CELL BIOLOGY

The study of cells is known as cytology. A cell is a fundamental unit of life. All organisms whatever their type or size are composed of cells.

The cell theory states that;

1. All living organisms are composed of cells.
2. All new cells are derived from other cells.
3. Cells contain the hereditary material of an organism which is passed on from parent to daughter cells.
4. All metabolic processes take place within cells.

INVESTIGATION OF THE CELL STRUCTURE

Cells are investigated using microscopes. There are 3 main types of microscopes, i.e.

- Compound light
- Electron
- Phase contact

The 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 close together.

The electron microscope

It works on the same principle as the light microscope but instead of light rays, a beam of electrons is used. It magnifies objects over 500,000 times which compares with the best light microscope that magnifies only 1500 times.

Whereas the light microscope uses glass lenses to focus light rays, the electron beam of the electron microscope is focused using electron beams.

The image produced cannot be detected by a naked eye but is directed on a screen from which black and white photographs called photoelectron micrographs can be seen.

Advantages and disadvantages of the light and electron microscope

Light microscope	Electron microscope
(advantages)	**(disadvantages)**
It is easy and cheap to operate since it uses little or no electricity.	It is difficult and expensive to operate since it requires much electricity to produce an electron beam.
The natural colour of the specimen can be observed.	All images are in black and white.
It is small and portable.	It is very large and operated in special rooms.
It can view living and dead materials.	The high vacuum required kills the living materials.
Preparation of material is quick.	Preparation of material is lengthy and requires special equipment.
Materials are not changed or distorted by preparation.	Materials are changed or distorted by preparation.
Disadvantages	**Advantages**
It has a low resolving power i.e. 200nm.	Has a high resolving power of about 1nm.
It has a low magnifying power i.e. up to 1500 times.	Has a high magnifying power i.e. up to 500,000 times.

CYTOLOGY

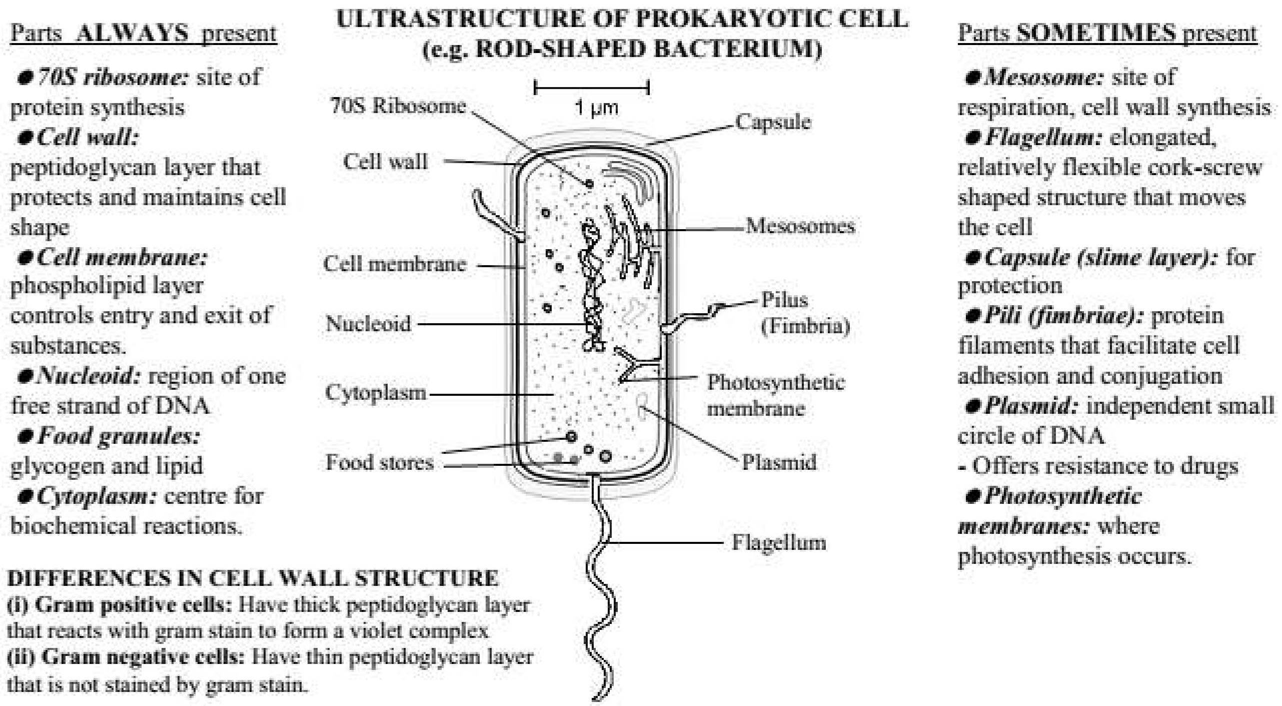
All cells are self-contained and self-sufficient units. They are surrounded by a cell membrane and have a nucleus or nuclear area.

Types of cells

There are two types of cells grouped according to their structure. They include ***prokaryotic and eukaryotic cells.***

Structure of prokaryotic cells

These are cells of bacteria. They are referred to as primitive cells because they are believed to have occurred in the earliest organisms. Their DNA (Deoxyribose Nucleic Acid) is not enclosed within a nuclear membrane therefore have no true nucleus. Such cells also have no membrane bound organelles.



(diagram in F.A page 30 fig 2.24)

The structure of eukaryotic cells

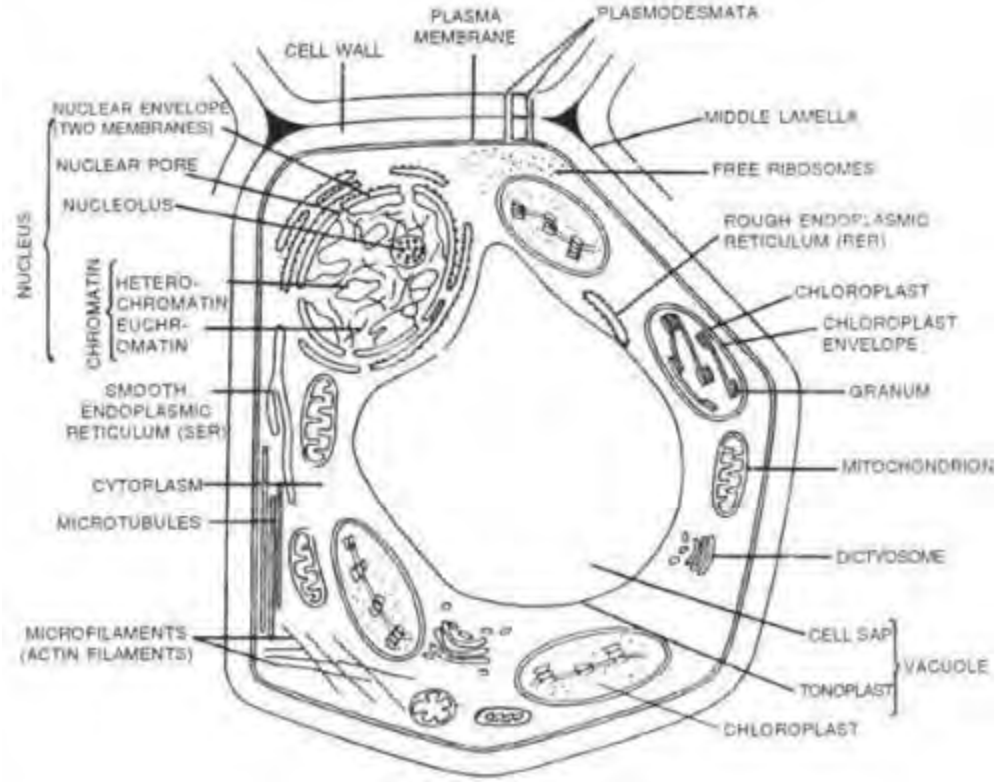
These are true cells that developed from prokaryotic cells. This development involved several stages which include:

i) Development of a nuclear membrane around the nuclear material forming a true nucleus.

ii) Development of membrane bounded organelles e.g. mitochondria and nucleus within the cytoplasm of the cell.

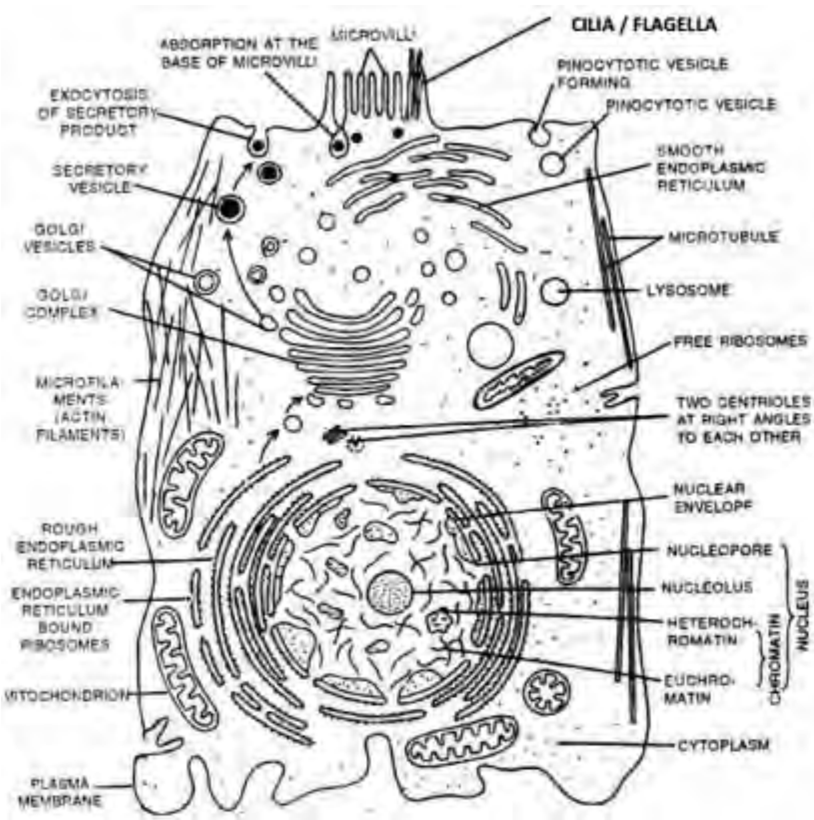
There are two main types of eukaryotic cells i.e. the plant cell and animal cell.

Structure of a plant cell



(diagram in B.S page 135 fig. 5.11)

Structure of the animal cell



(diagram in B.S page 135 fig. 5.10)

Differences between prokaryotic and eukaryotic cells

Prokaryotic cells	Eukaryotic cells
They lack a true nucleus since the genetic material is naked with scattered areas of nucleoplasm with no nuclear membrane.	Have a true nucleus with a membrane binding the genetic material.
There are no chromosomes but only circular strands of DNA.	Chromosomes are present on which DNA is located.
No mitosis or meiosis occurs.	Mitosis and meiosis occur.
Lack the membrane bounded organelles e.g. chloroplast, mitochondria.	Have membrane bounded organelles.
Flagella if present lack the 9+2 fibril arrangement.	Flagella have the 9+2 internal fibril arrangement.
Ribosomes are smaller.	Ribosomes are larger.

Differences between plant and animal cells

Plant cells	Animal cells
Cell wall present in addition to the cell membrane.	Cell wall absent, only cell membrane surrounds the cell.
Pits and plasmodesmata present.	Pits and plasmodesmata absent.
Plastids e.g. chloroplasts and leucoplasts are present.	Plastids absent.
Mature cells have large single central vacuole filled with cell sap.	Vacuoles e.g. contractile vacuoles if present are small and scattered throughout the cell.
Tonoplast present around the vacuole.	Tonoplast absent.
Cytoplasm confined to a thin layer at the edge of the cell.	Cytoplasm present throughout the cell.
Nucleus at the edge of the cell.	Nucleus anywhere in the cell but often central.
Lysosomes absent.	Lysosomes present.
Cilia and flagella absent.	Cilia and flagella present.
Starch granules used for storage.	Glycogen granules used for storage.
Middle lamella present.	Middle lamella absent.
Only meristematic cells are capable of division.	All cells are capable of division.
Few secretions released.	A variety of secretions released.

PARTS OF A CELL

1. Cytoplasm.

All cell organelles are contained within the cytoplasmic cell known as cytoplasm.
It is an aqueous material which is a solution of many cellular chemicals including simple ions like sodium, phosphates, chlorides, etc. and organic molecules e.g. ATP (Adenosine Tri Phosphate) and nucleotides.
It also contains storage materials like oil droplets.
Many important bio-chemical processes e.g. glycolysis occurs within the cytoplasm.
It is not static but capable of mass flow which is known as cytoplasmic streaming.

2. Cell membrane.

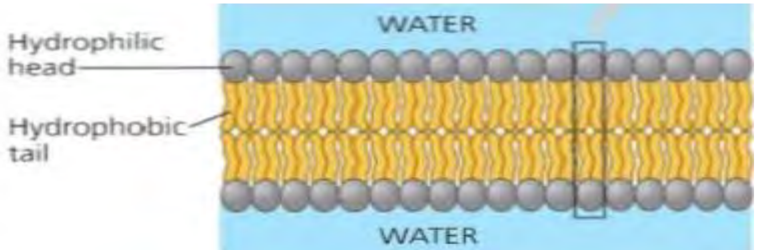
Its main function is to serve as a barrier between the cell and its environment.
It can permanently exclude certain substances from the cell while permanently retaining others.
Some substances can pass freely in and out of the membrane yet others can be excluded at one moment only to pass freely across at another occasion. Due to this, the membrane is said to be partially or semi permeable.
It is believed that the cell membrane is made up of two chemical groups i.e. proteins and phospholipids. There are two theories to explain the arrangement of these chemicals i.e.

i) The protein phospholipid sandwich theory (Davson Daniel model).
ii) The fluid mosaic model (Singer-Nicholson model)

The protein phospholipid sandwich theory

Phospholipids comprise of a hydrophilic (water loving) head and a hydrophobic (water repelling) tail. With this in mind, Davson and Daniel proposed a model of the cell membrane in which the phospholipid molecules formed a bi-molecular layer. The hydrophobic tails associated with each other at the center of the membrane with the hydrophilic heads extending towards the surface. At each side of the phospholipid was a layer of protein molecules.

The Daniel model of the structure of the cell membrane



Adopted from biology by Campbell and Reece

(Check diagram in F.A page 27 fig 2.21)

The fluid mosaic model

Singer and Nicholson suggested a modified structure of the cell membrane. The bimolecular phospholipid layer with its inwardly directed hydrophobic tails remained unchanged. However they suggested that the protein molecules vary in size and have a much less regular arrangement. They suggested that some proteins occur on the surface of the phospholipid layer while others extended into it and some even extended completely across.

They further noted that when viewed from the surface, the proteins are dotted throughout the phospholipid layer in a mosaic arrangement.

They further suggested that some proteins and lipids have short branching carbohydrate chains forming glycoproteins and glycolipids respectively.

Note: in this model, it is thought that protein also assist in the active transport of materials across the membrane.

The fluid mosaic model of the cell membrane

(**diagram in F.A page 27 fig 2.22A**)

Functions of the membranes

The phospholipid bi-layer provides the basic structure of membranes. It also restricts entry and exit of polar molecules and ions. The other molecules have a variety of functions.

1) The channel proteins and carrier proteins.
   These are involved in the selective transport of polar molecules and ions across the membrane.
2) Enzymes.
   Proteins sometimes act as enzymes e.g. the microvilli on epithelial cells lining some parts of the gut contain digestive enzymes in their cell surface membrane.
3) Receptor molecules.
   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.
4) 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.
5) The antigens

These act as cell identity markers or 'name tags'. They are glycoproteins that are proteins with branching carbohydrate side chains like antennae. There are an anonymous number of possible shapes to these side chains, so each type of cell can have its own specific markers. This enables cells to recognize other cells and to behave in an organized way. E.g. during the development of tissues and organs in multicellular organisms. It also means that foreign antigens can be recognized and attacked by the immune system.

6) Glycolipids
Also have branching carbohydrate side chains and are involved in cell-cell recognition. They may act as receptor sites for chemical signals. With glycoproteins they are also involved in sticking the correct cells together in tissues.

7) 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.t

8) Cholesterol
Act like a plug, reducing even further the escape or entry of polar molecules through the membrane.

MEMBRANOUS ORGANELLES

(refer to table in B.S on pages 137 and 139)

1. NUCLEUS

This is the most prominent feature of the cell. Its shape, size, position and its chemical composition of the cell vary from cell to cell but its functions are always the same, mainly to control the cell's activities and to retain the organism's hereditary materials (chromosomes). It's bounded by a double membrane known as the nuclear membrane (nuclear envelope).

It possesses many large pores which permit the passage of large molecules e.g. RNA between it and the cytoplasm.

The cytoplasm-like material within the nucleus is called nucleoplasm which contains chromatin but it is made up of coils of RNA bound to proteins. During cell division, the chromatin condenses to form chromosomes.

Within the nucleus, are one or two small round bodies, each known as the nucleolus which is the one responsible for the manufacture of RNA?

Functions of the nucleus

- ✓ It contains the genetic material of the cell in form of chromosomes.
- ✓ It is the control center for the chemical activities of the cell
- ✓ The DNA in the nucleus carries the instructions of synthesis of proteins.
- ✓ It's involved in the production of ribosomes and RNA
- ✓ It is essential for the cell division.

(Diagram in BS page 137)

2. CHLOROPLASTS

They belong to the large group of organelles known as plastids. Chloroplasts are bounded by a double membrane known as the chloroplast membrane or envelope.

Within the chloroplast envelope, there are some distinct regions.

Stroma

This is a colourless structure or matrix in which other structures are embedded. Such structures involve the grana. Each granum is made up of 2 to 100 closed fattened sacks called thylakoids, within the thylakoids are located at the photosynthetic pigments called chlorophyll. Some of the thylakoids are tubular extensions which interconnect adjacent grana.

Also present within the stroma are a series of starch grains which act as temporary stores for the products of photosynthesis. It also contains a small amount of DNA and oil droplets.

The structure of the chloroplast

(Structure in BS on page 201 fig. 7.7)

3. MITOCHONDRIA

These are found within the cytoplasm of all eukaryotic cells. Though in some cells like in the red blood cells, they may be absent. They are double bounded by a double membrane.

The outer of which controls the entry and exit of chemicals. The inner one is folded inwards 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.

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.

Respiratory enzymes are also located on the cristae. This means that the muscle cells have more mitochondria than the red blood cells

Transverse section of the mitochondria

(Diagram in B.S page 276 fig. 9.12)

Stalked particles/granules contain ATPase enzyme which increases surface area over which respiration occurs.

4. ENDOPLASMIC RETICULUM (E.R)

The ER is the system of membranes found out on the nucleus forming a cytoplasmic skeleton. The ER is an extension of the outer nuclear membrane with which it is continuous. The membranes form a series of sheets which enclose flattened sacks called cisternae when the membranes are lines with ribosomes; they are called rough endoplasmic reticulum (R.E.R). The RER is concerned with protein synthesis and it is most abundant in those cells which are rapidly growing or secrete enzymes.

In the same way, damage to a cell often results into increased formation in order to produce the proteins necessary for the cell repair.

Where the membranes lack ribosomes, they are known as smooth endoplasmic reticulum (S.E.R). The SER is concerned with lipid synthesis and is consequently in those cells producing lipid related secretions e.g. the sebaceous glands of the mammalian skin.

The general functions of the ER thus are:

- 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.

5. GOLGI APPARATUS/DICTYOMES

The Golgi apparatus has the same structure with the smooth ER but it's more compact. It is composed of stacks of flattened sacks made of membranes.

The stacks are fluid filled and pinch off small membranous sacks called vesicles at their ends.

There is always one Golgi apparatus on each animal cell but plant cells have large number of stacks known as dictyomes.

The Golgi apparatus is more developed in secretory cells and neurons and is small in muscle cells. This suggests that the Golgi apparatus plays some role in the production of secretory materials.

The apparatus plays the following functions:

- Produces glycoproteins e.g. Mucin required for the secretion by adding the carbohydrate part of the protein.
- Produces secretory enzymes e.g. digestive enzymes of the pancreas.
- Secretes carbohydrates such as those involved in the production of new cell wall.
- Transports and stores lipids.
- Forms lysosomes.

(Diagram in F.A page 19 fig. 2.10)

6. LYSOSOMES

This is a simple spherical sac bounded by a single membrane and containing digestive enzymes (hydrolytic enzymes). It has no internal structures which are visible. The word lysosome comes from two words 'lysis' meaning splitting, 'soma' meaning body. 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.

They isolate these enzymes from the remainder of the cell and in so doing they prevent them from acting upon other chemicals and organelles within the cell.

Functions of lysosomes

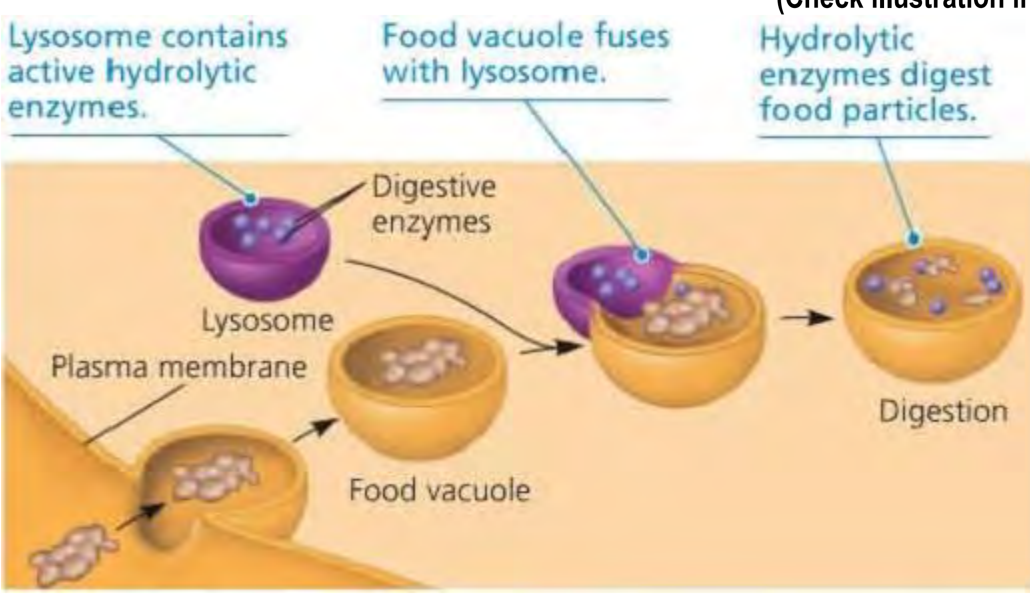
They digest materials which the cell consumes from the environment. In case of white blood cells, the material may be bacteria. In protozoa it is the food which has been consumed by phagocytosis. In either case, food is broken down within the lysosome, useful chemicals absorbed into the cytoplasm and wastes ingested by a cell.

They digest parts of the cell e.g. worn out organelles. After death of the cell, they are responsible for its complete breakdown a process called autolysis.

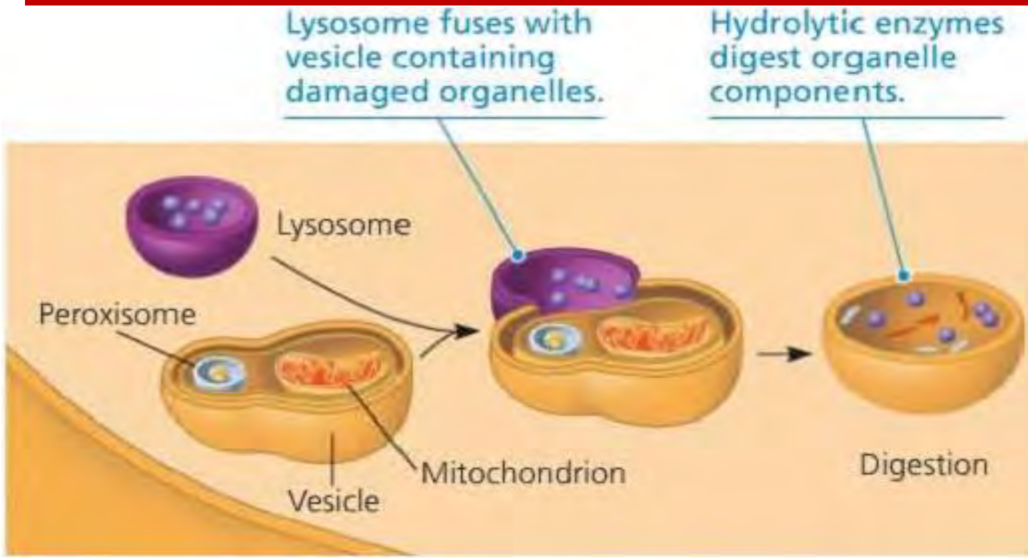
They release enzymes outside the cell (exocytosis) in order to break down other cells e.g. in the re absorption of tad pole tails during frog metamorphosis.

Functioning of lysosomes

(Check illustration in F.A page 21 fig 2.12)



Lysosome digesting food



Lysosome breaking down damaged cell organelles

7. MICROBODIES (PEROXOSOMES)

These are small roughly spherical organelles bounded by single membrane. They contain metabolic enzymes mainly catalase enzyme which catalyzes the breakdown of hydrogen peroxide which is a toxic bi-product of many chemical reactions within organisms.

Peroxides containing catalase are therefore more in metabolic reactions like those in the liver i.e.

$2H_2O_{2\,(aq)} \qquad 2H_2O_{\,(l)} + O_{2(g)}$

8. VACUOLES

These are fluid filled sacs bounded by a single membrane. Within mature plat 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 woody plants by providing the osmotic system which creates turgidity.

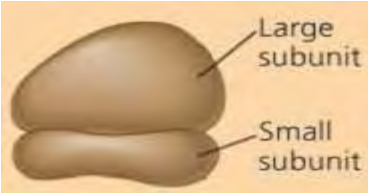
In animal cells, vacuoles are small, temporary and occur in large numbers. Common types include; food vacuoles, phagocytic vacuoles and contractile vacuoles which are important in osmoregulation in protozoa.

NON MEMBRANOUS ORGANELLES

RIBOSOMES:

These are small cytoplasmic granules found in cells.

- They occur in groups called polysomes.
- They are made up of RNA molecules and protein.
- They are important in protein synthesis.



STORAGE GRANULES

Every cell contains a limited store of energy. The store may be in form of soluble material e.g. the sugar found in the vacuoles of plant cells. It may also occur in colloidal form as grains within the cell.

Starch grains occur within chloroplast and in the cytoplasm of plant cells. Starch may also be stored in specialized leucoplasts called amyloplasts.

Food energy is stored as glycogen in glycogen granules in the cytoplasm of animal cells.

Oil/lipid droplets are also found within the cytoplasm of both plant and animal cells.

MICRO TUBULES

These are slender unbranched tubes occurring throughout living cells. Their functions are:

- They provide an internal skeleton to the cells thereby determining their shape.
- They aid in transporting materials within cells by providing routes.
- They form a frame work along which cellulose cell wall in plants is laid.
- They are major components of the cilia and flagella where they contribute to their movement.
- They are found in spindle fibres during cell division and within centrioles from which spindles are formed.

CILIA AND FLAGELLA

These are almost identical except that cilia are shorter and more numerous than flagella.

Both are 0.2 micrometers in diameter.

They are out-growth from cells and can beat either in one direction or both (cilia).

Their function is to move the whole organism e.g. cilia in paramecium or to move materials within an organism e.g. cilia lining the respiratory tract move mucus towards the throat.

Cross sections of a cilium shows that it contains a bundle of micro tubules which run longitudinally along its length arranged in a way that there are two in the center surrounded by a ring of 9 paired ones called doublets. This arrangement is described as the 9+2 pattern.

The transverse section of the cilium

(Diagram in F.A page 23 fig. 2.16B)

CENTRIOLES

These are small hollow cylinders about 0.3-0.5 μm long and about 0.2 μm in diameter. They occur in pairs in most animal cells. Each contains a triplet of micro tubules.

They arise from a distinct region of the cytoplasm called centrosome. Each centrosome has two centrioles. As cell division proceeds, the centrioles migrate to opposite poles of the cell where they synthesize the microtubules of the spindle.

MICROFILAMENTS

These are very thin strands about 6 nm in diameter. They are made up of a protein called actin and a smaller proportion of myosin since these are the two proteins involved in muscle contraction. It means that microfilaments play a role in movement within cells and of the cell as a whole.

MICROVILLI

These are tiny finger-like projections about 0.6 micro meters in length on the membranes of certain cells e.g. those lining the intestines and kidney tubules.

The microvilli are massed together and appear similar to bristles of a brush hence the term brush border given to the age of cells basing microvilli.

Each microvillus contains bundles of actin and myosin filaments hence allowing them to contract which along with their large surface area facilitate absorption.

CELLULOSE CELLWALL

It is found in plant cells made up of cellulose micro fibrils embedded in an amorphous polysaccharide matrix. The matrix has polysaccharides e.g. pectin or lignin.

Functions of a cell wall

i) It provides support in herbaceous plants. As water enters the cell osmotically, the cell wall resists expansion and internal pressure is created which provides turgidity of the cell and the plant as a whole.
ii) It gives direct support to the cell and the plant by providing mechanical strength. The strength may be increased by presence of lignin in the matrix between the cellulose fibres.
iii) It allow movement of water through and along it hence contributing to movement of water in the plant as a whole especially in the cortex of the root.
iv) It stops loss of materials from the cell to the outside since it is less permeable than the cell membrane.
v) The arrangement of the cellulose fibrils in the cell wall gives the overall shape of the cell.
vi) It is a store of some food reserves.

THE DIVERSITY OF CELLS

(refer to F.A pages 28 and 29)

This diversity is seen between different species and within a single species. Structures like the chromosomes, mitochondria, endoplasmic reticulum and ribosomes are common in all cells but the shape, form and contents in individual cells show much variation.

Thus the cells of hydra differ from those of human though they share the same basic features and some perform the same function.

Within the body of a hydra, there are seven types of cells and these include:

1. Epithelial cells:

These possess a shape suitable for lining the surface of the body, organs and cavities within it.

2. Glandular cells:

These are suitable for producing a secretion e.g. mucus.

3. Erythrocytes (red blood cells):

These convey oxygen around the body since they are loaded with a red pigment haemoglobin.

4. Leucocytes (white blood cells):

These defend the body against diseases.

5. Nerve cell/neuron:

These contain slender arm-like processes that transmit electrical impulses through the nervous system.

6. Sensory cells:

These are capable of electrical activity which is generated by specific kinds of stimulation like light, sound, touch, etc.

7. Muscle fibres:

These are capable of movements since the electrical activity is accompanied by contraction since they are elongated.

Other cells found in animals below the level of mammals i.e. skin of animals include the following;

8. Flame cells:

These are found in flatworms and play an important role in osmoregulation.

9. Nematoblast/stinging cells:

These are found in sea anemones, hydra and jelly fish for piercing and poisoning prey due to their toxic fluid.

10. Musculo-epithelial cells:

These contain one side that contributes to the lining of the body whilst.

Other cells found in plants include;

11. Photosynthetic cells:

These build up complex molecules

Others include parenchyma cells, epidermal cells, guard cells and collenchyma cells.

MOVEMENT IN AND OUT OF CELLS

The various organelles and structures within a cell require a variety of substances in order to carry out their reactions. In turn they form products which are useful and some are wastes.

Most of these substances pass in and out of the cell in the following ways;

- Diffusion
- Osmosis
- Active transport
- Phagocytosis
- Pinocytosis

DIFFUSION

This is the movement of gaseous molecules from a region of high concentration along a concentration gradient.

Concentration gradient refers to the difference in concentration between two points of a diffusing particle.

Diffusion occurs because the molecules are in a random motion e.g. if molecules are closed in a vessel occupying one side and are in random motion, they collide with each other and the sides of the vessel.

Some particles on the side of high concentration start to move to the side of low concentration meaning that movement is in one direction only at the beginning hence a large concentration gradient and therefore rapid diffusion.

After a short time, particles spread themselves evenly in the vessel and at this point the rate of movement from one side to another is equal thus no concentration gradient and no net diffusion hence the particles are said to be in a dynamic equilibrium.

Factors affecting the rate of diffusion

1) **Temperature:**
   Increase in temperature increases the rate of diffusion since temperature increases the kinetic energy of the molecules hence more collisions and vice versa.
2) **Size of diffusing particles:**
   The larger the particles the lower the rate of diffusion and the smaller the particles the higher the rate of diffusion.
3) **Surface area over which diffusion occurs:**
   The larger the surface area the greater the rate of diffusion and vice versa.
4) **Concentration gradient:**
   The greater the concentration gradient, the higher the rate of diffusion and vice versa.
5) **Density of the diffusing particles/molecules:**
   The denser the diffusing particles, the lower the rate of diffusion and vice versa.
6) **Distance over which diffusion occurs:**
   The larger/bigger the distance the lower the rate of diffusion and vice versa.

Question: ***with examples, discuss the factors affecting the rate of diffusion.***

Types of diffusion

1. **Simple diffusion:**
   This is a type of diffusion where molecules and ions do not need carrier molecules to be carried across the membrane.
2. **Facilitated diffusion:**
   This is the diffusion where by molecules/ions are connected to other molecules to carry them across the membrane. The carrier molecules are mainly protein molecules, e.g. glucose molecules are not able to diffuse quickly through the membrane on their own. Therefore they combine with globular proteins in the cell membrane to carry them across.

OSMOSIS

This is the movement of water molecules from a region of their high concentration to a region of their low concentration across a semi-permeable membrane. OR

It is the movement of water molecules from a dilute solution to a concentrated solution across a semi-permeable membrane.

If the solution is separated from its pure solvent e.g. water, different forces act on these solution causing water molecules to come in a particular direction.

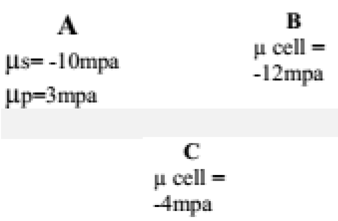
Terms used in osmosis

1) **Osmotic potential:**
   This is the capacity of a solution to allow in water molecules by osmosis. Therefore a concentrated solution has a higher osmotic potential than a dilute one.
2) **Osmotic pressure:**
   This is the force that must be applied to stop water molecules from entering that solution, i.e. a dilute solution has a higher osmotic pressure than a concentrated solution.
3) **Water potential of a cell (μ_{cell}):**
   This is the ability of water molecules to move out of a cell by osmosis. A dilute solution has a higher water potential than a concentrated one. ***It has a negative value.***
4) **Solute potential (μ_s):**
   It is a measure of the amount of solute in the solution. It is also defined as the degree of lowering the water potential. ***It always has a negative value***.
5) **Pressure potential (μ_p):**
   This is a force extended on the cell contents by the cell wall as a result of reaching the cell wall after water absorption. ***It has a positive value.***

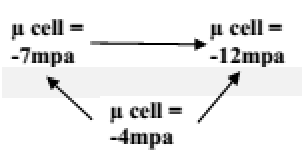
Water potential, solute potential and pressure potential all act on a cell at the same time in the following way;

Water potential (Negative) μ cell = Solute potential (Negative) μ s + Pressure potential Positive) μ p

For example: the diagram below shows 3 adjacent cells



a) Calculate the water potential of cell A.
b) By means of arrows, show the direction of water movement between the cells.



c) Explain why water potential of sucrose solution has a negative value.
   This is because water has a water potential of zero therefore sucrose having a negative value (lower water potential) enables water molecules to move into sucrose solution by osmosis and cannot move out of the solution.

Osmotic relations in cells

Cells owe most of their properties due to the permeability of their cell membrane. In case a cell is surrounded by pure water or a solution whose solute concentration is lower than that of the cell's contents, water flows into

the cell by osmosis and this brings about the swelling of the cell. In this case, the solution is said to be hypotonic since the osmotic pressure of the external solution is lower than that of the cell.
And if the cell is surrounded by a solution whose solute concentration and osmotic pressure exceeds that of the cell, water flows out of the cell hence it shrinks. In this case the external solution is said to be hypertonic.
If the solute concentration of the cell and its surrounding medium are the same, there is no net flow in either direction and the external solution is said to be isotonic with the cell.
The osmotic flow of water into a cell is called endosmosis. The osmotic flow of water out of a cell is called exo-osmosis.

(Check B.S page 431 fig. 13.4)

From the above illustration, the potential energy of the water molecules on the left is greater than the potential energy of the water molecules on the right. Hence this potential energy is called water potential.

Note: check point:

Which cell has the higher (less negative) water potential? Cell B
In which direction will water move by osmosis? From cell B to A
At equilibrium the two cells will have the same water potential, which will be the average of the two, namely -1000kpa. Assuming that Us does not change significantly, what would be Up at equilibrium in cell A and cell B?
Cell A at equilibrium: Up =U-Us
Up=1000kpa
Cell B at equilibrium: Up=U-Us
Up=400kpa

Water flows from a region of high water potential to a region of low water potential. At s.t.p. water is given an osmotic potential of zero. The presence of solute molecules due to the component of the water potential is called osmotic or solute potential.

Osmosis and plant cells

Plant cells have a solute concentration higher than that of the surrounding region. Since they are surrounded by a weak solution, water is drawn into the surrounding by osmosis bringing about the swelling of the cell.

Summary of plant cells placed in hypotonic and hypertonic solutions

(Check F.A page 52 fig. 4.5)

As water flows into the vacuole by osmosis, an internal hydrostatic pressure develops which presses the protoplasm against the cell wall. This is called turgor pressure and it is opposed by a back pressure exerted by the cell wall against the cell contents. This back pressure tends to force water out of the cell and is called water potential.
When turgor pressure reach its maximum and the cell wall can no more be stretched, full turgor is said to be achieved i.e. the cell becomes fully turgid.

Importance of turgidity

- It supports plants and maintains their shape and form.
- Holds stems erect i.e. the herbaceous plants.
- Holds leaves in flat, horizontal position.

When a cell is immersed in a higher solute concentration solution, its volume decreases hence the protoplast shrinks to an extent of pulling away from the cell wall. This shrinkage is called plasmolysis.
Plasmolysis usually happens to plants exposed to extremely salty water.
Wilting is the phenomenon where the stems and leaves of a plant loose more water by evaporation than they can absorb.

Plant water relations

Here, we consider 3 forces i.e.

i) Water potential of the whole cell
ii) Osmotic potential of the sap
iii) Pressure potential

In case the plant cell is plasmolysed (placed in a strong sucrose solution) and then placed in pure water, water immediately enters the sap vacuole by osmosis and the protoplast begins to expand.

As the influx of water continues, the protoplast goes on expanding until it comes into contact with the cellulose wall. When this point is reached, the influx of water starts being opposed by the inward pressure of the cell wall i.e. pressure potential.

The water potential of the cell now becomes less negative than the osmotic potential of the sap by the amount of the pressure potential. As this continues, full turgor is reached, where the cell can expand no more, water potential of the cell reaches zero and osmotic potential of the sap is exactly counter balanced by the pressure potential.

Below is a graph illustrating the relationship between the water potential of the cell (µcell), osmotic potential of the sap (µs) and pressure potential (µp) of a plant cell at different states of turgor and plasmolysis

(F.A page 54 fig. 4.6)

Water potential (Negative) µ cell	=	Solute potential (Negative) µ s	+	Pressure potential Positive) µ p

In a cell which is plasmolysed to the extent that the protoplast loses contact with the cell wall;

µp = 0 and µcell = µs

At full turgor, µp is equal and opposite of µs, so µcell = 0.

