrestrial	Mammals
Tri methyl amine oxide	Marine	Marine fish

EXCRETION AND OSMOREGULATION IN REPRESENTATIVE ANIMALS.

a. AQUATIC ANIMALS

These fall into three main categories:-

- Those living in fresh water
- Those living in sea water; marine
- Those that live in both estuaries and migratory organisms.

FRESH WATER ORGANISMS

The main osmo regulatory problem facing these organisms is that they live in an environment with a lower external osmotic pressure (OPe) than their internal osmotic pressure. (OPi) i.e. OPi>OPe. The danger here is the osmotic influx of water across the semi permeable surfaces of their body and loss of ions into water.

There are two possible solutions to these;

- ✓ Eliminating water as fast as it enters after reabsorbing salt in it. In fresh water protozoa e.g. amoeba, paramecium, it is achieved by the use of the contractile vacuole.
- ✓ Actively taking in salts from the surrounding water e.g. the fresh water shore crab uses antennal glands to take in salts.

OSMOREGULATION AND EXCRETION IN AMOEBA

- ➢ Amoeba has no specialized excretory organs, these being unnecessary for its size.
- ➢ The excretory products diffuse out from the general body surface as soon as the concentration rises above that in the surrounding medium.
- ➢ The streaming movement of the cytoplasm aids this process as the amoeba moves along.
- ➢ The internal osmotic pressure of the amoeba is greater than that of the external medium. This results in water entering the cytoplasm by osmosis.
- ➢ The water is secreted into the contractile vacuole as fast as it is entering. The contractile vacuole expands and eventually discharges its contents to the exterior through small pores in the cell membrane.
- ➢ Salts are pumped back into the cytoplasm by active transport using energy from the numerous mitochondria that lie close to the vacuole membrane.

FRESH WATER FISHES; TELEOST LIKE NILE PERCH, TILAPIA OPi>OPe

- The excretory and osmo regulatory organs of the fish are the gills and kidneys. The internal body fluids of fresh water bony fish are more concentrated than their environment. Despite having a relatively impermeable outer covering of scales and mucus, there is a considerable movement of water by osmosis and loss of ions by diffusion through the highly permeable gills which are also organs of excretion for ammonia.

- They are liable to osmotic influx of water via the gills, lining of the mouth cavity and pharynx. They overcome the problem in the following ways;

❖ Maintaining a high filtration rate in the kidney which is achieved by having numerous and large size of glomeruli.
❖ Having kidneys with high abilities to reabsorb salts such as sodium ions in their tubule leading to production of hypotonic urine.
❖ Possession of chloride secretory cells in their gills which actively absorb salts from the surrounding as it passes through the gills.
❖ Removal of their nitrogenous wastes inform of ammonia which is highly toxic and requires a lot of water for excretion.
❖ Absorption of salts taken in with food along the gut.

MARINE ORGANISMS; TELEOST FISHES OPe>OPi

The main osmo regulatory problem facing these organisms lies in the fact that they live in hypertonic environment than their tissues. As a result they tend to lose water by osmosis across the highly permeable gills which may result into physiological drought; dehydration of tissues. They overcome this problem by;

❖ Conserving water by replacing it at a faster rate as it is lost. The marine teleost (bony fish) such as cod are able to swallow sea water and actively absorb salt across their intestinal walls as a result water flows by osmosis due to the osmotic gradient.
❖ Actively removing the excess salts or ions from their tissues to the surrounding water. They possess chloride secretory cells in their gills which actively removes the excess salts from the body.
❖ By eliminating nitrogenous wastes mainly in the form of Trimethylamine oxide, a compound which is soluble in water and nontoxic. This requires less water than ammonia for elimination.
❖ Possession of kidney reduced in size and number of glomeruli to maintain a low filtration rate to conserve water.
❖ Having secretory cells in their gut that actively absorb the salts.

MARINE ELASMOBRANCHS/ CARTILAGINOUS FISH

Marine elasmobranchs like sharks, rays and dog fish have body fluids which are hypertonic to sea water. They maintain this situation by;

❖ Retaining urea to which their tissues are tolerant so that the osmotic pressure of the body fluids is raised to the point that is slightly exceeds that of the surrounding sea water. The slight influx of water resulting from the hypertonic situation is readily expelled by their kidneys. The retaining of urea is made possible by its reabsorption in the kidney tubules.
❖ Marine elasmobranch therefore do not need to swallow sea water and do not eliminate excess salts from the body.

MIGRATORY FISHES

✓ They are also called euryhaline fishes; they are adapted to living in both fresh and marine water. Examples of the euryhaline fishes include salmon, eel, etc.
✓ Salmon spends its first years in fresh water, it then moves to the sea water but again returns to the freshwater to breed after which it goes back to the sea. A similar event also occurs in the eel except that the eel breed in the sea and

then the young eels swim to the fresh water to complete their growth. When mature the adult migrate to the sea again.

- ✓ The migratory fishes are adapted to live in both fresh water and sea water in a way that, when they are in fresh water, the gills pump salt into the body, this helps them to maintain a constant osmotic pressure in fresh water and while is sea water the euryhaline chloride secretory cells in gills actively pump salt out of the body in this way they are able to maintain a constant osmotic pressure of their body fluids hence surviving in both environments.

NOTE: gills of other fish can pump salts in only one direction enabling the organisms to survive in either fresh or marine water alone. Because the euryhaline gills can actively pump salts in and out of their bodies, these adaptations enable them to;

- ✓ Survive in both marine and fresh water
- ✓ Exploit resources maximally in their environment
- ✓ Reduce over crowing and competition

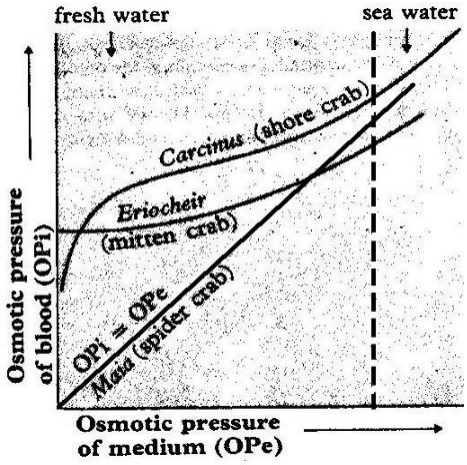
EXCRETION AND OSMOREGULATION IN AQUATIC ARTHROPODS

- ✓ In another group of arthropods, the aquatic crustaceans e.g. the shore crab carcinus, is water eliminated by a pair of another antennal gland. It is a structure which lies in the haemocoel just in front of the mouth region and opens to the exterior through a small pore situated underneath the base of the antenna; each antennal gland consists of a small sac called the **coelom**, which is connected to a large sponge-like cavity the labyrinth.
- ✓ This in turn connects to the bladder which opens into the exterior by small pore at the base of the antenna. The antennal glands are responsible for excretion of nitrogenous products. Fluids which are rich in the nitrogenous products are filtered into the end sac and into the labyrinth from the surrounding blood and the body tissues.
- ✓ The urine secreted is found to be isotonic with the blood. This is composed by the gills that absorb salts from the surrounding medium and secret them in the blood against concentration gradient. This maintains the internal osmotic pressure relatively higher than that of the external environment.

Osmo regulation in Cray fish

- ✓ Like the carcinus, the Cray fish has a pair of antennal glands. But its antennal gland is able to reabsorb salts and hence capable of producing hypertonic urine. The salt reabsorption is a process which takes place in the coiled tubule linking the labyrinth with the bladder.
- ✓ Analysis of each section of the tubules reveals that the content at the end sac and labyrinth are isotopic with the blood, but as the urine flows along the coiled tubules, salts are removed from it.
- ✓ In this case, excess water is eliminated and salts are instead held back. And the internal osmotic pressure is relatively higher than external osmotic pressure.

Graph showing the effects of changing the solute concentration of the external (ope) on the internal osmotic pressure (opi) in aquatic invertebrates



- In the body fluids of marine invertebrates, the concentrations of the various ions are usually different from those in the surrounding sea water.
- ***Carcinus* Variation:** Opi of carcinus is low in fresh water, increases rapidly with slight increase in Ope, then increases slowly thereafter with increase of external concentration. Osmoregulation breaks down and opi increases rapidly with transition into highly concentrated external medium / sea water.
- ***Explanation:*** Marine Crustacean experiencing reduced salinities are subjected to osmotic influx of water from the surrounding medium. In *Carcinus maenas,* urine production increases with progressive dilution of the medium to prevent increase in internal volume and hydrostatic pressure which would rise to a lethal level. E.g. transfer of crabs from 100 % to 50% sea water results in increased urine production within 5 minutes of dilution of the medium.
- Likely habitat: estuarine / brackish water; neither fresh water nor sea water

▪ ***Eriocheir:*** **Variation:** Opi of Eriocheir is relatively constant in fresh water, slightly increases with salinity, save with too much concentration.

- ***Explanation:*** Eriocheir has osmo regulatory abilities even with much dilution except in highly concentrated external medium.
- Likely habitat**:** fresh and brackish water
- ***Maia***: **variation**: A change in ope results in a similar change in opi of blood, which is an indicator that Maia cannot osmo regulate at all. Likely habitats include fresh water, sea water and brackish water

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b. TERRESTRIAL ANIMALS.

Many terrestrial animals face an osmo regulatory problem mainly resulting from water loss by evaporation. They try to overcome the problem in the following ways i.e. adaptation for water conservation.

Structural adaptations:

→ By having water proof integuments such as keratinized structures e.g. the dry scales of reptiles, feathers of birds, hair and Cornified epithelium/skin of mammals. These structures greatly reduce water loss in addition to protection.
→ Mammals and birds also produce oil from the sebaceous glands of the skin.
→ The waxy cuticles of arthropods e.g. insects which are impermeable to water; therefore prevents water loss.

Physiological adaptations;

→ Reducing glomerulus filtration rate e.g. in desert animals, they often have fewer and smaller glomerulus e.g. desert frog.
→ Production of non-toxic nitrogenous wastes e.g. insects, reptiles and birds. Excrete uric acid, an insoluble nontoxic substance to conserve water.
→ By reabsorbing water. Desert mammals e.g. the kangaroo rat have very long loop of Henle and produce hypertonic urine. In insects water reabsorption is via

the rectum. In birds, reptiles and amphibians water reabsorption is via the cloaca.

→ Using metabolic water. This is the water produced during cell respiration. In some desert animals like the kangaroo rat and camel, it is an important source of water mainly from fatty respiration.

→ By having tissues that are tolerant to water loss e.g. camel which can go as long as two months without drinking.

Behavioral adaptations.

→ The kangaroo rat reduces on evaporation by remaining in its humid burrow during the heat of the day.

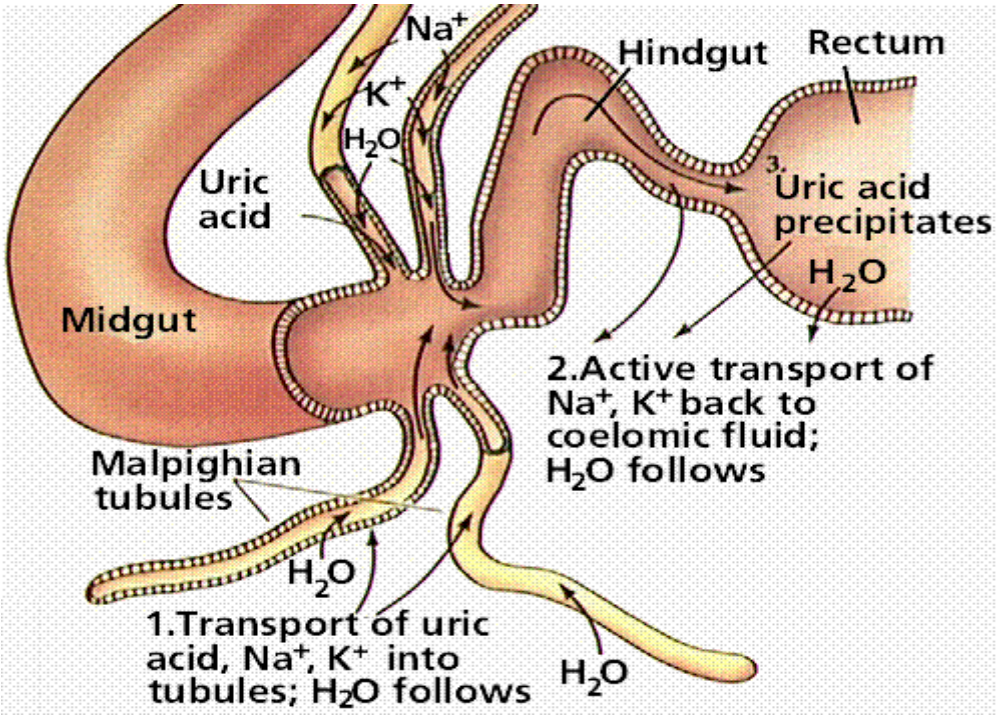
→ Earthworms burrow into soil and hide there when the surface becomes hot and dry.

→ Aestivation as shown by the lung fish and earthworms.

OSMOREGULATION IN A TERRESTRIAL INSECT

× The malpighian tubules in insects serve both excretory and osmo regulatory functions. They are tubules that lie in the intercellular space of the abdomen and are bathed in the haemolymph; the tubule has two distinct regions on upper segment (distal to the gut) and a lower segment (proximal to the gut).

× The malpighian tubules open into the gut at one end while their free ends floats in the blood filled body cavity, the insect's tissue produce nitrogenous waste in the form of soluble potassium urate which is liberated into the blood and taken up by cells lining in the malpighian tubules.



× In the cells of the tubules, the potassium urate reacts with water and Carbon dioxide to form potassium hydrogen carbonate and uric acid. The potassium hydrogen carbonate is reabsorbed back into blood and uric acid is deposited into the lumen of the tubules. The absorption of the potassium hydrogen carbonate into the haemolymph increases the osmotic pressures of in the

haemolymph, and this causes water to be reabsorbed back into the body tissues.

- As the uric acid moves towards the gut, more water is reabsorbed vigorously back into blood, the proximal end becomes filled with solid crystals of uric acid. Water is further reabsorbed by the folded walls of the rectal gland the urine is more concentrated.

- **Illustration in understanding biology page 478 fig 23.2**

Adaptation of insects to water loss.

- An almost impermeable waxy layer covering their exoskeletons which reduces water loss from the body surface.
- The only openings to the body for gaseous exchange are pairs of small holes in certain segments. These are called spiracles.
- There are valve like structures in the spiracles to reduce water loss from the tubes that lead from the spiracles to the cells.
- The excretory product is semi solid, not liquid i.e. uric acid.
- Cleidoic eggs, meaning that the embryo develops inside an egg with a relatively impermeable shell that prevents water loss.
- The problem of preventing water loss by excretion is overcome by specialized excretory organs called malpighian tubules which produce and excrete the almost insoluble waste substance uric acid.

OSMOREGULATION IN AMPHIBIANS AND REPTILES

Amphibians being the first terrestrial vertebrates, their kidney is identical to that of fresh water fishes.

- ✓ Body fluids of amphibian are hypertonic to fresh water resulting in; osmotic influx of water which is counteracted by the kidneys expelling large volumes of urine, salt loss by diffusion which are replaced actively across the skin.
- ✓ During aestivation, amphibians instead of the usual ammonia form urea, which is less toxic and therefore can be retained until water is available for excretion
- ✓ Amphibia never drink water hence water gain is osmotic via the skin or in food consumed.

Reptiles minimize water loss by;

- ✓ Laying Cleidoic eggs with waterproof embryonic membranes and supporting shell possession of waterproof keratinized skin and scales.
- ✓ Possession of kidneys with reduced glomeruli hence low rate of glomerular filtration
- ✓ Production of insoluble uric acid which is almost non-toxic and therefore requires little water for elimination
- ✓ Absorption of water by the cloaca from faeces and nitrogenous wastes.

EXCRETION AND OSMOREGULATION ANNELIDS

Examples; earthworms, lug worms, and leeches.

- In earth worm and osmo regulatory structures are known as nephridia. Each segment of the earth worm has a nephridium apart from the first and the last segment. Each nephridium is made up of ciliated funnel shaped structures called nephrostome. The nephrostome rests on the septum. It leads to the next posterior segment as long coiled tubule. The far end of which enlarges to form

a temporary chamber known as the bladder. The bladder communicates with the outsides through a pore known as nephridiophore.

Functioning of the nephridia

- The nephrostome lies in the fluid cavity. The fluid is a lymph containing glucose. Amino acids, salts, urea, and ammonia.
- Muscular contraction and movement of the cilia lying in the tubules permits fluids to enter the nephrostome and passes down the tubules as the fluid move along, useful materials such as amino acids, glucose, minerals salts, some proteins and water.
- All these materials are reabsorbed in the cells lying I the tubules. While ammonia and urea are secreted into the tubules. The tubules are well supplied by network of blood capillaries and useful materials are returned into the blood capillaries hence into the blood streams.
- The nitrogenous wastes continue into the bladder, they ate temporarily restored before being excreted out of the body of an earth through the nephridiophore. The waste fluid is called urine.

EXCRETION IN PLANTS

Plants do not have as many problems regarding excretion as do animals. This is because of the fundamental differences in physiology and mode of life between animals and plants.

- Catabolism in plants proceeds at much lower rate than in animals. There is hardly any accumulation of waste products in metabolism.
- Waste nitrogenous compounds are built into new protein
- Plants metabolism chiefly rely on the carbohydrates as opposed to the proteins in animals. The byproducts are less toxic hence they less toxic and lack need for excretion.
- Plants do not synthesize in excess their organic requirements for example plants manufacture the only amount of protein necessary for satisfy immediate demands.
- The wastes products produced in the plants by certain metabolic activity are raw materials for other biological process for instance oxygen produced during photosynthesis are utilized during aerobic respiration, while the Carbon dioxide released as a byproduct during respiration is a potential raw material during photosynthesis.
- Many of the waste products of plants of plants are stored in dead tissues, within leaves or the bark of the tree and these are periodically shed off.
- Organic acids which might which might prove harmful to plants combine with excess cations are precipitate out as insoluble crystals which can be safely stored in the plant cells e.g. calcium ions and sulphate ions are taken up together, but sulphate is used up immediately in amino acids synthesis leaving an excess of calcium ions. The calcium ions combine with excess of oxalic and pectic acids to form harmless insoluble products, such as calcium oxalo acetate and calcium pectates.
- Other ions such as iron and manganese and organic acids, such as tannic acid and nicotic acids pass into leaves where they accumulate and contribute into the characteristic autumn colour off the leaves prior to their loss during abscission waste. Some of the substances are ate eliminated through petals of flowers, fruits, and seeds.

- Aquatic plants have the advantage of losing most of their metabolic wastes by diffusion directly into the water surrounding them.

OSMOREGULATION IN PLANTS

Terrestrial plants suffer from water loss mainly by transpiration; therefore much of their osmoregulation is about water conservation. Plants can be grouped into the following categories according to how much water is available in their natural environments; as earlier discussed!

A. Hydrophytes.

These are plants which grow either partially or completely submerged in water. They have no problem in obtaining water and their structural adaptations are as a result of high water content and deficient supply of oxygen. E.g. the Canadian pondweed, water lily etc.

- ✓ They are spongy so that they can float on water.
- ✓ They have no protective cuticle but have a thin layer to allow excessive evaporation of water and easy absorption of oxygen by diffusion.
- ✓ They have numerous stoma located on the upper leaf surface to increase the rate of transpiration.

B. Halophytes.

These are plants that live in sea water especially of high salinity. Plants in estuaries and salt marshes are also included in this category. These species of plants like the sea weed can tolerate increases in salinity and their osmo regulatory problem is the prevention of water loss by osmosis. They tend to absorb ions actively by their roots which raise their solute concentration above the surrounding water. Many of them store water and excess salts may be excreted using salt glands in their leaves.

C. Mesophytes.

These are plants which grow in well watered soil and they include most of the terrestrial plants. Usually the water they lose by transpiration is readily replaced by uptake from the soil, therefore they are not highly adapted to conserve water. However their leaves are protected by a cuticle and they possess more stomata on the lower side than the upper side of the leaves to reduce water loss. They have variable leaf shape, abscission; leaf fall and an ecological distribution based upon tolerance to dehydration.

D. Xerophytes

These are plants which grow in dry regions like hot deserts where water is very scarce. They are adapted to survive extreme water scarcity in various ways;

i) Structural adaptations.

- ✓ Some have tissues which are tolerant to desiccation e.g. ferns and mosses.
- ✓ Many can survive dry periods as seeds or spores in order to avoid a long period of drought. They germinate only when water is available. They grow quickly and flower within a short period.
- ✓ Some have a very deep root network to absorb water down the soil. Many Mediterranean trees and shrubs e.g. acacia, oleander and palms.
- ✓ Others have extensive shallow root networks which grow out horizontally close to the surface. This enables them to absorb maximum water after a short shower e.g. cacti and marram grass.
- ✓ Others store water in their stems and leaves called succulents having juicy tissues. E.g. desert cactus, prickly pear etc.

- ✓ Some have sunken stomata, some possess hairy leaves, folding of leaves in order to minimize water loss.

ii) Physiological adaptations.

- ✓ Some reverse the normal stomatal rhythmic opening at night and closing during day. They take up carbon dioxide at night, store it and use it during day.
- ✓ Some shed their leaves to reduce transpiration e.g. the vine cactus (ocotillo). This is another way of solving the physiological drought.

 For more adaptations please refer to ecology.

END OF TOPIC HOMEOSTASIS, EXCRETION AND OSMO REGULATION

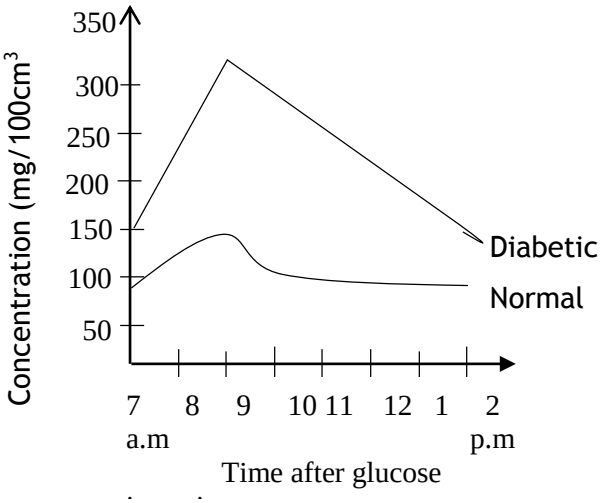
You are such great as you have capably regulated your internal systems very well that no matter what nothing can ever change your content. Now we have looked at the principles of homeostasis in such a way that we covered the major aspects a homeostatic system should have. We went to homeostasis in animals in clear detail including man, fish; fresh and marine, insects, unicellular organisms; amoeba, plants. Looked at osmoregulation in a variety of organisms and as excretion. Thank you, am aware you can try out the questions below successfully!

1. a Outline the main features of the kidney nephron.
   b. Explain how the mammalian kidney produces urine that is hypertonic to blood
   c. Describe how the nephron regulates the PH of blood.
2. Two mammals were exposed to varying air temperatures, and each time the temperatures were varied, various metabolic rates were determined, and the results of the findings tabulated.

Environmental temperature / 0C		-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45	50
Relative metabolic rate	Mammal A	4.0	3.5	3.1	2.6	2.2	1.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2
	Mammal B						5.0	4.0	3.0	2.0	1.1	1.1	1.1	1.1	1.2	1.3

a) Plot suitable graphs to show these relationships.
b) Describe each of the graphs you have plotted.
c) Explain the observed patterns of relationships.
d) Why did the experiment fail to determine the relative metabolic rate of mammal B for temperatures above 500C and below 50C?
e) Assuming that mammals A and B show very close evolutionary relationships, distinguish between their relative sizes and show how they are related to their survival strategies in different environmental conditions

3. The figure shows the blood levels in a normal and diabetic individuals, after both individual were gives a sugar solution at 7.00 a.m. Study and answer the questions that follow.



(i) Compare the levels of glucose between the two individuals (5marks)
(ii) Give explanation for the observed pattern of the levels of blood glucose in the two individuals (5marks)
(iii) What is the significance of the physiological process illustrated in the figure

4. (a) What is meant by negative feedback mechanism in the body process?
   (b) Describe how each of the following affects the metabolism of carbohydrates
      (i) Insulin
      (ii) Adrenaline
5. Describe how tissue fluid and pH are maintained in animals.
6. With reasons give examples of animals which produce each of the following excretory products;
   i. Ammonia
   ii. Trimethylamine oxide
   iii. Urea
   iv. Uric acid
7. Describe what would happen to a person who develops a malfunctioning liver.

12. COORDINATION

This is the ability of an organism to detect and respond to changes in their internal and external environment. OR
Coordination is the transmission of both chemical and electrical messages; hormones and impulses respectively from one part of the body of an organism to another part in response to a specific stimulus.
Coordination is a major component of irritability; sensitivity.

Definitions of important terms

1. **Irritability**; this is the ability of an organism to detect and respond to a stimulus in the environment; power to respond to a stimulus.
2. **Stimulus**; this is a change in the external or internal environment to which an organism responds e.g light, temperature, etc.
3. **Response**; this is a change shown by an organism in reaction to a stimulus e.g blinking of the eye, walking away from too much light.
4. **Impulse**; this is a nervous information transported along nerves in a nervous system.
5. **Effectors**; these are cells or organs in an organism where a response to a stimulus occurs. E.g common effectors in animals are glands and muscles
6. **Receptors**; these are cells or organs that receive the stimulus and change it into a nervous impulse; sense organs
7. **Internal environment**; this is the immediate surroundings of cells. In animals the internal environment is the tissue fluid.
8. **External environment**; this is the surrounding of the entire organism.

CONCEPTS OF RECEPTION AND RESPONSE IN PLANTS

There are two main types of response in plants and these are.
Nastic response / movement and Tropisms.

NASTIC RESPONSE

Is a **non-directional** movement of part of a plant in response to an external stimulates. It mainly depends on the intensity of the stimulus. E.g. Opening of flowers, opening and closing of stomata, folding of leaves e.g. *mimosa pudica*.

Characteristics of a nastic response

- It involves changes of turgidity of plant cells.
- It is a rapid response.
- It occurs in any part of a plant
- The response is not related to the direction of the stimulus
- It is induced by non-directional stimulus.

TROPISMS.

These are growth movement of a part of a plant in response to a **directional** stimulus. The direction of the response is related to that of the stimulus and in most cases the plant moves towards or away from the stimulus.
They may be positive / negative depending on direction taken. If the growth is directly towards the stimuli then it is positive and if the growth is directly away from the stimuli then it is negative.
Each response is named according to the nature of the stimulus.
The following are types of tropisms named according to stimuli
Detail;

a) **Phototropism; light;** in almost all plants, shoots bend towards a directional light source; positively phototropic, some roots bend away; are negatively phototropic and leaves position themselves at right angles to a directional source of light; are diaphototropic.
b) **Geotropism; gravity**; in almost all plants, shoots bend away from gravity; are negatively geotropic and roots are positively geotropic. The leaves of dicotyledonous plants position themselves at right angles; diageotropic.
c) **Hydrotropism; water**; almost all plant roots bend towards moisture while stems and leaves show no response.
d) **Chemotropism; chemicals**; some fungal hyphae grow away from the products of their metabolism; negatively chemotropic. Pollen tubes grow towards chemicals produced at the micropyle; are positively chemotropic.
e) **Thigmotropism; touch**; the tendrils of peas twine around supports. The shoots of beans spiral around supports.
f) **Aerotropism; air**; pollen tubes grow away from air; negatively aerotropic.

Characteristics of tropisms;

- It involves growth
- It is a slow response
- It occurs at the shoots and root tips
- It is related to the direction of stimulus
- It is induced by directional stimulus

Importance of tropic response

- It enables plants leaves to trap maximum sunlight by enabling plant shoots to grow upright.
- It enables plants to become firmly anchored in the soil by the roots growing towards the ground.
- It enables plant roots to absorb or obtain water which is necessary for plant growth.
- It enhances fertilization in plants since the pollen tubes grow towards the chemicals of the embryo sac.
- It enables climbing plants to gain support by twinning around the support.
- Tropisms allow plant parts to alter direction in response to changing conditions in the environment.

COMPARISON OF NASTISM AND TROPISM

Similarities;

- Both are brought about by external stimulus.
- Both occur in plants
- Both involve movement of plant parts.

Differences between Nastic and tropic response.

Tropic.	**Nastic**
➢ Depend on direction of stimulus.	Does not depend on direction of stimulus.
➢ Are growing movements	Can either be growth or turgor pressure
➢ Occur because of hormones (Auxins)	Aren't controlled by hormones.
➢ Take part in growing parts of the plant(shoot tip and root tip)	Take place in any part of plant.
➢ Are usually Slower	Are usually Faster

TACTIC RESPONSE

This is where a freely motile entire cell or organism moves in response to a directional stimulus. The direction of the response is directed related to that of stimulus being towards it; positive or away from it; negative. Taxes occur in both plants and animals although common in animals.
As in tropisms, the type of stimulus determines the name of the tactic response. Examples include;

a) **Phototaxis; light;** euglena swims towards light provided it is not too intense; positive phototactic. Earthworms and woodlice move away from light; negatively phototactic.
b) **Thermotaxis; temperature**; the green alga, *chlamydomonas*, will swim to regions of optimum temperature. Motile bacteria behave the same way. Blowfly larvae and many other small animals move away from extremes of temperature.
c) **Chemotaxis; chemicals**; antherozoids of mosses, liverworts and ferns, are attracted to chemicals produced by the archegonium; positive chemotactic. Many animals show negative chemotactic responses to specific chemicals.

PLANT HORMONES

- Plants possess no nervous system and so plant coordination is achieved almost entirely by hormones.
- These hormones are organic substances which in low concentrations cause changes in other parts of the organism.
- Plant hormones almost always affect some aspect of growth.

✓ Plant hormones are sometimes known as plant growth substances; they are chemical substances produced in plants which accelerate, inhibit or otherwise modify growth.
✓ Growth at the apices of plants occurs in three stages;
✓ Cell division, cell elongation/ enlargement and cell differentiation; plant hormones may affect any, or all of these processes.

There are five groups of growth substances;

1. Auxins
2. Gibberellins
3. Cytokinins
4. Abscisic acid
5. Ethene/ ethylene

Note;

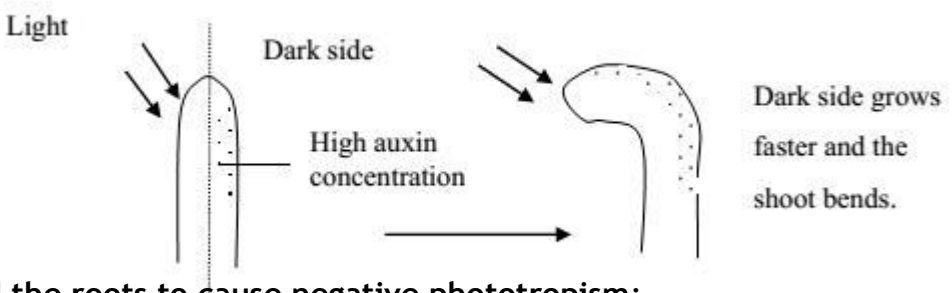
i. When two hormones act together to reinforce an effect, it is known as **synergism.**
ii. When two hormones have opposing actions, it is known as **antagonism**. For example auxins induce apical dominance whereas cytokinins prevent it.

AUXINS

Auxins are a group of chemical substances of which Indole acetic acid (IAA) is the most common.
The auxin IAA is a derivative of the amino acid tryptone and is largely produced at the apices of shoots and roots.
The transport of auxin occurs in one direction; from tip and thus its movement is polar. Short distance transport e.g from cell to cell occurs by diffusion however long distance transport occurs along the phloem.

AUXINS AND PHOTOTROPISM

Unilateral light/ unidirectional light causes a redistribution of auxin so that a greater amount travels down the shaded side.
As one effect of auxin is to cause **cell elongation**, the cells on the shaded side elongate more than those on the illuminated side.
The shoot therefore bends towards the light side; positive phototropism.



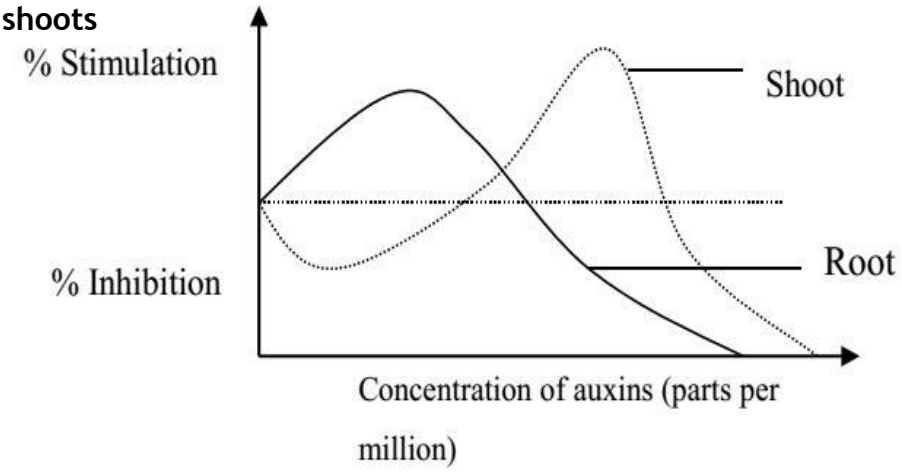
Auxin and the roots to cause negative phototropism;

- A root exposed to unilateral light accumulates auxin on its shaded side. The cells on this side elongate more rapidly and eventually the root bends towards the light side.
- Roots are more are more sensitive to auxin concentration than the stems; they respond to lower auxin concentration.
- As the concentration of auxin increases, the growth of roots stops being stimulated and becomes inhibited.
- When the shoot tip is illuminated from one side, auxins diffuse to the dark side there by causing faster growth on the dark side which then becomes longer than the illuminated side. This causes the shoot to bend towards light.
- It should be noted that many cases when the root is inhibited, the stem is stimulated and thus the growth of the root is reduced as the rate of growth of the stem is increased.

Note;

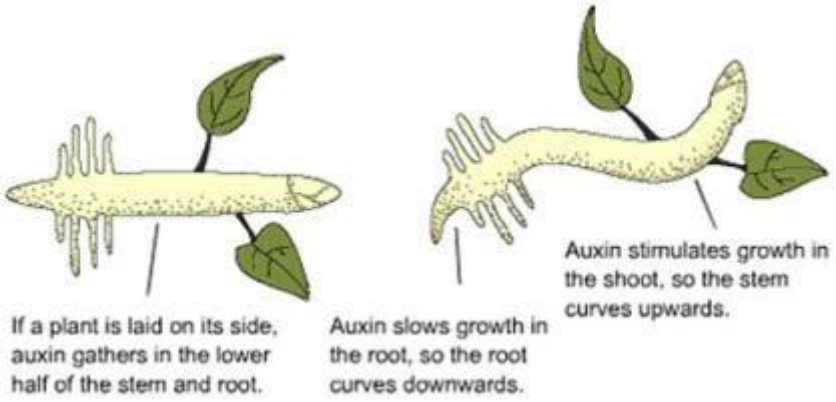
- In shoot, generally higher concentration of auxins is necessary to stimulate faster growth but in the root, high concentration of auxins generally inhibits growth such that only minute quantities of auxins are necessary for faster growth. However, in both the shoot and the root, too much of auxins inhibit growth because they are toxic.

Graph showing the effect of auxins concentration on the growth of roots and shoots



AUXINS AND GRAVITY

- During germination, there is differential distribution of auxins in the embryonic shoot (plumule) and the embryonic root (radicle).
- In the horizontally placed shoot, there is a high concentration of auxins on the lower side due to gravity, causing faster growth at the lower side than on the upper side such that the shoot bends away from the ground. The ecological significance of this is so as the shoot can obtain light for photosynthesis.
- In the horizontally placed root, due to gravity, auxins also get more concentrated on the lower side as a result inhibits growth on the lower side and the rate of growth becomes higher at the upper side than the lower side, causing curvature and bending of the root into the ground for support and absorption of water and nutrients.



Functions of IAA

- It brings about elongation of the apical meristems both the shoot and root.
- Promotes enlargement of many fruits by stimulating the cell walls to stretch in more than one direction.
- It promotes cell division in vascular cambium.
- It can induce parthenocarpy i.e. development of fruits in absence of pollination.
- When applied to cuttings, it induces or promotes rooting.
- It allows the growth of apical and terminal buds but inhibits growth of lateral buds such that cutting off the terminal bud causes the lateral buds to develop into branches. This phenomenon is known as ***Apical dominance***.
- It suppresses abscission of leaves and fruits, preventing premature leaf and fruit fall. In this way IAA acts antagonistically to Abscisic acid (ABA).

Horticultural value of synthetic auxins

Currently, a number of synthetic auxins are being used in horticulture and they are preferred to IAA because;

- They are physiologically more active and since they do not occur naturally, enzymes to break them down quickly are absent in plants, hence they continue exerting their effects.
- They are required in small quantities, making them economically viable
- Being much less expensive than IAA, they are easily affordable.

In general, synthetic auxins perform the following functions in horticulture;

1. **For fruiting and root initiation**; Naphthalene acetic acid (NAA) and Indole butyaric acid (IBA) induce fruiting in absence of pollination. The foliar spray on pineapples, oranges, mangoes etc. causes fruiting and resultant fruits lack seeds increasing the edible part of the fruit. When applied to stem cuttings, they induce the development of roots.

2. **Retard abscission**; preventing premature leaf fall
3. **For potato storage**; Methyl ester of Naphthalene acetic acid inhibits the sprouting of potatoes increasing their self-life.
4. **Used as selective weed killers**; 2,4D (2,4-dichlorophenoxy acetic acid) is a selective weed killer. It kills broad learned dicot weeds. It is used in several cereal crops to clear weeds though it can also be used in plantations since it does not affect monocots or gymnosperms. However, they should be used caringly and sparingly since they are toxic to man.

GIBBERELLINS

- Gibberellins get their name from the fungus *Gibberella Fuji* that causes the disease called foolish seedling disease of rice seedlings. The infected seedlings have their stems becoming excessively tall without producing flowers.
- The substance which the fungus was producing was isolated and analyzed and was found to be a plant hormone which was then called Gibberellin. Gibberellins are present in greatest concentration in immature seeds, roots and shoot apices, buds, young apical leaves and embryo. They are transported to the various parts of the plant through the vascular tissues.
- The main effect of gibberellins is to promote cell elongation and so increase growth.

Functions of gibberellins

- **Causes bolting in rosette plants**; causes rapid production of flowers and seeds; some plants like cabbage have a number of leaves around the shoot apex and the internode length is greatly reduced giving it a rosette.
- **Internode elongation**; they bring about stem elongation e.g. in the genetically dwarf varieties for example corn plants. These can be induced to grow to normal height by the application of gibberellins.
- **Breaking seed dormancy**; they stimulate synthesis of an enzyme alpha (α) amylase. As the seed imbibes water, it secretes Gibberellins which diffuse to the Aleuronic layer secreting more enzymes. In this way, gibberellins work antagonistically to Abscisic acid that causes seed dormancy.
- Breaking bud dormancy; they break the dormancy of buds acting antagonistically to ABA.
- They can induce parthenocarpy e.g. in Apples and pears.
- They increase the fruit size and bunch length in grapes.
- Control flowering; induce flowering in some long day plants and inhibit flowering in some short day plants.
- Promote production of auxins
- Inhibits root initiation.
- Reverse dwarfism.

CYTOKININS

- Scientists tried to find out a chemical substance required to stimulate cell division in tissue cultures. Later, coconut milk was found to contain a substance that promotes cell division and this was named kinetin which induced cell division or cytokinesis.
- The first natural cytokinin was chemically identified from the maize seed and it was named Zeatin. Both of these (kinetin and Zeatin) are collectively called cytokinins. They are produced in areas of rapid cell division or actively growing regions like the seeds, fruits, shoot and root apices.

Functions of cytokinins.

In most cases, cytokinins act in presence of auxins and sometimes with gibberellins. Basically, they're known to stimulate cytokinesis; cell division;

- ☑ Along with auxins, they promote cell division in the apical meristems. When both auxins and cytokinins are present mitosis gets accelerated but when only one hormone is present, there is no change in activity. So their action is synergistic.
- ☑ Promote or control apical dormancy; they act antagonistic to auxins while auxins stimulate growth of the apical meristems and inhibit lateral meristem growth or growth of lateral buds, cytokinins stimulate growth of lateral buds and inhibit apical meristems. Application of both auxins and cytokinins causes complete breaking of dormancy and dominance.
- ☑ They promote cell differentiation in the callus. Callus can be defined as the undifferentiated cells in the embryo that can develop either into the root or shoot. With more cytokinins and less auxins, the shoot develops while if there are less cytokinins and less auxins, the roots develop.
- ☑ Delay ageing/ senescence; cytokinins promote cell division and inhibits cell breakdown hence promoting synthesis of proteins and chlorophyll in leaves. Because of this, they enable the plant leaves to remain green. Cytokinins are applied to harvested vegetables e.g. cabbage to keep them green.

SENESCENCE

This is the gradual decline in the smooth functioning of an organism ultimately culminating into death. In annual plants growth occurs for a period of one year flowers develop, produce fruits and seeds and finally senescence follows.

Characteristics of senescence

- There is a decrease of functional capacity of whole or part of the organism.
- There is an increase in metabolic failure
- There are increased mistakes in protein synthesis effectively resulting into mutations.
- Cellular break down increases and there is accumulation of waste products

ABSCISIC ACID (ABA)

This is concerned with leaf and fruit fall. As the fruit ripens, the levels of auxin falls and ABA levels increase, causing formation of an abscission layer which cuts off the supply of nutrients to the fruit. Finally the fruit is weakened and blown off by wind or falls under its own weight.

Abscisic acid inhibits growth and so works antagonistically to auxins, gibberellins and cytokinins.

Effects of Abscisic Acid

- ➢ Abscission of leaves and fruits
- ➢ Inhibits mitosis in both apical and lateral buds causing their dormancy. Seed and lateral and apical dormancy can be broken if the ABA levels fall or if a growth promoter such Gibberellins is applied.
- ➢ Stomatal closure; ABA is known as a stress hormone and it causes closure of the stomata during severe drought.
- ➢ It causes seed dormancy;
- ➢ It decreases the synthesis of proteins causing yellowing of leaves.

ETHENE/ ETHYLENE

It is an issue of common knowledge that fruits ripen faster when covered in paper bag or when an injured fruit is kept with other raw ones, they ripen faster. It was found that ripening is due to gaseous plant growth regulator called ethylene. Ethylene is produced by nearly all plant organs and it escapes from the plant surface in gaseous form.

Effects of ethylene

- Fruit ripening; it promotes ripening of fruits like bananas, apples, citrus fruits etc.
- It inhibits stem elongation and stimulates the transverse elongation of the stem.
- It together with ABA, promotes leaf and fruit fall. In horticulture, ethylene is used to induce ripening of fruits. First the fruits are kept unripe and transported in well ventilated compartments. Later, ripening is enhanced by releasing synthetic ethylene.
- It promotes ageing and it is usually produced in relatively higher quantities by ageing fruits and leaves.
- Breaks dormancy in plants
- Induces flowering

CONTROL OF FLOWERING

Plants respond to the variations in day length and temperature and will produce flowers in a particular season only. At the equator, the day length is approximately 12 hours and almost constant throughout the year but in temperate regions day length varies from 9 to 15 hours.
Summer is marked by long day length and winter by short days.
The response of a plant to changes in day length (photoperiod) to carry out any physiological activity such as flowering is called ***photoperiodism***.

PHOTO PERIODISM

This is the response of an organism to changing length of days/light and nights/dark.
Flowering plants have been divided into three groups on the basis of their response to the photoperiod.

- Short day plants
- Long day plants
- Day neutral plants

SHORT DAY PLANTS

- ✓ These require a short day length but long nights to flower. They only flower when the days become shorter than the critical length; 12hours. They need an uninterrupted night for flowering and are actually known to be long night plants.
- ✓ Experimental evidence has actually shown what are regarded as short day plants are actually long night plants and that the length of the nights is the effective stimulus for flowering other than the day length.
- ✓ Short day plants **do not** flower if given short days and long nights interrupted by flashes of white light. The flashes may be for a very restricted time lag like one minute only but will inhibit flowering. On the other hand, if the short days are interrupted with brief periods of darkness but when long nights are not interrupted the plants will flower.

- ✓ Short day plants basically flower during autumn and winter when the nights are becoming progressively longer. Examples include soya beans, tobacco and sugar canes.

LONG DAY PLANTS

- ✓ These require long days and short nights and will only flower when the light period exceeds a certain critical length of the day. The short night is again more essential in triggering flowering than the long day hence they are best described as short night plants.
- ✓ They in fact even flower when the short night period is interrupted hence do not require a constant/uninterrupted dark period. Long day plants flower in summer when the days are becoming longer and nights shorter.
- ✓ In both long and short day plants interruption of the day period with periods of darkness has no effect, hence the night length is more important than the day length in stimulating flowering.
- ✓ Long day plants flower even when the short night is interrupted with light flashes.
- ✓ Examples include; barley, clover, wheat

DAY NEUTRAL PLANTS

- ✓ These flower regardless of day length i.e. do not respond to the length of photoperiods. They flower after the period of vegetative growth, regardless of the length of the photoperiod. Examples include cucumber, tomatoes, cotton garden peas etc.

Comparison of long and short day plants

Short day plants	Long day plants
• **Flowering is induced by long nights, longer than the critical length.**	• Flowering is induced by short nights, shorter than the critical length.
• **Flowering is inhibited by interruption of the dark period.**	• Interruption of the short night period has no effect i.e. Flowering still occurs.
• **Uninterrupted long night is critical**	• Short night is critical but does not necessarily mean not to be interrupted.
• **Flower in winter and autumn**	• Flower in summer.

PHYTOCHROME SYSTEM

During flowering, light is perceived by the pigment phytochrome. Phytochrome is a protein in nature and exerts its effect in two inter-convertible forms;

- Phytochrome far red; Pr; absorbs red light at wavelength 660nm
- Phytochrome red; Pfr; absorbs light in the far red region of the spectrum at wavelength of 730nm.
- These two forms are inter-convertible such that as one absorbs light, it is converted to the other form in a period that may vary from second to several minutes depending on the form in question.

1. **Pfr ⟶ Pr; far red light, darkness(although it is slower in darkness)**
2. **Pr ⟶ Pfr; red light, daylight**

- These conversions are possible even with a short exposure to appropriate light wavelength. These conversions are also brought by daylight and darkness;
- Phytochrome red absorbs red light in the range of the sun contains mainly red light which converts Pr to Pfr. This is reversed during the night during when the far red radiations dominate and slowly convert Pfr to Pr

ROLE OF PHYTOCHROME IN FLOWERING

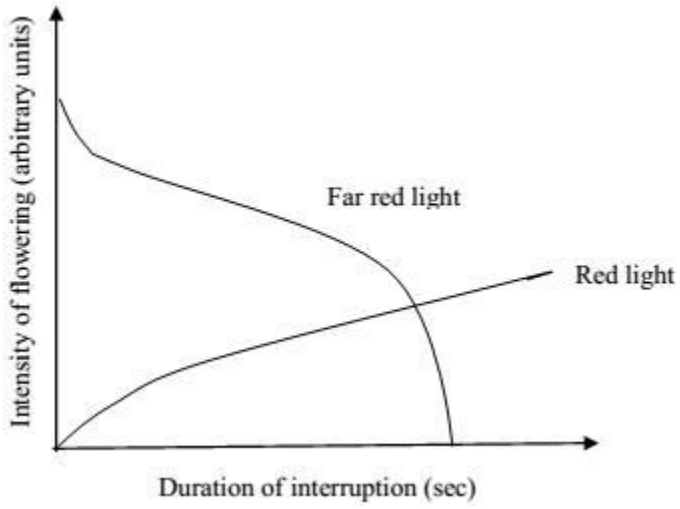
a. Long day plants;

- These require longer days and shorter nights than critical length. During the day, the visible range contains more of the red light which converts Pr to Pfr which stimulates flowering in long day plants but inhibits flowering in short day plants.
- Interrupting the short night with flashes of red light has no significance on flowering.
- Long day plants can also flower after a short exposure to red light and the night/ darkness is interrupted with flashes of light. This is because red light is quickly absorbed by phytochrome red and converted to phytochrome far-red to induce flowering.

b. Short day plants;

- These require long nights which are not interrupted with any flashes of white light. Short day plants are therefore also called long night plants because the night is more important than the day and they need a long night than critical length.
- Interrupting a long night period with red light is as effective as daylight in stopping flowering in short day plants.

Graph showing the effect of red light and far red light interruption of the night period on flowering of a plant.



Note; flowering is thought to be controlled by a hormone Florigen located in the axillary and terminal buds where it stimulates flowering,
Florigen occurs in an inactive form.
In long day plants, Pfr activates inactive Florigen to an active form to induce flowering.
In short day plants, Pr activates inactive Florigen to active form to induce flowering.

i. It is long night that provides sufficient periods of time to slowly convert Pfr to Pr. Nights have high concentrations of far red light which converts Pfr to Pr so short day plants are stimulated by far red light converts Pfr to Pr to induce flowering in short day plants but inhibiting flowers in long day plants.

ii. Interruption of long nights with white light inhibits conversion of Pfr to Pr and this inhibits flowering in short day plants. However, interruption by far red

light does not inhibit flowering. Similarly interruption first by red light followed by far red light result into flowering.

iii. It is therefore the last treatment with light of a certain type that is effective since the effects of far red light and red light are antagonistic each reverses the effect of the other.

iv. Generally, seeds germinate when exposed to red light of the visible range of the spectrum while far red of the visible range of the spectrum inhibits germination. At night, there is a high concentration of far red light which slowly converts Pfr to Pr which inhibits germination. Pr is very stable but physiologically inactive.

v. During the day, the visible radiations contain mainly red light of the visible range which is the active form but unstable and it breaks dormancy promoting germination.

Comparison of effects of red light and far red light

Red lights effects	Far red light effects
• Stimulates flowering in long day plants	• Inhibits flowering in long day plants
• Inhibits flowering in short day plants	• Stimulates flowering in short day plants
• Stimulates germination of some seeds	• Inhibits germination of some seeds
• Phytochrome red changes to phytochrome far-red	• Phytochrome far red changes to phytochrome red
• Stimulates formation of plant pigments	• Inhibits formation of plant pigments
• Induces increase in leaf area	• Prevents increase in leaf area
• Inhibits elongation of internodes	• Promotes elongation of internodes

N.B; **Vernalisation;** this is the exposure of plants to low temperature conditions for initiation of flowering. Temperatures that is as low as 0^0C can induce flowering in dormant buds. The hormone involved is called Vernalin and the process is associated with increased levels of growth promoters.

RESPONSE AND BEHAVIOUR IN ANIMALS

In order for organisms to survive, they must respond appropriately to changes in their environment. And thus;

1. Behaviour; refers to the response an individual animal makes towards a stimulus it receives. Or
2. Behaviour; refers to the way how animals respond to their environment and other members of the same species. I.e. What an animal does when it is interacting with its natural environment. Or
3. Behaviour; refers to an internally directed system of adaptive activities that facilitate survival and reproduction of an organism.

Ethology is the scientific study of animal behavior, particularly when that behaviour occurs in the context of an animal's natural environment. It is possible because behaviour has a genetic basis and is unique to each species.

Every animal has genetic information locked up in it for coding for certain behaviors. Therefore it is the potentiality of behavior that is inherited. These code anatomical and biochemical characteristics of any animal. They also lead to the formation of structures and organs involved in behaviour development.

How behaviour comes about

- ✓ Since behavior has a genetic basis, it has therefore evolved under the influence of natural selection.
- ✓ Each species is adopted to meet different conditions
- ✓ Differences in behavior between closely related species must have a survival value e.g. some animals are social others are not; some are monogamous others are not.
- ✓ The process by which animals alter their behavior through learning or hormonal mediated changes in order to cope with inevitable changes in the environment is referred to as adaptability of behavior.

TYPES OF BEHAVIOUR

There are three types of behaviour;

1. Innate / instinctive behaviour: natural, inborn patterns of behaviour e.g. suckling in newborns.
2. Learned behaviour: behaviour acquired through experience / practice.
3. Complex behaviour: combination of innate and learned components.

INNATE BEHAVIOUR

- It is a behaviour that appears to be performed in virtually the same way by all the members of a species. It is said to be stereotyped because the same response is observed when the same stimulus is given at different periods.
- Natural, inborn behaviour that is genetically programmed hence inherited.
- It does not involve a single clear cut category of behavior but rather it is a collection of responses that are predetermined by inheritance.

Innate behaviour includes;

- Instinct behaviour
- Simple reflexes
- Aggression
- Biological rhythms
- Social organizations
- Territorial behaviour
- Social hierarchies
- Reproductive behaviour
- Altruism.
- Migration

Characteristics of innate behaviour

1. It is inherited and not acquired, although some modifications may arise from experience.
2. It is similar in all members of a species and there are no individual differences other than those between male and female.
3. It is unintelligent and often accompanied by no appreciation of the purpose it serves.
4. It often comprises a chain of reflexes; completion of each link in a chain provides a commencing stimuli of the next.

Advantages of innate behaviour

- Innate responses are generally rapid – organisms can react quickly to their environments (predators etc.) e.g. the earth worm quickly / rapidly withdraws into its burrow, away from the danger.
- Innate behaviour suits species that have short lifespans – they don't have time to learn behaviors

- Suits species with no parental care/solitary lifestyles as they can't learn behaviour from other members of the species.

Detail;

1. **INSTINCT BEHAVIOUR**

i. Instinct behaviour: This is a pattern of behavior that is found universally among the members of a species and occurs without the need for prior learning and experience, and which is relatively constant. Or

ii. Instinctive behavior is a behavior that consists of rigid stereotyped patterns of movement which are similar in all individuals of one species.

Note;

- ✓ These are inherited behavioral patterns that occur in response to a particular stimulus for the first time an individual is exposed to that stimulus.
- ✓ A response is said to instinctive as long as there is no learning process identified with its development but is coordinated by central nervous system.
- ✓ The instinctive responses that appear readily in such animals Include: Copulation in insects, nest building in birds, feeding of the young etc.

Importance of instinctive behaviour

- × It is biologically important for the young ones to be protected by instinctive behavior than older animals which will have had time to learn.
- × It is of great advantage in animals with a short life span. Higher animals however have got a large brain that allows for greater learning and flexibility in behavior

2. **SIMPLE REFLEXES**

- A simple reflex is a quick automatic response to stimulus. A reflex action is behavior in which a stimulus produces a specific short lived response.
- Simple reflexes are the simplest form of innate behavior as they are simple, automatic response of a body to a stimulus that involves no conscious control/ involuntary e.g. Pull hand away from hot surface, baby feeding, horse tail swatting at flies.
- Reflexes enable bodies to respond quickly to a stimulus protecting them from harm and in this situation they are called; *E*scape/ withdrawal reflexes
- Escape/ withdrawal reflexes theses are involuntary responses which follow a specific pattern in response to a given harmful stimulus.

Example: Earthworms withdraw underground in response to vibrations on the ground

3. **ORIENTATION BEHAVIOUR**

- ✓ This is a type of behavior that involves coordinated movement of motile organisms in response to external stimuli.
- ✓ This behavior is critical in maintaining an organism in a favorable environment. These behaviors have adaptive value for survival by helping the organism locate or avoid the source of a stimulus.

They movement maybe by walking, flying, swimming among others.

Types of orientation;

a. **Kinesis:**

- This is a random movement of an organism in which the rate of movement is related to the intensity of stimulus, but not to its direction. It maybe; orthokinesis, which involves changes in speed of movement or klinokinesis, which involves changes in the rate of turning.
- Example: Woodlice move around rapidly and randomly when exposed to light until they find better conditions then they stop moving or move slowly.

b. **Taxis:**
   - Taxis is a movement of an organism in response to the direction of stimulus. Movements towards a stimulus are positive; those away from a stimulus are negative.
   - Example: Fly maggots move away from light sources; negative Phototaxis

c. **Fixed Action Pattern (FAP):**

Inborn behavioural response triggered by a very specific stimulus, which once initiated, continues until completed. Each FAP is triggered by a unique stimulus known as a sign stimulus / key stimulus, or, if it is a signal from one individual to another, it is called a releaser**;** any movement by a small nearby object.

Unlike simple reflexes, FAPs may involve a whole body response and often require a threshold level of internal readiness; drive.

Examples of FAPs:

i. Toad capturing a grasshopper / prey; **releaser**. A toad can starve even though it is surrounded by dead insects because it cannot recognize non-moving animals as prey
ii. If, while the female graylag goose is rolling the egg back to the nest, the egg slides off to the side, she continues repeated movement to roll any objects like cans which are outside the nest, using her beak and neck, until they reach the nest; **Sign stimulus** is the egg outside the nest.
iii. Yawning in humans;
iv. A female digger wasp digs a nest hole and in it constructs small cells, each of which it provides with a paralyzed caterpillar to act as a food source for the offsprings. The wasp was then lays a single egg on the roof of each cell and seals the cell. If upon sealing the cell another caterpillar is placed where it is visible to wasp, the wasp opens the cell, adds the caterpillar, lays another egg and seals the cell. **Please identify the stimulus**!

4. AGGERESSIVE/ AGONISTIC BEHAVIOUR

- ✓ This is a group of behavioral activities including rituals, physical attacks on the organism but not associated with predation. It is behaviour which is associated with conflict or fighting or contests involving two individuals.
- ✓ It involves both threatening and submissive behaviors which determine which competitor gains access to some resource such as food, nesting sites and mates. Fights rarely end in death but may result in serious injury.
- ✓ They are highly ritualized and resemble tournaments. This is because killing or seriously injuring the loser would be disadvantageous because the loser may not necessarily be less healthy or weaker but may not be mature.
- ✓ Serious fights occur in animals which have weapons that can inflict motor injury but most of the time the loser is capable of quick flight. Fighting immediately stops when the loser turns away or surrenders thus assuming a submissive posture to the victor.

Examples

i. In wolves, the throat which is the most vulnerable part is exposed to the opponent. This inhibits further attack.
ii. In birds, some species turn the back of the head to the opponent and the rival stops fighting.
iii. In cichlid fish, the fish lie side by side and beat each other by tails. It they cannot decide who has won, they face each other pull and push by the jaws until the loser folds the dorsal fin.

iv. Deer match side by side eye each other on the corner of the head, face each other and clash the antlers (horns). If one exposes the posterior view, the rival waits until they face each other again and fight.

Advantages of Aggression

- Spacing out individuals and promoting distribution of a species. Spacing out is achieved by natural hostility
- In ground breeders e.g. gulls, spacing out is a means of defense against predators because a great concentration of prey in case eggs or chicks would attract the predators. Hence territorial fighting keeps individual groups far apart.
- Competition for mates by fighting selects fitter individuals for propagation of the species.

Note; The evolutionally process whereby the displays become modified to form social signals is called **ritualization**; is the use of displays/symbolic activities so that no serious harm is done to either combatant.

5. TERRITORIAL BEHAVIOUR/ TERRITORRIALITY

A **territory:** a physical space an animal defends against other members of the same or different species however usually of the same species.

Territoriality; is the defense of an area occupied by relatively exclusively by an animal or a group of animals.

The main reasons for territoriality are; Control food supply, Retreat; shelter; nest, and access to females; space for sexual display; courtship among others.

Note;

- ✓ Animals that have territories mark and defend their space by singing e.g. birds, urinating e.g. mammals, constantly standing guard e.g. carpenter bees, releasing pheromones e.g. some insects

Examples of territorial behaviour;

- In antelopes the most basic form of territoriality is that shown by forest antelopes in which a pair forms a territory to breed. These forest species do not use vocal and visual displays but rather live in a world of scent, marking their territories by means of their prominent scent glands and dung piles.
- The Agamid lizards have a dominant male with several females and subdominant males. The dominant male of Agama is very conspicuous with a bright orange head and a blue tail in contrast to the subdominant ones. Subdominant males resemble the brown females. It is only this dominant male that defends the territory by displaying its bright colours.
- Many species of weaver birds rest in colonies and the nests are built by the males which display noisily to the females by hanging beneath their nests and flapping their wings vigorously. Each male builds several nests and if he succeeds in attracting more than one female, each female uses a separate nest. The male defends a small volume of air around his nests including nearby twigs and chases away any other male who attempts to intrude. However all birds form a colony and mix freely while feeding.

Advantages of territoriality

- Reduces competition for resources such as food, space, etc.
- Conserves energy during critical periods
- Prevents over-crowding and exhaustion of food supplies
- Enhance bond pair formation which facilitates reproduction in most animals

- Strengthens and maintain bond pairs by associating the animals within a territory
- Permits improved defense of nests, nestlings and adults
- Guarantees food supply to young ones by keeping off all other animals that would feed on it.
- Limits mating to fit individuals and hence increase the overall fitness of the population.
- Minimizes epidemics since contact between animals and population density are limited.

Disadvantages of territoriality

- Cost of defending territory including risk of physical contact, and displays of strength.
- Need to be vigilant for intruders.
- Defending territory is time that could be feeding or mating.
- Vocal or visual communication of territory ownership makes the individual vulnerable to predation.
- Difficult for smaller animals to hold territory; i.e. more likely to be attacked than larger animals
- Difficult to move if resources exhausted.
- Importance of territory size. If too large, then hard to maintain control. If too small, not enough resources for effort of defending.
- Higher risk of predation if territory within predator's territory.
- Easy for predators to find.
- Ever present threat of take-over as surplus of animals without territory.
- Extra vigilance required at certain times of the year e.g. breeding season.

6. SOCIAL BEHAVIOUR

- ✓ It is a form of behavior that involves interactions between two or more animals of the same species. It is most clearly seen in animals which organize themselves into social groups called societies such.
- ✓ There are means of communication between members of a group and an appreciation of each individual's role in a group. There is a social hierarchy or pecking order, with each individual having its own fixed status within the group.
- ✓ Examples include; birds; chicken, insects; bees, cattle etc.

Advantages of social behaviour;

- Species in large groups suffer less predators even when the predator is successful; the chance that one is picked is very low.
- Predators are more successful at catching large prey when hunting in groups than when hunting on their own.
- Wood lice buddle together and survive desiccation better.
- Honey bees build hives with an internal air- conditioning system created by thousands of work be fanning with their wings
- Males able to hold on to resources show their evolutionary fitness and are attractive to females.
- Exclusive access to food, particularly at times of shortage.
- Exclusive area for breeding and raising young.
- Space for sexual display and courtship.
- Spacing of animals avoids competition.
- Reduces aggression / conflicts.
- Improves local knowledge of predators and resources.

Disadvantages of social behaviour;

- Competition for food
- Competition for male and some monopolize female.
- Intraspecific competition may be a means of regulating population size
- Reduces individual's chances of being eaten
- Cost of defending territory including risk of physical contact, and displays of strength.
- Difficult for smaller animals to hold territory; i.e. more likely to be attacked than larger animals
- Difficult to move if resources exhausted.
- Importance of territory size. If too large, then hard to maintain control. If too small, not enough resources for effort of defending.
- Higher risk of predation if territory within predator's territory.
- Easy for predators to find.

7. SOCIAL ORGANISATION

- ✓ Ants, bees and termites are social insects living in colonies and have an organization based on a caste system. Individuals often assume specialized roles which increases the overall efficiency of the group. The roles include; food finding, reproduction, offspring rearing and defence.
- ✓ Cooperation between members of the society, sharing and division of labour depend on a stereotyped pattern of behavior and effective means of communication. In insect societies, differences in body structure and reproductive potentials affect their roles within the society a feature called polymorphism.
- ✓ Polymorphism is the existence of organisms of different species in different forms e.g. termites include the queen, king and workers. In bees, there are; queens, workers and drones. These forms are known as polymorphs or castes

8. SOCIAL HIERACHY/ DOMINANCE HIERACHY

a) A dominance hierarchy is a form of social ranking within a group in which some individuals are more subordinate than others. Or
b) A dominance hierarchy is a social ranking of each member in a social group. Or
c) A dominance hierarchy refers to social rankings of each member within a social group according to status. Or
d) A dominance hierarchy is a form of animal social structure in which a linear or nearly linear ranking exists, with each animal dominant over those below it and submissive to those above it in the hierarchy.

- ✓ Such a hierarchy is common amongst species of fish, birds like hens and mammals like baboons, wolves, etc.
- ✓ The ability to form a dominance hierarchy is innate, but the position each animal assumes may be learned.
- ✓ The term ***pecking order*** comes from a dominance hierarchy that is formed by chickens. The top-ranking chicken can peck any other chicken. The chicken lowest in the hierarchy is pecked at by all the other chickens in the group.

Examples;

a. If several hens unfamiliar to one another are put together, they respond by pecking each other. Eventually the group establishes a clear peck order hence a linear dominance hierarchy. In such a group, one individual is the tyrant and dominates and controls behaviour of all others by threats. The next is subordinate only to the tyrant but subdues the rest. The third is subordinate

only to the above two and dominates the rest and so on, down the line to the lowest.

In such cases, learning often reduces the amount of fighting because each individual learns which of its companions is stronger and thus must be avoided or which members are weaker and can therefore be intimidated.

b. Wolves live in packs and within the pack a dominance hierarchy exists among females. The top female controls mating of others. When food is abundant, the top female mates and allows other females to do so. When food is scarce, she allows less mating hence making more food available for her own young.

Importance of dominance hierarchy

- Reduces aggression, establishes order and stability in the group.
- Influences resources among population (food, water, etc.)
- First choice of mating is maintained; only fit individuals.
- Subordinate remains to obtain food, avoid predators.

SOCIAL BEHAVIOUR IN HONEY BEE COLONY

- ✓ The honey bee colony uses a caste system where there are distinct types of bees each with a specified role in a group.
- ✓ The queen is the single fertile female, the remaining workers are sterile as a result of licking a pheromone off the body of the queen.
- ✓ All males, drones are fertile.
- ✓ Social cooperation in bees is exposed during foraging for food.

HONEYBEE DANCE

Honey bee dancing is performed by a worker bee that has returned to the honey comb after foraging missions, informing other workers about both the distance and direction where the food is from the hive.

There are three forms of dance;

Round dance: Communicates only distance from the food source within 50 meters from the hive. It involves running around in narrow circles, suddenly reversing direction to her original course. It does not indicate direction of food.