ACTIVE TRANSPORT

This is the movement of molecules and ions from a region of low concentration to a region of high concentration against a concentration gradient.

Active transport only takes place in a living system that is actively producing energy by respiration. Temperature and oxygen concentration which affect the rate of respiration also affect active transport. Active transport takes place by means of carriers in the cell membrane i.e. protein in nature. These carriers act as one way valves.

PHAGOCYTOSIS (Cell-eating)

This is the process by which cells take in large particles. Examples of cells include white blood cells which take up bacteria and amoeba which feeds on a variety of small organisms.

Process of phagocytosis

i) The plasma membrane invaginates to form a flask-like depression enclosing the particles.
ii) The neck of the flask then closes and invagination becomes sealed off as a phagocytic vessel or food vacuole which migrates towards the centre of the cell.
iii) The particles are now digested by enzymes secreted into the vesicle from lysosomes which fuse it.
iv) The soluble products of digestion are then absorbed into the surrounding cytoplasm.

PINOCYTOSIS (Cell drinking)

Tiny pinocytic channels are continually being formed at the cell surface by invagination of the plasma membrane.

Pinocytic channel provide a means by which liquids can be brought into the body of the cell, and their breaking up into numerous vacuoles aids distribution and increases the surface area across which absorption can take place.

***

"If you want to change the fruits, you will first have to change the roots. If you want to change the visible, you must first change the invisible." Harv Eker. T. 2005

CHEMICALS OF LIFE

These are compounds needed to maintain life of living organisms. They are divided into two groups, i.e.

i) Inorganic compounds e.g. water, vitamins, salts, acids and roughages.

ii) Organic compounds e.g. carbohydrates, lipids, proteins and nucleic acids.

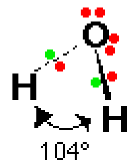
WATER

It is the most important inorganic compound in life and most abundant within living organism.

A human cell contains about 80% water and the whole body has over 60% water.

Water is formed when two hydrogen atoms combine with an oxygen atom by sharing electrons. The shape of a water molecule is triangular and the angle between the nuclei of atoms is approximately 105^0

Water molecules form weak hydrogen bonds with other water molecules nearby and its bonds give it the unique properties.



Properties of water

i) It is liquid at room temperature.

ii) 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.

iii) Water expands as it freezes unlike other liquids which contract on cooling.

iv) Water reaches its maximum density above its freezing point at 4^oC 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.

v) 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.

vi) It has a high latent heat of fusion i.e. much heat must be removed before freezing occurs.

vii) It has high adhesive and cohesive properties preventing it from breaking under tension.

viii) It is colourless and transparent.

ix) It has a low viscosity i.e. water molecules slide over each other very easily.

x) 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.

QUESTION: ***HOW DO THE PROPERTIES OF WATER RELATE TO ITS BIOLOGICAL ROLE?***

1) Water is transparent and this allows light penetration in aquatic habitats to enable photosynthesis of aquatic autotrophs and visibility of aquatic animals.

2) Water has a low viscosity and this allows for smooth flow of water and other dissolved substances in an aquatic medium for easy transport.
3) It has a high surface tension providing support to aquatic organisms and allowing movement of living organisms on water surface.
4) 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.
5) 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.
6) 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.
7) 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.
8) 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.
9) Water is liquid at room temperature providing a liquid medium for living organisms and metabolic reactions and a medium of transport.
10) It has high adhesive and cohesive forces creating enough capillarity forces for transport in narrow tubes of biological systems.
11) It is a universal solvent hence providing a medium for biochemical reactions.
12) Water is a polar molecule allowing solubility of polar substances, ionization or dissociation of biochemical substances.
13) Water is incompressible thus providing support in hydrostatic skeleton and herbaceous stems.
14) Water is neutral hence does not alter the pH of cellular components on their environment.
15) A water molecule is relatively small for easy and fast transport across a membrane.

QUESTION: *OUTLINE THE ROLE OF MINERALS AND IONS IN BIOLOGICAL SYSTEMS.*

1) They are components of smaller molecules e.g. phosphorus is contained in ATP and iodine is contained in thyroxin, etc.
2) They are constituents of large molecules e.g. proteins contain nitrogen and sulphur, phospholipids contain phosphorus, nucleic acids contain nitrogen and phosphorus, etc.
3) They are components of pigments e.g. haemoglobin and cytochromes which contain ion, chlorophyll contain magnesium, etc.
4) They are metabolic activators e.g. activates glucose before it is broken down in cell respiration, calcium ions activate ATPase enzyme during muscle contraction.
5) They determine the anion, cation balance e.g. Na^+, K^+ and Ca^+ are important in transmission of impulses and muscle contraction.
6) They determine the osmotic pressure and water potential so that it does not fluctuate beyond narrow limits e.g. Na^+, K^+ and Cl^- are involved in water balance in the kidneys.
7) They are constituents of structures in cell membranes, cell walls, bones, enamel and shells.

CARBOHYDRATES

These comprise of a large group of organic compounds which contain C,H and O. they have a general formula $C_X(H_2O)_Y$ though some do not conform to it e.g. deoxyribose $C_5H_{10}O_4$.

Main functions of carbohydrates

- They are a primary source of energy being oxidized in the body to release energy.
- They are structured components of cells e.g. cellulose making up the cell wall.
- They are determinants of osmotic potential of body fluids therefore maintain blood pressure.
- They are recognized units on the surface of body cells, i.e. they are component structures of the surface cell membranes recognized by antibodies.

Types of carbohydrates

1. Monosaccharides (single unit sugars)
2. Disaccharides (double unit sugars)
3. Polysaccharides (several unit sugars)

MONOSACCHARIDES

Monosaccharides (mono=one, saccharide= sugar) are substances consisting of one molecule of sugar. They are also known as simple sugars.

Properties of monosaccharides

- They have a sweet taste
- They dissolve in water
- They form 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.***

Monosaccharides are named using a suffix 'ose'. They contain either an aldehyde group (CHO) and are called aldoses or they contain a ketone group (C=O) and are called ketones. Monosaccharides have a general formula $(CH_2O)_n$ where:

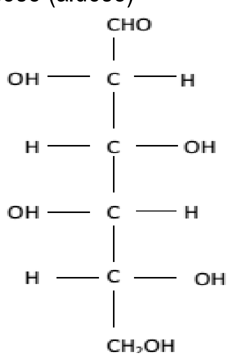
- n=3 (triose sugar)
- n=5 (pentose sugar)
- n=6 (hexose sugar)
- n=7 (heptose), etc.

The most frequent monosaccharides are the hexose sugars; glucose, fructose and galactose.

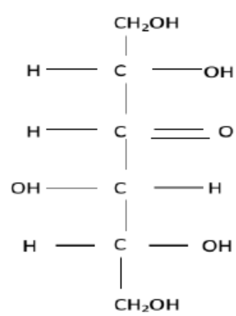
HEXOSE SUGARS

These are sugars with molecular formula $C_6H_{12}O_6$ and structural formulae as shown below:

Glucose (aldose)

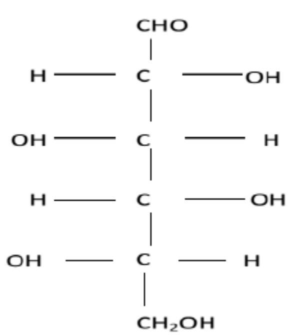


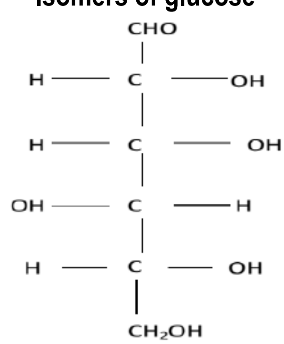
Fructose (ketone)

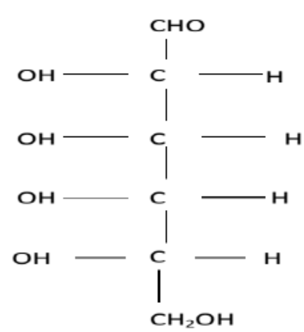


Glucose can exist in a number of isomers where it has different structural formulae remaining with the same molecular formulae.

Isomers of glucose

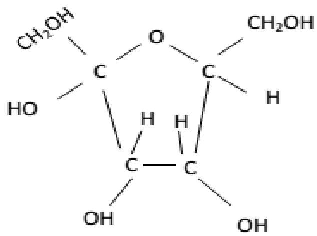


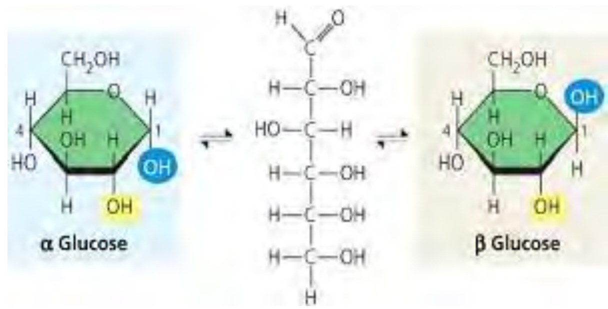




The hexose sugars can exist in straight or chain form as shown above or in ring form as shown below:

Fructose

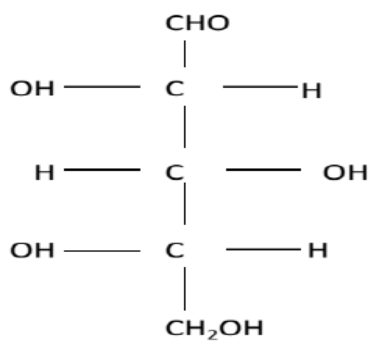




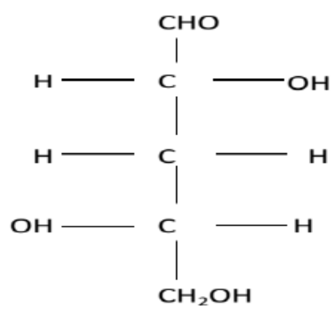
PENTOSE SUGARS

They have 5 carbon atoms. They are found in nature as ribose and deoxyribose. They exist in straight and ring forms.

Ribose

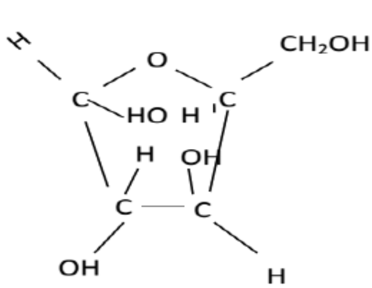


Deoxyribose

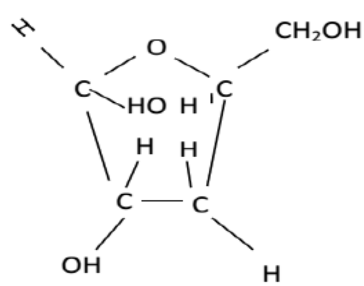


Ring forms

Ribose



Deoxyribose

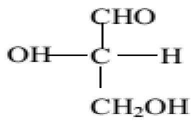


Ribose occurs in co-enzymes, adenosine triphosphate (ATP) and ribonucleic acid (RNA). Deoxyribose occurs in DNA (Deoxyribo Nucleic Acid).

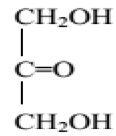
TRIOSE SUGARS

They contain 3 carbon atoms. The two occurring trioses are glyceraldehyde and dehydroxyacetone. Both of them are found in plant and animal cells playing a role in carbohydrate metabolism.

Glyceraldehyde

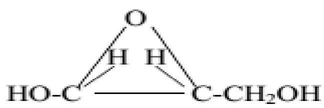


Dehydroxyacetone

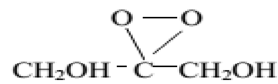


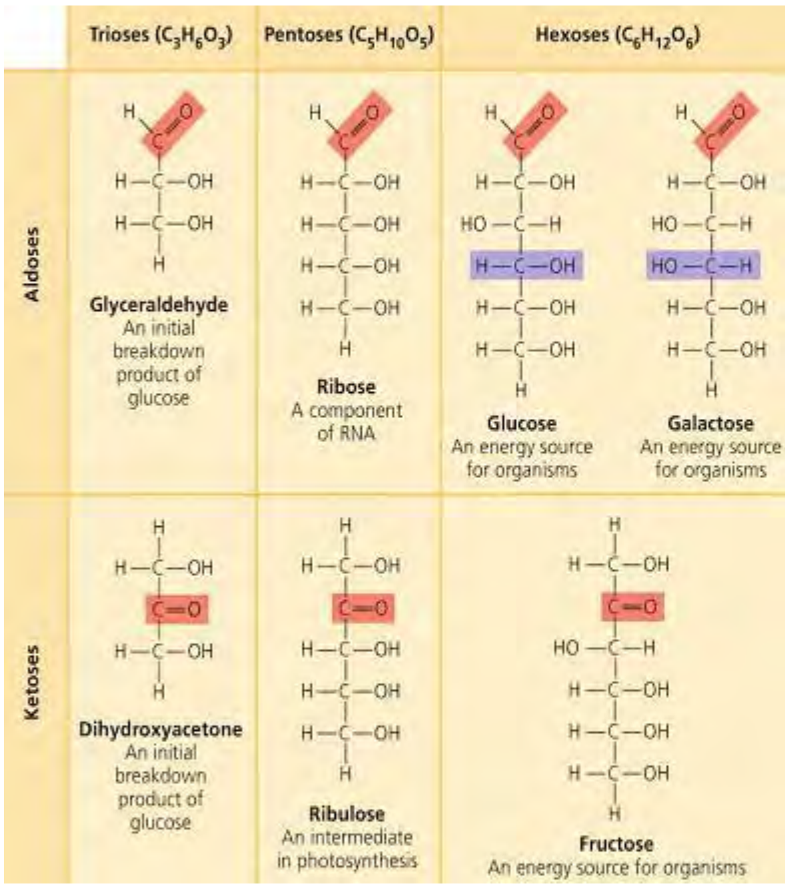
Ringed forms

Glyceraldehyde



Dehydroxyacetone





DISACCHARIDES

Monosaccharides combine together in pairs to form disaccharides. This union involves loss of a water molecule and therefore the reaction is a condensation reaction. The bond formed is a glycosidic bond. The most common disaccharides are:

1. Maltose formed from linkage of two glucose molecules. It is common in most germinating seeds and cereals.
2. Sucrose from union of glucose and fructose. It is the main form in stems of sugar canes and roots of sugar beets which are sources of commercial sugars.
3. Lactose resulting from the union of glucose and galactose and found in milk.

The disaccharides have the following properties:

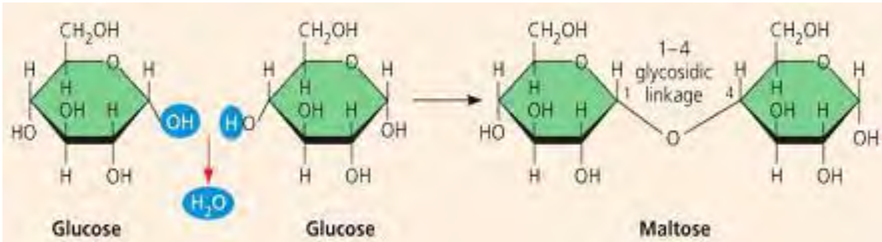
i) They are sweeter than monosaccharides
ii) They can be crystallized
iii) They are soluble in water

iv) Do not change the colour of Benedict's solution when heated with it (apart from maltose)- they are known as non-reducing sugars
v) Can be broken down into simple sugars by dilute mineral acids and enzymes

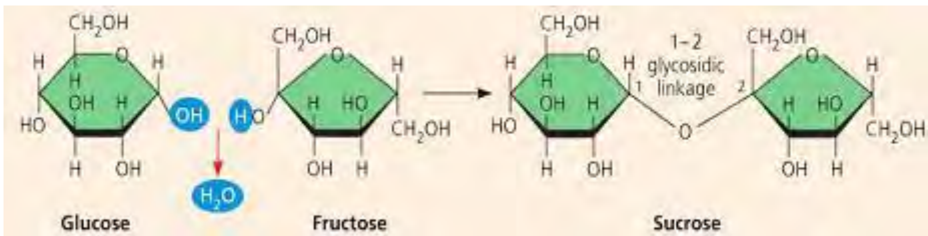
Note: Maltose can also be formed as a product of starch hydrolysis.

Formation of maltose

$C_6H_{12}O + C_6H_{12}O$ -------- $C_{12}H_{22}O + H_2O$



Formation of sucrose



POLYSACCHARIDES

Many monosaccharides may combine by condensation reactions to form polysaccharides. A number of monosaccharides which combine may be variable and the chain can be branched or unbranched.

Properties of polysaccharides include:

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

The chains may be folded to make them compact which are ideal for storage. Such a large size of the molecules makes them insoluble in water and suitable for storage as they exert no osmotic influence and do not easily diffuse out of the cell.

Starch is the main storage material in green plants while glycogen is for animals.

Upon hydrolysis, polysaccharides are broken down into their constituent monosaccharides.

Not all polysaccharides are used for storage e.g. cellulose is a structural polysaccharide giving support and strength to the cell walls.

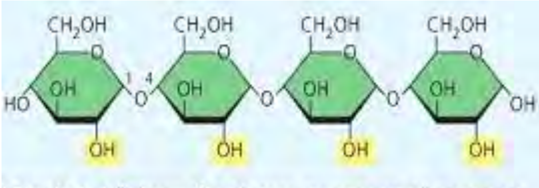
STARCH

It is found in plant parts in form of granules. It is a reserve food formed from any excess glucose during photosynthesis.

It is common in seeds e.g. maize where it is the main food supply during germination.

Structure:

It is a polymer of α-glucose molecules which are held by glycosidic bonds forming chains of α-glucose units which get folded or coiled into a helix.



) Starch: 1–4 linkage of α glucose monomers. All monomers are in the same orientation. Compare the positions of the —OH groups highlighted in yellow with those in cellulose (c)

Starch has two components i.e. amylose and amylopectin, that is, 20% amylose, 79% amylopectin and 1% other substances e.g. phosphates and fatty acids.
Amylose stains deep blue with iodine while amylopectin stains red to purple with iodine.
Amylose is structurally unbranched while amylopectin is branched.

QUESTION: *HOW DOES THE STRUCTURE OF STARCH RELATE TO ITS ROLES?*

- It is a polymer of α-glucose molecules hence a large molecule making it relatively insoluble in water hence an ideal storage molecule.
- The α-glucose molecules are held by glycosidic bonds which can be broken down to free glucose molecules from the stored starch for ATP synthesis during respiration.
- The starch molecule is coiled into a helix with a hydroxide group projecting interiorly making it insoluble in water hence exerts no osmotic effects in cells and is ideal for storage.
- The chains of α-glucose units can be folded to form starch grains for easy storage.

GLYCOGEN

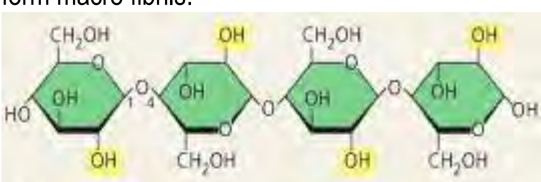
It is a major polysaccharide storage material in animals. It stored mainly in the liver and muscles. It is also made up of α-glucose molecules and exists as granules. However its chains are shorter (10-20 glucose units) and is more branched. Glycogen is more soluble than starch.

CELLULOSE

It comprises up to 50% of a plant cell wall and in cotton it makes up to 90%.
It is a polymer of about 10000 β-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.

Structure:

It is a polymer with straight chains of β-glucose units held by 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: 1–4 linkage of β glucose monomers. In cellulose, every other β glucose monomer is upside down with respect to its neighbors.

Note: starch lacks the structural properties possessed by cellulose because it lacks cross linkages.
The stability of cellulose makes it difficult to digest and therefore not a good source of food to animals except those which have cellulase producing microorganisms which live in them in a symbiotic way e.g. in the rumen of cattle, goats, sheep, etc.

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.

Enzymes that digest starch by hydrolyzing its α linkages are unable to hydrolyze the β linkages of cellulose because of the distinctly different shapes of these two molecules. In fact, few organisms possess enzymes that can digest cellulose. Humans do not; the cellulose in our food passes through the digestive tract and is eliminated with the feces. Along the way, the cellulose abrades the wall of the digestive tract and stimulates the lining to secrete mucus, which aids in the smooth passage of food through the tract. Thus, although cellulose is not a nutrient for humans, it is an important part of a healthful diet. Most fresh fruits, vegetables, and whole grains are rich in cellulose. On food packages, "insoluble fiber" refers mainly to cellulose.

Some prokaryotes can digest cellulose, breaking it down into glucose monomers. A cow harbors cellulose-digesting prokaryotes in its rumen, the first compartment in its stomach (Figure 5.9). The prokaryotes hydrolyze the cellulose of hay and grass and convert the glucose to other nutrients that nourish the cow. Similarly, a termite, which is unable to digest cellulose by itself, has prokaryotes living in its gut that can make a meal of wood. Some fungi can also digest cellulose, thereby helping recycle chemical elements within Earth's ecosystems.

QUESTION: ***HOW DOES THE STRUCTURE OF CELLULOSE RELATE TO ITS ROLES***

i) Cellulose is a polymer of straight chains of β-glucose units held by glycosidic bonds with OH groups projecting outwards from each chain forming cross linkages of H bonds with adjacent chains.
ii) The cross linking binds the chains together offering much tensile strength.
iii) The micro fibrils in cell walls are arranged in several layers offering protection to the plant cell preventing it from bursting when water enters by osmosis.
iv) The arrangement of micro fibrils in cell walls contributes to turgidity hence offering support.
v) The parallel layers of cellulose are fully permeable to water and solutes.
vi) The arrangement of micro fibrils determines the shape of the cells and hence plant organs since it determines the direction in which cells expand as they grow.
vii) The glycosidic bonds holding the β-glucose units in cellulose can be broken down in presence of enzyme cellulose so that a free glucose molecule can be respired.

OTHER POLYSACCHARIDES

1. **Chitin:**
   Chemically and structurally, chitin resembles cellulose but differs in possessing an acetyl group (NH-OCH_3) instead of one of the OH groups. Like cellulose, it has a structural function and is a major component of exoskeleton of insects and crustacea. It is also found in fungal cell walls.
2. **Insulin:**
   It is a polymer of fructose and found as a storage carbohydrate in some plants.
3. **Mucopolysaccharides:**
   This group includes hyaruronic acid which forms part of the matrix of vertebrae connecting tissue. It is found in cartilage, bones, vitreaous humor of the eye, synovial fluid, etc.
   Heparin, an anti-coagulant also contains mucopolysaccharides.

FOOD TESTS ON CARBOHYDRATES

1. **Test for reducing sugars**

The reagent used is Benedict's solution (blue) or Fehling's solution (blue). Boiling is required.

Procedure	**Observation**	**Conclusion**
To 1 cm^3 of food solution, add 1 cm^3 of Benedict's solution and boil.	Colourless or turbid solution turned to a blue solution, then to a green solution, to a yellow precipitate, to orange precipitate and to a brown precipitate on boiling.	Little or Moderate or Much or Too much; reducing sugars present.
	Colourless or turbid solution turned to a blue solution which persists on boiling.	Reducing sugars absent.

If Fehling's solution is used, the change is from blue solution to orange precipitate if reducing sugars are present. It remains a blue solution if they are absent.

Examples of reducing sugars include:

1) Glucose (present in grapes)
2) Fructose (present in many edible fruits)
3) Galactose (present in milk)

4) Maltose (present in germinating seeds)

The conclusions based on colour changes are according to the following observations:

Blue ***solution***- no sugars

Green ***solution***- little sugars present

Yellow ***precipitate***- moderate sugars present

Orange ***precipitate***- much sugars present

Brown ***precipitate***- too much reducing sugars present

2. Test for non-reducing sugars

procedure	Observation	conclusion
To 1 cm^3 of food solution add 1 cm^3 of dilute hydrochloric acid and boil, cool under water then add 1 cm^3 of sodium hydroxide solution, followed by 1 cm^3 of Benedict's solution and boil.	Colourless or turbid solution turned to a blue solution, then to a green solution, to a yellow precipitate and to a brown precipitate on boiling.	Little or Moderate or Much or Too much; non-reducing sugars present.
	Colourless or turbid solution turned to a blue solution which persists on boiling.	Non-reducing sugars absent.

Note:

i) When boiled with dilute HCl, the non- reducing sugars breaks down into the reducing sugars.

ii) Sodium hydroxide solution or sodium hydrogen carbonate powder is added to neutralize the acid so that Benedict's solution can work.

Examples of non-reducing sugars include:

1) Sucrose (present in sugar cane)
2) Lactose (present in milk)

3. Test for starch:

The reagent used is iodine which is a brown or yellow solution).

Procedure	Observation	Conclusion
To 1 cm^3 of food solution, add 3 drops of iodine solution.	Colourless or turbid solution turned to a black or blue-black or blue solution or brown solution with black specks.	Much or moderate or little starch present.
	Colourless or turbid solution turned to a yellow or brown solution.	Starch absent.

LIPIDS

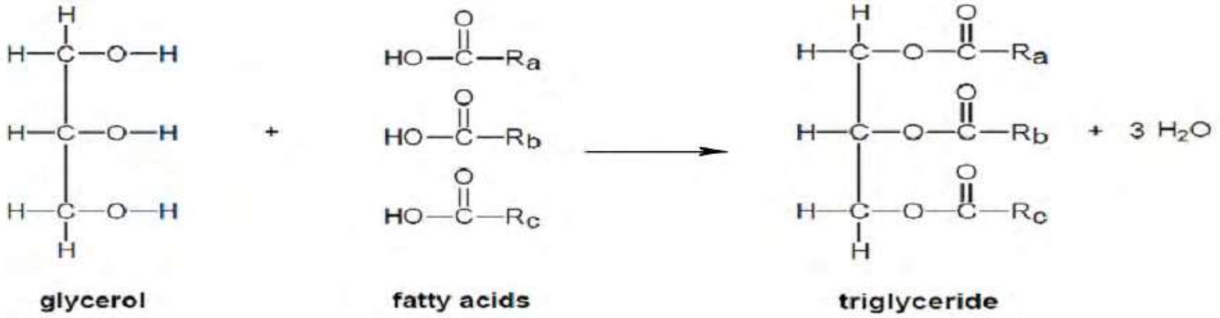
These are large group of organic compounds. Like carbohydrates, they contain carbon, hydrogen and oxygen but the proportion of oxygen is smaller than in carbohydrates hence they are more reduced than the carbohydrates.

Lipids are insoluble in water.

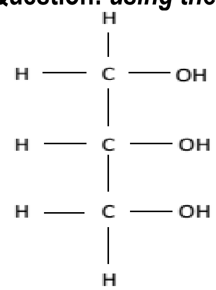
They are of two types i.e. fats and oils. Fats are solid at room temperature while oils are liquids at room temperature.

Lipids are made of fatty acids and glycerol. 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.

Formation of a triglyceride



Question: ***using the structural formula:***



For glycerol, and molecular formula $CH_3(CH_2)_nCOOH$ for a fatty acid, show the formation of a triglyceride from fatty acids and glycerol.

FATTY ACIDS

All occurring lipids have glycerol and therefore it is the nature of the fatty acids which determines the characteristics of any particular lipid. All fatty acids have a carboxyl group (COOH), the reminder of the molecule being a hydro carbon chain of varying length.

These chains may possess one or more double bond in which case it is said to be unsaturated. If it possesses no double bonds, it is said to be saturated.

Nature of fatty acid	General formula	Saturated/unsaturated	Occurrence
1. Butyric acid	C_3H_7COOH	Saturated	Butter fat
2. Linoleic acid	$C_{17}H_{31}COOH$	Unsaturated	Seed oil
3. Oleic acid	$C_{17}H_{33}COOH$	Unsaturated	All fats
4. Palmitic acid	$C_{15}H_{31}COOH$	Saturated	Animal & veg fat
5. Selotic acid	$C_{25}H_{51}COOH$	Saturated	Wood oil
6. Arachidic acid	$C_{19}H_{39}COOH$	Saturated	P.nut oil

From the table, it is seen that the hydrocarbon chains may be very long forming long tails which extend from the glycerol molecules. These trails are hydrophobic (water repelling) which makes the lipids insoluble in water.

Question: ***explain why lipids are insoluble in water?***

PHOSPHOLIPIDS

These are lipids in which one of the fatty acid groups is replaced by phosphoric acid.

CH_2O-OC-fatty acid

CHO-OC-fatty acid

CH_2O- phosphoric acid

Phosphoric acid is hydrophilic in contrast to the remainder of the molecule, having an end attracting water while the other end repelling it gives the phospholipid its characteristics as one the components of the cell membrane.

WAXES

These are formed by combination of fatty acids with an alcohol other than glycerol. Their major function is water proofing in plants and animals. They are also storage compounds in seeds e.g. castor oil seeds.

STEROIDS

These are related to lipids e.g. cholesterol in animals used to synthesize sex hormones. Other steroids include vitamin B and bile acids.

FUNCTIONS OF LIPIDS

Structural:

i) They are components of the plasma/cell membrane.
ii) They form subcutaneous fat in the dermis of the skin hence insulating the body since they are poor conductors of heat.
iii) They are components of the waxy cuticle in plants and insects there by preventing water loss (desiccation).
iv) They form a component of the myelin sheath of nerves hence playing a role in the transmission of impulses.
v) They protect delicate organs e.g. the heart and kidney from injury.
vi) They coat on fur of animals enabling it to repel water which would otherwise wet the organism.
vii) They are component of adipose tissue.

Physiological:

i) They provide energy through oxidation.
ii) They are solvents for fat soluble vitamins (ADEK).
iii) They are a good source of metabolic water to desert animals, young birds and reptiles while still in their shells.
iv) They are a constituent of the brown adipose tissue which provides heat for temperature regulation (thermogenesis).

Other functions:

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

QUESTION: *WHAT PROPERTIES DO LIPIDS POSSES AS STORAGE COMPOUNDS?*

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

TESTS FOR LIPIDS

They are tested for using the emulsion test or the grease spot (translucent spot) test.

a) Sudan III test:

Procedure	Observation	Deduction
To 1 cc of food solution, add 1 cc of Sudan III and shake.	A turbid solution turns a red emulsion.	Lipids present.
	Turbid or colourless solution remains a turbid or colourless solution.	Lipids absent.

b) The emulsion test:

The reagents used are ethanol and water.

Procedure	Observation	Deduction
To 1 cc of food solution, add 1 cc of ethanol and shake. Then add 5 drops of water and shake.	A turbid solution turns to a cream emulsion	Lipids present.
	Turbid or colourless solution remains a turbid or colourless solution.	Lipids absent.

c) Translucent spot test:

Procedure	Observation	Conclusion
Add 2 drops of test solution on a piece of filter paper. Allow to dry and observe under light.	A translucent spot or patch is left on the paper.	Lipids present
	No translucent spot is formed on the paper.	Lipids absent.

PROTEINS

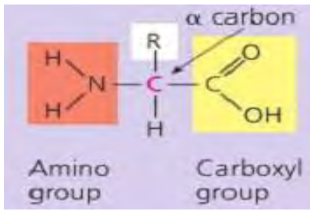
These are organic compounds of large molecular mass and insoluble in water. In addition to C,H and O, they always contain N, usually S and sometimes P.

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.
Their building blocks are the amino acids.

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



Where R is a variable

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.

Zwitter ion (no overall charge)

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 isoelectric point of an amino acid.

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.
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. Therefore being amphoteric, amino acids are buffers.
NOTE: a buffer solution is one which resists the tendency to alter its pH even when small amounts of acid or base are added to it.
Questions: ***how do amino acids act as buffer solutions?***

TYPES OF AMINO ACIDS

1. Essential Amino acids

These are amino acids that cannot be synthesized by the body and therefore got from the diet that the organism feeds on. They include:

- Histidine
- Isoleucine
- Leucine
- Proline

- Phenylalanine
- Valine
- Arginine
- lysine
- Methionine
- Tryptophan

2. Non-Essential amino acids

These are amino acids that are synthesized by the body through a process called transamination. They include:

- Tyrosine
- Alanine
- Glycine
- Serine
- Theonine
- Cystine
- Cystein
- Aspartic acid
- Glutamic acid
- Asparagine

Proteins can be classified into: **first class proteins** which contain all the essential amino acids e.g. from beans and **second class proteins** which are deficient of one or more essential amino acid.

FORMATION OF 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. These bonds include:

1. Disulphide bond:

It is formed between sulphur containing groups on any two cysteine molecules.

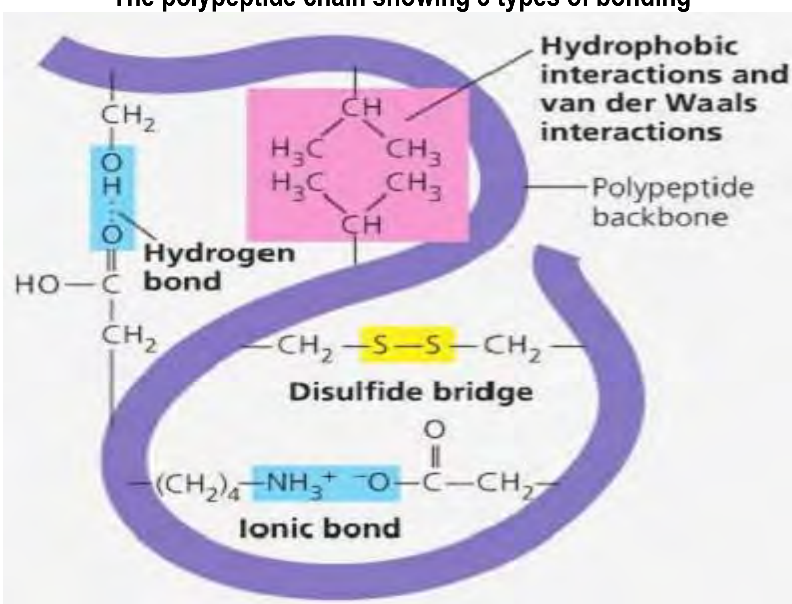
2. Ionic bond:

It is formed between NH_3^+ and COO^- groups.

3. Hydrophobic interactions:

These are interactions between non polar R groups which cause the proteins to fold as hydrophobic side groups.

The polypeptide chain showing 3 types of bonding



PROTEIN STRUCTURES

There are 3 main protein structures i.e. primary structure, secondary structure and tertiary structure.

Primary structure

It is a sequence of amino acids in a polypeptide chain. It is made up of 2 polypeptide chains held together by di-sulphide bridges. The sequences of amino acids of a protein dictate its biological functions. Examples of primary structures are insulin and lysosomes.

Secondary structure

It is maintained by many ionic bonds which are formed between neighbouring COO^- and NH_3^+ groups.

The hydrogen atoms of the NH_3^+ group of one amino acid is bonded to the oxygen atom of the COO^- group of another amino acid. Such structures are found in vertebrate skins, horns, nails, claws, beaks and feathers.

Its hardness and stretch ability vary with a degree of cross linkage between di sulphide bridges and neighbouring chains. They are joined together by hydrogen bonds between adjacent chains.

Tertiary structures

The polypeptide chain coils extensively forming a compact globular shape. 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 falls to shield the hydrophobic side groups from the aqueous surrounding and at the same time exposing hydrophobic side chains.

Quaternary structure

It is a combination of several polypeptide chains clumped together and associate with non-protein parts to form complex proteins e.g. in haemoglobin.

TYPES OF PROTEINS

1. **Fibrous proteins (**plays structural roles**)**

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 in made of such proteins.
It has a primary structure which is a repeat of tri peptide sequence (glycine, proline and alanine) and forms a long unbranched chain.

2. **Globular proteins (**plays metabolic roles**)**

They have a highly irregular sequence of amino acids in their polypeptide chains. Their shape is compact and globular. All enzymes are globular proteins. Others include hormones and haemoglobin.

3. **Conjugated proteins**

These are proteins which incorporate other chemicals within their structure. The non-protein part is the prosthetic group and plays a virtual role in the functioning of the proteins e.g.

Name of protein	Where it is found	Prosthetic group
Haemoglobin	Blood	Haem (iron)
Mucin	Saliva	Carbohydrate
Casein	Milk	Phosphoric acid
Cytochrome oxidase	Electron carrier path way	Copper
Nucleoplasm	Ribosomes	Nucleic acid

QUESTION: ***HOW DOES THE MOLECULAR STRUCTURE OF PROTEINS RELATE TO THEIR ROLES?***

i) 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.
ii) 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.
iii) Some proteins function as hormones regulating metabolic processes. These are globular and soluble in water e.g. insulin which regulates metabolic activity.
iv) 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.
v) 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.
vi) Some proteins are involved in immunological responses hence protecting the body. These are globular e.g. antibodies, fibrinogen and thrombin.
vii) Some proteins are contractile e.g. they are fibrous with a secondary structure e.g. myosin and actin filaments in muscles.
viii) Storage proteins are toxins and soluble and water with a globular structure e.g. snake venom, bacteria toxins, etc.
ix) Some proteins are insoluble in water e.g. ovalbumin that occurs in egg white, casein in milk, etc.
x) 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.
xi) Globular proteins in blood are buffers since they are soluble in water.

DENATURATION OF PROTEINS

The dimensional structure of the protein is due to weak ionic and hydrogen bonds. Any agent which breaks these bonds causes the three dimensional shape to be changed to a more fibrous form. This process is known as denaturation.

In case the actual sequence of the amino acid is not altered but only the overall shape of the molecule is changed.

Factors causing protein denaturation

Factor	Explanation	Example
1. Heat	Causes the atoms of the protein to vibrate more thus breaking the hydrogen and ionic bond.	Coagulation of albumen (egg white becomes more fibrous).
2. Acids	Addition of hydrogen ions in acids combine with COO^- of amino acids and form COOH ionic bonds are hence broken.	Souring of milk by acid and lowering pH of casein making it insoluble.
3. Alkalis	Reduced number of H^+ cause NH^+ group to loose H^+ to form NH_2 therefore ionic bonds broken.	Souring of milk by alkalis.
4. Inorganic chemicals	Ions of heavy metals e.g. mercury and silver combine with COO^- groups destructing the ionic bonds.	Enzymes are inhibited by being destructed in presence of ions e.g. cytochrome oxidase.
5. Organic chemicals	Organic solvents alter hydrogen bonding with a protein.	Alcohol denatures certain bacterial proteins. This is what makes it useful for sterilization.
6. Mechanical force	Physical movement can break hydrogen bonds.	On stretching a hair, the hydrogen bonds in the keratin helix is extended and hair stretches.

Functions of proteins

VITAL ACTIVITY	PROTEIN EXAMPLE	FUNCTION
1. Nutrition	• Digestive enzymes e.g. trypsin, amylase, etc. • Fibrous proteins in grana lamellae • casein	• catalyses, hydrolysis of proteins to peptides. • Helps to arrange chlorophyll molecules to receive unlimited light. • Assists in transporting of food in filter feeder. • Storage of proteins in milk.
2. Respiration and transport.	• Haemoglobin. • Myoglobin • Prothrombin/fibrinogen • Antibodies.	• Transport of oxygen. • Stores oxygen in muscles. • Required for blood clotting. • Essential for defense.
3. Growth	Hormones e.g. thyroxine	Controls growth and metabolism.
4. Excretion	Enzymes e.g. urease	Catalyzes reaction in ornithine cycle and helps in protein break down and urea formation
5. Support and movement	Actin/myosin	Makes it easy for muscle contraction.
	Collagen	Gives strength with flexibility in tendons and cartilage.
	Keratin	Tough for protection e.g. in scales, claws, nails, hooves, etc.
	Sceleratin	Provide strength in insect exo-skeleton
6. Sensitivity and co-ordination.	Hormones e.g. insulin	Control of blood sugars
	Vasopressin	Control of blood pressure
	Rhodopsin	Visual pigments in retina.
7. Reproduction	Hormones e.g. prolactin	Induces milk production in mammals.
	Chromatin	Gives structural support to chromosomes.
	Chitin	Storage of proteins in seeds which nourishes the embryo.
	Keratin	Forms horns and anthers which are used for sexual display.