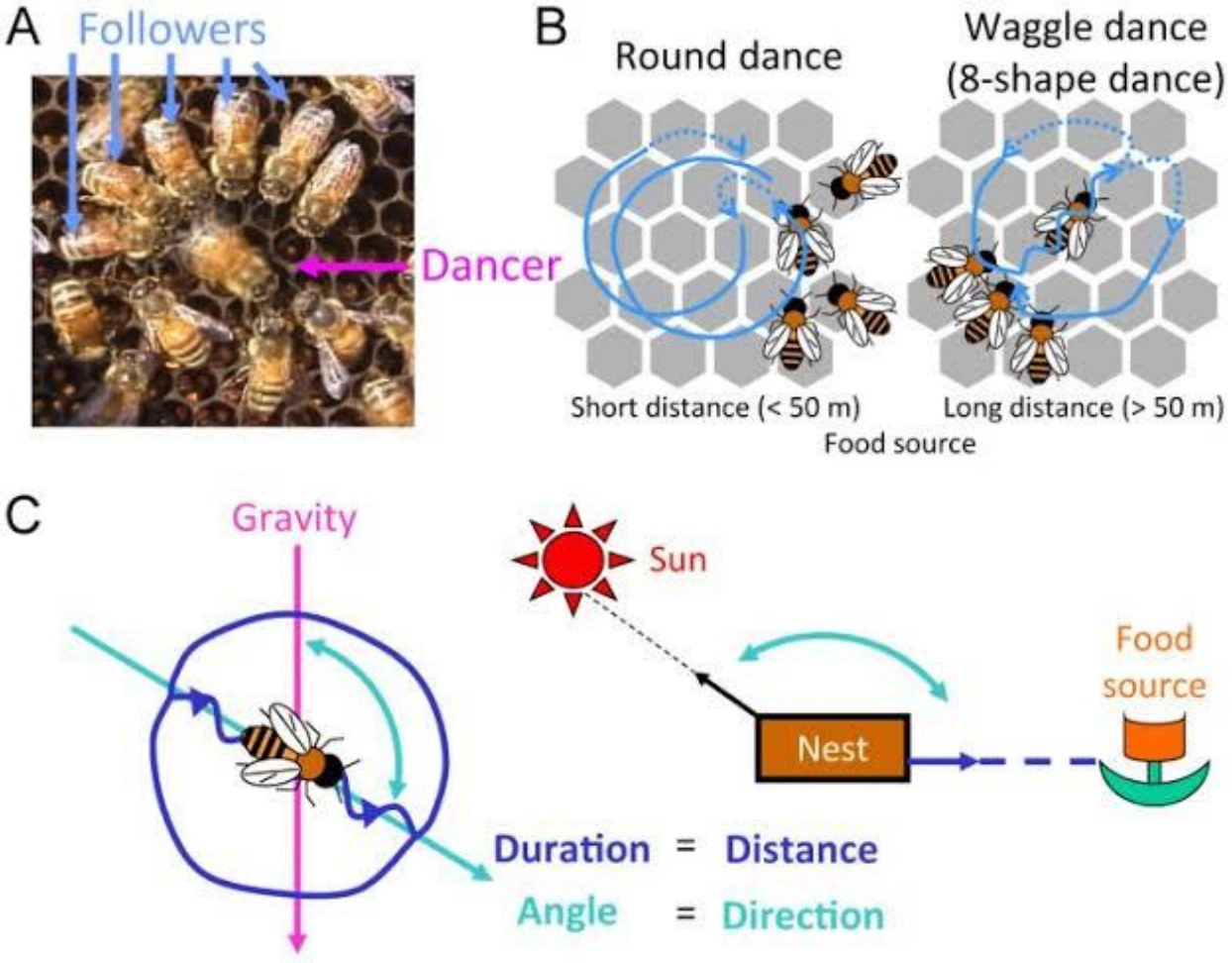
Sickle dance: Communicates only distance from the food source between 50 and 150 meters from the hive. This dance is crescent-shaped and represents a transitional dance between the round dance and a waggle dance.

Waggle dance/ wag-tail dance: Communicates both distance and direction. Is performed by bees foraging at food sources that are more than 150 meters from the hive.

How waggle dance is performed

- This is a more complex dance. The worker bee moves in a figure-of-eight pattern as follows;
- A bee that performs a waggle dance runs straight ahead for a short distance, returns in a semicircle to the starting point, runs again through the straight course, then makes a semicircle in the opposite direction to complete a full figure-eight circuit.
- While running the straight-line course of the dance, the bee's body, especially the abdomen, wags vigorously from side to side.
- The duration of the waggle phase is proportional to the distance from the food source; 1 second = 1 Km.
- The orientation of the dancing bee during the straight portion of her waggle dance indicates the location of the food source relative to the sun.

- The angle that the bee adopts, relative to vertical, represents the angle to the flowers relative to the direction of the sun outside the hive.



Note;

i. In all dances, the speed at which it is performed is inversely proportional to the distance away from the hive that the food lies.
ii. The bees are even able to locate food even on cloudy days because they are able to determine the plane of polarized light, which penetrates the cloud cover and so are able to locate the sun.
iii. Honey bees have an internal biological clock that permits them to have a continually changing picture of the sun's movement during the day.

9. REPRODUCTIVE BEHAVIOUR/ COURTSHIP BEHAVIOUR

For an organism that reproduces sexually reproductive success depends on finding a mate. During the course of evolution an amazing diversity of pattern of courting and mating have arisen.

Choosing a mate

- ✓ It must be understood that the phrase choosing a mate does not imply that organism consciously try to decide with whom to mate. For the vast majority of species 'decision' is made when one almost is certainly subconscious.

Species-specific signals

At the most basic level a mate must be an individual of the same species but the opposite sex. In many species what ensures that the right individuals mate with each other is courtship.

COURTSHIP

i. Courtship Behaviour: is a set of display behaviour in which an animal attempts to attract a mate and exhibit their desire to copulate.
ii. Courtship is the heterosexual reproductive communication system which leads to the sexual act of mating
iii. Courtship is a complex behavior pattern designed to stimulate organism to sexual activity.
   - ✓ It is usually associated with pair formation in those species where both sexes are involved in rearing offsprings such as baboons. Courtship behavior is controlled primarily by motivational and releasing stimuli and leads to mating.
   - ✓ Attracting a mate is often a big problem for animals because they have to respond to hormonal changes within their bodies and changes in the environment.
   - ✓ Many auditory and visual displays have only evolved in order to solve the problem of finding a mate. This is why animals sing, dance, exude scents, change colour, change sight etc.

Examples:

- Singing in male birds
- Peacocks display flamboyant plumage colors and prominent tail feathers
- Preening; sit with their bodies touching one another to show that they are not intending to harm their partner.
- Dancing in birds
- Building nests in birds

Advantages of courtship behaviour

- It synchronizes the time of producing with the availability of food.
- Allows pair bonding which leads to successful mating/tightens pair bond between mating pairs.
- It synchronizes gonad development so that gametes mature at the same time to ensure that fertilization occurs when mating takes place.
- It minimizes breeding between members of different species i.e. ensures that pairing occurs between partners of the same species most likely to produce fertile offspring.
- Suppresses negative tendencies like avoidance of body contact, escape behavior and cannibalism (spider) i.e. from predating to sexual. However, after copulation her behavior reverses to aggressive and she eats her mate.
- Courtship has the initial function of attracting a partner who may be at a distance.
- Provides protection to courting individuals.
- Stimulates mating of individuals i.e. to sexual activity.
- Courtship behavior is developed in sexually mature individuals and therefore mating between immature individuals which can't produce offspring is avoided/ induces mating.

NB. Synchronizations are achieved by secretions of the pituitary gland.

PARENTAL CARE

- ✓ These are the activities a parent animal does to ensure the survival and development of its young. Parental care is mostly developed in the higher animals; the birds and mammals.

- ✓ In birds it involves activities like feeding, warming, watering, nesting etc of the young.
- ✓ In mammals it involves training the young on how to recognize food and escape from danger.
- ✓ In man, the highest form of parental care is exhibited. It involves cultural transmission and language, Parental care is instinctive and does not decrease as the animals mature just as reproduction. The activities associated with the parental care are of evolutionary significance for they ensure the survival of the species.

Advantages of parental care to organisms:

- It strengthens the love bond between the parents and their offspring's.
- It protects the young offspring's from predators.
- It promotes the survival of the young offspring's until they reach maturity. This ensures continuity of the species.
- During parental care, the young animals learn from their parents some behavioral patterns of the species Such as search for food. Feeding and recognition and escape from predators.

10. BIOLOGICAL RYTHMS

- ✓ These are cyclical activities that are a basic characteristic of animal life. I.e. regularly repeated behavioral patterns.
- ✓ These are behaviors or developments that occur as part of a life cycle. They can occur often, like sleeping every night, or can occur once, like an insect developing from a larva. Biological rhythms can be:
- ✓ **Internal; endogenous;** controlled by the internal biological clock e.g. body temperature cycle
- ✓ **External; exogenous;** controlled by synchronizing internal cycles with external stimuli e.g. Sleep/wakefulness and day/night. Many terrestrial insects appear to be controlled by exogenous rhythms which are related to periods of darkness and light. E.g. drosophila emerge from pupa at dawn whereas cockroaches are most active at the onset of darkness and rest at dawn.

Types of biological rhythms

i. **Circadian rhythms**: endogenously generated rhythms with a period close to 24 hours. They are controlled by light e.g wake-sleep cycle.
ii. **Diurnal rhythms**: a circadian rhythm that is synchronized with the day/night cycle.
iii. **Ultradian rhythms**: biological rhythms e.g. feeding cycles with a period much shorter i.e. frequency much higher than that of a circadian rhythm.
iv. **Infradian rhythms**: biological rhythms with a cycle of more than 24 hours (e.g. the human menstrual cycle.
v. **Circannual:** these are biological rhythms with a cycle of a seasonal or annual basis. Examples: hibernation in bears, frogs, toads, salamanders bury themselves in mud during the winter, migration of birds.

11. MIGRATION

a. Migration this is an Inborn, seasonal, long-distance travel of animals to specific locations, usually with a return.
b. Orientation: organism is capable of detecting compass direction (N, S, E, W) using cues from the environment
c. Navigation: organism is capable of detecting its position as well as orientation, (N, S, E, W) of something – river, ocean, mountain range, etc)

Examples of migration:

- Some species of Gallinaceous and raptorial birds migrate from valley to mountain peaks.
- Salmon return to native streams to breed after several years at sea.
- Deer and Caribou, African ungulates are mammals engaged in overland migrations.
- Some sharks, whales move northern oceans for calving and southern areas for breeding and other marine mammals are engaged in long distance oceanic migrations

Note;

- Migration is triggered by seasonal changes in weather, air temperature or day length, or changing food supply.

Examples: wildebeest move towards rain in the dry season, some animals move from one food source to another, while others migrate to particular breeding areas.

How migration is brought about;

It maybe cause by hormonal changes in which cause called endogenous or by environmental changes in which case it is called exogenous. Examples;

- Sun compass - movement of sun; angle of sun; polarized light; pattern of light based on sun's position and reflection on water
- Geomagnetic compass; sensitivity to magnetic North and the earth's magnetic field
- Star compass or position of moon
- Other visual cues - patterns of waves; cloud patterns; landmarks
- Smell; Sound, Electric charges
- Young animals may learn when and where to migrate by following their parents

Advantages of migration

- Return to specialist site for breeding that does not need all year round food supply, and often no (or few) predators.
- Move to where food/prey available when not breeding, particularly with young (i.e. maximize feeding opportunity).
- Stationary can mean increased predator risk.
- Constant temperature conditions: escape bad weather and lower temperatures (and greater risk of death), especially to give birth.
- Able to have specialist breeding site (e.g. no predators) and another site for feeding.
- Flexible strategy - some members of the species can migrate and others not depending on where live.
- Stationary animals risk exhausting food supply using it all year round, particularly if competition from other species.
- Opportunity for different members of the species to meet, and greater breeding variety
- Ideal when specialist food required because the earth's resources are not evenly distributed.
- Birds migrating at night usually safe from predators as few day-time birds of prey adapt to night-time hunting.

Disadvantages of migration

- Large amount of energy required to travel long distances.
- Problems and risks of navigation.
- Risk of forgetting sites or not being able to find again.

- Leave home territory empty allowing for invaders, and then fights on returning.
- Risk at temporary stopovers from lack of local knowledge about predators.
- Vulnerable to weather changes or poor conditions in one year.
- Many decisions required including optimal fuel load and optimal time of departure.
- Other risks like the change from salt to freshwater or vice versa for some fish.
- Evolutionary maladaptive behaviour in some cases; e.g. green turtles feed on eastern coast of South America but breed on Ascension Island (south Atlantic).
- Risks of night-time migration if animals normally active in day-time (e.g. bat predation of birds).

DISPLACEMENT ACTIVITY

- ✓ Displacement activity is where an animal which is in state of stress or frustration will perform behaviour which is out of context or irrelevant or performs a behaviour in a wrong situation to try and ease the anxiety developed.
- ✓ For example two birds that are fighting may suddenly begin to peck at the ground. In humans when in tense situation we perform displacement activities such as stroking the fore head, scratching an ear, or walking up and down, alter quarreling with a wife a man can resort to smoking cigarettes or drink alcohol.
- ✓ Displacement activity serves a useful purpose of preventing open conflict. It is also revealed that much of the courtship behaviour evolved from the displacement activities arising from frustration. This occurs when the male's sexual motivation builds up but cannot be released until the appropriate signal is given by the females, some of his sexual motivation is channeled into forms of behaviour which constitute courtship.

VACUUM ACTIVITY

- ✓ This is when an animal is frustrated its motivation builds up but no sign stimulus is provided to release the appropriate behaviour as a result it performs the behaviour in the wrong situation. For example a cock deprived of a mate will display courtship behaviour to another object such as a bucket. A bird goes through motions of building a nest even if there is no nest materials available,

ANTI-PREDATORY BEHAVIOUR

a. Mimicry

Superficial resemblance of two or more organisms that are not closely related taxonomically. E.g. the non-poisonous viceroy butterfly mimics the poisonous monarch butterfly.

i. **Batesian mimicry**: the palatable species mimics other distasteful species e.g. viceroy butterfly mimics the poisonous monarch butterfly, the harmless hoverfly mimics the painful stinging wasp

ii. **Mullerian mimicry**: both the mimic and mimicked maybe unpalatable or dangerous e.g. the five spot Burnet moth and related moths.

b. **Camouflage**

The use of any combination of materials, coloration, or illumination for concealment, either by making animals difficult to see, or by disguising them as something else.

i. **Warning colouration**

Conspicuous colouration that warns a predator that an animal is unpalatable or poisonous e.g. the poisonous frogs, some snakes, monarch butterflies and some grasshoppers.

ii. **Disruptive colouration (Disruptive camouflage or disruptive patterning)**

A form of camouflage that works by breaking up the outlines of an animal with a strongly contrasting pattern, thus decreasing detectability.

Predators which look at them may not be able to recognize them without their distinct shape being obvious.

iii. **Cryptic coloration**

Coloration that allows an organism to match its background and hence become less vulnerable to predation or recognition by prey

ALTRUISM AND KIN SELECTION

Altruistic behavior is one in which an individual; the donor performs an action that helps another animal (the recipient) with no apparent advantage to itself.

Altruistic behaviour is the behaviour or activities carried out by one organism so as to promote the survival of other organisms of the same species, sometimes at the expense of its own life

KIN SELECTION

This is the evolutionary mechanism that selects for those behaviour that increase the inclusive fitness of the donor.

Examples of altruism;

- Some animals give alarm calls which warn others of the approach of a predator e.g. ground squirrels. The alarm caller is most likely attacked because when it calls, the others run into the burrows with it going down last.
- A female baboon protects and cares for its offspring for almost six years
- Female birds protect their nestlings from unfavorable weather conditions such as rain
- Female monkeys care for young ones of others.
- Defence of the bee hive and the queen by the worker bees.

Note; this behaviour ensures the continuity of the species in the population and the continuous transmission of their genes to the next generations.

The instinctive (innate) behaviors (species characteristics behavior) depend on stimuli and motivation.

TYPES OF STIMULI

There are 3 types of stimuli:

a. Motivational stimuli.
b. Releasing stimuli (releasers)
c. Terminating stimuli.

Motivational stimuli:

- Are those which determines the animal's state of responsiveness e.g. temperature, light, smell.

Releasing stimuli (releasers):

- Are features the environment (Specific stimuli) which causes/elicit particular responses when the animals encounters them.

Terminating stimuli:

- ✓ These are those features of the environment (stimuli) which bring an act of behaviour to an end.
- ✓ In feeding behaviour, the smell of the food act as a motivational stimulus since they raise the animals' state of responsiveness while the sight of the food may act as a releasing stimulus, unleashing feeding behaviour and a full stomach may act as a terminating stimulus bringing feeding behaviour to an end.

Note;

- × In general, a releaser is any feature of the environment which can be shown to evoke a behavioural response in courtship; the releasers may be features of an individual such as colour, shape or particular markings.
- × To respond to a specific stimulus, there must be a mechanism in the receptors or brain which filters out the relevant features of the stimuli from the irrelevant ones. This is referred to as stimulus filtering mechanisms.

Functions of the releasers:

- They serve as signals initiating appropriate behaviour and coordinating interactions between different individuals.
- In sexual reproduction releasers are important in changing an animal's normally aggressive behaviour to sexual behaviour. E.g. in spider the male waves its pedipalps to the aggressive female; this changes the female's behaviour from predatory to sexual.
- It is also important to bring one act of behaviour to an end and sometimes the same stimulus may start another act of behaviour. Example in blood sucking bugs, the muscular abdominal pump stops operation, and sucking ceases when the pressure of blood in the abdomen reaches certain critical level. In mammals, full stomach causes mechanical stretch which brings feeding to an end.

MOTIVATION

- ✓ This is a term used to describe the internal state which must precede a specified act of behaviour.
- ✓ It results from the animal's internal physiological state such as levels of different hormones in the body. This is in turn determined by motivational stimuli such as temperature and light.
- ✓ E.g. in certain birds sexual behaviour in spring is brought, about by increasing day-length (Photoperiodism) i.e. the eyes receive the light stimulus, which is transmitted to the brain; reaches the pituitary gland which secretes gonadotrophic hormones, the gonads are also activated to produce sex hormones, including reproductive behaviour.
- ✓ Courtship and mating in the stickle back only takes place in the spring when the female's sex urge reaches its height as a result of various environmental and physiological condition.

PHEROMONES

A pheromone is a chemical substance produced by one animal which influences the behaviour of another organism. Examples;

- ☑ Social insects (ants, bees, and termites) release pheromones that elicit alarming, mating, and foraging in other members of their species.

☑ The pheromone from the mammary glands of domestic rabbit releases immediate nursing behavior by their babies (pups).

The importance of pheromones

- They are important in marking out territories.
- Used in attraction of mates e.g. unmated female cockroaches secrete a chemical substance from the surface of their body which stimulates males to court them.
- They are also responsible for bringing the different sexes together in insects, marine worms etc.
- In social animals like bees, they play an important part in directing the development and behaviour of different castes in the colony. E.g. Pheromones produced by the queen bees prevent workers from building queen cells in which a new queen would be received.
- Pheromones also serve as releasers or build up motivation towards a particular type of behaviour.

THE ROLE OF HORMONES ON THE BEHAVIOUR:

Hormones are involved in the building up of motivation and therefore it influences behaviour in the following ways.

- Hormones affect the growth of nervous connections in the brain.
- It may alter the sensitivity of peripheral receptors. Example In rats, the male hormone enhances sexual behaviour by raising the sensitivity of the penis.
- They may enhance or suppress the performance of effectors e.g. hormones may cause degeneration of a muscle; there by preventing a particular response.
- Hormones may directly affect nerve cells and synapses within the central nervous system. This may block inhibitory or open up excitatory pathways.

COMMUNICATION IN ANIMALS

✓ Communication is the transfer of information from one animal to another.
✓ Communication in animals occurs when one individual uses intentional, specially designed signals or displays to modify the behaviour of others. Communication can occur within species (intraspecific) or between species (interspecific).The former are mostly important in reproductive success while the latter mostly includes warning signals.
✓ Therefore communication involves passage of information whose effect may be to; encourage approach, performance of a corporate act and prevent attack or induce withdrawal in animals

There are four types of communication in animals;

Olfactory communication.

✓ This is the use of odors/scents, which are diffused and persistent in space and time. Unicellular organisms with chemoreceptors can recognize members of their own species using olfactory means.
✓ Chemical signal are well developed in insects, fishes, salamanders, and mammals. They often reveal the animals underlying physiological and sexual states.
✓ Chemicals that are synthesized by one organism and that affect the behaviour of another member of the same species are called pheromones.

Visual Communication

✓ This is a directional kind of communication based on sight. It is always associated with displays which involve facial and ear expressions, hair erections, tail post position and general body posture.

- ✓ Almost all-animal coloration is protective either by being concealing or by warning.

- ✓ **For example;** most predators watch movements of the prey and the prey that keeps still until the last moment undoubtedly rely on its color to protect it from being seen. Visual communication is important to many animals because a large amount of information can be conveyed in a short time but may have some

Disadvantages:

- Various objects in the environment may block the line of sight
- Signals may be difficult to see over a long distance
- Signals not effective at night
- Signals may lead to detection by predators

Vocal/Acoustic/Auditory Communication

- ✓ Sound allows much information to be communicated in a short time. Acoustic communication is also exceedingly abundant in nature, likely because sound can be adapted to a wide variety of environmental conditions and behavioral situations. Sounds can vary substantially in amplitude, duration, and frequency structure**.**
- ✓ There are two categories of sound in animals: **Call notes:** that are species specific and inherited. (A call note is a brief sound whose function is to give warning about the presence of an enemy) and **true songs:** that are partly inherited and partly learned. (True songs are usually for attraction and serve an important function in mate selection and bonding between parents and juveniles).

Tactile Communication

- ✓ This refers to communication between animals in physical contact with each other. The antennae of many invertebrates and the touch receptors in the skin of vertebrates function in tactile communication**.** Some examples of tactile communication include; Birds preening the feathers of other birds and Grooming in primates and Fighting (the last resort of tactile Communication).

LEARNED BEHAVIOR

Learning is the adaptive change in behaviour that occurs as a result of experience or practice.

- ➢ Learned behaviour: behaviour acquired through previous experience or practice.

Features x-tics of learned behaviour:

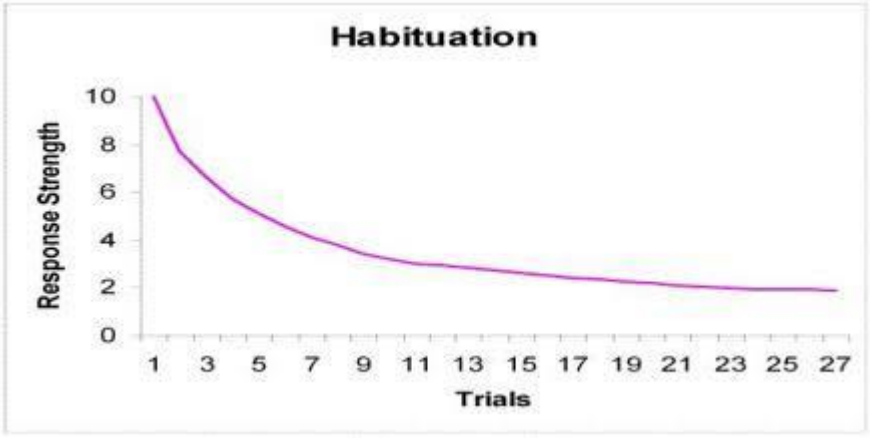
- They are not inherited but acquired during life time of an individual.
- Learned behaviour tends to vary from one individual to the other. Therefore not common among all members of the same species.
- They are adaptable i.e. the learned behaviour can be modified if the environment changes.
- Some learned behaviour are species specific and cannot be altered once established while others are very flexible.

TYPES OF LEARNING

- ✓ Habituation
- ✓ Associative learning
- ✓ Imprinting
- ✓ Exploratory learning
- ✓ Insight learning

1. HABITUATION

- ✓ Habituation is a form of learning in which an animal gradually ceases to respond to a continuously repeated stimulus not associated with reward or punishment.
- ✓ Habituation is learning to "ignore" stimuli that are not important, irrelevant, or repetitive
- ✓ This is the loss of response to a constant stimulus after repeated exposure. Thus habituation is a form of learning in which repeated exposure to a stimulus results in decreased responsiveness.
- ✓ It is believed that habituation is caused by **synaptic accommodation**



Examples of habituation;

- A sudden loud noise causes a horse to bolt on initial exposure, but if it is subjected to repeated noise, the responsiveness decreases.
- A snail scrolling across the board can be made to withdraw into its shell by hitting the board firmly, repetition of this action result in a snail ignoring this stimulus.
- Hydra contacts when disturbed by a slight touch; it stops responding however, if disturbed repeatedly by such a stimulus
- A scarecrow stimulus will usually make birds avoid a tree with ripe fruits for a few days but they later become habituated to it and they may even land on it on their way to the fruit tree.
- In species that rely on alarm calls to convey information about predators, in this case animals stop giving alarm calls when they become familiar with other species in their environment that turn out not to be predators.

Advantages of habituation

- It enables animals to avoid wasting time and energy responding harmless stimuli that do not threaten their survival or and reproduction.
- It allows an animal's nervous system to focus on stimuli that signal food, mates, or real danger that may be beneficial to its survival.
- Habituation enables a young animal to understand neutral elements in the environment such as movements due to wind.
- It enables an animal to save energy by not responding to non-harmful stimuli over and over again.

2. IMPRINTING

Imprinting is a form of behavior in which a young animal learns to recognize and follow the organism it sees right from the time it is born.

✓ This is learning that is limited to a specific time period in an animal's life and that is generally irreversible or is a form of learning that occurs during a brief, genetically determined critical period in the lives of animals, usually shortly after birth. A particular stimulus becomes permanently associated with a particular response.
✓ One result of imprinting is the formation of a strong bond between two animals, often between a new offspring and its parent. The limited phase in an animal's development when the learning of certain behavior can occur is called sensitive period.

Examples of imprinting.

-Shortly after giving birth, a mother goat is sensitive to the smell of her kid for about an hour. During this critical period, a few minutes contact with any kind, is sufficient to accept it as her own.
-Nestling respond to their parents' calls a few minutes after hatching
-Mother birds and mammals are able to recognize their young ones shortly after birth.
-Goslings, ducklings and chicks become attached to the organism they interact with during the sensitive period.

Significance of imprinting

× Allows an animal to learn the characteristics of its parent so that it can recognize its parents and other members of its species.
× Enables adult animals to recognize their own offspring.
× Allows effective communication between parents and offspring to take place.
× Enables the migratory salmon fish to trace their way back to fresh water streams to spawn.
× It plays an important role in song development in birds.
× It enable a young animal to acquire rapidly skill possessed by the parents
× It also enables a young animal to closely follow its parents which gives it protection

3. INSIGHT LEARNING

✓ It is the immediate comprehension; understanding and the response to a new situation without trial and error. It involves mental reasoning and Intelligence. Insight learning is the highest form of learning in which an animal applies thinking and reasoning in order to solve problems.
✓ For example chimpanzees will acquire bananas fixed to the roof or their cage by piling up boxes upon which they can climb to reach them. In the same way sticks may be joined together to form a long pole which is used to obtain bananas which is out of reach outside the cage.
✓ A child uses stones to hit at mango fruits which are high on the tree.

Significance of insight learning

☑ It enables organisms to sense danger easily and escape from it.
☑ They develop abilities to use tools.
☑ They improve ability to solve problems not encountered before.
☑ Organisms become highly adaptable to the environment.
☑ It enables an animal to solve quickly new problem without mistakes.
☑ It enables an animal to use its past experience in one situation to easily solve a similar problem.

N.B: Intelligence is the ability of an animal to solve unfamiliar problems.
Animals are able to show insight learning due to memory

MEMORY

This is the ability to store and recall past experiences. It maybe;

a. **Short term memory**: This lasts for a short time. It is easily disrupted

b. **Long term memory**: This lasts for a long time (many years). It is relatively permanent and resistant to change.

4. ASSOCIATIVE LEARNING

✓ This is a type of learned behavior whereby an animal learns to associate a particular response with a reward or punishment. I.e.an animal learns that a particular stimulus or response is linked to a reward or punishment.

✓ In associative learning the animal remembers its past experiences and modifies its behaviour accordingly.

It is divided into conditioned conditioning and operant conditioning/ trial and error

Two types of associative learning

(a) Classical Conditioning:

- A process in which an animal learns to associate a previously neutral stimulus with a behavior once triggered by a different stimulus
- This a form of learning in which a behaviour that is normally triggered by a certain stimulus comes to be triggered by a substitute stimulus which previously had no effect on the behaviour. Therefore, it involves association between meaningless stimulus and meaningful stimulus.

Features of classical conditioning;

- It is the association of two stimuli presented together.
- It is a temporary condition.
- The response is involuntary.
- It declines without repetition.
- Removal of the cerebral cortex causes loss of the response.

Examples;

- Honey bees learn to associate floral colors and fragrances with the presence of nectar.
- Pavlov's Dogs salivated on hearing the sound of a bell in expectation of food, yet initially it was the food smell that stimulated salivation.

Case study "Pavlov's experiment"

× The conditioned reflex is shown by a classical experiment performed on dogs by Ivan Pavlov.

× In his experiment. Pavlov allowed dog, to hear the sound of a bell and observed that the dogs did not salivate at all.

× He then presented the dogs with the taste of powdered meat and measured quantity of saliva produced. In another instance, he presented the powdered meat and immediately rang the bell. This was repeated many times.

× He later rang the bell alone without presenting meat and he observed that the dogs salivated in response to it implying that the dogs had learned to associate the bell with food. He called the new stimulus (the bell) as conditioned stimulus and the response a conditioned reflex if however the bell is rang a lone without presenting of the food several times. It leads to reduction in the quantity of the saliva produced until the conditioned stimulus failed to produce any conditioned response.

(b) Operant conditioning /Instrumental learning / 'Trial-and-Error' learning):

✓ A form of adaptive learning in which an animal learns to carry out a particular action in order to receive a reward or avoid an unpleasant experience. So in this form

of associative learning the animal learns to associate one of its own behavioural acts with a positive or negative effect.

✓ An animal's spontaneous movement may by chance produce a reward and the animal learns by trial and error to repeat the same behavioral patterns. The reward may often be pleasure of performing an action more accurately than before.

✓ This is probably the most appropriate category for the learning of new mortar skills e.g. Predators quickly learn to avoid certain species of prey with painful experiences like porcupines and young mammals and birds perfect their prey catching skills.

- Humans learn to play the piano by a trial and error form of practice.

Characteristics of operant conditioning

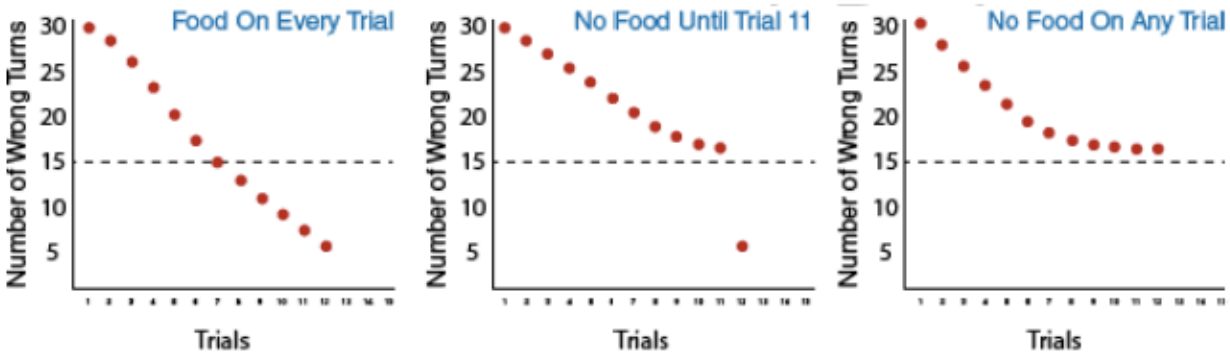
- It is improved by repetition
- The associative stimulus follows the action
- It is temporary in nature
- Removal of the cerebral cortex does not result in loss of response

Factors that affect learning by trial and error

- The speed with which it ceases to make errors.
- The length of time it can remember without repeated trials.
- The complexity of the situation to which it responds

Case study of a rat in a maze;

A rat is placed at the entrance to a complicated maze which has an empty food box at the other end. In the first trial the rat makes numerous blind routes as it traverses the maze. The rat is rewarded with food when eventually it reaches the end. In subsequent trials it makes fewer and fewer mistakes and gets through the maze and reaches its end much quicker until eventually it makes no mistakes at all.



Ecological significance of associative learning;

- Enhances acquisition hunting skills in a variety of predators.
- Enhances mimicry in a variety of animals to avoid predators.
- Allows animals to easily find and select food basing on associations they make in their environment.
- Increase chances of an animal's survival by avoiding undesirable stimuli.

5. LATENT LEARNING (EXPLORATORY LEARNING)

This is a behavioral pattern that arises when an animal stores information while exploring its environment.

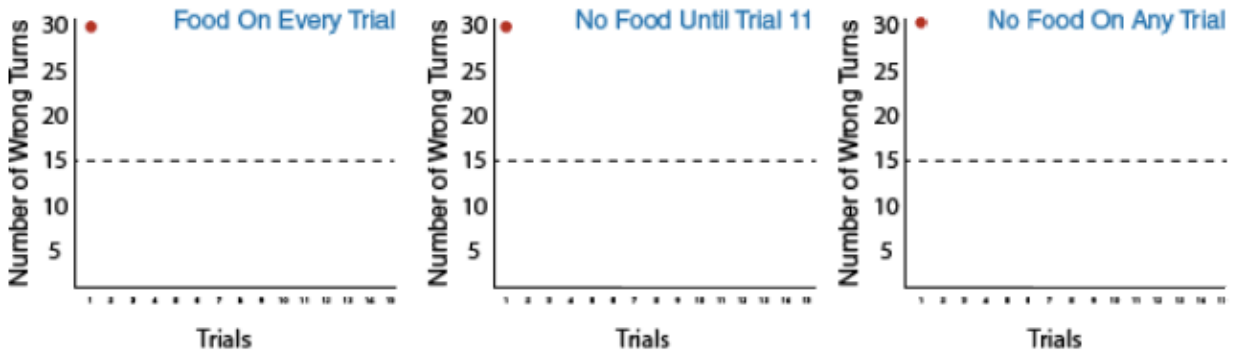
Animals explore new surrounding and learn information that has no apparent value at the time, but may be remembered and used later when necessity arises. Examples;

- Rabbits / rats / mice explore their burrows, which may save them in case of an emergency.
- A sand wasp remembers the pattern of surrounding landmarks to help her find the nest when she returns.
- Worker ants can remember a series of landmarks along a trail and follow them (in reverse order) back home to the nest site.
- A hen uses previous experience to regroup eggs in the nest using wings.

Case study of a rat in a maze;

A rat placed in a maze with no reward as a stimulus will later complete the maze, when a reward is present more rapidly than a rat which has never been in the maze.

Graph showing latent learning in a rat that has been in the maze before



Comparison of innate behaviour and learned behaviour

INNATE BEHAVIOUR	LEARNED BEHAVIOUR
1. Heritable; encoded in DNA and passed from generation to generation	1. Non-heritable; acquired only through observation or experience
2. Intrinsic; present in animals raised in isolation from others	2. Extrinsic; absent in animals raised in isolation from others
3. Stereotyped; performed in the same way each time by each individual	3. Permutable; pattern or sequence may change over time
4. Inflexible; not modified by development or experience	4. Adaptable; capable of modification to suit changing conditions
5. Consummate; fully developed or expressed at first performance	5. Progressive; subject to improvement or refinement through practice
6. Unintelligent and automatic	6. Intelligent and intellectual

COMPLEX BEHAVIOR

Most overt behavior is neither 100% innate nor 100% learned. Sometimes innate behaviors may be modified (or modulated) through practice and experience.

Example: In locusts the ability to fly is innate, but an older, experienced individual consumes less energy (per unit time) than a novice flier. This suggests that the older insect has “learned” to fly more efficiently.

GENERAL PRINCIPLES OF RECEPTION AND RESPONSE IN ANIMALS.

- All organisms experience changes in both their internal and external environments. Their survival depends upon responding in an appropriate way to these changes, and they have therefore developed elaborate means of detecting stimuli.
- To some degree, all cells are sensitive to stimuli, but some have become highly specialized to detect a particular form of energy. These are known as receptor cells.
- These receptors convert whichever form of energy it is that they respond to into a nervous impulse in so doing they work as **biological transducers**.

RECEPTION OF STIMULI

- ✓ A stimulus is any change in the environment of an organism. It may be physical stimulus or physiological involving changes in temperature pressure light etc. Stimuli may be internal or external.
- ✓ Internal stimulus is the change in the internal environment of an organism such as change in blood pressure, solute potential of blood, CO_2 concentration of blood etc. Internal stimulus is physiological in most cases involving changes in physiology of an organism.
- ✓ Whether internal or external a stimulus is received by the receptors that may be internal or external.
- ✓ External receptors are found on the integuments of the organism such as the skin in higher organisms. After registering a stimulus, the energy in it is converted into an action potential that is taken as an impulse to the brain for interpretation.
- ✓ Receptors consist of sensory cells which may be single or concentrated to form a sense organ like the eye, ear, nose, etc.

CLASSIFICATION OF RECEPTORS

They are classified according to the stimulus they respond to;

1. **Chemoreceptors**; are sensitive to chemicals like changes in carbon dioxide concentration of blood
2. **Photoreceptors**; are sensitive to light and they are concentrated in the eye.
3. **Baroreceptors**; are sensitive to pressure changes like change in blood pressure
4. **Mechanoreceptors**; are sensitive to mechanical deformations like touch, hearing, balance etc.
5. **Thermoreceptors**, sensitive to changes in temperature or heat.
6. **Proprioceptors**; sensitive to changes in position of an organism to gravity e.g. those concerned with balance.

TYPES OF RECEPTORS

There are basically two types, viz;

a) **Extero receptors**; these are found in the integuments of the animal and receive changes in the external environment.

b) **Intero receptors**; these are located in or on the internal organs such as Gastro intestinal tract, blood vessels etc. and they are sensitive to changes in the internal environment.

OPERATION OF A RECEPTOR CELL

- ✓ When stimulated, the sensitive part of the receptor cell develops a receptor potential or a generator potential that is a result of depolarization of the membrane of the receptor cell.
- ✓ A generator potential is a localized non-propagated electrical voltage across the receptor cell membrane. It increases with increase in the intensity of the stimulus.
- ✓ Depolarization is as a result of difference in permeability to Na^+ and K^+ ions.
- ✓ When the receptor cell is stimulated it becomes more permeable to Na^+ ions causing an influx of Na^+ making the inner membrane potential positive relative to the outside.
- ✓ This creates a receptor potential which if it exceeds the threshold intensity, an action potential is obtained and the impulse is fired off to the brain.

Differences between generator potential and action potential

Generator Potential	Action Potential
The amplitude of a generator potential increases with stimulus intensity	Amplitude of an action potential is always the same
Occurs in receptors only	Occurs in neurons
Localized	Propagated
Disobeys all or nothing law	Obeys all or nothing law

PROPERTIES OF RECEPTORS

a) Adaptation

✓ If a stimulus is maintained, receptor cells are able to adapt to it so that the stimulus no longer causes an impulse, however strong it is.

✓ If the receptor is continuously stimulated, it ceases to respond due to failure of producing a receptor potential and hence an action potential.

✓ E.g. one feels some discomfort upon putting on some coarse sweater or shirt which eventually disappears or on entering a room, you may notice a clock ticking, yet after some time you become unaware of its presence in the room.

✓ The mechanism of adaptation is not very clear but it is believed to be due reduced permeability of the membrane to sodium ions as result of continuous stimulation.

Importance of adaptation;

- Adaptation prevents damage to the receptor cells.
- It prevents wastage of energy by preventing receptors from responding towards trivial stimuli of high frequency.
- It increases the efficiency of the nervous system to process information about changes in the environment.
- It prevents overloading of the central nervous system and effectors so that there is no excessive discharge of impulses.

b) Convergence and summation

✓ Convergence is when several receptor cells synapse with a single sensory neurone e.g. in the rod cells of the mammalian eye. Convergence gives a summed response which increases sensitivity to the eye.

c) Lateral or mutual inhibition

✓ Receptor cells can be stopped from firing impulses by special synaptic connections. As a result, certain impulses are transmitted only when required.

✓ When two neighbouring receptor cells are stimulated simultaneously, they produce a lower response than when stimulated separately. This causes mutual inhibition, the advantage of this is increased visual acuity in the mammalian eye; resolving power.

d) Precision

✓ Receptors are able to transmit the information precisely without alteration

✓ At the fovea, each cone synapses with its own bipolar neurone connected to a single optic nerve fibre. The cones are packed close together about 7 million at the fovea. It is therefore possible for the images of two separate objects to fall onto different cones separated by at least one in between. Two separate signals are sent to the CNS via two different optic nerves. This is known as the revolving power of the eye; the ability to discriminate between two separate objects close together

e) **Transduction;** Receptor cells are capable of changing physical stimuli into an electrical impulse.

f) **Sensitivity**; receptor cells are able to detect the slightest change in their environment; stimulus.

EFFICIEENCY OF RECEPTORS

- This is the how fast and accurately the receptors sense changes in the environments
- The efficiency of receptors is ensured in two ways; by their properties and by the synaptic connections of their never supply.

How receptor properties ensure their efficiency;

× Transduction: all receptors are capable of converting a physical stimulus into electrical impulses. This ensures that each stimulus is registered in form of an electrical impulse.

× Sensitivity: receptors can detect even the slightest of a stimulus for which they are meant. In this way, they have a low threshold of stimulation so that even small changes in a stimulus can be registered and transduced into an electrical impulse.

× Precision: receptors are precise in transmission of information. They receive and transmit the exact information about a stimulus without any alteration. This ensures that they send the exact information to the brain about the changes in the environment.

× Inhibition. The transmission of certain impulses in the receptors can be inhibited. This is important because it ensures that the receptors transmit only that information which is of use to the organism it a particular time.

× Adaptation: receptors can adapt and therefore stop firing impulse if a stimulus is maintained over a long time. This is important in protecting the organism against over stimulation and also allows the receptors to record and therefore report only changes in the stimulus.

How synaptic connections of receptors ensure their efficiency.

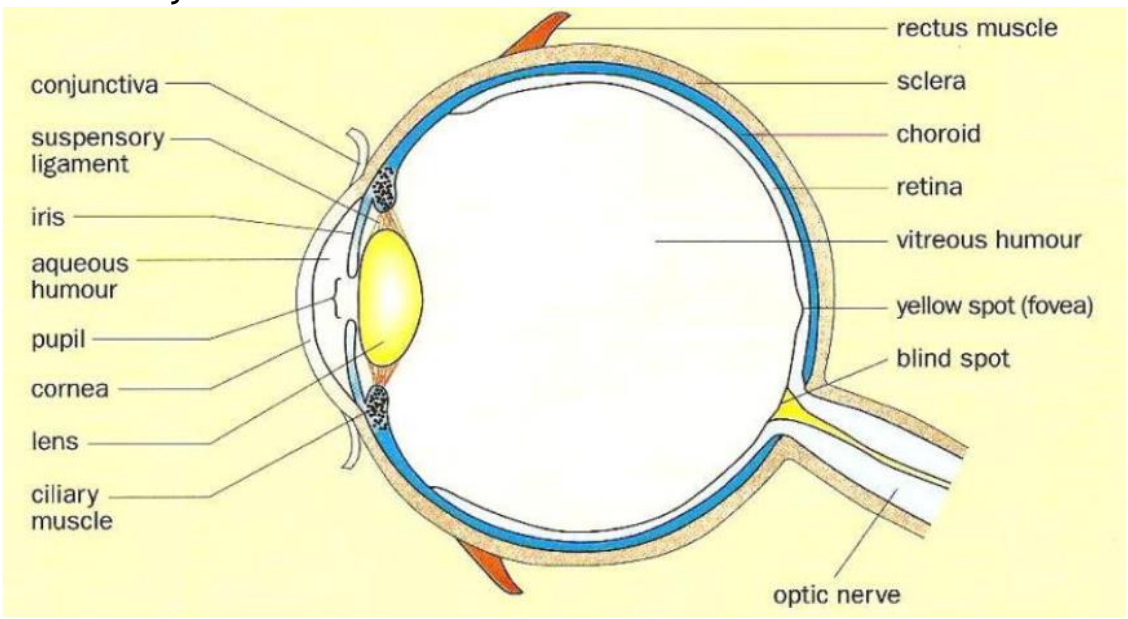
× Convergence and summation: Many sense cells may be connected to one sensory membrane, a phenomenon called convergence. This provides a high degree of sensitivity to the receptor cells; small sub threshold impulses converge on the sensory neuron and summate into an impulse which can be fired in the neuron.

× Inhibitory synaptic connections with inhibitory neurons. These are important in regulating the frequency of firing of the receptor cells.

SENSE ORGANS/ RECEPTOR ORGANS

1. THE MAMMALIAN EYE

Structure of the eye



Or check understanding biology page 548 fig 27.18

Or functional approach 306 fig 19.10

- The eyes are a pair, each being spherical structure located in a bony socket of the skull called the orbit. It may be rotated within its orbit by rectus muscles which attach it to the skull.
- The globe of the human eye, or eyeball, consists of the sclera, a tough white outer layer of connective tissue, and a thin, pigmented inner layer called the choroid. At the front of the eye, the sclera becomes the transparent cornea which lets light into the eye and acts as a fixed lens. Also at the front of the eye, the choroid forms the doughnut-shaped iris, which gives the eye it colour.
- By changing size, the iris regulates the amount of light entering the pupil, the hole in the center of the iris. Just inside the choroid, the retina forms the innermost layer of the eyeball and contains layers of neurons and photoreceptors.
- The eye is made up of two compartments which are fluid filled and these are;
- Aqueous humour; this is a clear watery salt solution filling up the anterior compartment of the eye. It supplies nutrients to the lens and cornea and maintains the shape of the cornea.
- Vitreous humour; it is a clear transparent jelly like substance filling up the posterior compartment of the eye. It maintains the shape of the eyeball and supports both the lens and the retina.

Functions of the parts

1. **Sclera**; is an opaque outermost converging of the eye, it is transparent at the front to form the cornea. It maintains the shape of the eye ball and protecting all the inner layers of the eyes.
2. **Cornea**; it is a thin transparent part of the sclera forming a bulge; convex surfaces at the front being transparent. It allows light to pass through into the eye and due to its convex nature, it helps in focusing images of the objects on the retina
3. **Conjunctiva**; a thin transparent layer present on the cornea and continuous with the skin over the eye. It protects the cornea.

4. **Choroid**; a pigmented layer present below the sclera. Pigmentation prevents internal reflection within the eye. It also provides nutrition to the retina.
5. **Ciliary body**; attached to the choroid and consists of the ciliary muscles whose contraction and relaxation enable the eye to focus near and distant objects. These muscles are under the control of the autonomic nervous system and they alter the shape of the lens.
6. **Suspensory ligaments**; the thread like ligaments that attach the ciliary body to the lens. They hold the lens in position.
7. **Iris**; it forms a pigmented circle attached to the ciliary body in front of the lens.
8. **Pupil**; refers to the opening in the iris and controls the amount of light entering the eye. In bright light the size of the pupil reduces and in dim light it becomes longer.
9. **Retina**; the innermost light sensitive layer consisting of two types of photoreceptor cells called rods and cones. It is where an image of the object is formed.
10. **The blind spot:** This is a region where the nerve fibers leave the eye to enter the optic nerve. It has no light sensitive cells; cones and rods. When an image falls on this point, it is not taken to the brain thus blind spot.
11. **Eye lids:** These protect the eye and remove any foreign bodies that enter it. Regular blinking enables the spread of the fluid all over the exposed surface of the eye.
12. **Eye lashes:** They prevent dust particles and other objects from entering the eye.
13. **The lens:** It is transparent elastic and biconvex and held by suspensory ligaments and it refracts light to make an image on the retina by changes in thickness.
14. **Ciliary muscle:** They are collected in the ciliary body and they are set of smooth muscles controlled by the autonomic nervous system. They alter the shape of the lens. Their contraction results into the spherical shape of the lens and the relaxation results in the flattening of the lens.
15. **Fovea (yellow spot**); slightly depressed area of the retina containing cones only. It is here that the sharpest image is formed
16. **Optic nerve**; consists of fibres of sensory neurons and leaves the eye ball from the back side. It carries visual information from retina to the brain.

WORKING PRINCIPLES OF THE EYE

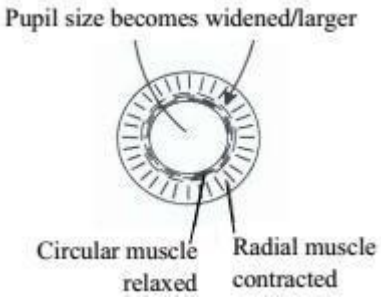
- Control the amount of light entering the structure.
- Focuses the images of the external world by the lens system
- Registering images on sensitive surface
- Processing a captured image to produce a pattern which can be seen.

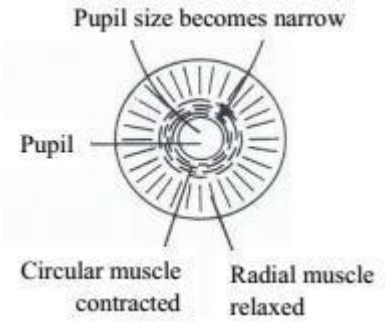
OPERATION OF THE EYE

❖ This is done by the pupil and the iris. The iris muscles contract to regulate the size of the pupil. The iris muscles are of two types; the circular and radial muscles that work antagonistically.
❖ In bright light, the circular muscles contract and the radial muscles relax reducing the size of the pupil and hence the amount of light entering the eye.
❖ In dim light, the circular muscles relax while the radial muscles contract. This increases the size of the pupil and consequently the amount of light entering the eye.
❖ Controlling the amount of light entering the eye is important because if too light reaches the retina, cones may not be stimulated at all. If the quantity is too great the retinal cells maybe over stimulated causing dazzling.

Table summarizing control of the amount entering the eye

In dim light	In bright light
Radial muscles contract	Circular muscles of the iris contract
Circular muscles relax	Radial muscles relax
Pupil widens and more light enters the eyes	Pupil becomes smaller and narrower and less light enters the eyes.



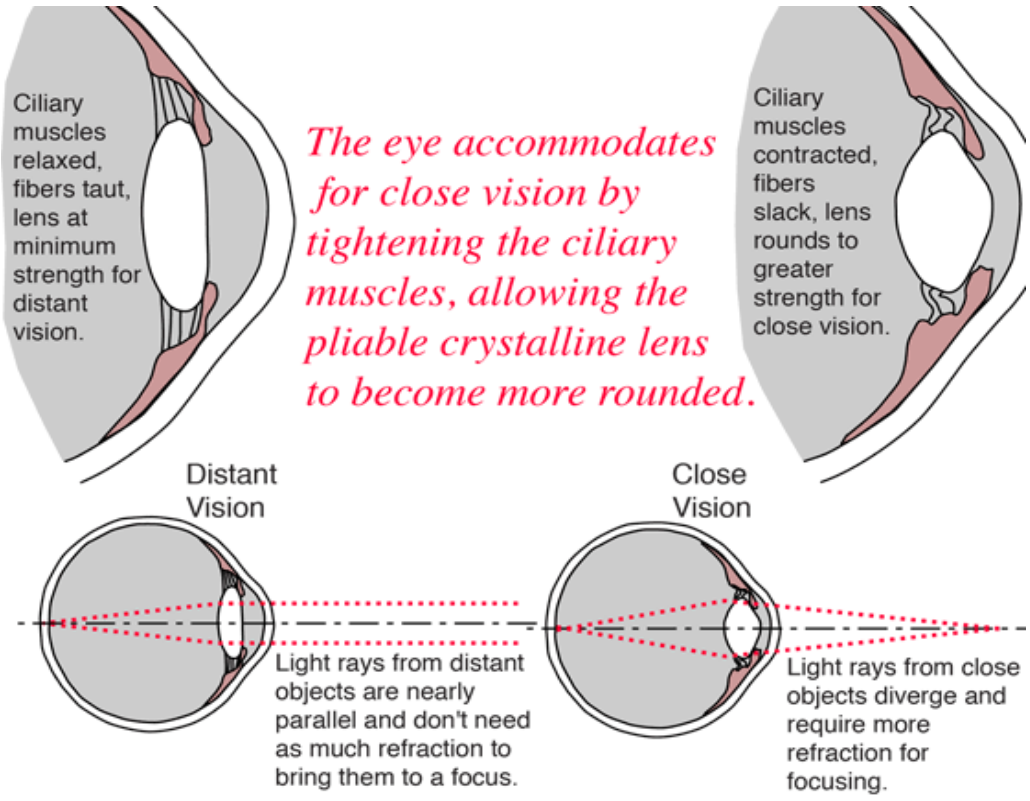


ACCOMODATION

The lens makes fine adjustments to bring a sharp focus on the retina. The ability of the lens to focus far and near objects and form an image on the retina is called accommodation.

a) Distant objects

Rays from a distant object are parallel rays and need less degree of convergence if they are to focus an image on the retina. Once they reach the eye, the circular ciliary muscles relax and the radial ciliary muscles contract making the lens thinner and less convex. When the lens is thinner, its powers of convergence decrease.



The effect of contraction of the radial ciliary muscles exerts force on the suspensory ligaments which appear stout.

b) Near object

Rays from a near object are divergent rays; these rays need greater powers of convergence if they are to form an image on the retina. Otherwise they may form an image behind the retina. To achieve high degree of convergence, the lens becomes thicker and shorter (more convex). This is achieved by contraction of the circular ciliary muscles and relaxation of radial ciliary muscles.

THE RETINA

✓ The photosensitive part of the eye is the retina. It consists of cones and rods that are light sensitive cells. Rods and cones are two types of photoreceptor cells both of which contain light sensitive pigments formed from vitamin A but differ in shape and in function.

✓ Rods are more sensitive to light but do not distinguish colours; they enable us to see at night, but only in black and white.

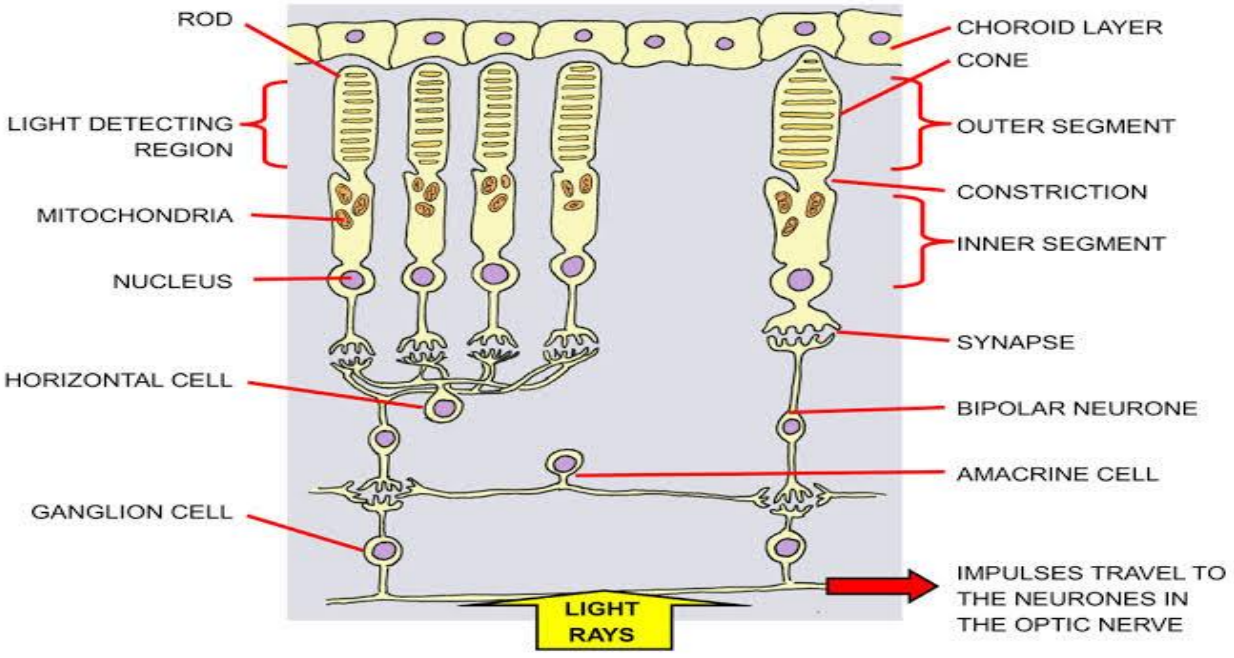
✓ Cones provide colour vision, but, being less sensitive, contribute very little to night vision. There are 3 types of cones. Each has a different sensitivity across the visible spectrum, proving an optimal response to red, green, or blue light.

✓ The relative numbers of rods and cones in the retina varies among different animals, correlating to some degree with the extent to which an animal is active at night.

✓ The distribution of rods and cones varies across the human retina. Overall, the human retina contains about 125 million rods and about 6 million cones.

✓ The fovea, the centre of the visual field, has no rods, but has a very high density of cones; about 150,000 cones per square millimeter. The ratio of rods to cones increases with distance from the fovea, with the peripheral regions having only rods. In day light, you achieve your sharpest vision by looking directly at an object, such night light shines on the tightly packed cones in your fovea. At night, looking directly at a dimly lit object is ineffective, since the rods-the more sensitive light receptors; are found outside the fovea. Thus, for example, you see a dim star best by focusing on a point just to one side of it.

Structure of the retina



The retina is composed of 3 layers of cells containing a characteristic type of cells;

i) **Photoreceptor layer; outermost layer**: This contains the photosensitive cells, the rods and cones partially embedded in the microvilli of pigment epithelium cells of the choroid.

ii) **Intermediate layer**: This contains bipolar neuron with synapses connecting the photoreceptor layer to the third layer. Horizontal and Amacrine cells are found in this layer and enable lateral inhibition to occur.

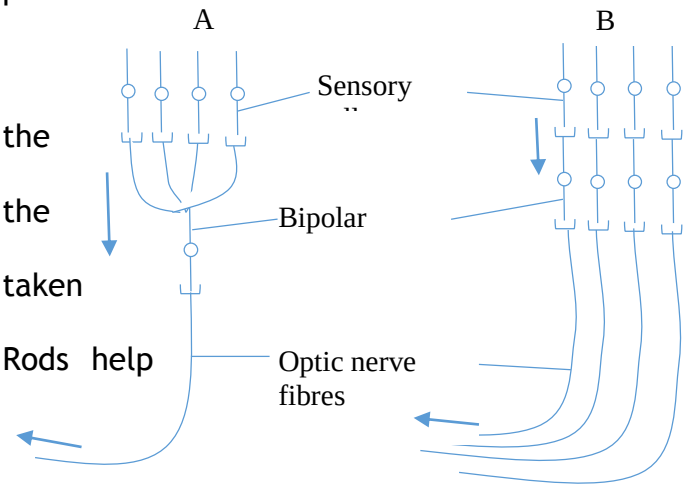
iii) **Inter surface layer**: This contains ganglion cells with dendrites in contact with bipolar neuron and axons of the optic nerves.

*** understanding biology page 550 fig 27.23 and 27.22**

***functional approach 4th edition page 302 fig 19.6**

STRUCTURE AND COMPOSITION OF RODS AND CONES

1. **Outer segment**; which is photo sensitive region where light energy is converted into receptor potential/ generator. The entire outer segment is composed of flattened membranous vesicles containing the photosensitive pigments.
2. **Constriction;** the outer segment is almost separated from the inner segment by an in folding of the outer membrane. The two regions remain in contact by cytoplasm and pair of cilia which pass between the two.
3. **The inner segment**; that is metabolically active packed with numerous mitochondria providing energy for visual process and polysomes for synthesis of proteins involved in the production of membranous vesicles and visual pigments. The nucleus is located in this region
4. **Synaptic region**; here the cones and rod cells form synapses with bipolar cells. Rods form many synapses with a single bipolar neurone. This is called <u>synaptic convergence</u> and increases visual sensitivity but reduces visual acuity; resolving power of the eye. In figure **A**



the Sensitivity is increased due to summation when light of low intensity simultaneously falls on all three rod cells creating receptor potentials which sum up to exceed threshold intensity and no action potential is given. The impulse is not to the brain unless light is of high intensity.

the

taken

Rods help us to see as much as possible in conditions of poor illumination like in darkness or in dim light and objects appear to be black, white or shades of grey.

Cones enable us to see only when there is bright light like during the day.

Mono synaptic bipolar cells link one cone to one ganglion cell and this gives the cone greater visual acuity than the rods this is because each cell transmits impulses to the brain and identified as a single point so the brain identifies many single points. The high <u>visual acuity</u> in the cones is also because they are highly packed at fovea with direct connection to the optical nerves. In figure **B.**

***functional approach 4th edition page 304 fig. 19.8**

VISUAL PATHWAY

- Signals from rods and cones can follow several different pathways in the retina. Some information passes directly from photoreceptors to bipolar cells to ganglion cells.
- In other cases, horizontal cells carry signals from one rod or cone to other photoreceptors and to several bipolar cells. When an illuminated rod or cone stimulates a horizontal cell, the horizontal cell inhibits more distant photoreceptors and bipolar cells that are not illuminated. The result is that the light spot appears lighter and the dark surroundings even darker. This form of integration, called lateral inhibition, sharpens edges and enhances contrast in the image. Amacrine cells distribute some information from one bipolar cell to several ganglion cells. Lateral inhibition is repeated by the interactions of the Amacrine cells with the ganglion cells and occurs at all levels of visual processing in the brain.
- A single ganglion cell receives information from an array of rods and cones, each of which responds to light coming from a particular location. Together, the rods or cones that feed information to one ganglion cell define a receptive field-the part of the visual field to which the ganglion can respond.
- The fewer rods or cones that supply a single ganglion cell, the smaller the receptive field. A smaller receptive field results in a sharper image, because the information as to where light struck the retina is more precise. The ganglion cells of the fovea have very small receptive fields, so visual acuity; sharpness in the fovea is high.

DIFFRENCES BETWEEN RODS AND CONES

Rods	**Cones**
Enable us to see in dim light and at night	Enable us to see in bright light or during day
Outer segment is rod shaped	Outer segment is cone shaped
Cannot help in distinguishing colours, objects appear black, white or shades of grey	They help in distinguishing colours
Contain a photo sensitive pigment called Rhodopsin	Contain a photosensitive pigment called Iodopsin
Very sensitive to low light intensities	Are sensitive to bright light and respond to specific wavelengths of light (visible range)
More numerous and are uniformly distributed in the retina	They are less numerously dispersed and are tightly packed together at the fovea (yellow spot) to give a sharp image.
Show synaptic convergence	No synaptic convergence

Note;

- Nocturnal animals e.g. owls have mainly rods in their retina and hence have a great ability to see in the dark.
- Cats and other nocturnal mammals have a reflecting layer called **tapetum**, behind the retina. This reflects back light into the eye and so affords further opportunities for rod cells to absorb it. This greatly improves vision in dim light and it is the reason why cats' eyes give bright reflections when light shines on them; it is light reflected from the tapetum which is seen

- Pigeons and active flying organisms have mainly cones in their eyes and can see various colours as well as judging distance during flight to avoid accidents

COLOUR VISION

❖ Colour perception is due to the presence of the three types of cones in the retina; red, green and blue. This is a trichromatic theory of colour vision which states that different colour and shades are produced by the degree of stimulation of each type of cone produced by light reflected from an object."

❖ These three cones are sensitive to specific wavelengths of light which may red, green or blue.

❖ Different colours are seen or perceived due to the degree of stimulation of the cones e.g. equal stimulation of the three cones produces white colour while stimulation of none produces black colour. Stimulation of red and green simultaneously produces yellow colour.

❖ Other colours are perceived by combined stimulation of these three. "Use knowledge for colour combination"

COLOUR BLINDNESS

This is a genetic disorder or hereditary disease due to absence of a particular kind of cone/cones in the retina. Lack of a particular cone type in the retina makes someone to fail perceive wavelength of that colour e.g. absence of green cone means that a person cannot distinguish between green and blue while a person lacking red and green cones suffers from red-green colour blindness whereas a person with reduced number of red and green cones will have a difficult of distinguishing a range of red-green shades.

NIGHT BLINDNESS

• Deficiency of vitamin A leads to decreased synthesis of Rhodopsin, the pigment present in rods since they cannot function without rhodopsin the person cannot see well in dim light or at night, a condition known as Night blindness.

BINOCULAR VISION

× Binocular vision occurs when the visual fields of both eyes overlap so that the fovea of both eyes are focused on the same object. It has several advantages over monocular vision and these include;

- Larger visual fields.
- Damage to one eye is compensated for by the other e.g. it cancels the effect of the blind spot and provides the basis of stereoscopic vision.
- Stereoscopic vision depends upon the eyes simultaneously producing slight different retinal images which the brain resolve as one image.

MECHANISM OF PHOTO RECEPTION/ TRANSDUCTION OF LIGHT

Vision in dim light

✓ Rods contain the photo sensitive pigment called Rhodopsin. Rhodopsin is made up of two molecules, a protein **scotopsin** and a vitamin A derivative **retinal**.

✓ Absorption of light by rhodopsin shifts one bond in a retinal from a *cis* to a *trans* arrangement, converting the molecule from an angled shape to a straight shape. This change in configuration destabilizes and activates rhodopsin by splitting it into its constituent compounds; retinal and opsin this process of splitting is called **bleaching**.

This splitting in turn leads to creation of a generator potential in the rod cell, which if sufficiently large, generates an action potential along the neurons leading from the cell to the brain as;

✓ When rhodopsin is split, the outer segment of the rod cell becomes less permeable to sodium ions yet the segment continues to pump out the sodium ions. This creates a high negative potential inside the rod cell higher than the normal.

✓ The high negative potential inside the rod cell creates a hyperpolarization of the rod cell. This hyperpolarization is inhibitory to impulse transmission. The bipolar neurone linked by synapses to the rod cell also responds by producing a hyperpolarization.

✓ However, the optic nerve fibres supplied by the bipolar neurone responds to this by producing a propagated action potential. The action potential is transmitted as an impulse to the brain for interpretation.

✓ Light activates rhodopsin because it changes the color of rhodopsin from purple to yellow, light activation of rhodopsin is called "**bleaching**."

✓ This explains why in bright light rods become non-functional since their rhodopsin is bleached.

✓ However in absence of further light stimulation, Rhodopsin is formed. This is called **dark adaptation** and in total darkness it takes about 30 minutes for all the rods to adapt and the eye to achieve maximum sensitivity. This explains why in moving from well lit room to darkness, objects cannot be seen immediately but sooner or later the objects become clearly visible.

Note:

1. Before the rod cell can be activated again in the same way above, the opsin and retinal must first be resynthesized into rhodopsin. This resynthesis is carried out by the mitochondria found in the inner segment of the cell, which provide ATP for the process.
2. Resynthesis takes longer time than splitting but is more raid in lower light intensity.

Vision in bright light

✓ The same mechanism in rod cells occurs in cone cells except that the pigment here is **iodopsin**. This is less sensitive to light and so a greater intensity is required to cause its breakdown and so initiate a nerve impulse.

✓ Iodopsin splits into a protein **photopsin** and a **vitamin A** derivative retinal.

Rods are more sensitive than the cones because:

• Their pigment is readily broken down and regenerate faster than that of the cones. That's why they are mostly used for vision during conditions of low illumination or darkness.

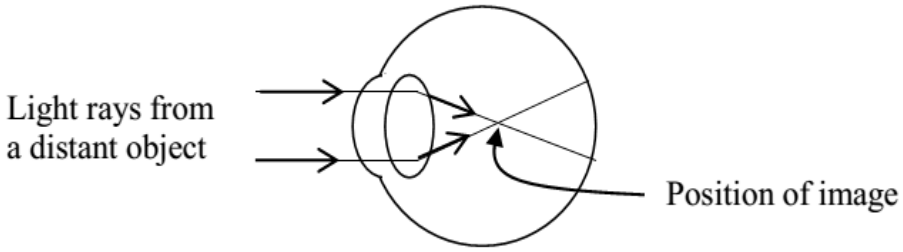
• They show retinal convergence where separate rods add up or summate to build a generator potential up to a threshold.