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.

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.

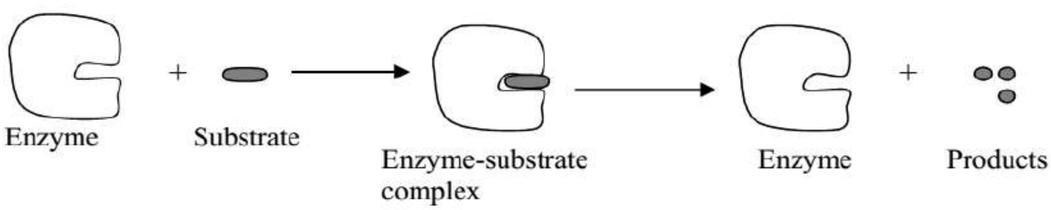
This infinite contact is maintained until the reaction is complete. The precise and specific fit between enzyme and substrate is sometimes compared with the lock and key mechanisms.

The lock and key mechanism

The widely accepted mechanism by which enzymes are known to work is the "**key and lock" hypothesis**.

The hypothesis suggests that the enzyme has a specific region known as the active site where the substrate fits like a key fits in a lock. The substrate must have a complementary shape to the active site of the enzyme. In this hypothesis the key is analogous to the substrate and the lock to the enzyme. When the substrate combines with the enzyme, an enzyme- substrate complex is formed. This breaks down to release the products and the enzyme, which can pick other substrates.

Illustration



It is suggested that the active sites may not be exactly the same shape. It is believed that when the substrate combines with the enzymes, it causes a small change to occur in the same shape of the same shaped enzyme molecule thereby enabling the substrate to fit more in the active site. This is known as ***induced fit.***

The hypothesis says that when the substrate molecule enters the active site, it causes the enzyme to change its shape so that the two molecules fit together more tightly.

Enzyme inhibitors

Enzymes may be inactivated by substrates called inhibitors which interfere with catalytic processes. This effect may be produced in several ways.

1. Active sites at the enzyme may be blocked by the formation of the enzyme inhibitor complex. This is known as ***competitive inhibition*** and occurs when inhibitor molecule is structurally similar to the usual substrate of the enzyme.
2. The inhibitor may react irreversibly with the enzyme to form an inactive non-enzymatic end product.
3. The inhibitor may alter the shape of the enzyme at its point of activity so that the enzyme substrate complexes cannot form. This is known as non-competitive enzyme inhibition.

Allosteric enzymes

These are enzymes that occur in two forms, i.e. active and inactive.

The inactive form is shaped in such a way that the substrate will not fit into its active sites. Therefore for such enzymes to work, it must be transformed into the active form.
Allosteric enzymes can be inhibited by molecules which do not combine with the active site but with the other parts of the enzyme. In this case, the inhibitor prevents the enzymes from changing into the active form, and substrates which bring about this are known as allosteric inhibitors.

Co-factors and prosthetic groups

In some instances an enzyme must be associated with smaller molecule in order to function properly. Such molecules are known as co-factors. The co-factors may be inorganic like metal ions or organic substances like nucleotides.
A co-enzyme acts as a carrier for transferring chemical groups from one enzyme to another. Examples of co-enzymes include Nicotinamide Adenine Dinucleotide (NAD).
Sometimes the function of the enzyme is carried out by a non-protein group, known as prosthetic group e.g. cytochrome oxidase has an iron prosthetic.

Classification of enzymes

Enzymes are classified depending on the type of reaction they catalyze. The following are some of the classes of enzymes.

1) **Isomerase;** these catalyze reactions involving isomerism
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.

Enzyme can also be described as being intracellular or extracellular. Intracellular enzymes are those which catalyze reactions inside the cells producing them, e.g. all respiratory enzyme are intracellular. Extracellular enzymes are those produced by a cell to catalyze reactions outside that cell. All digestive enzymes in man are extracellular.

Nomenclature of enzymes

Enzymes are named by adding a suffix “ase” to their substrates. A substrate is a substance, which the enzyme acts upon, or simply it is the raw material for the enzyme.

Examples of enzymes and their substrates

Enzyme	Substrate
Peptidase	Peptides
Lipase	Lipids
Maltase	Maltose
Sucrase	Sucrose
Lactase	Lactose
Cellulase	Cellulose

Some enzymes however retained their names they had before this convention. Such enzymes include pepsin and trypsin.
Sometimes the enzymes digesting carbohydrates are generally called carbohydrases and those digesting proteins as proteases.

PROPERTIES OF ENZYMES

1) They are all protein in nature.
2) They are specific in their action i.e. they catalyze specific food i.e. Maltase on Maltose.
3) They speed up the rate of chemical reactions (they are catalysts).
4) They are effective even in small amounts.
5) They remain unchanged at the end of the reaction.

6) They are denatured by high temperatures since they are protein in nature and are inactivated by low temperatures.
7) They are inactivated by inhibitor chemicals (poisons e.g. cyanide).
8) They work at a specific PH. (either acidic or alkaline).
9) Their reactions are reversible.
10) Their activity can be enhanced by enzyme activators e.g. chloride ions activate amylase.

FACTORS AFFECTING ENZYME ACTIVITIES

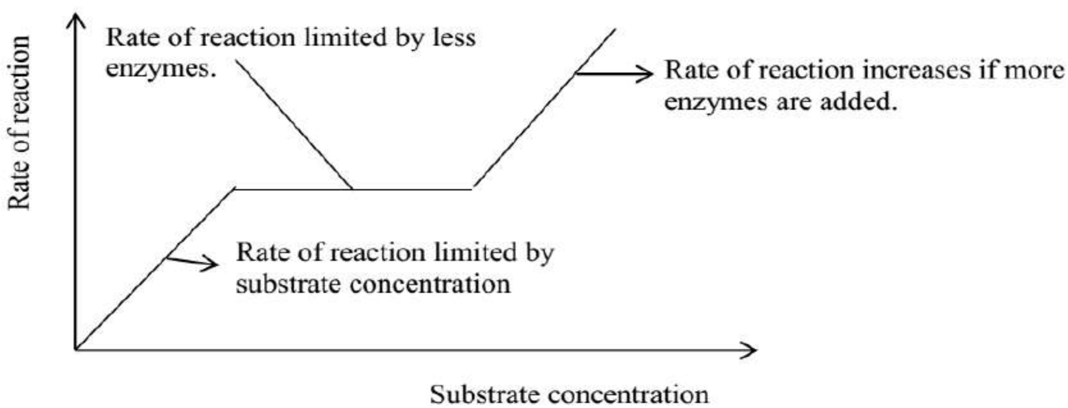
To investigate the effects of a given factor on the rate of enzyme controlled reactions, all other factors should be kept constant and at optimum levels so as to obtain accurate results.
The factors are:

i) Temperature
ii) Concentration of the substrate
iii) PH of the medium
iv) Presence of activators
v) Presence of inhibitors
vi) Concentration of the enzyme

1. Concentration of substrate:

A substrate is a substance (food) acted upon by the enzyme to form simpler products.
The rate of enzyme reaction increases with increase in substrate concentration and enzymes work slower when the substrate concentrations low.
However, further increase in substrate concentration will not increase enzyme reaction rate since all its active sites are fully saturated with food.

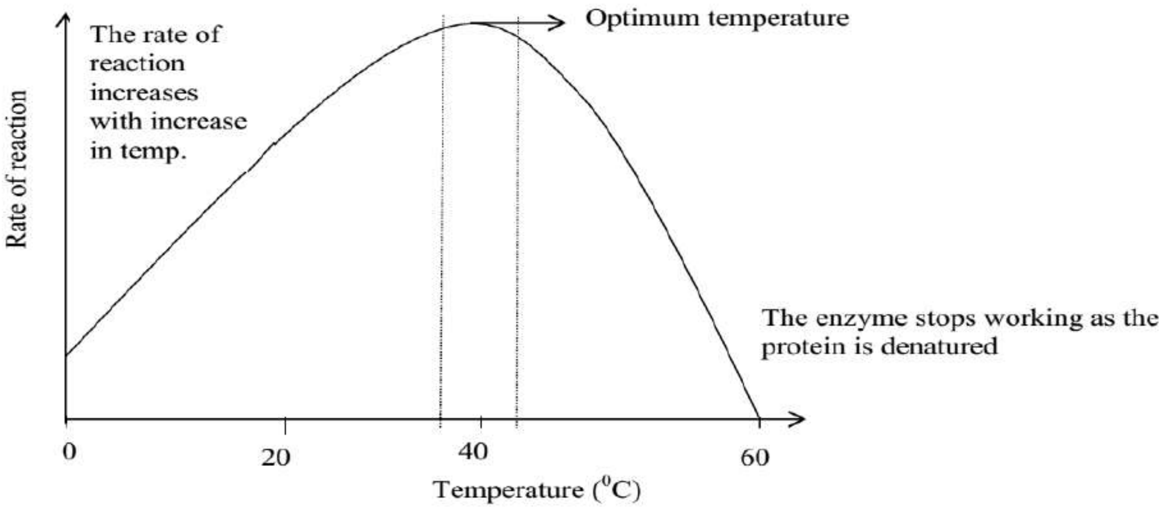
A graph showing how the rate of reaction varies with substrate concentration



2. Temperature:

Enzymes work best at optional temperatures of (approximately 37^0 C). At very low temperatures, the rate of enzyme reaction is very slow because the enzyme is inactive at such low temperatures.
As the temperatures increase, the rate of reaction also increases gradually until it attains a peak where it has maximum activity and this always correspond at optimal temperatures. An optimal temperature is which promotes maximum enzyme activity. However with further increase in temperature, the rate of reaction decreases exponentially, sharply, steeply since at high temperatures, the enzyme is denatured ie the active site of the enzyme which is (protein in nature) is a altered (changed) or completely destroyed.

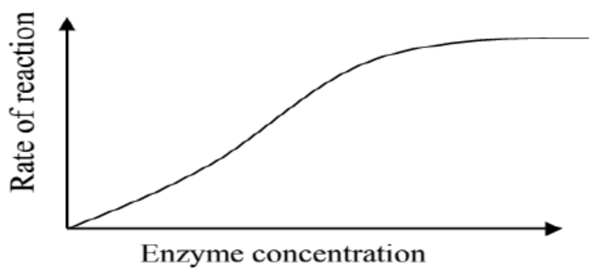
A graph showing the variation of enzyme activity with temperature



3. **Enzyme concentration:**

As the concentration of the enzymes increases, the rate of reaction also increases until all the substrates are being acted upon when the rate finally becomes constant.

A graph showing variation of enzyme activity with enzyme concentration

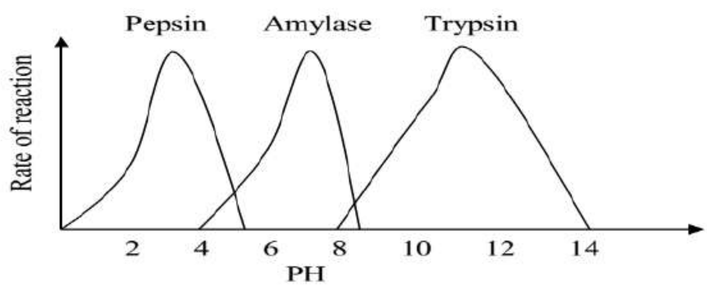


4. **The PH of the medium.**

Enzyme reactivity is reduced or stopped completely if placed in a medium whose PH is different from that in which it works best (optimum PH).

PH varies slightly above or below an enzyme's optimum PH resulting in a marked fall in the enzyme efficiency. E.g. pepsin enzyme in the human stomach has a maximum activity with in acidic pH of 1.5 and 2.5 while the enzymes in the duodenum e.g. trypsin work at maximum with in alkaline pH of 8.5 to 9.5.

A graph showing variation of different enzyme activity with PH



5. **Presence of enzyme inhibitors**

Enzyme activities decrease in presence of enzyme inhibitors and increase in their absence.

6. **Presence of activators**

Enzyme activators increase with presence of enzyme activators and decrease with absence of enzyme activators.

NUCLEIC ACIDS

These are made up of chains of individual units called nucleotides. Nucleic acids carry the genetic code that determines the order of amino acids in proteins. Genetic material stores information, can be replicated, and undergoes mutations. They differ from proteins as it has phosphorus and **NO** sulphur.

There are two types of nucleic acids i.e.

i) DNA (Deoxyribo Nucleic Acid)
ii) RNA (Ribo Nucleic Acid)

Both types of nucleic acids are present in the nucleus of the cell.
DNA is found only within the nucleus while RNA is found within the nucleus (nucleolus) and in the cytoplasm.
RNA is usually associated with ribosomes and responsible for protein synthesis.
RNA is one stranded while DNA is double stranded hence having a higher molecular mass than that of RNA.

The nucleic acid structure

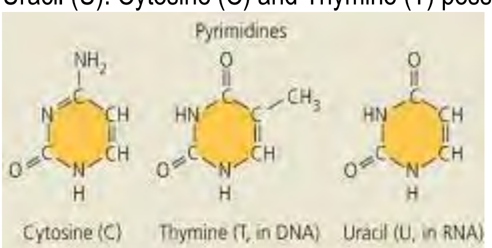
These are big molecules built from 3 types repeating sub-units i.e.

i) Nitrogenous bases (purines and pyrimidines)
ii) Pentose sugars
iii) Phosphate units.

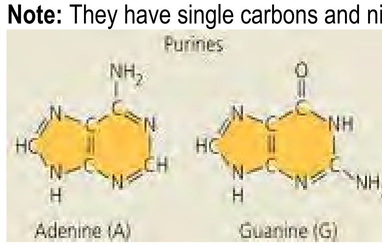
1. PURINES AND PYRIMIDINES (NITROGENOUS BASES)

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.



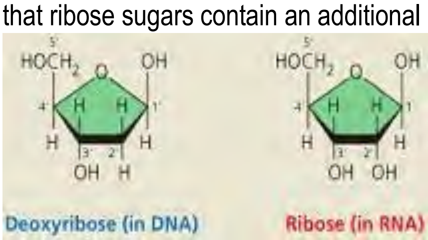
Note: They have single carbons and nitrogen rings



Note: they have double carbons and nitrogen rings

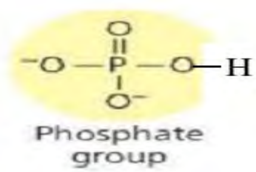
2. THE PENTOSE SUGAR UNITS

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.

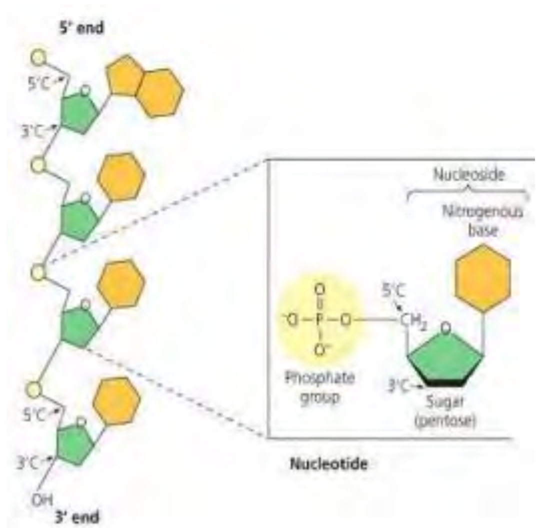


3. PHOSPHATE UNITS

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.



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

RIBONUCLEIC ACID (RNA)

The RNA molecule is made up of long chains of nucleotides incorporating the pentose sugar ribose and any of the four bases i.e. adenine and guanine (purines) or cytosine and thymine (pyrimidines).

The base uracil is found exclusively in RNA while the other bases also occur in DNA. RNA chains exist as single strands.

RNA exists in 3 types, i.e.

i) Messenger RNA (mRNA)

It forms an intermediate link between the nucleus and cytoplasm to facilitate the transfer of genetic information from the nucleus to the cytoplasm.

It is single stranded and forms 3-5% of the total RNA in the cell. mRNA is synthesized in the nucleus, a process known as transcription. It is synthesized of a DNA template after DNA has unzipped. Once completed, the mRNA strand then moves through the nuclear pore to the cytoplasm.

ii) Transfer RNA (tRNA)

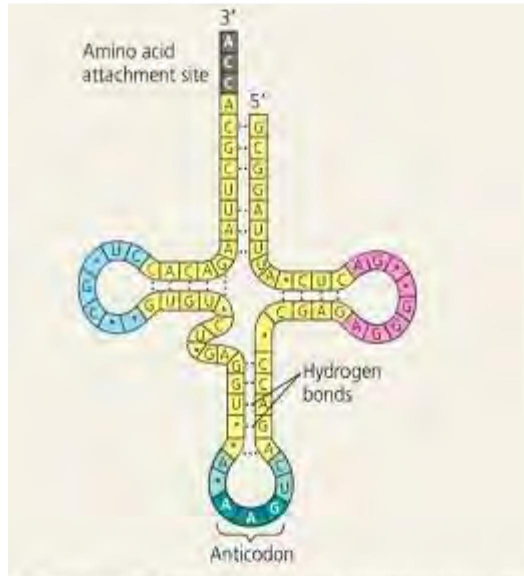
There is about 20 types of tRNA each coding for a particular amino acid. The function of tRNA is to pick up amino acids from the amino acid pool and delivering them to the site of protein synthesis i.e. on the ribosomes for alignment into polypeptides.

iii) Ribosomal RNA (rRNA)

It is the most abundant in the cell forming 80% of the total RNA. It is found in the cytoplasm where it is associated with the protein molecules which together form the ribosomes that are assembling sites during protein synthesis.

rRNA plays an important role in translating the sequence of amino acids into a polypeptide chain in the cytoplasm.

Structure of tRNA



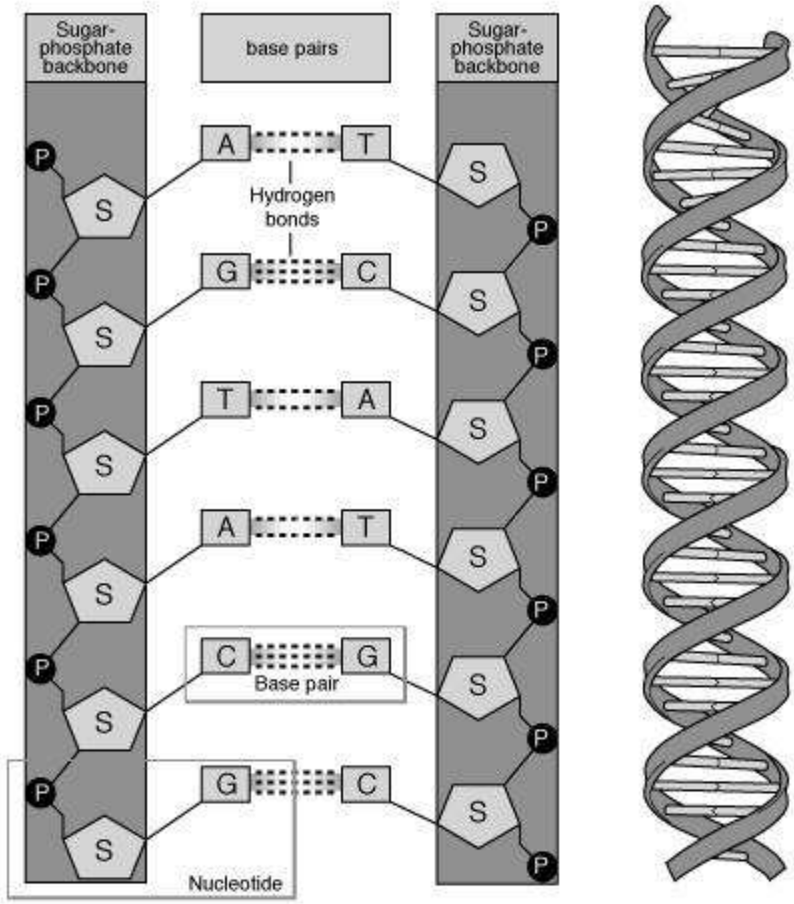
Two-dimensional structure. The four base-paired regions and three loops are characteristic of all tRNAs, as is the base sequence of the amino acid attachment site at the 3' end. The anticodon triplet is unique to each tRNA type, as are some sequences in the other two loops. (The asterisks mark bases that have been chemically modified, a characteristic of tRNA.)

DEOXYRIBO NUCLEIC ACID

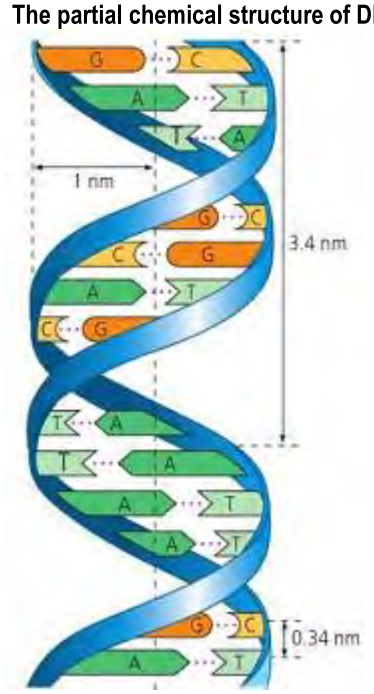
This has a very high molecular weight and its structure is more complex than that of RNA. It is similarly made up of long chains of nucleotides but in this case, the sugar unit is a pentose deoxyribose and the pyrimidine base uracil is replaced by thymine.

DNA chains do not occur singly but paired together by weak hydrogen bonds across the bases to form ladder like constrictions. These bases can only link in a specific way where a purine must always link with a pyrimidine. In this case, adenine bonds with thymine while guanine bonds with cytosine.

Structure of the DNA double helix



The partial chemical structure of DNA



Phosphorylated nucleotides

The addition of a phosphate group to an organic molecule has the effect of increasing the reactivity of that molecule. Nucleotides may also require additional phosphate groups with an increase in reactivity. An example of this is Adenosine tri phosphate (ATP) which has two extra phosphate groups linked to the molecule by high energy bonds. This molecule acts as an energy carrier during several reactions.

Other important nucleotides

Many nucleotide derivatives act as co-enzymes acting in conjugation with other specific enzymes as carrier molecules by transferring a group of atoms from one molecule to another.

Nicotinamide adenine dinucleotide (NAD) is a phosphorylated derivative and Flavine adenine dinucleotide (FAD) both act as hydrogen carriers.

Co-enzyme A, also a nucleotide derivative acts as an acetyl carrier molecule.

Similarities between RNA and DNA

- Both contain guanine, cytosine and adenine.
- Both are found in the nucleus.
- Both are made of long chains of nucleotides.
- Both are made up of a base, sugar and a phosphate group.
- They both form the genetic material.
- Both of them contain four bases and two of them are derived from purines and the others from pyrimidines.

Differences between RNA and DNA

DNA	RNA
Contains thymine	Contains uracil
Made up many nucleotide chains	Made up of a single nucleotide chain
Double stranded	Single stranded
High molecular weight	Has a low molecular weight
Has got hydrogen bonds	Lacks the hydrogen bonds
Found exclusively in the nucleus	Found in the nucleus and cytoplasm
It is of one type.	It is of three types i.e. mRNA, rRNA and tRNA.

PROTEIN SYNTHESIS

Protein synthesis requires the supply of amino acids, energy and information. When these are grouped or brought together, proteins are synthesized in 3 types, i.e. Transcription, Activation and Translation.

Transcription

This is the process of transferring part of the coded information of DNA in the nucleus to the ribosome in the cytoplasm. It involves a nucleic acid molecule made of RNA, known as mRNA, which is a single stranded molecule manufactured in the nucleus from one strand of DNA double helix referred to as coding strand.

The enzyme catalyzing the reaction of transcription is known as RNA polymerase. The beginning of protein synthesis starts by RNA polymerase attaching itself to the DNA double helix and the hydrogen bonds are broken down in the region of DNA to be coded (copied) and the DNA strand unwinds.

One DNA strand is then coded by base pairing of ribo-nucleotides, which are condensed together to form a strand of mRNA. The base sequence of mRNA is complementary to the coding strand of DNA. Once formed, the mRNA passes out into the cytoplasm and becomes attached to the ribosome.

Amino acid activation

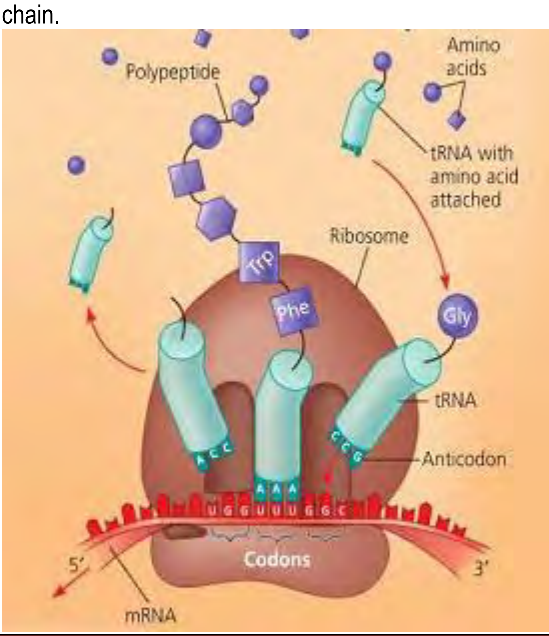
Amino acids are activated for protein synthesis by combining with a short length of RNA known as transfer RNA (tRNA). The activation process involves ATP for provision of energy.

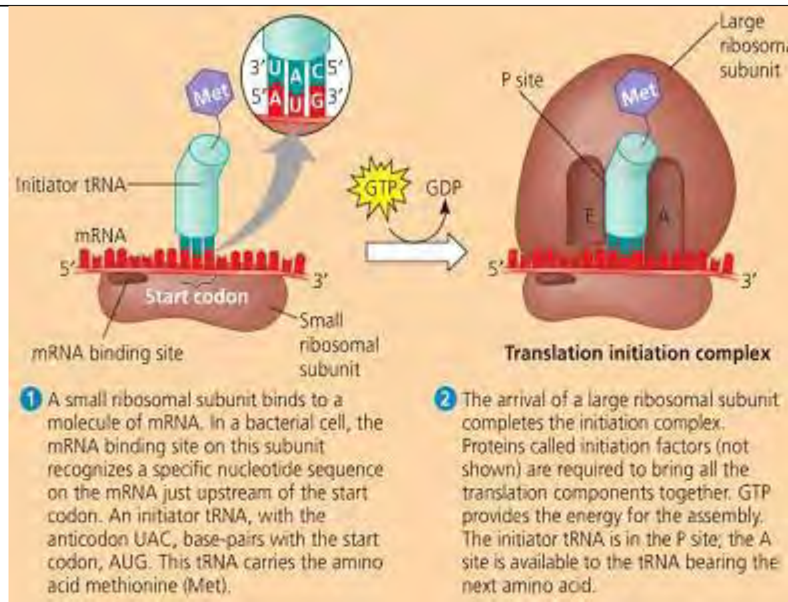
There are more than 20 amino acids coded for in all proteins. All tRNA have a globally leaf shape but differ in sequence of bases known as anticodon which is exposed on one of the leaves. This anticodon is complementary to the codon of mRNA.

Each type of tRNA binds with a specific amino acid. The amino acid molecules join to the free ends of tRNA molecules. The tRNA amino acid complexes now move to the ribosomes.

Translation

This process occurs in the ribosomes. It is mainly placing of the activated tRNA anticodon to the right mRNA codon by the ribosome in order to make a polypeptide chain.





Ribosomes move along the length of the mRNA strand reading the codon from the start codon starting at one end of the mRNA molecule. A ribosome works its way along the mRNA positioning the anticodons of the tRNA on the complementary codon of the mRNA strand.

In the ribosome, complementary anticodons of amino acids, tRNA complexes are held in place by hydrogen bonds.

The amino acids are then joined by peptide bonds therefore meaning that the ribosome is acting as a supporting frame work, holding the mRNA and two amino acids.

tRNA complexes together and enables and enzyme to catalyze the formation of a polypeptide bond between the adjacent amino acids.

The ribosomes move along the mRNA and as it does it positions two activated tRNA having one amino acid at the same time.

The ribosome has two sides, A and P sides. At the starting codon, the side A is attached to the first tRNA which the P side is empty.

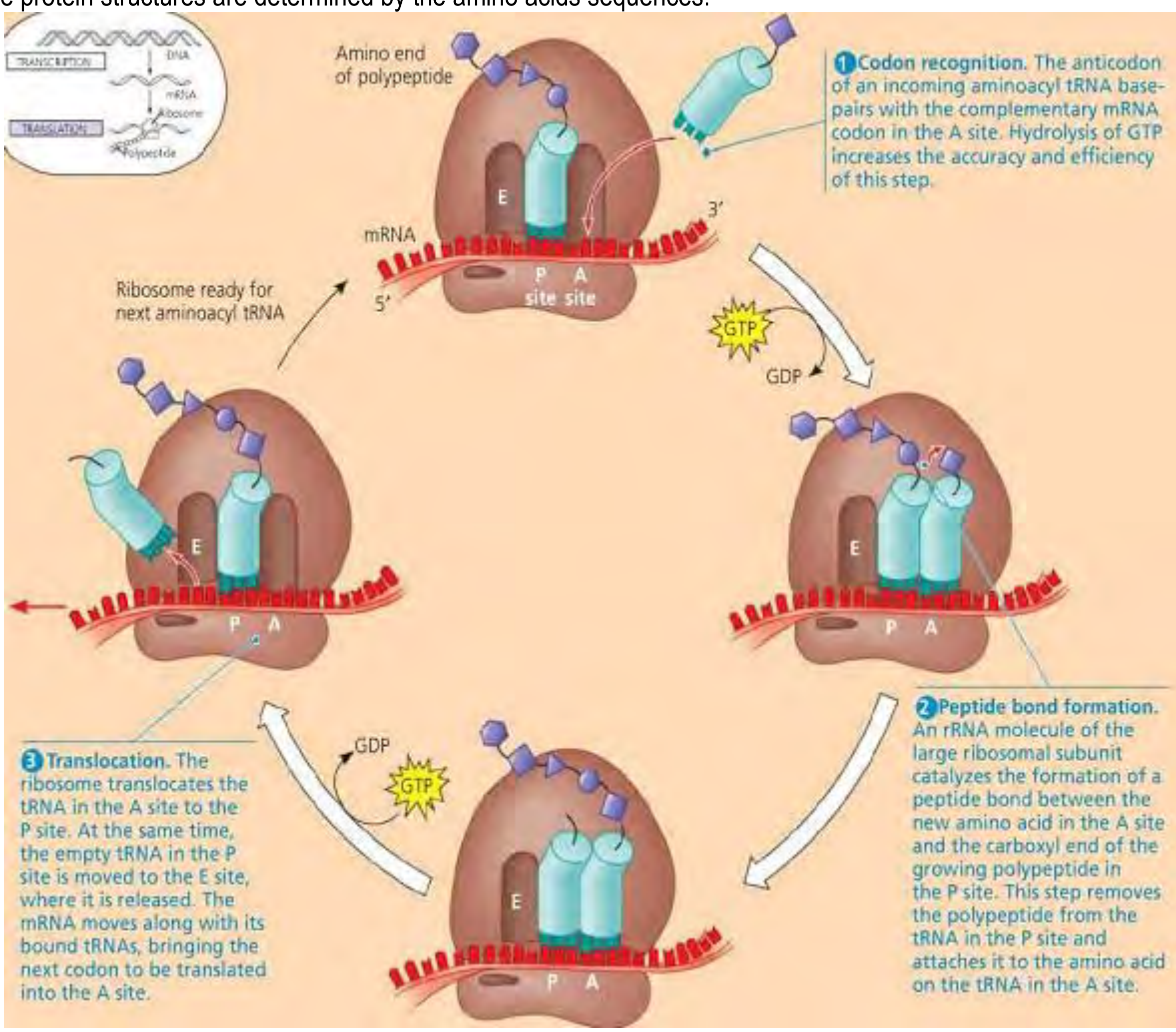
When it continues to move, a second tRNA attracts itself to the empty side corresponding to the second codon of mRNA.

The presence of the second amino acids on the second tRNA stimulates the formation of a polypeptide bond between the amino acids.

This makes the earlier tRNA to loose contact from the mRNA and its amino acids making it free going back to the cytoplasm.

For further activation, the ribosome continues to move along the codons of the mRNA, placing the activated tRNA in their right positions, together with their amino acids in the process forming a polypeptide chain which is released into the cytoplasm when the ribosome reaches the stop codon.

The protein structures are determined by the amino acids sequences.

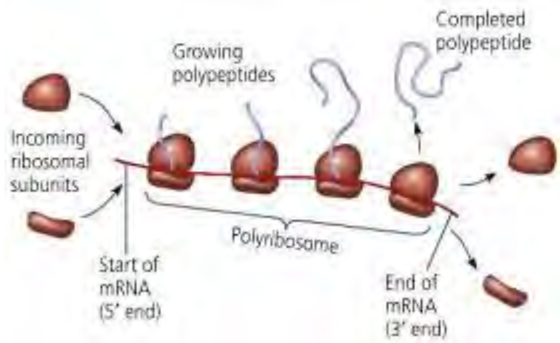


Polysomes/polyribosomes

These are groups of ribosomes, connected by a common strand of mRNA and synthesizing different types of polypeptide chains simultaneously. This arrangement means that several polypeptide chains are made at the same time, on one mRNA molecule.

When synthesis is completed, the polypeptides are moved from the ribosome to the cytoplasm and constructed into the proteins for internal use by the cell or for secretion.

Diagram illustrating synthesis of proteins by polysomes



Questions:

1. *How does DNA regulate the synthesis of proteins? (protein synthesis but focus on DNA)*
2. *Outline the role played by the different types of RNA in protein synthesis.*

THE GENETIC MATERIAL

This is the material that is responsible for the transmission of hereditary traits or characteristics form one generation to another.

Characteristics of a hereditary material

i) It should be able to carry out self-replication i.e. make exact copies of itself for the onward transmission of its features to the off springs.
ii) It should be stable in structure i.e. it should not change erratically losing its structure during transmission.
iii) It should have the capacity to change i.e. to provide new material for creation of a new inheritance feature that can improve linkage of off springs. This can be done through mutation.
iv) It should have the capacity to store information correctly preferably in a code which can be read and interpreted at an appropriate time.
v) It should be strategically located in the part of the body where it can be protected against metabolic reactions but have the ease to transmit information to all body parts e.g. in the nucleus.

Evidence of DNA as a hereditary material

Early researchers scrutinized many molecules in the body to find out which ones could have characteristics that fit the hereditary material. Proteins were seen as the best candidates since they were versatile in nature and were dominant in body parts. Proteins however are unstable as they constantly change and they are metabolically active and even not self-replicating.

Friedrich later eliminated proteins as the best candidate and identified a macro molecule he named 'nuclein' which appeared to satisfy most of the essential characteristics. Nuclein was later renamed DNA.

Characteristics of DNA as a genetic material

i) Consistency of DNA content in the nucleus. Diploid nuclei from cells in any species and at different stages of mitosis all contain the same quantity of DNA.
ii) The gamete nuclei contain half the quantity as expected.
iii) Unlike other cell components, DNA remains stable and intact as a large molecule.
iv) DNA is not metabolized at any stage.
v) DNA has the capacity to mutate. Mutagens like U.V. light bring about changes in the DNA molecule which acts as a basis for new material of inheritance. Mutation is however limited and does not change the whole organism.
vi) Presence of DNA in chromosomes which are the materials of hereditary.
vii) Ability of DNA to replicate.

DNA REPLICATION

One of the most attractive features of DNA is that it can increase in amount before a cell divides. In order for DNA replication to occur, the two strands should be capable of unwinding. The process of DNA replication is catalyzed by enzymes.

A model for DNA replication (the basic concept)

In this simplified illustration, a short segment of DNA has been untwisted into a structure that resembles a ladder. The rails of the ladder are the sugar-phosphate backbones of the two DNA strands; the rungs are the pairs of nitrogenous bases. Simple shapes symbolize the four kinds of bases. Dark blue represents DNA strands present in the parent molecule; light blue represents newly synthesized DNA.

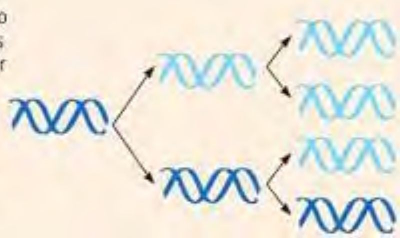
(a) The parent molecule has two complementary strands of DNA. Each base is paired by hydrogen bonding with its specific partner, A with T and G with C.

(b) The first step in replication is separation of the two DNA strands. Each parental strand can now serve as a template that determines the order of nucleotides along a new, complementary strand.

(c) The complementary nucleotides line up and are connected to form the sugar-phosphate backbones of the new strands. Each "daughter" DNA molecule consists of one parental strand (dark blue) and one new strand (light blue).

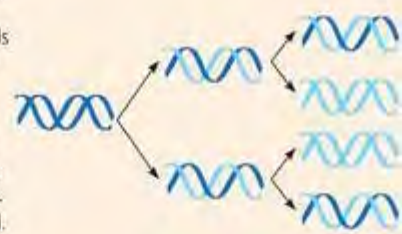
There are three hypotheses put forward to explain the process of DNA replication:

1) **The conservative hypothesis**
Here, no unwinding occurs but the DNA molecule acts as a stimulant to direct the reaction. All the DNA strands formed are directly similar but not complementary to the parental strands. This hypothesis has not received any scientific backing and appears impractical.



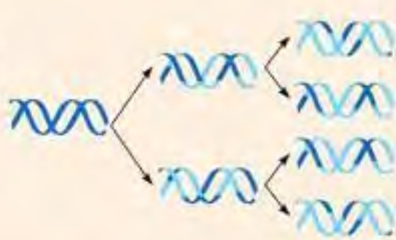
Conservative model. The two parental strands reassociate after acting as templates for new strands, thus restoring the parental double helix.

2) **The semi-conservative hypothesis**
The DNA double helix unwinds and produces two DNA strands. Therefore the parent molecule act as a template where by each strand is used to manufacture another complementary strand thus one strand is directly conserved and only one new strand is manufactured.



Semiconservative model. The two strands of the parental molecule separate, and each functions as a template for synthesis of a new, complementary strand.

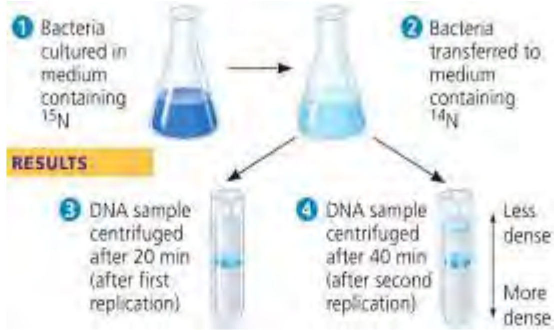
3) **Dispersive hypothesis**
According to the hypothesis, DNA initially disintegrates and then re-assembles alongside with the new complementary nucleotides adding to form new helices.



Dispersive model. Each strand of *both* daughter molecules contains a mixture of old and newly synthesized DNA.

Note: Meselson and Stahl performed an experiment to find out whether DNA replication follows the conservative, semiconservative or dispersive model. They cultured E. coli for several generations in a medium containing nucleotide precursors labeled with a heavy isotope of nitrogen, ^{15}N. They then transferred the bacteria to a medium with only ^{14}N, a lighter isotope. Two samples were taken from this flask, one at 20 minutes and one at 40 minutes, after the first and second replications, respectively. They could distinguish DNA or different densities by centrifuging DNA extracted from the bacteria.

They then compared their results to those predicted by each of the three models.
The first replication in the ^{14}N medium produced a band of hybrid (^{15}N- ^{14}N) DNA. This result eliminated the conservative model.
The second replication produced both light and hybrid DNA, a result that refuted the dispersive model and supported the semiconservative model. They therefore concluded that DNA replication is semiconservative.



DNA AND THE CHROMOSOME STRUCTURE

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

i) **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).

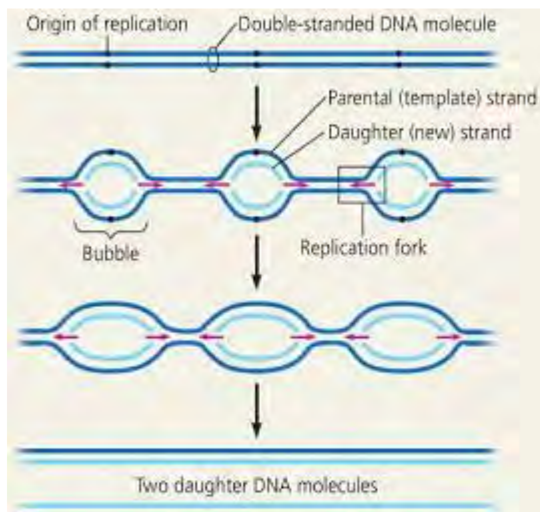
ii) **Eukaryotic chromosomes:**
They are in higher plants and animals. Each cell contains several pairs of chromosomes. The chromosomes are large and they change their form and structural organization at different stages of the cell cycle.
Each chromosome is made up DNA and an equal quantity of protein weight by weight. The DNA protein complex found in chromosomes is known as nucleoprotein or chromatin.

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. Replication of DNA in eukaryotic chromosomes occurs by the semiconservative method but would be very slow due to its length taking about 16 days to manufacture one strand.
To avoid the slow speed, DNA opens up as many as 6000 ***replication forks***. Replication takes place at all the forks almost concurrently and the cycle is completed in 3-4 minutes.



DNA AND GENES

The genetic code

This refers to the way genetic information is encoded or arranged on the DNA strand. It is a known fact that a lot of genetic information is stored and transmitted by the DNA molecule.
Such information is arranged in form of a code of base pairs on the DNA strand. To be able to utilize this information e.g. during the manufacture of amino acids, proteins, enzymes, hormones, etc. the code must be read and interpreted correctly and the secret information released and transformed into products.

Reading the code

A code (DNA) is usually located in the nucleus yet the products of reading it are found in the cytoplasm. Therefore, information has to be transferred from the nucleus to the cytoplasm in order to make the products. Both transfer and utilization of information is done through a special molecule called RNA. This is a nucleic acid that has the capacity to move out of the nucleus therefore transfer information.

What is a gene?

It is a unit of hereditary located on the positions called gene loci on the chromosome. Genes who code for polypeptides are of two groups:

1) **Structural genes:** these code for function of proteins e.g. enzymes, hormones, antibodies, etc.
2) **Regulatory genes:** these serve to control the activity of other genes.

The DNA strand has two regions;

i) The split gene area, which is the coded area and made up of coding sequences known as exons.
ii) The non-coding area is made up of redundant DNA and is composed of non-coding sequences called introns. The function of introns is unknown.

The code dictionary/genetic code

The genetic code is a set of rules by which information encoded within genetic material is translated into proteins by living cells. There are four bases on the DNA strand that are used for coding of amino acids. Their combination ought to give a coding total of 20 amino acids found in the body. If each base was on its own codes for an amino acid, only four amino acids would be coded. If the bases acted in pairs only 16 amino acids would be coded. In both cases, 20 amino acids are not arrived at it. It therefore appears reasonable to theorize that 3 base pairs are required for coding an amino acid.

Second mRNA base

First mRNA base (5` end of codon)	U	C	A	G	Third mRNA base (3` end of codon)
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
U	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
U	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
U	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
C	CUC Leu	CCC Pro	CAC His	CGC Arg	C
C	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
C	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
A	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
A	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
A	AUG Met	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
G	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
G	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
G	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

Having established that each amino acid is determined by a triplet base pair, it has been used to establish and read the code dictionary. The three base pair hypothesis means that to code for the 20 amino acids occurring in the body, 64 possible combinations exist. The 44 combinations are not used in amino acid coding and are referred to as degenerate or nonsense codons/stop codons. Because of this, more than one but nearly similar triplet can code for an amino acid.

The three bases of an mRNA codon are designated here as the first, second, and third bases, reading in the 5` to 3` direction along the mRNA. () the codon AUG not only stands for the amino acid methionine (met) but also functions as a “start” signal for ribosomes to begin translating the mRNA at that point. Three of the 64 codons function as “stop” signals, marking the end of a genetic message.

General characteristics of the genetic code

i) ***Universal:*** This means that the same codons are used to specify the same amino acids in all forms of life.
ii) The code is ***degenerate*** i.e. more than one codon can code for one amino acid. Some amino acids like methionine and tryptophan are coded by only one codon but many others are coded by several codons. Therefore, a code has excess codons. These codons are known as synonymous.
iii) The code is ***non-ambiguous*** i.e. no one codon can code for more than one amino acid.
iv) The genetic code is ***triplet*** i.e. it has got three bases.
v) The principle of ***co-linearity:*** It is ***collinear*** because the sequence of codons on the mRNA corresponds to that of the amino acid on the polypeptide chain. The linear order of nucleotides in DNA determines the linear order of codons in mRNA.
vi) ***Non-over lapping*** except in some viruses. From the starting of mRNA the sequence of bases read in blocks of three, correspond to the sequence of amino acids, without any overlapping of bases. For example if the bases from the starting are AUGCCAAUC the sequence of codons is AUG/CCA/AUC and not AUG/GCC/CAA/AUG. No single base in a sequence takes part in the formation of more than one codon.
vii) ***Non sense/termination codons:*** Some triplets do not code for any amino acids i.e. they punctuate the process of protein synthesis. They include UAA, UAG and UGA.
viii) The genetic code has ***initiation or start codons***. AUG specifies methionine, AUG when present at the first position of the mRNA, acts as a start signal thus called start codon. It means all polypeptides begin with the first amino acid as methionine which is later removed enzymatically. If AUG appears in the middle of mRNA, it simply codes for methionine.

***

“Whatever the mind of man can conceive and believe, it can achieve” (Napoleon Hill, 1983).

CLASSIFICATION OF ORGANISMS

Classification is defined as the grouping of organisms together basing on the features they have in common.

Taxonomy is defined as the science of classification.

Braches of taxonomy

Nomenclature is the giving of names to organisms.

Systematics is the placing of organisms into groups basing on their similarities and differences.

Binomial nomenclature is the assigning of two Latin names to each organism. The first name/word is the *generic* name and the second name/word is the *specific* name.

In binomial nomenclature, the following rules are observed;

i. The generic name starts with the upper case (capital letter) while the species name starts with a lower case (small letter).
ii. Unless written in italics, the two words must be underlined separately e.g. Homo sapiens/ *Homo sapiens.*

THE TAXONOMIC HIERARCHY

This is the descending order in size of the taxonomic group is Kingdom, Phylum (division in plants), Class, Order, Family, Genus and Species.

Each taxonomic group is called a taxon or taxa (plural). Each taxon posses a diagnostic feature i.e. features which are unique (peculiar) to that group e.g. presence of vertebral column is a diagnostic feature for phylum Chordata. Fur is a diagnostic feature for class mammalia and feathers are peculiar to birds.

What is a species? This is a group of organisms having many common physical and other features and if sexually reproducing, they can breed to produce fertile offsprings.

WAYS OF CLASSIFYING ORGANISMS

Artificial classification: this is based on one or a few easily observable characteristics for simplicity and convenience.

Natural classification: this considers natural relationships between organisms e.g. internal and external features. The features considered include;

- Embryology
- Physiology
- Biochemistry
- Cell structure
- Behavior

Phylogenetic classification: this is based on evolutionary history (phylogeny) of organisms. Organisms belonging to the same group are believed to share a common ancestor. It bases so much on fossil evidence.

Phonetic classification: this is based only on observable characteristics and all characters are considered to be of importance. A lot of data is collected and the degree of similarity between different organisms is usually calculated by computers.

NOTE: classification today is mostly natural and phylogenetic.

SPECIMEN IDENTIFICATION AND KEYS

A specimen key involves listing observable characteristics of organisms and matching with those features which are diagnostic in a particular group.

The characteristics used in keys should be readily observable morphological characters. They may be qualitative e.g. shape or quantitave e.g. number of segments. The characteristics must be constant for that species and not subject to variations as a result of environmental influence, colour and size are highly discouraged.

Dichotomous key

This is a simple diagnostic key in which pairs of statements called **leads**, each dealing with a particular characteristic is numbered e.g. 1, 2, 3, e.t.c. The paired statements of each lead should be contrasting and mutually exclusive. Such that by considering them in order, a large group of organisms are broken down into progressively smaller groups until the unknown organism is identified. An example of a dichotomous key for indentifying arthropods is shown below,

1 a) Has 8 legs……………………..W
b) Has 6 legs………………………2

2 a) Has long antennae……………..X
b) Has short antennae……………..3

3 a) Has proboscis………………….Y
b) Has mandibles…………………Z

THE FIVE KINGDOMS

A. Prokaryotae
B. Protoctista
C. Fungi
D. Plantae
E. Animalia

VIRUSES

Viruses do not fit in any of the above kingdoms because they are on the border of living and non-living things. Viruses have a simple structure consisting of a small piece of nucleic acid either DNA or RNA which in most viruses is surrounded by a protein or a lipoprotein.

Characteristics of viruses

i. They lack a cellular structure i.e. they are acellular
ii. They are the smallest living things 20-300nm in diameter
iii. They are obligate endoparasites i.e. they can only live parasitically inside other cells.
iv. They depend on host cells for reproduction
v. Viruses are highly specific i.e. each virus recognises and infects a particular host.
vi. Most viruses enter their hosts by phagocytosis and pinocytosis

Reasons why viruses are considered to be living things

a. They posses genetic material
b. They can mutate and hence evolve
c. They carry out protein synthesis in host cells
d. They are capable self replication when inside host cells
e. They can transmit characteristics to the next generation
f.

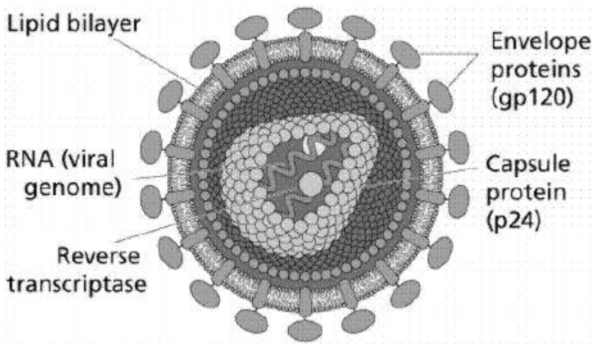
Reasons why viruses are considered to be non-living things

a. They can be crystallised
b. They lack enzyme systems
c. They cannot metabolise unless they are inside host cells
d.

<u>Generalised structure of a virus</u>

Core	This is the inner region in which the genetic material (DNA or RNA) is found. The DNA or RNA may be single stranded or double stranded
Capsid	This is the protective coat of protein surrounding the core. The Capsid is made up of subunits called **capsomeres.**
Envelop	This is found only in some large viruses

Structure of the HIV virus



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 reverse transcriptase enzyme converts single stranded RNA into double stranded DNA copies.HIV is referred to as a **retrovirus** because the enzyme reverse transcriptase, found in retroviruses, catalyses the conversion of viral RNA into DNA i.e. reverse transcription. The viral DNA made is then inserted into the host's DNA where it directs the production of more viral properties.

The envelope contains glycoproteins which bind specifically to helper T-cell receptors, enabling the virus to enter the helper T-lymphocytes.

Examples of viral diseases;

a. In plants
   i. Cassava mosaic disease
   ii. Tobacco mosaic disease
   iii. Tomato bush stunt disease
   iv. Southern bean mosaic disease
   v.
b. In animals
   i. Small pox
   ii. The Acquired Immuno Deficiency Syndrome (AIDS)
   iii. Rabies
   iv. Measles
   v. New castle disease
   vi.

KINGDOM PROKARYOTAE

Prokaryotes are organisms whose genetic material is not bound by a nuclear membrane.

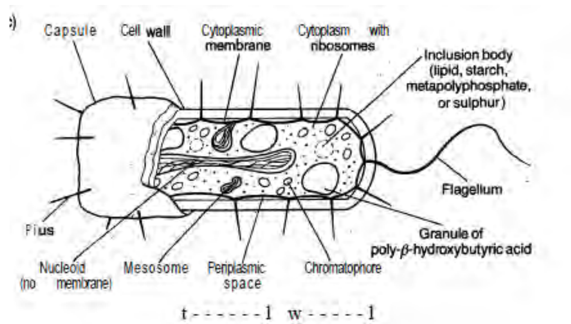
All members are unicellular and they belong to two main groups;

a. **Archaea**
   This group contains organisms that grow under extreme conditions e.g. halophiles which grow under extremely high salt concentration
b. **Hyperthermophiles**
   This group contains organisms that grow under very high temperatures.

BACTERIA

They are the smallest unicellular organisms and they are the most abundant.

Generalised structure of a bacteria



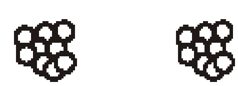
CLASSIFICATION OF BACTERIA

This is based on structural and metabolic features.

Classification by shape

There are four main shapes of bacteria and they are as follows;

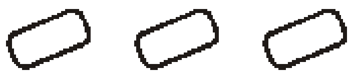
a. **Spherical shape** (cocci, singular = coccus)
   They may be clusters e.g. *Staphylococcus aureus* which causes boils and food poisoning.



   They may occur in pairs enclosed by a capsule, diplococci e.g. *Diplococcus* *pneumoniae* which causes pneumonia.

They may occur in chains, streptococci e.g. *Streptococcus thermopiles* which gives yoghurt the creamy flavor

b. **Rod shaped** (bacilli, singular = bacillus)
They may occur as single rods e.g. *Escherichia coli* which lives in the guts of humans and *Bacillus anthrax* which causes anthrax.



They may occur in chains e.g. Azotobacter which fixes nitrogen in the soil.

c. **Curved or spiral shaped**
Spiral shaped bacteria include *Spirillum* species

Curved shaped bacteria include the coma shaped (vibrios) bacteria such as *Vibrio cholera* which causes cholera.

d. **Filamentous bacteria**
This group includes *Actinomyces* which occur in the mouth and may cause dental caries.

Classification by method of respiration

a. **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.

b. **Anaerobic bacteria**
They respire without oxygen and obligate anaerobes are killed in the presence of oxygen. Facultative anaerobic bacteria can use oxygen but can respire without it.

Classification by methods of nutrition

a. **Autotrophic bacteria**
These bacteria manufacture their own organic food from carbon dioxide.
Photoautotrophic (photosynthetic) bacteria use energy of sun light to convert carbon dioxide into carbohydrates. Examples include; the blue-green bacteria, sulphur bacteria and cyano bacteria.
Chemoautotrophic (chemosynthetic) 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;
Nitrosomonas $NH_4^+ \longrightarrow NO_2^- + \text{Energy}$

Nitrobacter $O_2 + NO_2^- \xrightarrow[O_2]{} NO_3 + \text{Energy}$

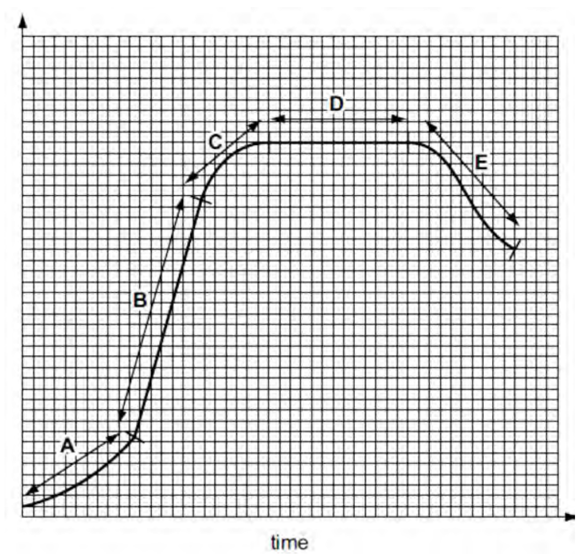
b. **Heterotrophic bacteria**
This feeds on already made organic food but in different ways.
Chemo-heterotrophic bacteria obtain energy from chemicals in food.
Saptrotrophic bacteria obtain their food from dead and decayed organic matter. Such bacteria secrete enzymes into the food, and absorb the soluble products of extra cellular digestion with the saptrotrophic 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 with legumes in the root nodules
Note: *Escherichia coli* contribute vitamins B and K groups. Rhizobium fixes nitrogen into the plants as it is provided with a shelter.

Classification by staining reaction

Gram positive bacteria; they stain purple with a gram stain. The cell wall lacks an extra outer membrane.

Gram negative bacteria; they stain pink with a gram stain. Their cell wall lacks an extra outer membrane which is made out of lipids and polysaccharides. The outer membrane gives them protection against penicillin and lysozymes.

POPULATION GROWTH CURVE OF BACTERIA



Lag phase (A). The population increases gradually as the bacteria are still adapting to their new environment and growth has not yet achieved the maximum rate. The bacteria also synthesises new substances.

Log phase (B). The population increases rapidly with time. The bacteria have adapted to the environment and enzymes have been synthesised to digest food which is in abundance so as to support the rapidly increasing population.

Decelerating phase (D) There is slow population growth because food has reduced.

Stationary phase (E) The population remains constant with time because the death rate equals to the rate of formation of new cells due to;

i. Stiff competition for decreasing food
ii. Depletion of oxygen (reduction of oxygen)
iii. Accumulation of toxic wastes from metabolism

Phase of decline (F). The population declines slowly because the cells stop multiplying due to exhaustion of oxygen, accumulation of wastes and exhaustion of nutrients.

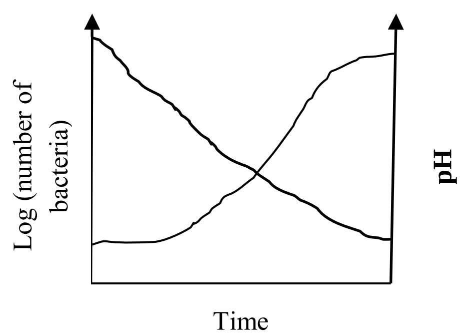
FACTORS WHICH AFFECT BACTERIAL GROWTH

1. Nutrient availability
2. Oxygen availability
3. Temperature
   i. High temperature speeds up bacterial population growth up to 40^0C after which it declines
   ii. Very low temperatures slow down bacterial growth because the enzymes become inactivated.
4. Availability of moisture
5. Accumulation of toxic waste products (carbon dioxide). Low pH results from the reaction between carbon dioxide, from respiration with water to form the weak carbonic acid.

   i.e.

   $$CO_2 + H_2O \longrightarrow H_2CO_3$$

Low pH inhibits bacterial population growth while high pH favours bacterial population growth.



ECONOMIC IMPORTANCE OF BACTERIA

1. They are cultured for research purposes
2. They facilitate the making of foods like yoghurt, cheese and vinegar
3. They are used for making antibiotics, amino acids and enzymes.

4. In humans, vitamin K and B complex are produced by the symbiotic bacteria (*E. Coli*) while in animals it is used to break down cellulose.
5. They cause decomposition of dead organic matter, hence enabling their disposal.
6. They take part in nutrient recycling e.g. the nitrogen cycle, carbon cycle and the phosphorous cycle.
7. On the other hand, bacteria cause food to get spoilt
8. Bacteria like *Thiobacillus* and *Disulphovibrio* produces sulphuric acid which destroys underground metal pipes.

KINGDOM PROTOCTISTA

Protists are eukaryotes and they may be unicellular or multicellular. They are placed under several phyla but those of much importance at this level include the following.

PHYLUM RHIZOPODA

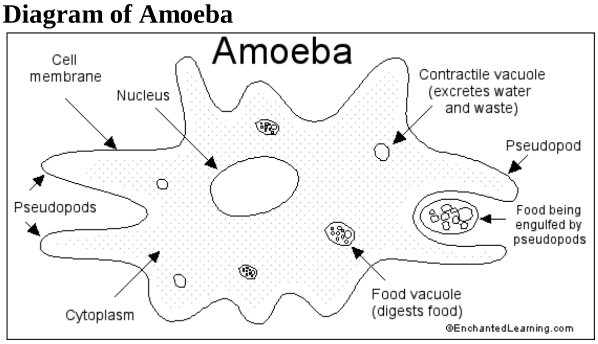
Examples include;

i. *Amoeba proteus* which lives in fresh water
ii. *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

Diagram of Amoeba



Functions of the parts

The **mitochondria** is used in the production of energy for the contractile vacuole

The **cytoplasm** is the place where all the important chemical reactions take place.

The **contractile vacuole** is used for osmoregulation

The **nucleus** is essential for directing activities

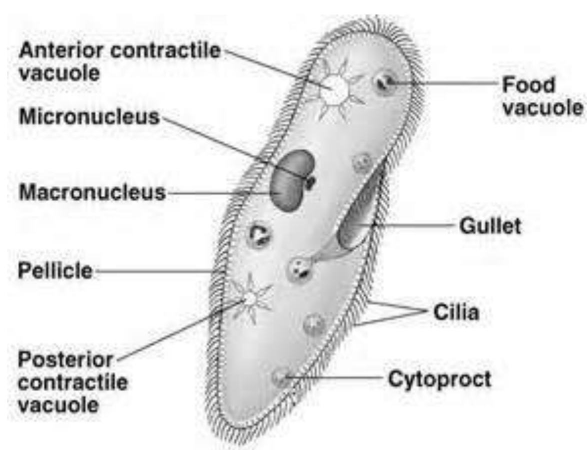
PHYLUM CILIOPHORA (CILIATES)

Examples include Paramecium, Stentor, Vorticella, Didinia e.t.c.

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.

Diagram of a paramecium



PHYLUM ZOOMASTIGINA (Flagellates)

Examples include trypanasoma which causes trypanasomiasis (sleeping sickness), trychomonas

Characteristics

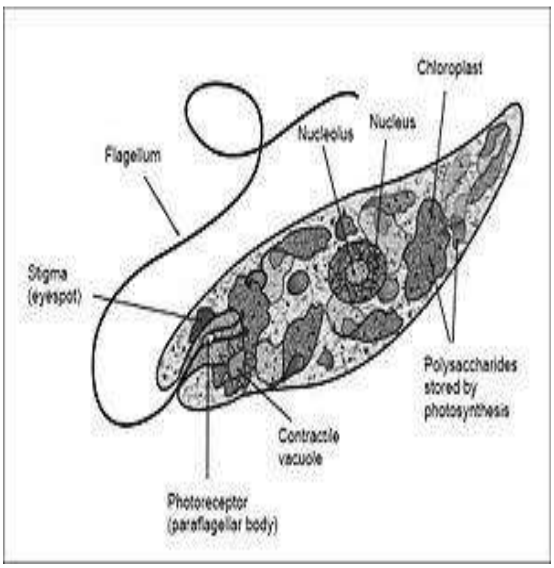
- They bear flagella for locomotion
- They are heterotrophic
- They are unicellular
- The reproduce both asexually and sexually
- They bear a 9+2 tubule arrangement

PHYLUM EUGLENOPHYTA

The only member is euglena which lives in an aquatic environment.

Characteristics

- They are mostly unicellular
- They reproduce asexually
- They move by flagella
- Some are photosynthetic while others are heterotrophic or autotrophic



PHYLUM APICOMPLEXA (sporozoans)

Members include plasmodium which causes malaria in humans

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

Life cycle 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. Fertilisation 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.

PHYLUM OOMYCOTA

Includes peronospora which grows on grapes and pythium which causes late potato blight and tomato rot

They are characterized by production of spores that bear flagella. Such spores are produced both sexually and asexually.

PHYLUM CHLOROPHYTA (green algae)

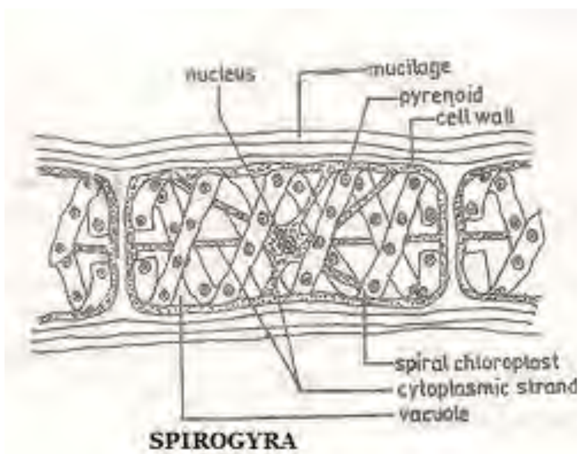
The members include volvox, chlorella and spirogyra

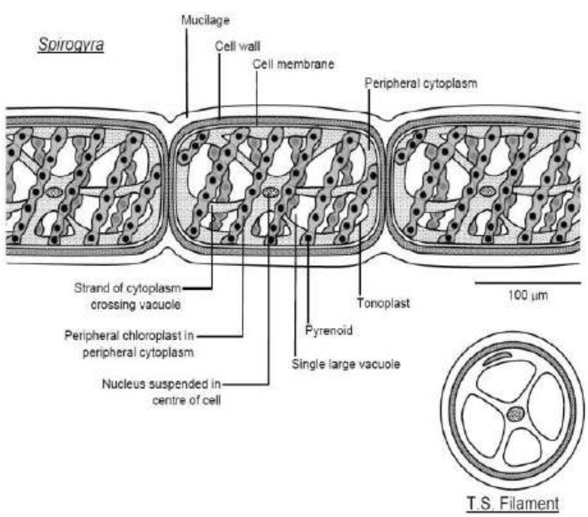
Chlorella which is a unicellular non filamentous alga that lives in fresh water ponds

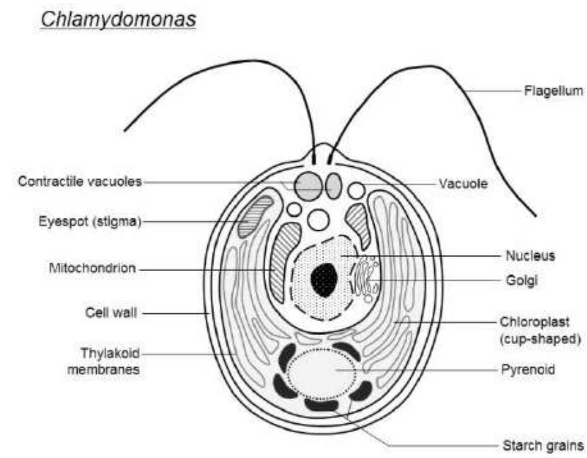
Chlamydominas which is a motile unicellular algae

Characteristics

- They contain chlorophyll and therefore they are photosynthetic
- Their cell walls contain cellulose
- They store starch
- They reproduce sexually and asexually
- Spirogyra is a filamentous algae that lives in fresh water ponds







Spirogyra is a filamentous algae that lives in fresh water ponds

PHYLUM PHAEOPHYTA

These are the brown algae. The members include Fucus, Laminaria and Ascophyllum.

Characteristics

- They posses 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 chodris.

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

ECONOMIC IMPORTANCE OF ALGAE

1. They can be used as fertilisers in farms
2. The carry out photosynthesis in oceans which:
    - Provide food for other organisms
    - Release oxygen
    - Reduce carbon dioxide which would cause acidity in water
3. Some of their products are useful in various industrial processes
4. Algae blooms result in severe pollution of water bodies.
5. Chlorella can be cultivated to provide Single Cell Protein (SCP) for humans and animal consumption

KINGDOM FUNGI

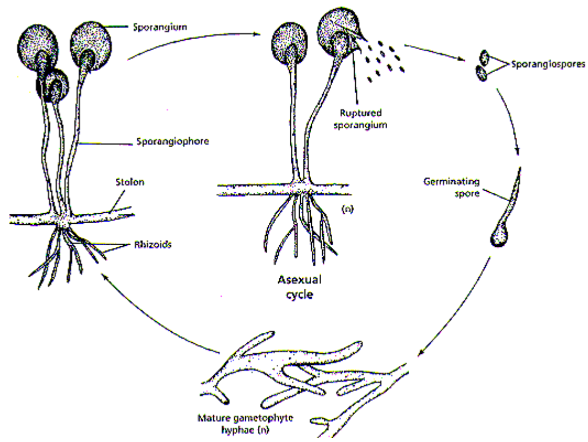
Characteristics that distinguish them from plants

- 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)

CLASSIFICATION OF FUNGI

PHYLUM ZYGOMYCOTA

Members include mucor and rhizopus (bread mould). They live in damp organic matter e.g. bread



Note;

a. The sporangium is black when ripe and colour less when immature. It produces spores for asexual reproduction
b. The sporagiophore is a vertically growing hypha that bears the sporangium.
c. Rhizoids which are root like structures

PHYLUM ASCOMYCOTA

Members include Penicillium, Aspergillus and Yeast sacchromycetes.

Characteristics

- Penicillium species form blue; some are green or sometimes yellow moulds on bread, decaying fruit e.t.c.
- 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, during aerobic respiration.

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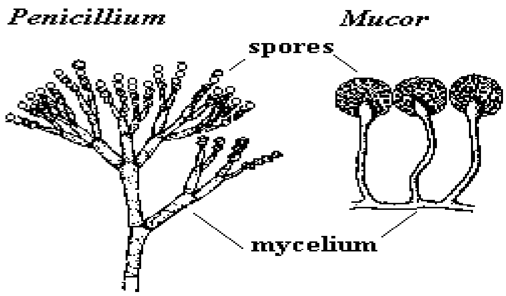
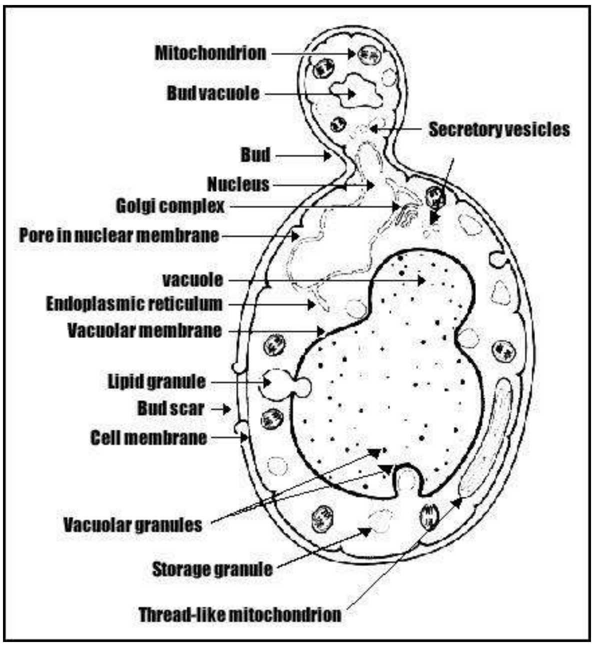




Characteristics of the yeast cell

- It has oval shaped cells
- It is unicellular
- Reproduces by budding
- Yeast produces ethanol during anaerobic respiration

PHYLUM BASIDIOMYCOTA

Members include mushrooms, toad stools, puff balls and rusts. Rusts attack cereal crops

Characteristics

- They reproduce asexually by sporulation
- They have septate hyphae

ECONOMIC IMPORTANCE OF FUNGI

1. They cause decomposition of sewage and organic material in soil
2. Penicillium and Aspergillus form antibiotics during aerobic respiration
3. Yeast forms alcohol during anaerobic respiration
4. Yeast is used in bread production
5. Fermentation of Aspergillus forms citric acid used in lemonade formation
6. Used for experimental purposes especially in genetic investigations
7. Fungi causes decomposition of stored food and deterioration of natural materials like leather
8. Some fungi cause plant diseases e.g. powdery mildew caused by *Erysphie graminae*
9. Some are poisonous to man
10. They cause skin irritations e.g. ringworms
11. They are eaten as food e.g. mushrooms

KINGDOM PLANTAE (plants)

Characteristics

- 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.

PHYLUM BRYOPHYTA (bryophytes)

The members include mosses and liverworts. The members live in damp shady soils or tree logs.

Bryophytes are the smallest land plants and they are thought to have evolved from green algae.

Characteristics

- They lack vascular tissues
- They lack true roots, stems or leaves
- Their body is a **thallus** which is differentiated into simple “leaves and stems”
- Alternation of generation occurs and the gametophyte generation is dominant

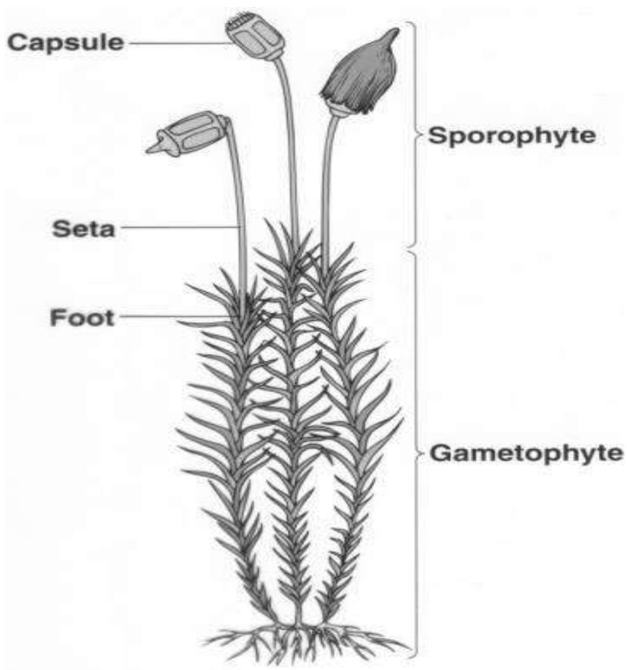
- The gametophyte is anchored by thallus rhizoids which grow from the stem.

NOTE: Water and mineral salts are absorbed by the whole plant surface because the plant surface lacks a cuticle; therefore water uptake occurs by **osmosis.**

Phylum bryophyta contains two main classes;

1. Class hepaticae (liverworts)
2. Class Musci (mosses)

EXTERNAL FEAUTRES OF A MOSS



ALTERNATION OF GENERATION

This is the occurancy of two or more generations within the lifecycle of an organism, a haploid gametophyte and a diploid saprophyte.

Generalised life cycle p.g. 39 in BIOLOGICAL SCIENCE

Description of alternation of generation in a bryophyte like a moss

A moss consists of two distinct forms in its lifecycle i.e. the haploid gametophyte which is dominant and the diploid sporophyte

The antheridia (sperm producing organ) and archegonia (egg producing organ) may be located on the same plant or different plants.

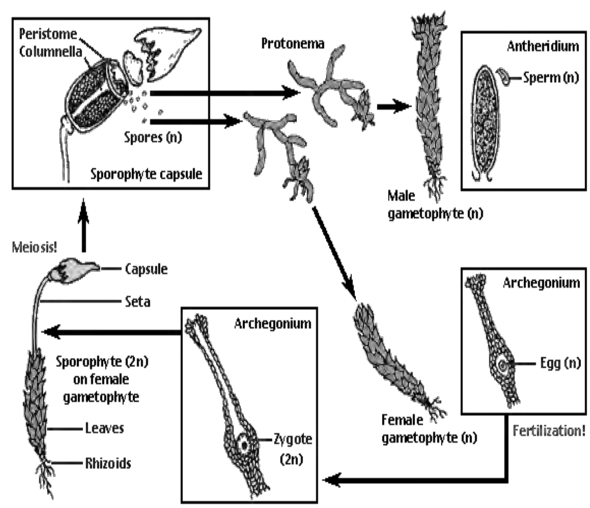
When mature, the antheridia shade their sperms (antherozoids) into the archegonia aided by the rain-splash.

The haploid biflagellate sperms fuse with haploid eggs (ospheres) to form a diploid zygote (oospheres)

The zygote develops into sporophytes which attach and survive on the gametophyte

When mature, the sporophyte produces haploid spores by meiosis. The spores are released by splitting of the spore capsule when dry.

When the spores land on moisten soils, they germinate into a protonema which later develops into a new diploid gametophyte



PHYLUM PTERIDOPHYTA (Filicinophyta or the ferns)

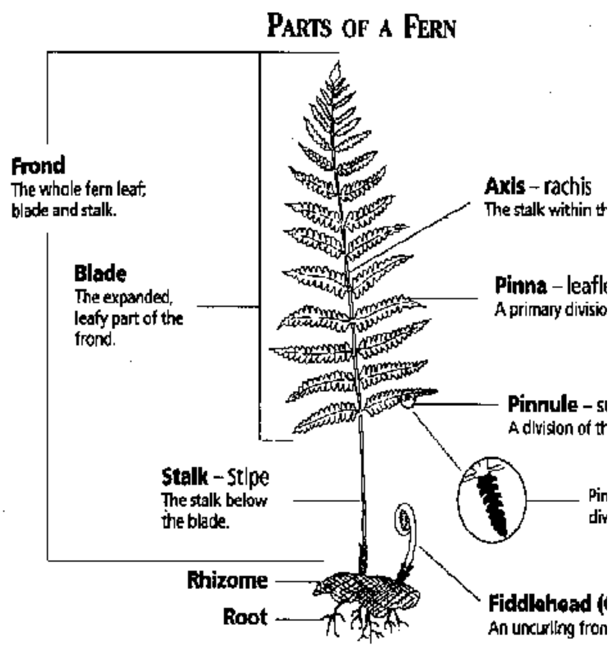
Members include; Pteridium and Dryopteris

Characteristics

- The vascular tissue (xylem and phloem) are present.

- The leaves are relatively large and are called fronds. The large surface area of the leaves increases the photosynthetic surface of the plant
- Spores are produced in sporangia (singular; sporangium), usually in clusters called sori (sorus, singular)
- Alternation of generation occurs and the sporophyte is dominant
- The gametophyte is reduced to a small simple prothallus
- The sporophyte generation posses true roots, stems and leaves.