EYE DEFECTS

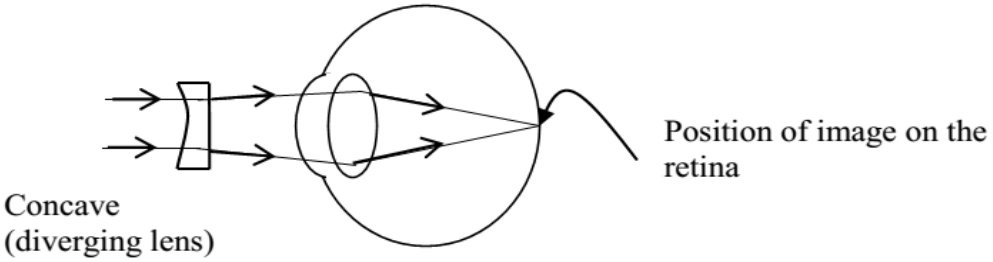
1. Myopia/ short sightedness

This is caused by large size of the eyeball such that the rays do not reach the retina and the lens being more convex i.e. with high convergence power, such that the image is formed in front of the retina.

Parallel rays from faraway objects are focused at a point in front of the retina and so the individual does not see faraway objects.

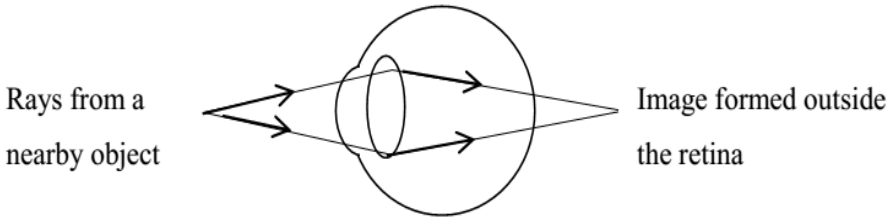


It is corrected by a biconcave lens which first diverges the parallel rays before they are finally converged and focused on the retina by the eye lens.

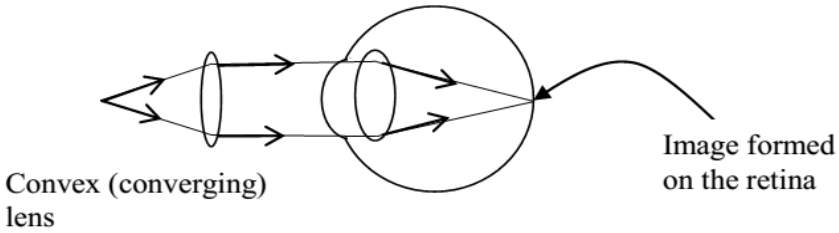


2. Hypermetropia or long sightedness

It is due to small eyeball than normal and the lens being less convex i.e. with low converging power. Rays from near objects fail to be converged and focused on the retina such that the objects get focused beyond the retina.



Long sightedness can be corrected by using biconvex lenses which supplement the converging power of the mammalian eye.



3. Astigmatism

This is caused by unequal refraction of the cornea and lens due to uneven curving in them. It results into some parts of the object being well focused on the retina and some not to be focused. It is normally due to old age. This can be solved by wearing cylindrical lenses.

4. Presbyopia

This condition occurs when the lens hardens due to old age and does not focus. It can be corrected by wearing spectacles with convex lenses or often 2 pairs of spectacles may be necessary i.e. a pair with convex lenses for close vision and a pair of concave lenses for distant vision or the 2 types of lenses can be combined into one pair known as bi-focal spectacles.

5. Cataract

It is a condition which occurs when an individual is aging. It is caused by the eye lens becoming opaque due to a thin covering formed on it. It is corrected by surgical removal of the thin opaque layer of the lens.

ROLE OF THE BRAIN IN VISION

- ✓ All light of whatever colour, intensity or pattern, which enters the eye is transformed into nerve impulses, all of which are the same. It is up to the brain to visualize these impulses into meaningful shapes.
- ✓ This it does by analyzing and interpreting the frequency of impulses and the origins of the neurones which carry them e.g from a green cone or green one.
- ✓ The visual association areas in the cerebral cortex of the brain match the incoming information with images already stored in these areas. Thus producing a meaningful interpretation.

THE ARTHROPOD EYE

Arthropods have two types of eyes;

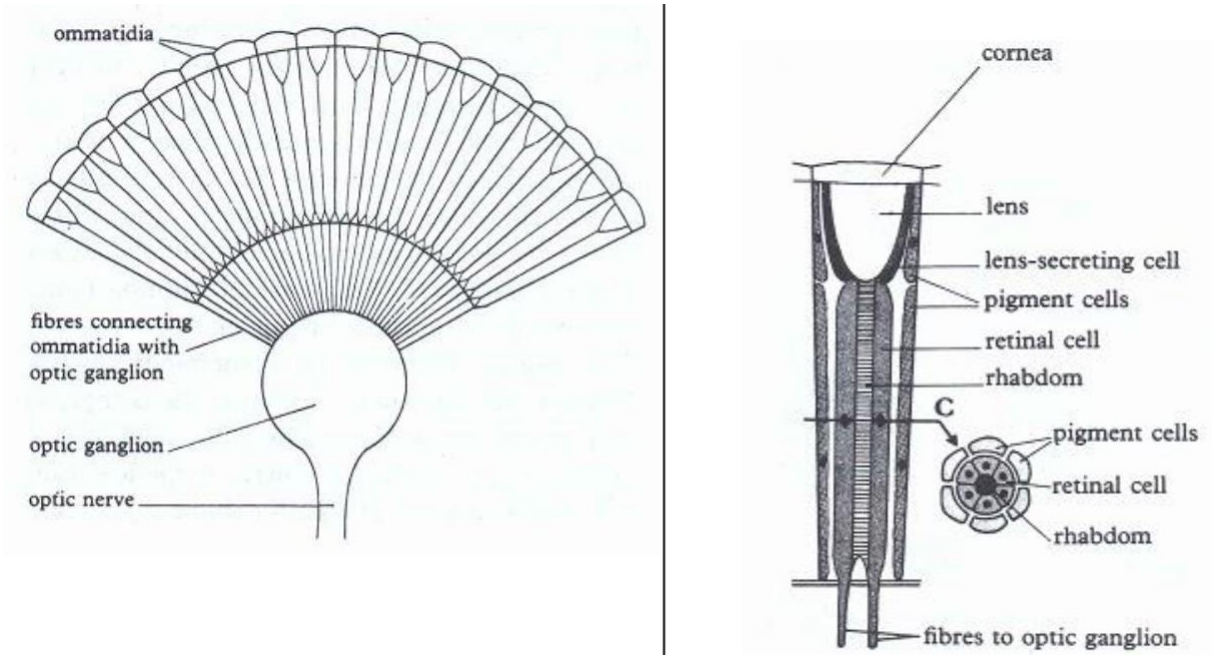
i) Simple eye; ocellus

• It is found in some larvae and consists of a single lens covering a few light sensitive cells. It can only distinguish light and dark but cannot form images.

ii) The compound eye

It is found in all Arthropods and is made up of numerous eyelets called ommatidia. Each ommatidium consists of a crystalline cone and a crystalline biconvex lens both of which focus light on the structure known as Rhabdom where a generator potential develops if it exceeds the threshold, an action potential is obtained is sent to the brain.

Diagram of a compound eye and ommatidium respectively



Or check functional approach page 308 fig 19.13

Functions of the parts;

- The lens converges light rays onto the tip of the Rhabdom.
- The pigment cells regulates the amount of light reaching the retinal cells. They also separate the omatidia.

- The Rhabdom is the light sensitive part of the ommatidium where photochemical stimulation occurs leading to depolarization of the membrane of the retinal cells.
- In the first step, light is focused on the photosensitive retinal cells. These cells contain microvilli that form the Rhabdom where the generator potential develops.
- The arthropod eye has a poor resolving power; low visual acuity because each ommatidium forms its image causing overlap of the image giving a mosaic appearance of the image. Because of the low resolving power, insects are very liable to accidents.
- However, the compound eye is very sensitive to many moving objects increasing sensitivity of the animal to the surrounding.
- Whereas the human eye can only distinguish about 50 flashes of light per second, the compound eyes of some insects can detect flickering at a rate six times faster. If they slipped into a movie theatre, these insects could easily resolve each frame of the film being projected as a separate still image- this is termed as **flicker fusion**;
- This a condition in an organism in which the sensation of flicker disappears and the light becomes steady after successive light flashes from a stationary light source.
- **Note;**
- The ommatidia would serve the same function as the rods and cones of the vertebrate eye but they are much larger and this brings about the reduced visual acuity in arthropods.

Advantages of having a compound eye;

- ❖ Malfunctioning of a single eyelet (omatidium) may be compensated by others.
- ❖ It has a wide field of view
- ❖ Very sensitive to moving objects

COMPARISON BETWEEN THE MAMMALIAN EYE AND COMPOUND EYE

Similarities;

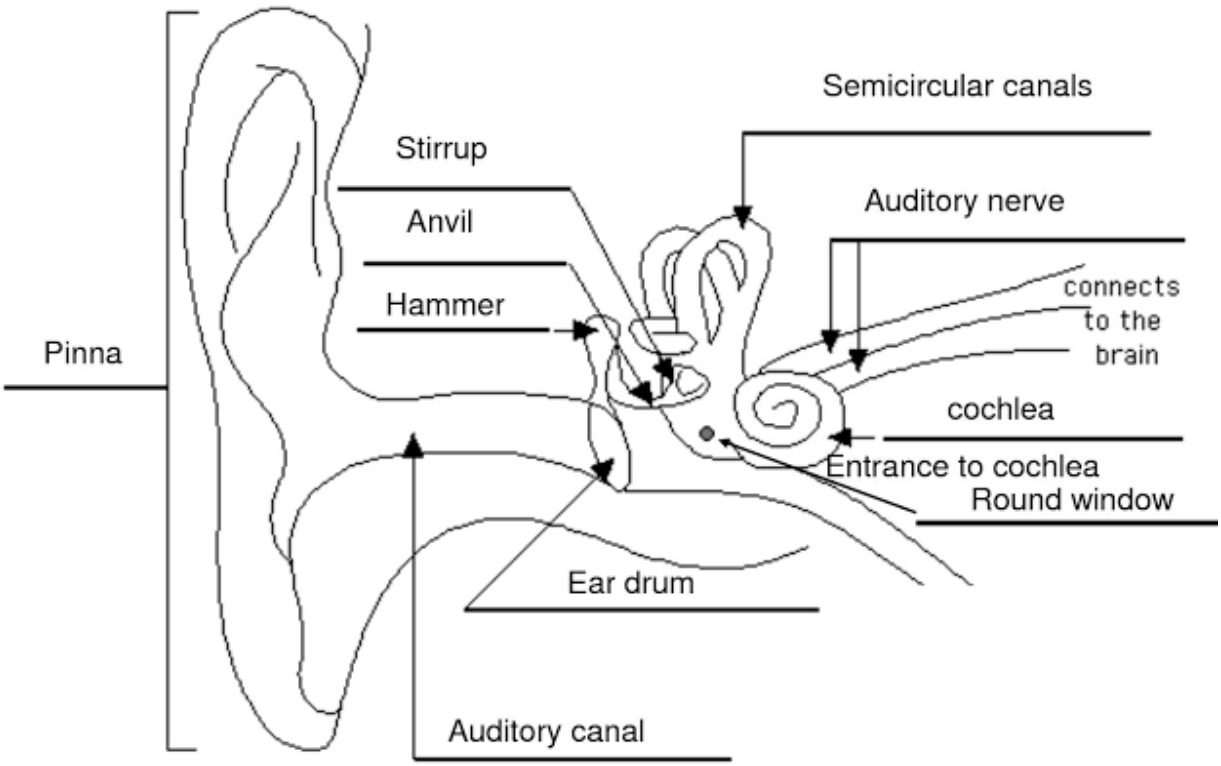
- ✓ Both contain pigmented cells.
- ✓ Both have the cornea.
- ✓ Both possess convex lens.
- ✓ Both have nerve fibres to the brain.
- ✓ There is overlap of image in both.

Differences;

Compound eye	Mammalian eye
No rods and cones.	Rods and cones are present.
Consists of many repeated units able to function on their own/ ommatidia	The whole eye functions as a single unit.
Lens is crystalline	Lens is membranous
Has a rhabdom.	No rhabdom.
No muscles attached to it i.e. it's immovable.	Has muscles attached to it and is very movable.
Has no eye lids and isn't protected at all.	Has eyelids for external protection.
Has a fixed focus (no accommodation).	Has adjustable focus (accommodation is possible).
Overlap image is greater.	Overlap image is small.
Detect light parallel to its longitudinal access.	Detects light reaching it at all angles.
Has poor resolving ability and poor visual acuity.	Good resolving ability and greater visual acuity.
Shows near sightedness.	Can see both near and far objects.

THE MAMMALIAN EAR

The ear has **mechanoreceptors**; receptors that detect physical transformation associated with sound, gravity and displacement.
The ear performs three basic functions i.e. detection of:
▪Sound; hearing, Head movements and changes in gravity; balance or posture
Internal structure of the human ear;

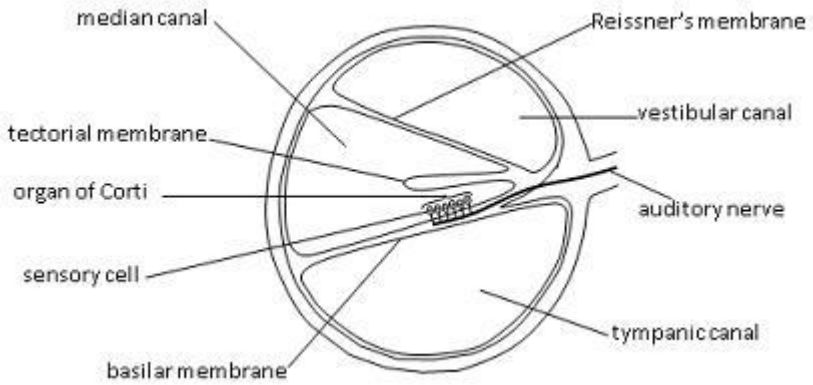


Or check understanding biology page 553 fig. 27.25
Or functional approach 4th edition page 311 fig.19.16
FUNCTIONS OF THE PARTS.
1. **The pinna**; this is an immovable cartilaginous structure that leads into the auditory canal.
2. **External auditory meatus**; it focuses, collects and concentrates and deflects sound waves into the auditory canal. The auditory canal ends at the ear drum and it transfers sound waves from the pinna to the ear drum.
3. **The ear drum; tympanic membrane**; it is a delicate membranous structure that separates the middle and the outer ear and vibrates in response to the sound waves tapping on its outer surface. It transmits the sound waves to the middle ear.
4. **The middle ear**; it has three bones called the ear ossicles which vibrate in response to the vibrations of the middle ear. The ossicles are the malleus, incus and stapes in that order. It also has the Eustachian tube which helps to balance air pressure on either sides of the ear drum.
5. **The inner ear**; it is filled with fluid and consists of a complex system of canals separated by membranes. The inner ear is made up of two parts; the cochlea and the vestibular apparatus; semi-circular canal which controls body balance and orientation.
6. **The cochlea**; it is involved in hearing while the vestibular apparatus is for balance. The cochlea consists of the organ of corti with sensory hair cells that are sensitive to vibrations and movements of the fluid in the canal.

THE MECHANISM OF HEARING

- The pinna receives sound waves, concentrates them and then deflects or sends them into the auditory canal and they finally reach the ear drum causing it to vibrate.
- The vibrations are transmitted to the three ear ossicles; malleus, incus and stapes which vibrate in turn and their vibrations amplify the sound waves by 22 times
- The last ear ossicles in series transmit the vibrations to the oval window that vibrates displacing the perilymph in the oval window which in turn vibrate displacing the perilymph in the vestibular apparatus or canal.
- When the perilymph is displaced, it causes vibrations of the Reissner's membrane resulting into displacement of the endolymph in the middle or median canal. This in turn causes vibrations of the basilar membrane hence displacing perilymph in the tympanic canal.
- Pressure waves in the perilymph and endolymph cause sensory hair cells of the organ of corti attached to the basilar membrane to rub or pull against the tectorial membrane.
- The distortion of the sensory hair cells changes their permeability to sodium and potassium ions becoming depolarized, creating a generator potential or a receptor potential in the sensory hair cells and on reaching the threshold intensity, an action potential is produced in the axons of the auditory nerve firing off an impulse to the brain for interpretation.
- The mammalian ear is capable of distinguishing between frequency or pitch and intensity or loudness of sound waves.
- Low sound intensities stimulate a few sensory hair cells while high intensity sounds stimulate many sensory hair cells. High frequency sounds stimulate the basilar membrane at the base of the cochlea while low frequency sounds stimulate it at the apex. In each case, the patterns of impulses to the brain are interpreted accordingly.

Structure of the cochlea



Or check understanding biology page 554 fig 27.26
Or functional approach 4th edition page 311 fig. 19.16
NOTE: the organ of corti is made up of the tectorial membrane, basilar membrane, auditory neuron and the sensory hair cells.

BALANCING IN MAN

- The vestibular apparatus of the inner ear consists of the utricle/ Utriculus, saccule/ sacculus and the 3 semi-circular canals, all of which are filled with the endolymph. The three semi-circular canals are at right angles to each other and each one has a swelling at the base called the Ampulla.
- The semi-circular canal opens the utricle and then in turn connected to the saccule. The balance receptors are present in the utricle, saccule and the Ampullae

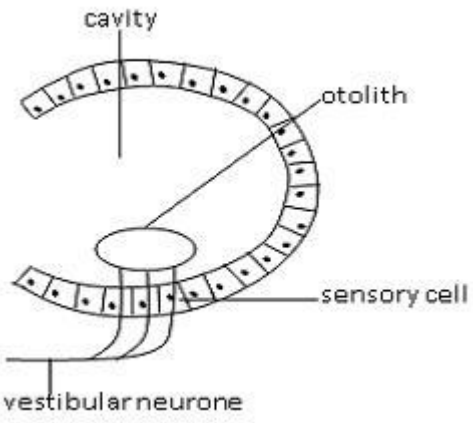
of the semi-circular canals. These receptors contain sensory hair cells which are sensitive to the position of the head with respect to gravity.

- The three semi-circular canals are so arranged that the movement of the head in any plane can be detected by these cells. The sensory hair cells in the saccule and utricle are embedded in a fluid made up of calcium carbonates called otoliths or otocolium. Otoliths is found in the maculae organ containing sensory hair cells within the saccule and utricle. The sensory hair cells in the ampullae are found in the cristae organ embedded in the endolymph.

MECHANISM OF BALANCE

Balance in man involves sensation of a static equilibrium which is achieved by the saccule and utricle. It also involves sensation of a dynamic equilibrium achieved by the 3 semi-circular canals

Sensation of a static equilibrium



✓ The utricles consist of a patch of sensory hair cells embedded in crystals of calcium carbonate (otoliths). In static position when the head is stationary and upright, the otoliths sets a balance over the sensory hair cells under the influence of gravity. In this case, no impulses are taken to the brain and the body is said to be balanced relative to gravity.

✓ By varying the position of the head, the pull of gravity over the hair cells also changes e.g. different influences of the pull of gravity result into patterns of impulses to the brain via the vestibular nerve which then interprets the position of the head relative to gravity.

Sensation of a dynamic equilibrium

✓ This is achieved by the three semi-circular canals. The Ampulla receptors consists of the cristae organ with sensory hair cells embedded in a fluid called endolymph. The semi-circular canals are arranged in the three planes, vertical, horizontal and lateral planes. The vertical canal detects movements in the upward and down ward directions. The horizontal canal detects backward and forward motion e.g. when one nods the head while the lateral canal detects sideways movement e.g. when rotates in a rotator.

✓ When the head moves in one particular direction, the fluid in the relevant canal also moves in a direction opposite to that of the head. This puts a mechanical strain on the sensory hair cells causing them to become depolarized and firing an impulse to the brain

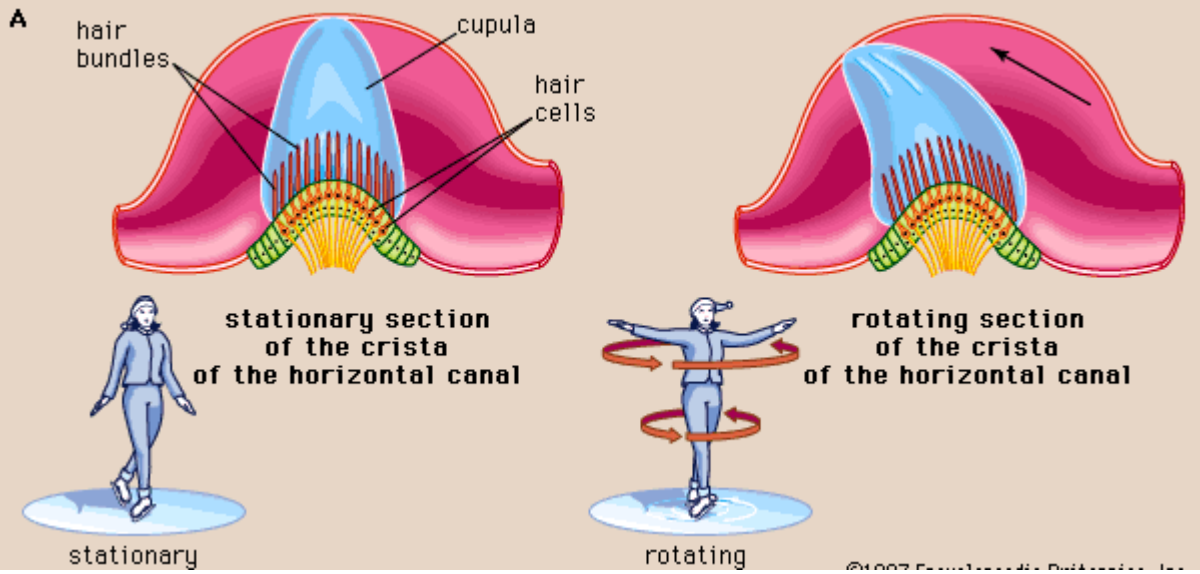
✓ The pattern of the impulses to the brain depends on which canal has been deflected and at what speed, therefore the brain interprets the direction and speed of movement

Note;

1. When someone rotates in a rotator, at constant speed and suddenly stops, feelings of dizziness occur but soon the dizziness disappears
2. When the head rotates, the fluid in the relevant canal also moves in the opposite direction since the rotator is rotating at constant velocity, the fluid also moves at a

constant velocity so the acceleration of the fluid is zero and the brain senses a static equilibrium.

3. When the rotator stops suddenly, due to inertia of the fluid in the canal, it continues to rotate such that the brain interprets movement of the head yet the body is in static equilibrium. This creates temporary dizziness.



Or check understanding biology page 555 fig. 27.27
Or functional approach 4th edition page 313 fig. 19.18

ECHOLOCATION IN BATS

- Bats fly so swiftly at night without seeing but do not collide with obstacles on their way. This is done because they use sound orientation in the environment.
- They are able to use echoes of the sound they produce to detect on their way, a phenomenon known as echolocation.
- Bats produce sound of high frequency; short wave length which are far beyond which man can perceive and use thus can't hear sounds used in echolocation.

Major advantages of sound of echolocation

✓ These sounds do not spread so wide and their echoes are so refined that they pin point the obstacle on which they are correctly reflected.
✓ These sounds having short wave length, they allow location of even small objects.

COORDINATION IN ANIMALS

- As an organism becomes more complex, shifting from a unicellular state to a multicellular state, coordinating different parts of the body amongst themselves and with the environment becomes necessary.
- All higher animals have evolved two systems that control and coordinate the different parts of the body;

1. The nervous system
2. The endocrine system

- These systems enable the organism to respond to an external stimulus. The nervous system is comparatively faster compared to the endocrine system; its effects are localized and it involves electrical and chemical transmission. However these two systems interact and are responsible for maintaining a steady state within the body.

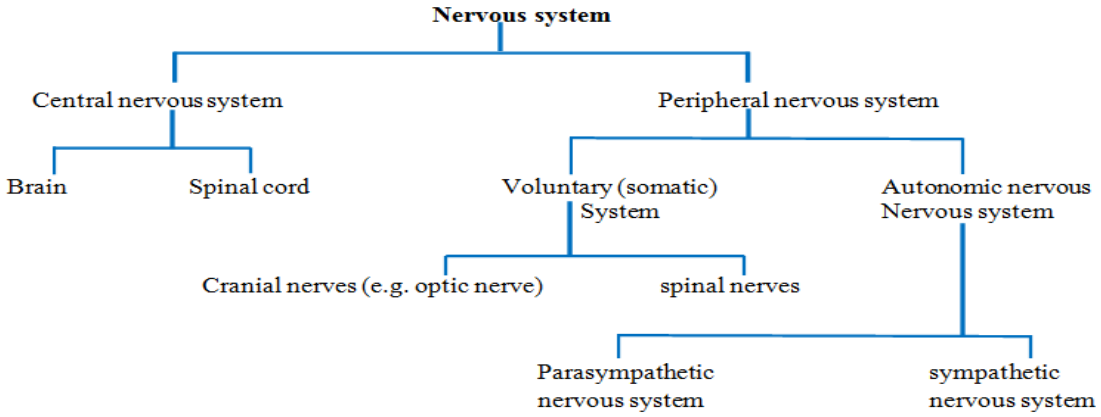
THE NERVOUS SYSTEM

Functions of the nervous system

- The nervous system works by; carrying impulses; electrical messages from sensory receptors like the ears, eyes, nose, tongue, etc. to the nerve centres; the central nervous system for purposes of interpretation.
- From the CNS, the messages are carried to the respective effectors which may be muscle, glands or any tissue. For example when a foreign particle falls on the eye, the message goes to the brain informing it of the disturbance; from the brain, the message comes back to the tear glands which respond by producing tears to clear the eye.
- The nervous system receives the changes on the external environment detected by receptors and takes the messages to the central Nervous System for interpretation and after interpretation and analysis; the message goes back to the effectors mainly muscles, tissues and glands.
- The nervous system stimulates and or inhibits the activity of various muscles and glands according to the kind of information received e.g. arrival of food in the stomach sends a nervous message to the gastric glands making them to start secreting gastric juice. However, arrival of acidic chyme in the duodenum inhibits the gastric glands by a nervous message stopping the release of gastric juice.
- The nervous system controls many activities of internal organs e.g. the heart, liver, lungs, kidney and the Gastro-intestinal tract whose activity is not controlled by the individuals.
- By controlling and coordinating the different activities of the body, it maintains metabolic stability within the body such that levels of substances remain constant in the body with minor variations.
- In multicellular animals, all stimuli are detected by specialised cells known as receptors. This sensory information is transmitted by specialised cells called **neurones** to the effectors which produce a response.

PARTS OF THE VERTEBRATE NERVOUS SYSTEM

The vertebrate nervous system consists of two main parts the central Nervous System and the Peripheral Nervous system.



i. The Central Nervous System (CNS);

It consists of the brain and the spinal cord. It is made up of thousands of nerve cells called neurones. It coordinates, integrates and controls the various nervous activities of the body.

ii. Peripheral Nervous system

This is further divided into two categories; Voluntary nervous system and involuntary nervous systems;

Voluntary nervous system

✓ This consists of nerves outside the CNS which connect the brain and spinal cord to all parts of the body controlling activities that the individual has voluntary control over. If is made up of two types of nerves; cranial and spinal nerves.

✓ Cranial nerves are those arising from the brain and serve all organs on the head while spinal nerves arise from the spinal cord and serve other voluntary organs.

Involuntary/Autonomic Nervous System

✓ This consists of nerves connecting organs where the individual has little or no voluntary control over.

✓ It basically controls activities of internal organs like heart, liver, spleen, kidney, and the gastro intestinal tract.

✓ It is made up of the; **sympathetic nervous system** and **Parasympathetic nervous system**

✓ These two oppose each other in their activity i.e. when the sympathetic stimulates a gland to release its secretions, the parasympathetic inhibits it hence they are antagonistic. While the sympathetic is made up of only spinal nerves, the parasympathetic has cranial nerves in addition to the spinal nerves.

✓ The cranial nerve of parasympathetic Nervous system arising from the brain is called the **Vagus nerve** and it goes to control activities of abdominal organs.

THE CENTRAL NERVOUS SYSTEM

The central nervous system (CNS) is the coordinator of the nervous system. It comprises a long, approximately cylindrical structure called the spinal cord and its anterior expansion called the brain.

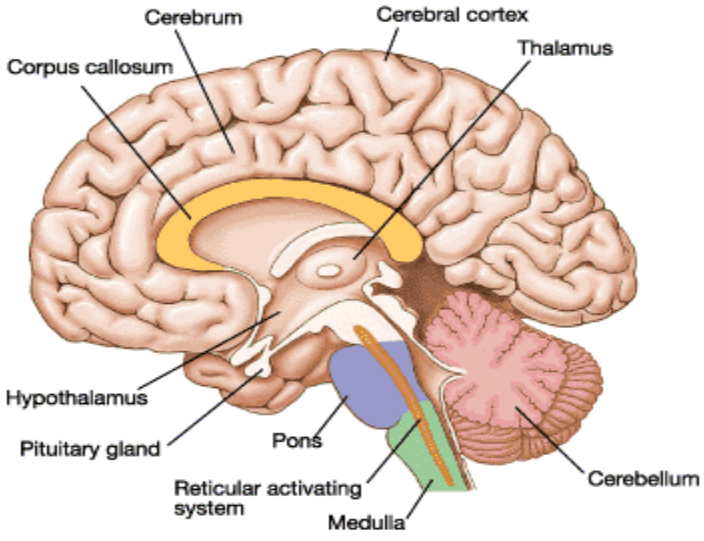
THE HUMAN BRAIN

❖ This is a highly specialized organ present in a bony case called the cranium protecting it from external injuries.

❖ It mainly consists of nervous tissue and to the outside is the grey matter and the inside white matter.

❖ The brain can be differentiated into three main regions' fore, mid and hind brain

The structure of the brain.



Or check understanding biology page 542 fig 27.15

Or functional approach 4th edition page 286 fig 18.20

a. The fore brain; it is composed of;

Cerebrum

× This is the largest part of the brain and proportionally large in man than any other animal. It consists of two cerebral hemispheres. The right and the left separated by the corpus callosum.

× The hemispheres have an outer region of grey matter called the cerebral cortex.

× The surface area of the cerebral hemisphere is increased by being highly folded.

The cerebrum is a region of many activities concerned with three basic areas;

Sensory areas; these receive information from sensory organs like the eyes, ears, nose, and give impressions of what we see, hear and smell

Motor areas; these send back information after interpretation to the respective organs.

Association areas; these interpret the incoming information basing on past experiences. The association areas are associated with memory, learning reasoning and intelligence. The association areas include;

- Visual association areas; these associate what we see with what is already stored in the brain so as to be interpreted.
- Auditory association areas; these associate what we hear with the information already stored in the memory units
- Olfactory association areas; these interpret the smell signal as it reaches the brain.
- Speech effector centres; these coordinate movement of lips, tongue and breathing in order to allow the person speak coherently.

Note; The association areas are named so because;

- They associate the incoming information with the information previously perceived and stored in the memory units.
- They interpret the information and give it meaning depending on the stored information

× The cerebrum is a region of intelligence and other higher activities. Therefore any damage to the cerebrum results into the victim losing memory reasoning capacity but would retain feeding, sleeping etc. as these are controlled by the medulla.

The thalamus

× This is the region present at the centre of the cerebrum. All the information reaching the cerebrum from the spinal cord and must pass through the thalamus.

× Its function is to interpret the information and channeling it to the appropriate association area of the cerebrum.

× It is also important for perception of pleasure and pain and plays a role in awareness.

Hypothalamus

× This is found just below the thalamus and it controls most of the involuntary activities or the activities of Autonomic nervous system such as pressure, water balance, temperature, regulation of hunger etc.

× It is also a reflex control centre associated with feeding, sleeping and emotions.

× In association with the pituitary gland, it controls the release of many hormones from the anterior pituitary.

× It is also an endocrine gland

b. The mid brain

× This basically connects the fore brain to the hind brain. It houses both visual and auditory reflex centres. The reflexes they control include the movement of the head to fix an object or locate sound.

c. The hind brain

It consists of cerebellum, pons and medulla.

The cerebellum

- It has two cerebellar hemispheres just like the cerebrum.
- The cerebellum is concerned with the control of muscular movement and body posture. It is also a control centre for reflex actions and maintenance of body balance.

The pons

- Just above the medulla without any specialized function, only to send impulses to cerebellum is the pons.

Medulla oblongata

- It is the most posterior part of the brain and is continuous with the spinal cord. It carries nerve fibres connecting the spinal cord to the brain, therefore all communications between the brain and spinal cord pass through the medulla oblongata.
- It controls involuntary activities like sneezing, coughing, vomiting including activities of internal organs like cardiac frequency blood pressure, breathing rate etc. where the individual has no voluntary control.

NOTE;

a. Nerve fibres carrying impulses from the spinal cord to the brain on the left crossover with those carrying impulses from the brain to the spinal cord on the right at medulla. This crossover is necessary because the white matter of the spinal cord is on the outside and the grey matter in the interior which is the reverse in the brain. Because of this crossover at the medulla on one side causes paralysis on the opposite side of the body.

b. Diffusely situated throughout the brain stem is a system responsible for stimulating the cerebral cortex and so to rouse the body from sleep. The stem is responsible for maintaining wakefulness.

c. It also monitors impulses reaching and leaving the brain stimulating some and inhibiting others.

d. By doing so it concentrates the brain activity upon issues of most importance at any one time e.g. visual sense may be enhanced if one is looking for small needle.

THE SPINAL CORD

- ✓ The spinal cord is a tubular or cylindrical structure running down the medulla and located within the vertebral column. The distribution of the grey and white matter is the reverse of what is present in the brain; the grey matter is in the centre and the white to the outside.
- ✓ In the centre of the spinal cord runs a fluid canal called the central canal filled with extracellular cerebral spinal fluid.
- ✓ The grey matter is H-shaped or butterfly shaped consisting of intermediate neurons or its cell body and cell body of the motor neurons whose axon is found within the ventral horn.

The white matter consists of two types of nerve fibres;

a. The ascending nerve fibres which run from the spinal cord to the brain.

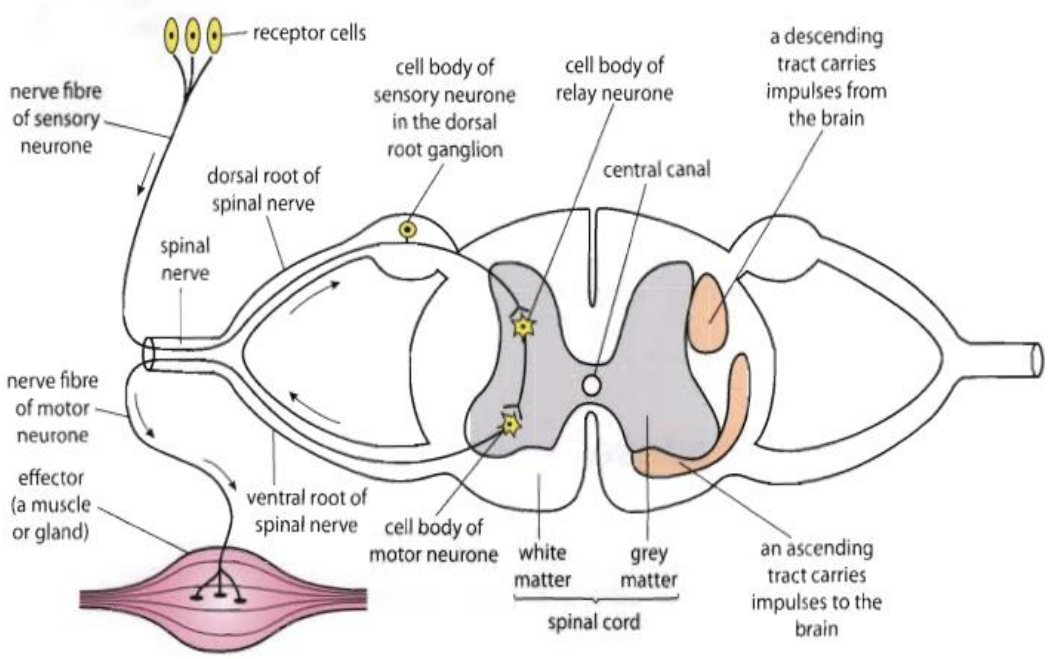
b. Descending nerve fibres running from the brain to the spinal cord carrying information from the brain to different parts of the spinal cord.

- ✓ While the ascending nerve carry sensory information to the brain, the descending nerves carry motor information from the brain to the spinal cord.

REFLEX ACTION

- This is a short-lived, rapid, automatic, involuntary and stereotypic response to a stimulus which is not under the conscious control of the brain. The passage of the impulse from the receptor to the effector to bring about a reflex action is known as the reflex arc, i.e. the nervous pathway that transmits information rapidly.
- A reflex arc can be described as mono-synaptic if it has only one synapse located between the sensory and effector neurones in the spinal cord, for example, the knee-jerk reflex. In a knee-jerk reflex, the stimulus is usually generated by a blow to the tendon below the knee-cap. This tendon is connected to the muscles that extend the leg and therefore hitting it stretches it. The muscle spindles work as receptors and the impulse is generated out of the stretching. The sensory neurone transmits the impulse to the spinal cord. The impulse crosses the synapses between the sensory neurone and the motor neurone. The motor neurone transmits the impulse back to the muscle responsible for extending the leg. This muscle then contracts upon receiving the impulse, causing the lower leg to jerk upwards. This is an example of negative feedback, i.e. stretching of the muscle stimulates the shortening of the muscle.
- Reflex arcs involving two or more synapses within the central nervous system as a result of the inclusion of the intermediate neurone are called **poly-synaptic reflex arcs**, e.g. withdrawal of the hand from a sharp object.

Illustration of reflex action



Or check functional approach page 277 fig 18.15
Or understanding biology page 539 fig 27.12

Note:

1. Spinal reflexes; these are reflex actions that pass through the spinal cord and are interpreted there e.g. withdrawing a hand from a hot object.

2. Brain/cranial reflexes; these pass through the brain and are interpreted there e.g. closing of the eye when an object is approaching, coming of tears when one is cutting onions, etc.

3. Instinctive/simple reflex actions; these are reflexes that do not require learning but are inborn e.g. suckling in human infants, making of a web by a spider, withdrawing a hand from a hot object.

4. Some reflexes are more complex in nature than the simple reflexes so far described, **Conditioned reflexes**; these are forms of reflex actions where the type of response is modified by past experience. They are coordinated by the brain and learning forms the basis of all conditioned reflexes. For example salivation on the sight and smell of food, toilet training, etc.

***Conditioned reflex in regards to Pavlov as earlier covered in learned behaviour**

Importance of reflex actions

- ✓ They enable animals avoid danger.
- ✓ They control activities in the body, which we do not have conscious control over.
- ✓ They form a basis of some animals' behaviour, e.g. amoeba.
- ✓ They allow the body to make automatic adjustments to changes in the external environment, e.g. the iris-pupil reflex in response to change in light intensity

THE PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system consists of two types of nerves; Spinal nerves arising from the spinal cord and the cranial nerves arising from the brain. These nerves fibres are named according to;

1. Direction of nerve impulse flow;

a) Afferent nerves; these conduct message from the peripheral organs to the brain and spinal cord.

b) Efferent nerves; these conduct nerve impulses from the central nervous system to the peripheral organs (effectors).

2. Depending on the function;

a) Sensory nerve fibres; these carry sensory information from the sense organ to the CNS.

b) Motor nerve fibres; these carry motor information from the CNS to the peripheral organ

Note:

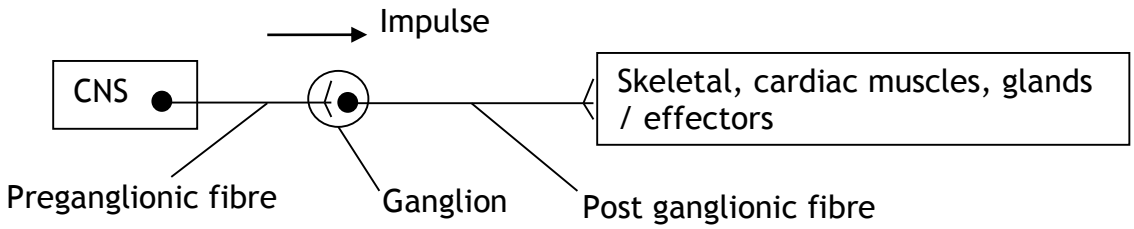
i. The sensory and motor neurons or afferent and efferent neurons are linked by the intermediate/relay neurons found in the grey matter. The spinal nerves run from the spinal cord to the peripheral organs and they carry both sensory and motor information.

ii. The sensory neurons enter via the dorsal horn while the motor neurons leave via the ventral horn. They are linked by the intermediate neurone.

iii. The cranial nerves arise from the brain and they may be sensory or motor, the tenth cranial nerve is called the Vagus nerve which carries information to the internal organs.

THE AUTONOMIC NERVOUS SYSTEM (ANS)

- It is that part of the peripheral nervous system controlling involuntary activities. It is made up of two parts; sympathetic and parasympathetic nervous system whose actions oppose each other i.e. are antagonistic
- They control activities of internal organs such as heart beat, peristalsis, breathing rate, sweating etc. most of the activities of the Autonomic nervous system do not involve the conscious control of the brain particularly the higher centres that involve learning memory ad intelligence.
- However, the ANS is controlled by the medulla and hypothalamus which control involuntary activities including activities of smooth muscles.
- The structure of the ANS is composed of 2 neurones, the preganglionic neurone and the post ganglionic neurone.



***understanding biology page 540 fig 27.13**

NOTE:

- ✓ Each organ gets a parasympathetic as well as a sympathetic nerve fibre regulating its activities. The ganglionic fibres of both systems release a chemical transmitter substance called Acetylcholine hence are called cholinergic fibres.
- ✓ However the post ganglionic fibres are different from the sympathetic nervous system, they release Noradrenaline hence are called Noradrenergic fibres. This is the most important functional difference between the two systems.
- ✓ The most structural difference is that the preganglionic fibres of the sympathetic nervous system are sort while the post ganglionic fibres are long. For the parasympathetic nervous system the pre-ganglionic fibres are long and the post ganglionic fibres are short.
- ✓ These two systems usually produce opposite effects e, g. if the sympathetic relaxes an organ the parasympathetic contracts it and in general, the sympathetic has a positive effects while the parasympathetic has a negative effects. Also the effects of the sympathetic system have the general results of preparing the body for an emergency (similar) to Adrenaline hormone e.g. dilating the pupil speeding up heartbeat, causing hair to stand etc.

Comparison between sympathetic and parasympathetic nervous systems

Sympathetic	Parasympathetic
Pre-ganglionic fibres are short and post ganglionic fibres are long	Pre-ganglionic fibres are long and the post ganglionic are short.
Ganglion close to the Central nervous system (spinal cord)	Ganglion close to the effector organs
Releases Noradrenaline at the effector	Releases Acetylcholine at the effector
Emerge from spinal cord	Emerge from the brain
Generally excitatory	Generally inhibitory
Dominant during emergency e.g. danger, shock and activity	Dominant during rest

Generally increases heartbeat, ventilation rate, secretion of sweat, induces ejaculation, releases adrenaline from the adrenal glands, increases blood pressure and volume and dilates pupils	Generally decreases heartbeat, ventilation rate, no release of sweat, stimulates erection, inhibits release of adrenaline, reduces blood pressure and volume and constricts pupils
Generally inhibits secretion of saliva, peristalsis and secretion of alimentary canal juice	Generally stimulates secretion of saliva peristalsis and secretion of alimentary canal juice
Only spinal nerves present	Spinal and cranial nerves present

Comparison of the effects of sympathetic and parasympathetic nervous system

Target Organ/Tissue	Parasympathetic Stimulation	Sympathetic Stimulation
Effect on organ:	Inhibitory effect / relaxation	Excitatory effect / stress
Motor neurone releases:	Acetylcholine (ACh)	Norepinephrine (noradrenaline)
Iris of eyes	Constricts pupil	Dilates pupil
Bronchi, bronchioles	Constricts tubes	Dilates tubes
Blood vessels	- Dilates blood vessel	- Constricts blood vessels
	- Lowers blood pressure	- Raises blood pressure
Heart	- Lowers heart rate	- Raises heart rate
	- Lowers stroke volume	- Raises stroke volume
Intercostal muscles	Lowers breathing rate	Raises breathing rate
Salivary glands	Stimulates secretion of salvia	Inhibits secretion of salvia
Gut	Stimulates peristalsis	Inhibits peristalsis
Sweat glands	No effect	Increases sweat production

Note;

- ✓ The sympathetic Nervous system though causing general vasoconstriction, dilates those arterioles serving vital organs such as skeletal muscles
- ✓ The sympathetic nerve serves to the sweat glands produces Acetyl choline instead of the Noradrenaline, a characteristic of the PNS.
- ✓ The erector pili muscles and sweat glands do not have a parasympathetic supply.

Differences between the Central and autonomic nervous systems

Central nervous system	Autonomic nervous system
There is conscious control over it	No conscious control over it i.e. controls involuntary activities
One nerve between CNS and the effector organs	Two nerve fibres between CNS and effector organs.
Controls activities of skeletal muscles	Controls activities of smooth muscles, cardiac muscles and glands.
Higher centres of the brain are involved in the control; cerebrum	Hypothalamus and medulla control the activities of the system

NERVOUS TISSUE AND THE NERVE IMPULSE

A neurone (nerve cell) is a specialised cell adapted to rapidly carrying electrochemical changes called nerve impulses from one part of the body to another.

General structure of a neurone

✓ A neuron has two distinct regions a cell body; centron and axon.

✓ The cell body contains a nucleus and a granular cytoplasm in which are numerous cell organelles like mitochondria, Golgi apparatus etc. The cytoplasm also contains prominent granules called Nissl's granules which are really groups of ribosomes rich in RNA and are concerned with protein synthesis.

✓ Nerve fibres that conduct impulses to the cell body are called Dendrons. They are small, relatively wide and terminate into small branches called dendrites.

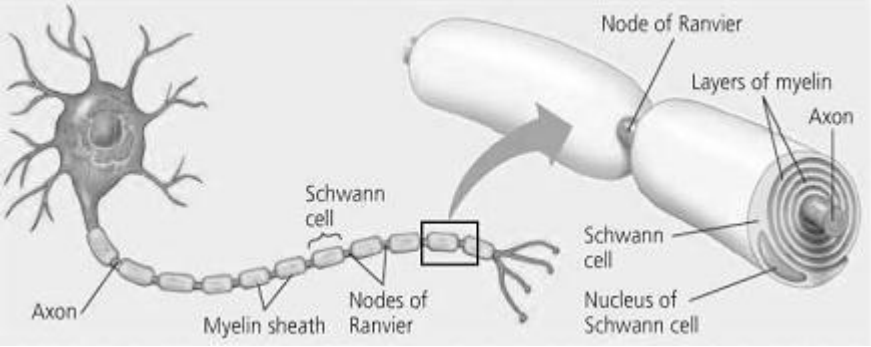
✓ The nerve fibres that conduct impulses away from the cell body are called Axons. The axon is thin and may continue for several metres in length.

✓ The axons of nerve fibres are elongated to conduct impulses away from the cell body for long distance. Thus, though the entire neurone is able to transmit impulses, the axon being an enormously elongated extension of the cell is a special adaptation for this purpose.

✓ It terminates into small branches which form small swellings known as synaptic knobs which release a transmitter substance known as Acetyl choline or Noradrenaline.

✓ The nerve fibres may be myelinated as most spinal nerve fibres or non myelinated as in the ANS. The myelinated fibres are surrounded by a fatty sheath called the myelin sheath secreted by the Schwann cells.

✓ The sheath is interrupted by the nodes of Ranvier at a given interval along the axon. Non-myelinated fibres however do not have the nodes of Ranvier since they lack the myelin sheath. Such fibres are possessed by all invertebrates.



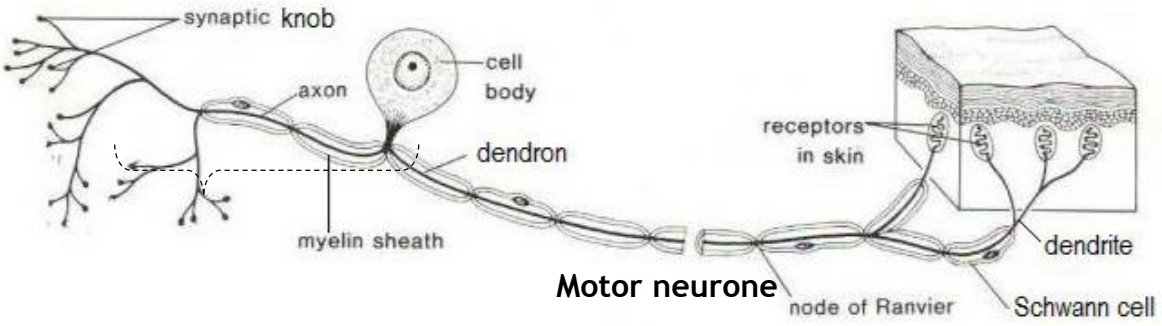
Or check understanding biology page 527 fig 27.2

Or check functional approach page 263 fig 18.1; A, B, C and D

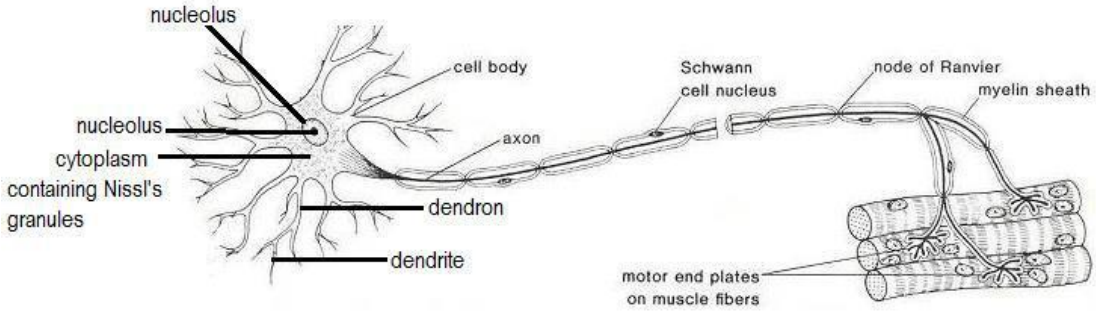
These are the types of neurons that exist;

1. **Sensory neurone**; this transmits impulses from receptors to the CNS. Sensory neurons have their cell bodies located in the dorsal root ganglia of the spinal nerves
2. **Motor neurones**; they transmit impulses from the CNS to the effector organs mainly muscles and glands. These have their cell bodies located in the central nervous system. They are connected by the relay neurons or connector neurons.
3. **Relay/ interneuron/ internuncial neurones**; this is a neurone found in the central nervous system and carries impulses from the sensory neuron to the motor neuron.

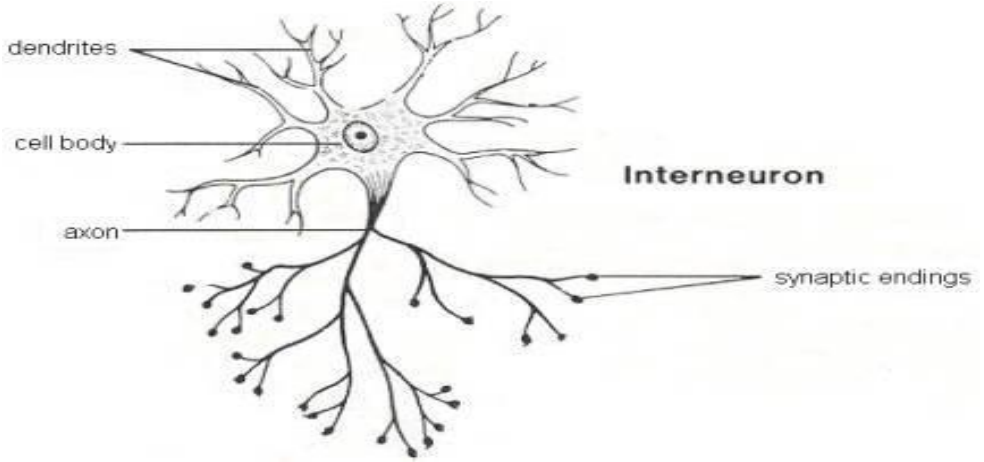
Sensory neurone



Motor neurone

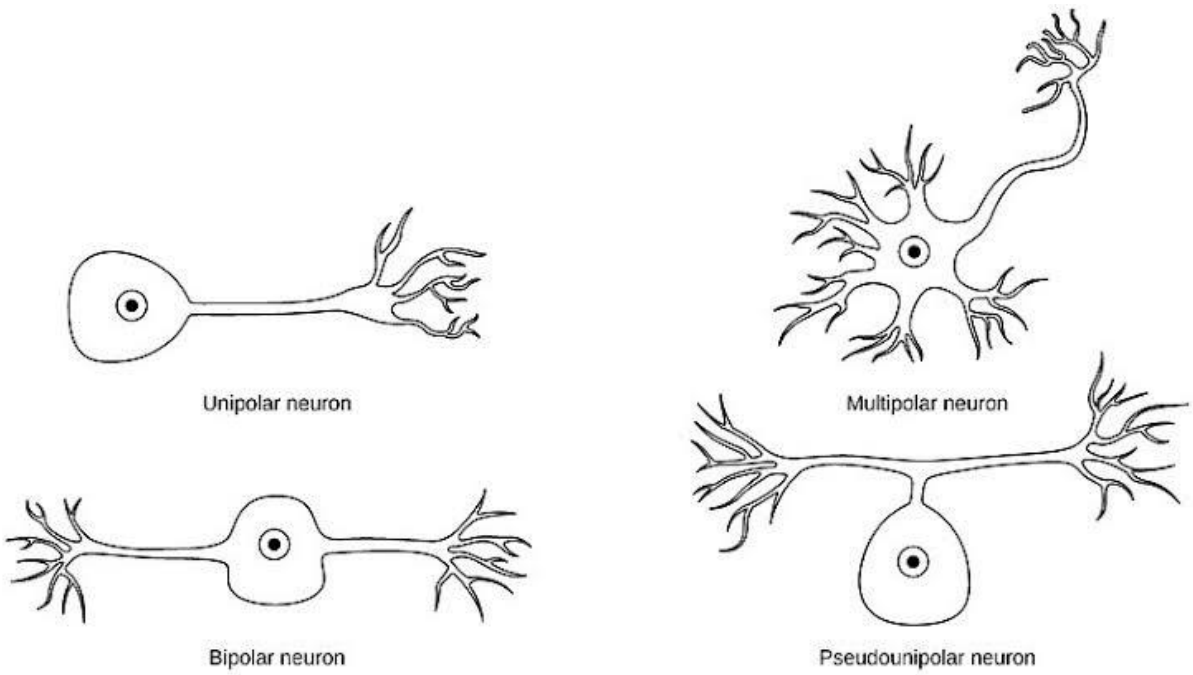


Relay neurone



Note; <u>the neurones can as well be classified according to the number and arrangement of dendrites and axon</u>**; * refer to nervous histology**

1. **Unipolar; motor neurone**; has one extension; short dendrites and long axons. The dendrites and the cell body are located in the spinal cord; the axon is outside of the spinal cord. It serves to conduct impulse to an effector
2. **Bipolar; sensory neurone;** has two extensions; long dendrites and short axon. It has long dendrites and short axons. Cell body and dendrite are outside of the spinal cord; the cell body is located in the dorsal root ganglion. It serves to conduct impulses to the spinal cord.
3. **Multipolar; relay neurone**; has many extensions; this possesses a single axon and many dendrites and dendritic branches allowing for the integration of a great deal of information from other neurones. It has short dendrites but axon length varies it is entirely within the spinal cord or CNS. It serves to interconnect the sensory neuron with appropriate motor neurone.
4. **Pseudounipolar neurone**; branched unipolar neurone; this has one extension from its cell body. It has an axon that is split into two branches.



*** understanding biology page 529 fig 27.13**

Differences between dendrites and axons

Axons	**Dendrites**
Take information away from the cell body	Bring information to the cell body
Smooth Surface	Rough Surface (dendritic spines)
Generally only 1 axon per cell	Usually many dendrites per cell
No ribosomes	Have ribosomes
Can have myelin	No myelin insulation
Branch further from the cell body	Branch near the cell body

COMPARISON OF NEURONES AND OTHER BODY CELLS

Similarities; all;

- are surrounded by a cell membrane
- have a nucleus that contains genes
- contain cytoplasm, mitochondria and other organelles
- carry out basic cellular processes such as protein synthesis and energy production

Differences;

Neurons	**Other cells in the body**
Have specialised extensions called dendrites and axons.	Lack dendrites and axons
Communicate with each other through an electrochemical process.	No such electrochemical communication
Contain neurotransmitters	No neurotransmitters

NEUROGLIA CELLS

- Since the nervous tissue lacks connective tissue filling up space between the nerve cells, the spaces are filled up by specified non-nervous cells known as neuroglia cells. Besides they perform many other functions which include;

- Some specialized neuroglia cells called microglia are phagocytic moving around the nervous tissue engulfing foreign particles; pathogens. In this way they are protective in nature.
- Some provide nourishment to the nervous cell they are nutritive in nature.
- They are rich in RNA molecules hence are involved in memory.

IMPULSE TRANSMISSION ALONG THE AXON AND POTENTIAL CHANGES DURING IMPULSE TRANSMISSION

Polarization of the neurones membrane

- Sodium is on the outside, and potassium is on the inside.
- Cell membranes surround neurons just as any other cell in the body has a membrane. When a neuron is not stimulated; it's just with no impulse to carry or transmit; its membrane is **polarized**.
- Being polarized means that the electrical charge on the outside of the membrane is **positive** while the electrical charge on the inside of the membrane is **negative**. The outside of the cell contains higher concentration of sodium ions (Na^+) and chloride ions (Cl^-) and the inside of the cell contains higher concentration of potassium ions (K^+) and organic ions.

a) **Resting potential**;

- This is the potential that exists in an axon at rest i.e. when it is not stimulated.
- This is the potential difference that exists between the outside and inside of an axon membrane when it is not stimulated. When an axon is in the resting state, i.e. when is not transmitting an impulse, a potential difference is maintained between the inside and outside of the axon.
- The inside of the axon is negatively charged to the extent of -70mV and the outside is positively charged up to +70mV.

Creation of the resting potential;

✓ The extracellular fluid has high concentration of Na^+ and low concentration of K^+ whereas the axoplasm has a high concentration of K^+ and low concentration of Na^+ and a high concentration of organic anions (COO^-)

✓ The axon membrane is more permeable to K^+ ions 20times than to sodium ions (Na^+). As a result K^+ diffuse out of the axoplasm rapidly much more in in number than the Na^+ entering.

✓ The outward movement of positive ions means that the inside becomes slightly negative relative to the outside. So as more potassium ions move out, the less able they are to do so.

✓ At this stage, the potassium voltage gates are open but the sodium voltage gated channels are closed.

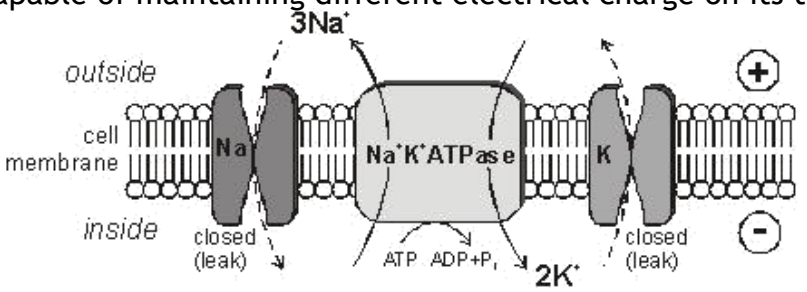
✓ In time an equilibrium is established whereby the rate at which potassium ions leave is exactly balanced by the rate of entry.

✓ The net effect is a high concentrations of cations on the outside compared to the inside.

✓ It is therefore the electrochemical gradient of potassium ions which largely creates the resting potential.

Maintenance of the resting potential

✓ The differences in concentrations of ions across the membrane are maintained by the active transport of ions against their concentration gradients.
✓ A sodium-potassium pump operates along the membrane which pumps out sodium ions and pumps in potassium ions using energy from hydrolysis of ATP.
✓ As a result of their pump, $3Na^+$ ions are expelled in exchange of 2 incoming K^+ ions. The net result is a greater concentration of cations outside the membrane resulting into a negative potential inside and a positive potential outside.
✓ At this stage, the membrane is said to be polarized and has a resting potential of -70mV relative to the outside. It shows that the membrane surrounding the axon is polarized i.e. capable of maintaining different electrical charge on its two sides.



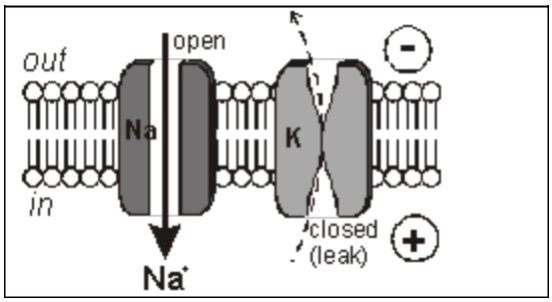
Note;

The sodium and potassium channels are **voltage-gated**, which means that they can open and close depending on the voltage across the membrane

***more about active transport was covered earlier in movement in and out of cells**

b. Action potential.

- This is a rapid change in the membrane potential of an excitable cell, caused by stimulus-triggered, selective opening and closing of voltage sensitive gates in sodium and potassium ion channels.
- This is the potential change that occurs across the membrane when the membrane is stimulated.
- It has two main stages; depolarization and repolarization;



Depolarization;

✓ When an impulse passes at a certain point on the axon, the above situation is momentarily reversed. A disturbance occurs at a point of stimulation and brings about changes in the potential in that area, the inside of the axon suddenly become positive relative to the outside.
✓ This sudden reversal of the resting potential which accompanies the impulse is what is referred to as the action potential. In this situation;
✓ Reversal of the permeability of the membrane to Na^+ and K^+ ions. The membrane behaves more permeable to sodium ions than the potassium ions because the Na^+ channels open while the potassium channels close. As a result, Na^+ ions diffuse rapidly inside the membrane along a steep concentration gradient. This causes an increase of positive ions inside the axon.

✓ The relatively high negative potential inside encourages the inward movement of the positively charged sodium ions.
✓ Because of the above two factors, the inner membrane becomes progressively less and less negative but more positive to the extent of +40mV. At this stage, the axon is said to be depolarized.
✓ **"sodium ions move inside the membrane during period of action potential"**

Note;

i. The action potential is extremely short lived lasting for about one or two milliseconds after which the original resting potential is restored again. The impulse can then be looked at as simply a wave of depolarization which passes along the axon.
ii. Local currents on both sides of the membrane cause depolarization of the next section of the membrane and so the action potential and therefore the impulse advances along the axon.

c. Repolarization;

- After the inside of the cell becomes filled with Na^+, the region of positive charge causes nearby voltage gated sodium ion channels to close.
- Just after the sodium ion channels close, the gated ion channels on the inside of the membrane open to allow the K^+ to move to the outside of the membrane rapidly. With K^+ moving to the outside, the membrane's repolarization restores electrical balance.
- Again the Na^+-K^+ pump mechanism operates pumping out $3Na^+$ against $2K^+$ inside. The net effect is the inside becoming negative relative to the outside in order to attain a resting potential; recovery phase
- **"Potassium ions move outside, and sodium ions stay inside the membrane"**

NOTE:

- Provided the stimulus exceeds a certain value, called the **threshold value** an action potential results. Above the threshold value the action potential remains constant regardless of the size of the stimulus.
- In other words the action potential is either generated, in which case it is the same or it is not. This called the **all or nothing law**.
- The all or nothing law states that "The magnitude (size) of the action potential (nerve impulse) is independent of and is not a function of the intensity of the stimulus, provided the stimulus is of threshold value"

d. **Hyper polarization**

✓ When the K^+ gates finally close, the neuron has slightly more K+ on the outside than it has Na^+ on the inside. This causes the membrane potential to drop slightly lower than the resting potential
✓ Following the entry of Na^+ after the impulse has been transmitted the channels also allows in Cl^- ions increasing the concentration of anions inside. This makes the inner membrane potential more negative than usual a condition called hyperpolarization and this inhibits the transmission of an impulse, immediately following the previous until the situation returns to normal.
✓ **"More potassium ions are on the outside than there are sodium ions on the inside."**

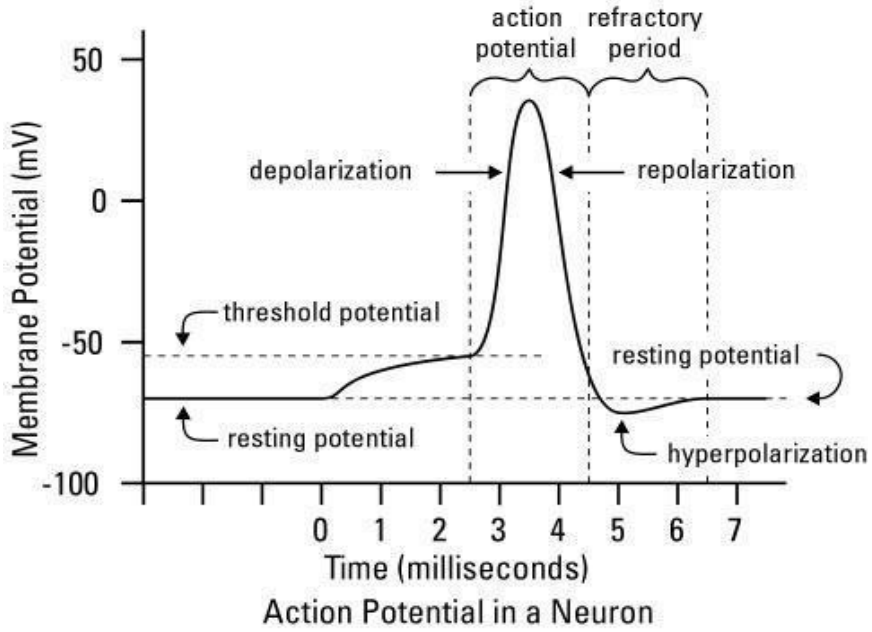
e. Refractory period

✓ This is the period during when the next impulse cannot be transmitted following the previous. This is the in-excitability that accompanies the recovery phase of an axon.

✓ The refractory period occurs when the Na+ and K+ are returned to their original sides: Na+ on the outside and K+ on the inside. While the neuron is busy returning everything to normal, it doesn't respond to any incoming stimuli. After the Na+/K+ pumps return the ions to their rightful side of the neuron's cell membrane, the neuron is back to its normal polarized state and stays in the resting potential until another impulse comes along.

✓ **"Potassium returns inside, sodium returns outside."**

IMPULSE TRANSMISSION ALONG THE AXON MEMBRANE



Action Potential in a Neuron

Mechanism of nerve impulse transmission along unmyelinated neurone.

1. At resting potential there is a high concentration of sodium ions outside and a high concentration of potassium ions inside the neurone.

2. When the neurone is stimulated sodium ions voltage gated channels open and sodium ions rush into the axon along a concentration gradient. This causes depolarization of the membrane.