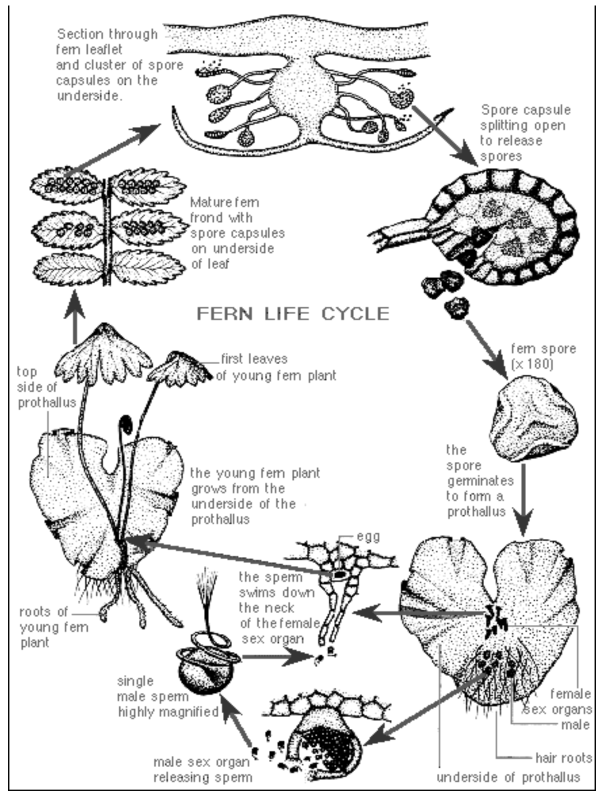
  The roots penetrate the soil to absorb water and dissolved mineral salts



ALTERNATION OF GENERATIONS IN A FERN (Pteridophyte/filicinophyte)

A fern consists of two distinct forms in its life. The diploid sporophyte, which is the dominant stage and the haploid gametophyte

- The diploid spore (mother cell) inside the sporangia divide
- When mature, the protecting covering (indusium), shrinks and catapults the spores of the sporangia
- The spores germinate into a heart-shaped prothallus which is the gametophyte
- Prothallus bears antheridia which produces haploid sperms and archegonia which produces eggs by mitosis
- On rupturing, the ciliated sperms from the antheridia swim towards the fertile eggs in the archegonia
- The zygotes develops into sporophytes



COMPARISON BETWEEN A MOSS AND A FERN

Similarities

- Both form spores
- Both grow in damp soils/ organic matter
- Alternation of generation occurs in both
- In both the gametophyte is anchored by the rhizoids

Differences

Moss	Fern
No vascular tissue	Vascular tissue present

No sorus	Sorus present at leaf underside
Spore capsule present	No spore capsule
Saprophyte is attached to gametophyte	Gametophyte is attached to sporophyte
It lacks true roots, leaves and stems	True roots, stems and leaves are present
No rhizoids	Rhizoid present
Gametophyte not heart shaped	Gametophyte is heart shaped
Leaves are simple and small	Leaves are relatively large

COMPARISON OF ALTERNATION OF GENERATION BETWEEN MOSSES AND FERNS

Similarities

- Spore formation occurs in spore bearing sporangia
- Sporophytes are diploid while gametophytes are haploid
- Spores form by meiosis whereas gametes are formed by mitosis
- Sexual and asexual reproduction occurs
- Male gametes are motile while eggs are non motile
- In both there's only one dominant stage
- The gametophyte bears the archegonia
- Sperms formed in the antheridia are brought into contact with the eggs by some mechanism

Differences

Moss	Ferns
The sperms are biflagellate	The sperms are ciliated
Sporophytes grow on the gametophyte	Sporophyte is self supporting
Spores germinate into a protonema first and then into a gametophyte	Spores germinate directly into a gametophyte
Gametophyte is a dominant generation	Saprophyte is a dominant generation
There is much dependency on water for growth, spore dispersal and gamete transfer	There is less dependency on water, only being used for gamete transfer and spore germination
Gametophytes may or may not bear both sexual reproductive organs	Gametophytes always bears both sexual reproductive organs

SIGNIFICANCE OF ALTERNATION OF GENERATION

1. Spores cause rapid multiplication of species
2. Different habitats of the ecosystem are exploited by the different generations
3. It enables plants to cope with adverse environmental conditions
4. Reduces chances of extinction
5. Gametes are formed by meiosis which brings about genetic variations

PHYLUM CONIFEROPHYTA

Members include Cedars, Horches and Christmas tress i.e. Firs and Spruce

Characteristics

- They bear cones in which spore producing sporangia and seeds develop
- They lack fruits and flowers
- The seed is naked i.e. it is not enclosed by the ovary wall.
- Leaves are usually needle-like with a thick waxy cuticle

Economic importance

1. A source of soft wood for timber
2. Pine nuts are used in cooking
3. Spruce and firs are used as Christmas trees

PHYLUM ANGIOSPERMOPHYTA

This phylum includes all flowering plants

Characteristics

- They flowers in which sporangia, spores and seeds develop
- The seeds are enclosed in an ovary

- After fertilisation, the ovary develops into a fruit
- There are two classes of Angiospermatophyta
    - Monocotyledon
    - Dicotyledon

Monocots	Dicots
Embryo sac has one seed leaf (cotyledon)	Embryo sac has two seed leaves (cotyledons)
Have scattered vascular bundles in the stem	Have a ring of vascular bundles in the stem
Flower parts are usually in 3's or multiples of 3	Flower parts are usually in 4's or 5's or multiples of 4 or 5
Calyx and corolla are not usually easily distinguishable	Calyx and corolla are easily distinguishable
They are usually wind pollinated	They are often insect pollinated
Have narrow leaves with parallel venation	Have broad leaves with network venation

Challenges or problems faced by plants

1. Desiccation/ dry out
2. Support in air/ 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 e.t.c.

Summary of adaptations of seed bearing plants to life on land

1. Leaves possess stomata for gaseous exchange
2. Leaves and stems are covered by a waxy cuticle which minimises water loss
3. They possess true roots which enable water and dissolved mineral salts to be absorbed
4. They undergo secondary growth which enable seed bearing plants to compete effectively for light and other resources
5. The fertilised ovule (seed) is retained for sometime on the parent plant (sporophyte) from which it obtains protection and food before dispersal.
6. Fertilisation is not dependent on water therefore reduces necessity for water inside the sporophyte which is well adapted for terrestrial life.

The adaptations above may also be considered as the advantages of seed bearing plants over mosses and ferns

KINGDOM ANIMALIA

General characteristics

- Their cell walls lack cell walls
- 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

Definition of terms

1. Tissue
This is a group of cells, often similar in structure and origin, operating together to perform a specific function

2. Tissue differentiation
This is the specialisation of tissue for different functions

3. An organ
This is the structural distinct part of the body which usually performs a particular function.
An organ is made up of similar types of tissue which are highly organised and have structural relationship with each other.

4. Organism
This is the interrelationship of different organ systems which together perform a specific function

5. Symmetrical body
This is the body which when cut, may produce halves which are mirror (identical) images of each other.

Bilateral symmetrical body
This is the body which can be divided into two identical halves along one plane only.

Radial symmetrical body
This is the body which can be cut along more than one plane to produce halves that are identical to each other.

6. Asymmetrical body

This is a body which cannot produce halves that are mirror images of each other if cut along any plane.

LEVELS OF ORGANISATION

Four levels of organisation are recognised;

1. Unicellular level (single cell organisation)

Protists have all the functions which are carried out by an organ system being performed by a single organelle in the cell. Such organisms include paramecium, amoeba plasmodium e.t.c.

2. Tissue level of organisation

These are primitive multicellular animals in which physiological processes are carried out mainly by isolated cells and tissues. Apart from reproductive organs, there are no structures that can be regarded as organs but most of the cells are integrated to form tissues.
Such animals represent a stage in evolution preceding the development of organs and organisms which are the characteristics of higher forms.
Tissue level is considered to be between the colonial and unicellular levels of organisation.
Tissue level of organisation includes animals such as hydra.

3. Colonial level of organisation

These organisms have different types of cells each carrying out a different function. They are therefore regarded as colonies of single cells rather than multicellular individuals e.g. sponges

4. Organ level of organisation

Plants, mammals and the majority of animals have their functions carried out mostly by organ and organs systems

Advantages and disadvantages of unicellular level of organisation

Advantages

1. Their small size enables living in a variety of habitats
2. There is less food intake
3. There is no need for the development of complex excretory organs since they take in less food.
4. No necessity for development of complex circulatory and gaseous exchange structures since simple diffusion combines with their large surface area to volume ratio
5. There's no need for development of complex support systems like cartilage, bones, xylem e.t.c.

Disadvantages

1. Predators

Advantages and disadvantages of multicellular level of organisation

Advantages

1. Worn out cells are easily replaced by cell division
2. Multicellularity allows tissue specialisation which increases efficiency in performing body functions
3. They have complex physiological mechanisms which enable the maintenance of a relative constant internal environment
4. They have a larger complex support system which increase the chances of catching prey but also reduces chances of predation
5. They have an efficient sensory system due to tissue specialisation which enables animals to escape from predators quickly.

Disadvantages

1. They require large quantities of food
2. They require specialised locomotory structures to enable motion
3. They produce a large quantity of waste products hence a necessity for development of complex excretory systems
4. They have a small surface area to volume ratio that requires development of transport systems since simple diffusion cannot supply enough nutrients to the animal

PHYLUM CNIDARIA (Cnidarians)

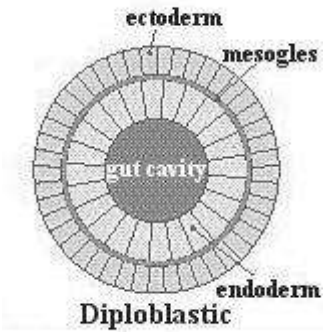
Members include Hydra, Obelia, sea anemone, Portuguese man of war and Jelly fish.

Characteristics

- They are **diploblastic animals** i.e. they have two cell layers separated by the mesogloea (a Jelly-like non-cellular layer)

The mesogloea may contain cells that have migrated from other layers.

Transverse section through the body of Cnidarians



- They have nematoblasts (stinging cells) which when touched (stimulated) release a chemical which can be used to capture prey or used to defend against predators

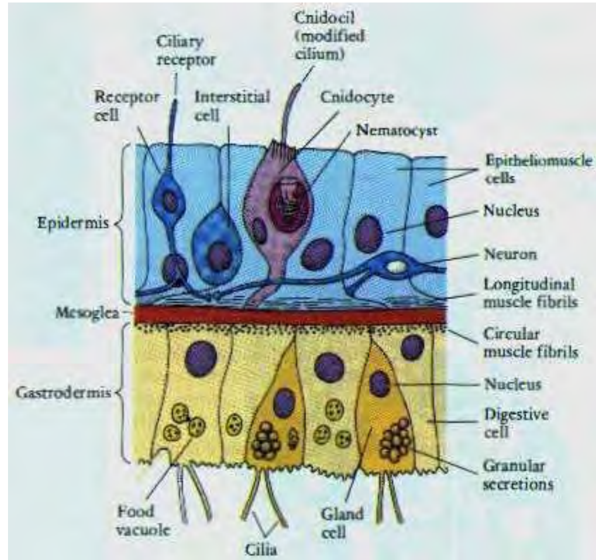
Nematoblasts occur in the ectoderm and when touched, can inject toxins into the prey/ predator which results into paralysis of the small animals.

- They are radially symmetrical i.e. the body can be divided into equal halves by more than one straight line/plane which passes through the central body
- They exhibit polymorphism i.e. individual cells have specialised shapes with different functions

Polymorphism is the existence of the cell organisms in a number of morphologically distinct forms.

- They have tentacles which bear stinging cells called nematoblasts

The structure of a body wall of hydra



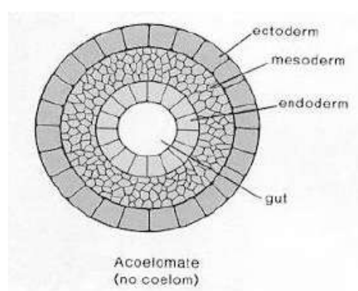
Hydra belongs to the tissue level of organisation which enables cells to act together in a relatively coordinated manner so as to carry out various functions effectively.

PHYLUM PLATYHELMINTHES

Members include tapeworm (taenia), blood fluke (Schistosoma), liver fluke (Fasciola hepatica) and planaria

Characteristics

- They are Triploblastic i.e. the body is composed of three layers, the outer ectoderm and the inner endoderm and between these two is the mesoderm



- They have bilateral symmetry i.e. The body can only give two equal and opposite halves if cut along one plane.
- They have an un-segmented body

- Their bodies are dorsal ventrally flattened
- They are hermaphrodites, often with elaborate precautions to minimise self fertilisation
- They have flame cells for excretion and osmoregulation

Significance or importance of possessing a mesoderm in the body

1. It allows triploblastic organisms to increase in size and thus results into the considerable separation of the alimentary canal from the body wall
2. Used in forming a variety of organs which may combine together and contribute towards an organ system of organisation
3. It enables the improvement of muscular activity by triploblastic organisms. It's necessary because of their increased size which renders the use of flagella or cilia inappropriate.

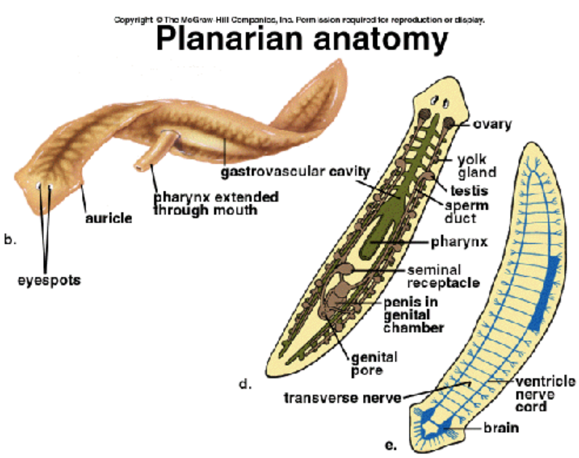
There are three classes in phylum platyhelminthes

Class Turbellaria

Members in this class include planaria which lives under stones in fresh water streams.

Characteristics

- The cuticle is absent
- The enteron is present
- They have delicate soft bodies
- They have sense organs in the adult stage
- Cephalization occurs

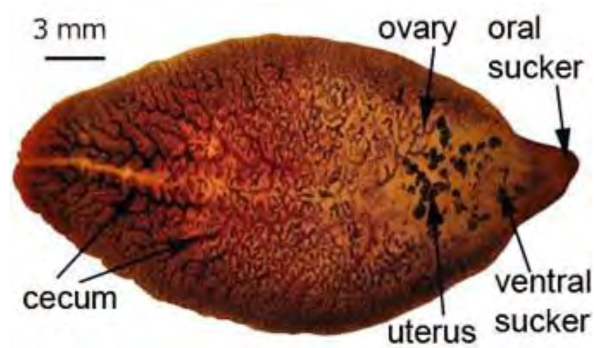


Class Trematoda (flukes)

Members include Fasciola (lever fluke) and Schistosoma (blood fluke) which causes Schistosomiasis (Bilharzia) in tropical countries.

Characteristics

- They have a leaf-like shape
- They bear suckers for attachment to the host
- They have a thick outer cuticle
- The enteron is present
- They are endoparasites (live inside the body) or ecto parasites (live on the outer surface of the host)



Class Cestoda (tapeworms)

Examples include *Taenia solium* and *Taenia*

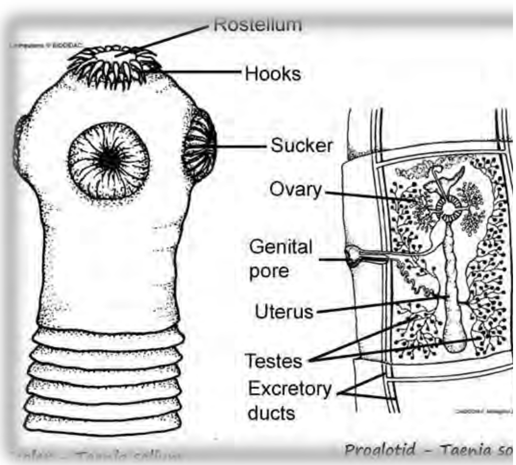
Saginata

Characteristics

- They are endoparasites.
- They have flattened elongated bodies with a distinct head called scolex which bears hooks and suckers for attachment to the host.
- The body is divided into proglotidds which are able to break off.
- They have no mouth/gut (enteron).
- They use the host digested food by absorbing it directly through the integument.
- There is a thick cuticle for protection against the host's enzyme digestion.
- They lack cilia.

ADAPTATIONS OF PLATYHELMITHES TO A PARASITIC MODE OF LIFE

1. They have a special way of gaining entry into the body of the host but 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. Flatworms produce inhibitory substances to prevent their being digested by host enzymes.
4. They have complex lifecycles. Fasciola and Taenia have a secondary host which transfers one parasite from the primary host to another.
5. They have a very high reproductive output. Adults devote much of their energy and body space to sexual reproduction.



PHYLUM NEMATODA (round worms)

Members include;

a. *Ascaris Lumbricoides,* which is an intestinal parasite
b. *Wucheriria bancroft*, which infects the human lymphatic system and causes elephantiasis
c. *Thread worms* which are endoparasites of dogs and cats plus humans, mainly children.

Characteristic features

- They are triploblastic
- They have bilateral symmetry
- They have an un-segmented cylindrical body
- Their alimentary canal is straight from the mouth to the anus.
- Their sexes are separate
- They lack cilia
- A cuticle of protein is present
- Some are free living plant and animal parasites
- They are elongated and round in cross-section with pointed ends

PHYLUM ANNELIDA (segmented worms)

General characteristics

- They are coelomate and triploblastic
- They have no Chitineous cuticle
- They possess Chitineous bristles called *chaetae*
- They exhibit *metameric segmentation* i.e. their segments are repeated and are of the same age and size
- They have bilateral symmetry

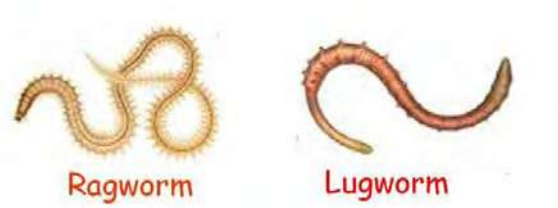
The main classes of phylum annelida include;

Class Polychaeta (marine worms)

Members include the rag worm (Nereis) and lug worm

Characteristics

- The sexes are separate
- Most are marine
- Most of them have a distinct head
- The chaetae are numerous and occur on later projections of the body called *parapodia*
- They lack the *clitellum*

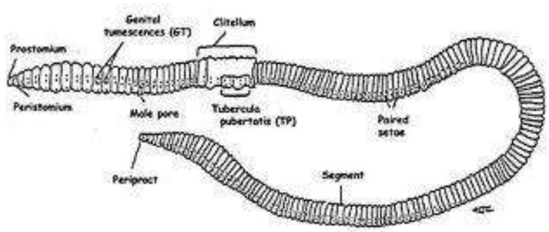


Class Oligochaetae (earthworms)

- They possess relatively few chaetae

- No larval form
- They have a less distinct head
- They lack parapodia
- They are hermaphrodites
- They live in fresh water or soil
- *Clitellum* is present. The clitellum is a saddle-like region of oligochaetae which is prominent in sexually mature animals. Contains mucus glands which secrete a sheath around copulating worms binding them together, the resultant cocoons houses the fertilised eggs during their development

Examples include Lumbricus



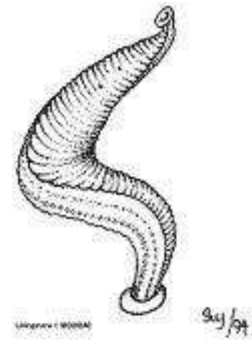
Biological importance of earthworms

1. They mix soil layers
2. They burrow tunnels which improves aeration and drainage of the soil
3. They add organic matter to soil by excretion and death
4. Secretions of the gut neutralise acidic soils
5. Dead vegetation is pulled into the soil where decay takes place

Class Hirudinea

Members include Hirudo the medicinal leech

- Free living carnivores
- No chaetae or parapodia
- No distinct head
- No clitellum
- Some are ecto-parasites with anterior and posterior suckers



THE COELOM

This is the main (secondary) body cavity of many triploblastic animals, in which the gut is suspended. The principal mode of origin is by separation of the mesoderm from the endoderm. It contains a fluid (coelomic fluid) which receives excretory wastes and/ gametes, which reach the exterior via ciliated funnels and ducts.

Biological significance of the coelom

1. It provides space in which internal organs can grow, develop and function independently of each other
2. It contains coelomic fluid which bathes the organs and can act as a hydrostatic skeleton
3. It allows the animal's internal organs to move independent of each other and move independent of the whole body e.g. the gut can perform peristalsis without causing the body wall to move into waves of contraction
4. Coelomic fluid may be used to circulate food, waste materials and respiratory gases although these functions are mainly carried out by the body vascular system.

Problems caused by the coelom

i. It separates the body wall from the gut, causing difficulty in transporting digested food and respiratory gases resulting into the development of transport system
ii. Increased size and complexity requires a more complex coordination system, therefore a more elaborate nervous system

PHYLUM MOLLUSCA

Characteristics

- These are triploblastic coelomate animals
- They have soft bodies which are covered by a calcareous shell i.e. shell containing calcium. These shells are produced by special epidermal tissue called *mantle*
- They have an un-segmented body with a head, foot with a visceral hump is a central mass of internal organs
- They have bilateral symmetry

The classes of phylum mollusca include;

Class Gatropoda

Members include slugs and Helix (the garden snail)

Characteristics

- They have a distinct head with eyes and sense tentacles
- The shell when present is single and often coiled
- They have a radula (a tongue-like organ) armed with rows of teeth, with which they feed

Class Pelycopoda

Examples include mussels, oysters and clams.

Characteristics

- No tentacles
- Head reduced
- The shells have two halves
- They are filter feeders

Class Cephalopoda

Examples include squids, octopus and cat fish.

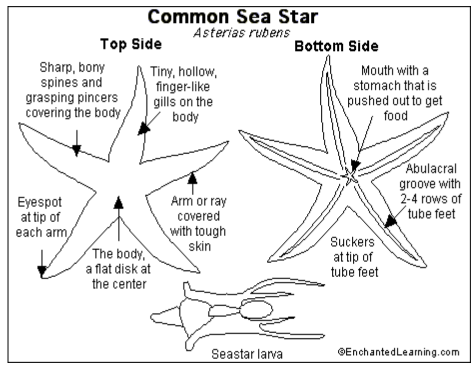
They possess a head like structure i.e. false head

PHYLUM ECHINODERMATA

Examples include starfish, sea cucumbers, sea lilies, brittle stars and sea urchins.

Characteristics

- Their skin bears spines hence the name of the phylum
- Adults show penta-radiate symmetry (5-way symmetry) but their larval forms show bilateral symmetry
- The mouth generally occurs on the lower side (oral side) while the anus occurs on the upper side (literal side)
- They lack a proper circulatory system
- They are exclusively marine inhabitants
- They have a calcareous skeleton
- They move slowly by the concerted action of numerous suctorial tube feet



PHYLUM ARTHROPODA

Arthropods contain more species than any other phyla. Insects in particular, account for more than half of all known arthropods. Insects have been successful in exploiting every type of habitat because they have undergone adaptive radiation i.e. they suited for flying, burrowing, living in aquatic areas, parasitism e.t.c.

Diagnostic features of arthropods

Possession of jointed appendages for feeding, locomotion and sensory purposes

Possession of an exoskeleton comprising of a chitineous cuticle and sometimes calcareous matter which makes it rigid and stiff at the mouth parts but flexible at the joints

Other characteristic features

- Triploblastic coelomate
- Bilateral symmetry
- Metameric segmentation

- The coelom is much reduced and the main body cavity is a haemocoel i.e. the coelom is almost completely displaced during devolvement by another cavity called the haemocoel which is filled with blood

NOTE

- Arthropods are at a high danger of blood loss from injury because they have the open blood system
- The high blood volume in arthropods enables them to maintain a high metabolic rate allowing them to be very active animals

Disadvantages associated with the presence of an exoskeleton

1. It'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

The groups of arthropods include;

Class Crustacea/ crustaceans

Members in this phylum include; Lobsters, Barnacles, Water fleas, Daphnia, and Astacus

Barnacles are sessile and remain attached to rocks by the head. Wood lice are the only terrestrial crustacean.

Characteristics

- Two pairs of antennae
- A pair of compound eyes
- Gaseous exchange occurs by gills
- Three pairs of mouth parts (jaws)
- They are mainly aquatic
- Head and thorax are not distinctively separate i.e. they possess a cephalothorax

Class Chilopoda

This class has Lithobius, (the centipede)

- Terrestrial and mainly carnivorous
- Have a clearly defined head, but all other body parts are similar
- They possess one pair of antennae
- They possess one pair of mouth parts (jaws)
- Eyes, either simple or compound, are absent
- Numerous identical legs i.e. one pair per segment
- No larval form
- Gaseous exchange occurs by the trachea

Class Diplopoda

The only member of this class is the millipede.

Characteristics

- Mainly terrestrial
- Mainly herbivorous
- The head is distinct but all other body segments are similar
- One pair of mouth parts
- One pair of antennae
- Eyes, either simple or compound, are absent
- Numerous identical legs with two pairs per segment
- They lack a larval form
- Gaseous exchange is by the trachea

Class Arachnida

Members include mites, ticks, scorpions, spiders (Epeira, the web spinning spiders) e.t.c.

Characteristics

- Mainly terrestrial
- Mainly carnivorous
- Two major body divisions present i.e. a cephalothorax and abdomen
- No antennae
- No true mouth parts but a pair of appendages are used for capturing prey and the second pair is used as sensory palps.
- Simple eyes present but no compound eyes
- Four pairs of walking legs
- No larval form

- Gaseous exchange is by lungs or gill books or trachea

Class Insecta

Diagnostic features

a. Three main body divisions i.e. head, thorax and abdomen
b. Three pairs of legs on the thorax, one pair per segment
c. Three thoracic segments i.e. prothorax, mesothorax and metathorax.

Other characteristic features

- Mainly terrestrial
- No gills in adults
- They have simple eyes
- Usually three pairs of mouth parts
- Gaseous exchange occurs by trachea
- Lifecycles commonly involves metamorphosis

Subclass Apterygota, these are wingless insects and they include Lepisma (silverfish) a common inhabitant of bathrooms and kitchens

Subclass Pterygota, these are winged insects which are further divided into two;

a. Exopterygota
This is whereby the wings develop externally.
They undergo incomplete metarmorphosis i.e. Hemimetabolus
Examples include;
- Locusta (the long horned grass hopper)
- Periplaneta (cockroach)
- Dragon flies

b. Endopterygota
The wings develop internally.
They undergo complete metamorphosis i.e. holometabolus

Egg → larva → pupa → adult

The larval stage is specialised for eating and growing. They are known by such names as caterpillars and grab
The adult is specialised for dispersal and reproduction

Examples include;
- Pieris (butterfly)
- Apis (honey bee)
- Musca (housefly)

Some orders of class insecta

Order Orthoptera

Examples include crickets, grasshoppers and walking sticks.

Characteristics

- 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

Order Dictyoptera

Examples include cockroaches and mantids 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.

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

Order Hemiptera

It includes all the bugs, and their characteristics include;

- Piercing and sucking mouthparts
- Two pairs of membranous wings

Order Homoptera

It includes aphids and cicadas. Their characteristics include the following;

- They have piercing and sucking mouth parts
- Incomplete or complete metarmorphosis
- Some species can reproduce without mating
- Some are wingless, others possess one or two pairs of membranous wings

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

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 to pairs of usually broad wings which possess scales

Order Diptera

Members include houseflies, mosquitoes and midges. Their adult characteristics include;

- Two large compound eyes
- Piercing mouth parts
- Complete metarmorphosis
- The two front wings are transparent and the two hind wings are reduced to halteres which serve as balancing organs during flight

Order Siphnoptera

This order includes the fleas and their characteristics include;

- They are wingless
- They lack eyes
- They exhibit incomplete metarmorphosis
- They possess piercing mouthparts

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 metarmorphosis

PHYLUM CHORDATA

During their lifetime, all chordates possess the following structures;

1. Notochord

This is a rigid but flexible dorsal rod which consists of vacuolated cells surrounded by a tough outer coat. In primitive chordates, a notochord prevents shortening of the body so that most of the force of muscle contractions is transmitted into bending movements, which are useful for swimming.

2. Hollow dorsal nerve cord (central nervous system)

This is formed by invaginations from the outer wall layer (ectoderm) of the embryo and develops as a group of cells which is later closed off at the top.

3. Pharyngeal gill slits (visceral clefts)

These are perforations on either side of the pharynx which occurs in all chordate embryos.

In vertebrates, the number of slits is greatly reduced and may be modified for different purposes. For example, in fish and larval amphibians, their walls are lined with feathery gills which are used for gaseous exchange. In fish and larval amphibians, their walls are lined with feathery gills which are used for gaseous exchange. In reptiles, birds and mammals, the only opening which remains is the Eustachian tube in the ear. In primitive chordates, visceral clefts are retained for straining food particles from water.

Other features possessed by my most but not all chordates include;

4. **Post anal tail** i.e. a post anal extension of the body or a true tail
5. **Segmented muscle blocks** (myotomes) which are considered as a secondary adaptation for swimming.
6. **Closed circulatory system** in which blood flows forward ventrally and backwards dorsally

Phylum Chordata is divided into two main groups

a. Acraniata

These are chordates without a skull and the notochord remains i.e. it is not replaced by a vertebral column.
Acraniates are sub-divided into two;

Tunicata (urochordata)

Members of this subphylum include the sea squid and its characteristics include;

- The notochord is present
- The adult tunicates are sessile filter feeders which are enclosed in a tunic.

Cephalochordata

Members of this phylum include amphioxus and its characteristics include;

- The larvae are free swimming
- The adults possess a pharynx which is modified for filter feeding
- The notochord persists

b. Craniata (vertebrata)

These are chordates with a cranium (skull) enclosing the brain. The notochord is replaced by a vertebral column made of cartilage/bone.
They have two pairs of limbs/fins.
They have a well-developed central nervous system
Vertebrates are subdivided into the following taxa.

Subphylum Agnatha i.e. craniates without jaws or jawless fishes

Class cyclostomata

Members include Hampreys and Hag fish. Their characteristics include;

- No paired fins
- Semi ectoparasites i.e. they attach onto the body of fish, sucking on the fish's blood.
- They have numerous gills
- They have round suctorial mouthparts and a rasping tongue
- They have a well-developed notochord in adults.

Subphylum Gnathosotomata i.e. craniates with jaws. It includes all the following classes.

Class chondrichtyes

Examples of members of this phylum include dog fish, skates, rays and sharks. Their characteristics include;

- The skin bears placid scales (tooth-like scales)
- The skin contains dermal dentricles i.e. tooth-like structures with a central pulp cavity surrounded by an outer covering of enamel
- Pectoral and pelvic fins are paired
- Visceral clefts are present as separate gill openings (5 pairs)
- The anus is ventrally positioned
- They are poikilothermic
- They are marine dwellers.
- The tail is heterocercal i.e. the dorsal lobe of the tail fin is usually larger than the ventral lobe and this enables balancing since a swim bladder is lacking
- They have a cartilaginous skeleton

Class osteichthyes

Members include tilapia, perch and the herring. Their characteristics include;

- Bony endo skeleton
- Mouth is terminal
- Visceral clefts present i.e. separate gill openings (4 pairs) but covered by a bony flap called operculum
- The skin bears a cycloid and others ctenoid scales
- Fertilisation is external
- The tail is hormocercal
- They are poikilothermic
- The swim bladder is present
- Some are marine while others are fresh water dwellers

Class crossopterygota

It includes the lung fish.

- They have paired fins
- They are mostly predators
- They live mostly in fresh water

Class amphibia

Members include Bufo (toad), Rana (frog), newts and salamanders. Their characteristics include;

- Partly aquatic and partly terrestrial
- Have simple sac-like lungs
- Have a soft moist skin used as a supplementary gaseous exchange surface
- They have two pairs of pentadactyl limbs
- Breeding occurs in water i.e. fertilisation is external
- They are poikilothermic
- Visceral clefts (gills) are present in aquatic larvae and gills are present in adults
- Newts and salamanders possess tails in adults and in the larva stage but frogs and toads possess the tail in the larva form only.

Class reptilia

Members of this class include alligators, crocodiles, snakes and reptiles.

- They exhibit internal fertilisation
- They have a bony endo skeleton
- They have a dry scaly skin with horny scales
- They are poikilothermic
- They have soft shelled eggs
- They are mostly terrestrial
- Gaseous exchange occurs by lungs
- They lay a cleidoic (shelled egg)

Class aves

This class includes all birds and their characteristics include;

- The skin bears feathers
- Their legs bear scales
- Fore limbs modified into wings
- They exhibit internal fertilisation
- They lay well developed cleidoic eggs
- They are homeothermic
- They possess lungs for gaseous exchange

Class mammalia

The characteristics for the members of this class include;

- Having mammary glands
- Possession of a pinna (external ear)
- They are endothermic or homeothermic
- Fertilisation is internal
- The skin bears fur with two types of glands i.e. the sebaceous glands and the mammary glands
- They are mostly viviparous i.e. they give birth to active young ones rather than laying eggs

Subclass prototheria

It includes all egg laying mammals e.g. the spiny anteater and the duck billed platypus. They lay large yoked eggs but like other mammals, their young ones suckle.

Subclass theria

These are non-egg laying mammals which are divided into groups;

a. **Meta-theria/marsupial mammals**
   These are mammals which have porches in which the young ones are located and suckle for most of their development, having been born in a very immature state e.g. kangaroo

b. **Eutheria/placental mammals**
These are mammals whose young ones develop to mature ones while in the womb or placenta before they are born. Examples include humans

Some orders of class mammalia include;

1. Order insectivora which includes moles and shrews
2. Order carnivora which includes cats and dogs.
3. Order cetacea which includes dolphins and whales
4. Order chiroptera which includes bats
5. Order rodentia which includes rats
6. Order primate which includes chimpanzee, humans, monkeys, apes and lemurs.
7. Order proboscidea which includes the elephant
8. Order ungulate which includes cattle, sheep, horses and goats.

Problems faced by animals living on land

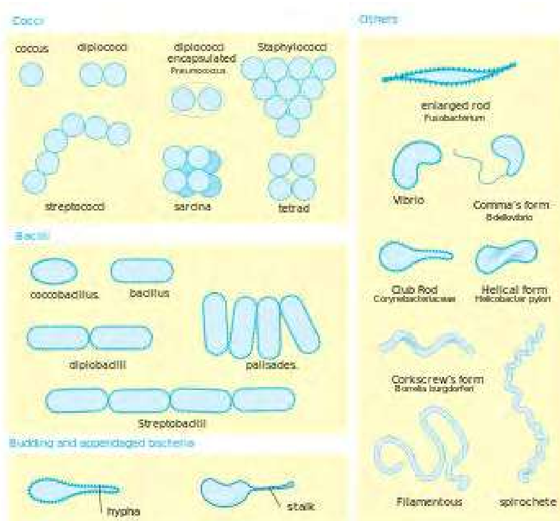
i. Obtaining support
ii. Water loss
iii. Gaseous exchange
iv. Homeostasis
v. How to reproduce without water

Adaptations of animals to live on land

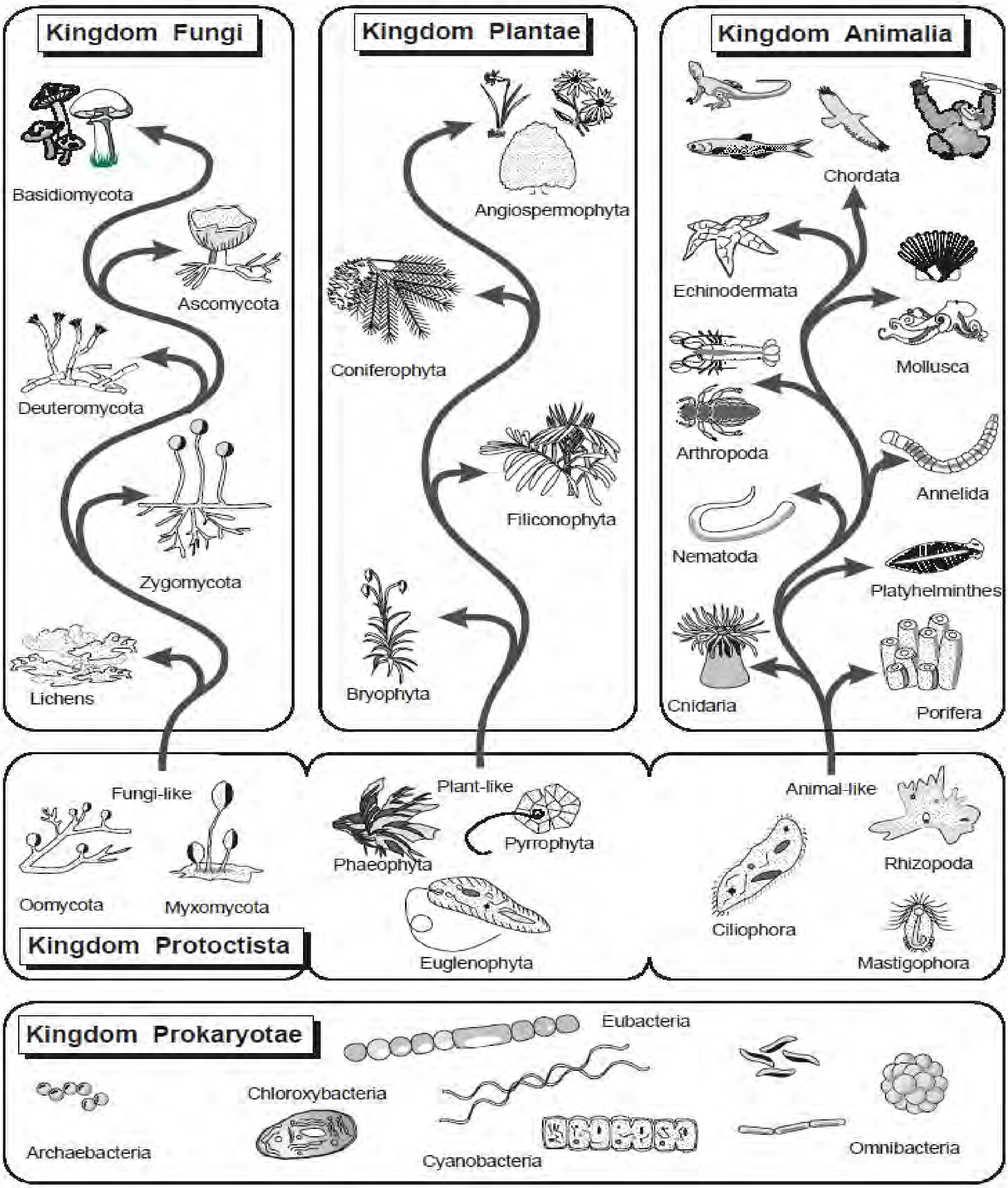
1. Oxygen being less soluble and more plentiful in air than in water has led to the animals developing moist gaseous exchange surface coupled with breathing mechanisms e.g. lungs in invertebrates
2. To avoid desiccation, various animals have developed different mechanisms e.g. amphibians are restricted to damp habitats. Reptiles, birds, mammals and insects have a water tight surface layer which enables them to inhabit dry areas. Reptiles and birds produce a semi-solid nitrogenous waste containing uric acid which requires less water.
3. Internal fertilisation and production of shelled eggs in reptiles and internal development in mammals enables them to conserve water and become fully terrestrial. Amphibians have failed to overcome the problem of reproducing on land as they keep reverting to water for egg laying to prevent them from drying.
4. Air provides very little supply to terrestrial animals because of its low density as compared with water which has a high density. These animals have developed skeletons for support in air and muscular mechanisms for locomotion.

Amphibians, reptiles, birds and mammals have strong muscles and they are tetrapods (four limbed animals) with limbs built on the pentadactyl. This enables the body to be lifted off the ground and propel the animal forward.

5. A variation in environmental conditions, most especially temperature has been overcome completely only by birds and mammals by evolving homeothermy i.e. they generate heat within their tissues physiologically and maintain a constant body temperature independent or external conditions. This provides optimum conditions for enzyme reaction and proper brain development. All other remaining terrestrial animals are poikilothermic and regulate their body temperature by bathing in the sun e.g. reptiles



The Five Kingdoms



ECOLOGY

Definition;

- ✓ Is the scientific study of the complex relationships between organisms and their environment.
- ✓ These interactions determine the distribution and abundance of organisms within a particular environment.
- ✓ ***Environment*** is the immediate surroundings of an organism.

❖ Organisms live within a relatively narrow sphere (land, water and air) and the earth's surface and this is known as **Biosphere/ecosphere** .

❖ The biosphere is divided into two major regions namely;

i. Aquatic regions; made up of fresh water(lakes and ponds, rivers and streams, wetlands), marine water(oceans) , and estuaries.

ii. Terrestrial regions covering a few meters deep in the soil and a few kilometers into the atmosphere.

❖ On land, there are several biogeographical areas, each with specific conditions that support distinct species of plants and animals. Such areas include the present day continents.

❖ Some of these areas may possess similar physical conditions, therefore supporting similar plants and animals; these areas are collectively called **Biomes**.(*a large ecological area on earth's surface with distinctive plant and animal groups which are adapt that particular environment*)

Biomes include ; ***tropical rain forests***, ***tundra regions*** (ground is frozen much of the year and vegetation is sparse), ***Hot and dr desert regions*** (evaporation is high and there is too much heat), ***cold deserts***(precipitation coming from colder water sources tha rain, such as snow or ice), ***temperate region*** (winters and summers).

❖ Organisms have developed adaptations to live in each of the biomes e.g desert organisms offer the most extreme adaptations to li both intensive hot and drought condtions i.e desert animals are able to feed less often, thus conserving energy both by slowly metabolizing food and by not frequently hunting or foraging; while marine organisms are adapted to osmo regulate in highly sali environment.

❖ Biomes are further divided into zones,each with its unique properties e.g

i. A forest biome is divided into **ground zone**(consisting of millipedes & earthworms) , and **canopy zone/aerial zone;** (consisting of birds & monkeys); with each of these zones supporting different animals that are adapted to the condition within them.

ii. Aquatic biome divided into **surface** , **intertidal** ,& **benthic zones;** with the organisms in the intertidal zone withstandir wave action e.g snakes, snails, those in benthic zone not able to withstand wave action e.g sponges, while organisms requiring much air supply e.g photosynthetic algae inhabiting surface zone.

iii. Desert biome divide into **surface** and **subterranean zones**; with those in surface zone adapted to withstand extreme hea while those in subterranean able to survive in low oxygen content.

NB The zones in a biome are subdivided into **habitats**(***specific locality where an organism normally lives within the environment***) with set physical conditions that support specific organisms

Examples of habitats include; leaf litter for earthworms, intestines of man for tapeworms, ponds for frogs, beside the water storage t for toads, kitchen for cockroaches, etc.

ECOLOGICAL NICHE*:*

- ♣ Is the role and position any species has within its habitat, and its interactions with living and non-living environment.
- ♣ Describes how an organism meets its need for food and shelter, how it survives, and how it reproduces; therefore reduces ir specific competition for resources.

Example.

Consider a forest habitat, with leaves scattered on the ground; an old rotting log sitting on a forest floor; earthworms may be seer under the soil feeding on decaying organic matter; with centipedes eating small beetles and other organisms; colony of ants work and feeding on dead insects; millipedes strolling around feeding on decaying leaves; therefore all these organisms are filling an ecological niche looking at where they live, how they survive and how they reproduce.

Types of ecological niche.

➢ Realized niche;

Occurs in the presence of predators, competitors, and parasites; limiting the habitat and roles performed by an organism Its smaller in size.

➢ Fundamental niche;

Occurs in the absence of predators, competitors, and parasites; allowing the organism experience a larger habitat and perform a variety of roles .

ECOSYSTEM

✓ it is natural unit of environment composed of living (biotic) and non-living (abiotic) components whose interactions leac a self-sustaining system.

(i) Water (aquatic) ecosystems may be fresh water bodies (e.g. lakes, ponds, rivers) or marine water bodies (e.g. sea, ocean).

Organisms in water may be of large size (nektons) e.g. fish, whales, turtles or very tiny (planktons) e.g. phytoplanktons zooplanktons.

(ii) Land (terrestrial) ecosystems include forests, deserts, savanna, etc and in water (aquatic).

Examples of abiotic components:

i. climatic factors, which include; Temperature, Light, Wind, Humidity, rainfall etc
ii. soil (edaphic) factors e.g. Soil pH, Soil air, Inorganic particles, Soil water , Organic matter (dead organic matter and liv organisms), Soil temperature etc
iii. Topography
iv. Other physical factors e.g fire and wave action etc

Question. How do abiotic factors affect the distribution and abundance of organisms?

(i) ***Climatic factors***

Temperature

- Affects physiological processes (respiration, photosynthesis, and growth etc) in organisms which in turn influence their distribution.
- Ultimate heating and cooling of rocks cause air to break and crack into small pieces and finally form soil.
- These changes in turn may result into migration of organisms e.g birds to avoid over heating or freezing.
- Low temperatures inactivate enzymes while excessive temperatures denature enzymes.
- High temperature increase transpiration and sweating
- Low temperatures break dormancy of some plants.
- Temperatures stimulate flowering in some plants e.g cabbage (vernalisation)
- Exposure to low temperature(stratification) stimulate germination in some seeds after imbibitions.

Organisms have evolved to have structural, physiological and behavioral adaptations to maintain their temperature in an optimum rar

(i) ***adaptations of animals for life in hot and dry deserts***.

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(seasonal response by animals to drought or excessive heat during which they become dormant, and metabolic rate followed by body temperature fall to the minimum required for maintaining the vital activities of the boc allows them to survive extremes of hot temperatures e E.g. African lungfish burrows into mud till the dry season e earthworms , garden snails , desert rats, termites also aestivate
- 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

(ii).***adaptations of animals for life in cold environments***

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(is seasonal response by animals to cold temperature during which they become dormant, body temperature metabolic rate fall to the minimum required for maintaining the vital activities of the body) The animals, said to be in 'd sleep' ably reduce energy needs to survive the winter when food is scarce allowing them survive extreme cold condition in polar bears.
- Gathering in groups to warm themselves e.g penguins

Rain fall;

- Amount of rainfall in a given area determines the abundance, distribution and types of plants in the area

Ecological significances of water

- ✓ Habitat for many aquatic organisms e.g frogs, fish etc
- ✓ Raw material for photosynthesis; main energy source for body processes of other organisms
- ✓ High thermal capacities ; acting as cooling agent for terrestrial organisms e.g plants during transpiration, some animals during sweating.
- ✓ Agent for fruit, seed, spore, larva and gamete dispersal
- ✓ Condition for germination
- ✓ Highly transparent; therefore allowing light to reach acquatic organisms, for photosynthesis; and aquatic predators to loc their prey
- ✓ Important factor in decay and decomposition ; therefore increases in recycling of nutrients in an ecosystem.

Humidity;

Amount of water in the atmosphere;

Accordingly , organisms within areas of low humidity are adapted to avoid excessive loss of water by;

- ✓ Having reduced number of sweat glands e.g in kangaroo rat
- ✓ Presence of leaf spines in cactus plants; to reduce surface area over which water is lost through transpiration.

- Controls other activities of animals like feeding, hunting, and movements e.g earth worms experience a larger ecological ni when the environment is humid.
- Controls opening and closure of stomata; therefore affecting rate of photosynthesis and transpiration.

Wind / air currents;

It influences the following ,

- dispersal or migration of flying mammals, winged insects; thus reducing the level of competition.
- Pollination
- Dispersal of seeds and spores; increasing the spread of non-motile organisms e.g fungi and some bacteria.
- Takes part in rain formation
- Current and wave formation in seas and lakes enables distribution of mineral salts.
- Increase transpiration; thus promoting water and mineral salt uptake from the soil by plant roots
- Increases evaporation and reduces sweating.
- Causes physical damage to vegetation and soils e.g soil erosion.
- Increases dissolution of oxygen in aquatic bodies; thereby increasing aerobic activities of organisms.

Light (intensity, quality, and duration)

Influences many physiological activities of organisms ie

- ✓ It is a source of energy for photolysis (breakdown of water during photosynthesis.).
- ✓ Absence of light causes etiolation (elongation of shoot inter nodes).
- ✓ Induces flowering in long-day plants e.g. barley, but inhibits flowering in short day plants.
- ✓ Phototropism, by redistributing auxins on the darker sides of shoots and roots, with cells on darker side elongating more than those on illuminated side.
- ✓ Germination ; some seeds are positively photoblastic; germination only in presence of light while other do not require li to germinate.(are negatively photoblastic)
- ✓ Stomatal opening and closure; with most plant species opening their stomata during day(when there is light) and closing during night (in absence of light/darkness).
- ✓ Predation ; (hunting and killing of prey by predators require certain levels of illumination and visiblility)
- ✓ Courtship; with some animals preferring light so as to carry out courtship while others prefer darkness
- ✓ Light breaks dormancy of seeds.
- ✓ Stimulates synthesis of vitamin D in mammals; where lipids(sterols) in the dermis are converted to vitamin D by uv ligh
- ✓ It enables the mechanisms photoreceptions in eyes
- ✓ Absence of light results in failure of chlorophyll formation in plants i.e. plant remains yellow, and leaves fail to expand.
- ✓ Photoperiod affects migratory and reproductive behaviour in various animals e.g. sunlight polarised by water acts as a compass for migration of salmon fish.
- ✓ Necessary for the germination of certain seeds e.g. lettuce

(ii) ***Topography***.;

- Refers to the nature of the landscape, which includes features like mountains, valleys, lakes etc.
- High altitude is associated with, low atmospheric pressure; low average temperatures,; increased wind speed; decreased partial pressures of oxygen, thus few organisms live permanently here.
- Slope reduces water logging and there is a lot of soil erosion preventing proper plant establishment especially at steep sl
- At low altitudes, average temperatures are high, high atmospheric pressure, partial pressures of oxygen are high, and in some places there is water logging.

Assignment. Describe different adaptations of organisms that live in high altitude.

(iii). ***Edaphic(soil) factors***,

- Soil formed by chemical and physical weathering of rocks, possess both **living components**(living organisms like bacte fungi, algae and animals like protozoans, nematodes earthworms, insects, burrowing mammals) and **non living compon** **(**particles of various sizes)
- Also present are; mineral salts, water, organic matter, and grasses.

Soil Ph

- ❖ Influences physical properties of soil and availability of certain minerals to plants, thus affecting their distribution in so i.e tea and coffee plants thrive well in acidic soils
- ❖ Affects activity of decomposers e.g in acidic medium, the rate of decomposition is reduced, subsequently recycling of m in an ecosystem reduced.

Water content;

- ❖ Varies markedly in any well defined soil,
- ❖ Any finely drained soil holding much water as possible is said to be at full capacity
- ❖ Addition of more water which cannot be drained away leads to water logging; and anaerobic conditions , affecting mine ion uptake by active transport, subsequently affecting osmotic uptake of water , due to decreased osmotic potential gradient, causing plants to dry out.
- ❖ Plants like rice, marshes, and sedges have developed air spaces among root tissues , allowing some diffusion of oxygen aerial parts to help supply the roots.

to the soil.

- Burrowing organisms e..g earthworms improve drainage and aeration by forming air spaces in the soil.
- Earthworms also improve soil fertility by mixing of soil, as they bring leached minerals from lower layers within reach o plant roots.
- They also improve humus content , by pulling leaves into their burrows
- Also press soil through their bodies making its texture fine.

Air content;

- Spaces between soil particles is filled with air from which plant roots obtain oxygen by diffusion for aerobic respiration,
- Also essential for aerobic respiration by micro organisms in the soil that decompose the humus.

(iv) *Salinity*;

- ♣ Is the measure of salt concentration in aquatic bodies and soil water.
- ♣ Determines the osmotic pressure of water; therefore the organisms have developed structural, behavioral, and physiolog adaptations to osmo regulate in the respective salt concentration, **(read adaptations of fresh water fish, marine water and migratory fish to their osmo regulatory problems**).
- ♣ Mineral salts in water affect the distribution of plant species, which in turn affects the animals that depend on plants for food.
- ♣ Plants growing in soils deficient of certain salts, e.g insectivorous plants in nitrogen deficient soils, obtain nitrogen feedi on insects.

Significances of mineral salts to plants

- ✓ Mineral salts together with other solutes determine the osmotic pressure of cells and body fluids
- ✓ Determinants in anion and cation balance in cells, e.g Na^+ and Cl^-, involved in transmission of nerve impulses
- ✓ Constituents of certain pigments like haemoglobin, and chlorophyll containing iron and magnesium respectivel
- ✓ Metabolic activators; some ions activate enzymes, e.g chloride ions activate salivary amylase, magnesium activ enzymes in phosphate metabolism, and phosphorus as phosphate is required in activation of sugars during Glycolysis in tissue respiration.
- ✓ Mineral salts like potassium are involved in formation of cell membrane and opening of stomata;
- ✓ Development of stem and root e.g. calcium pectate in formation of plant cell wall. Etc

(v) Fire;

Types of fire

- ➢ Natural fires; are set up by natural causes like lightening, volcanic eruptions etc
- ➢ Artificial fires; are set up by man either intensionally or carelessly
- ➢ Wild fires; burn in the direction of wind
- ➢ Early fires; set up at beginning of dry season
- ➢ Prescribed fires; under ecological management where prevention measures are taken when stting up the fire.

Properties of fire

- ➢ Fire intensity;
  Is the heat content of the fire,
  Depends on environmental factors such as wind, temperature as well as the amount and type of vegetation.
- ➢ Fire duration;
  Is the time taken by the fire to destroy a given area.
- ➢ Fire severity; is measured in terms of major vegetation destroyed by the fire.

Ecological effects of fire

Positive effects

- ✓ Removes old leaves and stimulates trees and grasses to produce new buds.
- ✓ Breaks dormancy (seed dormancy), incase seed coats are hard and impermeable.
- ✓ Causes release of mineral nutrients in form ash; on burning organic matter, releasing nitrate and phosphate compou into soil, and subsequently improving on soil fertility.
- ✓ Improves on visibility of organisms such as predators, prey, mates allowing them easily carry out their activities.
- ✓ Improves on food productivity in terms of quality, quantity and productivity, because after burning new species wi high protein content grows.
- ✓ Destroys pests
- ✓ Controls undesirable plant species and weeds

Negative effects

- ✓ Increase soil erosion; leading soil infertility
- ✓ Kills slow moving animals e.g snails, earthworms
- ✓ Destruction of habitat for most of the animal species may leading migration or extinction
- ✓ Increases fire resistant species.
- ✓ Reduction in population density and biodiversity.
- ✓ Destroys food for animals like herbivores which may lead to starvation and eventually death.
- ✓ Air pollution by products such as carbon monoxide and carbon dioxide, increasing on global warmimg.

Adaptations of plants to fire

Thick succulent shoot system to reduce the effects of heat.
Grasses grow in tussocks to protect the young growing buds.
Some tree stems are succulent i.e. store water 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.

(b). ***Biotic / living components:*** these are the plants, animals and decomposers.

THE MAJOR BIOTIC / LIVING COMPONENTS OF ECOSYSTEMS

1. Producer: ,

- are autotrophs capable of synthesizing complex organic food materials from simple inorganic food raw materials e.g car dioxide and water.
- Examples include; large green terrestrial plants e.g trees, shrubs, grass. For aquatic ecosystem, the producers are micros algae, blue green bacteria. Others are flagellates like euglena, volvox, chlamydomonas etc. They are collectively called **Phytoplanktons (**microscopic marine producers)

NB; Some producers use chemical energy derived from breakdown of chemical compounds like sulphur to convert carbon dioxide and water into high energy compounds like carbohydrates e.g sulphur bacteria i.e they are **chemosynthetic**.

2. Consumer:

- Are organisms that get energy and nutrients by feeding on other organisms or their remains .
- Are classified as;

(i) **Primary consumers(Herbivore):**

- ✓ A consumer that eats plants.
- ✓ E.g. insects, birds, most mammals(grazers),
- ✓ In aquatic ecosystem, they include; water fleas, fish, crabs, mollusks, and protozoans, collectively known as **zooplanktons**(microscopic marine consumers).

(ii) **Secondary consumers(Carnivore):**

- ✓ A consumer that eats other animals.
- ✓ E.g. birds of prey like eagle, kites, kingfishers; and lions, cheetahs, tigers, hyenas, snakes, big fish,

(iii) **Tertiary consumers**:

- ✓ These feed on both primary and secondary consumers
- ✓ Can be predators that hunt and kill others for food or scavengers(animals that feed on dead organisms but do not kill them
- ✓ E.g. vultures, hyenas, marabou stocks etc

(iv) **Omnivore**: A consumer that eats both plants and animals .e.g. man, pigs,etc

3. Decomposer:

- ✓ An organism that feeds on dead organic matter.
- ✓ Classified into;

(i) **Detrivore/ macro decomposers**;

- ✓ An animal that eats detritus.(dead and waste matter not eaten by consumers)
- ✓ E.g earth worms, rag worms, mites, maggots, wood lice, termites etc.

(ii) **Saprophyte**:

- ✓ A microbe (bacterium or fungus) that lives on detritus.

Importance of decomposition:

(1) It enables dead bodies to be disposed off which, if left would accumulate everywhere.
(2) Recycles nutrients to be used by other organisms e.g. Mineral salts are released from dead bodies into soil for plant growth.
(3) Unlocks trapped energy in the body of dead organisms.

ENERGY FLOW THROUGH AN ECOSYSTEM

- The sun is the primary source of energy in the ecosystem.
- Light energy is trapped by photosynthetic organisms (green plants, algae, and some bacteria); converted into chemical en by during photosynthesis.
- It is then transferred from one feeding level to another through feeding relationships like ***food chains*** or ***food webs.***
- Most of the energy from sun getting the earth's surface is reflected by vegetation, soil, and water or absorbed and radiated t atmosphere; leaving only between 5%-10% for the producers to make use of.
- Along the food chain, only a small proportion of the available energy is transferred from one feeding level to another; mucl energy is lost as heat during ***sweating and evaporation***, ***excretion*** , ***respiration***, **egestion,** and some remains locked up in indigestible parts of the plant like cellulose, or bones, hooves, hair, skin etc of animals.
- The number of organisms decrease at each successive feeding level because of the great energy losses, so the energy left in organisms is little to support large numbers of top consumers; limiting the length of food chain(not exceeding five trophic levels feeding level in a food chain containing given amount of energy).

TROPHIC EFFICIENCY/ ECOLOGICAL EFFICIENCY

- Is the percentage of energy at one trophic level that is converted into organic substances at the next trophic level.

Productivity in ecosystem

- ✓ Is the amount of organic material manufactured by organisms.

Can be measured using several methods i.e

-Harvest crop
-Through oxygen production of the given area of the ecosystem.
-Amount of carbon dioxide consumed during photosynthesis.
.-Rate of consumption or use of raw materials

- ✓ Can be divided into;

(i) **Gross productivity**; is the total amount of energy and organic matter stored in an organism over a period of time.
(ii) Net productivity; is the amount of energy and organic matter stored in an organism and passed onto the next trophic le
(iii) Primary productivity; Is the amount of energy and organic material stored in primary producers.

The initial amount of energy incorporated into primary producers during photosynthesis is called **Gross primary productivity (G.P.P)** .
The amount of energy transferred from primary producers to primary consumers is called **Net Primary Productivity (N.P.P).** It as well be called dry mass of the harvest crop**.**
Therefore, GPP- assimilation (respiration & metabolism) =NPP
(iv**). Secondary productivity**; Is the amount of energy incorporated into the body of consumers . Also known as **Gross seconda productivity.**
Net secondary productivity; is the amount of energy that can successfully be transferred from one consumer to another.
Carnivores have a higher secondary productivity than herbivores because ;

- ♣ Diet of carnivores is rich in proteins; easily digestible and therefore absorbed efficiently, allowing little energy to be los Herbivores their diet mainly consists of plant materials which are not easily digested.
- ♣ Carnivores do not have symbiotic microbes to consume part of the energy of their diet in their digestive tracts,
- ♣ Their faeces contain much less undigested matter.

Net secondary productivity is higher in exotherms than in endotherms, because;

- ♣ Energy from absorbed food, is used in replace the lost heat to their surrounding, inorder to maintain a constant body temperature, unlike exotherms that depend mostly on behavioral means to maintain their body temperature.

FOOD CHAIN AND FOOD WEB.

FOOD CHAIN

- ❖ A linear sequence of energy flow from producers through a series of organisms in which there is repeated eating and be eaten.
  Two types exist i.e
  (i) Grazing food chain (ii) Detritus food chain

(i). Grazer food chain,

- ♣ starts with autotrophs (producers)/ green plants which convert carbon dioxide & 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). E.g.
  Grass→millipedes→toads→snakes→hawks
  Green algae→haplochromics→tilapia→kingfisher

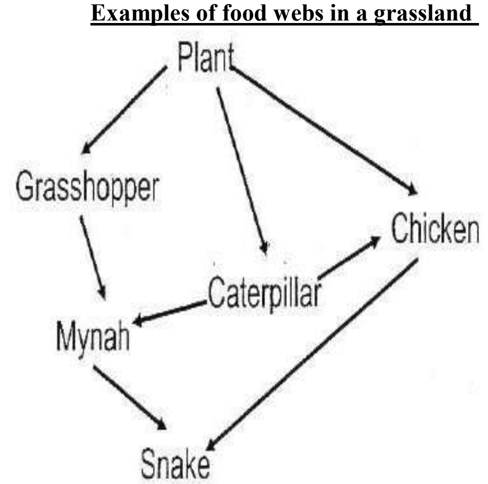
(ii) Detritus food chain

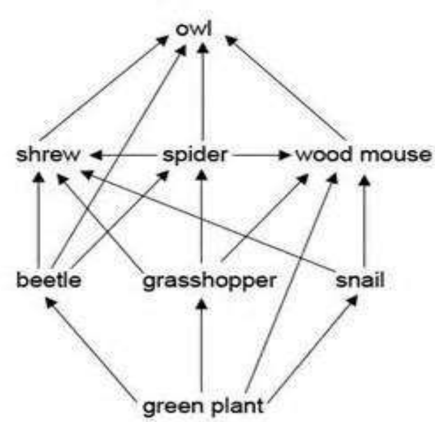
- ♣ is the one where the consumers obtain energy from fragments of dead decaying organic matter.
- ♣ exists in both aquatic and terrestrial habiats.
- ♣ 1^{st} trophic level is occupied by a decomposing organic matter
- ♣ E.g Tree log → wood lice - → toad → python
  Dead animal→ maggot→birds→ python

FOOD WEB

- ♣ is a complex nutritional interrelationship that illustrates alternative food sources and predator for each organism.
- ♣ In a food web, there are several food chains.

Examples of food webs in a grassland





EXERCISE

1. Construct a food web using the following organisms: phytoplanktons, mosquito larvae, small fish, large fish, and crocod
2. (a) With reference to a **named** ecosystem, what is meant by the following terms;
   (i)energy flow (ii) trophic levels (iii) food web
   (b). Discuss the interactions between the living and non living components of such an ecosystem.
3. (a) What is an ecosystem?

NB. Techniques used in constructing food webs and food chains

- ❖ Direct observation of organisms as it feeds so as to establish the organisms prey.
- ❖ Examination of stomach content through dissecting the animals' stomach
- ❖ Faecal method; observation of faecal materials egested by an animal.
- ❖ Use of radioactive tracers to label the environment from which organisms obtain their food and then trace them in the organisms gut.

Assignment. State the advantages and limitations of the above methods

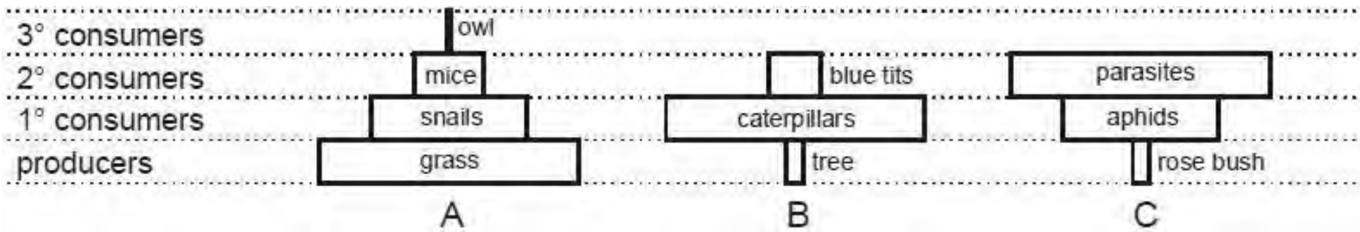
ECOLOGICAL PYRAMIDS

- ❖ These are histograms that provide information about feeding (trophic) levels in ecosystems.

Three types exist i.e
(i).pyramid of numbers
(ii) pyramid of biomass
(iii) pyramid of energy

NB. ***Length of a given bar is proportional to the number, energy or biomass at a given trophic level in a given area.***

(i) **pyramid of numbers.** It is a histogram representing the numbers of different organisms at each trophic level in an ecosystem at any one time.



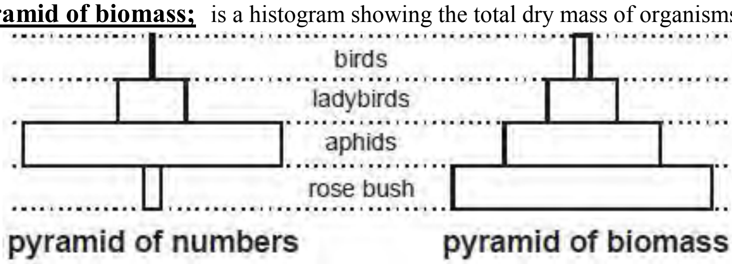
NB.

- o As a pyramid is ascended, the number of organisms decreases but the size of each individual increases.
- o In some cases, the consumers may be more than the producers e.g in a parasitic food chain, inverted pyramids **B** & **C** ar obtained, because parasites progressively become smaller and many along a food chain.

Limitations of pyramid of number

- o Drawing the pyramid accurately to scale may be difficult e.g where there a million plants.
- o Pyramids may be inverted
- o The trophic level of an organism may be difficult to ascertain.
- o The young forms of species may have a different diet from adults.

(ii) **pyramid of biomass;** is a histogram showing the total dry mass of organisms present at each feeding level



Advantages

- ✓ Reduces the possibility of forming inverted pyramids because its construction depends n biomass of organisms

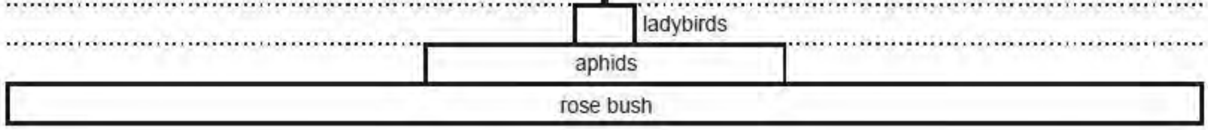
  NB. Inverted pyramid of biomass is typical of an aquatic ecosystem,because diatoms(phytoplankton) have a lower biomas with higher productive rate(caused by so rapid turnover rate), therefore capable of supporting a larger biomass of zooplanktons.

Disadvantages/limitations of pyramid of biomass

- ✓ Does not allow for changes in biomass at different times of the year e,g deciduous trees have larger biomass in summer tha winter when they shed off leaves.
- ✓ Does not take into account rate at which biomass accumulates e.g a mature tree has a large biomass which increases over n years.
- ✓ Impossible to measure exactly biomass of the organisms in an ecosystem, because the sample used may not true representa of the whole population.
- ✓ Results may not be accurate, e.g where killing is not allowed, the results are obtained by estimating the fresh mass.

(iii) **pyramid of energy flow** it is a histogram showing the total amount of energy present at each feeding level.

- ✓ Because only a proportion of energy is in a trophic level is transferred to the next, energy pyramids are never inverted no they have a central bulge.
- ✓ More informative than than pyramids of numbers and biomass because it shows the amount of energy required to support ea trophic level.
- ✓ Energy values may be expressed variously as kJ/ m^2 / yr^1 or kCal /m^2/ yr^1.
- ✓ explains why the earth can support more people if they eat at lower trophic level (by consuming grains, vegetables and fruits directly rather than passing such crops through another trophic level and eating grain eaters.



Advantages

- ✓ 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.

Disadvantage:

- ✓ Obtaining the necessary data required in constructing pyramids of energy flow is difficult.

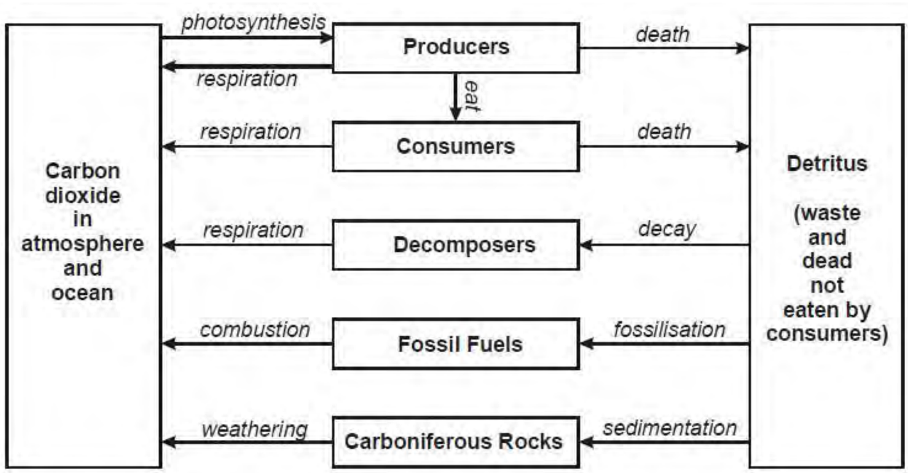
MATERIAL CYCLING/BIOGEOCHEMICAL CYCLING (NUTRIENT CYCLING)

✓ process by which chemical compounds of a particular element that constitutes living matter are transferred between living organisms (biotic phase) and non-living environment (abiotic phase).

✓ Are driven directly or indirectly by incoming solar energy and gravity

(a). **CARBON CYCLE**

- ❖ Based on carbon dioxide gas, making up 0.036% of the volume of the troposphere and is also dissolved in water.
- ❖ Carbon fixation involves the reduction of carbon dioxide to large organic molecules during photosynthesis and chemosynthesis.
- ❖ During aerobic respiration by all organisms, carbon dioxide is returned to the atmosphere or dissolves in water.
- ❖ Over millions of years, buried deposits of dead plant debris and bacteria are compressed between layers of sediment to f the carbon-containing fossil fuels e.g. coal, oil and natural gas, which when burnt release carbon dioxide into air.
- ❖ 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.
- ❖ In marine ecosystems, some organisms take up dissolved carbon dioxide molecules, carbonate ions and bicarbonate ions these ions react with calcium ions to form calcium carbonate ($CaCO3$) to build their shells and skeletons.
- ❖ 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.
- ❖ Weathering processes release a small percentage of carbon dioxide from limestone into the atmosphere.



How human activities affect the carbon cycle

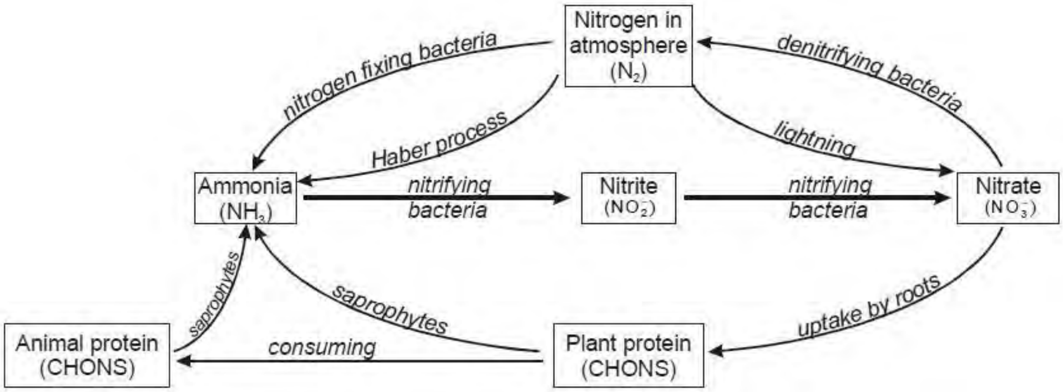
i) Cutting trees and other plants that absorb CO_2 through photosynthesis increases carbon dioxide in the atmosphere.

ii) Burning of fossil fuels like coal, petroleum oil etc and wood adds large amounts of CO_2 into the troposphere.

(b) **NITROGEN CYCLE**

- ❖ Nitrogen is the atmosphere's most abundant element, with chemically unreactive nitrogen gas making up 78% of the volume of t troposphere. However, N2 cannot be absorbed and metabolized directly by multicellular plants and animals.
- ❖ Atmospheric electrical discharges in the form of **lightning** causes nitrogen and oxygen in the atmosphere to react and produce ox of nitrogen, which dissolve in rainwater and fall to the ground as weakly acidic solutions .
- ❖ **Nitrogen fixation** occurs when the nitrogen in soil is reduced to ammonium ions, catalysed by(i) nitrogen-fixing bacteria which be free-living e.g. **Azotobacter** and **Clostridium**; **symbiotic bacteria in root nodules** e.g. **Rhizobium or blue- green algae** e.g Nostoc.
- ❖ **Nitrification** occurs when ammonium compounds in soil are converted first to nitrite ions(highly toxic to plants) by ***Nitrosomon*** **bacteria** and later to nitrate ions by ***Nitrobacter*** **bacteria**.
- ❖ **Ammonification** (putrefaction) occurs when decomposers e.g. saprophytic bacteria and fungi convert nitrogen-rich organic compounds, wastes like urea and dead bodies of organisms into ammonia and ammonium ion-containing salts.
- ❖ **Assimilation** occurs when inorganic ammonia, ammonium and nitrate ions are absorbed by plant roots to make nucleic acids, am acids and protein.
- ❖ **Denitrification** occurs when mostly anaerobic bacteria e.g. ***Pseudomonas denitrificans*** and ***Thiobacillus denitrificans*** in water

then into nitrogen gas and oxygen. Nitrogen gas is released into the atmosphere while oxygen is used for the respiration of these bacteria.



How human activities affect the nitrogen cycle

1. 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 (i) damages trees (ii) corrodes metals (iii) upsets aquatic ecosystems.
2. The inorganic fertilizers applied to soil are acted upon by anaerobic bacteria to release nitrous oxide into the stratosphere, where it (i) contributes to ozone depletion (ii) contributes to green house effect.
3. Nitrogen is removed from top soil when we (i) harvest nitrogen-rich crops (ii) irrigate crops (iii) burn or clear grasslands and forests before planting crops
4. 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.
5. The accelerated deposition of acidic nitrogen containing compounds e.g. NO2 and HNO3 onto terrestrial ecosystems stimulates growth of weeds, which outcompsete other plants that cannot take up nitrogen as efficiently.

Qn. **(a) Describe the flow of energy and the cycling of carbon and nitrogen in any named ecosystem.**

(b). Suggest reasons why felling and removal of forest trees result in changes in the levels of nutrients in the soil.

(c**) WATER CYCLE/ HYDROLOGICAL CYCLE**

- is powered by energy from the sun and by gravity, and it involves;
- evaporation(conversion of water into water vapour)
- Transpiration (evaporation from leaves of the water extracted from soil by roots and transported throughout the plant)
- Condensation (conversion of water vapour into droplets of liquid water)
- Precipitation (rain, hail, snow and sleet/freezing rain)
- Infiltration (movement of water into soil)
- Percolation (downward flow of water through soil and permeable rocks to ground storage areas called aquifers)
- Runoff (down slope surface movement back to the sea to resume the cycle)

Further reading Advanced Biology by simpkins & Williams page 674-675

HOW BIOTIC FACTORS AFFECT THE DISTRIBUTION AND ABUNDANCY OF ORGANISMS

NB. Biotic factors are those that arise in organisms interacting with each other.

Examples include (i) diseases (ii) competition ,(iii) parasitism, (iv) pollution,(v) pollination &dispersal,(vi) anti biosis(vii) mimi

(a**) Human influence**.

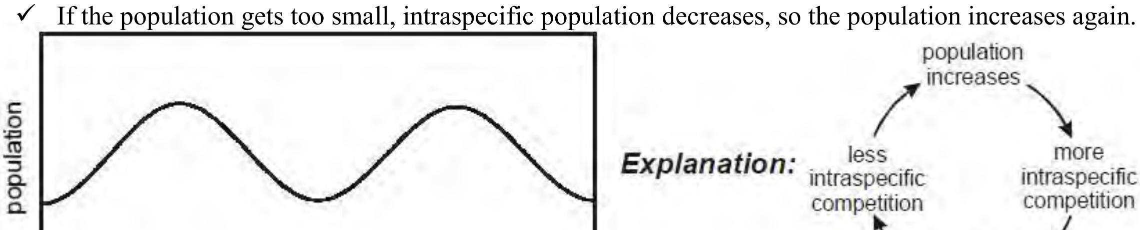
- Of all living organisms, humans exert most influence on the distribution and survival of other species through a multitu activities like pollution, deforestation, farming, construction etc
- Man is also a predator hunting down many animals to a point of extinction.

(b**) Competition**

- This is a relationship whereby two individuals of the same species or different species struggle to obtain resources which are in limit supply.
- E.g plants competing for light, carbin dioxide, water, minerals, pollinators , and sites for spores and seeds to germinate v animals compete for food, mates, breeding sites and shelter from predators.

(i) intraspecific competition

- ✓ is the competition between members of the same species for the same resources.
- ✓ Intraspecific competition tends to have a stabilising 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.



(ii**) 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;

(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 or
(iv) become extinct in that area, otherwise two species can never occupy exactly the same ecological niche.

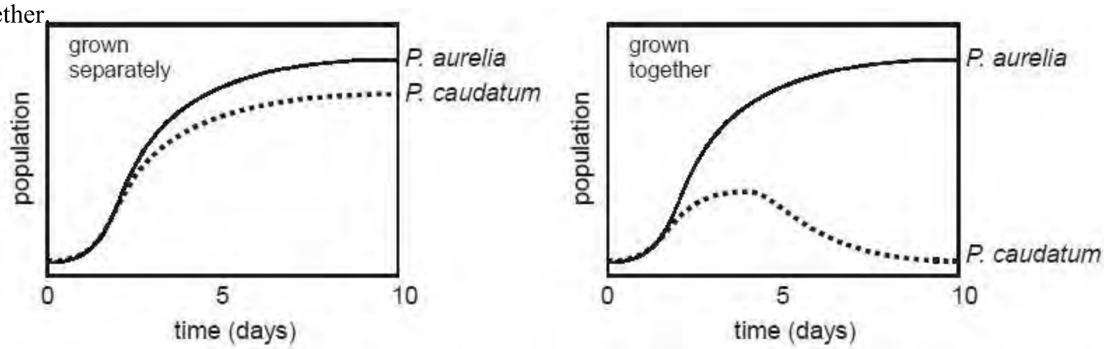
According to **Gause's (Russian biologist) competive exclusion principle** " no two species can occupy the same ecological niche"

e.g (i). Two species of flour beetles, *Tribolium castenum* and *T. confusum* were kept in the laboratory in bottles of flour acting a habitat and providing food for them, under variable temperature conditions(24-34) and humid condtions(very humid , 70%RH& 30% RH).

Observation. At high temperatures and in veryhumid conditions, *Tribolium castenum* succeded better , while at low temperatu and very dry conditions *T. confusum* did better.

Whatever the conditions, only one of the species eventually survived.