3. Localized electrical circuits are established which cause further influx of sodium ions and so progression of the impulse. Behind the impulse, potassium ion voltage gated channels open and potassium ions begin to leave the axon along a concentration gradient.

4. As the impulse progresses, outflux of potassium ions causes the neurone to become repolarized behind the impulse.

5. After an impulse has passed and the neurone is repolarized, sodium ions are actively expelled by the potassium-sodium ion pump in order to increase the external concentration and so allow the passage of another impulse.

CHARACTERISTICS OF NERVES AND PROPERTIES OF NERVE IMPULSES

a. **Nerves are excitable units**; they respond to stimuli by transmitting an impulse along their length. Normally the impulses are set up in nerve cells as a result of excitations of receptors. However, excitation can occur as a result of application of any appropriate stimuli which causes local depolarization of the membrane.

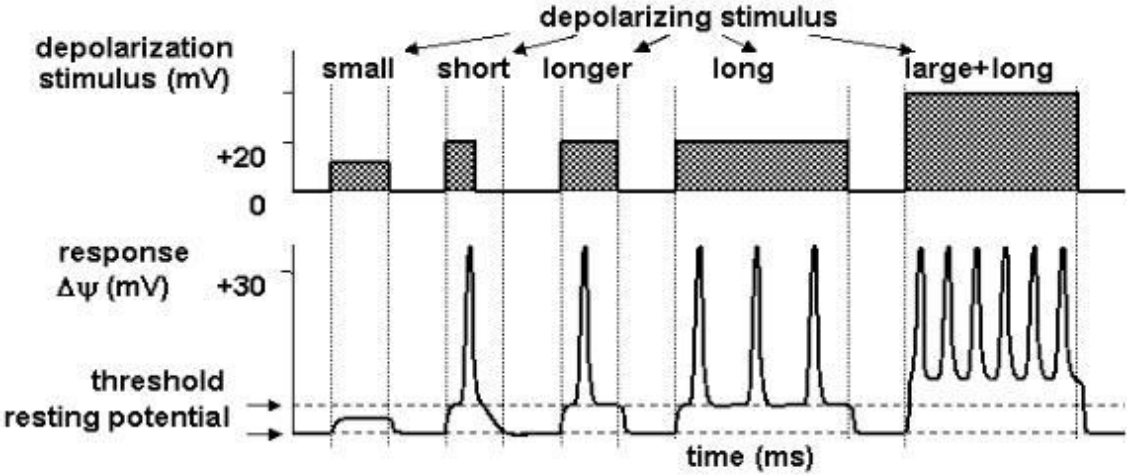
b. **They have threshold stimuli**; this is the strength of the stimulus that is required to generate an action potential. It must be of maximum magnitude below which an

action potential cannot be obtained. The stimuli less than the threshold value are called subliminal stimuli/ sub threshold stimuli.

c. Their action follows the all or nothing/none law

✓ There is always a threshold value needed to stimulate a nerve fibre. If the stimulus is below the threshold value, no action potential can be evoked. However if it is above the threshold value, the action potential is evoked and the impulse is transmitted. Further increase in the strength of the stimulus does not increase the size of the action potential so it does not affect the rate of transmission.

✓ Consider one end of an axon stimulated with a series of electrical shocks of gradually increasing intensity as shown below.



Or check functional approach page 268

✓ When the strength of the stimulus is below the threshold intensity no action potential is evoked. If it is increased beyond the threshold intensity a full sized potential is evoked. Further increase in the intensity of the stimulus however does not give a larger potential.

✓ This is an illustration of the all or nothing/none law which states that "the response of an excitable unit (in this case an axon) is independent of the intensity of the stimulus" or "the size of the action potential is independent of the intensity of the stimulus provided it exceeds a certain threshold value. *earlier covered were you able to recall?*

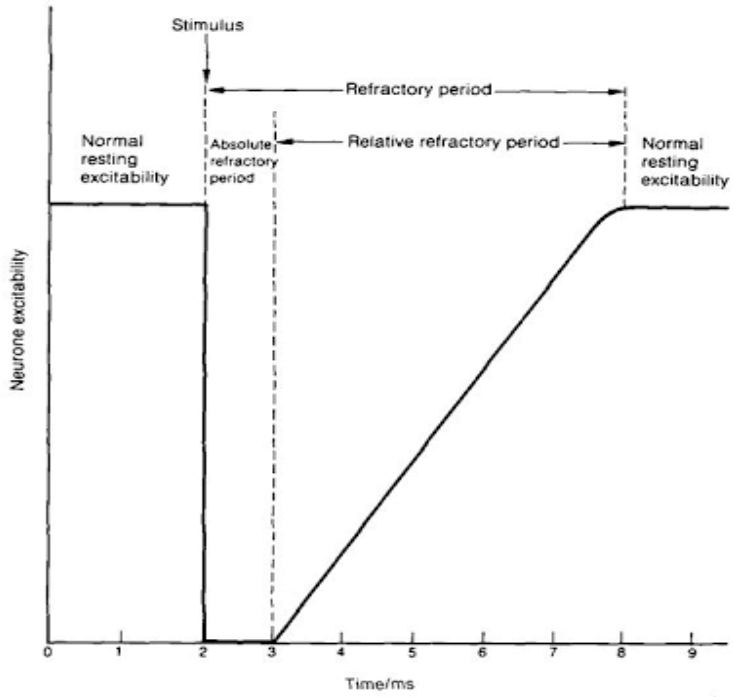
d. Refractory period

× After an axon has transmitted an impulse, it is impossible to transmit another one for a short period. The reason for it has been active; the axon has to recover before another action potential can be transmitted. Ionic movements have to occur so that the membrane is polarized.

× The refractory period is defined as the time lag that occurs following the transmission of the previous impulse that the nerve fibre is unable to transmit another or a second impulse.

× It is due to hyperpolarization or the inner membrane potential becoming more negative than usual. There are two types refractory period;

✓ **Absolute refractory period**; this lasts for a very short period of time during which the axon is completely incapable of transmitting an impulse following the previous impulse however intense the stimulus may be.



Graph illustrating neurone excitability before and after a nerve impulse

✓ **Relative refractory period**; this lasts for a longer time and during this period a second impulse may be transmitted provided that the stimulus is abnormally stronger than usual. The next impulse can only be transmitted if the stimulus is abnormally strong.

Importance of refractory period

It is important that impulses re not transmitted immediately following one another. This is because the following reason;

- The action potential can only be propagated in the region which is not refractory i.e. in the forward directions, the action potential is therefore prevented from spreading out in both directions thus ensuring that the impulse flow **is unidirectional** i.e. it cannot be reversed.
- It enables successive action potentials to be separated from each other preventing confusion between one stimulus and the other, and also setting up an upper limit to speed/ frequency of transmission of the impulses.

FACTORS THAT AFFECT THE SPEED OF TRANSMISSION OF AN IMPULSE

❖ For the nervous system to be efficient, it must transmit impulses as rapidly as possible. This ensures that the organisms detect the stimuli as fast as possible and so the responses taken are rapid. The response for instance may be to escape from an enemy, danger or a predator.

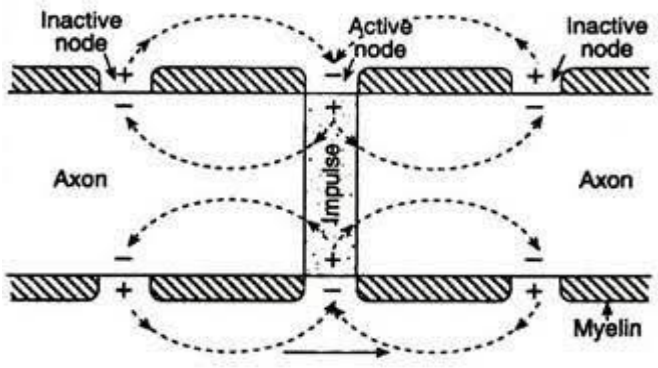


Fig. 8.32 : Diagrammatic representation of local current flow around an impulse of an axon in the myelinated nerve fibre (saltatory donduction) representing movements of positive charges. A straight arrow reveals direction of propagation

❖ The velocity of transmission of the impulse along the axon membrane depends on the three main factors;

1. Myelin sheath

The myelin sheath is a fatty insulating material around the axon membrane. In myelinated nerve fibres, it is absent at intervals called nodes of Ranvier and ionic exchanges and depolarization only occur at the nodes of Ranvier, so the action potential can jump or leap from one node to the next. This increases the speed of transmission grossly. This type of conduction is known as **Saltatory conduction**.

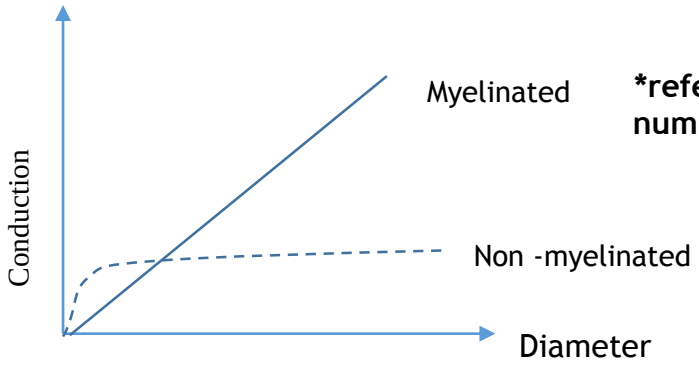
- The myelin sheath also acts as an insulator preventing depolarization in areas where it's present. Thus myelinated nerve fibres conduct impulses far more rapidly than the non-myelinated nerve fibres. The majority of the vertebrate axons are myelinated and have transmission speeds up to $100ms^{-1}$.

***understanding biology page 533 fig 27.9**
***functional approach page 269 fig 18.8**

2. Axon diameter

- The greater the diameter of the axon i.e. the thicker the axon, the faster is the speed of nerve impulse transmission. The impulses travel slower in thinner axon than the thicker ones. Since invertebrates have non-myelinated nerve fibres, they usually have thicker axons to transmit the impulses rapidly. The giant squid for instance has giant axons and can conduct at $100ms^{-1}$. This is because the axoplasm usually offers resistance to the flow of impulses but the longitudinal resistance of axoplasm decreases with the diameter of the axon.
- Also large axons have larger surface areas over which ionic exchange can occur increasing the speeds of the action potential.

Graph showing changes in impulse conduction speed with total diameter



***refer to UACE 2015 Biology paper 1 number 44. Try out the questions on it.**

3. Temperature

- Active animals usually maintain a high and constant body temperature. They conduct impulses at higher speeds. Less active organisms commonly ectotherms have low body temperature and impulse transmission is slow.
- The ionic movements are directly related to the kinetic energy of the ions. Endotherms, due to their high body temperatures have their ions having raised kinetic energy of the ions at the point of depolarization speeding up the transmission of impulses. Ectotherms in contrast have low body temperatures; hence their kinetic energy of the ions is lower resulting into low transmission.

Note:

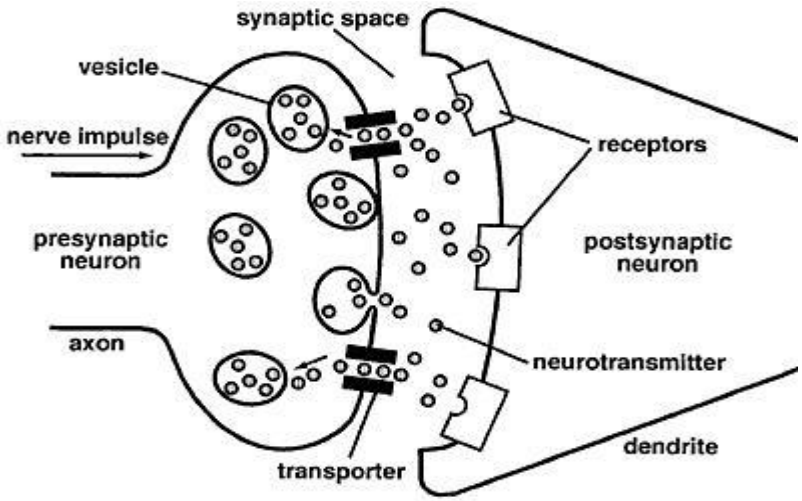
1. Resting membrane potential also affects transmission velocity however effect of resting membrane potential changes on conduction velocity is quite variable. Usually, any change in the RMP in either direction hyper polarization or depolarization slows down the conduction velocity.

SYNAPTIC TRANSMISSION

THE SYNAPSE

The synapse is the space between two adjoining nerve fibres. It is a region of functional contact without physical contact between the two nerve fibres.

The synaptic knob is a swelling at the axon terminal of one neuron filled with numerous mitochondria important for provision of energy and several sac-like vesicles called synaptic vesicles. The vesicles are membrane bounded vesicles containing transmitter substances such as Acetyl choline.



Between the end of the knob and the adjoining nerve cell, a small but definite gap called the synaptic cleft bounded on one side by a pre-synaptic membrane and a post synaptic membrane on the other side is found.

***understanding biology page 534 fig.27.10**

***functional approach page 271 fig 18.12**

Mechanism of Synaptic transmission

1. When an impulse arrives at the synaptic knob, it causes depolarization of the pre-synaptic membrane making it more permeable to calcium ions which diffuse from the cleft and enter the synaptic knob.
2. The Ca^{2+} ions fuse with the synaptic vesicles, activates them and causes the vesicles to move towards the pre-synaptic membrane.
3. On reaching the pre-synaptic membrane, they fuse with it and release their neurotransmitter substance which may be Acetyl choline or Noradrenaline for cholinergic and noradrenergic fibres respectively into the cleft by exocytosis.
4. The empty synaptic vesicles move back into the cytoplasm where they are later refilled with the neurotransmitter substance and the transmitter substance diffuses across the cleft and upon reaching the postsynaptic membrane, it fuses with specific receptor molecules.
5. The transmitter substance thereby changes the permeability of the post synaptic membrane to sodium and potassium ions. In the case of excitatory synapses, the membrane becomes more permeable to Na^{+} ions causing an influx of sodium ions. This makes the inside positive relative to the outside hence making the membrane depolarized, creating an action potential known as excitatory synaptic potential.
6. Meanwhile once the transmitter substance has depolarized the post synaptic membrane, it is immediately destroyed. In this case Acetyl choline is hydrolyzed by the enzyme acetyl cholinesterase also called cholinesterase. The resulting choline and ethanoic acid (acetyl) diffuse across the cleft and are actively transported into the synaptic knob where they recoupled together and stored in the synaptic vesicles using energy provided by the numerous mitochondria in the synaptic knob. For instance Noradrenaline, the transmitter substance diffuses back into the synaptic knob. At the same time, Ca^{2+} ions are actively pumped out of the synaptic knob back into the cleft.
7. The excitatory synapse is called excitatory post synaptic potential (EPSP). It is smaller but longer lasting than the action potential. A single EPSP may not be enough to transmit an impulse but many of them may summate to exceed the threshold value. The EPSPs build up as more neurotransmitter substances arrive until sufficient depolarization occurs to exceed the threshold value so as to fire off an impulse in the axons of the adjoining nerve fibres. The additive effect is known as ***temporal summation***.
8. Hyperpolarization also occurs in the synapses making the inside more negative than usual due to the influx of chloride ions creating inhibitory post synaptic

potentials (IPSP). These are inhibitory to impulse transmission and a refractory period is required before the next impulse is transmitted across the synapse.
Note; breakdown of acetylcholine is important so as to prevent successive impulses merging at the synapse.

Functions of synapses

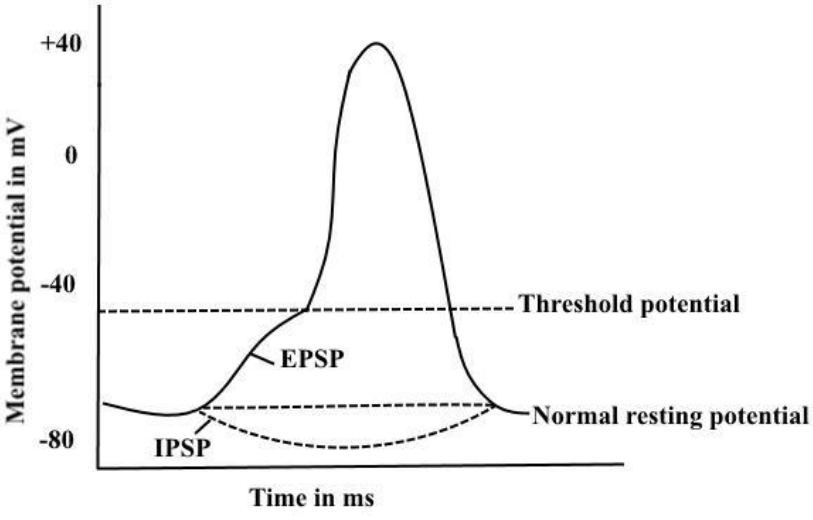
a) Because receptor sites are found on only the post synaptic membrane both in the synapses and the neuromuscular junction* to be looked at in locomotion. It ensures that the impulse flow in only **one direction**. This makes the nervous system very precise.
b) **Amplification and facilitation**; a nerve cell may fire off an impulse as a result of excitation by a single synaptic knob if the arrival of the impulse at a particular knob releases enough transmitter substance to depolarize the post synaptic membrane and generate an action potential.
× Other nerve cells in contrast can only fire when excited through two or more synaptic knobs simultaneously. In this case, a single synaptic knob cannot produce enough transmitter substance to fire an impulse. Several synaptic knobs act together to produce enough neurotransmitter substance and the effects of each summate to excite the nerve cell. This phenomenon is termed as **spatial summation**.
× Some nerve cells will send an impulse only when they receive two or more impulses from a single knob in quick succession. Summation also occurs because the amount of neurotransmitter when the knob receives a single impulse is insufficient to trigger off an impulse in the post synaptic nerve. However a second impulse provided it arrives sufficiently soon after the first one releases more transmitter substances which together with the first generate an impulse in the nerve cell. This is known as **temporal summation** and it involves a process known as **facilitation**. The first impulse fails to cross the synapse but it leaves an effect which facilitates the passage of the second impulse. Release of the transmitter by weak stimulus may also not be enough to depolarize the post synaptic membrane.
× However continuous release of the transmitter substance at different positions of the synaptic membrane may cause excitatory synapses to sum up and exceed the threshold intensity so as to fire off an impulse in the adjoining nerve fibre. This makes the nervous system very sensitive even to weak stimuli.
c) **Accommodation/adaptation;** if a synapse is bombarded with powerful stimulus over a long period of time, the high frequency of the impulses in the pre-synaptic membrane causes considerable release of neurotransmitters in the cleft and the impulses are fired in the post synaptic membrane. With continued high-level stimulation, there comes a time when the post synaptic nerve cell fails to respond and the impulses are no longer generated. This occurs when;
- The supply of the neurotransmitter substance gets exhausted and its resynthesis cannot keep pace with the rate at which impulses reach the synapse. In this state the synapse or neuromuscular junction is said to be **fatigued** or **accommodated**. This is useful in preventing damage to an effector due to continuous stimulation.
- Accommodated synapse has to be given time to recover and regenerate new supplies of transmitter substance before it can transmit again
d) **Discrimination**; the numerous weak background stimuli can be filtered out before they reach the brain by the synapse. This is made possible because the excitatory synapses they create do not exceed the threshold value to fire off an impulse to the brain. This enables the individual not to over respond to very weak background stimulus unless it becomes strong enough to deserve attention.

e) **Integration**; this is the function of synapses in the higher centres of the brain. Stimulation of various nerve fibre sharing the same synapse enables integrating various information which may be auditory, visual or olfactory producing accommodated response.

Inhibition of nerve impulse transmission at the synapse

✓ Certain synaptic knobs inhibit the nerve cells to which they are attached. The arrival of an impulse at such synaptic knobs makes the inside of the post synaptic nerve cells more negative than usual causing an inhibitory post synaptic potential.
✓ This will make it more difficult for excitatory post synaptic potentials to build up and generate an impulse in the nerve cell.
✓ Transmission of an impulse across the synapse may also be inhibited post synaptically either by blocking receptor sites or mimicking transmitter substances by such chemicals as;
✓ Atropine; this blocks the action of acetyl choline by stopping it from depolarizing the post synaptic membrane.
☑ Curare; also blocks action of acetylcholine
☑ Muscrine; mimics the action of Acetylcholine
☑ Nicotine; also mimics the action of acetylcholine
☑ Gamma Amino butyaric acid (GABA) inhibits the action of acetylcholine
☑ Organo phosphates e.g. DDT and organo-chlorides also prevent the action of acetylcholine
Fortunately, when these inhibitors are removed, the synapses may resume their normal functioning.

Note;
1. Some chemicals enhance and prolong the effects of acetylcholine and thus facilitate transmission across the synapse by destroying or preventing the action of cholinesterase enzyme. For example esorine and strychnine that prevents cholinesterase from destroying acetylcholine.
2. An impulse reaching the synapses may facilitate the passage of subsequent impulses or inhibit them. Sometimes an impulse may cross the synapse unimpeded or it may be blocked. However the impulse reaching the synapse can never be reversed i.e. impulse flow is always unidirectional.



Comparison between EPSPs and IPSPs

✓ EPSPs are graded potentials that can initiate an action potential in the axon, whereas IPSPs produce a graded potential that lessens the chance of an action potential in an axon.
✓ In EPSP, small depolarization is created whereas in IPSP small hyperpolarization is created.
✓ EPSP helps bring postsynaptic membrane closer to threshold whereas IPSP helps bring postsynaptic membrane further from threshold.

✓ In EPSP, membrane becomes more excited whereas in IPSP membrane becomes less excited

The role of the synapse

- They transmit information between neurones.
- They filter out low frequency impulses.
- They act as valves to ensure that impulses pass across them in one direction only.
- They are junctions allowing impulses to be divided up along many neurones or merge into one.
- To protect effectors from damage by overstimulation.
- Synapses may be involved in memory and the learning process.

NOTE: the time lag between the time a stimulus is present in the environment and the time a neuron responds, due to synaptic transmission is called **response latency**

THE ENDOCRINE SYSTEM

- The principal function of the endocrine system is to control, coordinate and integrate various processes and activities of the body. In the body, there are a number of glands either exocrine or endocrine glands.
- ***Exocrine glands*** release their secretions into the ducts while **endocrine glands** release their secretions into blood, for this reason they are also known as **ductless *glands*** and are far away from the site of action.
- Exocrine glands because they have ducts, release their secretions near the sites of action. Most of the glands are either exocrine or endocrine but some like the pancreas are both exocrine and endocrine.
- They are composed of different kinds of tissue which function differently e.g. the exocrine part of the pancreas produces pancreatic juice while the endocrine part secretes glucagon and insulin that are involved in sugar or glucose regulation or metabolism in the body.
- Endocrine organs release hormones directly into blood and then hormones transfer messages from one part of the body so they are known as informational molecules**;** proteins and nucleic acids.

Properties of hormones

✓ They are synthesized by ductless glands known as endocrine glands.
✓ They are produced at place other than their sites of action.
✓ They travel through the blood stream to other parts where cause changes
✓ The structures that respond to hormones are called **target organs** and they are highly specific. *target cells are cells that can recognize and respond to specific chemical signals.
✓ They are secreted in response to a stimulus which may be external or internal and they are called chemical messengers
✓ They stimulate or inhibit the activities of the target organs thereby regulating its activity.
✓ They are effective in such small quantities that it is often even difficult to detect them in the blood stream.
✓ Hormones are rapidly destroyed or altered immediately after their action is over.

N.B; **A neurosecretion is** a chemical messenger that is synthesized, stored and released into blood by **neurosecretory cells;** nerve cells in the brain and brings about specific physiological action which may either be excitatory or inhibitory away in target organs.

Comparisons between endocrine and the nervous system

Similarities

- Both release chemical substances as a mode of communication. For nervous system, transmission across the synapse is chemical and endocrine system, hormones are released.
- Both are controlled by the brain
- Both provide a means of communication in the body.
- Both respond to stimuli, transmit a message and produce a response.

Differences

Hormonal communication	**Nervous communication**
Hormonal action lasts for a longtime e.g. the growth hormone exerts its effects during growth.	A nerve response is very short lived and rapid e.g. the contraction of the muscle cell
Hormonal action is delocalized with a wide spread effect on the body	A nerve message is localized affecting only a particular part of the body like the knee jerk.
Hormonal messages are only chemical	Nervous message both chemical and electrical
Messages travel via the blood stream	Messages travel in a nerve cell or neuron
Largely controlled by the pituitary gland (master gland).	Controlled by the brain and the spinal cord.

Differences between enzymes and hormones

Enzymes	Hormones
They do not carry messages and act as biocatalysts to bring about reactions	Known to be chemical messages or informational molecules
Secreted by the exocrine glands	Secreted by the endocrine glands.
Released through the ducts	Released directly into the blood stream
Are protein in nature	Not necessarily protein. They may be steroids or polypeptides
Operate at or near the site where they are produced	Operate at different sites other than where they are produced
Are very specific e.g. lactase will only act on lactose.	Hormonal responses have a wide spread effect e.g. growth hormone may act on bones and other parts of the body.

Mechanisms controlling secretion of hormones

The mechanisms controlling the release of hormones by glands include;

1. The presence of a specific metabolite in the blood stream e.g. high levels of glucose in blood cause the release of the hormone insulin from the pancreas which sets up mechanism to lower the blood sugar level to normal.
2. The presence of another hormone in the blood stream for example many of the hormones released from the anterior pituitary glands are simultaneously hormones which cause the release of other hormones from other glands e.g. follicle stimulating hormone from the anterior pituitary stimulates the ovary to release the hormone oestrogen.

3. Stimulation by the autonomic nervous system e.g. the release of the hormones Adrenaline and Noradrenaline from the adrenal medulla is due to arrival of a nerve impulse from the autonomic nervous system in situations of stress fear or danger.

MODE OF ACTION OF HORMONES

Once released, the hormone goes to the receptor site of the target organ where it exerts its effects. Many of the hormones have specific region on their molecular structure called the active site similar to that possessed by enzymes.
It is used for attachment of the hormones to the receptor cells of the target organ and once attached the hormones may exert its effects at any one of the following levels;

- The cell membrane
- Enzymes located in the cell membrane/ second messenger system
- Cellular organelles
- Gene level (DNA)

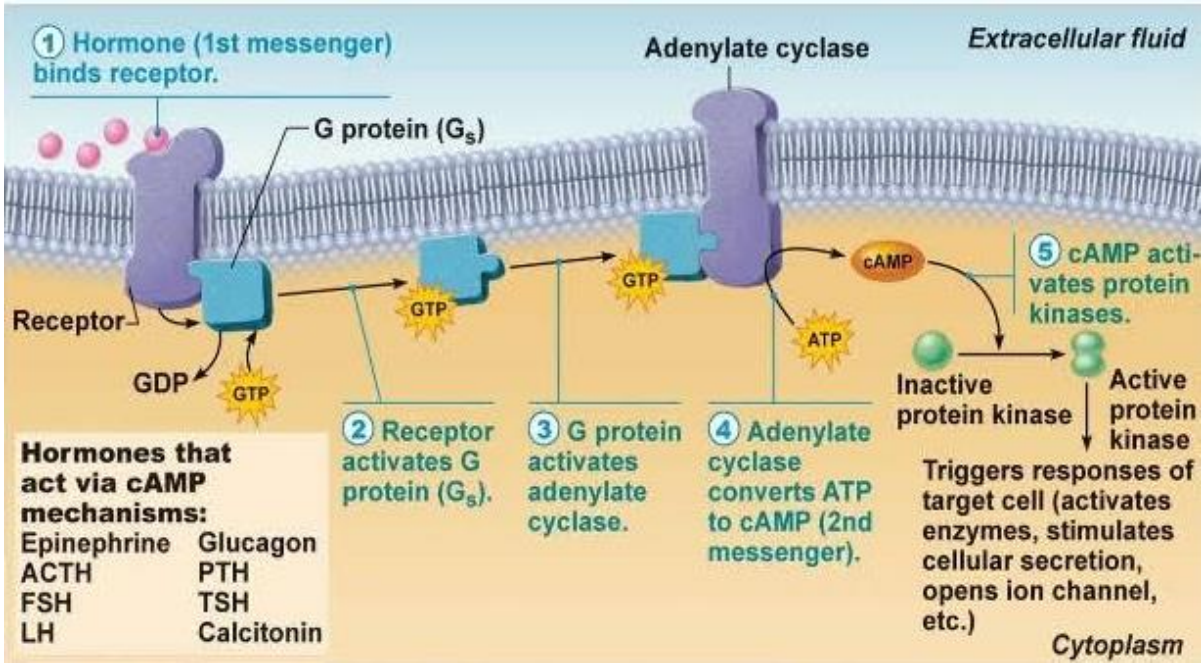
1. At the level of the cell membrane/ alteration of cell permeability;

- The hormone binds itself to the cell surface membrane of its target cells, and alters the permeability of the membrane towards a certain metabolite. For example;
- When insulin is released into the blood stream in response to high glucose levels in blood. It travels to the liver cells (hepatocytes), binds with the receptor cells on the cell membrane increasing the permeability of the cell membrane to glucose which is mobilized from the blood stream and taken into the cells where it is converted into glycogen and stored.
- Adrenaline works on smooth muscle cells by opening or closing ion channels for sodium or potassium ions or both, changing membrane potentials and either stimulating or inhibiting contraction as a result.

2. At the level of enzymes in the cell membrane/ second messenger system;

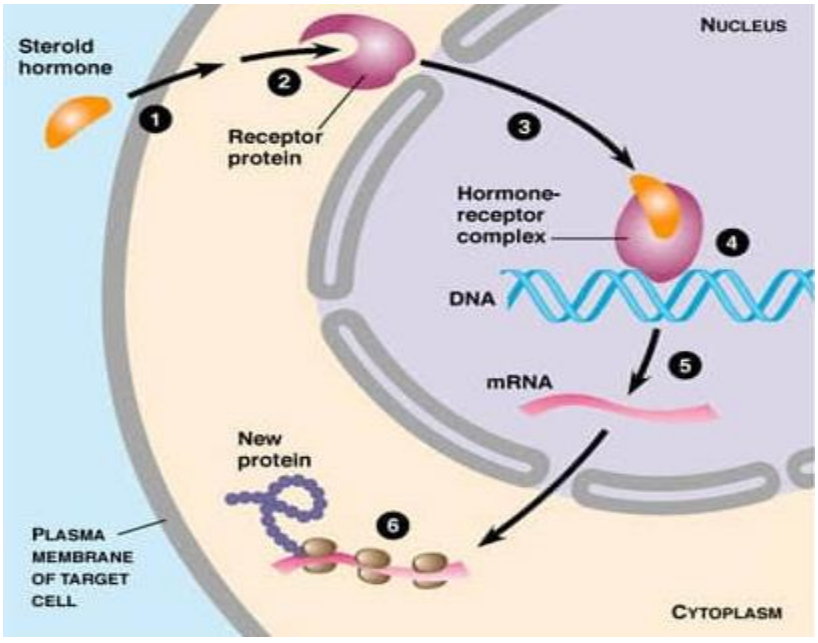
- Some hormones, bind themselves to the receptor site on the surface membrane of their target cells forming a hormone receptor complex.
- This complex activates a guanine binding protein (G-protein); the receptor protein which then activates an enzyme Adenyl cyclase, which enters the cytoplasm, and catalyses the hydrolysis of Adenosine triphosphate (ATP) into cyclic Adenosine monophosphate (cyclic AMP, cAMP), which serves as a second messenger, which can trigger a wide variety of responses, depending on the type of stimulated cell. For example;
- For adrenaline,
- Cyclic AMP activates enzymes within cytoplasm such as inactive Phosphorylase kinase enzyme converting it to active phosphorylase kinase enzyme which activates inactive glycogen phosphorylase enzyme into active glycogen phosphorylase. Once activated, glycogen phosphorylase enzyme catalyzes the conversion/ hydrolysis of glycogen to glucose increasing the blood sugar level and can be respired to release energy; an Adrenaline effect on the body.
- This is achieved by use of a two messenger system in which a very small amount of the hormone; 1st messenger can lead to the synthesis of comparatively high concentrations of a 2nd messenger which in turn evokes a correspondingly large response by activating enzymes in the cell. This is known as cascade effect. Ca^{2+} * to be seen in TSH activity and cyclic AMP (cAMP) are examples of second messengers.

N.B: adrenaline is also known as epinephrine



*** Advanced biology by Micheal kent fourth edition section 10.3 fig 2;**
***Understanding biology page 521 fig 26.7**

3. **On cellular organelles;**
   - The hormone thyroxine exerts one of its effects on the enzymes of the electron transport system within the mitochondria. This causes release of energy in form of ATP needed for controlling basal metabolic rates. This is one of the effects of thyroxine in the body



4. **Effects on genes/ binding to receptors inside the cell/ gene interaction;**

- The hormone diffuses into the cytoplasm of their target cells, for example the <u>steroid hormones</u> such as insect moulting hormone Ecdysone, and bind to the receptor site of a receptor protein, to form a hormone-receptor site complex, such as an Ecdysone-receptor site complex. This complex passes via the nuclear pore into the nucleus and attaches on DNA in this it has a direct influence on the chromosomes by activating the genes which code for synthesis of proteins used for formation of an adult cuticle. Activation of the gene leads to transcription and the formed messenger Ribose nucleic acid/mRNA moves to the cytoplasm and attach on the ribosome for protein synthesis including enzymes to catalyse different reactions.

Other examples of hormones that use gene interaction are; thyroid hormones, oestrogen, progesterone, testosterone.

Note;

- The attachment of the hormone-receptor complex on DNA changes the amount of certain proteins manufactured by the cell. It increases or decreases others, this modifies the activities of the cell and brings about a specific response to the hormone.

***Advanced biology by Micheal kent section 10.3 fig.1**

Summary of the effects of the hormones on the target cells

- ✓ Hormones may affect the target cells by altering the cell membrane permeability or affecting enzyme activity or gene activity.
- ✓ Lipid soluble hormones such as thyroxine and steroids pass through the target cell membrane and act directly with the target cell.
- ✓ Some hormones affect enzymes in the Electron transport chain.
- ✓ Hormones that are polar, act on the target cell membrane so as to cause production of a second messenger inside the cell.

MAMMALIAN ENDOCRINE GLANDS

The hypothalamus-pituitary gland

- ✓ The hypothalamus and pituitary glands are too very important control centres in the body. The hypothalamus is part of the fore brain present just below the thalamus.
- ✓ In the hypothalamus, there are two nerve centres identified as nerve centre one and nerve centre two which receive information from the high centres of the brain and pass over to the pituitary glands.
- ✓ Nerve centre I is connected to the anterior pituitary by a portal blood vessel while the nerve centre II is connected to the posterior pituitary by a specialized neurone.
- ✓ The chemicals released by the hypothalamus are called **releasing hormones (RH)** or **releasing factors (RF)** which stimulate the pituitary gland to secrete the specific hormones.

Diagram showing mammalian endocrine glands

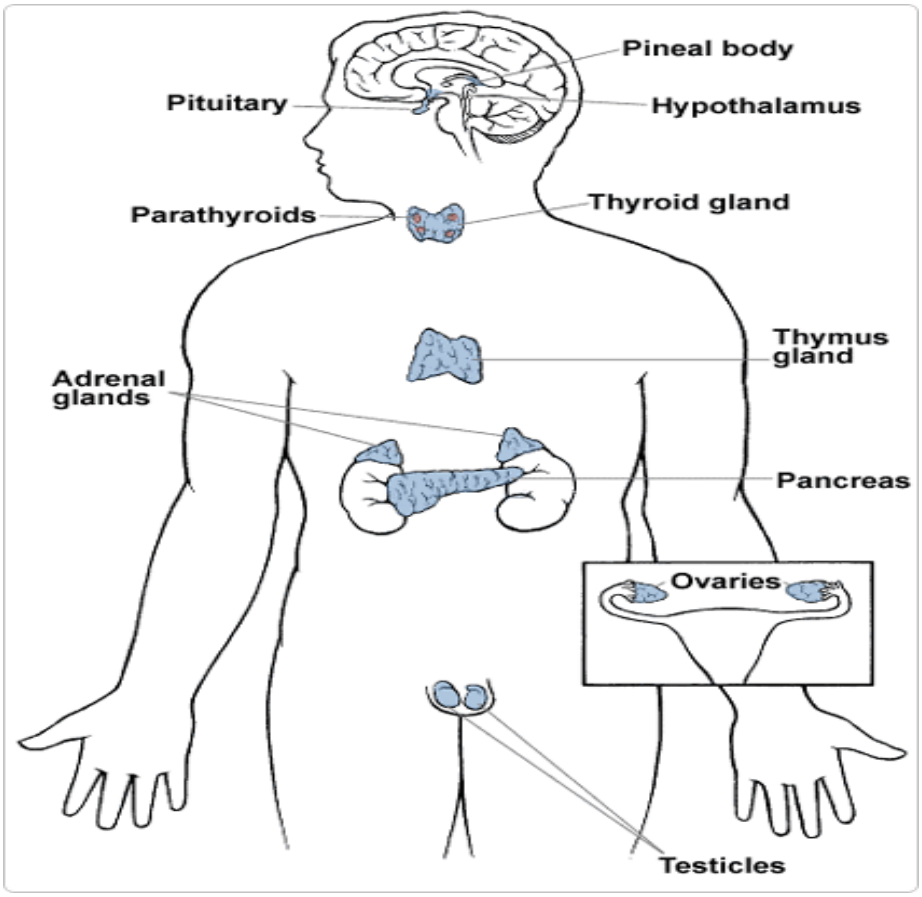
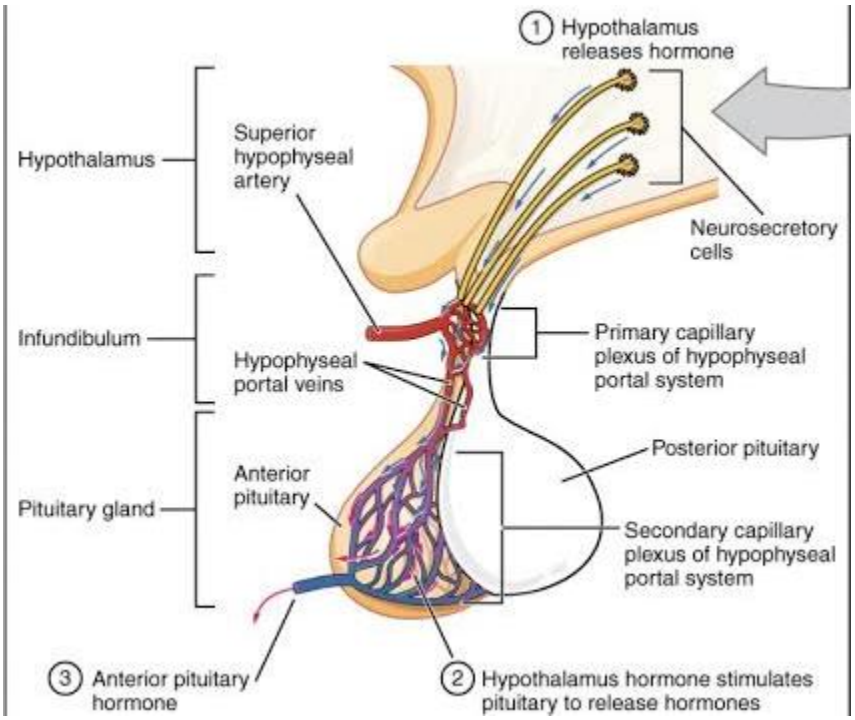


Diagram showing the relationship of the pituitary gland and hypothalamus.



***Understanding biology page 514 fig 26.1 and page 515 fig 26.2**
*** Functional approach page 296 fig 18.31**
*** Micheal kent section 10.4 fig 1. Or B.S 3rd edition page 602 fig 17.18**

Chemical substances released by hypothalamus and anterior pituitary gland

Hypothalamus	Anterior pituitary glands
FSH releasing factor	FSH
L.H releasing factor	LH
ACTH releasing hormone	ACTH
TSH releasing hormone	TSH
GH releasing/inhibiting factor	GH
Prolactin releasing/inhibiting factor	Prolactin

- ✓ The hormones released by the anterior pituitary are **six** and exert their effects on the various endocrine glands where they cause release of other hormones; they have other endocrine glands as their target. Hormones from anterior pituitary are called **trophic hormones**. A tropic hormone is one which influences/ stimulates activity of other endocrine glands to release a hormone; they are specific to endocrine glands. The only non-trophic hormone is growth hormone which rather than influencing other endocrine glands, affects body tissues as well.

The hormones from the anterior pituitary glands and the endocrine glands they affect include;

Hormone from pituitary	Gland affected	Hormone released in endocrine glands
F.S.H	Ovary	Release of oestrogen and progesterone
L.H (Luteinising hormone)	Ovary and testis	Progesterone and testosterone respectively
T.S.H (thyroid stimulating hormone)	Thyroid gland	Thyroxine (T_4), tri-iodothyronin (T_3), Calcitonin
A.C.T.H (adrenal cortical tropic hormone)	Adrenal cortex	Glucocorticoids Mineralocorticoids
GH (Growth Hormone)	Body tissues	
Prolactin	Mammary glands	Sex corticoids Milk (not hormones)

Note;

1. The posterior pituitary gland does not produce any hormone. However it stores two hormones produced by nerve centre II in the hypothalamus. These hormones are **oxytocin** and **anti-diuretic hormone (ADH).**
2. The pituitary gland is called a Master gland because it produces a number of hormones many of which influence the activity of other endocrine glands.

THE HYPOTHALAMUS

The is small in size "from the diagram" but performs vital functions as follows;

1. It regulates activities such as thirst, sleep and temperature control.
2. It monitors the level of hormones and other chemicals in blood passing through it.
3. It controls the functioning of the anterior pituitary gland. *this is why the pituitary gland is not fully a master gland*

4. It produces antidiuretic hormone and oxytocin which are stored in the posterior pituitary gland.

Hormonal control of thyroxine production

- As noted above, by monitoring the level of hormones in the blood, the hypothalamus exercises control of them. For example the control of thyroxine production;
- The hypothalamus produces thyroid releasing factor (TRF) which passes to the pituitary gland along blood vessels.
- TRF stimulates the anterior pituitary gland to produce thyroid stimulating factor (TSH).
- TSH stimulates the thyroid gland to produce thyroxine.
- As the level of thyroxine builds up in blood, it suppresses TRF production from the hypothalamus and TSH production by the anterior pituitary gland.
- By this level of negative feedback, the level of thyroxine is maintained constant.

GROWTH HORMONE (GH) (SOMATOTROPHIN)

It is produced by the anterior lobe of the pituitary gland. GH exerts its effects on the body tissues causing general body growth through;

- Stimulating cell mitosis and protein synthesis
- Stimulating retention of calcium in the body for bone and teeth development.
- Stimulating elongation of long bones

Effects of deficiency of GH

Lack of the hormone GH has different effects in adults and children.

1. In children, insufficient GH causes **dwarfism** either due to stoppage of growth of long bones or less growth and elongation of bones while excess; too much growth hormone causes excessive elongation of the bones resulting in a condition called **Gigantism**.
2. In adults, too much of growth hormone may cause over enlargement of parts like the hands, feet and jaws, but has no effects on long bones because by then growth of the long bones is complete, tissues being laid down in hands and feet which become greatly enlarged. This gives the individual a chimpanzee like appearance, a condition called **acromegaly**.

VASOPRESSIN OR ANTI-DIURETIC HORMONE (ADH)

- It is produced by the nerve centre II, ADH is stored by the posterior pituitary glands. It exerts its effects on the kidney tubules particularly the distal convoluted tubules and collecting ducts where it increases their permeability to water so that much of it is reabsorbed into the blood. The result is production of small volumes of very concentrated urine.
- Failure to produce enough of ADH results into an individual to produce large volumes of dilute urine, a condition referred to as **diuresis**. The condition is medically called **diabetes insipidus**. Individuals suffering from this condition take large volumes of water to compensate for that lost in urine. *earlier covered osmoregulation in man*

OXYTOCIN

- It is produced by nerve centre II in the hypothalamus and then stored in the posterior pituitary glands. It causes contraction of the uterine muscles during

birth. Normally it is given medically to pregnant mothers to induce labour pains.

- Oxytocin also results into contraction of the mammary glands producing milk immediately after birth, a process termed as milk let down. Failure to produce enough oxytocin causes delayed birth and insufficient milk let down.

THE THYROID GLAND

The thyroid gland produces three hormones; tri-iodothyronin (T_3), tetra-iodothyronin (T_4)/ thyroxine and Calcitonin. The hormones are important for the following activities;

- ✓ Regulating the basal metabolic rate and they bring about the breakdown of sugars and fats to release energy.
- ✓ Promote physical growth and mental alertness
- ✓ Stimulate tissue differentiation e.g. the hormone Thyroxine is important during metamorphosis of the frog changing from tadpole to an adult.

Tri-iodothyronin and thyroxine hormones

- ❖ These are chemically and functionally similar (both contain iodine), however thyroxine contain 4 iodine molecules while tri-iodothyronin contain 3 iodine molecules.
- ❖ They both regulate the growth and development of cells and regulate the metabolic rate. They also help in the oxidation of glucose by the cells.
- ❖ This has an effect of increasing the heat production thus these hormones are produced when an animal is exposed to extreme coldness, emotional stress and hunger.
- ❖ The overall function is to increase the rate of metabolism thus thyroxine work in conjunction with adrenaline and insulin.
- ❖ In conditions of low iodine levels, tri-iodothyronin is produced instead of thyroxine in order to maximize the use of limited iodine. If the thyroid gland is unable to make adequate supply of this hormone and results into under activity of the gland.

DISORDERS DUE TO THYROID HORMONE IMBALANCE

HYPOTHYROIDISM

- ✓ This occurs when there is a deficiency of thyroxine hormones. It may be due to either malfunctioning of the thyroid gland or inadequate supply of iodine in the diet. It leads to general slowing of metabolic activities e.g. slow respiration rate, reduced heart rate, reduced blood pressure, mental inactivity; reduced mental activity, individual feels cold at all times, and the individual feels tired and sluggish.
- ✓ The basal metabolic rate is lowered significantly and it arrests both physical and mental development. Hypothyroidism in general has different effects in children and adults which include;

❖ **Cretinism in children**; this is a disorder in children where thyroid secretion is less from childhood. It leads to dwarfism with serious mental deficiencies such individuals are called **Cretins**. The children have reduced body growth with infant expressions. A cretin/dwarf individual of age 15 may be so retarded that he/she cannot feed him/herself.

The child may be pot-bellied, pigeon chested with a protruding tongue. Blood pressure, heart rate, body temperature, and basal metabolic rates are all below normal.

Cretinism can be cured if detected early by administration of suitable doses of iodine.

- **Myxoedema**; it is a disorder in adults and less serious as growth of the body is already complete. However, the person looks dull, lacks alertness, intelligence and initiativeness. Blood pressure, heart rate, body temperature, and basal metabolic rates are all below normal.
- **Simple goitre;** it is the enlargement of the thyroid gland which gets visible as a swelling in the neck region. The person shows symptoms of hypothyroidism since iodine a major component of the thyroxine hormone and its deficiency in the diet leads to production of less thyroxine.
  The pituitary gland secretes increased amounts of thyroid stimulating hormone in response to low levels of thyroxine and this induces more and larger cell to grow in the thyroid gland, so as to take up the little iodine in the blood stream. In this way the gland keeps on enlarging and goitre is formed.
  Goitre is prevalent in iodine deficient or poor regions of the world.0it can be compensated for by taking iodized salt in food.

***understanding biology page 518 biology around us.**
*** Functional approach page 296 fig 18.30**

HYPERTHYROIDISM

- This is caused by over activities of the thyroid glands and too much iodine in the diet, leading to an excess of the hormone thyroxine in the blood stream. It leads to a condition called **exophthalmic goitre**, visible as a swelling in the neck region. Goitre is accompanied by the bulging of the eyes a condition known as **Exophthalmos**.
- Hyperthyroidism is characterized by increased metabolic rates (B.M.R), rapid respiration, increased heart rate, sweating, increased body temperature and blood pressure. It leads to physical and mental restlessness, the person tends to lose weight due to rapid burning of food.
- Goitre is generally controlled by injecting controlled doses of radioactive iodine that is taken up by the thyroid gland killing some of the cells.

CALCITONIN

- ✓ It is concerned with calcium metabolism in conjunction with parathormone from the parathyroid glands. Calcitonin controls the level of calcium ions in blood. It is produced to respond to high levels of calcium ion concentration.

PARATHYROID

They produce parathormone which maintain the level of Ca^{2+} in blood at a higher concentration in order to allow normal muscles and nervous activity.
The hormones rise the level of Ca+ in 3 ways;

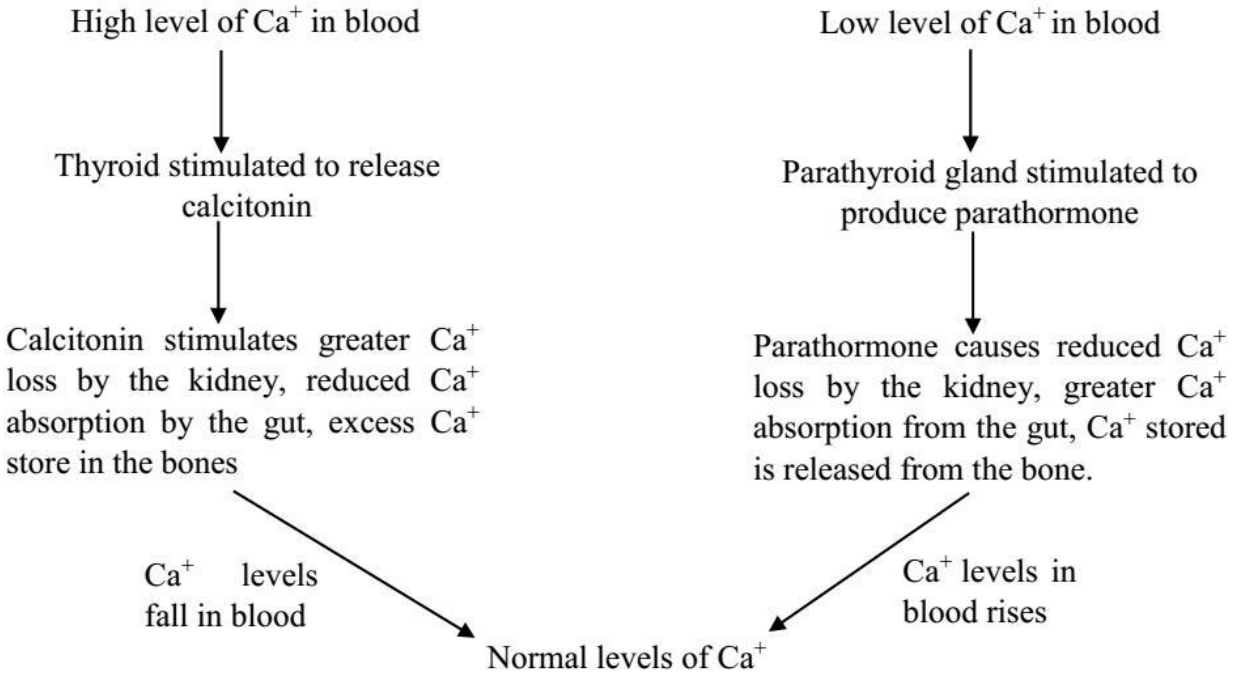
- Increases the level of Ca^{2+} absorption from the gut
- Increases the rates of Ca^{2+} reabsorption by the kidney at the expense of phosphate ions/ reduces loss of calcium ions by the kidney.
- Causes the release of Ca^{2+} from the bones into the blood stream.

Note: it works **antagonistically** with calcitonin

i. Over production of parathormone leads to excess removal of calcium ions from bones making them brittle and reliable to fracture. This over production also causes excess calcium ions to be removed from the kidney causing a disease called **kidney stones.**

ii. Under production of those hormones results into low levels of calcium ions in blood leading to nervous disorder and uncontrolled contraction of muscles.

Summary of calcium control



ADRENAL GLANDS (SUPRARENAL)

It is a small yellowish gland present above the kidneys, hence the name **suprarenal**. Each gland is made up of two regions, the outer adrenal cortex and the inner adrenal medulla which function independently.

Adrenal cortex;

The adrenal cortex produces three principle hormones; Mineral corticoids, Glucocorticoids and the sex corticoids. All of which are steroids produced from cholesterol.

1. **Glucocorticoids** are concerned with carbohydrate metabolism by carrying out carbohydrate-fat inter-conversions depending upon the need of the body e.g. cortisol and hydrocortisone

- In stressful conditions like pain, shock, emotional distress, extreme cold conditions, the hypothalamus stimulates the anterior pituitary gland to produce the adrenocorticotrophic hormone (ACTH). This in turn causes the adrenal cortex to increase the rate of Glucocorticoids release including the cortisol. When stress is prolonged, the size of adrenal glands increases. Glucocorticoids fight stress in the following ways:
- Rise the blood sugar level by inhibiting insulin and leads to the formation of glucose from fats and proteins.
- Increases the rate of glycogen formation in the liver.
- Increases the uptake of amino acids by the liver. These are deaminated to form more glucose or are used in protein synthesis.

Deficiency of Glucocorticoids leads to the **Addison** disease with symptoms of low blood sugar level, reduced blood pressure and fatigue. Over production of glucocorticoids causes high blood pressure due to excessive breakdown of proteins.

2. **Mineral corticoids** are concerned with mineral salts metabolism in the body for example Aldosterone. * refer to osmoregulation for action of aldosterone*
3. **Sex corticoids** perform the same functions as sex hormones from the ovaries and testes e.g. promoting secondary sex characteristics. An example of sex corticoids is hormone corticosterone

Adrenal medulla

The adrenal medulla produces two hormones, adrenaline and Noradrenaline that are also called Epinephrine and norepinephrine respectively.
Both hormones arise from the same tissue and they are concerned with preparing the body for emergency; fight-flight action through;

- Reduced blood flow to capillaries near the body surface by diverting it to organs required for emergency.
- Dilation of the eye pupils to increase light entering the eye so as to see the enemy.
- Decreased gastro-intestinal activity such as decreased gastric acid mobility.
- Increased blood pressure and blood sugar level such that the sugar is metabolized in order to produce energy needed for emergency.

EFFECTS OF ADRENALINE AND NORADRENALINE

Effect	Function
Bronchioles dilates	Air is more easily inhaled and more oxygen is made available for the production of energy by glucose oxidation.
Glycogen in the liver is converted to glucose	Increases blood sugar level making glucose available for oxidation.
Heart beat rate increases and the volume of blood pumped per beat increase.	Increases the rate which glucose and oxygen are distributed to tissues.
Blood is diverted from digestive and reproductive system to vital organs e.g. Liver, lungs and muscles.	Blood rich in oxygen and glucose is diverted from tissues with low energy need to those with high energy need.
Peristalsis and digestion inhibited.	Inhibition of the process diverts them to muscles, liver and lungs that need more energy.
Sensory perception increases.	It produces rapid reaction to stimulus.
Mental awareness.	To allow big response to stimuli.
Pupil of the eye dilates.	Increases the range of vision and perception of visual stimulus.
Erector muscles of hair contract.	Gives an impression of increased size of fighting the enemy.

THE PANCREAS

It is both an exocrine and endocrine gland. The exocrine part produces digestive juices while the endocrine is made up of tissue cells called Islets of Langerhans that are made up of alpha (α) and beta (β) cells which secrete the hormone glucagon and

hormone insulin respectively. These hormones are secreted in response to varying levels of glucose in blood and are solely concerned with glucose metabolism.

THE THYMUS GLAND

- ✓ This plays an important role in the production of antibodies and the development of immune system. It produces the T-lymphocytes; Thymus gland derived lymphocytes that migrate to the lymph nodes ready to attach any pathogens. The gland is more developed in young animals since their bones are not fully developed and cannot produce enough B-lymphocytes; bone marrow derived lymphocytes.

THE PINEAL GLAND

- ✓ It is a small gland located in the mid brain. It was thought to be a vestigial organ but is now suspected to be an endocrine gland. It is thought to produce two important hormones melatonin; sleep awakes hormone and serotonin
- ✓ Melatonin makes the skin of mammals pale while serotonin is an antigonal hormone; anti F.S.H and L.H. It inhibits action of the two hormones

Note; the following are hormone like substance due to mode of action;

1. **Prostaglandins;** they are produced throughout the body and are found in the semen. They bring about contraction of the uterus to push the sperm up to the oviduct.
2. **Endorphins;** they act in such a way that they reduce pain, induce thyroxin activities, influence hibernation, lower ventilation and cardiac rate. They act by attaching on the receptor sites on the cells of the human brain.

SUMMARY OF MAIN ENDOCRINE GLANDS OF MAMMALS, HORMONES AND FUNCTIONS

Gland	Hormone	main function
Thyroid	Thyroxine	Raise basal metabolic rate
	Calcitonin	Opposes action of parathormone
Parathyroid	Parathormone	Controls concentration of calcium and phosphate ions in blood
Pancreas	insulin	lows blood sugar concentration
Adrenal medulla	adrenaline	prepare body for emergency; metabolic rate increases,
Adrenal cortex	Aldosterone	Controls concentration of K^+ and Na^+ in blood
	Cortisol	Prevent excessive immune response
	androgens	Promotes development of testes and secondary sexual characteristics
Pineal body	melatonin	causes concentration of melanin in frog's skin; promote sexual development in mammal
Testes	Androgens	Promotes development of testes and secondary sexual characteristics
ovaries	Estrogens	Promotes development of ovaries secondary sexual characteristic of female control menstrual cycle and pregnancy.
Pituitary	Thyroid stimulating	Causes the thyroid gland to secrete

(anterior lobe)	hormone	thyroxine
	Adrenocorticotrophic (ACTH)	Cause adrenal cortex to secrete adrenal cortical hormones
	Growth hormones	Stimulate growth
	prolactin	Causes mammary gland to secrete milk
	Follicle stimulating hormone	Controls testes and ovary
	Luteinizing hormone	Controls testes and ovaries
Pituitary (posterior lobe)	Antidiuretic hormone (ADH)	Causes reabsorption of water in kidney
	oxytocin	Causes contraction of uterus at birth

END OF TOPIC COORDINATION

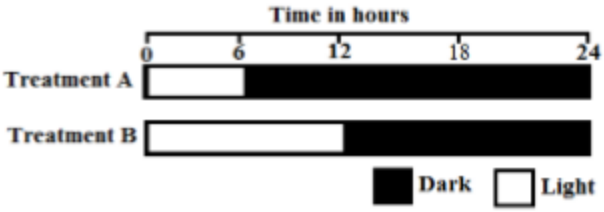
I thank you so much right from where we started the topic coordination up to now you have stayed confident and looked at how best you can coordinate your activities now. Let me hope it was an easy task. Anyway we stared with coordination in plants in which case we looked at tropisms, nastic responses, photoperiodism and as well flowering, went to small organisms were we looked at tactic responses we looked at principles of behaviour in animals, went in detail of receptors in animals, sense organs based on the eye and ear, looked at the nervous system; the central and autonomic nervous system, endocrine system and finally we were done am sure you mastered all the concepts in detail.

Now I beg you try out the following questions.

1. a. explain the following processes involved in transmission of impulses;
   i. the formation of the resting potential.
   j. The formation and transmission of an action potential

b. how does a retina transduce light into a nerve impulse.

2. Two groups of short day plants were each subjected to one of two different treatments of light and dark periods as shown in the diagram.



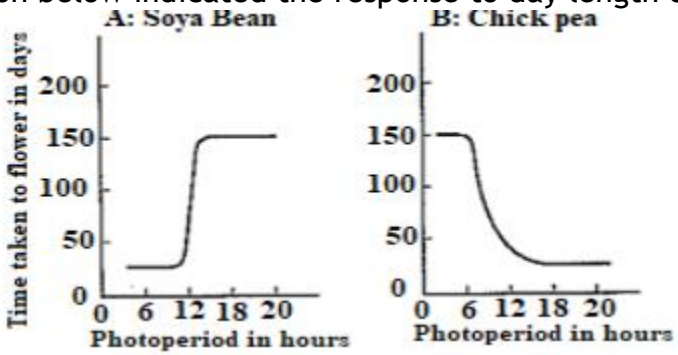
(a) Which treatment would you expect to trigger a flowering response? Give a reason for your answer.

(b) In a second series of treatments, two groups of short day plants were each subjected to long dark periods, as in treatment A, interrupted by a short period of light. One group was exposed to a short period of red light and the second group exposed to a short period of far-red light. What flowering response would you expect for each group? Give a reason for your answer in terms of phytochrome conversions.

(i) Red light interruption

(ii) Far-red interruption.

3. (a)What is photoperiodism?
(b) How does the photoperiod affect
(i) Flowering
(ii) Dormancy in plants
(iii) Breeding behaviour in animals.
4. (a)State what is meant by the term photoperiodism?
(b)The graph below indicated the response to day length of two flowering plants.

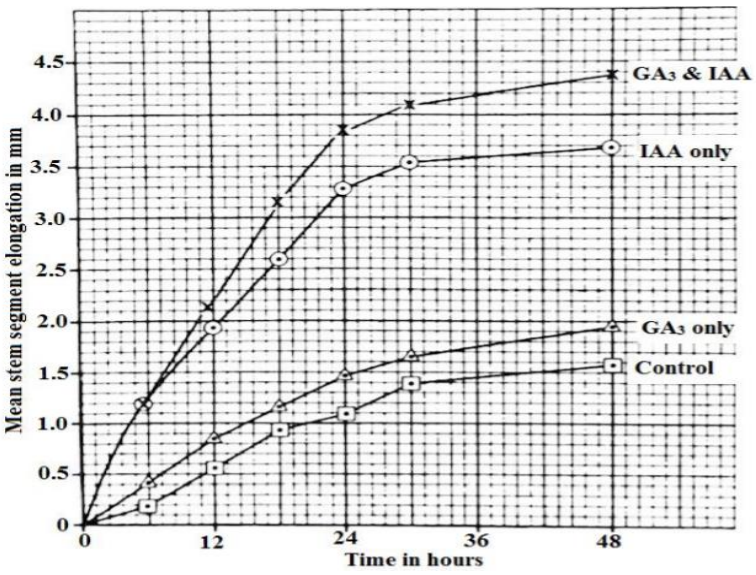


(i) Which of these plants will flower under long-day conditions
(ii) Give a reason for your answer.
(c) (i) Where is phytochromes produced?
(ii) Briefly describe the role of phytochrome in the flowering process
(iii) How does the response to phytochromes differ in short-day and long-day plants?
(d) Chrysanthemum plants flowers are produced commercially under glass throughout the year. At certain times of the year growers, cover the greenhouse with black polythene for a part of the day. Account for this in terms of photoperiodism.
5. Cylinders of approximately equal size were cut from a large potato tuber using a cork borer. They were divided into two groups A and B. The mass of each of the cylinders was measured and recorded. Single cylinders from group A were each placed into a different sucrose solution. Cylinders from group B were treated similarly except that 0.1 g of gibberellic acid was added to each solution. After 4 hours, each cylinder was removed from its solution, reweighed and the percentage change in mass calculated. The results are given in the table.

	Percentage change in mass	
	Group A	Group B
Sucrose molarity	Sucrose solution only	Sucrose solution and gibberellic acid
0	7	42
0.1	6	38
0.2	5	36
0.3	1	27
0.4	-4	6
0.5	-8	3
0.6	-14	-3
0.7	-17	-4
0.8	-16	-7

(a) How should the potato cylinders be treated immediately before weighing?
(b) (i)Plot the data for group A only on graph paper. (ii)Comment briefly on the information shown by the graph.

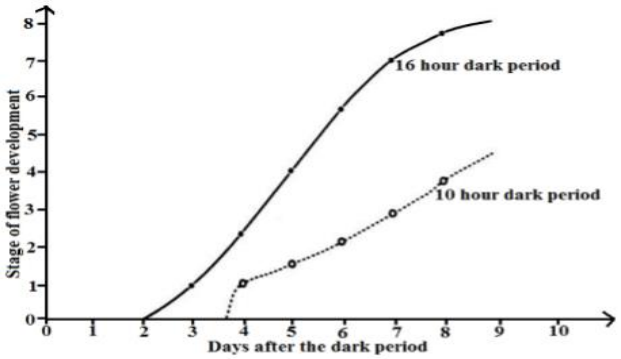
(c). A IM sucrose solution has a water potential of -3.40 MPa. Use this information, and the graph you have plotted, to determine the water potential of the potato tissue. Show how you arrived at your answer.
(d) Gibberellic acid is produced naturally in potato tubers, where it stimulates the production of carbohydrate enzymes.
(e) Account for the different results for groups A and B of the potato cylinders.
6. Describe the part played by plant hormones in the life cycle of a flowering plant under the following;
(i) Dormancy
(ii) Growth
(iii) Response to stimuli
(iv). Fruit formation
7. (a) What is meant by the term photoperiodism?
(b)How does the photoperiod affect
i. flowering,
ii. Dormancy in plants.
iii. Breeding behaviour in animals?
8. Plants and animals respond to changes in their environments through systems of receptors and effectors.
(a) Compare the ways in which angiosperm and mammalian receptors are linked to effectors.
(b) The relative day length (the photoperiod) may influence the activities of flowering plants, particularly the flowering process itself.
i. What part of the plant is involved in the perception of the photoperiod? What is the evidence for this?
ii. Different species of flowering plant respond differently to changes in the photoperiod. How these different species categorized and what are is the stimulus, which leads to flowering in each category? How does this influence the time of flowering?
9. (a) Distinguish between tropism and nastic movement.
(b). Compare the actions of auxins and gibberellins in higher plants.
10. Briefly define the following terms and give one example of each.
(a) Photo taxis
(b) Photo periodism
(c) Vernalisation



11. An experiment was carried out to investigate the effect of an auxin, Indole Acetic Acid. (IAA) and Gibberellic acid (GA3) on the elongation of segments of pea stem. A control group of pea segments received on added IAA or GA3 other groups of pea segments were treated with equivalent quantities of IAA only, GA3 only or both IAA and GA3. The results are shown in the graph.
(a) Describe the effect of each of the following plant hormones on the mean stem segment elongation

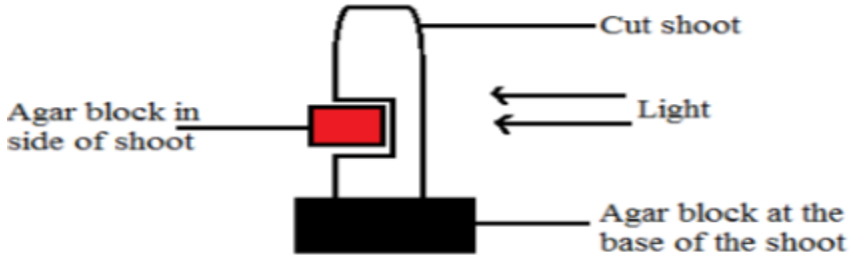
(i) Gibberellic acid (GA3)
(ii) Indole acetic acid (IAA)
(b) (i) With a reason, state the biological relationship exhibited by gibberellins and IAA (ii) Explain the difference in the effect on the mean stem segment elongation when the pea plants were treated with IAA only and when treated with a mixture of IAA and GA3.
(c) Describe the role of GA3 in seed germination
(d) How have farmers used IAA to their benefit?

11. Flowering in the cocklebur plant occurs as a result of exposure to a period of darkness. The development of the flower has been divided into eight stages (0- no flower, up to 8- fully flower).
The graph shows the average stage of flower development for two batches, each of ten plants, one of which was kept in the dark for 16 hours and the other for 10 hours.



(a) Compare the effect of length of dark period on flowering in the cocklebur plants.
(b) Explain the difference between the two batches of plants after eight days.
(c) Suggest reason(s) why there was a delay between the exposure to darkness and start of flower development

12. The diagram shows how the movement of auxin through plant shoots was investigated. Shoots were removed from young plants and each was placed on a block of agar. A second block of agar was placed in the side of each shoot where a portion of its tissue had been cut away. Samples of shoots treated in this way were left for several hours. Half the shoots were left in darkness and half were left with a light source from one side.



The concentration of auxin collected in the two blocks of agar from each shoot was measured. The table shows the mean percentage of auxin found in the two blocks of agar from each shoot.

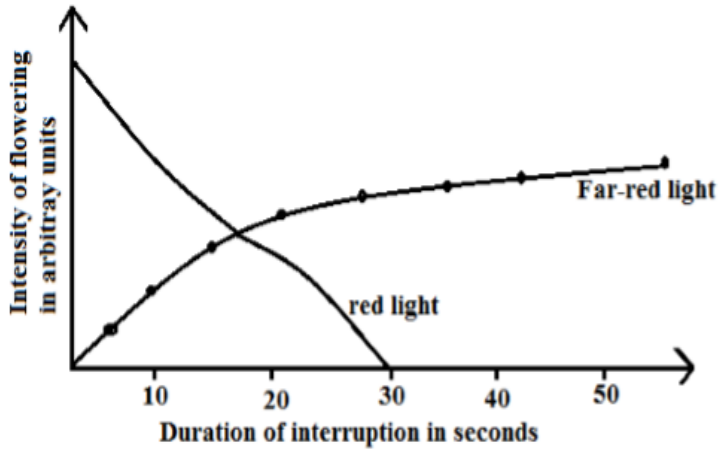
Location of block	Mean percentage of auxin collected in the two agar blocks from each shoot	
	Shoot in dark	Shoot lit from side
Side of shoot Base of shoot	27 73	35 65
Both blocks	100	100

(a) What do the results of this investigation show about the movement of auxin? (b) Explain how the movement of auxin shown in this experiment enables intact plants to photosynthesise efficiently.

13. Three healthy, unrelated species of flowering plants A, B and C were subjected to a range of different light and dark treatments. The results are shown in the table below.

		Treatments					
		1	2	3	4	5	6
Hours of light		15	14	13	12	11	10
Hours of darknes		9	10	11	12	13	14
Species	**A**	+	+	+	+	-	-
	B	-	-	-	-	+	+
	C	+	+	+	+	+	+

(a) State the photoperiodic group to which each species belongs, giving a reason in each case. (i) A (ii) B (iii) C
(b) Describe how the phytochromes controls flowering response exhibited in species A and B
(c) What would be the effect of flashing light during darkness, on each of the specimens? (i) A (ii) B (iii) C
14. (a) What is meant by apical dominance?
(b) State the causes of each of the following.
(i) Apical dominance
(ii) Seed dormancy
(c) What is the ecological importance of?
(i) Apical dominance?
(ii) Seed dormancy?
15. Figure below shows the effect of red light and far-red light interruption of night period on flowering of a plant.



(a) What is the effect of interruption of the night period by each type of light? (i) Red light (ii) Far-red light (b) Suggest the type of plant that would exhibit responses to light treatments as shown in the graph above. (c) How can the knowledge of the effect of red light and far-red light on flowering be utilised

LET ME HOPE YOU TRIED ALL OF THEM OUT! THANK YOU

13. SUPPORT AND MOVEMENT

SUPPORT IN TERRESTERIAL PLANTS

- ✓ Support in terrestrial plants has the following importance;
- ✓ Enables holding leaves to receive maximum sunlight for photosynthesis.
- ✓ Enables exposing of flowers in most suitable position for pollination.
- ✓ Allows holding of fruits and seeds in most possible favourable position for dispersal.
- ✓ Maintains plant shape.

SUPPORT MECHANISMS IN TERRESTRIAL PLANTS

Support in plants is mainly by the changes in turgidity, mechanical and vascular tissues;

1. **Turgidity;**

× Turgor pressure changes support plants in a way that, when fully turgid, the close packing of parenchyma cells in the cortex and pith of the stem causes them to press against one another to keep herbaceous plants and young woody plants erect. Absence or insufficient water reduces turgor pressure causing loss of support due to wilts.

2. **Mechanical tissues**

a. **Collenchyma** cells have uneven thickened cellulose cell walls, and are alive. Collenchyma tissue provide flexible support (a mechanical function) to stems and leaves, enabling withstanding the lateral force of the wind.
The walls of collenchyma cells can be deformed by pressure or tension and retain the new shape even if the pressure or tension ceases.
Location; in young plants, herbaceous plants and some organs such as leaves

b. **Sclerenchyma** fibres and sclereids have lignified cell walls and are dead when mature.
The tough and elastic cell wall of elongated fibres allow the cell to be deformed but can snap back to their original size and shape when the pressure or tension is released.
Provides great tensile or compressional strength in plants parts, such as in the vascular tissues of stems and roots and the bundle sheath of leaves
Support the tree while the elasticity allows the trunk and the branches to sway in the wind without breaking. Location; found in small groups in cortex, pith, phloem and shells of coconuts.

3. Distribution of vascular tissues; xylem vessels and tracheids

The distribution is related to the resistance of the various forces acting upon them, e.g. in land plants the stem is mainly exposed to bending stresses due to the action of wind while roots experience pulling stress.

(i) **Xylem vessels** and **tracheids** are dead, the cell walls are lignified and thickened which provides great mechanical strength to resist bending in the stem, reinforce against pulling in the root and are the most important supporting cells in the veins of leaves.

(ii) **Vascular tissues in young dicot stems;** location; at the root periphery; near edge, this increases the resistance to the bending stresses produced by wind or the passing animals.

(iii) **Vascular tissue in dicot roots;** location; at the root centre. The solid cylinder increases the tensile strength to resist the uprooting force produced by the pulling effect of wind. The solid cylinder also provides sufficient incompressibility against

the longitudinal compression by the load from overhead and against the lateral pressure exerted by the surrounding soil.

(iv) **In leaves,** vascular tissue is located at the upper side of the midrib and lateral veins and it extends throughout the leaf surface**.** This enables it resist shearing forces acting on the leaf blade by wind.

(v) **In woody stems,** the lignified secondary xylem tissues**;** known as wood; occupy most part of the woody stem, which makes the stem very hard and rigid to avoid fully depending on cell turgidity for support.

SUPPORT IN WOODY PLANTS

- In young woody plants, support is provided by the turgidity of the cells and the cellulose cell walls.
- In young woody plants, support is provided mainly by the lignified xylem vessels, tracheid and sclerenchyma tissue
- The walls of the xylem vessels and tracheid are thick and lignified. This hardens them, thus giving tensile strength and rigidity to the plant.
- The secondary thickening in the xylem cells deposit more wood to xylem or tissue to provide greater support in stems and roots.
- Support is enhanced by the central distribution of the xylem in the root. This helps to withstand the tugging strains of the aerial parts as they bend
- In the stem, xylem vessels exist as separate rod through the entire stem hence offering support against bending.
- Sclerenchyma tissue has thick and lignified cellulose cell walls which are impermeable to water, thus giving strength to the stem.

MODIFICATIONS OF PLANT ORGANS TO PROVIDE SUPPORT

- In woody plants, support is provided by development of xylem tissues and phloem tissues which have thick walls impregnated with lignin which is a tough substance that supports plants.
- Sclerenchyma tissues in stems have thick secondary walls which provide support and strength to the plant.
- Replacement of outer epidermal layer during development with stronger cork, providing additional support to as the plant increases in complexity.
- Development of extensive root system for firm anchorage in the soil.
- Modified roots like the buttress and prop roots, increasing the surface area of the stem base thereby providing extra support to the plant.
- Secondary thickening resulting from the activities of the vascular cambium, increasing thickness or girth of the stem or root thereby providing extra support to plants.
- Collenchyma tissue, provide support in young growing portions of the plants.
- Leaves of some plants such as passion fruit develop into tendrils to wind around stems of other plants or wind around other structures for additional support.

Support in aquatic plants

- ✓ Support in aquatic plants is primarily due to buoyancy in water. This buoyancy is provided by;
- ✓ Surrounding water whose density is higher than that of air hence providing a larger upthrust force and as well presence of numerous large air spaces or intercellular spaces in leaves and stems which form air filled cavities extending through the tissue to produce buoyancy.

Note; **buoyancy** is the upward force on an object that has been fully or partially immersed in fluid; it is therefore the ability of an object to stay afloat in a fluid.

Comparison between support in terrestrial and aquatic plants

Terrestrial	Aquatic
Requires mechanical support	Doesn't require mechanical support; buoyancy supports the plant
Highly lignified thick walled xylem	Poorly developed xylem
Small air spaces in stems	Numerous large air spaces in leaves and stems
Has collenchyma cells	Lacks collenchyma cells

LOCOMOTION AND MOVEMENT

Locomotion is the changing of position of the entire body of an organism whereas movement is the displacement of part of parts of an organism while the entire body is in one position.

There are three basic types of movement and their important as follows;

a. **Amoeboid movement**;
- ✓ This enables amoeba to move about to obtain food, avoid dangers, escape from the enemy among others.
- ✓ It also enables white blood cells such as phagocytes, macrophages of the lymph and Kupffer cells of the liver to engulf antigen, microbes and as well migrate into and the circulatory fluid.

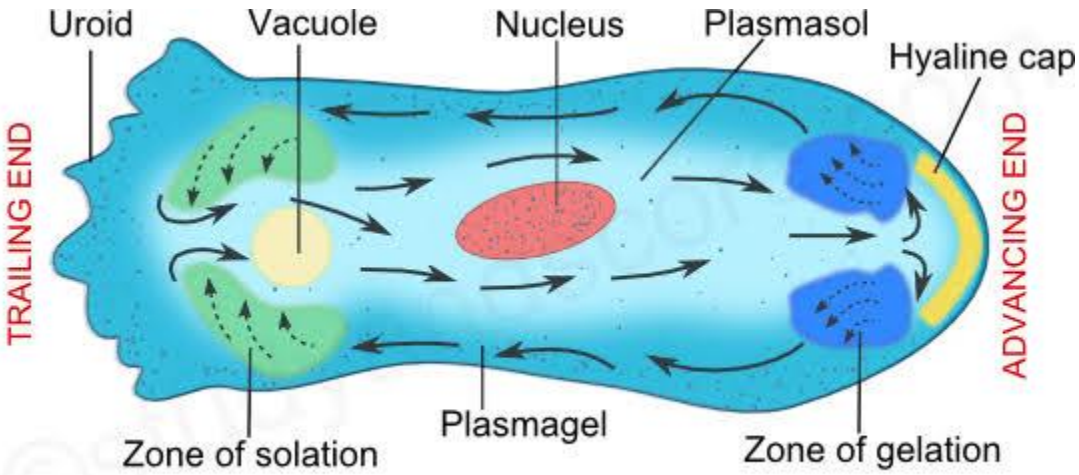
b. **Ciliary and flagellar movement**;
- ✓ Ciliary movement enables the paramecium to avoid danger, drive water and food particles into the gullet among others.
- ✓ In echinoderms, ciliary movement is crucial in driving water through the water vascular system which brings about locomotion.
- ✓ Ciliary movement of the cells lining the respiratory tract of human drives away microbes and dust particles towards the nose or mouth for disposal.
- ✓ Ciliary movement in the oviduct or fallopian tubes of human female moves ova towards the uterus.
- ✓ Ciliary movement in nephridia of annelids such as earthworm moves wastes out of the body.
- ✓ In mammals flagellum of the sperms enables them to swim through the female reproductive tract.
- ✓ Flagellum enables the movement of certain protozoans such as euglena.
- ✓ In certain molluscs, ciliary movement facilitates gaseous exchange by passing water currents over their gills.

c. **Muscular movement**;
- ✓ Muscular movements enable the animals to find food, mates, avoid predation, unsuitable environment conditions, flow of contents in the gut and arteries and positioning of eyes and external ears for effective functioning in some animals.

AMOEBOID MOVEMENT

- This is a type of movement that involves crawling motions characterized by protoplasmic protrusions to form structures known as pseudopodia.
- Various theories try to explain amoeboid movement however the sol-gel-sol theory is by far the most acceptable theory.
- It describes amoeboid movement as follows;

- ✓ For forward locomotion to occur, pseudopodium is formed anteriorly.
- ✓ The plasmalemma attaches to the substratum;
- ✓ Stimulation of the ectoplasm; plasma gel or gel at a certain point causes its conversion to plasmasol and flowing of the pressured plasmasol; endoplasm into the weakened area forming first a bulge and then a tube; **pseudopodium formation**;
- ✓ The movement is sustained by contraction of the outer gel layer which squeezes inwards, causing cytoplasmic streaming towards the tip of the pseudopodium; anterior end.
- ✓ Within the advancing tip of the fountain zone; anterior end, plasmasol is converted into a more rigid fluid called plasmagel/**gelation occurs** at the anterior end which is then deposited on the sides of the pseudopodium; The plasmagel or gel flows backwards into the posterior end along the ectoplasm;
- ✓ At the temporary posterior or hind end of the cell, plasmagel is converted into plasmasol in a process called **solation,** this then flows forwards into the newly formed pseudopodium so much that the whole body of the cytoplasm comes into it.;
- ✓ Now the plasmagel tube contracts and the body moves forwards. Soon after this a new pseudopodium is again formed in this direction.



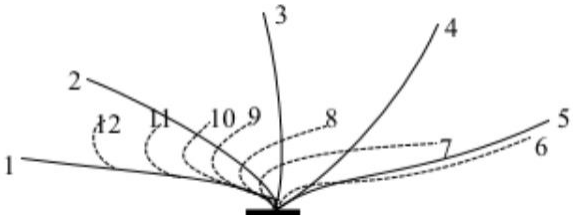
SOL GEL THEORY-AMOEBOID LOCOMOTION

* Functional approach page 342 fig 21.21

CILIARY MOVEMENT

- ✓ This is a type of movement in which there are rhythmical beating of fine hair like processes projecting from the cell membrane of certain cells; cilia.
- ✓ A ciliary beat cycle consists of an effective stroke; power stroke phase and a passive recovery stroke phase;
- ✓ For forward locomotion to be achieved, the cilium move backwards/**effective stroke** rapidly occurs, in this the cilium is more rigid and extended in a complete arc, this exerts a greater resistance to the medium or water/a push or thrust force is exerted onto the water ;
- ✓ This in turn generates a propulsive forward force in which the wave of effective stroke begins from points on the membrane/basal body and spreads in a single direction;

- ✓ The cilia beat in reverse when the power stroke is directed to the anterior end of the organism so as to propel it backwards while beating towards the posterior end, propels the organism forward.
- ✓ Then the cilium move forward; **recovery stroke** occurs; in this the cilium is more flexible and returns slowly by propagating a bend from base to tip in an unrolling motion, creating no thrust or resistance to water and thus reducing the drag forces.
- ✓ The cycles of the adjacent cilia are slightly out of phase so that they do not bend at exactly the same moment, resulting into a metachronal rhythm in which waves of ciliary activity pass along the organism from the front to the hind.
- ✓ *metachronal rhythm are movements produced by the sequential action of structures such as cilia, segments of worms or many legs producing the appearance of a travelling wave.



☺ **Please identify the cilia in recovery phase and those in power stroke. Give reasons for your identification.**

FLAGELLAR MOVEMENT

- ✓ In flagellar locomotion, the flagella cause wave like; undulating movements; which spread from the base up to the tip of the flagella, exerting a push on the water/thrust force, resulting into forward propulsive force to the organism/ cell.

EUGLENOID MOVEMENT

- ✓ This is a special form of flagellar movement. Unlike other flagellates, euglena has its flagellum at the anterior end and it causes forward movement by being pulled by other forces.
- ✓ Waves of activity are generated by the flagellum, they pass in a spiral fashion from the base to the tip with increase in amplitude and velocity of the wave causing the boy of the euglena to be rotated about its axis.
- ✓ The beat if flagellum in euglena has two components; waves pass from the its base to the tip along flagellum as well around it causing the organism to move forward and the same time to rotate around its axis such that it follows a spiral path through water.
- ✓ It is this spinning of the body of euglena round its axis that provides the major force that propels the body forward. Thus the whole body acts as the screw propeller.

MUSCULAR MOVEMENT

- This is a type of movement that involves muscles however muscles depend on the skeletal systems;
- *muscles in histology.
- Muscles are capable of bringing about movement because they can be excited, they can contract, they can relax, and they are elastic and can be extended which all are key to efficient movement.

SKELETAL SYSTEM AND LOCOMOTION

Organisms originally evolved in water which gave them support. Nevertheless some skeletal system was still necessary for support either as rigid framework for attachment of muscles or for protection.

When organisms colonized land, where air provides little support, a skeleton was therefore necessary to support them against the pull of gravity.
Functions of the skeleton;

- Support,
- Locomotion,
- protection

TYPES OF SKELETON

Skeletons take a wide variety of forms but are generally classified into three; hydrostatic, endo and exo skeleton.

HYDROSTATIC SKELETON

- As liquids are incompressible they can form resilient structure against which muscles are able to contract.
- This type of skeleton is typical of soft bodied organisms such as annelids where liquid is secreted and trapped within the cavities.
- Around the liquid, muscles are arranged segmentally. They are not attached to any part of the body but simply contract against one another.
- The arrangement of muscles is; circular and longitudinal muscles and they work antagonistically.

Advantages of a hydrostatic skeleton;

- It is elastic and can bend accordingly when the muscles contract thereby enabling the organism fit in narrower burrows.

Disadvantages of hydrostatic skeleton;

- Coelenterates that use a hydrostatic skeleton regularly face a loss of pressure as their skeleton is at the same time the gut.
- Due to lack of a strong supportive system, majority of the organisms with a hydrostatic system are small.
- The slow motion due to lack of effective ways to support a large body compromises the animals escape responses from danger; predation.
- The organisms are limited to moist habitats because of the need to minimize water loss by evaporation.

Description of locomotion in an earthworm;

Structure;* classification*

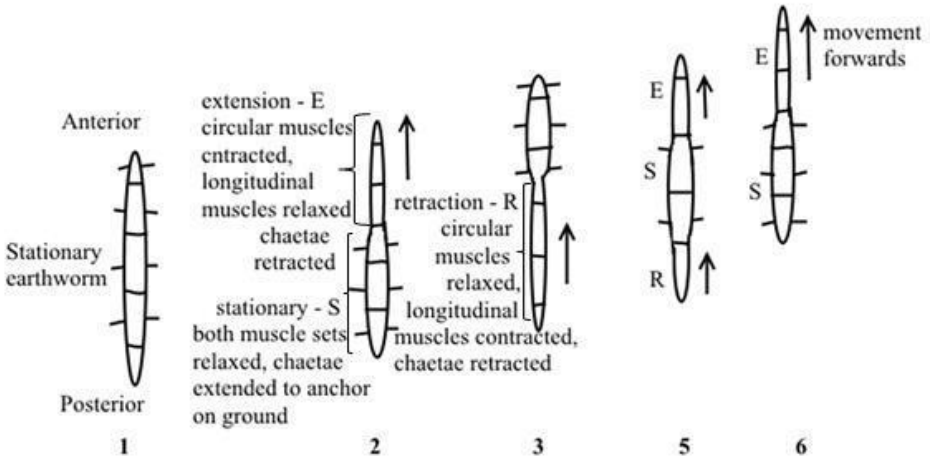
- ✓ The body of the earthworm is cylindrical; tubular, partitioned transversely into many small separate, but coordinated segments, enclosed by epidermis, a thick wall made of two layers of muscles i.e. circular muscles surrounding the cavity and longitudinal muscles running from anterior to posterior; the inside contains a highly pressured incompressible fluid-filled cavity; coelom; each body segment bears four pairs of chaetae (setae), except the first and last segments.
- ✓ Segmental partitioning prevents backflow of the coelomic fluid which would provide little elongation

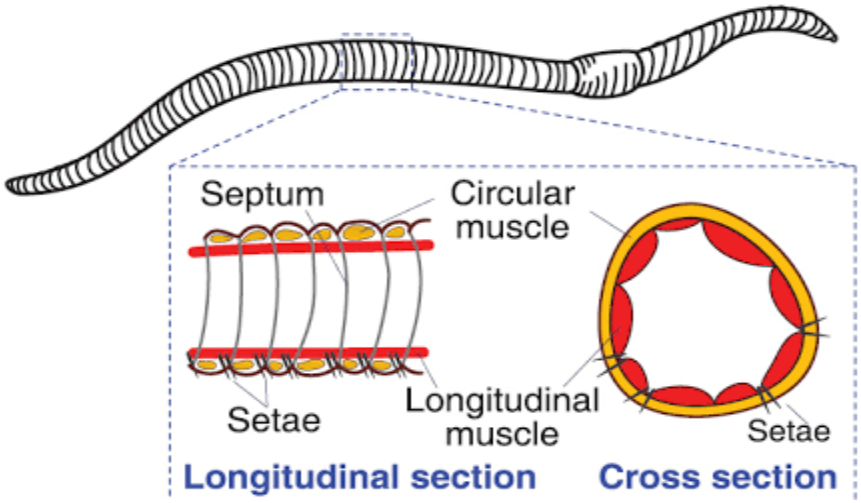
Mechanism of locomotion in earthworm

- Crawling/ movement is initiated when circular muscles at the anterior end contract while longitudinal muscles relax segment by segment backwards as a wave along the body, there by exerting pressure on the coelomic fluid, which is forced to move at right angles to the squeezing circular muscles, while at the same time the chaetae retract inwards in this region of contracted circular muscles. The net result is forward extension of the anterior end.

- The movement of the fluid stretches the set of longitudinal muscles, which then contract to stretch the circular muscles back to the relaxed position, causing segments to elongate and become thin.
- Forward extension of the anterior end is coupled with contraction of longitudinal muscles and relaxation of circular muscles in the more posterior segments causing body swelling and protrusion of chaetae in this region.
- As the successive peristaltic waves approach towards the rear end of the body, longitudinal muscles in the anterior region contract, circular muscles relax, the chaetae protrude to anchor at the ground and pull the rear end forward.
- Control of muscle contraction is brought about by a complex network of inter and intra-segmental neurones

***functional approach page 345 fig 22.4**
***Micheal kent section 11.1 fig4**





EXOSKELETON

- An exoskeleton is a more or less complete covering which provides protection for internal organs and a rigid attachment for muscles.
- It is characteristic of arthropods where it comprises a three layered cuticle secreted by epidermal cells.
- The outer layer, the epicuticle; is thin, waxy and so forms the waterproof covering.
- Beneath this is a rigid layer of chitin impregnated with tanned proteins and it is the exocuticle.
- The inner layer; endocuticle, is more flexible layer made of chitin. The exoskeleton may be impregnated with salts such as calcium carbonate which give it additional support.

Advantages of exoskeleton

- Exoskeletons contain rigid and resistant components to offer protection against predators, bacterial attack and desiccations while on land.
- Exoskeletons contain rigid components that offer support enabling maintenance of body shape.
- Exoskeleton of arthropods contains rigid framework of ingrowths known as apodemes which serve as attachment sites for muscles.
- In arthropods the exoskeleton is modified into appendages which offer rapid locomotion than the hydroskeleton.
- The arthropod skeleton contains various folds, flaps with parts modified for feeding and structures for respiration.
- Exoskeletons are often highly coloured for camouflage.
- It is jointed enabling flexibility

Disadvantages of exoskeleton

- Since exoskeletons are rigid, and do not allow growth of the body, in arthropods, they disrupt smooth and steady growth and must be periodically shed off to allow growth, which makes the animal temporary exposed for predation. The shed off is known as moulting or **ecdysis** *next chapter
- An exoskeleton cannot support large sized animals because their large volume and body mass necessitates a relatively larger and thicker exoskeleton.
- It requires modifications in movement; many individual muscles are attached to the outer shell in order to create movement.

LOCOMOTION IN INSECTS

Insects have two types of muscles;

i. Skeletal muscles; these are attached to the exoskeleton
ii. Visceral muscles; these are found in the gut

Attachment of muscles in insects

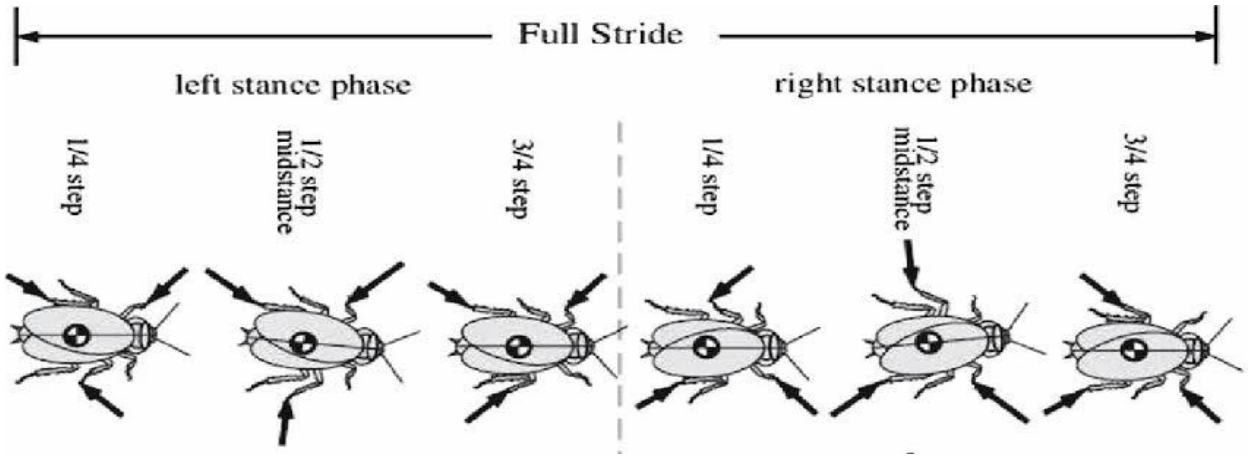
i. Some skeletal muscles using tonofibrillae attach on the cuticle through the epidermis.
ii. Others attach on the ridge like cuticle called apodemes and apophyses.
iii. Flight muscles attach on plate like invaginations called phragma in the thorax.

In order for locomotion to occur; there are antagonistic muscles that operate;

i. **Elevator** muscles working with **depressor** muscles; wings
ii. **Flexor** muscles working with **extensor** muscles; in legs

WALKING IN INSECTS

- ✓ Insects have six legs; 3 pairs of legs. For walking to take place all the six legs must be coordinated as follows;
- ✓ Bending and straightening of the limbs is brought about by the reciprocal innervation; one muscle is excited at the same time there other; antagonist is inhibited, of flexor and extensor muscle attached to the inner surface of the exoskeleton on either side of the joint.
- ✓ A limb bends by contraction of flexor muscle and relaxation of the extensor muscle simultaneously.
- ✓ A limb straightens by contraction of extensor muscle and relaxation of flexor muscle simultaneously.
- ✓ When the insect starts to walk, the second leg on one side and the first and third legs on the other side support the body off the ground as the other three move forward.
- ✓ The first leg on the side where there is the second leg stationary pulls the insect, while the third leg of the same side and the second leg of the other side push.
- ✓ The process is then repeated but this time around each of the group of three does what the other group has been doing.



FLIGHT IN INSECTS

Flight in insects is achieved by direct and indirect muscles depending on the size of the insect.

Direct muscles

- These are muscles that directly to the wings of larger insects such as dragon flies, mayflies, grasshoppers, locusts among others.
- They are synchronous muscles; one nerve impulse causes one muscle contraction which results into one wing beat and as well one contraction and relaxation per one neural impulse that is to say;
- The frequency of muscle contractions, relaxation and wing beat corresponds to the rate at which the impulses are sent by the nervous system.
- This causes the wing beat to be slower; less than 50 beats per second

Indirect muscles;

- These attach to the interior of the thorax not directly to wings of small insects such as houseflies, honey bees, mosquitoes, midges etc.
- They are asynchronous muscles; more than one contraction and relaxation is caused by one nerve impulse.

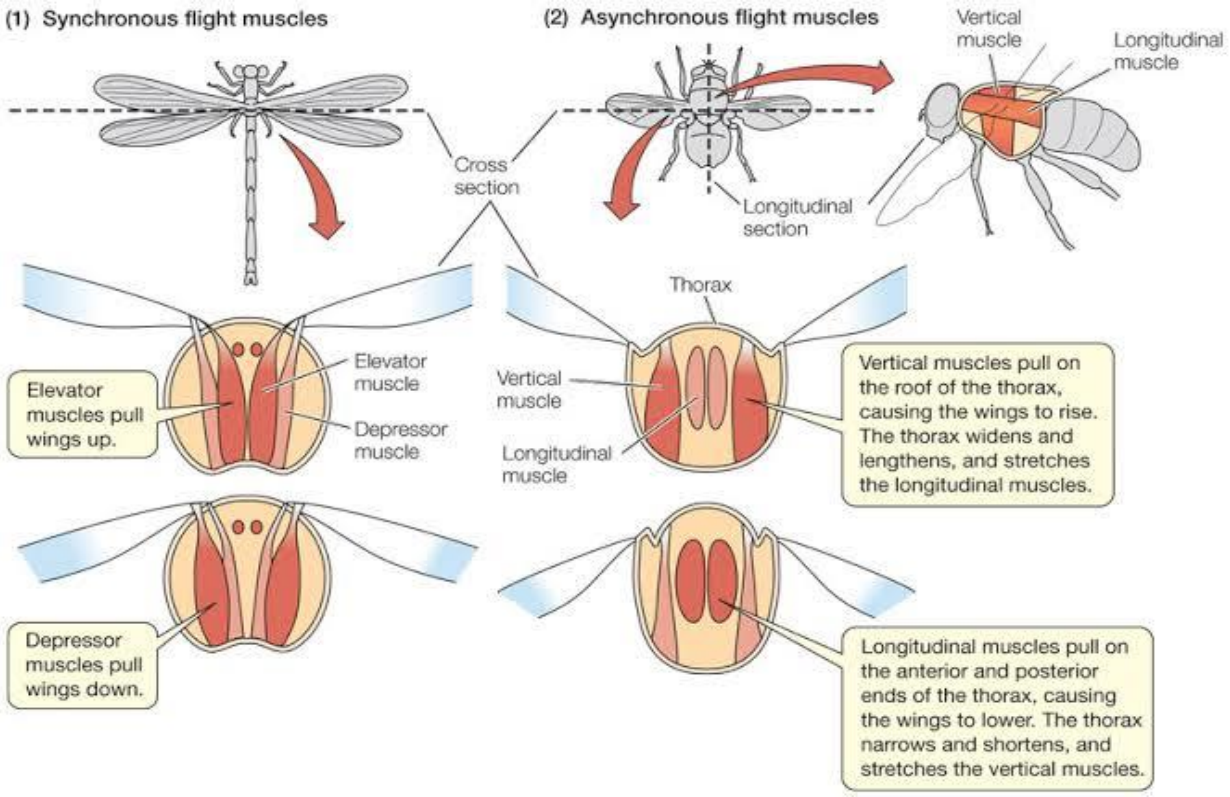
- In these, a single nerve impulse is required to initiate muscle contraction and a single impulse to stop muscle contraction.
- The muscles exhibit stretch reflex; automatic contraction in response to being stretched.
- Energy is conserved because of the elasticity of the thorax which enables it restore its shape.
- Frequency of wing beat exceeds rate of nervous system of sending impulses; more than 50 beats per second

ACTION OF DIRECT MUSCLES

a. During the **upstroke**; wing moving upwards, the elevator muscles contract, the depressor muscles relax at the same time, the wings are elevated; raised.
b. During the **down stroke**, the depressor muscles contract, the elevator muscles relax at the same time, the wings are depressed down; lowered.

ACTION OF INDIRECT MUSCLES

a. During the **upstroke**, the tergo-sternal muscles; elevator muscles contract, the longitudinal muscles; depressor muscles relax at the same time, the dorsal part of the thorax; notum is pulled downwards; flattens causing the wings to flip upwards; elevate.
b. During the **down stroke**, the longitudinal; depressor muscles contract, the tergo-sternal; dorso-ventral; elevator muscles relax at the same time, the thorax is compressed, its dorsal surface arches, bulges, the wings flip downwards; depress.



ENDOSKELETON

- An endoskeleton forms an internal framework within an organism.
- Endoskeletons occur in certain protozoans, molluscs; cephalopods and vertebrates.
- In the vertebrates, the skeleton is cellular although the bulk of it is non-cellular-matrix secreted by the cells.
- In the chondrichthyes; cartilaginous fish, cartilage forms the entire skeleton.

Advantages of endoskeleton;

- Vertebrates have a versatile support system and as a result, they develop faster and attain bigger bodies than invertebrates.
- It's jointed for flexibility to allow diverse range of locomotion such as digging, running, climbing etc.
- Endoskeleton does not limit space available for internal organs and can thus support larger weight.
- Bones are hard for protecting delicate internal organs such as the heart, brain, spinal cord, etc.
- Bone tissue is mineralized and hence is a mineral reserve for the body's physiological processes
- Mammalian bones manufacture defensive cells.

Disadvantages of the endoskeleton;

- Endoskeletons are enclosed in other tissues thus do not offer much protection from predators in some animals such as fish.
- Endoskeletons do not contribute in minimizing water loss from the body by evaporation.

JOINTS IN THE ENDOSKELETON

The skeleton has to fulfill two conflicting functions, on one hand it needs to be rigid in order to provide support and attachment of muscles whereas on the other side it has to be flexible to permit movement. This paradox has been overcome by having joints of the types;

1. **Immovable joints**; no movement is possible between the bones. A thin layer of fibre exists between the bones holding them firmly in position e.g bones of the skull and bones of the pelvic girdle.
2. **Partly movable**; only a little movement is possible between individual bones. Bones are separated from each other by cartilageous pads. It is divided into;

✓ Pivot joint; e.g between the axis and atlas vertebrae.
✓ Gliding joint e.g in the wrist and the ankle and between adjacent vertebrae.

3. **Movable joints**; synovial joints; there is considerable freedom of movement between bones; the actual amount depends on the precise nature of the joint. The articulating bone surfaces are covered with cartilage and separated from each other by a synovial cavity containing a **synovial fluid**. The synovial fluid serves to lubricate the joints in order to minimize friction between the articulating bones. It is divide into;

✓ Ball and socket; allows movement in all direction e.g shoulder and hip joint.
✓ Hinge joint; allows movement in only one direction e.g elbow, knee, fingers and toes joints.

***Micheal kent section 11.4 fig 2 and 3**
***Functional approach page 332 fig 21.7 A, B & C**

LOCOMOTION ON LAND

Locomotion in organisms has evolved; advanced with changes in the environments of the organisms in terms of resources among others.
Some organisms use air, land solely for locomotion, although some just like the insects covered above use both land and air.

Challenges to support and locomotion on land

- Terrestrial animals face a problem of supporting the weight of their bodies against the force of gravity
- The force of gravity which tends to pull the animal's body toward s the ground also makes locomotion hard.

- The low density of air makes it provide little support to the animal's body and no anchor for the propulsive devices.
- Wind blows animal's body, thus compromising the support mechanisms.

Due to the above challenges some organisms especially the amphibians have evolved use of water as a medium for most of their activities;
Locomotion on land is of five types in higher animals;

1. **Bipedalism**; propulsion using two rear legs
2. **Quadrapedalism**; propulsion using four legs
3. **Plantigrade**; waking with the podials and metarsals flat on the ground e.g in humans, kangaroo, rabbits, mice, rats, hedge hogs and raccoons.
4. **Digitigrade locomotion**; walking on toes with the heel and the wrist permanently raised e.g birds, wolf, dog, cat, lion and elephant.
5. **Unguligrade locomotion**; walking on the nail or nails of the toes; hooves with the heels, wrists and the digits permanently raised. Such as in zebra, horse, cattle, rhinoceros, camel, sheep, giraffe, moose, deer, antelope, gazelle and hippopotamus, pig, bison and goat

Note;

a. The Plantigrade foot offers a large surface area and thus organisms with it are more stable in locomotion as it can bear heavy weight however, it makes locomotion slower as it is made of many bones and joints which make the foot heavy and needs time to carry.
b. The digitigrades are the faster and have quieter locomotion which enhances chances of survival in both attaining prey and running away from predators.

***Micheal kent section 11.7 fig3**

BIPEDALISM

- This is a type of locomotion that involves walking, running, and standing on two rear legs.
- During walking, the calf muscle of the right limb contracts to raise the right heel; causing the ball of the foot; this is where the toes join with the rest of the foot, to exert a contact force on the ground; generating the ground reaction force which thrusts the body forward and slightly upwards
- The weight of the body shifts to the left foot which is still in contact with the ground to provide support.
- Extension of the right limb results in its heel touching the ground first to bear the body weight transferred to it from the left side.
- Further forward movement of the body exerts backward pressure against the ground through the right big toe.
- This sequence in which the right leg alternates with the left, heel-toe-action continues until walking ceases.

Note;

i. The ground reaction force is composed of a lift which thrusts the body off the ground and forward force that propels the body forward; the magnitude of propulsion depends on angle between the ground and the main axis of the limb.
ii. A large angle between the ground and the main axis of the limb; above 75^{o}C results in a large lift force which thrusts the body vertically upwards with no forward force, a relatively small angle results into a bigger forward force and a small upward lift.
iii. Standing on toes increases the surface area for supporting the body weight in balanced posture and sprinting on toes increases the effective length of limbs enabling one take longer strides that propel the body forward over a great

distance and a faster pace even if the speed of the limb movements remains the same; this explains why a man stands on soles but generally sprints on toes.

iv. Bending; crouching creates a small angle between the ground and the main axis of the limb, resulting into maximum forward force; lift rather than lift thereby propelling the body a greater distance; this explains why sprinters crouch before takeoff.

QUADRUPEDALISM

A quadruped is an animal having four limbs all specialized foe walking except humans and birds.

A tetrapod is a vertebrate having for limbs such as amphibians, reptiles, birds and mammals; although they are four it is capable of using only two for walking as well.

Mechanism;

- Contraction of extensor muscle causes each limb to act as a lever by extending and exerting a backward force that presses the foot against the ground thus thrusting the animal forward and slightly upwards because an equal but opposite force; reaction force is transmitted along the length of the limb against the body while contraction of the flexor muscle pulls the limb forward and lifts it off the ground.

During walking;

A. During walking only one limb is raised at a time; the other remain anchored to the ground to provide support to the tetrapod or increase its stability.
The sequence of movement is as follows;

1. **Left fore limb, right hind limb, right fore limb and finally left hind limb. OR**
2. **Left hind limb, left fore limb, right hind limb and finally right fore limb**

B. During slow running, tripod support is lost; support by the three stationary legs, this is because two fore limbs are moved together followed by the two hind limbs in the sequence of left fore limb, right fore limb, right hind limb and finally left hind limb.

C. During maximum speed running, a dog uses its back to attain speed. All the four legs may be lifted off the ground at the same time, with alternate upward arching of the back coupled with rear feet extension in front of the front feet and the front legs forward and rear legs rearward to increase stride length

N.B stability/ support in Tetrapods

- During locomotion a tetrapod ensures that it is stable enough to avoid collapsing off to the ground that gives a reason for the above mechanisms.
- Also the legs are moved in a way to maintain the centre of gravity in the remaining legs at their centre so that increases motion stability of the animals.
- This mechanical stability is reinforced by the reflexes from the vestibular apparatus in the inner ear from the muscle spindles from the mechanoreceptors in the soles of the legs. This enables the tetrapod remain in equilibrium; stable when two, three or four legs are taken off the ground simultaneously.

***Functional approach page 337 fig 21.13**

MUSCULAR TISSUE

Muscular tissue is derived from the mesoderm and is specialized for contraction. It is made up of contractile units called muscle fibers bound in a framework of vascular connective tissue which provides anchorage to the skeleton or skin.

As covered in histology, the muscle fibres maybe, smooth; involuntary; visceral or skeletal or cardiac muscles. *refer to histology.

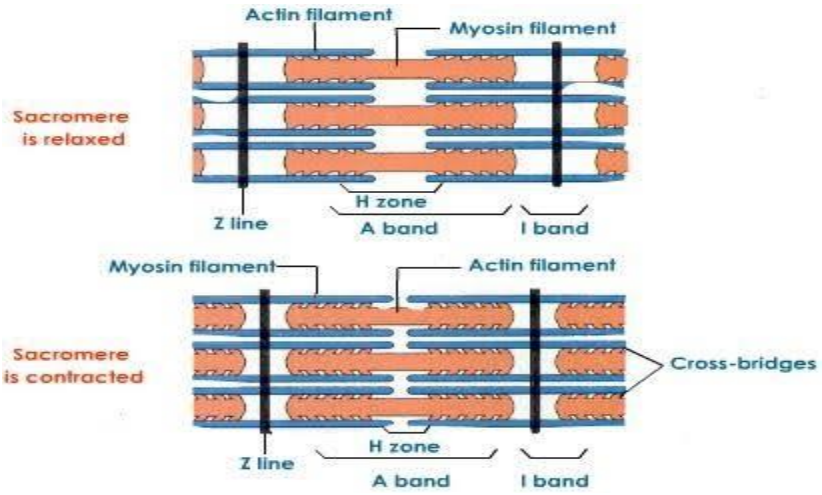
Recap of the skeletal muscle structure;

- Skeletal muscle is highly compartmentalized and each compartment is treated as a separate entity.
- The entire muscle is a collection of several muscle fibres bundles enclosed by connective tissue called epimysium.
- One muscle fibre bundle contains many muscle fibres surrounded by connective tissue called perimysium.
- One muscle fibre is enclosed by the endomysium, a meshwork of collagen fibres and fibroblasts.
- Each striated muscle fiber has fluid sarcoplasm; cytoplasm, bound by the sarcolemma; plasma membrane, it is multinucleate, cylindrical, with longitudinally oriented thread-like structures called myofibrils exhibiting periodic cross striations repeatedly.
- The sarcoplasm contains Golgi apparatus, mitochondria, ribosomes, glycogen, myoglobin, lipid droplets and sarcoplasmic reticulum.

Hope the recap was joyful; could you recall all?

STRUCTURE OF MYOFIBRIL

- ✓ One myofibril shows alternating cross striations; bands which are light; isotropic and dark; anisotropic bands.
- ✓ One myofibril is made of filamentous proteins; myosin which is thick and actin which is thin. These overlap to give the striated appearance.
- ✓ Anisotropic bands are made of both actin and myosin filaments whereas the isotropic bands are made of actin filaments only.
- ✓ Actin filaments are anchored at their midpoints to a central line called Z-line.
- ✓ The region from one Z-line to the next is called a sarcomere, which is the functional unit of the muscle contractions. Sarcomeres are sections of myofibrils that are separated from each other by areas of dense material called Z discs.
- ✓ A band; is relatively darker area within the sarcomere that extends along a total length of the thick filaments.
- ✓ The H-zone is the region in which there are only thick filaments, and no thin filaments at the centre of the A band of each.
- ✓ Within the H-zone is a central dark line called the M-line.
- ✓ I band is the region between adjacent A bands in which there are only thin filaments, and n thick filaments. Each I band extends across two adjacent sarcomeres.



***understanding biology page 568**

***functional approach page 321 fig 20.7.**
***Micheal kent section 11.4 fig.4**

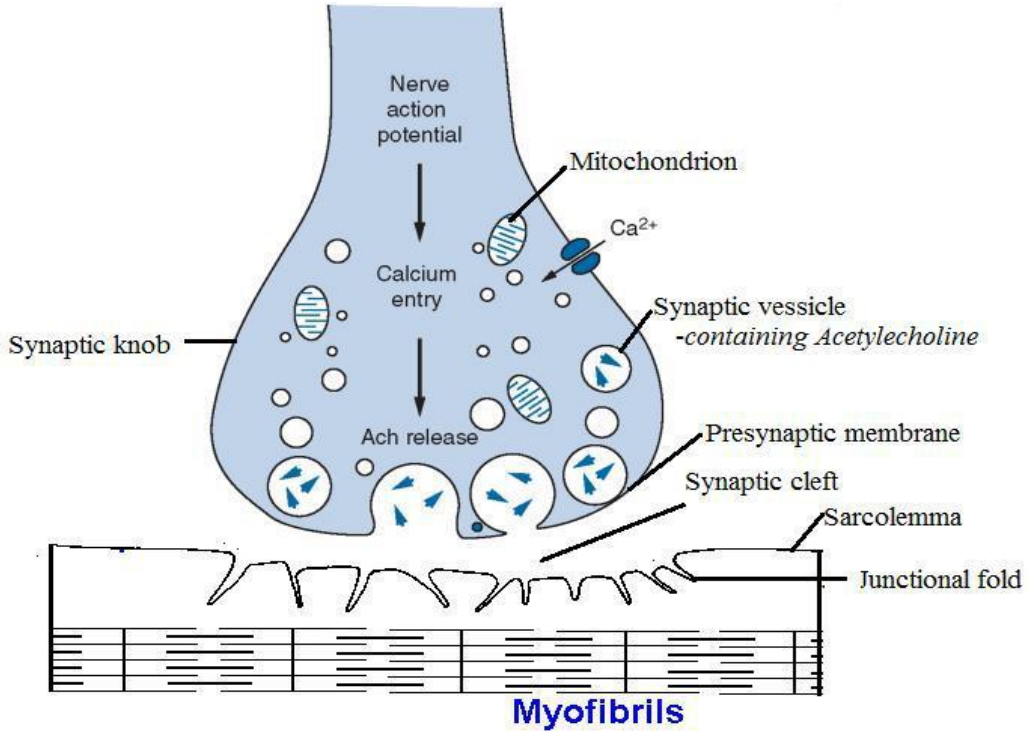
ADAPTATIONS OF THE SKELETAL MUSCLE TO IST FUNCTIONS

- ✓ Each muscle cell is long enough to allow considerable contractile effect.
- ✓ The fibres are parallel to each other so that contractile effect is transmitted along the same axis.
- ✓ Muscle fibres taper at both ends for interweaving to increase muscle strength.
- ✓ Muscle fibres have numerous mitochondria to provide ATP needed in muscle contraction.
- ✓ Cross bridges enable actin and myosin to fit into each other to allow muscle contraction.
- ✓ There is a rich supply of blood vessels to supply nutrients to and drain wastes away from cells.
- ✓ There are large quantities of myoglobin for storage of oxygen needed in aerobic respiration during exercising.
- ✓ There are motor end plates; neuromuscular junctions to allow innervation that results in contraction.
- ✓ There is a dense network of internal membrane system including transverse tubules for calcium ion storage which is very much needed in muscle contraction.
- ✓ Reciprocal innervation ensures antagonistic muscular contraction to bring about realistic movement.

MECHANISM OF MUSCLE CONTRACTION AND RELAXATION

Note; a single junction or synapse made between one motor neurone and one muscle fibre to bring about innervation is called a **neuromuscular junction** or **motor endplate.**

***UNDERSATNDING BIOLOGY PAGE 567 FIG 28.2**



Muscle contraction based on the sliding filament theory/ ratchet mechanism

During contraction

- Arrival of the action potential at the synaptic terminal of the motor neurone, causes the influx of calcium ions from the extracellular fluid into the presynaptic neurone cytosol.
- These cause the fusion of the synaptic vesicles containing acetylcholine with the presynaptic membrane releasing their contents by exocytosis.
- Acetylcholine diffuses across the synaptic cleft of the neuromuscular junction to depolarize the sarcolemma and trigger an action potential that spreads through the transverse tubules, causing the sarcoplasmic reticulum to release calcium ions into the sarcoplasm.
- Calcium ions bind to troponin of actin causing conformational changes in troponin-tropomyosin system. Thus troponin displaces tropomyosin which had been blocking the actin filament.
- The myosin heads now become attached to actin forming a cross bridge between the thick and thin filaments.
- An ATP molecule becomes fixed to the myosin head. Myosin thereby hydrolyses the ATP and undergoes a conformational change into a higher energy state.
- This is accompanied by energy release, ADP and an inorganic phosphate. This results into relaxation of the myosin head, this relaxation involves the rotation of myosin head, which flexes the cross bridge to move actin a small distance pulling Z- discs towards each other, thus shortening the sarcomere and the I-band.
- The collective flexing of many cross bridges by myosin to move actin in the same direction results into muscle contraction.
- *The contraction of muscle fibre is under the excitation contraction coupling; a sequence of events by which an action potential in the plasmalemma leads to force contraction through an increase in intracellular calcium ions and cross bridge formation and turn over.

During relaxation,

- ✓ Calcium ions are pumped back into the sarcoplasmic reticulum
- ✓ ATP binds to myosin head, detaching it from actin as the myosin head cocks or recharges.
- ✓ Troponin-tropomyosin complex which regulates actin and myosin interaction is reformed.
- ✓ The active tension disappears and the rest length is restored, completing the contraction relaxation cycle

Rigor mortis;

- As the separation of the myosin and action filaments requires the binding of ATP to myosin, and this can only be produced in living organism, the muscles at death remain contracted a condition known as rigor mortis.
- Also increased permeability of the sarcoplasmic reticulum to calcium ions that occurs at death, allows calcium ion influx into the sarcoplasm hence promoting the cross-bridge formation between actin and myosin.
- However the pumping of calcium ions from the sarcoplasm into the sarcoplasmic reticulum fails because of lack of ATP as respiration ceases. This causes the muscle to remain contracted.

MUSCLE TWITCH

This is a rapid muscle contraction in response to a single twitch
It is categorized as slow twitch and fast twitch depending on the type of muscle fibre.

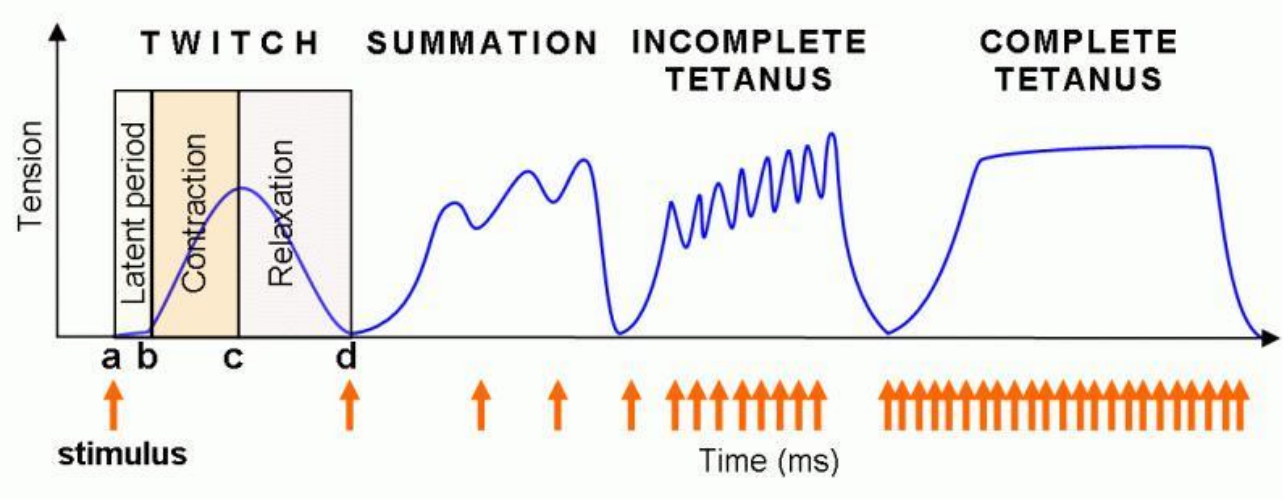
SLOW TWITCH FIBRES;

This contracts more slowly, less powerful, it last for a longer period thus suited for work which requires longer muscle contraction e.g athletics.
Common example is the calf muscle; *luganda "entumbwe"*

Adaptions of slow twitch fibres

- Large reservoir of myoglobin for storage of oxygen which facilitates aerobic respiration to avoid accumulation of lactic acid.
- Much glycogen to provide a source of metabolic energy.
- A rich supply of blood vessels to deliver oxygen and glucose needed in aerobic respiration to provide energy.
- Numerous mitochondria to produce ATP that maintains muscle contraction.

MUSCLE STIMULATION FREQUENCY, LENGTH AND TENSION



FAST TWITCH MUSCLE FIBRES

This contracts more rapidly, more powerfully, only for a short period of time hence suited for intense exercise such as weight lifting.
Common example is the biceps muscle.

Adaptions of the fast twitch muscles;

- Thicker and more numerous myosin filaments.
- High concentration of enzymes involved in aerobic respiration.
- Store phosphocreatine, a molecule that can rapidly generate ATP from ADP in anaerobic conditions and so provides energy for muscle contraction.

LATENT PERIOD

- ✓ This is a brief interval between stimulus application and the onset of muscle fibre contraction.
- ✓ During the latent period, excitation of the muscle fibre followed by contraction occurs.

Note;

1. The response of one muscle fiber is independent of the intensity of the stimulus, provided the stimulus exceeded threshold intensity.
2. The entire skeletal muscle does not obey the all or nothing law because the total amount of contraction depends on the number of muscle fibers that are contracting at a time.

3. Threshold potential, is the electrical potential at which an action potential is triggered.

TETANY

This is a smooth, sustained maximum contraction of a muscle in response to rapid firing by the motor neurone. The ability of a muscle to undergo tetany is dependent on the refractory period.

Refractory period

This is a sort period of inexcitability in a muscle cell following stimulation.
This is the amount of time it takes for an excitable unit membrane to be ready for a second stimulus once it returns to its resting state following excitation.

MECHANICAL SUMMATION/ UNFUSED TETANY

This is a condition in which multiple stimulation of a muscle fibre before full excitation results into a series of twitches added together to produce a more sustained contraction.
N.B summation occurs when two or more stimuli are delivered at the same time but the interval between the stimuli is long enough to cause to or more separate twitches in a muscle one after the other.

MUSCLE FATIGUE

- ✓ Muscle fatigue; a condition in which the muscle's capacity to produce maximum voluntary action or perform a series of repetitive actions is reduced.
- ✓ During a muscle fatigue, there is a decrease in the ability of a muscle to generate force.
- ✓ Muscle fatigue results when there is tissue oxygen deprivation, glycogen or phospho creatine depletion and increased level of blood and muscle lactic acid in an exercised muscle.
- ✓ As covered earlier, lactic acid id produced by anaerobic respiration.

MUSCLE METABOLISM

- Skeletal muscles at rest obtain much of their energy from aerobic respiration of fatty acids. During exercise, muscles turn to glycogen and glucose for energy.
- The energy obtained from cell respiration is important for providing ATP which causes movement of cross bridges during muscle contraction and as well calcium ion pumping into the sarcoplasmic reticulum to allow muscle relaxation.
- ATP can be obtained from skeletal muscles quickly by combining ADP with a phosphate derived from phosphocreatine. This compound was previously formed by the combination of creatine with an inorganic phosphate during cellular respiration.
- Skeletal muscles respire anaerobically during a heavy exercise because the cardio-pulmonary system requires a lot of time to pay the oxygen debt.
- Whether the exercise is light, moderate or intense it depends upon an individual's maximum capacity for aerobic respiration.
- The maximum rate of oxygen uptake in the body is known as aerobic capacity.
- The intensity of exercise can also be defined in terms of lactate threshold which the percentage of the maximum oxygen uptake at which a significant rise in blood lactate occurs due to anaerobic respiration.

LOCOMOTION IN FISH

- ✓ Most fish have a line of muscle blocks, called myomeres; myotomes, along each side of the vertebral column. To swim, they alternately contract one side and relax the other side in a progression which goes from the head to the tail. In this way, an undulatory locomotion results, first bending the body one way in a wave which travels down the body, and then back the other way, with the contracting and relaxing muscles switching roles.
- ✓ They use their fins to propel themselves through the water in this swimming motion.
- ✓ When myotomes on one side of body contract; those of the opposite side relax at the same time; the tail pushes against the water towards the contracted side; generating a thrust that can be resolved into 3 forces:

1. The **reaction force** which is the reaction of the water against the pushing action of the water and is equal and opposite of the thrust.
2. The **forward**; propulsive force that pushes the fish forward.
3. **Lateral drag**; sideways force that swings the tail towards the left and the head towards the right and thus slows; drags the fish. Lateral drag is countered by;

- Pressure of the water against the head
- Pressure of the water against the dorsal fin, both of which enable to move forward without swinging from side to side very much i.e. the lateral forces essentially cancel out.

TYPES OF LOCOMOTION IN FISH

There are majorly three types of locomotion in fish;

Anguilliform locomotion such as in eel;

- ✓ This is found in very long fish which throws many waves so that different parts of the body are moved simultaneously to the left and to the right.
- ✓ The entire body is thrown into a lateral undulation which progresses from the front to hind; anterior to the posterior.

Carangiform locomotion e.g dog fish, Nile perch etc.

- ✓ This is a form of locomotion found in long and large fish and commonly the bony fish.
- ✓ The posterior half of the body lashes from side to side. Such fish are equipped with a broad tail fin or caudal fin for increasing the large surface area.
- ✓ As the tail of the dog fish lashes, a number of forces are created, as the tail sweeps across the water, it exerts a backwards pressure on the relatively viscous water, as a result it experiences a reaction force, and this force can be resolved into forward and lateral component.
- ✓ The forward component drives through the water while the lateral component seeps the tail towards the left and the head towards the right.
- ✓ This lateral drag is counteracted by inertia or pressure of the water against the head and the anterior dorsal fin, as a result the fish moves forward without swinging from side to side.

Ostraciform such as ostracium; trunk fish

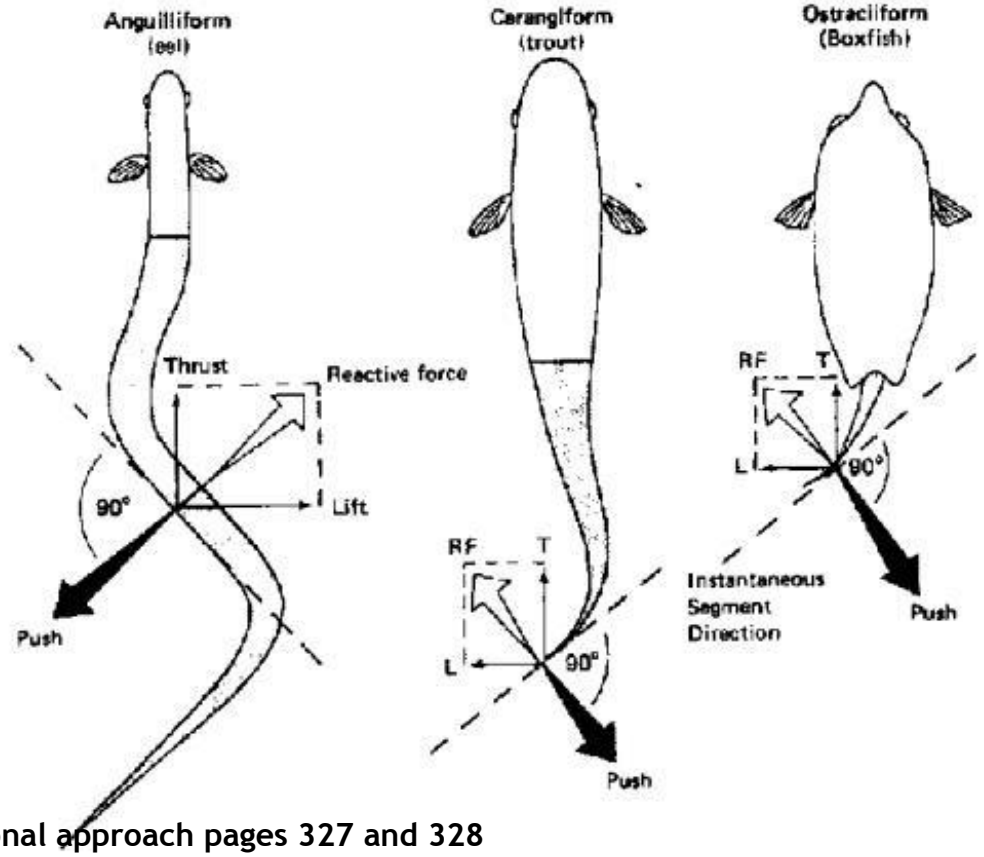
- ✓ This is a kind of locomotion found in small compact fish. It is achieved by a very small tail flapping vigorously from side to side. Following the forces as mentioned above.

Note;

i. The forms of locomotion above have the same mechanical principle and they apply to some invertebrates such as the round worms and some flagellated cells including the spermatozoa.

ii. Snakes also have lateral undulations which pass along their bodies from front to posterior.

ILLUSTRATION OF LOCOMOTION IN FISH



***functional approach pages 327 and 328**

***Micheal kent section 11.6 fig 1 a, b and fig 2 and understanding biology page 574**

SUPPORT IN FISH/ BUOUANCY IN FISH

ELSMOBRANCHS/ CARTILAGINOUS FISH

Examples include; sharks, skates, dog fish and rays.

- Support is provided by constant swimming using fins.
- These fish density is slightly greater than that of water and must swim continuously to avoid sinking. They are capable of maintaining this because;
- They possess large pectoral and pelvic fins which direct swimming upwards.
- They possess a heterocercal tail; a tail with smaller upper surface but larger lower lobes for generating much lift and forward motion.
- During forward motion, the pectoral and pelvic fins are all held at a slight angle to the long axis of the body, generating a force which can be resolved into upward and backward components.
- The upward component force lifts the anterior end up in water while the backward component; backward drag being small only slightly impedes motion and thus is easily suppressed.

TELEOSTS

Examples include Nile perch. These have swim bladder; air bladder to keep them in the water not having to provide a lift. The caudal fin becomes symmetrical, this type of tail transmits most of the force it generates against water in a forward direction.

- The pectoral fins having been freed from the support function, they become small fan like appendages used for stirring and breaking, this increases the locomotion speed.

- Support is provided by adjusting air in the swim bladder which may be; a closed swim bladder gilled with gaseous mixture of oxygen, nitrogen and carbon dioxide all secreted from blood vessels in its wall; common in bony fish, or an open swim bladder having a duct connection to the pharynx and operates as follows;
- Expulsion of air from the swim bladder increases the fish's relative density and it sinks, so if it's to stay afloat, the fish first swims to the water surface then gulps air into the swim bladder to decrease the specific gravitational force, so that the body is body weight equals that of the water displaced.

INSTABILITIES IN FISH

As the fish swims, it is subject to majorly three instabilities;

1. **Yawing;**

This is the lateral side to side deflection of the anterior part of the body resulting from the propulsive action of the tail; vertical axis rotation;
It is counteracted by majorly;

- General massiveness of the anterior part of the head
- Water's pressure against the body side
- Water's pressure against the vertical fins; dorsal, anal and ventral fins
- Lateral flattening; compression of the body.

2. **Rolling;**

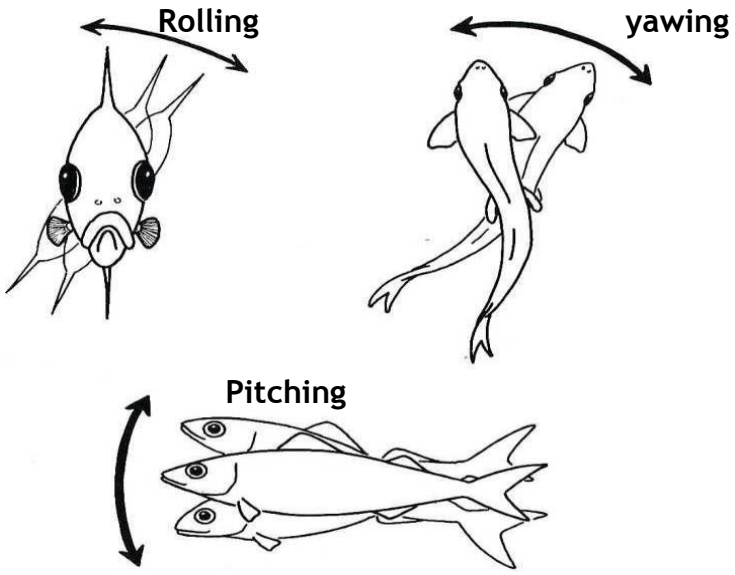
This is the rotation of the body about its longitudinal axis. It is counteracted by the dorsal, ventral and pectoral fins; both paired and unpaired fins.

3. **Pitching;**

This is the tendency of the fish's anterior end to plunge vertically downwards; transverse rotation about the axis. It is prevented by;

- Pectoral fins and to a lesser extent the pelvic fins; paired fins
- Dorso-ventral flattening of the body such as in dog fish

***Functional approach page 331 fig 21.5**
***Micheal kent section 10.6**



ADAPTATIONS OF THE FISH TO LOCOMOTION IN WATER

1. Fish's body is fusiform shaped; spindle shaped and laterally compressed; streamlined body shape to reduce water resistance during swimming.
2. The slippery layer of the mucus on the skin reduces resistance due to swimming.
3. The presence of many rayed fins; paired and unpaired enables the fish to swim and also maintain its balance; stability in water.
4. The lateral line enables sensitivity of fish and also functions as an echo location process for the fish to identify its surrounding in water.
5. Scales overlap and are arranged in a head to tail direction to reduce water resistance during swimming.
6. The swim bladder in bony fish maintains buoyancy.
7. Extensive blood vascular system supplies oxygen and nutrients to the muscle tissues for contraction and drain away wastes.
8. Body is highly muscular to generate a propulsive force against water resistance
9. The neuromuscular cavity is highly coordinated resulting in reciprocal innervation.
10. Presence of myotomes along the vertebral column whose alternate contraction and relaxation throws the body of fish into waves of motion that leads to forward movement.

LOCOMOTION IN BIRDS

Air is relatively a thin medium compared to water and it provides little support, therefore, flight involves more muscular limb than in swimming.

Adaptations in birds which have enabled them have successful aerial life

Structural adaptations

- ✓ Birds have a well streamlined body shape. This allows them to move smoothly in the air without much resistance.
- ✓ The sternum is extended into a large keel-shaped for attachment of flight large muscles.
- ✓ They have few mobile joints. This makes their bodies compact so that they can move smoothly as a whole in the air with less resistance.
- ✓ Down feathers as are filthy to provide high insulation.
- ✓ The bones of vertebral column are fused to reduce flexibility and provide a firm attachment for muscle.
- ✓ The forelimbs have become modified into wings which act as aerofoil, generating lift when passed into air.
- ✓ Flight feathers are large and strong to provide a large surface area for generation of force of flight and to resist strong air currents during flight.
- ✓ Ability to fold the legs away during flight further streamlines their body shape and reduces air resistance.
- ✓ They have prominent eyes located dorso-laterally on the head to provide a keen eye sight enabling them to judge distance correctly especially on landing.
- ✓ The endoskeleton is hollow to reduce weight, and many unnecessary bones are fused into a single structure e.g. some vertebrae, pelvic girdle, finger and leg bones.
- ✓ The vanes of the feathers have hooklets called barbules that zip them together, giving the feathers the strength needed to hold the aerofoil.
- ✓ The major wing bones have internal strut-like reinforcements to prevent buckling during stress.