(ii). Two species of *Paramecium Aurelia* and *P.caudatum* were grown separately in the same culture, then later cultured together.



Observation (i)When cultured separately, each specie has maximum population, only coming almost constant with time due
-Presence of toxic wastes which can poison paramecium.
-Heat generated during respiration may kill some paramecium.
-Decrease in food measures.
(ii)When the two species of paramecium are cultured together, *paramecium aurelia* gets competitive advantage over *P. caudatum* and after several days , *P. caudatum* gradually decreases and later decreases rapidly until it excluded hence competitive exclusion principle. *P.caudatum* therefore,goes to extinction.

Competitive advantages of *P.aurelia* are;

- High rate of reproduction.
- High growth rate.
- Good nutrient absorptive capacity/greater efficiency in obtaining food.
- Being small, it requires less food hence can easily survive when food is scarce.
- Survivorship, long life span.

HOW SPECIES REDUCE OR AVOID COMPETITION THROUGH RESOURCE PARTITIONING

Resource partitioning is the dividing up of scarce resources so that species with similar needs use them (i) at different times (ii) different ways or (iii) in different places.

- ➢ Some species that are in competition for the same resources have evolved adaptations that reduce or avoid competition o overlap of their fundamental niches.
- ➢ Resource partitioning decreases competition between two species leading to increased niche specialisation

Examples of resource partitioning:

(i).When living in the same area, lions prey mostly on larger animals while leopards on smaller ones.
(ii)Hawks and owls feed on similar prey, but hawks hunt during the day and owls hunt at night.
(iii)Each of the five species of common warblers (insect-eating birds) minimises competition with the others by (i) spending atlea 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, som mid way etc (ii) Consuming somewhat different insect species.
(iv)Different species of eagles in a forest feed at different times of the day e.g. bald headed eagles are most active early mornings evenings while the white-breasted eagles feed vigorously towards noon.
(v)When three species of ground finches of Galapagos Islands occur on separate islands, their bills tend to be the same intermedi 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.
(vi).In an abandoned field, drought tolerant grasses with shallow, fibrous root system grow near the soil surface to absorb moistu 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.

ii) Two competing species also may coexist by sharing the same resource in different ways or at different times.
iii) The tendency for characteristics to be more divergent when populations belong to the same community than when th are isolated is termed **character displacement** e.g Galapagos finches.

Question.

1.(a). Explain the role of competition in regulating the size of population.

(b). Duck weed grows on or near the surface of ponds. Its growth can be measured by counting the number of fronds. Two species of duckweed , *Lemna trisulca* and *Lemna minor* were grown separately, and together , in identical beakers in the laborat

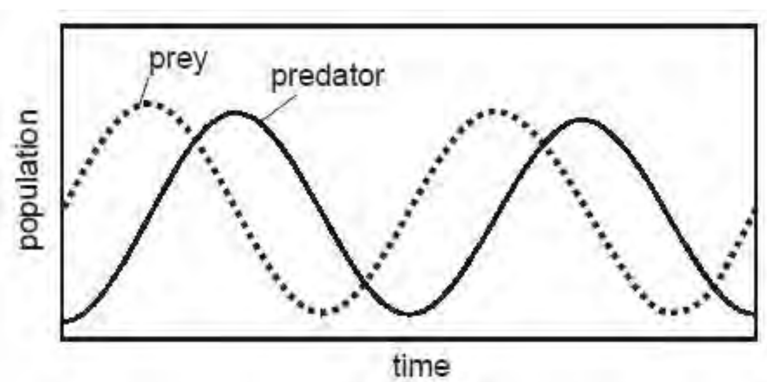
	Total number of fronds.			
	Species grown separately		**Species grown together**	
Days	***L. trisulca***	***L. minor***	***L. trisulca***	***L. minor***
0	30	30	30	30
16	63	78	48	105
36	126	142	84	234
46	177	225	84	324
54	165	276	48	360
60	129	219	45	354

(i).Draw graphs to compare the rates of growth of the two species when grown separately and when grown together.
(ii) What do the graphs suggest about the growth rate of the two species grown separately?
(iii)Account for this difference.
(iv)Offer an explanation for the interaction of the two species when grown together.
(v).Account for the changes in the growth rate between 46 and 60 days for *Lemna trisulca*.

(c.) **Predation.** This is a relationship whereby 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 material.

A predator is an animal that feeds on another live organism. A prey is the live organism that is fed on by the predator.

PREDATOR-PREY INTERACTIONS IN ECOSYSTEMS



Description of the changes in population numbers:
Initially, the population of the prey is higher that the population of the predator.
Within a short time, both populations of prey and predator increase rapidly.
The population of the prey reaches a maximum earlier the predator.
As the prey population decreases rapidly, the predator population continues to increase gradually for a short than time to a maximum then also decreases rapidly.
As the predator population continues to decrease, the prey population starts to increase rapidly, followed by a rapid increase in predator population. The cycle is repeated.

Explanation for the observed changes in populations:
At the beginning ,there are more prey than predator to provide food to the predators.
When the predator population is low, they get enough food and few preys are eaten so they both increase rapidly.
The large number of preys provides food to predators, so they reproduce fast and increase in numbers.
The increased predator population eats many preys and the prey population crashes.
The decrease in prey numbers causes the predators to starve and even their reproduction reduces, so the predator numbers crash.
Finally, the very low number of predators allows the prey population to recover, causing the cycle to start again.

Evolutionary significance of predator –prey

❖ Predation usually eliminates the unfit (aged, sick, weak). This gives the remaining prey access to the available food supply and also improves their genetic stock hence, enhances the chances of reproductive success and long ti survival, thus pass on their good traits to their off springs which can improve their evolution.

How are the predation suited for capturing prey?

- Have keen eyes for locating prey eg wolves, African lions hunt in groups.
- Preying mantis, chameleon have cryptic coloration/camouflage that enable them to walk to prey unnoticed..
- Nocturnal predators eg bats have highly developed sense for detecting sound made by prey.
- Some snakes which have glands to secrete poison (venom) which the fangs inject into prey to immobilize it (prey).
- Web-spinning spiders use their silky cob webs to catch small sized ground walking or flying insects.
- Ant-lions lay traps by making pits in the ground where preys fall
- Some have soft pads at the bottom of their feet so that they are not easily detected as they walk towards prey
- Some of stinging cells which paralyse their prey e.g sea anemones
- Have long and sharp canines which pierce and kill prey
- Well developed limbs which increase the speed of locomotion to chase and capture prey.

How are prey species suited to avoid predation?

- Possession of protective shells eg in tortoise and snails for rolling into armour-plated ball
- Possession of spines to prick the predators.
- In some lizards, the tail breaks off when attacked giving the animal (lizard) time to escape.
- Possession of spines (porcupines) or thorns (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 t background e.g. arctic hare in its winter fur blends into snow.
  NB. Camouflage is the ***use of any combination of materials, coloration, or illumination for concealment, either by ma animals difficult to see, or by disguising them as something else***.
  Exists in various forms;
  (i) **warning colouration** , conspicuous colouring that warns a predator that an animal is unplalable or poisonous e.g poisonous frogs, some snakes, monarch butterflies, and some grasshoppers(ii) **disruptive colouration/patterning** , wor by breaking up the outlines of an animal with a strongly contrasting pattern, thus decreasing detectabilitye.g. group of ze **(iii) cryptic colouration** allows an organism to match its background and hence become less vulnerable to predation e.g chameleon.
- Some prey species discourage predators with chemicals that are poisonous (e.g. oleander plants), irritating (e.g. bombar 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 t 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 distastefu the predator e.g. the non-poisonous viceroy butterfly mimics the poisonous monarch butterfly. **Batesian mimicry** occurs when the palatable species mimics other distasteful species e.g . viceroy butterfly mimics the poisonous monarch butterf the harmless hoverfly mimics the painful stinging wasp while **Mullerian mimicry** occurs when both the mimic and mimicked are unpalatable or 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 eg
- 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.
- Group defense, occurring among those that live and feed in herds

NB Predation

-Determines distribution and abundance of the prey because (i) an increase in the number of predators results into decre in the number of prey.(ii) predators will always be found in places of their potential prey.
-leads to dispersal of animals which reduces competition, since it involves movement of animals from place to place.
-is a biological control method.

(d) **Pollination and dispersal**

- Pollination is an ecological interaction because plants and animals interact with each other. Insects transfer pollen grains fr anthers to stigma.
- Dispersal of seeds and fruits introduces new plants to new habitats and this minimizes competition among species.
- Both interactions between the flowering plants and animals like insects , birds & bats may be highly elaborate and species specific.
- This co- evolution ensures that the distribution of the plants with their pollinations or agents of dispersal are related.e.g aru lily flowers are pollinated by dung flies.
  NB. ***Co evolution is a long term evolutionary adjustment of two or more groups of organisms that facilitate those organi living with one another.***
  Examples include; (i) Many features of flowering plants have evolved as a result of dispersal of plant's gametes by insects insects have in turn evolved special traits for obtaining nectar (ii) Grasses have evolved the ability to deposit silica in their leaves and stems to reduce their risks of being grazed, large herbivores have in turn evolved complex molars with enamel ridges for grinding up grass.

(e) **Antibiosis;** is the secretion by organisms chemical substances into their surrounding that may be repellant to members of the same species or different species e.g. penicillium (a fungus) secretes antibiotics that inhibit bacterial growth, ants release pherom to warn off other members of a species in case of danger.

Two types exist i.e(i) **intraspecific antibiosis** secretion by organisms chemical substances into their surrounding that may be repellant to members of the same species e,g male rabbits secrete pheromones from their submandibular salivary glands that are u to mark territory as a warning to other bucks that the territory is occupied.(ii)**interspecific antibiosis** secretion by organisms chemical substances into their surrounding that may be repellant to members of the different species e.g penicillium (a fungus) secretes antibiotics that kill or prevent the bacterial growth.

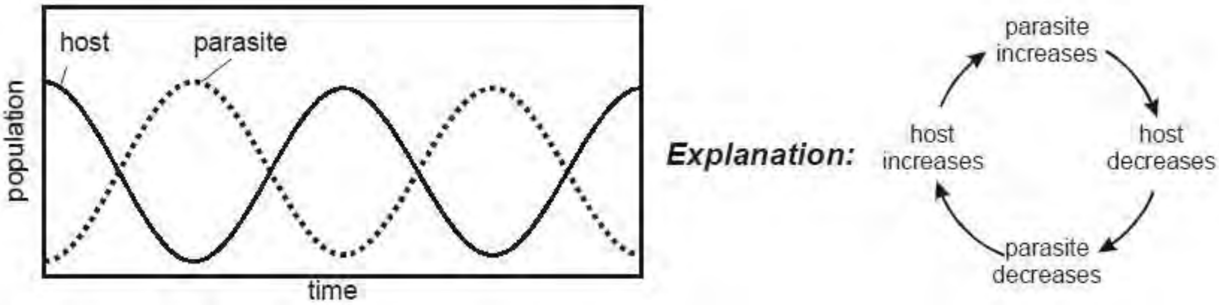
(f) **Parasitism**

An organism called **parasite** obtains part or all its nutrients from the body of another organism of different species called **host.**

The parasite is usually smaller than its host in size.

Parasites do not usually kill their hosts, but the host suffers harm.

killing the seedlings, lives as a saprophyte on their dead remains and others are **obligat**e (live on or in the host for their entire liv



(g) **Mutualism.** Is an interspecific association in which both organisms benefit.
Examples include.(i) cellulose digesting bacteria in gut of ruminants such as goats, cattle& sheep.Ruminants obtain sugars, aminoacids 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, vitamins.(iii) mycorrhizae(fungus and root of higher plants) .In **ectotrophic mycorrhiza** , 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 mycorrhiza** involves most of fungi inside tl 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; algae and fungus. Algae carries out photosynthesis, providing nutrients to the fungus while the fungi it is protected by the fungi from intense sunlight and dessication, minerals absorbed by the fungus are passed onto it.(v)hermit crab a sea anemones , with the hermit crab(*Eupagurus berhardu)s* obtaining defence from the stinging cells of anemones(*Adamsia)* & camouflaging from its predators. Sea anemones feed on food remains of the crab & obtains free transport from one area to anoth
(h) **Commensalism** Is an association between organisms of different species in which one benefits while the other neither benef nor its harmed.e.g (i)cow and white egrets, epiphytes and host plant.
Question**. Explain what is meant by the terms parasitism, mutualism and predation, indicating with the help of suitable examples how they differ from one another.**

ECOLOGICAL SUCCESSION

- This is a long- term directional change in the composition of a community from its origin to its climax through a numbe stages brought about by the actions of the organisms themselves.
- It is a process by which plants and animal communities in a given area change gradually over time, becoming replaced b different and usually more complex communities.
- Pioneers are first sets of organisms to occupy the area, collectively such organisms constitute the **pioneer community**.
- The process of succession continues through stages known as **seral** stages and there are a number of **sere** (complete succession) according to the environment being colonized.
  (i) **hydrosere**; succession in aquatic environment (ii)**halosere**;succession in salty environment(iii)**xerosere**; succession dry envirionments e.g deserts(iv**) lithosere**; succession on a rocky surface
- The first seral stage has pioneers and the final stage has a climax community, a final stable community at the end of succession, which a particular environment can sustain.
- Climax community is characterized by by (i) diverse species (ii) complex feeding relationships and (iii) progress increases in biomass.

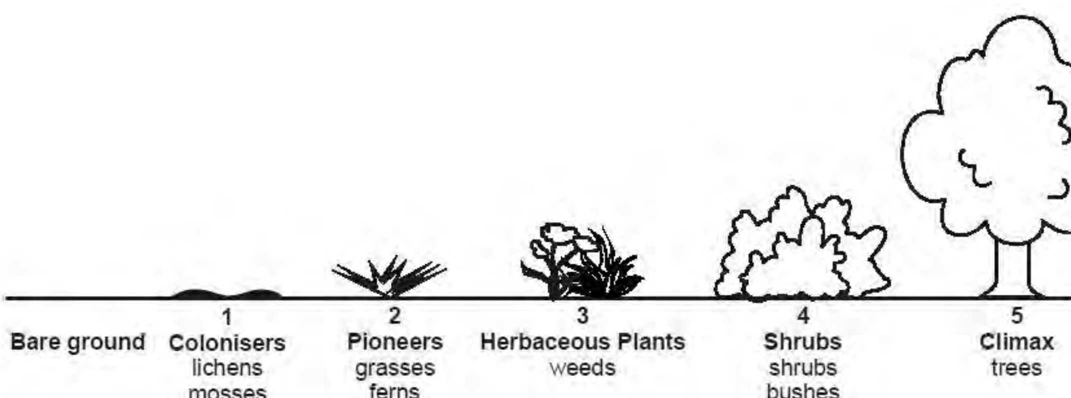
Types of succession

a) Primary succession
b) Secondary succession

a) Primary succession

This is the gradual change in species composition of an area that has never had any vegetation growing on it.
It occurs on Bare rocks exposed by erosion, Newly cooled lava, Newly created shallow ponds ,Sand dunes , Abandoned highway or parking yard.

An example of primary succession on land



Description of Primary succession on land

- Lichens and mosses attach to bare rocks and start forming soil by trapping wind- blown soil particles, producing tiny bit organic matter and secreting mild acids that slowly breakdown the rock. Alternate heating and cooling also causes break down of rocks.
- As patches of soil build up and spread, eventually the pioneer species are replaced by the early successional plants 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 death and decay of small grasses and ferns increase nutrients in soil.
- After a long period of time, the soil becomes deep, moist and fertile enough to support the growth of mid successional p species like herbs, large grasses, low shrubs and small trees that need a lot of sunlight.
- Late successional plant species (mostly trees that tolerate shade) later replace the mid successional plant species.
- Unless natural or human processes disturb the area, a complex forest community remains

(b) **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.
It occurs on abandoned farmlands, burnt or cut forests, heavily polluted streams, flooded land.
Due to some soil or sediment present, vegetation usually begins to germinate within a few weeks.
Seeds and spores can be present in the soil and can be carried from nearby plants by wind, birds and insects.
The ground may even contain resistant plants/vegetative organs of the colonizing plants that survived the changes.

Characteristics of the stages of primary succession;

a) Early succession

- Species grow very close to the ground and have low biomass.
- Species have short life span.
- Species are simple and small sized.
- Species diversity (number of species present in a habitat) is very low.
- Community is open ie allows space for other 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 tre
- The community is mostly 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
- Community is a mixture of producers, consumers and decomposers.
- Biomass is high
- Net productivity is low
- Community takes a longtime to establish.
- 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.

POPULATION DYNAMICS

These are changes in population in response to environmental stress or environmental conditions.
A population is a group of organisms of the same species living together in a given place at a particular time.

TERMS USED IN POPULATION STUDIES:

Population size: Number of individuals in a population.
Population density: Total number of organisms of a species per unit area (land) or per unit volume (water)
Population growth: A change in the number of individuals (increase-positive or decrease-negative)
Population growth rate; Change in number of individuals per unit time
Birth rate (natality): Number of new individuals produced by one organism per unit time (Humans: per year). Expresse the number of individuals born in a given period for every 1000 individuals e.g 36 births per 1000 people per year.
Death rate (mortality): Number of individuals dying per unit of time per unit of population (humans: number of deaths 1000 per year e.g. 20 deaths per 1000 people per year)
Environmental resistance: All the environmental factors acting jointly to limit the growth of a population.
Carrying capacity: Maximum number of individuals of a given species that can be sustained indefinitely in a given area land or volume of water.
Age structure/distribution*;* is the proportion of individuals of each age in a population.
The young-age group before reproduction
Middle age- reproductive age
Old age-age after reproductive stage

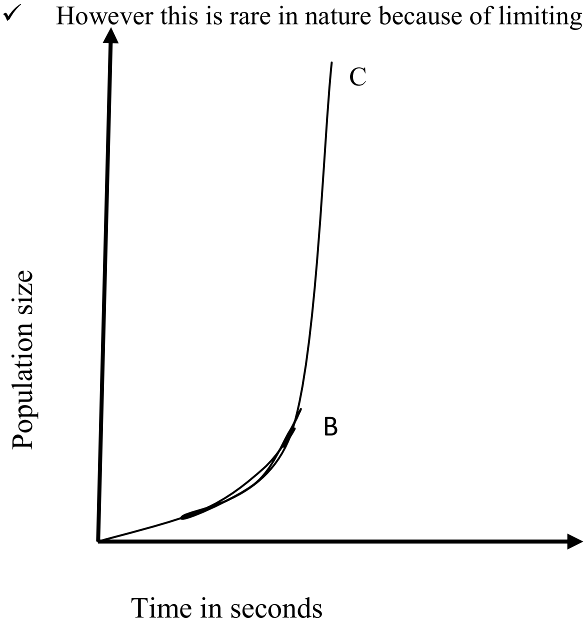
Immigration: Movement of individuals into a population from neighboring populations.
Emigration: Departure of individuals from a population.
Rare species: Species with small populations either restricted geographically with localized habitats or with widely scat individuals.
Endangered species: Species with low population numbers that are in considerable danger of becoming extinct.
Extinct species: Species, which cannot be found in areas they previously inhabited nor in other likely habitats
Population distribution/dispersion - distribution of organisms in a habitat. Three main types exist i.e (i) **uniform distribution** organisms are equidistantly placed due to severe struggle for resources in the environment.(ii)***Random distribution*** organisms are dispersed by chance with neither forces of attraction nor repulsion and the environment provi uniform factors.(iii) **clumped distribution** organisms aggregate into groups to gain better protection, feeding, reproduct etc. Clumped dispersion is the most common pattern of population distribution.
NB. Main characteristics of a population are (i)density(ii) dispersion(iii)age structure(iv) natality (v) mortality (vi) population size.

POPULATION GROWTH PATTERNS

- ❖ Population grows when(i) natality is greater than mortality (ii) immigration is greater than emigration
- ❖ Population growth may form a curve which is either (i) exponential population growth curve (J-shaped) (ii) logisti population growth curve(Sigmoid/S-shaped)

(i) **Exponential population growth (J-shaped curve)**

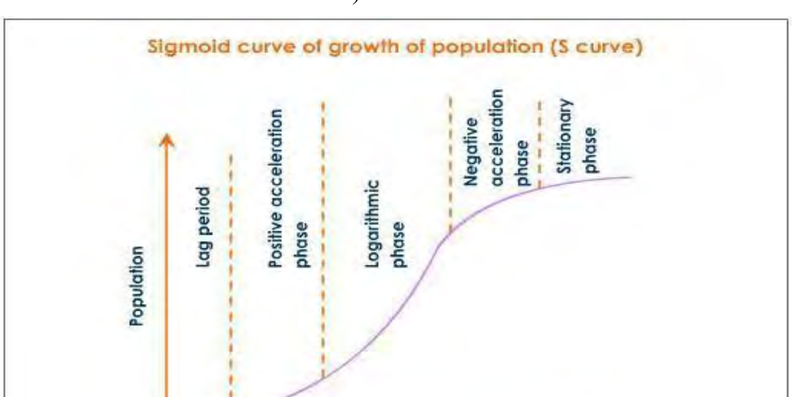
- ✓ It is a theoretical population growth curve in which the population growth rate increases with time indefinitely.
- ✓ Population growth starts out slowly and then proceeds faster and faster as the population increases.
- ✓ It occurs when resources are unlimited and the population can grow at its intrinsic rate of growth.(rate at which a population would grow if it had unlimited resources)
- ✓ However this is rare in nature because of limiting factors (environmental resistance).



Description
Number of individuals(population) is small. Their number increases gradually/slowly with time along AB. Later thw population size increases rapidly/sharply/drastically with time along CB
Explanation
Initially , the number of individuals increases gradually with time because the population size is small, thus few reproducir individuals, ,reproducing individuals are scattered within the environment, some may not have reached reproductive age, organisms are still getting used to their environment. Later on number of individuals increases rapidly because many individuals have now reached reproductive age, & number of reproducing individuals now gets bigger

(ii) **Logistic population growth curve sigmoid / s-shaped) .**

- Population growth starts out slowly and then proceeds faster to a maximum (carrying capacity) and then levels
- Population then fluctuates slightly above and below the carrying capacity with time.
- The population stabilises at or near the carrying capacity (K) of its environment due to environmental resistance(any factors that may prevent a population from increasing as expected eg predation, parasitism, and accumulation of toxic substances)



The actual factors responsible for the shape of each phase depend on the ecosystem, and this can be illustrated by considering two contrasting examples: **yeast** in a flask (reproducing asexually), and **rabbits** in a field (reproducing sexually).

PHASES	**YEAST IN A FLASK**	**RABBITS IN GRASSLAND**
Lag phase	Little growth while yeast starts synthesizing appropriate enzymes for new conditions.	Little growth due to small population. Individuals may rarely meet, so few matings. Long gestation so few births.
Acceleration phase	Slow growth because cells are getting used to conditions in the environment	Slow growth because of few reproducing individuals
Log phase (Logarithmic phase)	Rapid exponential growth. No limiting factors since relatively low density.	Rapid growth. Few limiting factors since relatively low density.
Deceleration phase (Negative acceleration phase)	Slow growth due to accumulation of toxic waste products (e.g. ethanol) or lack of sugar.	Slow growth due to intraspecific competition for food/territory, predation, etc.
Stationary phase	Population is stable (fluctuates slightly above and below the carrying capacity). Cell death is equivalent to cells formed	Population is stable (fluctuates slightly above and below the carrying capacity). Death rate is equivalent to the birth rate

How Population Density Affects Population Growth

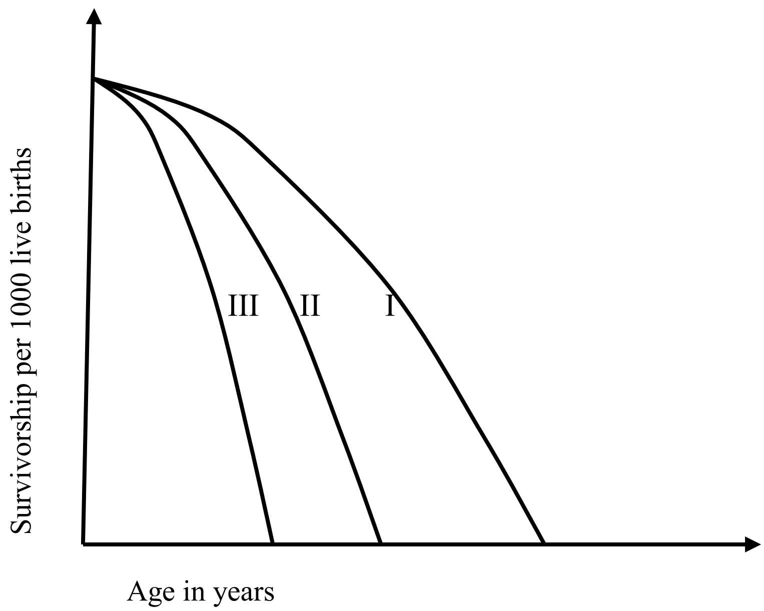
(a) Density dependent factors, are those factors whose effectiveness depends on number of individuals present in a unit space. The more individuals there are in the population, the greater the percentage of population that dies or fails to reproduce. These include; diseases, predation, competition for food, parasitism, pollution (accumulation of wastes etc.

(b) Density independent factors, are those 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. They include; temperature, rainfall, light, floods, soil nutrients, fire, drought, hurricanes and habitat destruction e.g. clearing a forest or fishing in a wetland, pesticide spraying. They are mainly abiotic factors.

SURVIVORSHIP

This is the percentage of an original population that survives to a given age.

Survivorship curve: is a graph which shows the number (or percentage) of surviving individuals of each age group of a population for a particular species.



(I) **Late loss curves**

Occurs in 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.

(II)**Early loss curves**

Occurs in annual plants, most invertebrates and most bony fish species; 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.

(III) **Constant loss**

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.

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

DETERMINATION OF POPULATION SIZE OF ORGANISMS

Importance of estimating population size

- Enables monitoring of population growth
- Enables determination of habitat requirements of species.
- Enables determination of carrying capacity in the area. i.e determine whether existing population are likely to be sustainable.
- Enables determination of age structure, and sometimes sex ratio of a population.
- It enables projection of how population size is likely to change with time for proper planning eg determining the peak populations of organisms e.g mosquitoes enables control measures to be prepared.

FACTORS TO CONSIDER BEFORE COUNTING ORGANISMS

- The area of land or volume of water or air under study should be determined.
- The nature of vegetation cover of the habitat.

- ❖ Behavior of the organism e.g. their level of hostility and excitement when disturbed.
- ❖ Topography of the area
- ❖ Type of habitat, terrestrial/aquatic.
- ❖ Risks involved during the exercise.
- ❖ Seasonal changes and its effect on organisms.

METHODS OF DETERMINING POPULATION SIZE OF ORGANISMS

(a)Total count:

This is the physical counting of every individual of a population in a specified area of ground.

It is effective for large animals living in unconcealed (exposed) habitats. It includes; (i) **Direct counting method** (using a low fl aircraft) (ii)**Aerial photography** (iii)**Drive and count** (iv)**Strip census** (v)**Removal method**

(i)Direct counting method using a low flying aircraft

Used to determine population of large animals.

Requirements

(i)An air craft e.g. a helicopter(ii) Survey map of the area (iii)Stationary (iv) binoculars

Procedure

An air craft is flown at low altitude over the study area a long several strips of known area

The number of organisms of given species under study is obtained by direct counting and recorded.

This is repeated several times. The average population density for all the sample is then calculated.

Advantages

- ❖ It gives a quick estimate of the population size
- ❖ Other studies on the population such as feeding habits, reproductive behavior, and predation can be carried out simultaneously.
- ❖ It reduces the risk of attacks from aggressive animals eg lions, buffalos, etc

Disadvantages

- ❖ It is expensive since it requires sophisticated air craft and skilled man power
- ❖ The sound made by the air craft may scare some animals which may hide in concealed areas e.g. under the trees.
- ❖ It's greatly hampered by some weather conditions e.g fog, misty or cloudy weather.
- ❖ Can only be used on large animals and those in open grass lands
- ❖ Not easy in very hilly areas.
- ❖ calculations involved may cause inaccuracy

(ii) Aerial photography.

Requirements

(i) Low flying air craft (ii) Good camera

Procedure

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

NB; **advantages and disadvantages are as seen above (direct counting**)

(iii) Drive and count method

Requirements

(i)Man power (ii)Stationary

Procedure

A number of people drive animals into a particular space/area and count them.

Advantages

i. It is quick and more accurate especially for slow moving animals and those that live in herds e.g. antelopes.

ii. 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

(iv) Stripe census

Requirements

(i) Map of the area (ii) Vehicle

Procedure

- ❖ 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 are**

Advantages

- ❖ It's quick
- ❖ It's cheap compared to aerial means

Disadvantages

- ❖ Moving vehicles scare away animals that may run into hiding

- Very many counts have to be made so as to come out with a reliable number.

(b) Counting by sampling

- This is when the number of organisms is determined in several sample plots that represent a known fraction of the total 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 behavior of organisms does not allow easy contact.

(i) Capture mark Release recapture method (Lincoln Index).

This method is used on highly mobile animals like fish, small animals like mammals e.g. rats, birds, ,arthropods eg inse like butterflies, moth, grass hoppers.

Requirements

(i) Suitable traps (ii) Suitable tags/label e.g. aluminum discs for fish, permanent ink for rats/mice

Procedure

- Traps are set up randomly over study area.
- After some time, the traps are observed for any captures made , a count is made for all animals captured in this first occasion., noted as **N1**.
- They are all marked using a suitable label or tag e.g. placing an aluminum disc on the ear of a mammal (rat).
- These animals are then released back to their natural environment.
- After allowing sufficient time for the population to mix thoroughly, the traps are set up again all over the study area.
- A count is made of all animals captured on the second catch noted as **N2**.
- A count is made of how many animals captured on the second catch have marks /labels; i.e. those that have been recaptu Noted as **N3**.
- The estimated total population**(P)** of animals in the area is then estimated using the Lincoln index as follows;

$$P = \frac{N_1 \times N_2}{N_3}$$

Where P-estimated total population of the area
N1- number of individuals captured on the first occasion.
N2- number of individuals captured on the second catch.
N3- number of individuals recaptured on the second catch.

Assumptions made when using the capture mark Release recapture method

- 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 organisms or make them conspicuous to predators.

Disadvantages/limitations

- It's only reliable when the organisms' range of movement is relatively restricted and defined.
- Animals often move in groups whose members recognize one another and avoid mixing with those of other groups.
- Many animals have particular localities where they confine, so the marked animals may not spread widely.
- Loss of marked individuals reduces those recaptured and this causes inaccuracy.
- The label may psychologically or physically disturb the organism.

Example

In an attempt to estimate the number of tilapia in a small lake, 625 tilapia were netted, marked and released. One week later, 8 were netted of which 129 tilapia had been marked. What is the estimated population size of tilapia?

$$P = \frac{N1 \times N2}{N3}$$

$$P = \frac{625 \times 873}{129}$$

P=4230 tilapia

ASSIGNMENT. In an investigation of a fresh water pond, 35 water bugs(**Notonecta**) were caught, marked and released . Three days later 35 water bugs were caught and 7 were found to be marked.

(a) What is the approximate size of population of water bugs in the pond? Show your working.

(b) Give three reasons why capture-recapture is unlikely to be an accurate way of assessing the size of water bugs.

(ii) Use of quadrat

This is suitable for slow moving animals and grass.

Requirements

(i)Metallic, plastic or wooden frame of a known area e.g. $1m^2$ (ii) Stationary

Procedure

The frame is randomly thrown several times in an area under investigation.
All individual within a quadrat are counted each time.
Population density is expressed as the average figure per metre squared.

Advantages

(i) It's accurate (ii) It enables comparison of different areas and species. (iii) It provides an absolute measure of abunda

Disadvantages

(i)Its time consuming. (ii) It's not suitable for first moving animals. (iii) It's not suitable for large sized animals. (iv) some plar e.g. grass species are indistinguishable and may disturb.

(iii) **Removal method**

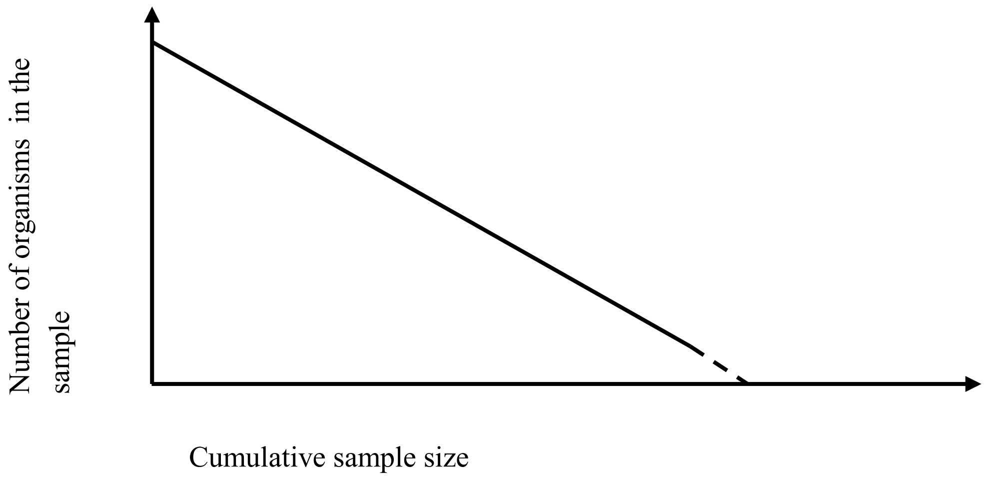
This is suitable for small organisms like insects and rats within a known area of grassland or volume of water.

After sweeping with a heavy net, counting and recording of the animals captured is done without replacement.

The procedure is repeated several times and gradually decreasing numbers of organisms and cumulative number of organisms captured 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 be captured, from which the populat is estimated. E.g.

Sample no	**Number of organisms in the sample**	**Cumulative sample size**
1	120	120
2	93	213
3	60	273
4	35	328



Assignment

Suggest and describe the suitable methods for estimating the population size of the organisms below. Give reasons for your choice of each method and outline the associated limitations.

a) Fish in a pond (b) Terrestrial plant (c) Large mammals

<u>REGULATION OF POPULATION SIZE</u>

Population size is naturally maintained at their normal carrying capacity depending on the resources in a given habitat. These populations controlled by homeostatic means depending on the density controlled factors e.g. food, pests, diseases, predators etc.

The population itself initiates the control measure i.e an increase in population stimulates environmental resistance which brings the population back to normal, and a decrease in population below carrying capacity, environmental resistance decreases, thus causing an incr in the number of organisms e.g. predator –prey relationship.

<u>Methods of population control</u>

(a) <u>Biological control method</u>

This is the eating or weakening of a pest species or weeds using other organisms called **control agents** e.g. natural predator, parasite or pathogen .E.g.. (i) Using cats to eat rats, (ii) using beetles to feed on the water hyacinth on Lake Victoria, (iii) placing fish in ponds to eat mosquito larvae.

Biological control aims at bringing the pest population to a level where they are economically un harmful.

Biological control method can be used to; (i) control of vector population (ii) control of parasites (iii) control of pathogens (bacteria& viru (iv)control of some plants e.g. weeds (v) control of pests.

<u>Steps involved in biological pest control</u>:

- Identifying the pest and tracing its origins, i.e. where it came from.
- Investigating the original site of the pest and identifying natural predators, parasites or pathogens of the pest.
- Testing the potential control agent under careful quarantine to ensure its specificity.
- Mass culturing of the control agent.
- Development of the most effective distribution / release method for the control agent.

NB. Biological control of population is very specific, thus useful organisms are not affected.

(b) <u>Chemical method.</u>

Involves use of chemicals by humans to eradicate harmful organisms

Are named according to the target organisms e.g. herbicides kill weeds, insecticides kill insects, fungicides kill fungi.

<u>Properties of an ideal pesticide</u>:

- 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.

Problems of using insecticides:

- Accidental misuse of toxic chemicals results in death of humans and domestic animal.
- Many are non-specific, killing non-target species, particularly natural predators of the pest species.
- Pest resistance occurs i.e. genetic variation enables a few individuals in the pest population to survive and may quickly reproduce
- There is pest replacement i.e. since most crop are susceptible to attack by more than one pest species, and the pesticide may be m deadly to one species than another, elimination of one species may simply allow another species to assume major pest proportion
- 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.
- **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) m occur. E.g. If Dichlorodiphenyl trichloroethane, DDT is sprayed on plants, to kill green flies, some survive, and absorb the chemi into their bodies. When eaten by small birds, DDT accumulates and when birds are eaten by other predators, e.g birds of prey, th accumulation of DDT reaches a level which burns up and kills the final consumer.

Questions

1. **(a)**What is a biological pest control?
 (b). What consideration must be made before application of biological pest control method?
 (c.) State two ways in which the chemical control method can upset an ecosystem
 (d) Suggest three characteristics of a good pesticide.
2. The table shows the amount of DDT in plants per million found in a variety of organisms associated with fresh water lake.

Site of DDT measurement	Amount of DDT in parts per million
water	0.0003
phytoplankton	0.002
zooplankton	0.004
Herbivorous fish	0.39
Carnivorous fish	0.89
Fish eating birds	14.2

(a) (i). Calculate how many times DDT is more concentrated carnivorous fish compared with its concentration in water
(ii) what do the results in a(i) show?
(b)Explain why the concentration of DDT changes from water carnivorous fish?
c) Explain how a pest sprayed with a pesticide may flourish afterwards?.

3. In an aquatic ecosystem which was affected by an insecticide, analysis of energy flow and concentration of the insecticide in each troph evel in a food chain was made. The results were shown in the table below.

Energy flow	pesticide
Producers	0.04
Herbivores	10
Carnivore 1	50
Carnivore 2	75

(a)Explain why from producers to consumers,(i) level of insectide increases(ii) t flow of energy decreases.(b) Give three ecological problems that may arise fron the use of pesticides.

NATURAL RESOURCES

- A natural resource is anything not made by man obtained from the environment to meet human needs and wants
- 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

Type of natural resource & its definition	Examples
i) ***Perpetual resources***. Resources that are replaced (renewed) continuously on human time scale.	(i) Solar energy (ii) wind (iii) tides.
ii) ***Renewable resources*** Resources that are replenished (replaced) fairly rapidly (hours to decades) hrough natural processes as long as the usage is not faster than the eplacement.	(i) Fresh water (ii) fresh air (iii) fertile soil (iv) animals and plants (Forests, grasslands)
iii) ***Nonrenewable resources*** Resources that exist in a fixed quantity or stock in the earth's crust. On the shorter human time scale, they are depleted much faster than they are formed.	(i) Fossil fuels (e.g. coal, oil, natural gas) (ii) metallic minerals (e.g. copper, iron, aluminium) (iii) non-metallic minerals (e.g. salt, clay, sand, phosphates).

Further terms associated with natural resource.

Term and definition	Examples and/or comments
i) *Sustainable yield* The highest rate at which a renewable resource can be used ndefinitely without reducing its availability supply.	In spite of the renewability, renewable resources can be depleted or degraded.
ii) *Environmental degradation* The process when the resources natural replacement rate is exceeded resulting into a decline in its availability	Urbanization of productive land, excessive soil erosion, deforestation, ground water depletion, over grazing of grass lands by livestock, reduction in the earth forms of wild life by elimination of habitats and

iii) *Recycling of resources* This is the reprocessing of a resource into new products	Old aluminum saucepans and copper items can be recycled
iv) *Reusing of resources* Using of resources over and over in the same form.	Glass bottles of alcoholic and soft drinks can be collected washed and refilled many times
v) Wild life This includes plants and animals that occur in their natural environment	Forests and wild animals

POLLUTION

- ❖ It is the release of substances or energy into the external environment in such quantities and for such duration that may cause har living organisms or their environment.
- ❖ **Pollutants** include; noise, heat and radiation as different forms of energy, many chemical compounds and elements and excret products.
- ❖ The parts of external environment affected include air, water and land.