Physiological adaptations

- ✓ The respiratory system is extensive and very efficient in supplying muscles with oxygen to facilitate much energy release needed in muscle contraction during respiration.
- ✓ Their efficient circulatory system powered by a four-chambered heart enables fast supply of oxygen and food to the body tissues and carry away wastes.
- ✓ The large brains that are connected to eyes coupled with high-speed nerve transmission enable quick decision making especially when landing.
- ✓ The large size of eyes in relation to their body size, coupled with eye keenness enable high visual acuity without crashing into objects.
- ✓ The flight muscles of most birds contain oxygen-carrying compounds, (myoglobin and cytochrome) for storing much oxygen which facilitates the release of much energy needed in muscle contraction.
- ✓ They have high body temperature which maintains the high metabolic rate for generating much energy.
- ✓ They have a high red blood cells count for efficient oxygen transport.

Others

- ✓ Many unnecessary parts like urinary bladder and pinna are totally eliminated while reproductive organs; testes, ovaries and oviducts are kept tiny during non-breeding seasons to reduce weight.
- ✓ They have ability to fold their legs on their body during flight so that not to cause unnecessary friction in air.

THE BIRD'S WING AS AN AEROFOIL/ AIRFOIL

An aerofoil is a structure whose shape and orientation provides lift, propulsion, stability or directional control in a flying object. Or
An aerofoil is any smooth structure which moves in air at an angle to the air stream.

An aerofoil-shaped body moved through air or fluid produces an aerodynamic force, which is the resultant force exerted by air in which the body is immersed, and is due to the relative motion between the body and the fluid.

Principles of an aerofoil

The four basic forces in operation when a bird is in flight are lift, thrust, gravity; weight and drag of which only gravity is constant, the remaining three forces are altered.
In a bird flying at a constant speed, all the four forces are in balance; equilibrium;

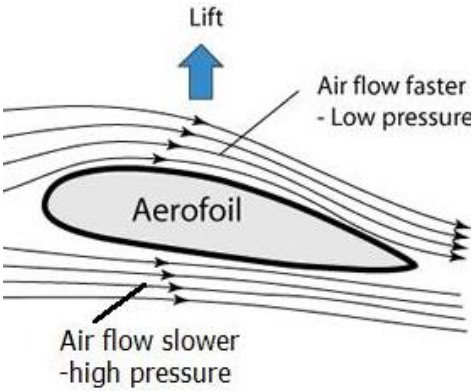
1. **Weight** is the continuous downward force; force of gravity that flying objects must constantly overcome to stay in the air. The opposing force of gravity is lift.
2. **Thrust** is the force generated by flapping the wings which moves the birds forward to oppose drag. In order to move forward, the bird must overcome drag. Drag can be reduced by streamlined shapes.
3. **Drag**; air resistance; this is the friction between moving object and air, which opposes thrust. The more streamlined the body is, the lesser the air resistance the object generates. Drag is higher when; the surface area of the object exposed to the fluid is higher. "Birds spread their wings to slow down or land", the object is moving faster, the fluid has more momentum or inertia; high viscosity and density such as at low altitudes. This is so because air at lower

altitudes has more oxygen to facilitate muscle contraction of wings but is thicker and thus increases drag.

4. **Lift** is the mechanical force generated by the wings which directly opposes the weight of the bird. Lift is higher when;
   The area of the bottom of the wing is larger, the animal is moving faster and the fluid viscosity and density are high this is because thicker air increases thrust by supplying the wings with more mass to move.

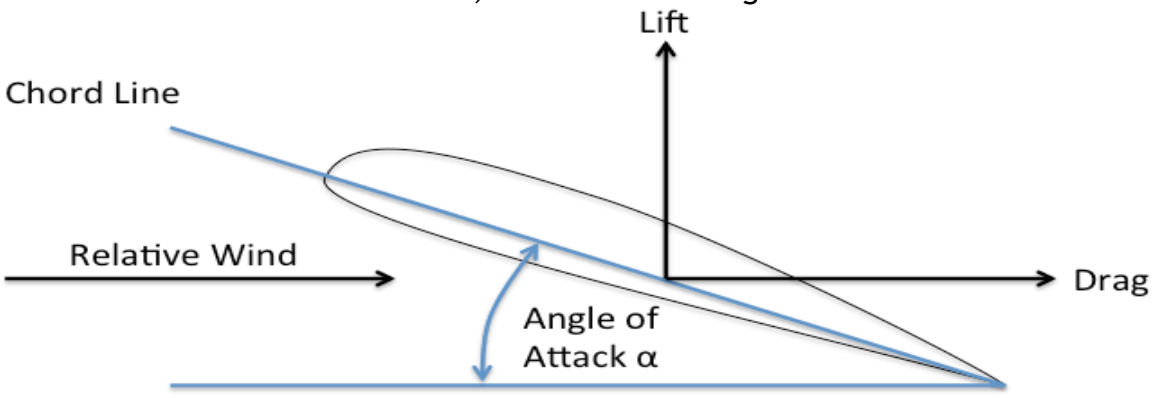
BERNOULLI'S PRINCIPLE AND AEROFOIL OPERATION

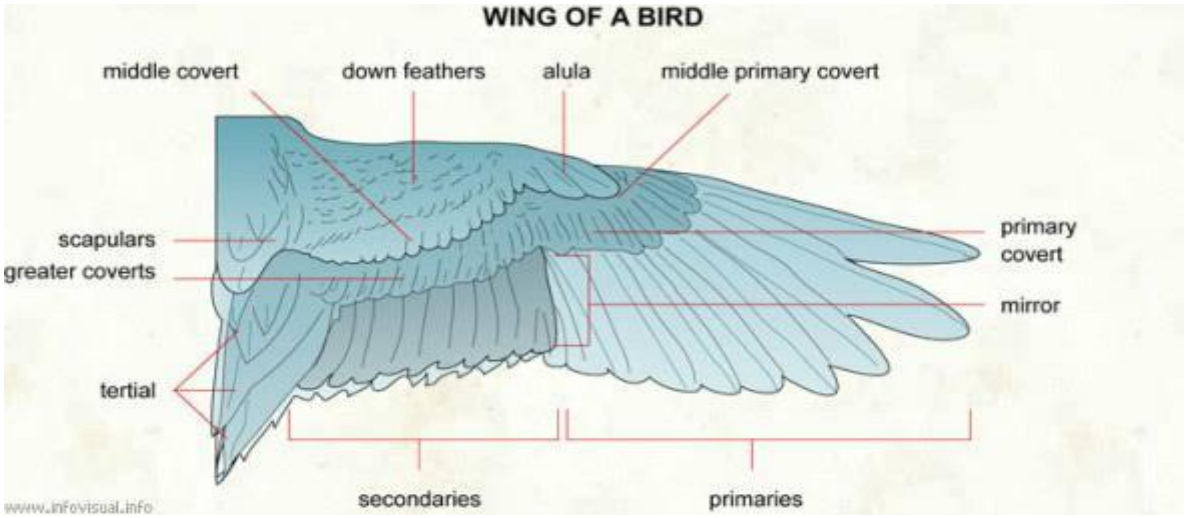
- ✓ As the bird flies, the air splitting at the front of the wings must rejoin at the back of the wings so as not to create a vacuum. The curved top surface being longer, forces air to move faster across the top than the bottom.
- ✓ Faster moving fluids create less pressure, so the bottom of the wings creates a greater pressure than the pressure exerted downward above the wing creating an upward force or lift.
- ✓ The faster air moves across the wing, the more the lift the wing will produce, so moving through the air by flapping increases this airflow and thus increases lift.
- ✓ The bird does not propel the air underneath its wing instead it adds it into the air with the leading edge to obtain the flow over the surface that it requires.



ANGLE OF ATTACK

- ✓ The angle of attack is the angle at which the leading edge of the wing cuts into the forward air flow.
- ✓ The angle of attack is therefore the angle of the wing relative to air flow.
- ✓ Increasing the angle of attack increases the volume of air diverted over the wing and leads to an increase in lift but this is at the expense of drag which quickly increases.
- ✓ In a bird excessive angle of attack results in air turbulence; interruption of airflow above the wing which causes a flight stall when landing or starting off.
- ✓ Angle of attack decreases with increasing speed.
- ✓ Air turbulence above the wing in birds is prevented by the **bastard wing**; alula and the end feathers both of which serve as sloths to smoothen airflow over the wings. The bastard wing is formed by the first four feathers on the first wing digit.
- ✓ If turbulence is not overcome, the bird loses height.





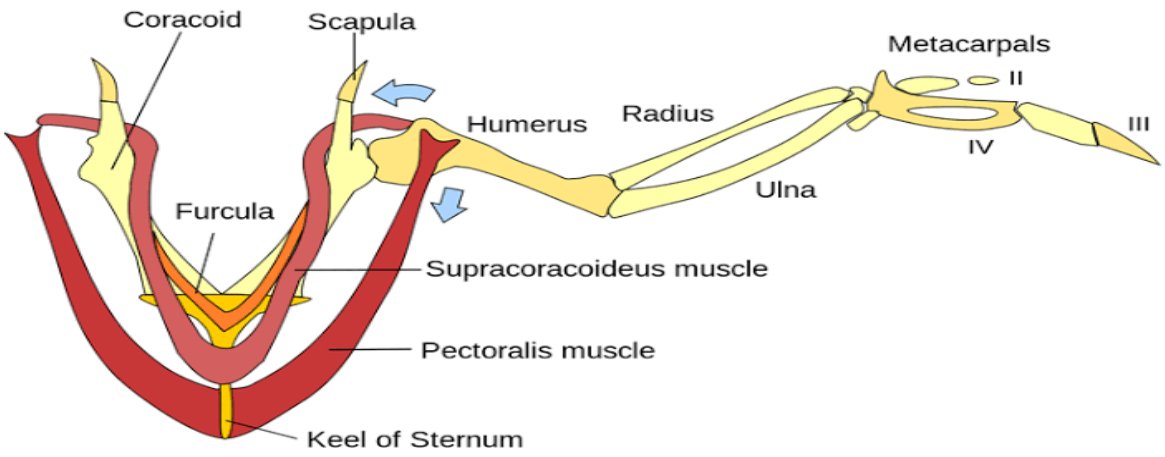
Summary of a bird's wing as an aerofoil

- ✓ The birds wing is an aerofoil in that the leading edge is broader than the trailing edge and the upper side being slightly convex while the lower side is slightly concave;
- ✓ so when the wing is held edge wise in a current of air at a slightly upwards angle; angle of attack, the air which flows above the wing is fast moving and exerts a low pressure, while that which is below the wing is slow moving and exert a high pressure.
- ✓ The air pressure gradient between the upper and lower surfaces of the wing provides a lift force which is transmitted to the main trunk of the body via the coracoid bone to enable the bird attain height.

Note;

- In calm air the molecules are moving randomly in all directions, however when air begins to move, most of the molecules are moving in the same direction.
- The faster the air moves, the greater number of air molecules moving in the same direction. So, air moving a bit slower will have more molecules moving in different directions.
- In the case of a wing, because air under the wing is moving a bit slower than the air over the wing, more air molecules will be striking the bottom of the wing than will be at the top. This explains why slower moving air generates more pressure on the wing than faster moving air.

FLIGHT MUSCLES IN THE THORACIC REGION OF A BIRD



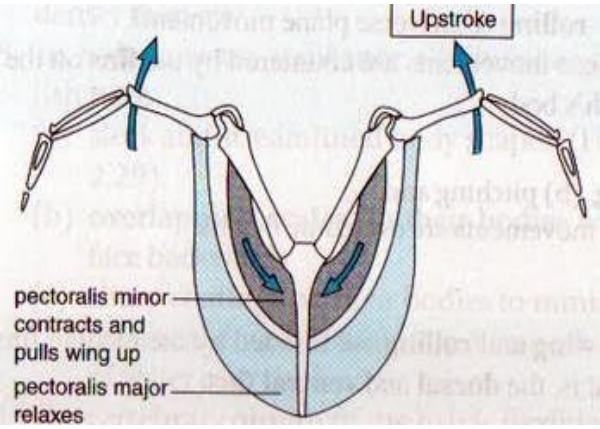
TYPES OF FLIGHT IN BIRDS

There are majorly four types of flight in birds; flapping, soaring, hovering and gliding.

MECHANISM OF FLAPPING FLIGHT

This involves the active movement of wings up; upstroke and down; downstroke.

- During the **upstroke** the pectoralis minor muscles; supracoracoideus muscles contract, the pectorolis major muscle relaxes at the same time; the wings are first abducted; elevated; raised; bent at the wrist, the arm is rotated slightly so that the leading edge is higher than the trailing edge; thus reducing the air resistance and the rush of air lifts the wing.



- The secondary feathers provide much of the lifting force and the primary feathers much of the forward force. The up stroke is more rapid than the down stroke.
- During the **down stroke**, the pectoralis major muscle contracts and the pectoralis minor muscle relaxes at the same time, abduction; elevation of the humerus to a nearly vertical position and also a retraction; pulling back of the wings to a horizontal position backwards; full extension of the elbow and wrist joints;
- Dropping of the leading edge relative to the trailing edge; pronation and slight protraction; stretching out of humerus.
- This is followed by the downwards and forwards movement of the wings until they lie parallel to and in front of the body due to the protraction of the humerus; stretching out of the humerus.

GLIDING FLIGHT

- ✓ When a bird is gliding, it does not have to do a lot of work, In this flight;
- ✓ The wings are held out of the body and do not flap. As the wings move through the air, they are held at a slight angle, which deflects the air gently downwards, pushing the air downwards causes a reaction force; lift in the opposite direction.
- ✓ There is also air resistance on the body and wings of the birds that would eventually cause the bird to slow down and then this mean it wouldn't have enough speed of flight, this is counteracted by the bird's ability to lean forward a little and go into a shallow dive. In this way, the lift force produced by the wings is angled forward slight and enables increase the flight speed; in so doing the bird would have converted gravitational energy into kinetic energy.

Note;

- ✓ Many different animals have evolved the capacity of gliding mechanism since it does not require a lot of energy to occur. Animals include lizards, fish, snakes, squirrels and opossums and primate called the flying lemur can glide

***Micheal kent section 10.6 fig4**

HOVERING FLIGHT

- Tis is whereby the wing moves up and down rapidly while it stays in the same position. The wing moves backwards and forward without changes in position and this because the forward force is counter balanced by the backward force.

SOARING FLIGHT

- ✓ This is a type of flight in which the wings are spread during the upstroke and down stroke
- ✓ Once the bird has gained momentum, the wings become stretched and stop flapping, the bird sails up and higher with the help of thermal up currents caused by temperature changes in the atmospheric air.
- ✓ In this case, the bird may remain at a constant height with its wings spread out and suddenly higher due to the air forces.

COMPARISON BETWEEN FLIGHT IN BIRDS AND INSECTS

Similarities; in both;

- Two types of flight can be achieved; gliding and flapping.
- Muscle contraction is coordinated by the nervous system
- Flight muscles work antagonistically
- Wings are attached on the skeletal element
- There is a high metabolic rate for provision of energy
- Wings are attached in the thoracic region
- Wings are used for flight
- Body shape is stream lined to minimize air resistance during flight.

Differences;

Flight in birds	Flight in insects
• All use direct muscles.	• Some use indirect muscles
• Rate of wing beat per second is low	• Rate of wing beat per second is high
• Air penetrates wing to reduce resistance	• Air does not penetrate wing
• Muscles are attached on endoskeleton	• Muscles are attached on exoskeleton
• Wing is thick, made up of bones, muscles and covered by feather	• Wing is thin, membranous and made of chitin; no feather
• Keel extension for muscle attachment	• Muscles are attached to tergum and sternum
• Supply of oxygen to active muscles is indirect; through blood	• Supply of oxygen to active muscles is direct; through tracheal system
• Turbulence is prevented by bastard wing	• Some insect orders have halters to prevent turbulence
• Flight muscles have myoglobin	• Flight muscles lack myoglobin

END OF TOPIC SUPPORT AND MOVEMENT

I grateful you have gone this far in understanding the concepts of neology so in this topic we have looked at support in plants, locomotion in animals and in annelids all in detail I wish you lack trying out the questions below. Thank you very much.

1. a. how do the following contribute to flight in large winged insects?
   i. flight muscles
   ii. Aerofoil nature of the insect's wing

c. Explain how modifications of plant organs provide support.

2. What problems of support and locomotion do terrestrial animals face?
   b. i. how is support achieved in woody plants?
   ii. Describe how plants are adapted to water loss

3. Describe the structure of the bone and cartilage
   b. how is the cartilage replace by bone?

4. a. how does a skeletal muscle differ from a smooth muscle?
   b. describe the process of skeletal muscle contraction.

14. REPRODUCTION, GROWTH AND DEVELOPMENT

REPRODUCTION

No individual can live indefinitely. Some of its cells may be worn out or damaged beyond repair or it may be killed by predator, disease or other environmental factors. If a species is to survive, it must therefore produce new individuals. This is achieved in two ways: Asexual reproduction and sexual reproduction.

Definition;

- ✓ It is the production of a new generation of individuals of the same species, during which there is transmission of genetic material from parents to their offspring to ensure continued survival of a species. Or
- ✓ Formation of separately existing individuals of the same species by existing organisms

Reproduction is achieved in two ways;

1. **Asexual reproduction;** is the production of offspring; new individuals from a single organism without the formation of gametes. The offspring referred to as clone are genetically identical to each other and to their parent, except when and if mutation occurs. Cloning is the process by which an organism reproduces asexually to give individuals in a population genetically identical to each other and to their parent.

The offsprings must be identical in asexual reproduction except for;

- The identical off springs may adapt to different environmental conditions
- Formation of some asexual cells like spores by meiosis
- Production of off springs occurs from a mutated cell.

2. **Sexual reproduction;** is the production of offspring by the fusion of haploid male and female gametes through fertilization to form a diploid zygote, which develops into the mature organism.

Note;

Reproduction is not all about increasing numbers of members of a given species, but it may also include;

- Increasing genetic variety to enhance species adaptation to the changing environmental conditions.
- Development of resistant stages in the life cycle which are capable of withstanding periods of drought, cold or other adverse conditions.
- Formation of spores, seeds or larva which may be used to disperse the offspring and reduce intraspecific competition

COMPARISON OF ASEXUAL AND SEXUAL REPRODUCTION

Similarities; in both;

- mitosis is involved
- there is production of offspring
- there is transmission of genetic material from parents to their offspring

Differences;

Sexual reproduction	Asexual reproduction
-Involves fertilization to form diploid zygote	-No zygote formation
-Offspring show genetic variability	-Offspring are usually identical to each other and to their parents; a clone
-Population numbers increase slowly	-Population numbers increase rapidly
-May involve one or two parents	-Always involves only one parent
-It is a less rapid process	- it occurs rapidly in favourable conditions
-Offspring mature slower	-Offspring mature faster
-Occurs among all living organisms	-Occurs mainly among plants and simpler animals
Male and female gametes produced by gametogenesis	-No game formation
Meiosis occurs	No meiosis occurs

ASEXUAL REPRODUCTION

Asexual reproduction occurs in mainly seven ways; fission, budding, fragmentation; sporulation, vegetative propagation, cloning and parthenocarpy.

1. **FISSION;**

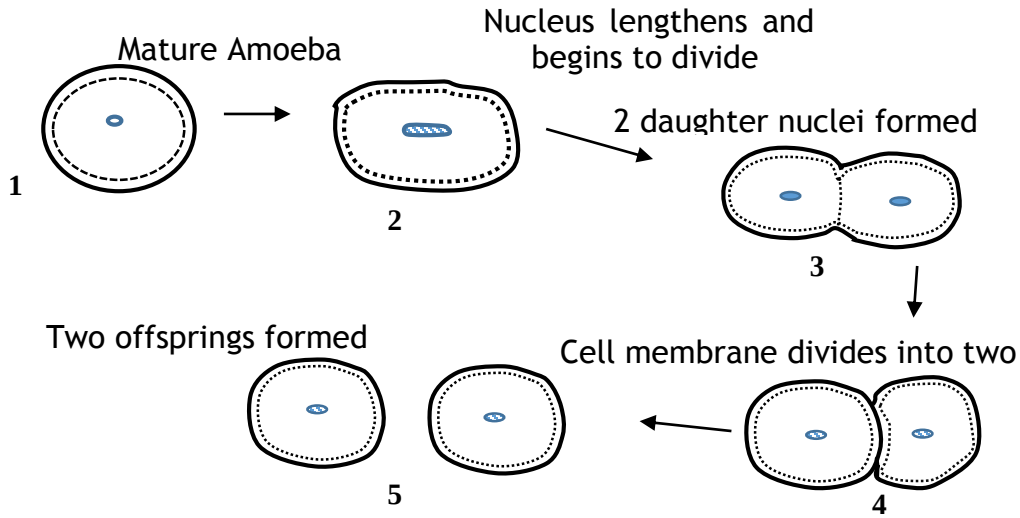
It is the division of the cell by mitosis into two or more equal sized daughter cells identical to the parent cell. It may be;

a. **Binary fission;** in this the organism or cell splits; divides into two parts which lead a separate existence; occurs in bacteria, amoeba, paramecium.

b. **Multiple fission; schizogony;** the organism splits into many parts which lead separate existence; occurs in plasmodium; a malaria parasite; immediately after infection as the parasite, when merozoites enters the liver and again as they invade the red blood cells.

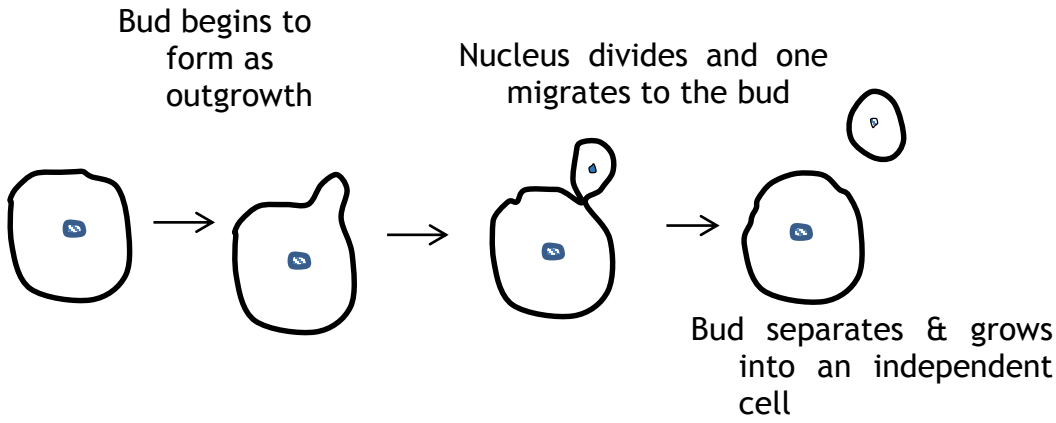
Binary fission in amoeba

The nucleoplasm replicates first followed by the cell as a whole



2. BUDDING:

- This involves the parent cell forming an outgrowth; a small bulge, which increases in size and finally drops off; detaches to become an independent organism. It occurs in flat worms e.g. *tapeworms, yeast, hydra, obelia*, and fungi.
- In yeast, budding results into two parts which are not of equal size and this makes it different from fission, in Bryophyllum and xerophytes in which buds may be completely small plants with small roots; miniature plants i.e. plantlets.



3. FRAGMENTATION:

- This is the breaking of a single organism into two or more genetically identical pieces, each of which is capable of regenerating into a new individual. It occurs in sponges, spirogyra, cnidarians, and flat worms.

4. SPORULATION; SPORE FORMATION:

- This the formation of small unicellular bodies called spores by cell divisions in organisms, which detach from the parent plant and grows into new organisms under favourable conditions. A spore is a haploid reproductive cell, usually unicellular, capable of developing into an adult without fusion with another cell.
- Spores such as those of bacteria are not reproductive but a means of surviving adverse conditions.
- Spores are small, light and easily dispersed.
- It occurs in fungi; Rhizopus, bacteria, mosses, ferns, Liverworts, algae and amoeba.

Sporulation in amoeba

- ✓ It starts when the nucleus of a single cell of amoeba divides repeatedly and each unit is enclosed in a bit of cytoplasm, but all are encased by one cell membrane.
- ✓ Some residual cytoplasm may be left which is discarded.
- ✓ The new nuclei with cytoplasm are surrounded by spore case; cyst to withstand unfavourable conditions
- ✓ The spores formed are released by bursting of the cell membrane.

5. VEGETATIVE PROPAGATION:

- This is asexual reproduction in which a differentiated part of plant other than the flower separates from to develop into a new individual plant. Parts of the plant such as root, stem, or leaf specialized to give rise to new individuals are called propagules and organs of vegetative propagation may also act as

perennating organs; organs that store food used in formation of a new offspring. The specialized structures include; bulbs, corns and rhizomes, stolons and tubers.

Vegetative organs and perennating organs

- ✓ Organs of vegetative propagation are the parts of the flowering plant other than the flower, such as root, stem, or leaf specialized for developing into new individuals when detached. Examples: rhizomes e.g. ginger, couch grass, canna lily and spear grass; corms e.g. coco-yam; luganda 'mayuni', crocus and gladiolus; stem tubers e.g. Irish potato, yams; root tubers e.g. sweet potato, dahlia; bulbs e.g. onion, garlic, tulip, swollen taproots e.g. carrot, turnip; stolons e.g. blackberry; runners e.g. straw berry, oxalis
- ✓ Perennating organs are plant parts specialised for storing food used to develop into new individuals, enabling plants bearing them to survive adverse environmental conditions like drought. Examples: rhizomes, corms, stem and root tubers, bulbs, swollen tap roots.
- ✓ During unfavourable conditions, the plant remains dormant but when conditions normalize, starch earlier stored is hydrolysed to sugar and translocated to the young buds, enabling early growth, sprouting, and photosynthesis when there is little competition for nutrients from other species.

Note;

i. All perennating organs are vegetative organs however not all vegetative organs are perennating.

ii. Root tubers and swollen taproots must bear a small part of old stem if they are to act as organs of vegetative propagation. The swollen root together with buds at the base of old stem form organs of vegetative propagation and perennation.

Vegetative propagation maybe natural or artificial depending on how it occurs; by self or induction.

NATURAL VEGETATIVE PROPAGATION

- ✓ It involves the use of the plant parts which are naturally capable of developing into new independent individuals.

Such parts include:

a. Modified stems like; rhizomes, corms, stem tubers, suckers, stolons, bulbs and runners
b. Modified leaves like: leaves of Bryophyllum
c. Modified roots like root tubers

Such reproductive parts have two adaptations; they have stored food for the nourishment of the new individual and they have buds capable of developing into new individuals

i. Rhizomes;

- These horizontally growing underground stems e.g. in ginger, canna Lilly, couch grass
- Has nodes; points where buds are located, the buds develop into new plants, has adventitious roots which absorb water for the new plant and is swollen with stored food and water to be used by the developing plant
- Examples of plants; iris, couch grass, canna and Solomon's seal

ii. Corms;

- This is a thick vertically growing underground stem swollen with stored food for use by the new plant has adventitious roots which absorb water for the

new plant and has nodes where buds are located, the water activates enzymes in the buds to use the stored food for development.

- Examples of plants; yams, crocus, montbretia, gladiolus, cyclamen.

iii. **Stem tuber**; this is also a swollen underground stem e.g. Irish potato. Has buds; eyes that develop into new plants and has food reserves Develops adventitious roots.

iv. **Suckers**; this forms as a lateral branch from the base of an underground stem of a plant like banana and pineapple. Has lateral bud and adventitious roots to develop into a new plant; when still developing, sucker obtains food from the mother plant.

v. **Stolon**; A long horizontal stem that grows under the surface of the soil Propagates by producing roots and shoots at the nodes. Examples oxalis, blackberry, etc.

vi. **Runner**; A slender stem that grows horizontally on the soil surface. Adventitious roots develop at the nodes. Has buds from which develop new aerial shoots, the new plant derives food from the old plant until it's able to carry out its own photosynthesis

vii. Bulbs; these are modified shoots for example in onions and garlic. A bulb acts as an organ of perennation as well as vegetative propagation. It has fleshy storage leaves with a short stem surrounded by brown scaly leaf remains of the previous year. Bulbs contain one or more buds which develop into new bulbs at the end of the growing season their roots are called adventitious i.e. they originate from their stem with no tap root.

viii. Leaves of brophyllum; Succulent leaf and contains food and water, Have buds at the notches. The buds develop into new plants, Develops adventitious roots at the notches for absorption of water from the soil

ARTIFICIAL VEGETATION

This is a mode of reproduction where man is involved in the propagation process. It is done in several ways, which include, budding, grafting, layering, cuttings, marcotting etc.

Budding; this is the process where a bud is detached from a plant and grown in suitable conditions into a new plant.

Cutting; Part of the stem, having at least a node with a bud is cut. Adventitious roots develop at the node and the bud develops into a new plant. E.g. cassava and sugarcane.

Grafting; this involves inserting a bud or a shoot onto another of the same species or closely related species. The root part of the graft is called a **stock** and it should have well developed root system. The part grafted onto the stock is called **scion** and it should have a dormant bud.

Layering; this is where a branch of a plant is bent to touch the ground. It thus involves pegging down of stem of runners e.g. strawberry into the soil to induce development of adventitious roots and after which the new daughter plants are detached from the parent plants by cutting after which it starts to grow as a separate self-supporting plant

Marcotting; the outer back of a branch at a point near the node is removed to cut off the passage of food from the leaves down to the stem. This point is wrapped with well-manured soil in a porous bag. Food then accumulates at the bud point causing rapid development of the bud and the growth of adventitious roots at the node. When fully developed, the shoot is cut off and planted into the soil.

Advantages of natural vegetative propagation

- It is a rapid means of reproduction and spread
- Offspring are genetically identical, preserving good strains.
- Perennating organs enable survival in adverse conditions
- Their dispersal and spread is independent of external agents hence the process is faster.
- Plants are less affected by environmental factors
- Females pass all of their genes to the offspring

Disadvantages of natural vegetative propagation

- Leads to overcrowding and competition for nutrients, unless separated artificially.
- New varieties cannot be produced, except by mutation resulting into reduced vigour and strength
- Diseases typical of a species are rapidly transmitted and can decimate a crop

General advantages of vegetative propagation

- Good genetic characters in plants are maintained.
- Plants without viable seeds can be grown by this method
- Does not involve two sexes since fertilization does not occur.
- No agents such as those for pollination are required.
- Favours high chances of reproduction
- It favours growth of off springs due to suitable conditions are created by parent.
- Off springs mature faster since there is a steady supply of food from parent.
- Shortens then life cycle of plants since off springs are produced at more advanced stages of development
- Requires no special organs to occur

General disadvantages of vegetative propagation

- If a plant has undesired characters, they are passed from parent to off springs and easily maintained.
- Creates high chances of overcrowding which leads to competition among individuals for food, light, space
- There is lack of variation in off springs which brings no hybrid vigour among them.
- There are high chances of disease transmission from parents to off springs.
- The off springs produced may not have resistance in the changing environment
- The organs of propagation cannot be stored for a long time in case of bad conditions like prolonged drought.

6. CLONING

✓ A group of genetically identical offsprings produced by asexual reproduction is a clone. The nucleus of every cell of an individual contains all the genetic information needed to develop the entire organism. It is therefore possible under suitable conditions to produce the whole organism from a single cell.

✓ If a cell divides mitotically it will produce a clone, if each cell of the clone is separated and allowed to develop into a complete organism, a genetically identical offspring is obtained.

✓ This is used in micro propagation during which cells are cultured to produce useful substance. Production of enzymes extracellularly, antibiotics, etc.

*culturing is the growth of an organism (s) in a controlled environment.

***Micheal kent section 14.8 fig 3**

7. PARTHENOGENESIS

- It is the development of an embryo from an unfertilized egg or one in which the male and female nuclei fail to unite following fertilization. Or
- This is the development of gametes into new organisms in absence of fertilization
- The parent is always diploid and gametes produced by mitosis or meiosis.

Types of parthenogenesis

a. Diploid parthenogenesis / mitotic parthenogenesis:

This is the development of embryo from unfertilized diploid eggs that were formed by mitosis instead of meiosis, resulting into diploid offspring, which are clones of the parent. It is a form used by organisms to rapidly build up numbers when conditions are favourable.

Diploid parthenogenesis in aphids

- ✓ In Aphids, it starts with the development of fertilized eggs. These hatch into diploid wingless females. The eggs in wingless females are formed by mitosis, diploid gametes are formed. The diploid gametes begin to develop into young aphids without fertilization inside their mothers.
- ✓ The parthenogenetic female aphids are laid when well developed; viviparity. The offsprings feed, grow and reproduce parthenogenetically for many generations especially in summer.
- ✓ In autumn, wingless diploid parthenogenetic female aphids produce diploid parthenogenetic males. The males and female aphids begin to produce their gametes by meiosis to form haploid gametes.
- ✓ Sexual reproduction occurs between them resulting into fertilization of haploid gametes to form diploid eggs which are laid in winter. They can lie dormant in soil or on the host plant until the following spring. The eggs hatch into diploid female aphid in spring, when the cycle begins again. Parthenogenesis in aphids is facultative.
- ✓ In plants, Apomixis occurs which is the formation of plant embryo from an unfertilized haploid egg cell or from a diploid embryo sac mother cell or from a diploid cell in the ovule without fertilization. It occurs in potatoes and citruses.
- ✓ **Parthenocarpy** is fruit development without fertilization, usually induced by auxins e.g. in apples

b. Haploid parthenogenesis / meiotic parthenogenesis:

- This is the development of embryo from unfertilized haploid eggs that are formed by meiosis and may develop directly into haploid offspring. It occurs in honeybees, wasps, ants, whiptail lizards.
- In honeybees, the queen bee can either fertilise the eggs as she lays them or allows them to pass unfertilized.
- Fertilized eggs become diploid females; females, and unfertilized eggs develop to become fertile haploid males; drones.
- If these females are fed honey and pollen they develop into workers. If they are fed a special food called royal jelly produced by workers, a queen results.

Advantages of parthenocarpy

- It avoids the problem in some animals of bringing together males and females at the right moment for successful fertilization.
- Produces a large number of organisms in a short time. E.g. in whiptail lizards all the parthenogenetic offspring are females, which all produce eggs, yet only half of the bisexual population are egg laying females.

- It eliminates in each generation all lethal genes that thrive in homozygous state

Disadvantages of parthenocarpy

- During sudden environmental changes, parthenogenetic species have limited capacity to shift gene combinations to adapt to the new conditions

Advantages of sexual reproduction

- It is reliable because it is less likely to be affected by adverse environmental factors like for the case of seeds.
- It leads to genetic consistence since there is no mixing of genes during reproduction.
- It results into early maturity because the organisms produced have enough food reserve from the parent.
- It is self-sufficient because it does not rely on external processes like pollination, fertilization and dispersal.
- It does not result in indiscriminate and wide spread distribution like in the case of seeds, which leads to wastage.
- It does not require formation of sex organs.
- It is a faster means of reproduction since only one parent is involved.

Disadvantages of asexual reproduction

- It leads to maintenance of bad characters.
- It does not introduce variations in the offspring since there is no gene mixing.
- It easily results into competition between offspring due to overcrowding.
- It gradually results into reduction of the strength and vigour of the succeeding generations.
- There is a high chance of disease transmission from parent to offspring.

SEXUAL REPRODUCTION

Sexual reproduction is the production of offspring by the fusion of haploid male and female gametes during fertilization to form a diploid zygote, which develops into the mature organism.

Advantages of sexual reproduction

- Brings about genetic variability in a population by recombining parental characteristics, enabling a species to adapt to the changing environmental conditions
- During the life cycle of the organism, resistant stages develop enabling survival of adverse conditions
- The formation of spores, seeds or larvae, which may be used to disperse offspring and so, reduce intraspecific competition.
- It leads to increased numbers of a population

Disadvantages

- May result into lethal combination of genes
- In some animals, it is difficult to bringing together males and females at the right moment for successful fertilization.
- It relies so much on external agents hence reducing chances of occurrence
- It is a slower method of reproduction.
- There is wastage in production of males, many of which fail to reproduce & thus consume resources that could be applied in the production of females
- Females only pass half of the genes to the offspring because the genome is halved at meiosis

Features of sexual reproduction;

- It involves production of gametes by two separate parents, a process called gametogenesis. Isogametes are identical though dissimilar genetically, Anisogametes; heterogametes differ slightly in size.
- It involves fertilization; Syngamy , the union of male and female gametes
- Bacteria reproduce by conjugation.

Forms of sexual reproduction;

REPRODUCTION IN BACTERIA

- ✓ This involves the transfer of DNA from donor cells to the recipient cell. The process involves breakage and re-union of DNA parts by certain enzymes. The DNA formed contains certain genes from both parent cells and is called recombinant DNA.
- ✓ Sexual reproduction in bacteria is by transformation, transduction and conjugation.

a. Transformation

- ✓ The donor and recipient do not come into contact. A short piece of DNA is released by the donor and actively taken up by the recipient. It replaces a similar but not identical piece of DNA.
- ✓ The two strands of recipient DNA separate, the piece of recipient DNA which has been replaced is later broken down, as is the second donor DNA strand. A hybrid DNA is formed and replication of the hybrid DNA takes pace.

b. Transduction

- ✓ A small double-stranded piece of DNA is transferred from a donor into a recipient by a bacteriophage. Some viruses have the ability to integrate their DNA with bacterial DNA. This replicates alongside with the host's DNA and passed from the bacterial generation to the next. Occasionally it becomes active and codes for the production of the new viruses.

c. Conjugation

- ✓ During this process, the two bacterial cells come into contact and a conjugation tube is formed between them. Through this tube, the genetic materials pass from the donor to the recipient. The donor is the male while the recipient is the female. The male contains a sex factor which is absent in the female. The sex factor is also called F-factor; fertility factor.
- ✓ During conjugation, the main chromosomes and plasmids are transferred from the donor cell tube; bridge. The plasmids carry the sex factor and the factors determining resistance to drugs. The plasmid and main chromosome exist in the cell as rings.

NOTE: refer to classification for alteration of generation

- It is the occurrence within the life cycle of an organism two or more distinct forms; generations, a haploid gametophyte and diploid sporophyte generations, which differ from each other in appearance, method of reproduction and genetic constitution.

Highlights of alteration of generation;

i. In bryophytes; the gametophyte is the dominant phase, their body is haploid, their body is divided into thallus and rhizoids, and they produce homospores.

ii. In pteridophyte, the sporophyte is the dominant phase, their body is diploid, have roots, stems and leaves, have vascular bundles and they produce spores which maybe homo or heterospores.

iii. In gymnosperms, the sporophyte is the dominant phase, the body is diploid, and have roots, stems, leaves and vascular bundles, produce heterospores, have seeds.
iv. In angiosperms, the sporophyte is the dominant phase, the plant body is diploid, have roots, stems, leaves, vascular bundles, produce heterospores, have seeds with testa and they have flowers

SEXUAL REPRODUCTION IN FLOWERING PLANTS

- The flower is the reproductive organ in flowering plants.
- The male gametes are found in the pollen grains produced by the anther while the female gametes are found in the ovules inside the ovary. The two gametes come together with the aid of pollination.

POLLINATION

Pollination is the transfer of pollen grains from the anthers; stamen to the stigma of the flower. It has two types;

a. **Self-pollination**; pollen from the anthers is transferred to the stigma of the flower on the same plant.
b. **Cross-pollination**; pollen from the anthers is transferred to the stigma of another flower on a different plant but of the same species.

Based on agents, cross pollination is categorized as follows:

i. Anemophily; wind pollination. Anemophilous flowers exhibit many features Entomophily; insect pollination;
ii. Hydrophily; water pollination; in hydrophilous flowers, pollen grains have same specific gravity as that of water to enable floating in water at any depth.
iii. Ornithophily; bird pollination; Ornithophilous flowers are tubular shaped, brightly coloured, with plenty of nectar, and generally odourless.

Characteristics of insect pollinated flowers

- They are large and conspicuous and if they are small, they are united to form large inflorescence.
- The petals are usually brightly coloured to attract pollinators
- They have nector and scent. They are usually scented to attract insects and mostly contain nector which is food for insects.
- They have shapes which encourage visiting insects to pick up pollen or brush it on the stigma. The stamen produce small quantities of sticky pollen grains which can adhere to the bodies of visiting insects.
- The anthers are small and firmly attached to the filaments and held in the best position to come in contact with the visiting insects
- The stigma are flat and lobe shaped and have a sticky surface to which the pollen can adhere of firmly attached

Characteristics of wind pollinated flowers

- They are usually small and inconspicuous but are borne in large inflorescences
- Usually are not brightly coloured
- They are never scented and have nector as these are mostly important in attracting insects
- They usually do not conform to any particular shapes but are usually small and exposed
- Stamens produce large quantities of small Powderly and smooth pollen

- Anthers are large and loosely attached to the long filaments. They can swing out easily and this helps in the dispersal of pollen grains.
- Stigmas are large and loosely attached to the long style. The feathery structure of the stigma provides a large surface area in which the pollen grains are flooding in the air may be trapped

Comparison of wind and insect pollinated flowers

Wind pollinated flowers	Insect pollinated flowers
Inconspicuous flowers, small and reduced in size	Conspicuous flowers, large with brightly coloured petals.
Petals may be absent or dull coloured if present	Petals present and often held in inflorescence if they are tiny and inconspicuous
No nectar and not scented	Produce nectar and or scent to attract insects.
Pollen produced in large quantity, light, smooth, small and may have wing-like extensions.	Pollen less in quantity, sticky, relatively heavy, and large pollen is produced.
Anthers are large	Anthers are small
-Stamens hang outside the flower to release pollen	-Stamens are confined within the flower.
stigmas are large, feathery or branched to trap pollen	Stigma relatively small, glandular, and sticky.
Stigmas hang outside the flower.	Stigma lies inside the corolla.
Flowers often unisexual, having male and female reproductive parts on separate flowers.	Flowers bisexual, enclosing reproductive organs e.g. stamens and carpels

Adaptation of plants to self-pollination

Physiological

- Stamens and carpels mature at the same time
- Hermaphrodite flowers may not open petals
- Hermaphrodite flowers may remain under ground
- Pollen is released onto the stigma by matured anthers before the petal opens.
- Pollen is compatible with the tissues of style, thus allowing for their germination.

Morphological

- Flowers are reduced and inconspicuous.
- Stamens are situated above the stigma or the anther is close to the stigma.
- Stigma often coiled to touch ripe anthers
- Style and filaments coil on one another
- Flowers failing to open e.g. in *commelina*

Adaptations of flowers to cross-pollination:

Physiological

- ✓ Stamens ripen before carpel; Protandry e.g. in salvia, deadnettle and dandelion or carpel ripens earlier; protogyny
- ✓ Self-incompatibility due to chemicals prevents germinating of pollen on the stigma of the same flower; self-sterility

- ✓ It is genetically controlled by self-incompatibility genes e.g. in pears pollen only becomes functional if the stigma surface on which it is has a different genetic composition.

Morphological

- ✓ Dioecious flowers have either stamens or pistil
- ✓ Stamens situated below the stigma.
- ✓ Hermaphrodite (bisexual) flower containing both sex organs.
- ✓ Production of nectar to attract insects.
- ✓ Hanging of stamens or whole flower downwards so that falling pollen drops clear of that plant.

Mechanisms which limit self-pollination in plants

- ✓ Dioeciousness, all flowers on the plant being either male or female e.g. pawpaw
- ✓ Monoeciousness, having separate male and female flowers on the same hermaphrodite plant.
- ✓ Heterostyly (differing style length), structure of the flower e.g. when a stigma is protected from coming into contact with its own pollen or stigma being taller than the anthers.
- ✓ Dichogamy; stamens ripening before carpel; protandry or carpel ripening earlier; protogyny.
- ✓ Self-incompatibility due to chemicals prevents germinating of pollen on the stigma of the same flower

DIFFERENT CONDITIONS THAT ARISE IN FLOWERING PLANTS

1. **Monoecious species:** are species in which individual plants bear separate male and female flowers e.g. maize, oak, sycamore, coconut, date palms, castor oil, pumpkin. This clearly limits the possibility of self-pollination
2. **Dioecious species:**

- These are species in which individual plants bear either only male or only female flowers, so that there are different sexes of the plant e.g., pawpaw and asparagus. Completely Dioecious plants are rare, although it is usual for a plant to be predominantly although not completely of one sex.
- Male Dioecious plants are usually found in dry soils whereas female Dioecious plants in moist soil because Pollen production does not require much water, while seed formation and fruit ripening require much water.
- Dioecious plants are usually wind pollinated because it may not be possible to have animal pollinators bring in pollen from the same plant species, which would reduce chances of fertilization; it is much easier for wind to bring in pollen from same plant species to increase chances of fertilization.
- Dioecious plants are rare because, half of the individuals in dioecious plants do not produce seeds, whereas all individuals in monoecious plants bear seeds and a lot of pollen is wasted in dioecious plants because the male and female plants are not necessarily together.

3. **Polygamous species:** are species in which individual plants bear three types of flowers: bisexual, male and female e.g. mango
4. **Dichogamy:** failure of the stamens and pistil to ripen at the same time in a hermaphrodite flower.
5. **Protandry:** it is the ripening of the stamens before the carpel in a hermaphrodite flower; bisexual e.g. in sunflower, white deadnettle, salvia, and dandelion; mainly insect pollinated flowers.

6. **Protogyny:** ripening of carpels earlier than the stamens e.g. in arum lilies, and wild varieties of: wheat, barley, and oats. Mainly wind pollinated flowers.

NOTE: protandrous flowers are more common than protogynous ones.

7. **Heterostyly:** it is a condition in which the style length is different in various flowers of an individual plant, so that pollen from a different flower only can bring about effective pollination. E.g. primrose, has two types of flowers that differ in length of style, with the pin-eyed flower having stamens situated below the stigma while in the thrum-eyed flower they are situated above.

SELF STERILITY/ SELF-INCOMPATIBILITY

- ✓ This is a condition, which results when the pollen and stigma recognize each other as being genetically related and pollen tube growth is either blocked or retarded. E.g. in clover and pears.
- ✓ Self-incompatibility is controlled by the *S*; self-incompatibility locus, which bears many alleles e.g. S_1, S_2, S_3, that regulate recognition responses between the pollen and stigma. It is categorized as;
- ✓ Gametophytic self-incompatibility, if any of the *S* alleles in the stigma matches with any pollen *S* allele, then the growth of that particular pollen tube with the allele which matches stops before it reaches the embryo sac, but other pollen tubes with alleles that don't match continue growing. Gametophytic self-incompatibility is determined by the haploid pollen genotype e.g. in petunias.
- ✓ Sporophytic self-incompatibility, if any allele in the stigma matches with either of the pollen parent *S* alleles, then not even a single haploid pollen germinates. Sporophytic self-incompatibility recognizes the genotype of the diploid pollen parent, not just the haploid pollen genotype e.g. in broccoli.

NOTE:

i. Self-pollination; promotes homozygosity; transmission of genotype in the population, resulting into decreased fertility, reduced resistance to disease, thereby reducing evolutionary potential of the species in the long run.

ii. Cross pollination; promotes genetic diversity, resulting into hybrid vigour, causing increased resistance to diseases, high yield, and earlier maturity, thereby providing greater evolutionary potential.

FLORAL STRUCTURE

A flower has essential and non-essential parts;

Essential organs are those which directly take part in reproduction i.e. androecium and gynoecium**.**

Accessory/non-essential organs; are those which assist but do not directly take part in reproduction i.e. corolla and calyx.

a. Androecium: It is the collective name for the male sex organs of a flower, the stamens, each of which consists of the filament, a stalk supporting the anther head at the tip, and the connective, containing vascular strand. Various terms are used to describe stamens.

- Gynandrous; stamens attached to pistils
- Versatile; the filament is attached to the anther at the middle, so that the anther is loose and can oscillate *e.g. maize and most grasses*
- Adnate; anthers placed on filament along lengthwise direction of filament
  Basifixed; filament attached to the base of the anther e.g. radish

- Dorsifixed; the tip of the filament is attached to the back of the anther; about the middle region e.g. passion flower.
- Staminode; infertile / sterile stamens
- Epipetalous; stamens attached on corolla
- Syngeneceous; a condition in which filaments free, but all anthers are fused
- Synandrous; stamens are united completely by both filaments and anthers *e.g. cucumber*
- Adelphous; anthers free, filaments united
- Monoadelphous; anthers free, filaments united but in just one bundle *e.g. hibiscus*.
- Diadelphous; anthers free, filaments fused to form two bundles *e.g. sweet pea, bean* Polyadelphous; anthers free, filaments united to form many bundles.

b. Gynoecium;

- Stigma may have one or more lobes, hairy, feathery, sticky, rough etc.
- Internally, ovary may be monocarpellary; single carpel), bicarpellary; two carpels, pentacarpellary; five carpels), etc. depending on the number of mainly chambers observed when cut or stigma lobes.
- **Placentation;** pattern of ovule arrangement may be **marginal** e.g. in beans, **parietal** e.g. in pawpaw, passion fruits and some cucumber, axile e.g. in oranges and lemons, **free central/central** e.g. in green pepper, **basal**; at base e.g. in mango, **Apical**; at apex e.g. avocado

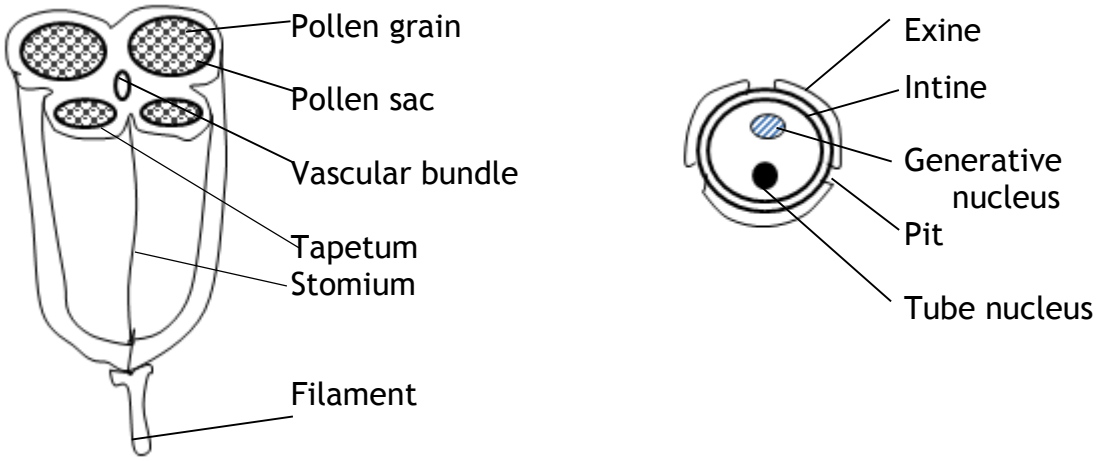
c. Symmetry;

Some flowers exhibit radial symmetry; **actinomorphic** such as buttercup whereas the flowers of others such as bean are bilaterally symmetrical; **zygomorphic**.

PRODUCTION OF GAMETES IN FLOWERING PLANTS

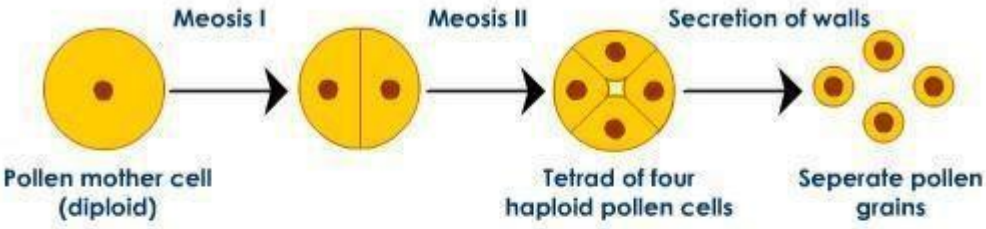
- ✓ The inner layer of cells in the wall of the pollen sac known as tapetum provides nutrients for the developing pollen grains.
- ✓ The pollen grains are released by the rupture of the stomium layer surrounding the tapetum which are lines of weakness.
- ✓ The pollen grain wall has thin areas through which a pollen tube may grow at a later stage.

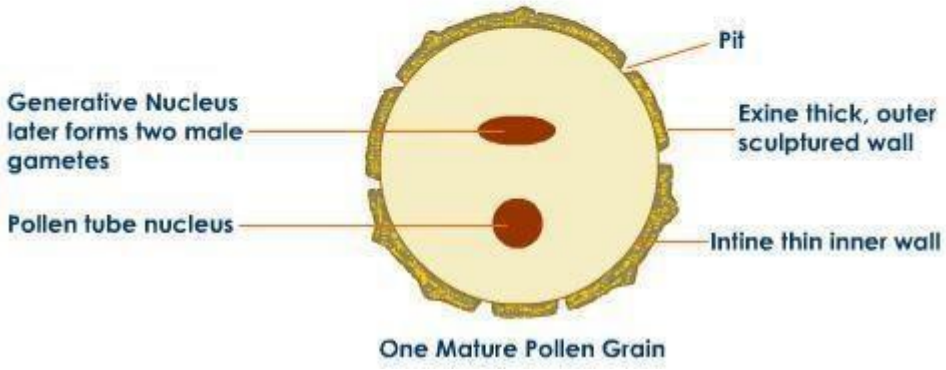
Illustration of the pollen grain



a. Production of male gametes/ pollen grains:

- The anther contains four pollen sacs; microsporangium, which contain diploid pollen mother cells.
- Each pollen mother cell divides meiotically to give four haploid pollen grains; a tetrad.
- The cells round off and are called microspores.
- The single haploid nucleus divides by mitosis to give the tube nucleus and generative nucleus.
- The cell thickens; develops a hard resistant, sculptured outer wall; the exine and an inner cellulose wall; the intine.
- When the pollen grains mature, the walls between each pair of pollen sacs breakdown and the anther lobe ruptures longitudinally along the line of weakness to release pollen grains.



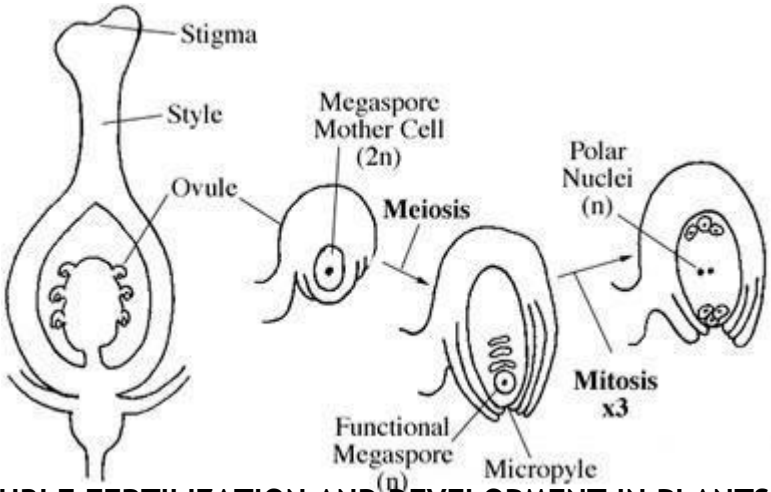


b. Formation of female gametes; ovum

- Each ovary develops one or more ovules, which contains a mass of cells, the nucellus, which is carried on a short stalk. The nucellus completely surrounded by two integuments, except at a small pore called **micropyle.**
- One cell of the nucellus develops into a diploid **embryo sac mother cell**.
- The embryo sac mother cell divides meiotically to give four haploid megaspore cells. The three cells nearest the micropyle degenerate while the remaining one enlarges to form the embryo sac. In terms of development, the embryo sac is the equivalent to the pollen grain of the male.
- The embryo sac nucleus divides mitotically to form two nuclei, which migrate to opposite poles, from where each undergoes two mitotic divisions to form four haploid nuclei at each pole.
- One nucleus from either end of the sac moves to the centre to form the polar nuclei.
- The remaining six nuclei each develops cytoplasm around it and gets enclosed in a thin cell wall, leaving two groups of three cells at each pole.
- Of the three cells at the micropyle end, one becomes the female gamete; egg nucleus.

- The remaining two nuclei near the micropyle, the **synergids** disintegrate while the three nuclei at the opposite end to the micropyle become the **antipodal cells** which play role further role in the process.

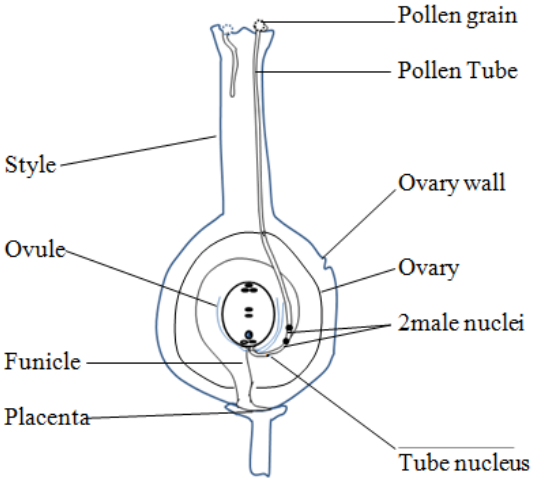
Illustration of the female gametes



DOUBLE FERTILIZATION AND DEVELOPMENT IN PLANTS

Double fertilization: is a unique process occurring only in flowering plants in which one male nucleus fuses with the functional egg nucleus to form a diploid zygote and another male nucleus fuses with the diploid secondary nucleus to form a triploid primary endosperm nucleus simultaneously.

- ✓ In angiosperms, the female gamete is protected within the carpel and the male gamete can only reach it via the pollen tube.
- ✓ When a ripe pollen grain lands on the right stigma, it sticks on the surface of the stigma as a result of the stigma secreting a sticky substance.
- ✓ The pollen absorbs water and the outer wall; exine breaks open and the inner wall; intine germinates to form a pollen tube that grows into the stigma down the style to the ovary. The epidermal cells of the stigma secrete sucrose and other nutrients needed for germination.
- ✓ The tube nucleus is positioned at the tip of the growing pollen tube controlling growth. The generative nucleus divides mitotically into a pair of male gamete nuclei which occupy a position just behind the tube nucleus. 2 male nuclei; 2 sperms formed by mitosis from the generative nucleus follow closely behind.
- ✓ Chemical substances in the style and embryo sac enable the unidirectional rapid growth of the pollen tube towards the ovary.

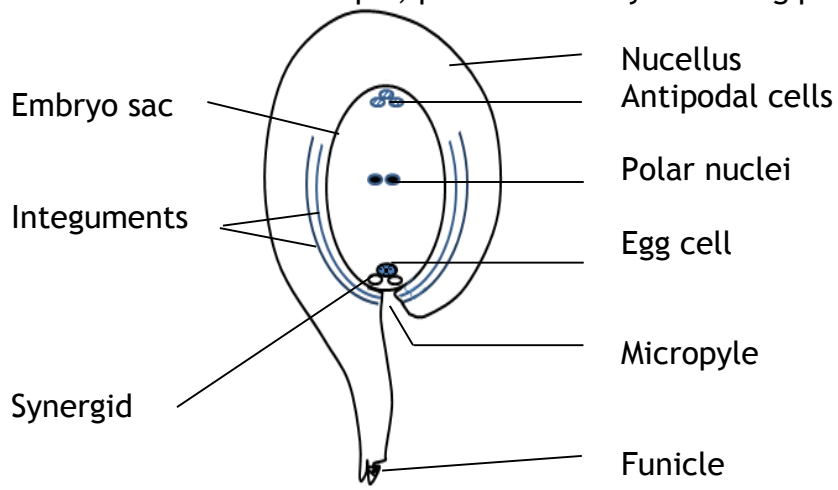


- ✓ After reaching the ovary, the pollen tube grows towards the ovule and usually enters through the micropyle, chalaza or integuments.

Note; many pollen tubes grow down the style simultaneously, and where an ovary has many ovules, a separate pollen tube penetrates each.

- ✓ The pollen tube then penetrates the embryo sac, bursts open and the tube nucleus degenerates, and the two male nuclei enter
- ✓ The first fertilization occurs when one male nucleus fuses with the egg cell to form a **diploid zygote**, while the second fertilization occurs when another male nucleus fuses with the two polar nuclei; diploid

secondary nucleus to form a **triploid primary endosperm** nucleus. This double fertilization is unique; peculiar to only flowering plants.



***Understanding biology page 225 fig 12.9**
*** Micheal kent section 14.4 fig 1**
***Functional approach page 396 fig. 24.19**

EVENTS AFTER FERTILIZATION

- ✓ The diploid zygote undergoes rapid mitotic divisions, growing and developing into the embryo. The embryo then differentiates into radical; young root, plumule; young shoot and cotyledon; seed leaves. The embryo is attached by a row of cells called suspensor to the expanding embryo sac, the suspensor provides nutrients.
- ✓ The triploid primary endosperm nucleus divides mitotically to become the endosperm; mass of cells which surrounds the developing embryo and provides it with nutrients. An endosperm is a semi-solid food storage tissue.
- ✓ The embryo sac expands; the existing nucleus becomes crushed so that the whole region within the integuments is filled with the embryo and endosperm.
- ✓ The ovule develops into a seed. The integuments become the seed coats and the outer integument becomes the seed testa.
- ✓ Water is removed from the ovule to fully become a seed which can withstand adverse environment conditions. The ovary develops into a fruit and the ovary walls become the pericarp; fruit walls.

Note;

- In some species such as maize, the endosperm remains whereas in others such as peas, it is quickly absorbed and stored in the cotyledon.
- The most common food stored in seeds is the carbohydrate. This is usually in the form of starch but some seeds such as maize and peas, store quantities of sugar.
- Many young seeds store sugar but this changes to starch as they mature and lipids are often stored in the cotyledon.

Thus in flowering plants, mostly propagation is by seeds;

Advantages of propagation by seeds

- Enable plants to be better adapted for land environment since water is less required for sexual reproduction
- Embryo is protected within the seed
- There is food reserve for embryo growth in the cotyledon or endosperm
- Seeds are easy to store
- Seeds are easy to disperse and transport

- Allows for mixing of genes which increases the hybrid vigour
- There is increased resistance to diseases
- Plants mature early
- There is tolerance to unfavourable conditions

Disadvantages of propagation by seed

- Seeds are easily destroyed by pests
- Seeds have limited food reserves
- Requires selection of suitable seeds
- Needs technical knowing
- Initial inputs are expensive
- Dispersal may not be easy because of the large size of seeds usually

Disadvantages of reproduction by seeds

- Seed formation involves meiosis which increases the chances of some desired traits being lost as variation will always occur.
- Since there is wastage of seeds due to limited chances of survival, the parent sporophyte must invest large amounts of materials and energy in seed production to ensure success.
- Seeds show dormancy and thus may fail to germinate when conditions that can break dormancy are unavailable.
- In dioecious plants, seed production requires two parents making the process more chance dependent.

FRUIT AND SEED DISPERSAL

This is the scattering of seeds and fruits from their parent; sporophyte.

Significance of fruit and seed dispersal

- Prevents overcrowding among members of the same species and thus reduces intraspecific competition among offsprings and parents for limited resources of light, water and air.
- It ensures colonization of new habitats thus increasing the chances of survival of the species.
- It ensures the species survives even under drastic climatic changes in one area such as drought, floods, fire among others

Agents/ mechanisms of dispersal

a. Wind dispersal;

This is scattering of fruits or seeds by wind movements; for this to occur, the seeds or fruits have the following characteristics;

- Possession of a pappus; white hair formed from sepals after fertilization. This provides a large surface area to operate a parachute such as in the cypsela *tridax*.
- They are usually small and light. This reduces their density and can easily float in air and thus easily blown by wind.
- They may have wing like structures such as samara fruit, seeds of *jacaranda* and Dutchman's pipe.
- They possess thread floss on seeds for easy falling off such as in cotton

b. water dispersal;

This is a rare form of dispersal since seeds can easily lose their ability to germinate if they stay in water for long.

Adaptations of seeds or fruits for water dispersal;

- Possession of air spaces in fruits and seeds to promote floating such as certain water lily has a spongy outgrowth from its seeds.
- Possession of fibrous hard mesocarp containing air spaces for floating such as in the coconuts.

c. Animal dispersal;

- The fruits are succulent but with indigestible cells.
- Possession of hooks e.g the *Bidens pilosa* which attaches the fruits onto the fur, skin or clothes of passing animals.
- Possession of sticky hairs on the fruit coat e.g *desmodium* which sticks on the animal's body.
- Some have attachment of swollen and succulent receptacles which are eaten like fruits e.g cashew nuts and apples

d. **Self-dispersal; explosive mechanism**.

- This is common in dry dehiscent fruits. These dry and split open along their lines of weaknesses to eject seeds to some distance e.g in pods of legumes and capsule of cotton.

ADAPATATIONS OF ANGIOSPERMS TO SURVIVAL ON LAND

- ❖ Presence of double fertilization resulting in the embryo and the endosperm. The endosperm is contained within the seed and provides nourishment for the growing embryo.
- ❖ Development of small flowers for insect pollinated species.
- ❖ Development of an open flower with feathery stigma and large pollen grains in wind pollinated species.
- ❖ Development of the fruit from the ovary wall. The fruits are edible to other animals and in this way dispersal of seeds are made possible.
- ❖ An alternation of generation where the sporophytes are the most dominant generation.
- ❖ Vegetative means of reproduction to escape adverse environmental conditions.
- ❖ Development of stamens which is composed of anther heads that produce large quantities of pollen grains leading to the successful systems of pollination.
- ❖ Reduction of the female gametophyte into embryo sac which is enclosed within the embryo for protection.
- ❖ Reduction of the pollen grain which enables the male gametes to be carried to the embryo sac by growth of the pollen tube, this avoids male gametes from being motile that would require water to effect fertilization yet water is scarce in terrestrial life.
- ❖ Self-fertilization where the gametes would not meet easily.
- ❖ Spore development in gymnosperms and fungi, mosses and ferns that are light for wind dispersal.
- ❖ Development of seed dispersal mechanisms.
- ❖ Development of ovary, style and stigma. Stigma provides sticky surface on which pollen grains lands and nourishes the growth of the pollen tube through the style into the embryo sac

SEXUAL REPRODUCTION IN ANIMALS

Terms associated with reproductive patterns:

1. **Oviparity;** animals deposit fertilized eggs in the external environment for development e.g. in all birds some reptiles and some fish.
2. **Ovoviviparity;** animals retain eggs in the mother's body to complete development, but embryos still obtain all of their nourishment from the egg yolk. The young are hatched from the mother's body when fully developed. E.g. in many reptiles and some fish
3. **Viviparity;** eggs develop to advanced stage in the mother's body and the embryo obtains nourishment directly from the mother's blood, rather than just from the egg yolk. E.g. in mammals
4. **Internal fertilization;** is where fusion of male and female gametes occurs inside the body of the female animal.
5. **External fertilization;** is where fusion of male and female gametes occurs outside the body of the female animal.
6. **Isolecithal eggs;** eggs with very little yolk that is evenly distributed in the egg. E.g. human eggs.
7. **Mesolecithal eggs**; eggs with moderate amount of yolk concentrated in the vegetal pole. E.g. in amphibians.
8. **Telolecithal eggs**; eggs contain an abundance of yolk that is densely concentrated at the vegetal pole of the egg. E.g.in birds, reptiles, most fishes.
9. **Gametogenesis;** the series of transformations that result into the formation of mature gametes.
10. **Spermatogenesis;** the series of transformations that result into the formation of male gametes.
11. **Oogenesis:** the series of transformations that result into the formation of female gametes.
12. **Menopause;** a period when ovulation and menstruation cease in human females.
13. **Primary sex organs:** organs, which produce gametes and secrete sex hormones i.e. the gonads; testes in males and ovaries in females.
14. **Secondary sex organs; accessory organs;** organs associated with testes or ovaries which play some roles in reproduction but other than gamete production and hormone secretion. E.g. penis, prostate, seminal vesicles, sperm duct in males, and fallopian tubes, uterus, vagina, mammary glands in females.
15. **Accessory or external sex characters;** are external characters, which do not play any direct role in reproduction but are distinct and enable sexes to be distinguished as male and female. E.g. low pitch voice and facial hair; males and high pitch voice; females.
16. **Gonads;** these are organs which produce gametes and are of two types; ovaries for ova production and testes for sperm production

Features of sexual reproduction in mammals

- Fertilization is internal
- Females go through a sexual cycle known as menstrual cycle
- Sexual cycle is restricted to the breeding season, except in humans and other primates, which are sexually receptive throughout the year
- Young ones are born at an advanced stage.
- There is display of courtship behaviour that leads to mating.

- Development of embryo is internal and completely dependent on the mother for food and protection.
- The young are fed on milk
- Parental care to the young is prolonged.

Features in reproduction that have led to the evolutionary success of mammals

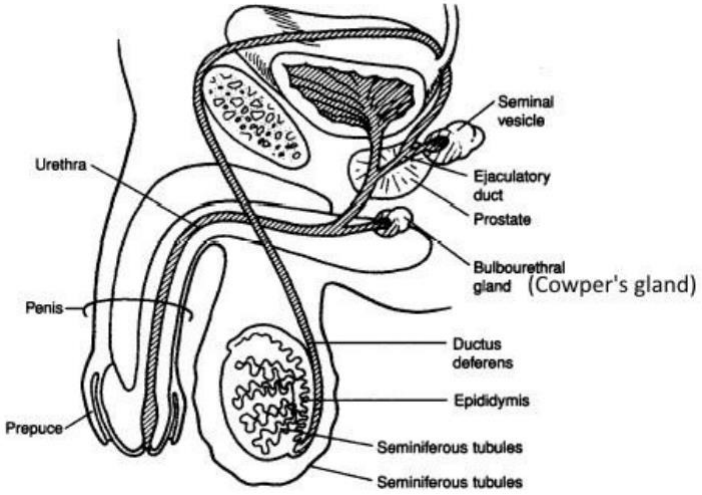
- Fertilization and development are internal to limit wastage of gametes and provide protection to the young respectively
- The breeding seasons coincide with the breeding cycle so that birth occurs at a time when environmental conditions are most favourable for growth of young.
- Feeding young ones on nutritious milk enables them to prepare for adult food as the digestive system develops.
- Secondary sexual characteristics enable easy identification of mating partners
- Parental care provides protection from predation and harsh environmental conditions to the young.
- Development of placenta enables gaseous exchange and the young to excrete wastes.
- Females are often more receptive to males during ovulation or the act of copulation stimulating ovulation

HUMAN MALE REPRODUCTIVE SYSTEM

Structure;

- ✓ It consists of two testes. The testes are connected to the ducts that store and transport sperms to the outside of the body via the penis.
- ✓ The penis consists of special connective tissues and supplied with network of numerous blood vessels and it is covered by elastic skin. The tip of the penis is an expanded, sensitive region known as glans, it is covered by a retractable skin called the foreskin.
- ✓ The testes are structurally enclosed within external sacs called scrotum. It is an extension of the abdominal wall. The testes develop in the abdominal cavity but descend into the scrotum before birth.
- ✓ The testes are paired oval glands. They contain connective tissue which has capillary networks and interstitial cells known as Leydig cells. A single testis is surrounded by fibrous coat separated internally by septum into a series of lobules. Within each lobule, there are coiled seminiferous tubule which can make a total length of over 500 metres.
- ✓ Between the tubules are interstitial cells which secrete the hormone testosterone. Each seminiferous tubule is lined by germinal cells of epithelium which by series of mitotic and meiotic divisions to give rise to the sperms.
- ✓ The seminiferous tubules join to form small ducts called vasa-efferentia which in turn join to form a six metres long coiled tube known as epididymis. The sperms are stored within the epididymis while gaining motility over a period of 18 hours.
- ✓ The epididymis leads to another muscular tube known as the vas-deferens; sperm duct which carries the sperms towards the urethra. Before this duct joins the urethra, it is joined to the ejaculatory duct leading from the seminal vesicle. The ejaculatory duct then passes through the prostate gland which produces an alkaline secretion that neutralizes the acidity of any urine within the urethra as well as aiding motility. Above the point are paired Cowper's gland, which secrete a sticky fluid into the urethra.

- ✓ The resultant combination of sperms and secretions is known as semen. The semen then passes along the urethra, a muscular tube which runs through the penis to the outside. The end of the penis is expanded to form a part known as the glans penis which is a sensitive region covered by a loose retractable skin known as the prepuce; fore skin.



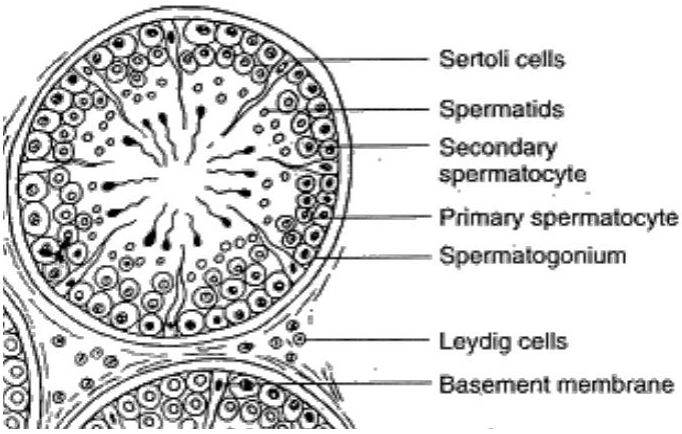
Understanding biology page 230 and 231
Functional approach page 387
Micheal kent section 12.2 fig.1

Summary of functions of the parts

PART	*FUNCTION*
Seminal vesicle	Secrets viscous fluid-containing fructose which acts as a nutrient for sperm cells.
Prostate gland	This gland secretes an alkaline, milky-white fluid that neutralizes the acidity of the Vagina.
Penis	Delivers sperms into the female reproductive organ.
Testis	Manufactures and store sperms.
Scrotal sac	Protects the testis.
Vas deferens	Conducts sperms from the testis to urethra during ejaculation.
Urethra	Passage of sperms and semen during ejaculation.
Cowper's gland	Produces mucus for lubrication of both the male and female urethra to ease copulation.

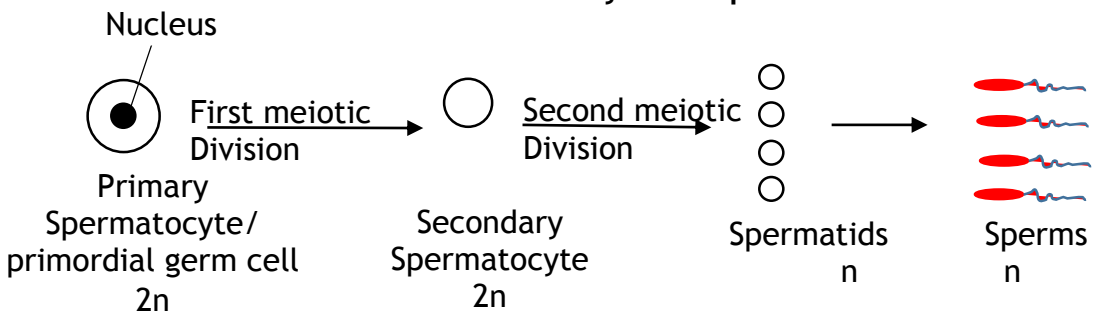
SPERMATOGENESIS

- Sperms are produced by a sequence of cell divisions in a process known as spermatogenesis followed by a complex process of differentiation.
- Spermatogenesis takes approximately 70 days and 300 million sperms are produced per ejaculation and the semen of a fertile man contains over 100 million spermatozoa per cm^3.
- The seminiferous tubes are sites for sperm production and are aligned by germinal epithelium cells which are referred to as **primordial germ cells**.
- During sperm production, diploid primordial germ cells undergo three successive mitotic divisions to form eight diploid cells known as spermatogonia. This is **the multiplication phase.**

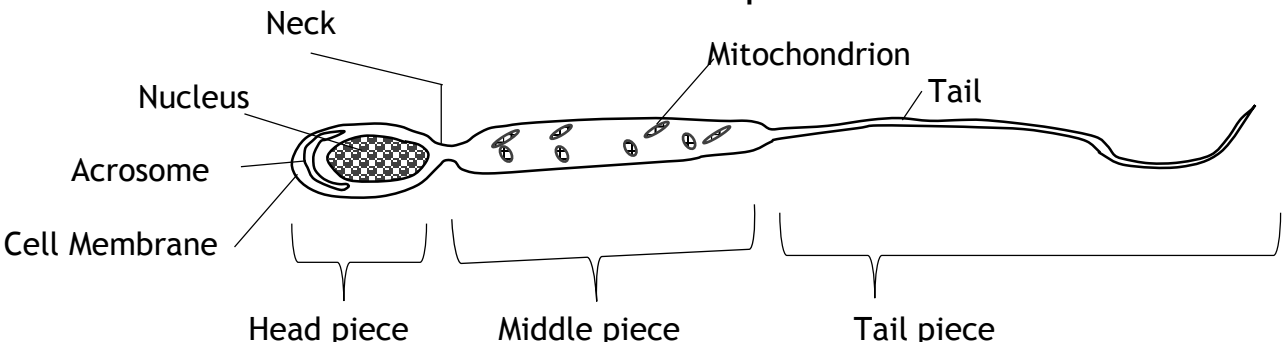


- The spermatogonia obtain nourishment and grow to form primary spermatocytes. This is the **growth phase.**
- The primary spermatocytes undergo the first meiotic division to form secondary spermatocytes and the second meiotic division to form spermatids that develop into spermatozoa; sperms after feeding on nutritive cells called sertoli cells which are found lining the seminiferous tubules. The sertoli cells;
- Provide nourishment to developing spermatids.
- Phagocytize; eat off the cytoplasm of spermatids.
- Secrete a fluid that carries spermatids through the tubules.
- Phagocytize foreign particles that invade the tubules
- This is known as the **maturation phase**

Summary of the process



Detailed structure of a spermatozoan



Functions of the parts;

1. Menopause; a period when ovulation and menstruation cease in human females.
2. Acrosome: Contains hydrolytic enzymes which facilitate the penetration of the egg membranes prior to fertilization.
3. **Nucleus**: Contain a haploid set of chromosomes, which on fusion with the egg restores the diploid state of organisms.
4. **Mitochondria:** They complete aerobic to release ATP required for contraction of filaments during the sperm's movement.
5. **Tail piece (Flagellum):** Enables motility of the sperm.

HORMONAL CONTROL OF SPERMATOGENESIS

- ✓ Interaction of hormones from the hypothalamus and anterior pituitary gland controls spermatogenesis
- ✓ The hypothalamic hormone, gonadotrophic-releasing hormone (GnRH) stimulates the anterior pituitary gland to secrete two gonad stimulating hormones, i.e. follicle stimulating hormone (FSH) and luteinising hormone (LH)/interstitial cell stimulating hormone (ICSH).
- ✓ FSH stimulates spermatogenesis by causing sertoli cells to complete the development of spermatozoa from spermatids. FSH also causes sertoli cells to release a peptide hormone inhibin that specifically inhibits FSH secretion.
- ✓ LH (ICSH) stimulates the Leydig cells; interstitial cells of the testes to secrete testosterone.
- ✓ Testosterone stimulates the growth and development of germinal epithelial cells; spermatogonia to form sperm, and also works with FSH to stimulate the sertoli cells.
- ✓ However, increased testosterone level inhibits the secretion of GnRH and LH.

Note;

- ✓ The general name for male sex hormones is androgens (e.g. testosterone), while oestrogen are the female sex hormones.
- ✓ Both androgens and oestrogens are present in male and female mammals, But in different proportions so that the degree of 'maleness' or 'femaleness' is variable depending upon the balance between the levels of androgens and oestrogens in the body.

Sperm formation

- ✓ During the stages after sperm formation, the sperms are immotile and are removed from the seminiferous tubules through the vasa-efferentia tubules into the epididymis.
- ✓ Within the epididymis, sperms are retained for 10-20 days where they develop and attain mobility. During sexual intercourse, they are moved into the sperm duct by peristaltic movement. Once they reach the prostate gland and Cowper's gland, they secrete their fluid secretion in addition to those from the seminal vesicle to form semen from which sperms swim out of the urethra.
- ✓ The sperms which have not been ejaculated within four weeks may be re-absorbed into the body.

SEMEN;

- ❖ In humans, each ejaculation consists of approximately $5cm^3$ of semen. While it contains around 500 million sperm, they comprise only a tiny percentage of the total volume. Semen contains;
- ❖ Sperm, sugars; which nourish the sperm and help in mobility, mucus; which forms a semi-viscous fluid in which the sperm swim, alkaline chemicals; which neutralize the acid conditions encountered in the urethra and vagina, which could otherwise kill the sperm.
- ❖ Prostaglandins; hormones which cause muscular contraction of the uterus and oviduct to enable the sperm reach the oocyte.

NOTE:

- ❖ The male gonads; testes develop in the abdominal cavity and descend into an external sac; scrotum prior to birth.
- ❖ The optimum temperature for sperm development is around 35^oC, 2^OC below normal human body temperature.

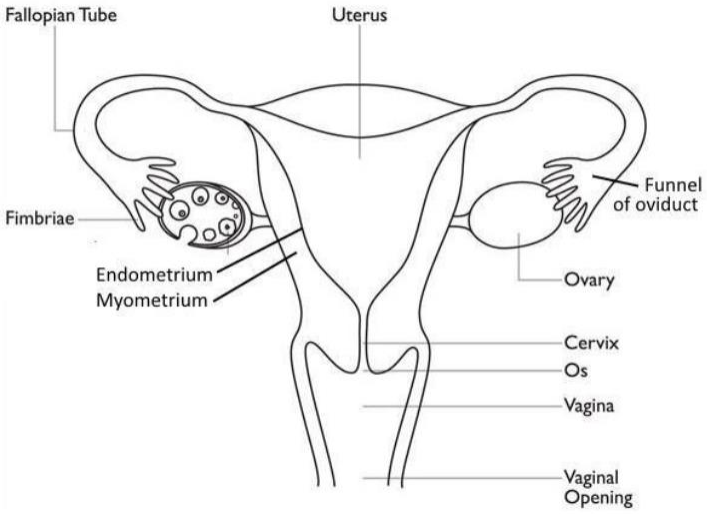
- ❖ The testes are kept at this temperature by the contraction and relaxation of the muscle in the scrotal wall. When the temperature exceeds 35°C the walls relax, holding the testes away from the body to assist cooling.
- ❖ When the temperatures are colder, the muscles contract to bring the testes as close to the abdominal cavity as necessary to maintain them at the optimum temperature.

FEMALE REPRODUCTIVE SYSTEM

- ✓ The female gonads are the ovaries which are suspended in the abdominal cavity by the ovarian ligaments. The external coat of the ovary wall is made up of the germinal epithelium which begins to divide to form oocytes when the female is still a fetus.
- ✓ At birth, about 400000 cells should have reached prophase 1 of the first meiotic divisions and are called primary oocytes.
- ✓ Every month after puberty one of these cells completes its development into a secondary oocyte.
- ✓ Close to the ovary is a funnel shaped opening of the oviduct known as the fallopian tube. The oviduct is 10cm long and has a muscular wall lying with a mucus secretory layer of ciliated epithelium. They open into the uterus or womb.
- ✓ The uterus has walls of smooth muscles and it's internally lined with mucus membrane known as the endometrium.
- ✓ The uterus opens up to the vagina through a ring of muscles known as cervix
- ✓ The vagina has wall of smooth muscles with an inner mucus membrane lined with stratified epithelium.
- ✓ The vagina opens to the outside through the vulva which is a collective name for the external organs. These organs consist of outer walls known as labium majora covering the inner more delicate folds; labium minora.
- ✓ Anterior to the vaginal opening is a small erectile known as the clitoris which is structurally the same as the penis in males.
- ✓ Between the clitoris and vaginal opening is an opening of the urethra.

N.B Clitoris is the most sensitive part of the vagina.

Diagram;



*** understanding biology page 233**
***Micheal kent section 12.2 fig 2**
***functional approach page 387 fig 24.11 A**

FUNCTION OF THE PARTS

PART	FUNCTION
Uterus	Provides suitable environment for growth and development of the fetus. It is also an area for implantation.
Vagina	Passage of sperms to the uterus. Passage of blood during menstruation. Allows passage of the fetus at birth.
Oviduct (fallopian tube)	It allows movement of fertilized egg towards the uterus for implantation. It provides suitable place for fertilization.
Cervix	Contains elastic muscles which allows its expansion during birth and it is the gate way to the uterus.
Vulva	This is a collective term for the external genitalia. It is made up of two skin folds that is the inner fold (labia minora) and the outer fleshy fold (labia majora). Labia minora contains mucus secreting glands which lubricates the vagina during sexual intercourse (copulation). Labia majora cushions the vagina and helps in sexual arousal. In the place where labia majora and labia minora meet is a bean-like structure called clitoris. This is the most sensitive part, which brings about sexual excitement in females.
Vagina	This is a muscular tube, which connects the vulva to the uterus. It has an average length of 10cm. It secretes acidic mucus, which prevents growth of bacteria and fungi. The mucus also lubricates the vagina. The vagina plays the following roles. is a passage for menstrual flow. is a birth canal. is where the male inserts his erect penis during sexual intercourse.

Functions of the female urinogenital system

- Production of the female gametes i.e. the ovum
- Reception of the male gametes i.e. the sperm
- Provision of a suitable environment for fertilization
- Provision of a suitable environment for the fetus development.
- Provision of a means for the expulsion of the developed fetus during birth.
- Secretion of hormones like oestrogen

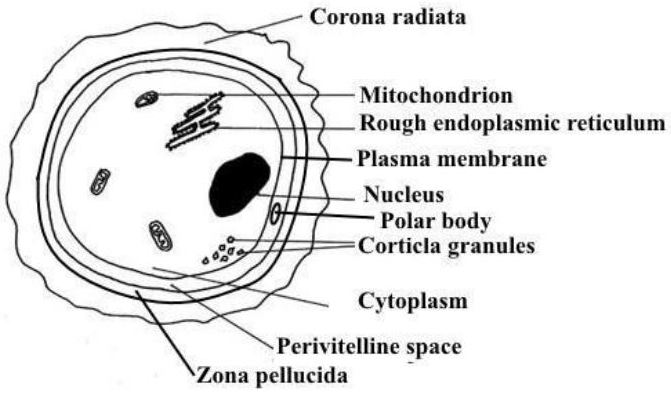
OOGENESIS/ OVA FORMATION

- Ova are produced by a series of cell division called oogenesis. During the ova formation, the primordial germ cells derived from the germinal epithelium cells lining the ovary undergo three mitotic divisions to form eight cells called oogonia. This is **multiplication phase**.
- These oogonia migrate towards the centre of the ovary. One of them grows larger to form primary oocyte while the rest encircles the growing primary oocyte. A primary oocyte is surrounded by a layer of follicle cells called primary follicles. The follicle cells are both mutative and protective.
- As the primary oocyte grows further, the follicle cells increase in number. The surrounding follicle cells form a wall many cells thick. As this occurs, a fluid called follicular liquid collects between the cells forming little cavities.

- ❖ As more and more fluid accumulates, the counties unite to form a layer of cavity pond. This the **growth phase**.
- ❖ Then the primary oocyte undergoes the first meiotic division to form a secondary oocyte and the first polar body, a layer surrounds the follicle cells; secondary oocyte. This layer is divided into two, a highly vascularised thick interna and a less vascularised and more fibrous thicker externa. The whole structure is now known as the Graafian follicle.
- ❖ The secondary oocyte is now known suspended into a stock of cells projecting into the cavity.
- ❖ The secondary oocyte may undergo a second meiotic division to form an ovum in the fallopian tube just before fertilization and a second polar body.
- ❖ In the fallopian tube, the first polar body in its first meiotic division also undergoes a second meiotic division to form two polar bodies hence the whole process produces three polar bodies and one ovum. This is the maturation stage;

NOTE: Polar bodies take the extra chromosomes resulting from meiosis in order for the ovum to carry haploid number of chromosomes and the unequal cytoplasmic division results into the formation of a large egg with the cytoplasm containing sufficient yolk for the development of the embryo.

Structure of the egg cell.



Functions of the parts;

Yolky cytoplasm: Contains fat and protein which nourish the developing embryo.

Cortical granules (lysosomes): Contain enzymes that alter the structure of vitelline membrane to prevent polyspermy at fertilization, to avoid upsetting the diploid state of the zygote.

Vitelline membrane: Undergoes structural changes that prevent polyspermy at fertilization

Nucleus: Contains 23 chromosomes that complete meiosis II at fertilization to provide female haploid nucleus

Polar body: Contains 23 chromosomes, but is non-functional and degenerate

COMPARISON OF OOGENESIS AND SPERMATOGENESIS

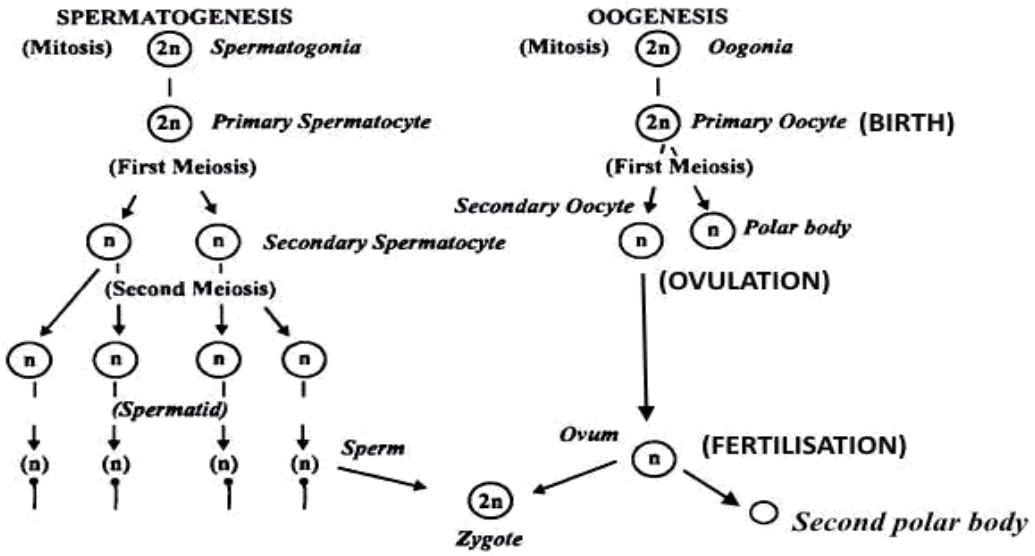
SIMILARITIES:

- Secretion of hormones like oestrogen
- Both begin with diploid germinal epithelial cells
- Mitosis and meiosis are involved in both
- Both yield haploid gametes
- Both occur in gonads

Differences;

Spermatogenesis	Oogenesis
Occurs in the seminiferous tubules	Occurs in the ovaries
Begins only at puberty	Begins before birth in the embryo
It's a continuous process and occurs all the time	A discontinuous process
Equal cytoplasmic divisions between meiosis 1 and 2 and no polar bodies are formed.	Un-equal cytoplasmic divisions and polar bodies are formed
All the processes are completed and sperms found in the testis only	The secondary oocyte released from the ovary and second meiotic division in the oviduct
Spermatids undergo differentiation to get transformed into sperms	No such stage in ovum formation
The sperm is comparatively very small	Ovum is comparatively large
Four spermatids are formed from one primary spermatocyte	Only one ovum is formed from the primary oocyte
Takes a relatively longer time to complete	Takes a relatively shorter time to complete

Diagrammatic summary of oogenesis and spermatogenesis



SEXUAL CYCLES

OESTRUS CYCLE

This is a period of high sexual excitement in mammals when an egg is released from the ovary into the oviduct; ovulation.

The only period within which the human female can be successfully impregnated is around the time of ovulation.

Different types of animals have sexual cycles of the different activity which occur so that fertilization takes place at a time which gives the off springs the best chance of surviving for example the of springs should be produced at a time when the climate and food availability are favorable. These include;

- ✓ **Monoestrus**; the female undergoes a period of single sexual activity during the year e.g deer

- ✓ **Polyoestrus**; the female undergoes a number of periods of sexual activity during the year, each separated by a period of sexual inactivity e.g horses.

NOTE: Continuous cycle;

- Continuous cycle; the female has more of less continuous cycle activity where the end of one cycle is followed immediately by the start of the other e.g humans and most primates.
- Oestrus cycle is a characteristic of non- primates.

MENSTRUAL CYCLE

- This is the timely; synchronized recurring sequence of changes in the lining of the uterus to make it ready to accept the embryo upon fertilization as well as changes in the ovaries of non-pregnant females which occur within a period lasting 28 days.

Definition; Menstrual cycle; Series of hormone related changes in the primate female reproductive system that result in monthly discharge of blood and uterine materials when fertilization fails.

- In human females, the onset of the first menstrual cycle is called **menstruation.** It is accompanied by monthly discharges of blood through the vagina and marks the start of day one of menstrual cycle and puberty.
- This takes place at around the age of 12 years but is varies widely between individuals. The menstrual cycle lasts for 28 days and continues until menopause at the age of 45 to 50 years.
- The events of the cycle are controlled by hormones to ensure that the production of an ovum is synchronized with the readiness of the uterus to receive it if it was fertilized.
- The flow of blood may last between 3 and 5 days depending upon feeding and environmental conditions.

The menstrual cycle is divided into four phases;

- Follicular phase, Lacteal phase, Ovulation and Menstrual phase

Note;

In the follicular phase; there is rapid development of the Graafian follicle during this phase. Follicle stimulating hormone stimulates the growth of the ovarian follicles and its continued development is controlled by Luteinizing hormone.

Regeneration of the endometrium occurs causing the thickening of the endometrium. This is controlled by the hormone oestrogen from the developing follicles.

HORMONAL CONTROL OF THE MENSTRUAL CYCLE

- ✓ The menstrual cycle is controlled by the interaction of various sex hormones where the action of one hormone is used to stimulate or inhibit the production of another. Four hormones control the menstrual cycle.
- ✓ Two of them are produced by the anterior lobe of the pituitary gland at the base of the brain. The other two hormones are produced by the ovaries but their production is stimulated by the pityuitary hormones. These hormones are referred to as gonadotrophic hormones.
- ✓ The gonadotrophic hormones include follicle stimulating hormone and leutenising hormone. These hormones stimulate the ovaries to produce oestrogen and progesterone respectively.

Gonadotrophic hormones

These are hormones produced by the pituitary gland and they stimulate the gonads; ovary and testes to produce their hormones. The functions of these hormones are;

FOLLICLE STIMULATING HORMONE (FSH)

In females

- Stimulates growth of the ovarian follicles
- stimulates the growing follicles to secrete the hormone oestrogen

In males

- Stimulates spermatogenesis by causing differentiation of spermatids into spermatozoa

OESTROGEN

- Stimulates growth and repair of uterine wall; endometrium.
- Stimulates the pituitary gland to produce luteinizing hormone
- Stimulates growth of milk-producing tissues in the mammary glands
- Low levels stimulates production of FSH
- High levels in blood stimulates the hypothalamus to secrete Gonadotrophic releasing hormone leading to increase in FSH and LH
- Small amounts stimulate breast development. Corpus luteum secretes small amounts of oestrogen and larger amounts of progesterone
- Placental oestrogen inhibits prolactin release and therefore inhibits lactation
- Placental oestrogen increases sensitivity of myometrium to oxytocin

LUTEINIZING HORMONE

In females

- Stimulates growth and rapture of Graafian follicle and secondary oocyte
- Causes ovulation to take place.
- Promotes development of the corpus luteum
- Stimulates production of progesterone from corpus luteum

In males

- Placental oestrogen increases sensitivity of myometrium to oxytocin
- Stimulates the synthesis of the hormone testosterone by the Leydig cells; interstitial cells of the testis.

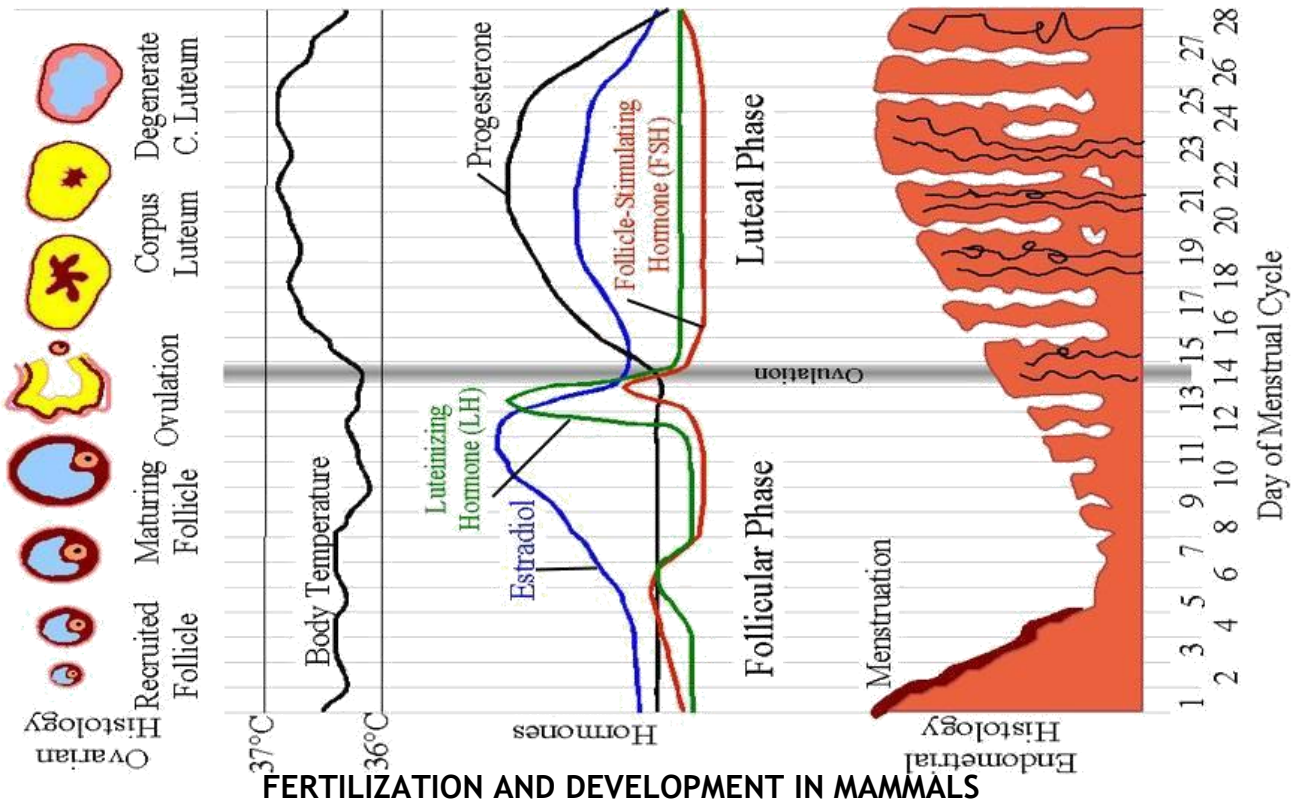
PROGESTERONE

- Maintains the thickening of uterine wall; endometrium in readiness for the implantation of blastocyst; young embryo.
- Inhibits the production of FSH and LH from the anterior pituitary gland
- Larger amounts stimulate breast development
- Low levels in blood triggers menstruation leading to loss of uterine lining
- Placental progesterone inhibits prolactin release and therefore inhibits lactation
- Placental progesterone inhibits contraction of myometrium; relaxes muscle and prevents miscarriage.

Note; the hormones are released in the order above; follicle stimulating hormone, oestrogen, luteinizing hormone and finally progesterone.

GRAPH MENSTRUAL CYCLE

***Understanding biology page 235 fig. 12.19**
***Functional approach page 390 fig 24.14**
***Micheal kent section 12.4 fig. 1**



FERTILIZATION AND DEVELOPMENT IN MAMMALS

In mammals for fertilization to occur many cases there are two stages involved; Courtship and mating. Courtship was covered earlier in behaviour under coordination in animals.

MATING/ COPULATION/ COITUS

- ✓ This is the process of sexual intercourse which involves the insertion of an erect penis into the vagina and ejaculation of the semen. It enables internal fertilization to be achieved in many animals.
- ✓ During coitus, erection of the penis occurs due to the increase in volume of blood in the spongy erectile tissue in the penis. This is caused by sexual stimulations that stimulate the parasympathetic nervous system.
- ✓ This causes vasoconstriction of the veins carrying blood away from the penis and vasodilation of the arterioles entering into the penis. The blood volume and pressure within the penis increase.
- ✓ In the erect state, the penis is inserted into the vagina. Secretion of the lubricating fluid by the vulva and vaginal lining and mucus secreted from the male Cowper's glands facilitates the entry of the penis.
- ✓ Rhythmic movements of the penis into and out within the vagina generate friction that stimulates touch receptors in the swollen head of the penis and in the erectile clitoris.
- ✓ This leads to sexual arousal which involves certain reflexes of the autonomic nervous system which include; increased heart beat, raised blood pressure, rapid breathing and dilation of the capillaries in the skin of the face and chest and pronounced sweating.
- ✓ Continuing tactile stimulation of the penis induces contractions of the smooth muscles of the epididymis, sperm duct, seminal vesicles and the prostate and Cowper's glands.
- ✓ Seminal fluids accumulate in the ejaculatory duct and in the urethra at the base of the penis. Sphincter muscle at the base of the bladder closes. All these activities are controlled by the autonomic nervous system.

- ✓ Ejaculation is then brought about by rhythmic, wave-like contractions of the voluntary nervous system. This occurs at the peak of sexual excitement referred to as **orgasm**.
- ✓ Seminal vesicles secrete mucus and a watery alkaline fluid that contains nutrients such as sugar fructose which is an energy source for the sperm. The secretions are carried into the ejaculatory duct.
- ✓ Prostate gland secretes mucus and slightly alkaline fluid which is released during ejaculation and neutralizes the acidity of the vagina making the sperm more active.
- ✓ Cowper's gland secretes mucus and an alkaline fluid into the urethra. The alkaline fluid neutralizes the acidity of any remaining urine, while the mucus lubricates vaginal wall to reduce friction during copulation
- ✓ Coitus is associated with emotional and psychological phenomena, controlled by the central nervous system or autonomic nervous system.

SEMEN

- Each ejaculation contains approximately $5cm^3$ with about 500 million sperms.

Semen contains;

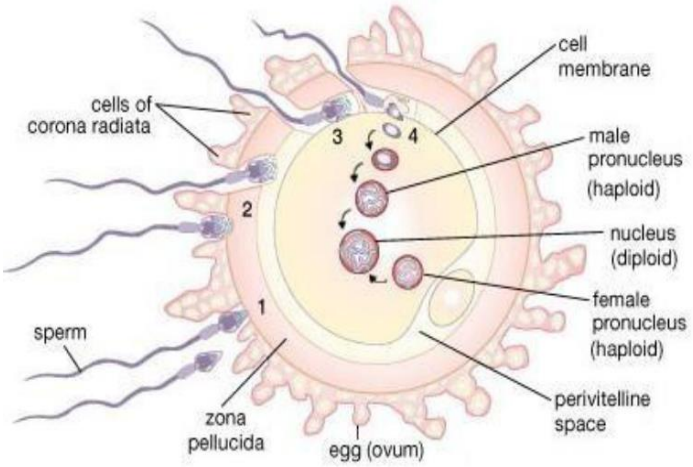
- Sperms about 100 million per cm^3
- Sugar i.e. fructose which nourishes sperms and make them motile
- Mucus which form semen viscous fluid in which the sperms swim
- Alkaline chemicals which neutralize the acid conditions in the urethra and vaginal tract which would kill the sperm
- Prostaglandin hormones which help the sperm to reach the ovum by causing the muscular contraction of the uterus and oviduct
- Calcium and vitamin C.
- Enzymes that activate sperms after ejaculation.
- Antibiotics that destroy any bacteria present.

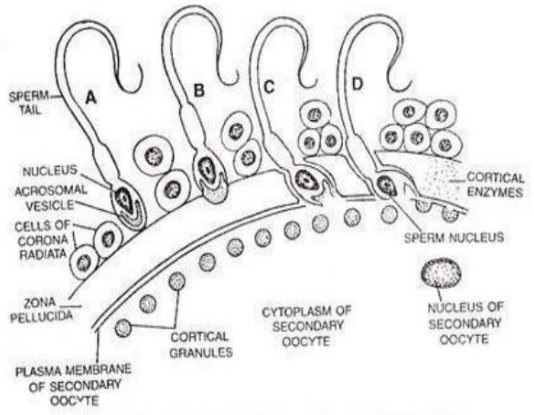
FERTILIZATION

Fertilization is the fusion of sperm and egg nuclei to form a diploid zygote.

- On entering the vagina, sperm spend about 7 hours being **capacitated**, after which they move towards the oviducts, aided by muscular contractions of the uterus and oviducts, and lashing of tail.
- A spermatozoon comes into contact with the oocyte by random movement.
- Acrosome enzymes hydrolyze a path in the granulosa layer of egg until the sperm head makes contact with zona pellucida.
- Sperm acrosome membrane ruptures to release hydrolytic enzymes; **acrosome reaction** and the acrosomal filament pierces through the oocyte membranes up to the plasma membrane of the oocyte.
- An electrical potential change in the oocyte membrane occurs**; fast block**, followed by fusion of cortical granules with plasma membrane to discharge their contents; **cortical reaction**, which creates an osmotic gradient that draws water into the space between the plasma membrane and vitelline membrane.
- The two membranes are lifted away and the vitelline membrane hardens; fertilization membrane to block polyspermy.

- While the sperm tail is lost and disintegrates, the nucleus expands and is now known as pronucleus.
- Entry of a sperm stimulates completion of second meiotic division of the secondary oocyte to form the second polar body, which disintegrates, and an egg.
- The haploid male and female pronuclei fuse to form a diploid zygote, which divides immediately by mitosis to form two diploid cells.





NOTE: Delayed fertilization is possible because within approximately 48 hours for sperm is still active and about 10-15 hours secondary oocyte is still functional. Therefore to result in pregnancy, sexual intercourse must occur not more than 48 hours before or 15 hours after ovulation.

Summary table of major stages

Process	Explanation	Significance
Sperm capacitation	The process of activation of mammalian sperm to fertilise the egg, during which the acidity and enzymes in the female genital tract cause perforation of the sperm head by removal of cholesterol and glycoprotein to allow entry of Ca^{2}+and the release of acrosome enzymes.	Entry of Ca^{2+} increases the beating activity of the sperm tail and also promotes acrosome reaction to enable sperm penetrate the egg.
Acrosome reaction	A process that occurs in the sperm head on making contact with a secondary oocyte, during which the cell and acrosome membranes rupture to release hydrolytic enzymes e.g. hyaluronidase and proteases.	Enables sperm head to penetrate the egg membranes.
Fast block	A process during which contact of the first sperm with the egg membrane is instantly followed by an electrical potential change in the egg membrane to prevent entrance of more than one sperm.	Prevents entrance of more than one sperm into the egg (polyspermy) that would upset the diploid state of the embryo.
Cortical reaction	A process that occurs following sperm penetration of the secondary	Formation of fertilization membrane prevents

	oocyte during which lysosomes (cortical granules) fuse with the plasma membrane and release their contents, causing the vitelline membrane to harden and form the fertilization membrane to prevent polyspermy	multiple sperm entry into the egg (polyspermy) that would upset the diploid state to cause death of mammalian embryo.

MAJOR EVENTS THAT OCCUR AFTER FERTILIZATION

- Cell division of the diploid zygote to produce two diploid cells
- Cleavage to form a blastocyst
- Secretion of particular hormones by the trophoblastic cells, the hormone secreted is the Human Chorionic Gonadotrophic Hormone (HCG); its function is similar to LH. It prevents breakdown of the corpus luteum. The corpus luteum therefore continues to secrete progesterone and oestrogen and they bring about increased growth and maintenance of the endometrium of the uterus.
- Loss of the endometrium is prevented and no more menstruation does occur.

IMPLANTATION

- The diploid zygote undergoes cleavage. This involves repeated mitotic cell division without growth in size. Many smaller cells form a solid mass called a morula which reach the uterus in three to four days.
- The mitotic cell division continues and the cells formed are called blastomeres.
- Blastomeres arrange themselves into a fluid –filled ball known as blastocyst with a central cavity called blastocoel.
- The outer layers of the blastocyst which consist of blastomeres are called the trophoblast. These cells by now are still contained in the zona pellucida.
- When the blastocyst arrives in the uterus, the zona pellucida gradually disappears over about two days.
- The trophoblast is allowed to make contact with the cells of the endometrium. The trophoblast begins to obtain nutrients from the endometrium of the uterus. The trophoblast cells multiply and between the sixth and thirteenth day, the blastocyst is embedded within the endometrium in a process known as **implantation**.
- The cells of the trophoblast differentiate into inner and outer layers. The outer layer is the chorion and forms chorionic villi.
- The regions of endometrium between the chorionic villi form interconnecting spaces. The trophoblast secretes hydrolytic enzymes which cause the arterial and venous blood vessels within this region of the endometrium to break down and blood from them fills the interconnecting spaces.
- At this early stage, the exchange of materials between the embryo and maternal blood occurs through the chorionic villi.

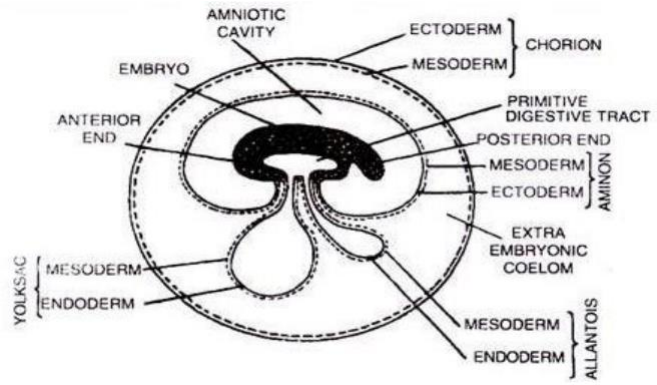
EXTRA-EMBRYONIC MEMBRANE AND EARLY EMBRYONIC DEVELOPMENT

After implantation, the embryo produces four extra –embryonic membranes. These are the embryos outside the embryo.

The amnion

- This is the inner most membrane lining the cavity which surrounds the embryo. The cavity is filled with fluid called the amniotic fluid.
- The embryo is suspended in this fluid and it supports the embryo and protects it against mechanical damage.

The chorion



- This is the outer most membrane derived from trophoblast cells.
- It contains chorionic villi which absorbs nutrients from the endometrium of the uterus. It therefore provides nourishment to the growing embryo.
- It also removes wastes from the developing embryo.

Allantois

- This is a sac –like outgrowth from the embryonic gut, it fuses with the chorion in the uterus wall.

The yolk sac

- Has no particular function in humans and becomes buried in the uterus.

Note; in birds and reptiles, it encloses the yolk and it is the source of fat and proteins for embryo. It therefore absorbs food from the separate yolk and transfers food to the gut of the developing embryo.

DEVELOPMENT OF THE PLACENTA

- During the early embryonic development, the outer cells of the blastocyst known as trophoblast differentiate into outer and inner membranes.
- The outer most membrane called the chorion. Two cavities develop within the inner mass of cells and the cells lining these cavities give rise to two membranes, the amnion and the yolk sac.
- The amnion is the inner most membrane and it surrounds the embryo. This membrane has a protective function. Between the amnion and the embryo is amniotic fluid which is secreted by cells of the amnion and fills the amniotic cavity.
- A sac like out growth develops from the embryonic gut and forms the fourth membrane known as the allantois. The allantois grows towards until it comes into contact with a chorion where it forms a structure rich in blood vessels called allanto-chorion. The later develops into a placenta.
- The cells of the inner cell mass between the early amnion and the yolk sac form a structure called the embryonic disc, which give rise to the embryo.
- The cells of the embryonic disc differentiate at an early stage and form an outer layer of cells, the ectoderm and an inner layer, the endoderm.
- At a later stage the middle layer mesoderm is formed. These three germ layers give rise to all the tissues of the developing embryo.
- The development of the three germ layers in this way is called **gastrulation** and this occurs 10-13 days after fertilization. The brain begins to develop from a tube developing from the ectoderm called the neutral tube in the third week.

Note; Brain is the first organ to develop.

STRUCTURE OF THE PLACENTA

✓ The placenta is only found in mammals. It is large, thick and long. It consists of cells derived from the fetus and the mother. The fetal part of the placenta consists of cells of the chorion which form finger –like projections known as chorionic villi.

- ✓ These increase the surface area for absorption of nutrients. The branches of the umbilical artery and umbilical vein form networks of blood vessels inside the chorionic villi.
- ✓ The blood vessels run between the fetus and the endometrium of the uterus in the umbilical cord. Umbilical cord is long, tough structure covered by cells derived from the amnion and chorion.
- ✓ The maternal part of the placenta consists of projections of the endometrium. Between this region of the endometrium and the chorionic villi are spaces; lacunae which are supplied with arterial blood from the arterioles in the uterus wall. Blood flows through the spaces from the arterioles to the venules in the uterus wall.

***Functional approach page 388 fig 24.12**
***Micheal kent section 12.8 fig 2**

Functions of the placenta

- Oxygen, water, amino acids and mineral salts and essential nutrients are transported from maternal to fetal blood to nourish the developing fetus.
- Carbon dioxide, urea and other waste products are transferred from the fetus to the maternal blood to allow their excretion by the mother and prevent harmful accumulation of wastes in the fetus.
- It enables antibodies to cross from the maternal blood circulation into the fetus. The antibodies protect the fetus against infections by certain diseases at early periods of birth.
- It allows exchange of materials between the fetus and mother without blood mixing. This is necessary as the fetal blood may be different from the mother's due to the influence of the father's genes. If incompatible blood mixes, agglutination occurs causing blockage in vital organs such as the kidney which may result into death.
- It prevents some pathogens and their toxins from crossing to the fetus. This protects the fetus against certain infections. Except pathogens of Rubella virus which can cross placenta causing maternal damage to the fetus and the HIV which can also pass to the placenta.
- It is as a barrier to maternal hormones and other chemicals in the mother's blood which could have an effect on the fetal development. However, some chemicals like nicotine, heroine and alcohol can cross causing damage to the fetus.
- The placenta takes over the role of hormone production as the pregnancy progresses. It acts as an endocrine gland and secretes hormones like; Human Chorionic gonadotrophic hormone, oestrogen and progesterone and human placental lactogen.
- As the two blood systems; mother and fetus, the placenta permits them operate at different pressures without harm to the mother or fetus.

Adaptations of the placenta to its functions

- Has the finger-like projection; chorionic villi of the allanto-chorion which is the tissue part of the placenta grows into the endometrium. This increases the surface area over which essential nutrients can be absorbed and exchange of materials occur.
- The blood vessels of the embryo lie close to the maternal blood vessels without their blood mixing; this reduces the distance over which rapid diffusion of substances take place. Oxygen diffuses into the fetus, while carbon di oxide

diffuses out of the fetus into the maternal blood and water cross the placenta by osmosis. The maternal and fetal bloods are constantly being replaced in the placenta to maintain a high diffusion gradient, resulting into rapid diffusion of materials across the placenta.

- Endometrium breaks down in region of the chorionic villi so placental villi are bathed in maternal blood, making exchange of materials more efficient but still keeping fetal and maternal blood separate.
- The blood of the fetus and mother cannot mix because there is no direct contact between the two blood vessels. Its significance is that, the fetus is not exposed to relatively high blood pressure of the maternal blood circulation and the mother and the fetus may be of different ABO blood groups.
- The nitrogenous waste products like urea diffuse from fetus to mother across the placenta. It is removed by the mother's kidney. Antibodies can cross the placenta from the mother to the fetus to protect the fetus against infection by certain diseases. This is known as passive immunity.
- Nutrients such as glucose, amino acids, lipids and mineral salts and vitamins across the placenta from the maternal blood circulation into the fetus. Glucose moves by facilitated diffusion. Ion such as sodium, potassium and calcium cross mainly by active transport and diffusion to a small extent. Amino acids iron and vitamins cross the placenta by active transport.
- There are numerous mitochondria in the cells lining the walls of the chorionic villi, these provide energy for active transport and pinocytosis/facilitated diffusion. The cell surface membranes contain protein carrier molecules used in uptake of materials into villi by active transport.
- The transport mechanism involved in the exchange of substances between mother and fetus is very efficient. Oxygen and nutrients diffuse from the maternal to the fetal blood transported in umbilical vein. Waste fetal products diffuse from the fetal to maternal blood in umbilical artery.
- The capillaries of the allantois in the villi form huge area for exchange and increase the rate of diffusion. The microvilli increase surface area further.

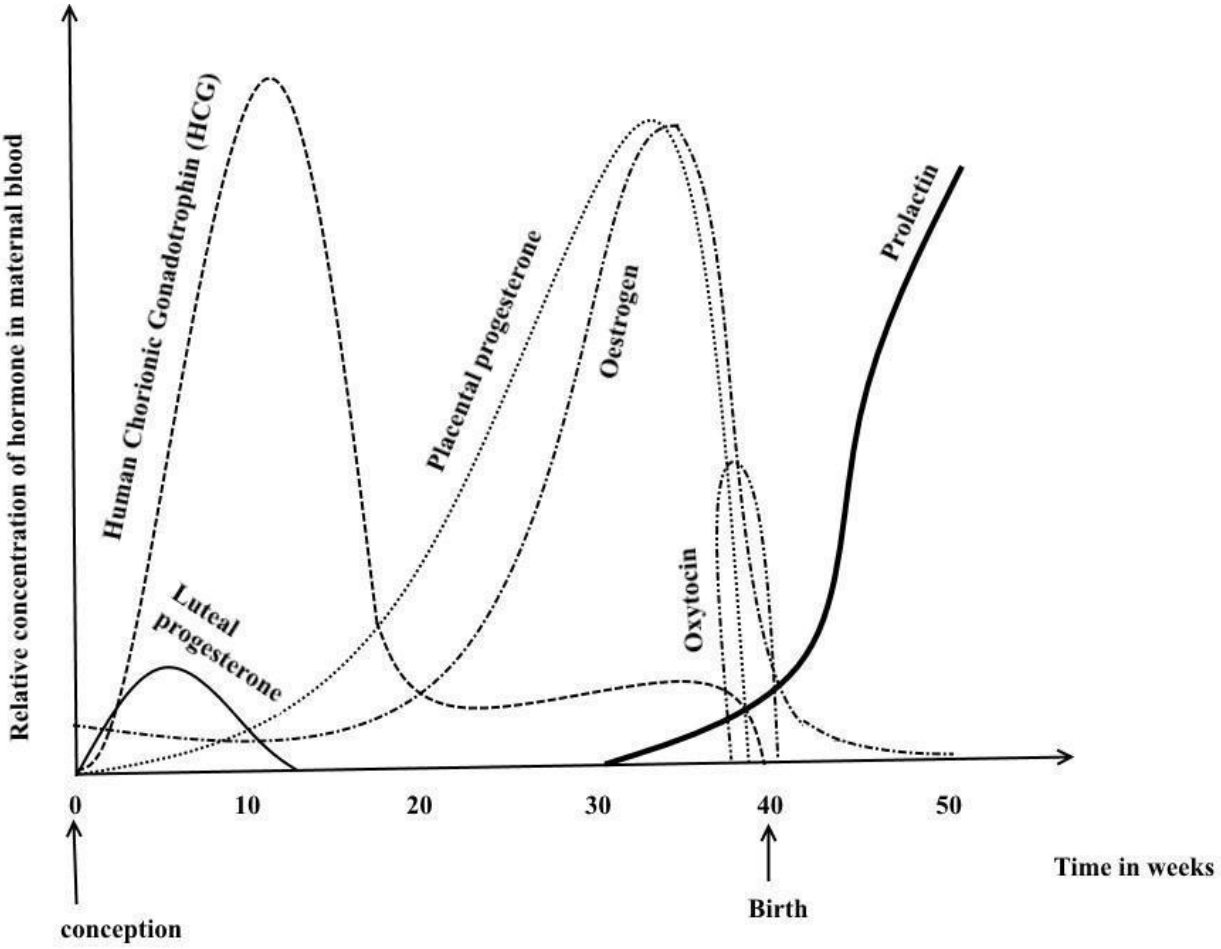
PREGNANCY AND HORMONAL CONTROL

- ❖ After fertilization, the zygote develops into a blastocyst. The outer wall of the blastocyst called trophoblast secretes Human chorionic gonadotrophic hormone, (HCG) which prevents the corpus luteum from breaking down and continues to secrete progesterone hormone and small quantities of oestrogen.
- ❖ These hormones maintain the continued development of the uterus and prevent menstruation. Progesterone inhibits the secretion of FSH from the anterior pituitary gland which prevents further development of follicles during pregnancy. After 3 – 4 months of pregnancy, the corpus luteum begins to degenerate and the placenta takes over the secretion of the hormones.
- ❖ The placenta plays an important role of producing reproductive hormones. It also secretes HCG, and prolongs the activities of the corpus luteum until four months of the pregnancy. Corpus luteum is responsible for maintenance of pregnancy and at this time the corpus luteum produces progesterone and oestrogen.
- ❖ In the absence of HCG, the corpus luteum degenerates. The presence of HCG in the urine of a woman is the basis of most pregnancy tests.
- ❖ After degeneration of the corpus luteum, placenta takes over the role of producing progesterone and oestrogen which prevents menstruation and

ovulation. Oestrogen also stimulates the growth of the mammary glands, increase in size of the uterine muscle cells and triggers the formation of receptors sensitive to the hormone oxytocin in the uterine muscles.

- ❖ Oxytocin stimulates the contraction of the uterine wall and the prostaglandin increases the strength and intensity of the contractions.
- ❖ Progesterone also stimulates the growth of the mammary glands, inhibits the contraction of the uterine muscles and inhibits the secretion of prolactin; a hormone that stimulates milk production.
- ❖ Relaxin secreted by the placenta causes relaxation of the connective tissues in the bones of the pelvic girdle and enlarges the cervix in preparation for birth.

CHANGES IN HORMONE CONCENTRATION DURING PREGNANCY



Please describe the changes in the concentration of the hormones. And check your answers with those in the table below showing expected observations and their explanations.

Hormone	Observations (Description)	Explanation
HCG (pregnancy hormone)	(a) Concentration very low at conception, (b) HCG Concentration increases rapidly at about 1 - 2 weeks after fertilization to a maximum at about 10 - 11 weeks of gestation.	(a) Before conception, HCG is secreted by the anterior pituitary and functions in a Luteinizing Hormone-like manner to promote ovulation and progesterone production during the menstrual cycle. (b) At implantation, trophoblast cells secrete HCG to: (i) Maintain the corpus luteum. (ii) Stimulate the corpus luteum to continue secreting

	(c) HCG concentration decreases rapidly to a minimum at about 19 – 20 weeks, and remains relatively constant after the 20th week until about 40th week when it drops to zero.	oestrogen and progesterone. (iii) Cause the blockage of any immune or macrophage action by mother on foreign invading placental cells. (iv) Cause uterine growth parallel to fetal growth. (v) Suppress any contractions by uterine wall during the course of pregnancy. (vi) Cause growth and differentiation of the umbilical cord (c) As the embryo grows, the placenta increases in size causing increased secretion of progesterone, which takes over some of the roles of HCG causing its secretion to decreases. A decrease in HCG causes degeneration of corpus luteum. At the 40th week the foetus is expelled therefore HCG secretion stops.

Progesterone "pro-gestational" hormone		
(a) Luteal progesterone	There is a slight rise to a maximum at about 4-6 weeks after conception followed by a rapid decrease thereafter to zero at 11 – 12 week.	Corpus luteum secretes luteal progesterone after ovulation, to ensure that the lining of the uterus stays intact and provides a nourishing environment for the egg to implant and develop. Without luteal progesterone, the lining of the uterus would slough off, ending the pregnancy.
(b) Placental progesterone	(i) Absent at conception. (ii) Concentration increases first slowly upto about 8-10 weeks, then rapidly to a maximum just before birth (40th week).	As the corpus luteum and ovaries become inactive in the later stages of pregnancy, progesterone secretion is by the placenta. As the pregnancy progresses, there is increased growth of the placenta, causing increased secretion of placental progesterone which: (i) Inhibits contraction of the myometrium (promotes relaxation) (ii) Increases mucus secretion in the cervix of the womb, forming a protective plug (promotes glandular activity in uterus) (iii) Stimulates growth of maternal part of placenta. (iv) Stimulates enlargement of the uterus. (v) Inhibits FSH release, thus prevents ovulation and menstruation. (vi) Causes enlargement of the breasts and growth of mammary glands.
		NB: After a meal, progesterone levels drop greatly (about 50%), explaining why blood test should be done early morning and before eating.
Oestrogen	(i) Concentration very low at conception (ii) Concentration remains relatively constant from conception to about 12 weeks. (iii) Concentration increases rapidly after 12	After ovulation, **Oestrogen** is initially secreted by the corpus luteum up to 12 weeks, hence the low and constant concentration. Afterwards, placenta takes over oestrogen secretion, therefore increased growth of the placenta causes increased secretion of oestrogen which: (i) Inhibits secretion of FSH (Follicle Stimulating Hormone) and LH (Lutenising hormone), both of which are involved in ovulation.

	weeks to a maximum just before birth.	(ii) Causes growth of the uterus and increases the sensitivity of the uterus to the hormone **oxytocin** which is involved in the processes of **birth** and **lactation**. (iii) Inhibits the secretion of prolactin, and thus inhibits lactation during pregnancy. (iv) Stimulates the development of mammary glands in preparation for lactation after the baby has been born. (v) Causes softening and relaxing of the ligament of the pelvic girdle.
Prolactin and Oxytocin	(i) Not secreted until after the 30th week. (ii) Prolactin secretion starts at about 31-32 weeks and increases, first slowly up to about 42 week then rapidly thereafter.	High levels of oestrogen and progesterone inhibit the secretion of **Prolactin** from the **anterior lobe of pituitary gland** and **Oxytocin** from the **posterior pituitary** until birth. When levels of Oestrogen and Progesterone decrease after birth, **prolactin** causes lactation. Towards parturition (birth), high levels of oestrogen promote uterine contractions and increased sensitivity of uterine wall to **oxytocin**, which causes the uterine muscle (myometrium) to contract.
Relaxin	Relaxin Peaks during the 14 weeks of the first trimester and at delivery	Causes increased: (i) Relaxation of ligaments, softening of cervix and inhibition of muscle contractions. (ii) Cardiac output, renal blood flow, and arterial compliance.

BLOOD CIRCULATION IN THE HUMAN FETUS

- The fetal blood circulation is similar to that of the adult, but showing some important differences. The reason for the differences is that the functions performed in the adult by lungs, liver and kidney and the gut are largely performed in the fetus by the placenta. Nutrients and oxygen are supplied to the fetus via the placenta and waste products of metabolism are returned to maternal circulation through the placenta.
- In the fetus, oxygenated blood from the placenta returns into the fetal blood circulation via the umbilical vein. The blood vessel ductus venosus carries oxygenated blood from the placenta and deoxygenated blood from the gut directly to the posterior (inferior) venacava by passing the fetal liver. The liver in the fetus manufactures blood but does carry the regulatory role it has in adult. Some blood from the umbilical vein flow directly into the liver.
- Partially oxygenated blood from the posterior venacava flows into the right atrium of the heart. This blood contains a mixture of oxygenated and deoxygenated blood. From the right atrium, most of the blood passes through an opening in atrial septum called foramen ovale into the left atrium. Some blood flows from the right atrium into the right ventricles and then pumped by the fetal heart into the pulmonary artery.
- The blood flowing in the pulmonary artery does not pass into the lungs, but is instead carried via ductus arteriosus directly into the aorta by passing lungs, pulmonary vein and the left side of the left atrium. This occurs because pressure in the pulmonary circulation is higher than in the aorta.
- Blood from the left atrium passes into the left ventricles and into the aorta which supplies blood to the head, upper limbs, trunk and lower limbs and

umbilical artery and the blood is eventually passed into the placenta where it absorbs oxygen and nutrients.

- ❖ The fetal blood circulation is maintained by high blood pressure in the pulmonary artery and this determines direction of blood flow through the fetus and placenta.

PARTURITION

- ❖ As pregnancy nears its end, the baby shifts around the womb and it attains a head face down position, with the head close to the cervix. The level of oestrogen rises, whereas the levels of progesterone decline.
- ❖ The posterior lobe of the pituitary gland is stimulated to secrete the hormone oxytocin into blood stream. Oxytocin causes contraction of the smooth muscle of the myometrium.
- ❖ At the same time, the fetal pituitary gland secretes adrenocorticotrophic hormone (ACTH) which stimulates the fetal adrenal glands to secrete corticosteroids. The steroid pass into blood sinuses in the placenta and cause maternal cells to produce the hormone called prostaglandins; neurosecretory hormone and decreases the secretion of progesterone.
- ❖ This removes the inhibitory effect of progesterone on contraction of the myometrium. Prostaglandin causes smooth muscles of the myometrium to contract. At the same time, the pressure of the fetal head against the cervix stimulates stretch receptors. Impulses from these receptors are transmitted to the mother's brain.
- ❖ The posterior lobe of the pituitary gland is stimulated to secrete the hormone oxytocin. Oxytocin causes contraction of the smooth muscles of the myometrium while prostaglandin increases the power of the contractions. The uterine contractions are weak at first but gradually increase in frequency and intensity causing labour pain.
- ❖ The physical and emotional stresses associated with labour stimulates the release of more oxytocin and prostaglandins, this is a positive feedback mechanism. The contractions are so strong that they push the baby out of the uterus.

CHANGES IN BLOOD CIRCULATION OF A FETUS AT BIRTH

- In a few weeks of life, foetal haemoglobin is replaced by adult haemoglobin since it is less suitable as a means of gaseous exchange with air
- At birth when the baby takes the first breath, there is increased partial pressure of oxygen in its blood together with the nervous reflexes occurring in its body results in the closure of ductus arteriosus.
- As a result of this, most of the blood vessels and the opening of pulmonary circulation results in the blood pressure in the left atrium exceeding that of the right atrium, causing the foramen ovale to close with the aid of a valve in its passage.
- Blood then passes from the right ventricle and pulmonary artery to the lungs.

LACTATION

- ❖ During pregnancy the hormones progesterone and oestrogen cause the development of lactiferous milk; glands within mammary glands.
- ❖ Following birth, the anterior lobe of the pituitary gland produces a hormone prolactin which causes the lactiferous glands to begin milk production.

- ❖ Suckling by the offspring causes the reflex expulsion of milk from the nipple of the mammary glands. The first milk formed is colostrum, it is mildly laxative and helps the baby expel the bile that accumulated in the intestines during fetal life.
- ❖ As well as essential nutrients, the milk contains antibodies which render some passive immunity to the newly born.

CAUSES OF INFERTLITY

- Complex changes in the hypothalamus, pituitary gland and ovaries can cause hormone imbalance to cause ovulation disorders. It's the most common cause of female infertility.
- Excess physical or emotional stress can disrupt the pattern of secretion of follicle-stimulating hormone (FSH) and luteinizing hormone (LH) and affect ovulation – evidenced by irregular or absent periods.
- Excessive overweight or underweight can disrupt the pattern of secretion of FSH and LH and affect ovulation.
- Auto-immune response - the body mistakenly attacks ovarian tissues.
- Premature loss of eggs from the ovary due to genetic problems or environmental insults such as chemotherapy causing ovulation failure, as well as a decreased estrogen secretion below 40 years.
- Too much prolactin secretion which reduces oestrogen production and may cause infertility due to pituitary malfunction or medications taken for another disease.
- Damage or blockage of fallopian tubes hence preventing sperm from getting to the egg or block the passage of the fertilized egg into the uterus.
- Implantation failure due to fibroids/tumors, inflammation, abnormally shaped uterus, cervical narrowing.
- Sometimes the cervix can't produce the best type of mucus to allow the sperm to travel through the cervix into the uterus.
- Low sperm count: less than 5 million sperm per ml of semen
- Impotence; failure of the penis to erect or ejaculate

PARENTAL CARE

***behaviour in animals; earlier covered.**

In mammals and birds there is the tendency to reduce the number of offsprings but to expend much of their time and energy in caring for them in order to ensure a high survival rate.

This is important in primates where parental care plays a big part in learning. It involves Protection from predators, Feeding, Provision of shelter and Training of offspring by the parents.

NOTE; in birds; reproduction majorly involves;

Fertilization which is internal, mating is preceded by elaborate courtship displays, hard shelled eggs; Cleidoic or amniotic eggs; eggs that develop within the amniotes of the parent which provides the embryo with fluid filled cavity for development, are laid in the external environment, eggs are incubated usually by the mother as the embryo develops and newly hatched young ones are fed and cared for by the parents. In this the yolk nourishes the embryo

INTERNAL FERTILIZATION

This is where a nucleus of a haploid male gamete fuses with nucleus of female gamete to form a diploid or triploid zygote inside the female organism and within female reproductive structure. Internal fertilization occurs in most mammals and angiosperms.

Advantages of internal fertilization

- The developing embryo is protected from the harsh external environmental conditions.
- Developing embryo is protected from their potential predators, increasing their chances of survivor.
- The embryo is readily and easily provided with soluble nutrients
- Embryos are provided with protection against mechanical damages
- High chances of fertilization and therefore more reliable and efficient
- Reduced wastage of gametes, since gametes not used for fertilization can be reabsorbed back into the body to provide nutrients
- In mammals, embryos grow in environment with optimum temperature and they survive i.e. suitable environments for embryo development

Disadvantages of internal fertilization

- Embryos are vulnerable to toxic chemicals that may be produced by the mother, causing destruction of the embryo
- The survival of the embryo depends on the mother's survival
- Embryo may contract certain disease from the mother
- The developing embryo may get nutrients which are not adequate

EXTERNAL FERTILIZATION

This is where the nucleus of a haploid male gamete fuses with a haploid nucleus of the female gamete to form a diploid zygote outside the female organism. It is common in amphibians and fish.

Advantages of internal fertilization

- The survival of the embryo does not entirely depend on that of the mother
- The embryo is free from the toxic chemicals produced inside the mother which would damage it
- The developing embryo gets enough food from the surrounding

Disadvantages of internal fertilization

- Growth and development of the embryo may be hampered by some harsh and unfavourable conditions
- There is rampant predation of the embryo by predators
- There is wastage of gametes since very many gametes are produced and which may not be utilized for fertilization
- Chances for fertilization is very low, it's not reliable and is inefficient
- Nutrients to the embryos may become scarce and not easily obtained

GROWTH AND DEVELOPMENT

Growth is an irreversible and permanent increase in dry mass of a living material. Development is an increase in complexity of a living material. It involves formation of new structures and cell specialization.

GROWTH

The growth in size of an individual cell is limited by the distance over which the nucleus can exert its control. For this reason when single – celled organism reach a maximum size, they divide to produce two separate individuals.

However to attain greater size organisms have developed many cells; have become multicellular. Although being multicellular has some disadvantages, they are outweighed by the advantages.

Advantages to an organism being multicellular;

- Cells may become differentiated in order to perform a particular function.
- Specialized cells performing one particular function lead to greater efficiency.
- It is possible to store more materials and so better able to withstand periods when they are scarce.
- If some cells are damaged, enough may remain to do the repair.
- It is easier to separate regions for different opposing conditions in a multicellular organism than in a single cell.
- Larger organisms have a competitive advantage over the small organisms.
- Large size provides some protection from predators because the organisms are simply too large to ingest.

Starting with an individual cell, growth of a multicellular organism is divided majorly into three stages;

- **Cell division**; this involves an increase in cell number as a result of mitosis and cell division.
- **Cell enlargement/ elongation**; an irreversible increase in cell size as a result of the uptake of water or the synthesis of living material.
- **Cell differentiation**; the specialization of cells.

It should be noted that growth involves some part of development like in the stage of cell specialization.

FACTORS AFFECTING GROWTH OF ORGANISMS

External factors

i) **Nutrients;** Growth of an organism increases in the availability of nutrients and decreases when nutrients are in short supply. This is because nutrients are used in the building up of new protoplasm and organic matter. Also nutrients can be oxidized to provide energy required for growth. Therefore lack of nutrients can lead to decrease in growth or even death.

ii) **Accumulation of the byproducts of metabolism (excretory substances):** Growth may be inhibited by metabolic waste products which are toxic to the body cells. Fortunately most plants and animals are not affected much because they can convert these substances to less toxic excretions.

iii) **Temperature:** Growth depends on bio-chemical reactions which are catalyzed by enzymes. Temperature affects growth by affecting enzymes which catalyzes the chemical reactions in the body. Increase in temperature to the optimum increases the rate of growth, beyond which retardation of growth occurs.

iv). **light:** In plants, light affects growth by affecting the rate of photosynthesis which adds more organic matter to the plant. Therefore increase in light intensity in green plants increases the rate of growth and decrease in light intensity decreases the rate of growth.

v**) PH:** The PH affects the activity of enzymes which catalyzes reactions in the body. This can result into decrease in growth of an organism.
vi). **Carbon dioxide**: In animals, carbon dioxide is a waste product of metabolism. If allowed to accumulate, it can lead to a decrease in the rate of growth while in plants carbon dioxide is a raw material for photosynthesis therefore increase in carbon dioxide concentration increases the rate of growth.
B. **Internal factors**
i) Hormones: In animals, the presence of growth hormones and thyroxin in blood increases the rate of growth while in plants the presence of auxins also increases the rate of growth.
ii**) Hereditary factors**: Growth is under the control of genes which determines the particular size of an organism.

 **You can broaden the explanation to fit specific organisms.**

MEASUREMENT OF GROWTH

Growth is estimated by measuring some parameter; variable over a period of time. The parameter chosen depends on the organism whose growth is to be measured.

- Growth can be measured at various level of biological organizations such as growth of a cell, organism, or population.
- At the level of a cell, number can be considered and as well mass however it's just a relative measurement as it cannot absolutely give accurate measurements.
- At the level of an organism, there are a variety of parameters that can be used such as length, area, mass and volume.
- In plants, growth curves for roots, stems, internodes, and leaves are often used to indicate growth. In this length and area are the common parameters used.
- In animals, length and mass are commonly used parameters to indicate growth.

Note;
i. Mass and length are commonly used but these may be misleading for example; a bush may not increase in height nut may continue to grow in size by spreading sideways.
ii. Although area and volume give an accurate indication of growth, but are often impractible to measure.
iii. The measurement of mass has its problems of variation for example if an organism takes in a large amount of water, its mass increases which may be considered as growth yet it's temporary.

Types of measurement using mass.

a) **Fresh mass;** this is the mass of the organism under normal conditions. It is also known as wet mass. It is easier to measure and doing so involves no damage to the organism.
It may however be inaccurate due to temporary fluctuations in water content.
b) **Dry mass;** this involves removing all the water by drying before weighing. It is difficult to carry out and permanently destroys the organisms involved, but does give an accurate measure of growth.

- True growth/ actual growth of an organism is reflected by changes in the amounts of constituents; dry mass other than water.
- In measurement of growth, many a times groups of organisms are used rather than an individual which means that measurement of growth is many times

based on changes in a population. For example growth of beans, growth of yeast cells, growth of bacteria, etc.

GROWTH PATTERNS

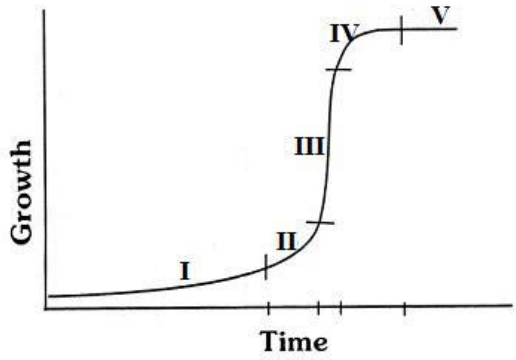
- ✓ When any parameter of growth is measured against set intervals of time, a growth curve is obtained.
- ✓ For many populations, organisms or organs, the growth curve is S-shaped is called sigmoid curve or the typical growth curve,

TYPICAL GROWTH CURVE:

This curve can be divided into four regions; parts;

1. **Lag phase**; I; little or no growth occurs.
2. The **logarithmic; log; accelerating phase; II**: rapid growth;

- There is a greater multiplication; increase in number of cells, increase in the amount of material present.



- The rapid growth phase may be limited by the nature of the organism under involved, it may as well be limited by externals factors such as food, predation etc.
- The exponential growth eventually declines and the rate of growth begins to reduce. The point at which this occurs is known as the inflexion point and at this point growth is at its maximum.

3. **Steady phase**; III; relatively constant growth. During this phase, the rate of growth increases and at any point growth is proportional to the amount of material or number of cells already present.
4. **Decelerating phase; IV; r**etardation phase: slowing growth;

- Growth becomes limited as a result of some internal factors such as the genotype of the individual or some external factors such as food or a combination of both external and internal factors.

5. **The stationary, plateau phase; V**: no growth;

- Here multiplication occurs but only at a rate that simply replaces those that have died. The size of the organism may remain constant but there is no increase in size.
- This phase usually marks the period where overall growth has ceased and the parameter under consideration remains constant. The precise nature of the curve during this phase varies depending on the species of organisms involved.

Exceptions to the typical growth curve;

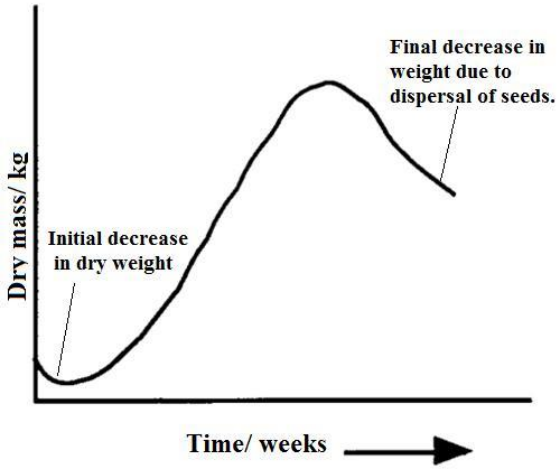
- When an organism continues growing till death like in monocotyledonous plants, invertebrates, fish and some reptiles and the curve continues increasing till that organism dies; thus showing positive growth.
- When the organism shows no measurable growth and the curve flattens e.g in the cnidarians thus showing zero growth.
- When the organism exhibits senescence and the curve tails off e.g in many mammals such as humans thus showing negative growth.

LIMITED AND UNLIMITED GROWTH CURVE

Growth in plants and animals shows two basic growth patterns. Limited; definite; determinate growth and unlimited; indefinite; indeterminate growth.

Limited growth;

- ✓ Growth in annual plants is limited and after a plant matures and reproduces, there is a negative growth or senescence before the death of the plant.
  - ✓ This is so because, the food reserves in the seeds are respired to produce energy for growth of roots and leaves.
  - ✓ Once the leaves begin to photosynthesize, growth proceeds in a sigmoid fashion. However, the liberation of fruits and sees at the end of the growing period, the mass of the plant decreases prior to death. This due to the natural limit of growth.



Unlimited growth;

- ✓ Woody perennial plants exhibit unlimited growth and have characteristic growth curve which is a cumulative series of sigmoid curves each of which represents one year's growth.
- ✓ With unlimited growth, growth continues until the plant dies. This kind of growth occurs in fungi, algae, and many animals particularly invertebrates, fishes, reptiles and monocotyledonous plants.



HUMAN GROWTH CURVE

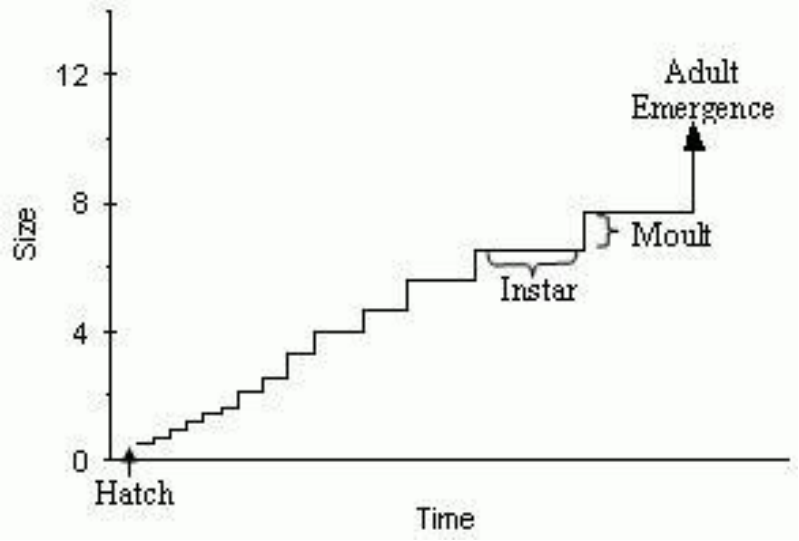
- In humans the growth curve of the whole body appears as a combination of two sigmoid curves. This is so because there are two phases of growth, one during the early years of life and the other during adolescence. Between these two phases, there is a period of relatively slow growth.

N.B. A period of rapid growth is known as a **spurt**.

POSITIVE AND NEGATIVE GROWTH

- × Growth can be positive or negative.
- × Positive growth occurs when synthesis of materials; anabolism exceeds breakdown of materials; catabolism.
- × Negative growth occurs when catabolism exceeds anabolism. For example in germinating seeds and the production of seedlings there is an increase in cell number, cell size, fresh mass, length, volume and complexity of form; anabolism, while at the same time dry mass actually decreases because reserves are being used up; catabolism. Thus germination includes a period of negative growth.

INTERMITTENT GROWTH/ GROWTH IN ARTHROPODS



☑ This is exhibited in most arthropods. As their exoskeleton is incapable of expansion, they have to moult periodically during growth. Before a new skeleton is has fully hardened, the arthropod is capable of expansion by taking up water to expand the skeleton as much as possible.

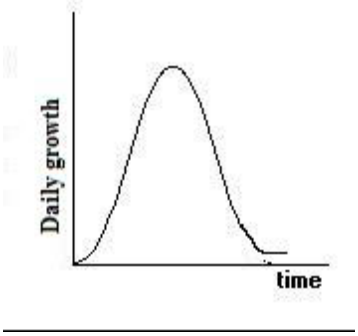
☑ Due to this their growth curve is discontinuous; it appears to be interrupted by a series of moults and spurts.

ISOMETRIC GROWTH

- This occurs when an organ grows at the same mean rate as the rest of the body. It occurs in fish and locusts. In these animals, the proportions of the structures remains constant; change in size is not accompanied by change in shape; form of the structure.
- In fish, depending on linear dimension, area, volume and mass, considering the head, tail and the entire body, increase in size of the body calls for the increase in size of the head and tail. Meaning that even if the fish grew very much bigger, the shape of the head and the tail would stay the same and proportionally show a related increase in size to the whole body

ABSOLUTE GROWTH CURVE

- This shows overall growth pattern and the extent of growth obtained by plotting data such as length, height or mass against time.



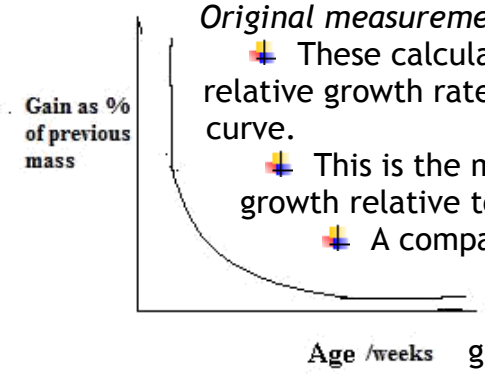
- The rate is measured as a change in a particular parameter such as height in a particular time.
- For example, it could be an increase in height of human over a period of one month. In particular, this curve shows a period when growth is most rapid and this corresponds to the steepest part of the absolute growth curve.
- The peak of the absolute growth curve marks the point of inflexion the sigmoid curve after which the rate of growths decreases as the adult size is attained.
- Generally, a bell shaped absolute growth curve is obtained from the sigmoid curve.

RELATIVE GROWTH RATE CURVE

This takes into account the existing size. Thus for example if a 3 year old and a 6 year old human grew each 5cm in height over a period of one year, they both have the have the same absolute growth rates, but however a 3 year old would be growing relatively faster and have a greater relative growth rate.

Relative growth rate (RGR) = $\frac{\text{Growth in a given period of time}}{\text{Measurement at the start of the time period}}$

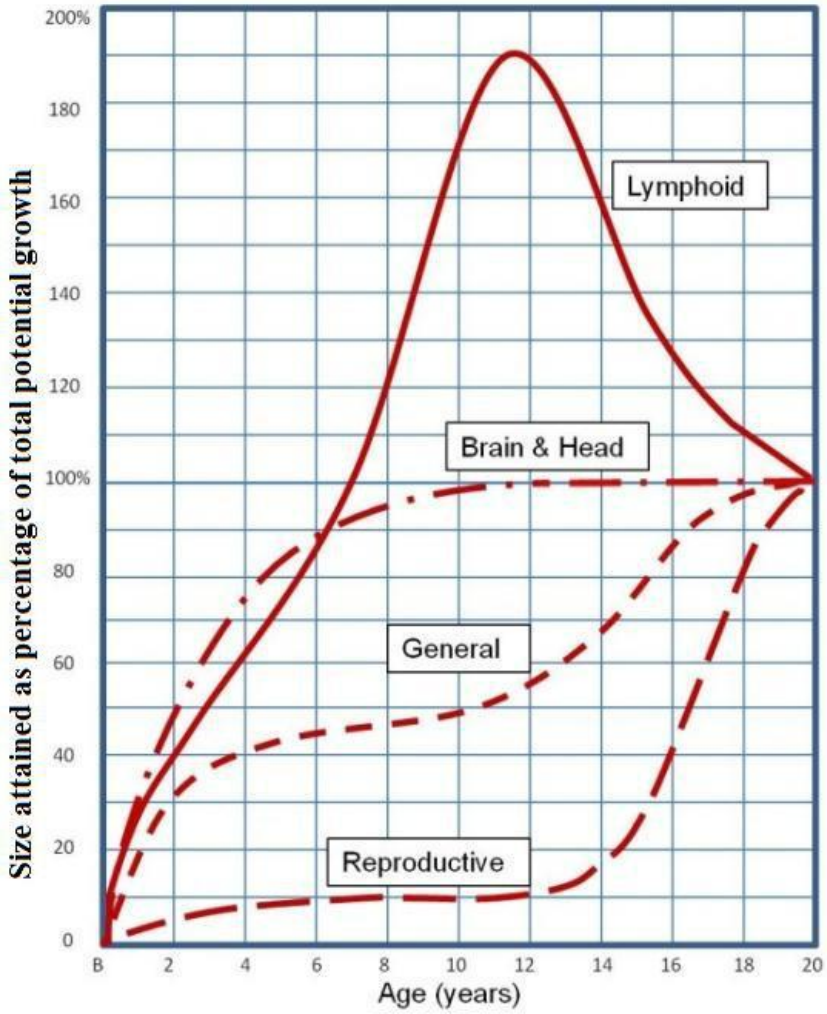
RGR = $\frac{\text{absolute growth rate}}{\text{Original measurement}}$



- These calculations give the relative growth rate. Changes in relative growth rate with time can be shown on the relative growth rate curve.
- This is the measure of the efficiency of growth; that is the rate of growth relative to the size of the organism.
- A comparison of relative growth rate curves for organisms grown or reared under different conditions shows clearly the most favourable conditions for a rapid growth and for growth over an extended period

ALLOMETRIC GROWTH.

- This occurs when an organ grows at a different rate from the rest of the body. Change in size of the organism is accompanied by change in shape of the organ.
- This pattern is a characteristic of mammals and illustrates the relationship between growth and development.



In animals, organs exhibit allometric growth.

✓ Lymphatic tissues, which produces white blood cells grows rapidly in early life when the risk of disease is greater and yet immunity has not been acquired. So the organism cannot defend itself from pathogens but must be protected from them. By adult life, the mass of lymph tissues is less than half of what it was in early childhood because the body has acquired immunity enough to defend it against infections.

N.B the thymus gland follows the same principle of the lymphatic tissues.

✓ The reproductive organs grow very little in early life but develop very rapidly with the onset of sexual maturity at puberty.

✓ Although in girls puberty occurs earlier than in males, this is because of the early secretion of oestrogen hormone that promotes development of reproductive organs and female sexual characteristics.

- ✓ In boys, the rapid increase is due to the testosterone hormone that maintains and enlarges the testes and as well responsible for the growth spurt in males at puberty.
- ✓ The head develops first as it accommodates the brain which has role of controlling the functioning of other body parts. In addition the brain develops and by the end of early childhood it cannot increase in size as it has to control the vital functions of the body for survival. The head is big is early development because it is where structures like the ear, mouth, nose arise from so it does enlarge to give room for development of the above structures.

RATE OF GROWTH

- This is dependent upon actual growth.
- Actual growth of an organism is the cumulative increase in size over a period of time.
- Rate of growth is a measure of the size increase over series of equal time intervals. For example instead of measuring the actual height of the plant we can measure the height over each 3 day interval.
- When rate of growth curve is plotted many a cases a bell-shaped curve is obtained.

GROWTH AND DEVELOPMENT IN PLANTS

GROWTH IN PLANTS

Growth in plants begins at the time of germination. Before the seed germinates, it may undergo a period of dormancy though exposed to conditions necessary for germination.

SEED DORMANCY

- ✓ This is a period or a state of suspended growth in viable seeds from the time of dispersal to the time of germination.
- ✓ In this period seeds fail to germinate in presence of water, oxygen and suitable temperature.
- ✓ They undergo certain internal changes described as <u>after-ripening</u> before they germinate.
- ✓ These changes ensure that premature germination does not occur. Mechanisms exist when the germination is synchronized with the onset of a season favourable for growth.

CAUSES OF SEED DORMANCY

- Hard seed coat
- Age of seed
- Lack of stimulating hormones
- Immaturity of seed
- Presence of inhibitors
- Light

ADVANTAGES OF AFTER RIPENING

- There's completion of embryo logical development i.e. when the embryo is immature.
- Physical and chemical changes may take place within the seed leading to improved germination.
- There may be germination inhibitors in the seeds these may disappear during these period.
- Germination stimulators may be synthesized leading to improved germination e.g. gibberellic acid internal physiological state of seeds and timing mechanism.

- Embryo logical immaturity.
- Embryo logical dormancy
- Presence of germination inhibitors e.g. ABA

TYPES OF SEED DORMANCY

1. **Innate; inborn / primary dormancy**; here the seeds after dispersal cannot germinate immediately. They only germinate after period of after ripening / storage this period leads to changes which are needed to improving germination.
2. **Induced; secondary dormancy**: seeds here achieve dormancy because of one factor missing
3. **Enforced dormancy**; is one which is thrust onto seeds by storage e.g. in stores, refrigerators.

BREAKING SEED DORMANCY

- Under natural condition, fire exposes seeds for radiation and it causes seed to germinate.
- Clearing of vegetation cover – this works for positively photoblastic seeds.
- By altering high and low temperatures. Some seeds in order to break dormancy need to hydrate them at low temperature (4 – 10^0C); stratification (cold storage). Stratification encourages

- Synthesis of germination promoters e.g. GA and decrease of germination inhibitors e.g. ABA.
- Improvement of seed coat permeability.
- Embryo development
  - Hard and resistant seed coat is broken by

-Breakdown by microorganisms in soil e.g. fungi
-Digestive actions enzymes of mammals, birds e.g. red pepper, passion fruits.
- Exposure to alternating low and high temperatures.
-Treatment of seeds using appropriate chemicals e.g. concentrated sulphuric acid, alcohol.
-Chipping / breaking of off pieces of seeds coat.

- Dormancy as result of embryo immaturity and is broken by allowing after ripening and chilling.
- Dormancy due to chemical inhibitors is broken by leaching seeds/ soils in which the seeds are planted; Stratification, treatment of seeds using germination stimulators e.g. GA, cytokinins etc.

Importance of dormancy

- Allows time for dispersal and hence colonization.
- Enables embryos to develop to full maturity.
- Transportation is easy.
- Prevents damage of fruits.
- Ensures longevity of seeds thus strong proper storage.

Note;
Longevity of the time the seeds last before they lose viability following shedding from the parent plant.
Wild species seeds last longer than their cultivated relatives e.g. ipomoea species and seeds can germinate after 43 years, India tutus 1000 years etc

External factors that affect germination

These are conditions in of the environment which must be present in order for germination to occur;

Light;

- The dormancy of some seeds maybe broken by light after water uptake, a phytochrome controlled response. It stimulates production of growth promoters such as gibberellins within the seed.
- Some seeds commonly require a cold period a process known as prechilling before germination to occur. This is associated with a rise in gibberellin activity and sometimes a reduction in growth inhibitors.
- It ensures that seeds pass through a cold spell of a particular length before germination and are less likely to germinate during a warm spell.
- This is so because cold treatments increase the permeability of the seed coat as well as changes in the levels of growth substances involved.

Temperature;

- Temperature affects enzyme controlled reactions such as respiration that produces energy for germination to occur, protein synthesis, that results into formation of new structures.
- At low temperatures, enzymes are inactive hence no energy production, at high temperatures, enzymes are denatured and therefore for germination to occur, optimum temperature is necessary.

Moisture;

- Water activates enzymes which hydrolyses the stored food for germination.
- Water is also important for dissolving and transportation of food within the embryo. Therefore for germination to occur, water musts be available. In absence of water germination may not occur.

Oxygen;

- This is required for aerobosis. Oxygen diffuses into the embryo via the thin seed coat or the micropyle.

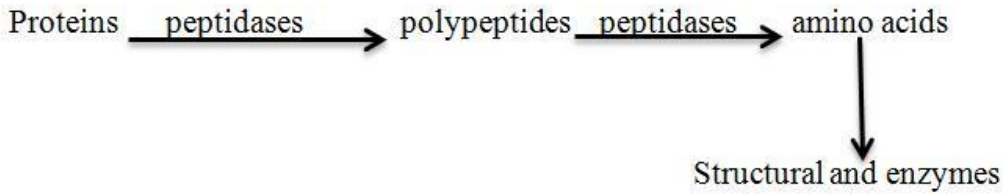
Soil structure;

-soil provide a substratum on which seeds germinate. Its structure affects germination. Response and subsequent establishment of seedling.
Microorganism activity help to perforate the seed testa, therefore improving the permeability of the seed to water and oxygen.

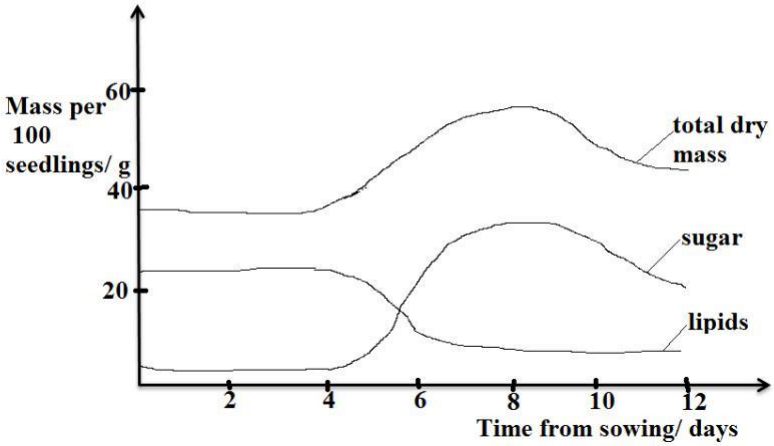
GERMINATION

This is the development of a mature embryo into a seedling.
This is the onset of growth in a seed after a period of dormancy. The seed embryo emerges and develops into a seedling capable of establishing itself as a new plant.

- The process begins with rapid uptake of water by imbibition and later by osmosis. Water causes the seed contents to swell and ruptures the testa; seed coat. Water also activates enzymes in the seed which hydrolyze insoluble storage materials into soluble substances.
- Proteins are converted into amino acids, carbohydrates such as starch are converted into glucose and fats are converted into fatty acids and glycerol.



- The soluble products are transported; translocated to the growing points of the embryo. The glucose, fatty acids and glycerol are respiratory substrates from which energy for growth is obtained.
- Glucose is also used in formation of cellulose cell walls.
- Amino acids are used in the formation of new enzymes and structural proteins within the new cells.



- Germination in starchy seeds e.g barley, synthesis of alpha amylase and other enzymes takes place in the outer layers of the endosperm in response to gibberellin secreted in the embryo. The outer layers contain stored protein which is the source of amino acids used in protein synthesis.
- Seeds which store lipid, convert them to fatty acids and glycerol. Each molecule of lipid yields three molecules of fatty acids and one glycerol.
- Fatty acids are either oxidized directly in respiration or converted to sucrose which is then translocated into the embryo.
- The swelling of the embryonic tissues formed and the softening of the testa ruptures the seed coat to allow the growth of the plumule and radicle.
- Temperature, oxygen and light now play a major role in controlling the physiological processes of germination.
- Root hairs develop in the region of maturation and the lateral roots may also develop further up. The plumule emerges from the cotyledons from which it derives its nourishment for some time.
- The seedling becomes an independent plant when foliage leaves reach above the ground level and becomes green to perform photosynthesis.

RESPIRATION IN GERMINATION

- ✓ Rates of respiration in both storage tissues and embryo are high owing to the intense metabolic activity in both regions. Substrates for respiration may differ in each region and may change during germination. To reveal this, respiratory quotient is used.
- ✓ Carbon dioxide is released and oxygen is used during respiration of seeds. The ratio of carbon dioxide released to oxygen used in a given period of time is called the respiratory quotient (RQ).
- ✓ RQ indicates the type of substrate oxidized and whether aerobic or anaerobic respiration is taking place.
- ✓ The testa of some seeds is relatively impermeable to oxygen so they respire anaerobically at the start of germination.
- ✓ Large heavy seeds such as broad beans have a small surface are to volume ratio which results in adequate supply of oxygen to respiring cells and they thus respire anaerobically.
- ✓ For these reasons the RQ can be greater than 1.0 during the first 24 to 48 hours; within two days of germination; anaerobic respiration.

- ✓ The RQ of seeds then falls to 0.7, this is because lipids are now being respired aerobically. However when a large quantity of lipids has been stored such as in castor seeds, the RQ at this stage may drop to as low as 0.35 owing to the aerobic conversion of lipids to sucrose.

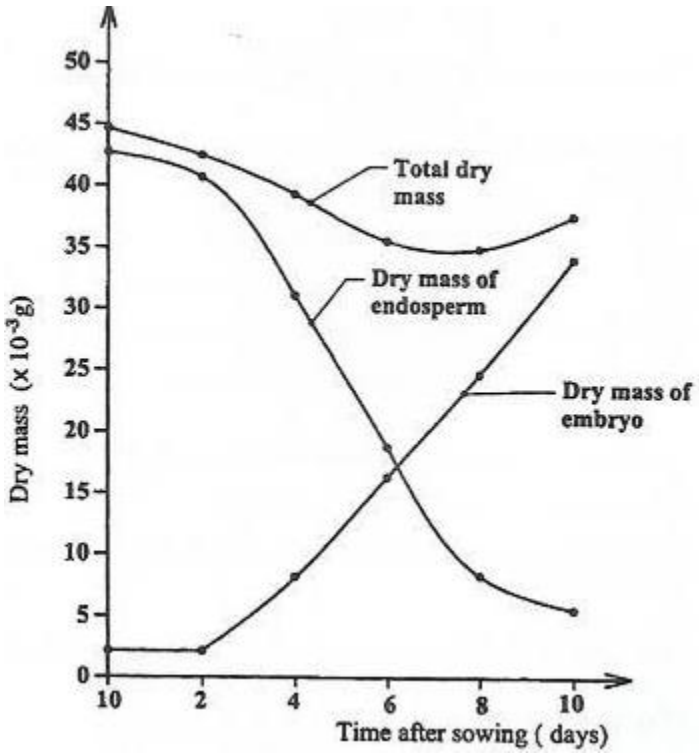
  $C_{16}H_{40}O_6 + 11O_2 \longrightarrow C_{12}H_{22}O_{11} + 4CO_2 + 9H_2O$:- RQ~ 0.36
- ✓ In carbohydrate rich seed the RQ increase to 1.0 as aerobic respiration of sugars goes underway.
- ✓ When the seeds start photosynthesing, the RQ gradually increases and finally becomes 1.0.

NOTE: To measure growth during germination; dry mass is used

CHANGE IN DRY MASS DURING GERMINATION

a) **Endosperm dry mass;** <u>decreases throughout germination</u>

- ✓ As a result of imbibition and osmosis, the endosperm becomes hydrated. This activates enzymes such as enzymes for respiration.



- ✓ Within the first 2 days, the respiratory enzymes oxidize the available simple molecules such as glucose for energy causing a gradual decrease in endosperm dry mass.
- ✓ The energy generated is used to synthesize digestive enzymes which break down starch, the main food storage form, in the endosperm to glucose. The glucose is then transported to the growing regions of the embryo causing more a rapid decrease in endosperm dry mass within 8 days of germination.
- ✓ Within about 10 days of germination, other food sources other than starch take effect.

b) **Embryo dry mass;** <u>increases in the first 2 weeks of germination</u>

- ✓ Within a period of 2 days of germination, the dry mass of the embryo is usually constant as this is a period of mobilization of seed for germination and no growth has taken place.
- ✓ Within 10 days of germination, the food molecules mobilized by digestion of stored food in the endosperm are transported to the growing regions of the embryo.
- ✓ The embryo starts to grow and so increase in dry mass this is then followed by the emergence of the first foliage leaf and starts photosynthesing this greatly increases the rate of growth of the embryo.

c) **Total dry mass of the seedling**; <u>decreases in the first week and increases thereafter;</u>

- ✓ In the first week, the overall loss in dry mass is due to the aerobic respiration which consumes glucose in both the endosperm and embryo. During this period, the rate of growth of the embryo less than compensates for the loss leading to an overall decrease in dry mass.

- ✓ After a week. The first foliage leaf emerges and starts photosynthesizing, resulting into an increase in stored food causing an increase in total dry mass of the seedling.

TYPES OF GERMINATION

There are two types of germination depending upon whether the cotyledons grow above the ground or remain below it.

1. **Hypogeal germination;**

- This is a type of germination where the epicotyl; region; internode above the cotyledons elongates faster than the hypocotyl; region; internode below the cotyledon. This causes the plumule to emerge out of the ground and the cotyledons remain underground.
- The epicotyl is hooked protecting the plumule tip from soil resistance. On exposure to light, the hooked epicotyl straightens, a phytochrome controlled response.
- Examples of plants; most cereals and broad bean.

2. **Epigeal germination;**

- This is a type of germination in which the hypocotyl elongates faster than the epicotyl thus becoming the first structure to emerge from the ground surface. The hypocotyl emerges while hooked in order to protect the delicate plumule from soil resistance, the cotyledons are carried above the ground. On exposure to light, the hypocotyl straightens and eventually the cotyledons dry and fall off.
- Examples; peas

NOTE:

- In monocots, the plumule is protected by a sheath celled coleoptile, which is positively phototropic and negatively geotropic. The first leaf grows out through the coleoptile and unrolls in response to light.
- On emerging into light, a number of phytochrome controlled responses occur rapidly in leaves collectively known as photomorphogenesis. The overall effect is the change from etiolation to normal growth. Expansion of the cotyledons or first true leaves and formation of chlorophyll starts the process of photosynthesis and net dry mass of the seedling starts to increase as it finally becomes independent of its food reserves.

MERISTEMS IN PLANTS

Growth in plants is confined to certain regions known as **meristems**

A meristem; is a group of cells which retain the ability to divide by mitosis, producing daughter cells which grow and form the rest of the plant body; actively growing tissues.

- ✓ The cells in the meristems are undifferentiated and are capable of repeated divisions by mitosis to form new cells.
- ✓ The cells have cell walls and large vacuoles. The daughter cells thus form the permanent tissue; cells which have lost the ability of division.

TYPES OF MERISTEMS

1. **Apical meristems;**

- These are found at the shoot and root apex; tips. They result into increase in length; primary growth which gives rise to primary plant body.

2. **Lateral; cambial meristems**;

- These are laterally situated in older parts of the plant parallel with the long axis of organs e.g cork cambium; phellogen and vascular cambium. They are

responsible for increase in girth that results in secondary growth. The vascular cambium gives rise to the vascular tissue, including wood; secondary xylem, cork cambium gives rise to periderm which replaces the epidermis.

3. **Intercalary meristems;**
   - These are located between regions of permanent tissue e.g at nodes of monocotyledonous plants, such as bases of grass leaves.
   - They allow growth in length in regions other than the tips. This is crucial if the tips are subject to damage e.g being eaten by herbivores, wave action among others.

TYPES OF GROWTH IN PLANTS

PRIMARY GROWTH:

- This is the first form of growth to occur which results in elongation of the shoot and root system. It starts at germination and continues at the apical meristems.
- In monocots and herbaceous dicots, primary growth is the only type of growth that occurs. It is a combined effect of the apical, and intercalary meristems but to a limited extent.
- In some plants growth continues from the lateral meristems; secondary growth. This is seen for shrubs and trees. Plants which lack extensive secondary growth are called herbaceous plants or herbs.
- A few herbaceous plants exhibit some part of secondary thickening e.g in the development of the additional vascular bundles in sunflower.

N.B primary growth involves majorly, cell division, cell elongation and cell differentiation.

APICAL MERISTEMS AND PRIMARY GROWTH

- ✓ A typical apical meristem cell is relatively small, cuboid, with a thin cellulose cell wall and dense cytoplasmic contents. It has a few small vacuoles and the cytoplasm contains small, undifferentiated plastid called proplastids.
- ✓ Meristematic cells are tightly packed together with no obvious air spaces between them. The cells are called initials.
- ✓ When they divide by mitosis one daughter cell remains in the meristem while the other increases in size and differentiates to form part of the permanent plant body.

PRIMARY GROWTH IN THE SHOOT

In the apical shoot meristem, cell division starts from the apex followed by cell enlargement and cell differentiation. Passing back from the dome shaped apical meristem, the cells progressively get older.

In the shoot, the apical meristem is composed of an outer coat called the tunica surrounding a central mass of meristematic cells called the corpus.

Cell division

- ✓ There are three basic types of tissues that occur in the meristem of the shoot;

a. Protoderm; this gives rise to the epidermis.

b. Procambium; this gives rise to the vascular tissues, including the pericycle, primary phloem, vascular cambium and primary xylem.

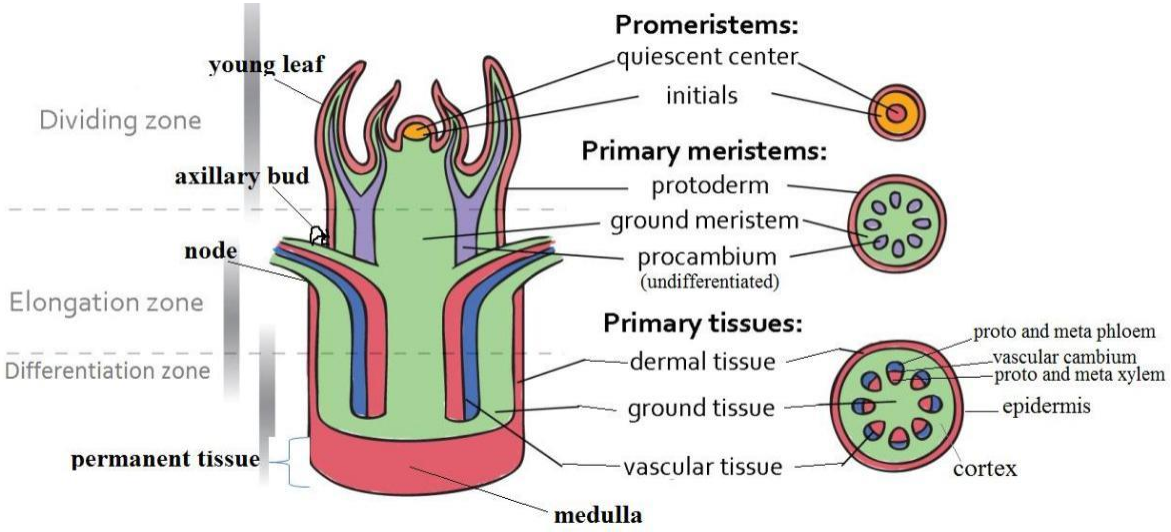
c. Ground meristem; this gives rise to the parenchyma tissues which in the dicots are the cortex and pith.

These meristematic tissues are produced by division of meristematic cells; initials at the apex.

In the region of cell enlargement/ elongation;

- ✓ The daughter cells produced by the initials increase in size mainly by osmotic uptake of water into the cytoplasm and then into the vacuoles.
- ✓ The small vacuoles increase in size, eventually fusing to form a single large vacuole. The pressure potential developed inside the cells stretches the thin walls and the orientation of the microfibrils in the walls determines the final shape assumed by the cells.
- ✓ As enlargement nears completion, many cells develop additional thickening of the cell walls either of cellulose or lignin depending upon the type of cell being formed. This may restrict further expansion but may not necessarily prevent it.
- ✓ Collenchyma cells in the cortex, for example, can continue elongating while extra cellulose is laid down in columns on the inside of the original cell walls.
- ✓ Thus they can render support to the plant while they are still growing.
- ✓ Developing sclerenchyma cells deposit thick layers of lignin on their walls and soon die. Thus their differentiation does not start until enlargement is virtually completed.

Longitudinal and transverse sections through the apex of a dicot



In the region of differentiation;

- The first cells to differentiate in the procambium are those of the protoxylem to the inside and to the outside protophloem. These are the parts of the primary xylem and phloem respectively, which form before elongation is complete.
- The protoxylem typically has only annular and spiral thickenings of lignin on tracheids. Both the protoxylem and protophloem elements soon die and generally get crushed and stretched to the point of collapse as growth continues around them.
- Their function is taken up by later developing xylem and phloem in the zone of differentiation.
- In this region, each cell becomes fully specialized for its own particular functions according to its position in the organ with respect to other cells.
- The greatest changes occur in the procambial strands, which differentiate into vascular bundles. This involves lignification of the cell walls of the sclerenchyma fibres and xylem elements, as well as development of the tubes a characteristic of xylem vessel and phloem sieve tubes.

- Between the xylem and phloem there are cells which retain the ability to divide. They form the vascular cambium, which is responsible for secondary thickening.

LEAF PRIMORDIA AND LATERAL BUDS

Development of the shoot also includes growth of leaves and lateral buds. Leaves arise as a small swelling or ridges called leaf primordia.

- ✓ The swellings contain groups of meristematic cells and appear at regular intervals, their sites of origin being the nodes and the regions between called the internodes.
- ✓ The pattern of leaf arrangement on the stem varies and is called phyllotaxis. Leaves may arise in whorls with two or more leaves at each node, singly in two opposite ranks or in a spiral pattern.
- ✓ Leaves are arranged in such a way to minimize overlapping, and hence shading only when fully grown so that they can forma a mosaic.
- ✓ The primordia elongate rapidly so they soon enclose and protect apical meristems, both physically and by the heat they generate in respiration. Later they grow and increase in area to form the blades.
- ✓ Buds also develop in the axils between the leaves and the stem. These are small groups of meristematic cells which normally remain dormant, but retain the capacity to divide and grow at a later stage.
- ✓ They form branches or specialized structures such as the flowers and underground structures such as the rhizomes and tubers.

Functions of apical shoot meristems

2. Gives rise to all primary tissues of shoot
3. Produces longitudinal growth in length
4. Leaf primordial gives rise to buds and leaves.
5. Procambium gives rise to vascular tissue and increase in girth of shoot.

PRIMARY GROWTH OF THE ROOT

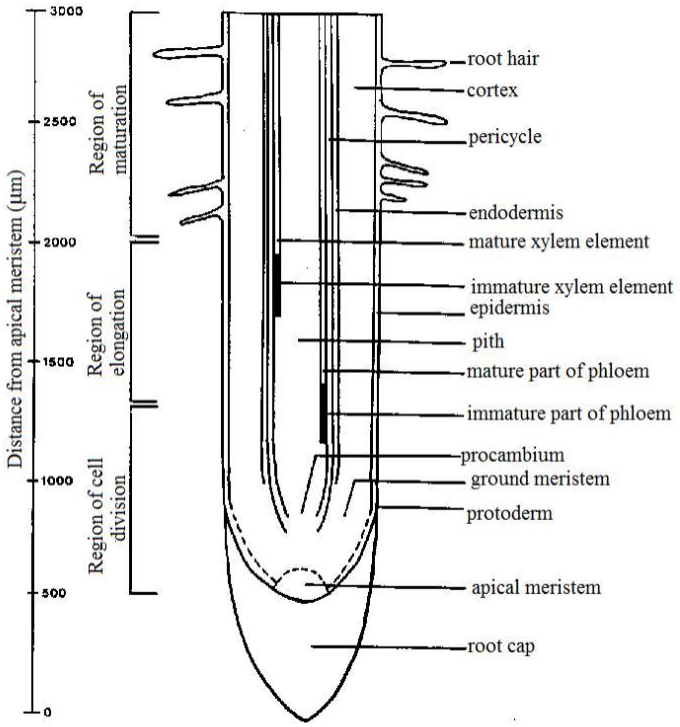
- At the tip of root apical meristem is a quiescent zone; a group of initials from which all other cells in the root can be formed; originate.
- To the outside, the cells of the root cap are formed. These become large parenchyma cells which protect the apical meristem as the root grows through the soil.
- They are constantly being worn out and replaced. They also have an additional function of sensing gravity. This is so because they contain starch grains which act as statoliths, sedimenting to the bottoms of the cells in response to gravity

***understanding biology page 581 below fig 29.3**

- Behind the quiescent centre, orderly rows of cells takes place and the meristematic regions; protoderm, procambium and ground meristem are formed.
- Behind this zone, there is mainly enlargement. The zone of enlarging cells extends and increases in length forcing the root tip down through the soil.
- Some cell differentiation begins in the region of cell division, with development of the first phloem sieve tube elements.
- Further back in the zone of enlargement, the xylem vessels start to differentiate also from the outside; exarch xylem in contrast to that in the stem which starts from the inside; endarch xylem.

- The first formed vessels are the protoxylem vessels and they exhibit the same pattern of lignification and the ability to stretch as cells around them grow.
- Their role is taken up by the metaxylem, which develops later and matures in the zone of differentiation after enlargement has ceased.
- Further differentiation is completed by development of root hairs from the epidermis.

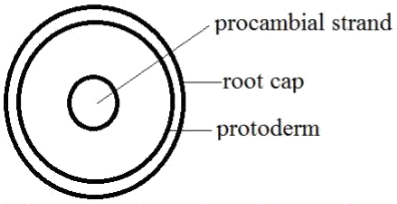
Longitudinal section through the root apex of a dicot



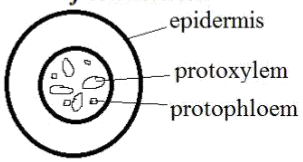
Functions of root apical meristems;

- The root cap protects the delicate growing tip.
- Cell division and expansion contributes to overall elongation of root
- Cell differentiation gives rise to different kinds of root tissues; xylem, cambium, etc.
- Vascular tissue contributes to increase in girth of the roots.

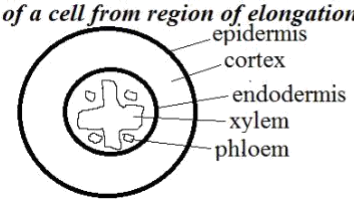
T.S of a cell from region of differentiation



T.S of a cell from region of cell division



T.S of a cell from region of elongation



SECONDARY GROWTH

Secondary growth is the growth which occurs after primary growth as a result of the activity of the lateral meristems.

It results in an increase in girth. It associated with deposition of large amounts of secondary xylem called wood which completely modifies the primary structure and is a characteristic feature of trees and shrubs.

Types of lateral meristem;

- **Vascular cambium**; which gives rise to new vascular tissue.
- **Cork cambium or phellogen**; which arises later to replace the ruptured epidermis of the expanding plant body.

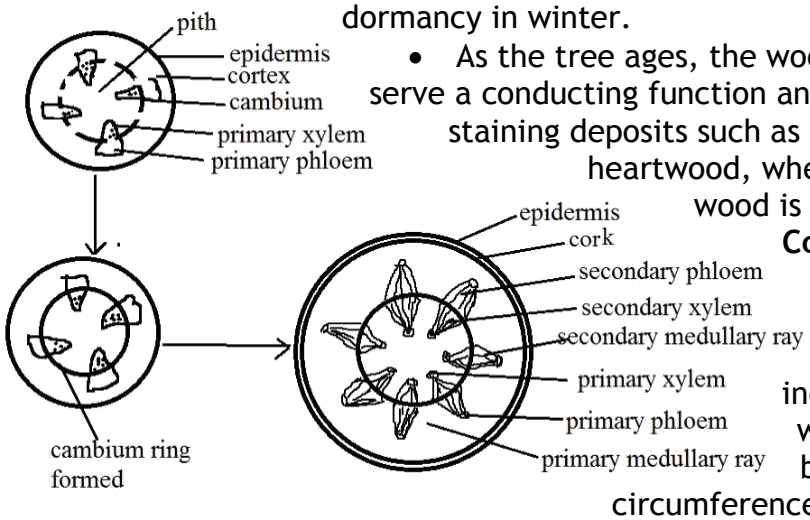
VASCULAR CAMBIUM

- ✓ There are two types of cells in the vascular cambium; the fusiform initials and the ray initials.
- ✓ Fusiform initials are narrower, elongated cells and divide by mitosis to secondary phloem to the outside or secondary xylem to the inside. Secondary phloem contains sieve tube and companion cells, sclerenchyma fibres and sclereids and parenchyma.
- ✓ Ray initials are spherical and divide by mitosis to form the parenchyma cells which accumulate to form rays between neighbouring xylem and phloem.

SECONDARY GROWTH IN WOODY DICOTYLEDONOUS STEMA

The vascular cambium

- This is originally located between the primary xylem and primary phloem of the vascular bundles. It becomes active very soon after primary growth is complete. During secondary thickening, fusiform initials produce large quantities of secondary xylem and lesser quantities of secondary phloem, while the ray initials have to produce rays of parenchyma.
- As the stem increases in thickness, so the circumference of the cambium layers increase and radial divisions of the cambial cells occurs.
- The original ray initials produce primary medullary rays which run all the way from the pith to the cortex. The rays maintain a living link between the pith and the cortex.
- They transmit water and mineral salts from the xylem and food substances from the phloem, radially across the stem.
- Also, gaseous exchange can occur by diffusion through intercellular spaces. The rays are used for food storage, an important function during periods of dormancy in winter.
- As the tree ages, the wood at the centres ceases to serve a conducting function and become blocked with darkly staining deposits such as tannins; it is called heartwood, whereas the outer conducting wood is called sapwood.



Cork cambium;

- As the secondary xylem grows outwards, tissues outside it become increasingly compressed, as well being stretched sideways by increasing the circumference.

Fig above shows Secondary growth in a dicot stem

- This affects the epidermis, cortex, primary phloem. The epidermis ruptures and is replaced by cork as a result of the activity of the second lateral meristem; cork cambium; phellogen. It arises immediately below the epidermis. Cork or phellem is produced to the outside of the cork cambium, while to the inside one or two layers of parenchyma are produced.
- As the cork cells mature, their walls become impregnated with a fatty substance called suberin, which is impermeable to water and gases. The cells gradually die and lose their living contents, becoming filled with air of with resin or tannins.

- The older, dead cork cells fit together around the stem preventing desiccation, infection and mechanical injury. They become compresses as the stem increases in girth and may eventually be lost and replaced by younger cells from beneath.
- At random intervals, slit openings; lenticels, develop in the cork which contain a mass of loosely packed , thin walled dead cells, lacking suberin. They are produced by the cork cambium and have large intercellular air spaces allowing gaseous exchange.

BARK

- ✓ Eventually a woody stem becomes covered with a layer commonly known as bark. Bark refers to either all the tissues outside the vascular system, or more strictly to those tissues outside the cork cambium.
- ✓ Peeling the bark from a tree strips tissues down to the vascular cambium, a thin layer of cells which is easily ruptured.
- ✓ It is usual for the cork cambium to be renewed each year as the girth of the stem increases, often a cork cambium arises in secondary phloem.
- ✓ In whichever case the bark will, over many years build up a layered appearance due to alternating layers of secondary phloem and cambium.

NOTE: Growth and development in humans is controlled by hypothalamus and pituitary gland * refer to coordination in animals*.

GROWTH AND DEVELOPMENT IN INSECTS

These are thus stages of development through which an organism passes during growth and development.
Insect metamorphosis is series of changes that occur between the larval and adult forms. They usually involve major reorganization of larval forms.

TYPES OF METAMORPHOSIS

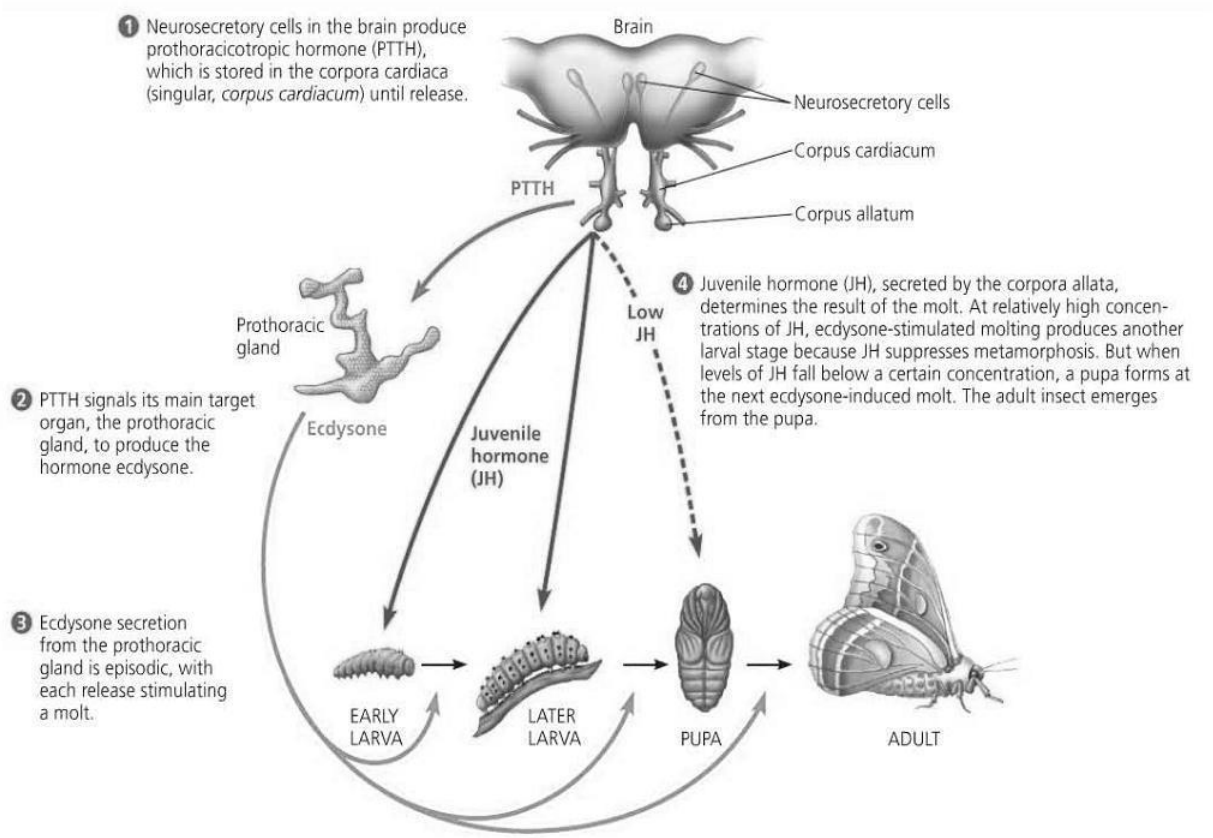
- **Hemimetabolous**; incomplete metamorphosis: the eggs hatch into nymphs which clearly resemble the adults except that they are smaller, lack wings, and are sexually immature. There are a number of nymphal stages between which moulting occurs. Examples of hemimetabolous insects; cockroach, grasshopper, and locusts.
- **Holometabolous**; complete metamorphosis: the eggs hatch into larvae which differ considerably from the adult. Each larva undergoes a series of moults until it changes its appearance and becomes a dormant stage known as pupa. After much reorganization of the tissues, within the pupa, the adult; imago emerges. Examples of holometabolous insects include; butterflies, housefly, bees, moth among others.

Importance of larval stage

- It allows for growth since between various moults, increase in size occurs.
- Prepares the insect for the dormant stages like building up resources.
- The larva and adults may occupy different ecological niches thus reducing competition and as well increasing the ecological range of insects.
- The larva maybe food to another organism thereby providing a link the food chain.

ECDYSIS

The shedding process is known as moulting or ecdysis and it takes place by secretion of a moulting fluid immediately beneath the cuticle.



This dissolves the soft inner part of the cuticle, leaving only the hard outer part. Meanwhile the new cuticle, soft at first is secreted by the epidermis. It is protected from enzymatic action of the moulting fluid by its protective surface. It is destined to become the hard cuticle for the next instar.

- Instars these are series of larval stages with each successive stage resembling the adult more closely.

The cuticle is composed of chitin, a complex nitrogen-containing polysaccharide. Hardening of the outer part is achieved by the chitin being impregnated with tanned; hardened proteins. Water proofing of the cuticle is achieved by the deposition of a layer of wax at the surface.

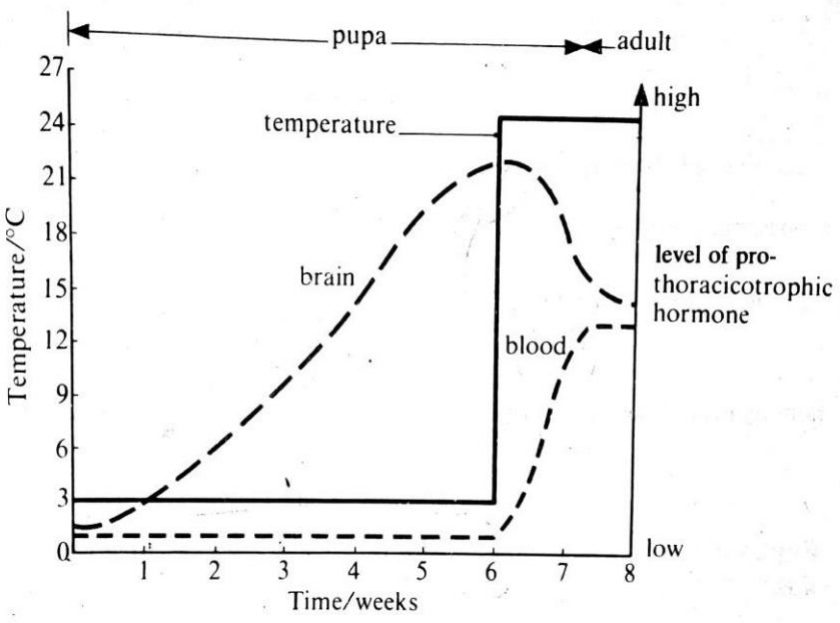
CONTROL OF INSECT METAMORPHOSIS

The control of insect metamorphosis involves three main hormones;
Ecdysone; moulting hormone and juvenile hormone; neotonin and brain hormone; prothoracic trophic hormone (PTTH)

- The **brain hormone**; PTTH is produced by the neurosecretory cells and is stored in the corpus cardiacum. This controls the production of the other two hormones; Ecdysone and juvenile hormone.
- **Moulting hormone** is produced by the prothoracic gland in the first thoracic segment; prothorax.
- **Juvenile hormone** is produced and stored in the corpus allatum. It ensures retention of the juvenile characters during early moulting. A low level of juvenile characters during early moulting of the larva forms into pupa.

Mechanism;

- ✓ Changes in light intensity or temperature or the distension of the gut following a meal causes brain to send impulses to the corpus cardiacum to release a hormone prothoracic trophic hormone. This flows into the pro thorax where it stimulates the prothoracic gland to secrete a steroid hormone, Ecdysone; moulting hormone this causes the shedding off of the cuticle and growth. It does so by switching genes needed to produce enzymes necessary for growth.



Graph showing changes in PTTH during moulting

- ✓ The moulting hormone certainly rises the metabolic rate, and increases the rate at which amino acids are built up into proteins in the growing tissues.
- ✓ Ecdysone exerts most of its effects in the epidermis. It causes the epidermis to thicken out and separate from the old cuticle, then new cuticle forms over the epidermis. This is so because of the moulting fluid secreted by the epidermis that contains enzymes, chitinase and protease these break down the old cuticle and the new cuticle is shielded from these enzymes by the new epicuticle.
- ✓ Old cuticle is digested and materials from it are reabsorbed and incorporated into the new endo cuticle.
- ✓ Regions immune to digestion are hardened sclerities of the exocuticle and old epicuticle.
- ✓ When the new cuticle is completely formed, the organism swells by taking in air or water and splitting the remains of the old cuticle and allowing organism to emerge.
- ✓ The new cuticle is soft and is hardened by tanned proteins. Eventually the larva metamorphoses into imago.

Note;

- ✓ Juvenile hormone secreted by the corpus allatum determines the product of the molt. At relatively higher concentration of juvenile hormone, ecdysone stimulated moulting produces another larva stage. At low level of juvenile hormone, causes formation of a pupa at another ecdysone induced moult.

METAMORPHOSIS IN AMPHIBIANS

- The initial stimulus is change in environmental temperatures or day length. This activates the hypothalamus to secrete the thyrotrophic releasing hormone, which enters the hypothalamico-hypopyseal portal system and through which it passes to the anterior pituitary gland stimulating it to secrete thyroid stimulating hormone which enters the general circulation and stimulates the thyroid gland to secrete thyroxine and triiodothyronine.

- These have direct effects on body tissues; causing atrophy; wasting away of tails and gills, accelerated growth of limbs, tongue, accelerated differentiation of the skin forming glands and chromatophores, change of larval visual pigment; porphyropsin to adult rhodopsin

Significance of moulting in amphibians

- Development of limbs for support and locomotion on land this is so as water provides more support however air provides less support.
- Development of the tongue for firm grip of prey to prevent it from escaping.
- Rhodopsin for vision; increases sensitivity to light making vision of prey, obstacles and entry into hidden burrows possible; nocturnal life.
- Chromatophores give skin colour for camouflage such as dark colour on the surface to blend on land.
- Lungs replace gills for external respiration this so because gills collapse in absence of water as it provides support and makes them moist for effective gaseous exchange.
- Tail is lost due to development of the four limbs for locomotion and support; the tail has role to play.
- Glandular skin to make the skin moist for dissolution of respiratory gases in order to ease their diffusion.

GROWTH AND DEVELOPMENT IN VERTEBRATES

This is development which follows fertilization in animals and can be divided into three stages.

1. **Cleavage;** the mitotic division of the zygote to form a ball of cells; blastocyst.
2. **Gastrulation**; the arrangement of cells into definite layers.
3. **Organogenesis**; the differentiation of cells to form organs.

CLEAVAGE

- After fertilization, the nucleus of the zygote divides mitotically, followed by cleavage of the cytoplasm, a series of smaller cells called blastomeres are formed. These divisions continue resulting in an embryonic structure called the blastula.
- The blastula has a cavity at the centre called a blastocoel. The extent of cleavage depends on how much yolk is present, as yolk inhibits cleavage. Where an animal has little or no yolk in the egg e.g in amphioxus, cleavage involves the whole cell and the blastomeres are small and equal in size.
- When much yolk is present in the egg as in the toad, it is normally concentrated at the vegetal pole, with much less, if any at the animal pole. Cleavage is inhibited at the vegetal pole and a few large cells called macromeres result. By contrast, cleavage occurs rapidly at the animal pole, producing many small cells called micromeres.

GASTRULATION

- This involves the in pushing of one side of the ball of cells to produce a cavity called the archenteron, which later forms the gut. The structure as a whole is called a gastrula. At this stage the cells of the structure have their final fates determined; it is possible to predict their functions in the developed organism.
- These presumptive areas, as they are called can be mapped with accuracy. During gastrulation the cells of these presumptive areas migrate to their correct germ layers.
- **The inner; endoderm, middle; mesoderm, and the outer; ectoderm**.

- The endoderm forms the; lining of the gut, bladder, lungs, liver, pancreas, thyroid glands and germinative epithelium.
- The mesoderm forms the: striated and smooth muscle, connective tissue; bone, cartilage, blood. Heart, reproductive system and eyes.
- The ectoderm forms the: skin, scales, hair, feathers, jaws, feather, jaws, nerves and central nervous system.

ORGANOGENESIS

- The cells of the gastrula continue to divide and become differentiated. The ectoderm folds inwards to become the neural tube which later develops into the nerve cord, the anterior part of which expands to form the brain. The embryo at this stage is called neurela.
- The mesoderm forms a notochord which in vertebrates is replaced by a vertebral column. The gut increases in length and become folded and gradually all the major organs such as the heart develop.
- At this stage a lot of differentiation of structures occurs takes place.

END OF TOPIC REPRODUCTION, GROWTH AND DEVELOPMENT

I am grateful we have shoot the syllabus dead. Great work as a group. I now expect the best of come the examination period. In the topic above we looked at a number of aspects starting with sexual reproduction, reproduction in flowering plants, fertilization and development in flowering plants, reproduction in mammals, sexual cycles, fertilization and development in mammals and finally growth.
Thank you very much now try out the questions below.

QUESTIONS:

1. Explain what is meant by term alternative generation? (02marks)
   b. Compare the life cycle of a moss and fern (13marks)
   c. What is the importance of alternative generation to the life of a moss and fern?
2. State the similarities and differences between bryophytes and pteridophytes
   b. Discuss the significance of alternation of generation to the life histories of plants
3. Explain why ferns are more adapted to terrestrial life than mosses. (08marks)
   b. How does temperature influence the following process in plant?
      i. Plant growth (07marks)
      ii. Plant distribution (05marks)
4. Describe the process of fertilization in higher plants
   (b) outline the events which tape place after fertilization
5. a)What is meant by double fertilization in flowering plants? (4marks)
   (b) Explain how:
   (i) asexual reproduction produces offspring identical to the parent (4marks)
   (ii) sexual reproduction cause variation among offspring. (5marks)
   (c) Under what circumstances may variation
   (i) occur in asexually produced individuals (3marks)

(ii) not occur in sexually produced individuals
6.Outline the events that lead to the formation of pollen grain in flowering plants.
b.How does the development of Embryo sac in flowering plants differ from oogenesis in humans? (4marks)
c.Give an outline of the life cycle of a named pteridophyte.
7. What is the effects of inbreeding in a population? (02marks)
(b) Describe the mechanism which limit inbreeding in plant (10marks)
(c) How does meiosis contribute to variation?
8. Some viable seeds are not able to germinate immediately they are dispersed from their parent plant even when all necessary for conditions for germination are provided. Discuss
9. The use of seed and other planting materials are common methods in plant propagation. Using named examples, give the advantages and disadvantages of each method
(a) Describe mechanisms which promote out-breeding in monoecious m plants.
(b) Explain how sexual reproduction cause variations
10(a) Describe the hormonal interaction in the human female from conception to birth.
(b) Suggest possible causes of infertility in human (10marks)
11. (a) Describe how the method of fertilization and other reproductive strategies in mammals have contributed to their evolutionary success.
(b) Give an account of hormonal control of spermatogenesis.
12. Describe the structure and function of human placenta (20marks)
13. Write an essay on the gametes and their formation (20marks)
14. (a) illustrate and label the principle parts of a spermatozoa indicating the function of each part
b. Compare the changes which take place in the reproductive organ leading to the formation of gametes in man
15. Outline the similarities in sexual reproduction between male flowering plant an animal.
b. Describe how hormones from the ovary and pituitary gland interact to control the human menstruation cycle.
16. (a) describe how the following tissues bring about growth in higher plants
i. Apical meristem
ii. Vascular meristems
b. How does growth in mammals differ from that in flowering plants?
17. (a) Describe the physiological changes that occur in a seed during germination
a. Giving reasons, suggest suitable conditions under which seeds for planting should be stored (06 marks)
(c). Even when supplied with suitable conditions for germination, some seeds remain dormant, explain the importance of dormancy in seeds. (04 marks)

UACE QUESTIONS FOR THE PREVIOUS YEARS FROM THE TOPIC ABOVE

YEAR	P1	P2		YEAR	P1	P2		YEAR	P1	P2
2015	43			2010		1, 3		2006	43	
2013	45			2009		5		2005		6
2012		1		2008	42, 43	2		2003	43	2, 4
2011		4		2007	43			2001	46	1

DETERMINING THE POPULATION OF MICROORGANISMS/ CELLS

- Micro-organisms are found many cases in solution. Thus method requires us to use microscopic knowledge as follows.

- The culture solution where number of micro-organisms is to be determined is obtained.
- Using a dropper a few drops are obtained from the solution and put on a microscopic slide of a microscope; preferably a cavity slide.
- A drop of methylene blue is added to the solution on a slide in order to immobilize them and either stop their motion or reduce it to enable us count clearly.
- By observing under low and high power, the number of organisms is counted taking in account of the area of view of the microscope.
- Viewing under low power and high power enable us to determine which power give a clear magnification. The procedure is repeated and the average of the counting is obtained.

This method applies to **yeast cells, bacteria, protozoa** among other micro-organisms.

ACQUIRED IMMUNE DEFIECIENCY SYNDROME

- AIDS is caused by the human immune deficiency virus (HIV). It is a spherical retrovirus.
- Once infected with HIV an individual is said to be HIV positive. As the virus remains dormant for about 8 years, on average, an HIV positive person does not show any symptoms during this period but can act as a carrier, often unwittingly spreading the disease.
- The concentration of the virus is high in semen, vaginal fluid and blood that's why it is commonly transmitted via sexual intercourse.
- Having entered blood HIV infects blood cells carrying T-helper cells. It becomes enclosed in the cell membrane and so its antigens do not stimulate an immune response from the lymphocytes in blood.
- Replication of the virus is controlled and it frequently becomes latent. It is in months or years that replication recommences

Symptoms;

- Oral rush, this often an early symptom, Tuberculosis and pneumonia, Loss of weight, Skin cancer; Kaposi sarcoma and loss of memory and coordination.

Note; AIDS has no cure. So the disease is deadly due to its effect on the T-helper cells.

Answer question 4 in advanced biology by Micheal kent section 15.20.

"More questions in simplified Approach to Advanced level biology by the same author"

WISH YOU THE BEST. THANK YOU.