Harm cause by pollutants.

- Disruption of life support systems for living organisms.
- Damage to wild life, human health and property.
- Nuisances such as noise and unpleasant smells, tastes and sights.

Categorisation of pollutants basing on their persistence in the environment

(a) Degradable (non-persistent) pollutants: Are the pollutants that are broken down completely or reduced to acceptable levels by natura physical, chemical and biological processes.

Biodegradation: is the breakdown of complex chemical pollutants into simpler chemicals by living organisms (usually specialised bacter e.g. sewage is a biodegradable pollutant.

(b) Slowly degradable (persistent pollutants): Are those that take a longer time to degrade e.g. DDT - an insecticide, and **plastics e.g. pla bags.**

c) Non-degradable pollutants: these cannot be broken down by natural processes e.g. the toxic elements lead, mercury, arsenic, selenium

TYPES OF POLLUTION

(a) AIR POLLUTION

Pollutant	**Source(s)**	**Effects/ consequences**	**Control measures**
(i) *Carbonmonoxide*	(i)Motor vehicle exhausts ii) Incomplete combustion of fossil fuels (iii) tobacco smoking	(i) Prevents oxygen usage by blood by forming carboxy-haemoglobin, which may cause death.(ii) Small concentrations cause dizziness and headache	(i)Efficient combustion of fuels industry an homes(ii) Avoid smoking.(iii) Vehicle exhausts g control e.g. in USA.
(ii) *Sulphurdioxide*	(i) Combustion of Sulphur containing fuels, oil, coal gas	(i) Causes lung diseases, irritation of eye surface, and asthma resulting into death if in high concentrations.(ii) Forms acid rain which increases soil PH.(iii) Reduces growth of plants and kills lichens. NB. *Lichens are indicator species for sulphurdioxide pollution.* *The presence of many lichen species indicates low level of sulphurdioxide pollution in that area.*	i) Use of Sulphur free fuel e.g natural gas.(ii) Installation of Sulphurdioxide extraction un in industrial fluels and chimneys.
(iii) *Ozone* ***(iv) Smoke***	(i) Motor vehicle exhausts ii) combustion of fossil fuels to form nitrogen dioxide which decomposes to form oxygen atoms that combine with oxygen molecules to form ozone. (i) House coal, smoke, soot ii)Motor vehicle exhausts iii) tobacco smocking iv) Incomplete combustion of refuse in incinerators and bonfires.	***Low level (tropospheric) ozone*** causes: (i) Internal damage to leaves hence reducing photosynthesis.(ii)Eye, throat and lung irritation which may result into death.(iii)Internal damage to leaves which severely reduces photosynthesis. (iv) Green house effect by absorbing and radiating heat which raises the temperature at the earth's surface. ***High level (stratospheric) ozone offers*** protection against excessive solar heat by absorbing solar ultraviolet radiation which would reach the earth's surface. (i) Causes lung diseases when inhaled (ii) Sunlight barrier, hence reducing photosynthesis.(iii)Stunted growth of plants (iv) Stomatal blockage hence reducing photosynthesis	(i) Vehicle exhausts gas control e.g. in USA (i)Usage of smokeless fuels (ii)Efficient combustion iii)No smoking iv) Vehicle exhausts gas control
(v) Dust	(i) Solid fuel ash (ii) soil (iii)	i)Lung diseases(ii) stomatal blockage	i)Installation of dust precipitato

		forms when temperature inversion occurs (layer of warm air traps cool air containing dust and smoke close to the earth' surface)	ii) Efficient combustion. iii) Wearing of face masks by factory workers.
(vi) ***Carbondioxide***	(i)Motor vehicle exhausts ii) combustion of fossil fuels	Increased carbon dioxide causes Green house effect – warming up of the earth's atmosphere as a result of the blanket of carbon dioxide, preventing escape of solar radiation higher into space.	(i)Planting more green plants, (i reduction in combustion of fossi fuels by relying on alternative sources of energy e.g. solar ener
(vii) ***Nitrogen oxides*** **(*nitric oxide & nitrogen dioxide)***	(i) Car exhaust emissions (ii) industrial fuel gases	(i)Acid rain formation(ii) contribute to green house effect	(i) Car exhaust control
Viii)Chlorofluorocarbons CFCs	(i)Aerosol propellants, (ii) refrigerator (iii) air conditioner coolants (iv) expanded plastics. E.g. bubbles in plastic foam used for insulation and packaging **(polyurethane form)**	Enters stratosphere, the chlorine reacts with ozone hence reducing the ozone layer and permitting greater penetration of UV light to cause global warming.	Ban on the use of CFCs
(ix) ***Noise***	(i) Discos (ii) road traffic, (iii0 engines (iv) machines, (v) aeroplanes(vi) firearms	(i) Hearing impairment,(ii) total deafness (iii) nervous disorders	(i) Effect laws against excess noise(ii)put on ear muffs and plugs while in industry
(x) ***Radioactive*** *fallout from explosion*	(i) Nuclear weapons(ii) nuclear power fuels.	Ionizing radiation causes cancer	Nuclear power controls

<u>GREENHOUSE EFFECT AND GLOBAL WARMING</u>

Greenhouse effect

- This is a description of the condition which results when greenhouse gases i.e. gases in the troposphere (atmosphere's inner m layer extending about 17km above sea level) like carbon dioxide, water vapor, methane and nitrous oxide allow mostly visible li some infrared radiation and ultraviolent radiation from the sun to pass through the troposphere to the earth, which transforms th solar energy to longer-wave lengths-infrared radiation (heat) which then rises into the atmosphere.
- Molecules of greenhouse gases absorb and emit this heat into the troposphere as even longer-wave-length infrared radiation, whi 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 of 0.8oC since 1900 as result of the enhanced natural greenhouse effect.

The origins of greenhouse gases are;

- ✓ Combustion of fossil fuels by motor engines and industries releases carbon dioxide and methane into the troposphere.
- ✓ Deforestation and clearing of grasslands reduces the uptake of carbon dioxide in photosynthesis.
- ✓ Ruminant fermentation produces methane, which is released into troposphere.
- ✓ Use of aerosol propellants, which contain CFCs that are 105 times worse than carbon dioxide as greenhouse gases
- ✓ Cultivation of rice in swamps and paddy fields causes anaerobic fermentation, which produces methane.
- ✓ Use of inorganic fertilizers cause 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 migration which are likely to cause pests/diseases to extend their ranges.
- ✓ Reduced cropped fields 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 human population.
- ✓ Greatly increased wild fires in areas where the climate becomes drier.

ACID RAIN

Formation

Combustion of fossil fuels releases sulphur dioxide and nitrogen oxides into the atmosphere.

Catalyzed by ammonia and unburnt hydrocarbons, these oxides react with water in the clouds to form solutions of **sulphuric aci** and **nitric acid**, which make up acid rain.

Effects

- ✓ Aluminum ions are displaced from soil by $SO4^{2-}$ ions into water where it interferes with gill functioning in fish causing death.
- ✓ Aluminum ions are displaced from soil by $SO4^{2-}$ 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 lame and chlorophyll in leaves.
- ✓ Contributes to humans 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 population when the pH lowers below 4.5

Prevention

- ✓ Installation of SO2 extraction units (wet scrubbers) in chimneys of industries.
- ✓ Cleaning up of exhaust emissions by encouraging several pollutants to react with one another to give less harmful produ in catalytic converters.
- ✓ Reduce coal use.
- ✓ Increase use of renewable resources.
- ✓ Tax emissions of sulphur dioxide, "polluter pays principle" should be adopted everywhere.

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.

(b) **WATER POLLUTION**

MAJOR CATEGORIES OF WATER POLLUTION

(A) *SEWAGE DISCHARGE INTO RIVERS*

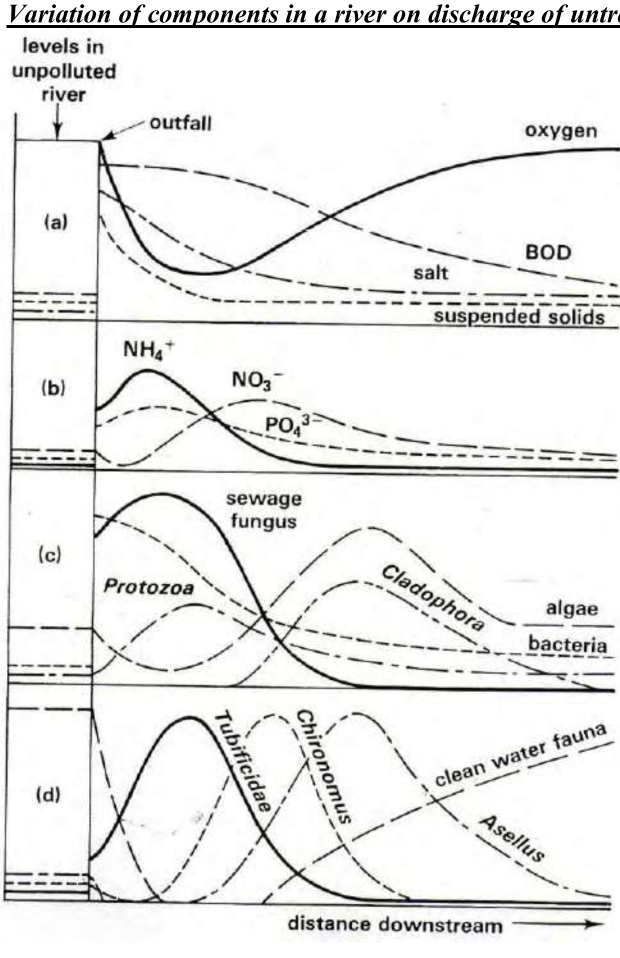
Sewage is liquid waste (composed of faeces, urine, water, detergents and other substances) from industries and/ or homes carrie through pipes called **sewers**.

Effects of untreated sewage discharge into rivers

Discharge of untreated sewage into a river has an immediate effect on the aquatic environment, causing many changes in both th **abiotic** and **biotic components**.

Some of these changes are due to specific chemical pollutants (e.g. heavy metals such as cadmium from industrial processes, an pesticides from agriculture, with the effects varying according to the chemicals present in the discharge.

Variation of components in a river on discharge of untreated sewage



(a) What is meant by the term biochemical oxygen demand(BOD)?

(b). Explain the changes in BOD shown in the diagram

(c.) (i) Explain the changes in nitrate level shown in the diagram.

(ii). Compare and comment on the curves for the sewage fungus and the algae in the diagram.

(d). Using evidence from the diagram, suggest a method by which an organism might be used as a pollution indicator.(Your answer should include practical details of your method)

(e) Suppose that the chemical works also discharged thermal pollution. Suggest one possible effect on the river's chemical content and one possible effect on its biological content.

Component(s)	Variation down stream	Explanation
(i) *Dissolved oxygen and B.O.D (Biological or biochemical oxygen demand)* NB. BOD is mass of oxygen consumed by microorganisms in a sample of water in a given time - usually measured as the mass (in mg) of oxygen used by 1dm^3 of water stored in darkness at 20degrees Celsius 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).	-Dissolved oxygen level is high in unpolluted water; decreases rapidly at sewage discharge to the minimum; and then increases gradually downstream, returning to a normal level further downstream. - B.O.D is very low in unpolluted water, increases rapidly at sewage discharge then decreases gradually downstream.	-Decomposition of organic components o sewage by aerobic bacteria coupled with reduced photosynthesis because of low illumination caused by suspended solids sewage rapidly reduce oxygen (cause oxygen sag) and create a high BOD at outfall. -The gradual increase of dissolved oxyge downstream is because of increased photosynthesis and dissolution from atmosphere. -The death of aerobic bacteria due to reduction in organic substances decrease BOD down stream.
(ii) *suspended solids*	-Suspended solids are very few before outfall, increase rapidly at the sewage discharge but progressively decrease downstream.	-Sewage discharge adds decomposable organic matter into the water at the point discharge, the progressive decrease downstream is due to bacterial consumpt and dilution by water.
(iii*) Living organisms* e.g Aerobic bacteria, sewage fungus((filamentous bacteria), algae(cladophora) and higher plants.	-Aerobic bacteria are very few before, but very many at outfall, then their population decreases rapidly immediately and gradually after out fall downstream. -Sewage fungus is contained in sewage population; increases to a maximum immediately after outfall, but decreases rapidly downstream to very low level. -Algae and higher plant populations decrease rapidly to a minimum at outfall but increase rapidly a short distance downstream and return to normal further downstream.	-Sewage contains aerobic bacteria that fe on organic substances, but population fal as availability of oxygen and nutrients diminishes. -Population increases at outfall because t sewage fungus thrives in anaerobic conditions and is very tolerant at high ammonia concentrations. -The rapid decrease in population results from reduced photosynthesis because of turbidity caused by suspended solids, the rapid increase is because of the high concentrations of nitrate ions and increas illumination because suspended solids reduce and water becomes clearer.
(iv) *Ammonium, nitrate and phosphate ions.*	-Ammonium, nitrate and phosphate ions concentration is very low before out fall. -NH_4^+ ions increase rapidly at discharge; more rapidly to a maximum just after outfall; then decreases first rapidly and later gradually to a very low level downstream. -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. -PO_4^{3-} ion concentration increases (1) rapidly at discharge, (2) gradually just after outfall to a maximum, then decreases gradually to a very low level downstream.	-Sewage contains NH_4^+ ions. Putrefying (ammonifying) bacteria convert organic nitrogen-containing compounds in sewag to NH_4^+ just after outfall. Downstream, NH_4^+ ions are converted to NO_3^- by nitrifying bacteria and further downstrea there is dilution by water. -NO_3^- ions first decrease due to consumption by sewage fungus abundan outfall, then gradually increase because NH_4^+ ions are converted to NO_3^- by nitrifying bacteria, then decrease gradua due to consumption by plants and algae. Sewage contains PO_4^{3-} ions from (1) detergents and (2) decomposition of orga matter, yet the consumption by autotrop is very low at outfall, accounting for the high PO_4^{3-} ion concentration. PO_4^{3-} ion gradual decline downstream is caused by (1) absorption by the progressively increasing populations of autotrophs (2) storage in sediments.
Clean water fauna	-The populations of clean water fauna are	-Clean water organisms

larvae) Asellus (fresh water louse), Chironomus(bloodworm), Tubifex and rat –tailed maggots(not indicated on the graph but it can be sketched basing on tolerance to pollution) **NB-** organisms above are **indicator species** of un polluted, well oxygenated water.	at outfall only appearing and increasing to normal with distance downstream. -*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. -Tubifex population increases rapidly to a maximum at outfall and then decreases rapidly downstream. - Chironomus population increases rapidly to a maximum at a slightly longer distance from outfall and then decreases rapidly downstream.	increase downstream because oxygen and food become available. -*Asellus* cannot tolerate anaerobic conditions at outfall and therefore dies an migrates to the relatively less polluted wa downstream where it shrives. -The increase in population of Tubifex, a Chironomus is because they are (i) relatively inactive to reduce oxygen dem and (ii) have haemoglobin with very hig affinity for oxygen enabling them to be tolerant to anaerobic conditions. The increase in their population downstream indicates the level of pollution in the wat Tubifex, is the most tolerant to anaerobic conditions, followed by rat tailed maggot and Chironomus. The decrease in population downstream is partly due to predation.

NB. (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 (1) ***volume of incoming degradable wastes in sewage*** (2) ***flow rate of the river*** (3) ***tempera of the water*** (4) ***pH level of the water.(5)existing population of microorganisms.***

(b) Indicator species ***are organisms requiring particular environmental conditions or set of conditions in order to survive and provid information about the environment e.g. can be used in ecological investigations to find out about both the present and past conditions soil and climate.***

(B) ***ADDITION OF INORGANIC CHEMICALS, PLANT NUTRIENTS AND SEDIMENTS INTO LAKES.***

Pollutant	Examples	Main human sources	Harmful effects
(i) ***Plant nutrients***	(i)Nitrate (NO_3^-) (ii) phosphate ($PO_4$3-) and (iii) ammonium (NH_4^+) ions. The nutrient enrichment of water bodies is termed ***eutrophication***	-Raw sewage discharge, detergents and other chemical release from industries, leaching of inorganic fertilizers e.g. NPK from farmland.	(i)Rapid growth of algae and green protists (algal blooming/dramatic first growth of algae) (ii) reduces light penetration in water leading t (iii) Death and decay of algae, which depletes water of dissolved oxygen, killing fish and othe aerobic animals. (iv) Excessive levels of NO_3^- if drank in water lowers the oxygen carrying capacity of blood and kill unborn children and infants **("blue bal syndrome").**
(ii) ***Sediment***	(i) soil (ii) silt	Land erosion	Can (i) cause turbidity / cloudiness in water; light penetration is reduced therefore reduce photosynthesis, (ii) settle and destroy feeding and spawning grounds of fish, (iii) clog and fil water bodies, shortening their lifespan (iv) disrupt aquatic ecosystems (v) carry pesticides bacteria and other harmful substances into water.
(iii***) Inorganic chemicals***	(i) acids, (ii) compounds of toxic metals like lead (Pb), mercury (Hg), arsenic (As) and selenium (Se) and (iii) salts e.g. NaCl in ocean water	Surface runoff, industrial effluents and household cleaners	(i)Drinking water becomes unusable for drinking and irrigation (ii) Lead and Arsenic damage the nervous system, liver and kidneys (iii) they harm fish and other aquatic life (iv) they lower crop yields (v) they accelerate corrosion of metals exposed to such water.

C. ***HEAT (THERMAL) POLLUTION***

Main human sources

Use of water as a coolant in industrial processes e.g. electricity generating plants.

Harmful effects

1) Lowers dissolved oxygen levels since solubility of most gases reduces with temperature.
2) Make aquatic organisms more vulnerable to disease, parasites, and toxic chemicals.
3) When a power plant shuts down for repair or opens, fish and other aquatic organisms adopted to a particular temperature range can be killed by the abrupt change in water temperature. This is known as **thermal shock**.
4) Some aquatic animals may migrate to water with favorable temperature.

Note:

Effects of eutrophication are more severe in water bodies where thermal pollution occurs because of;

1) Increased decomposition of organic matter and metabolism, which raise the demand for oxygen by higher organisms.

Questions

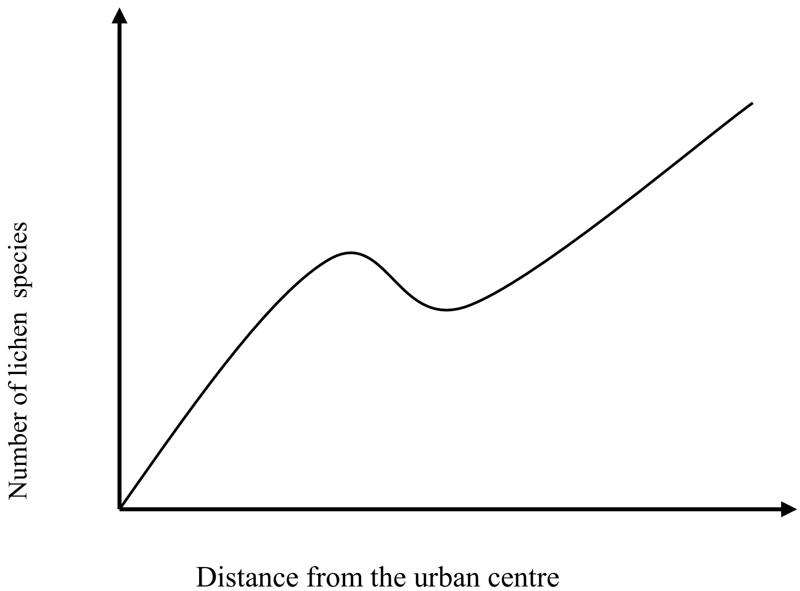
1.What are advantages and disadvantages of biological rather than chemical control of eutrophication?

Organisms live in their environment all the time; their presence (or absence) reflects the suitability of that environment for their living requirements at all times. A short-lived but severe pollution incident occurring at night would be reflected by the absence of sensitive organisms long after visible and chemical evidence of the pollution incident had disappeared. Biological indicators can therefore be a mor sensitive and representative reflection of environmental conditions. Chemical monitoring all the time can only be done for small water cou e.g small rivers , streams and remote areas. It also requires much time-consuming and, in the long term, expensive laboratory analysis Biological control requires reasonable expertise at identification and is also affected by seasonal factors.

2.(a) **State three ecological problems which arise from accumulation of domestic waste in urban communities.**

(b) Give two ways of reducing domestic waste in urban communities

(c.) The figure below shows the lichen species along 20km transect from the urban centre.



(i) Explain the trend in the lichen species with distance from the urba centre.

(ii) Suggest an explanation for the observed number of lichen species a a distance of 10km from the urban centre.

3. (a). **Describe the factors which influence the concentration of dissolved oxygen in a river.**

(b). Explain the presence nor absence of those organisms may be used as indicators of the concentration of dissolved oxygen

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? 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;
- i) Special creation theory
- ii) Spontaneous theory
- iii) Cosmozoan theory
- iv) Steady state theory
- v) Biochemical theory

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:
Suggested that life arose from nonliving matter on numerous occasions and it was prominent and prevalent in ancient Chinese.
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 Helment 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;

i) Spontaneous generation of life under the present day environmental conditions is not possible.
ii) 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
iii) 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.
iv) 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.
v) 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:

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.

Criticism/short comings of 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,
Lamarck however had his contribution towards 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.

DARWIN'S THEORY OF EVOLUTION (evolution through natural selection)

Charles Darwin visited Galapagos Archipelago islands and studied the finches which inhabited each of the island.
While they all had a 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.
The essential features of Darwin's theory included:

1. ***Over production of offsprings.*** He believed that all organisms produced a large number of offsprings which 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.
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 (N/S)

- 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

Exclusive:

Bishop Samuel Wilberforce Vs prof Thomas H Huxley; if he traced his decency from a monkey through his grandies - bishop. "I would rather have a monkey for an ancestor than being connected with man who uses expensive gifts to obscure the truth."- Prof.

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 hanger. The long necked giraffes survived and produced the long necked giraffes.

Modern theory of evolution (Theory of organic evolution)

With the contemporary evidence from research in genetics and molecular biology, the theory of evolution as stared by Darwin and Wallace was modified into what currently is known as **Neo-Darwinism.** This is the theory of organic evolution by n/s of genetically acquired 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:

i) Establish the fact that evolution has taken place in the past (past evolution)

ii) Demonstrate a mechanism which result in evolution (natural selection of genes)

iii) 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.

N.B: Neo-Darwinism may be defined as ***the theory of organic evolution by natural selection of inherited characteristics.***

The debate these days is not so much about whether evolution takes place but about how it takes place by natural selection of randomly generated mutation.

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.

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.
S.q Explain how n/s can lead to speciation

Types of natural selection

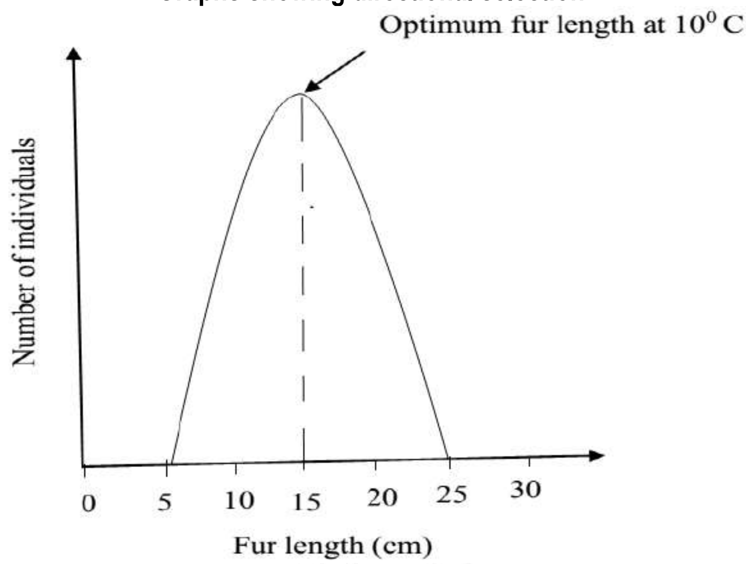
They are directional selection, stabilizing selection and disruptive selection.

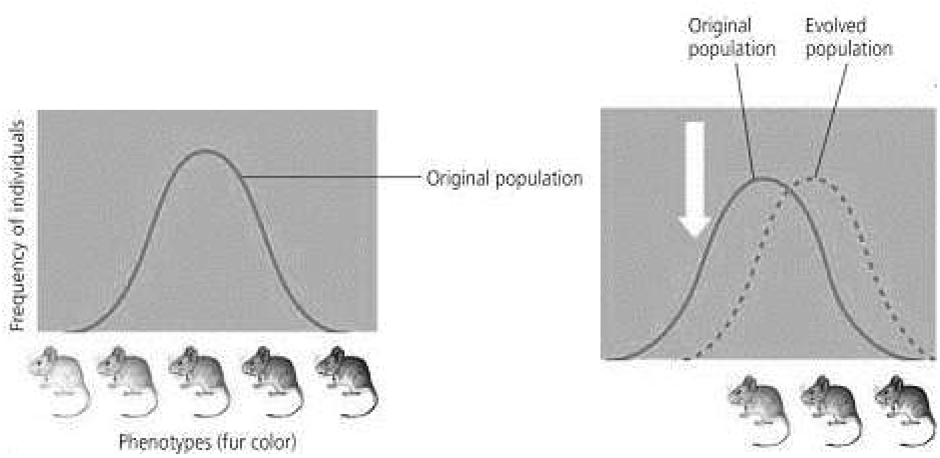
Directional selection

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 directional selection (progressive selection).
When environmental conditions change, there is a selection pressure on the species causing it to adapt to new conditions.
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 anti-biotics and selective breeding are examples of the operation of directional selection.

Graphs showing directional selection





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.

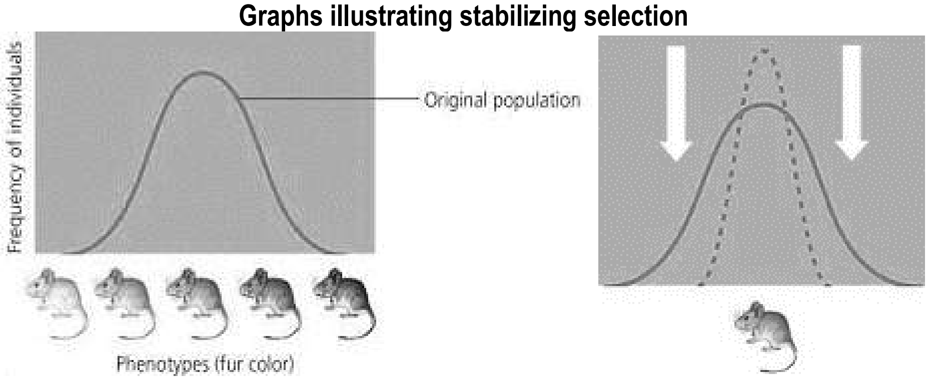
Stabilizing selection occurs in all population and eliminates extremes hence reducing variation in the population, thus no opportunity for evolutionary checkup. E.g. in the earlier example, it was seen that at 10⁰C there was an optimum fur length of 15cm. Individuals within a population however had a range of fur length ranging from 5cm to 25cm under normal climatic circumstances, the average temperature varies from 1 year to the next.

In a warm year with an average temperature of 15⁰C, 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 10⁰C 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.

Like ways, the absence of colder years would reduce the number of long haired individuals. The mean fur length would remain at 15cm but the distribution curve would show a much narrow range of length.

Graphs illustrating stabilizing selection



When the environmental temperature constantly remains the same (10⁰C), 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.

Disruptive selection

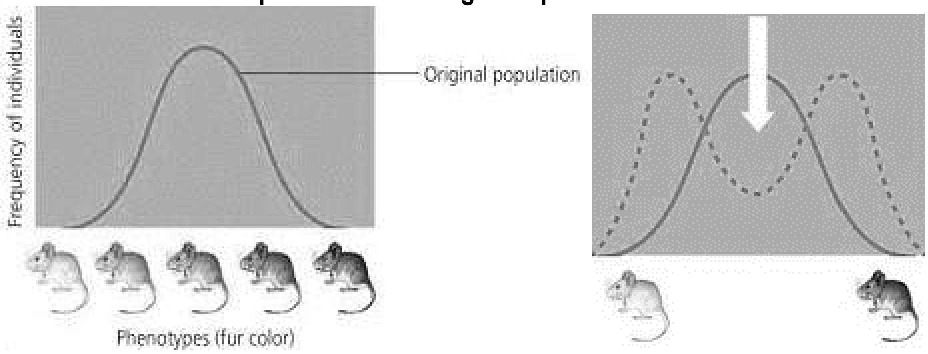
When natural selection favours the phenotype towards the extremes and selects against those near the mean, it is the reverse of stabilizing selection and may lead to splitting of a single gene pool into two hence two different species may arise (speciation) hence it is one of the agents of quick speciation.

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 5⁰C in winter and 15⁰C 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 20cm at an environmental temperature of 5⁰C while the other of 10cm optimum length at 15⁰C.

It's possible that the group with 20 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

Graphs demonstrating disruptive selection



NB: Disruptive selection may result into a population expressing two distinct phenotypes; this is referred to as polymorphism

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 and the existence of different forms of land snail *Cepaea nemoralis.*

There are two types of polymorphism; balanced/stable and transient polymorphism

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.

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.

Examples include the following.

- ✓ Insects resistance to insecticides, like flies and mosquitoes to Dichlorodiphenyltrichloroethane (DDT)
- ✓ Pests resistance to pesticides
- ✓ Heavy metal tolerance in grass and other plants
- ✓ Antibiotic resistance by pathogens e.g. bacteria to penicillin and methycilin
- ✓ Resistance to antimalarial drugs

How does the resistance arise?

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

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

NB: The most important example of n/s in action is illustrated by industrial melanism

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 (*Bistonbetularia)* are known to occur in two phenotypic forms (polymorphic) namely; *Bistonbetularia typica* and *Bistonbetularia 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 therefore had a higher selective advantage under a directional selection pressure provided by selective predation, which eliminated the light forms in favor of the dark forms. Over time, the relative numbers of the dark forms increased gradually while those of the light forms decreased; this is referred to as **industrial melanism.**

It is also a good illustration of transient polymorphism. The two forms can still interbreed successfully and are therefore of the same species.

Question: Explain the term industrial melanism in a peppered moth?

It is a process that led to evolution of melanic form of moths which took place during industrial evolution or development through natural selection in a way that mutant forms never appeared before the light background thus eaten by the birds. Industrial evolution led to a dark/black back ground thus the black moths which were favoured were not eaten. Therefore black moth became dominant and many.

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 (hybrid).

EVIDENCES OF EVOLUTION

These include;

1. Paleontology
2. classification
3. Geographical distribution
4. Comparative anatomy
5. Comparative embryology
6. Comparative bio chemistry

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”***(Haeckel)***.** 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

Co-evolution is the joint change of two or more species in close interaction **Predators** and their **prey** sometimes co evolve; parasites and their hosts; plant-eating animals and the plants upon which they feed also coevolve.

Another example of coevolution is between **plants and the animals that pollinate them**.

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:

i) A species originates in a particular area.
ii) Individuals continuously disperse to avoid over-crowding.
iii) As they encounter new environments as a result of dispersal, they adapt to meet the new conditions which is termed as adaptive radiation.
iv) Climatic topographical and other changes create barriers between the new varieties and their ancestors.
v) 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.

POPULATION GENETICS

Population genetics is the branch of biology that deals &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.

Some biologists believe that macroevolution results from a build-up of small changes due to microevolution. One common **misconception** about evolution is that individual organisms evolve. It is true that natural selection *acts* on phenotypic x-tics of individuals to determine the fate of genotype.

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.**

TERMS USED:

A population is a group of organisms of the same species living together in a given habitat at a given time.

A species refers to a group of organisms with similar features which can interbreed successfully to produce fertile offsprings.

Gene pool; Refers to the total variety of genes and alleles present in a sexually reproducing population. A population whose gene pool shows consistent change from generation to generation is said to be undergoing evolutionary change.

NB: A static gene pool is one where genetic variation is inadequate to bring about evolutionary change.

Allele frequency

Allele frequency refers to the total number of copies of a given allele expressed as a percentage of the total number of alleles for that gene in a population.
For example in human beings, production of body pigments is determined by a dominant allele while the recessive allele results into no pigment production (albinism). The frequencies of the dominant and recessive alleles are 99% and 01% respectively. Since the total percentage is 100%; 99 + 01 = 100. However, frequencies in population genetics are usually represented as decimals rather than percentages or fractions,
$\rightarrow$ 0.99 + 0.01 = 1.00.
Mathematically; if we let **p** and **q** to represent the dominant and recessive allele frequencies respectively,
Then **p + q = 1.. (I)**
From equation (i) above; if the allele frequency of either allele is known, the allele frequency of the other can be determined. E.g. If the allele frequency of the recessive allele is 25%,
Then q = 0.25. Using p + q = 1, p = 0.75.

Genotype frequency

Genotype frequency refers to the total number of individuals carrying a particular genotype expressed as a percentage of the total population.
In most populations, it's only possible to estimate the frequency of two alleles in a homozygous recessive state as this is the only genotype which can be directly observed phenotypically. E.g. 1 person in 10000 is albino. Albinism is known to be a recessive character, for the person to be an albino, they must be possessing two copies of the defective allele (homozygous recessive). 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's principle

It states that **"*The allele and genotype frequency of a large sexually reproducing population remains constant from generation to generation provided that disruptive factors like mutation and selection do not act*"**
The gene pool of such a population remains static and the population is said to be in Hardy-Weinberg equilibrium, it cannot undergo evolutionary change.
For this principle to hold, the following factors must be fulfilled:
i) Provided the population is sufficiently large that no genetic drift occurs.
ii) Mating should be random such that no sex selection occurs.
iii) All genotypes should be equally fertile such that there is no selection or genetic load.
iv) No mutations should occur as these tend to increase genetic diversity.
v) Provided generations do not overlap.
vi) There should be no emigration or immigration i.e. there is no gene flow between populations.
vii) Natural selection should not act, as this would favour some genotypes over others.
NB: In prevalence of the above factors, the frequencies of all alleles and genotypes will remain constant over generations. In case all or at least one of the above factors is reversed, the frequencies are prone to change and the stability of the population is upset. This initiates evolutionary change.

Hardy-Weinberg equation is a mathematical relationship between the frequencies of alleles and genotypes in a population. This can be used to calculate genetic changes in populations.
Considering a population with a certain gene occurring in two allelic forms, one homozygous for a dominant allele **A** and the other for a recessive allele **a**; all the F1 off springs will be heterozygous (**Aa**).
If the frequency (probability) of ***A* = *p*** while that of ***a* = *q*.** The results from a cross between two F1 organisms would be as follows:

F1 phenotypes	Heterozygous	*X*	Heterozygous
F1 genotypes	Aa		Aa
Gametes	A a		A a

Random fertilization	AA	2Aa	aa
	(p^2)	(2qp)	(q^2)

Therefore:
p^2 = homozygous dominant
2pq = heterozygous
q^2 = homozygous recessive
Genotype frequency (sum of the 3 genotypes) = 1
$p^2 + 2pq + q^2 = 1$
In mathematical terms p+q=1 is the mathematical equation for probability and $p^2 + 2pq + q^2 = 1$ is the binomial expansion of that equation i.e. $(p+q)^2$.
That is allele frequency is p+q=1 and genotype frequency is $p^2 + 2pq + q^2 = 1$

Examples

1. One person in 10000 is albino, i.e. the albino genotype frequency is 1 in 10000. Since albino is recessive;
   $q^2 = \frac{1}{10\,000} = 0.0001$
   $q^2 = 0.0001$
   $q = \sqrt{0.0001} = 0.01$
   Therefore the frequency of the albino allele is 0.01 or 1%
   Since p+q = 1
   p = 1 - q
   p = 1 – 0.01 = 0.99
   Therefore the frequency of the dominant allele in the population is 0.99 or 99%
   Since p = 0.99
   $p^2 = 0.99^2 = 0.9801$
   Therefore the frequency of the homozygous dominant genotype is 0.9801 or 98%
   2pq = 2x0.99x0.01
   = 0.0198
   The frequency of heterozygous genotype is 0.0198 or 2%
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

Factors responsible for changes in allele frequencies of the population

The 4 major sources of genetic variation within a gene pool are;

- Crossing over during meiosis
- Independent segregation during meiosis
- Random fertilization
- Mutation

Others are explained below:

Natural selection:

This tends to favour alleles and genotypes that produce environmentally adapted phenotypes, leading to increase in their frequencies while those that are less adapted to the environment are eliminated hence their frequencies decline.

Gene flow:
It refers to the movement/continual interchange of alleles from one population to another as a result of interbreeding among the members of the two populations. This results into introduction of new alleles hence from other populations leading to change in the allele frequencies of the population. However, gene flow is said to be conservative to evolutionary change in the long run. It tends to ensure uniform distribution of alleles in all populations which reduces genetic variation and increases uniformity among organisms as all populations share a common gene pool, this limits the action of n/s. For this reason, interrupting gene flow is a prerequisite to evolutionary change and speciation.

Mutations:
Mutations are random occurrences which change the genetic constitution of organisms. They greatly increase genetic diversity, where advantageous mutations are favoured by natural selection and disadvantageous ones are phased out.

Non-Random Mating:
This occurs when there is sexual selection (a mechanism on non-random mating). It occurs when the presence of one or more inherited characteristics increases the likelihood of successful fertilization. In such cases, only organisms having certain characteristics will have high chances of reproducing hence passing on their traits to next generations, while those without such features will have reduced reproductive potentials. Only some alleles will be passed to next generation leading to change in their frequencies
Examples include eye colour in drosophila (females prefer red-eyed males), colour patterns in insects and birds, petal size and colour in flowers etc.

Genetic drift:
This refers to the change in the gene frequencies within a population as a result of chance rather than by n/s
Although chance events occur in populations of all sizes, they alter allele frequencies substantially only in small populations.
A phenomenon associated with genetic drift is the ***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 (as it occurs in the founder population).
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,*** (named so because the population passed through a restricted path
Random genetic drift may lead to the following;
- ✓ Total loss of some alleles from the population, due to death of the few individuals carrying such alleles
- ✓ Total extinction of the population
- ✓ The population becoming much better adapted to the environment
- ✓ Wide divergence of the population from the parent population, and all these occur just by chance rather than n/s.

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.

Genetic load:
This is the existence within the population of disadvantageous alleles in heterozygous genotypes.
Very many disadvantageous alleles are able to exist in populations in heterozygous forms as in this form they are rarely expressed phenotypically for possible elimination by environmental selection, for example albinism, colour blindness, sickle-cell anemia, etc.
The maintenance of fairly high frequencies of a recessive allele which may be potentially hazardous in a homozygous recessive state is referred to as the **heterozygous advantage**.

The most obvious example is illustrated by the sickle-cell trait.
Sickle-cell trait is a condition when an individual has one copy of the normal allele for hemoglobin production and a recessive allele for abnormal hemoglobin. Such heterozygotes/carriers have both normal and sickle-shaped red blood cells and this is referred to as sickle-cell trait.
Sickle-cell carriers have consistently shown a high resistance to malaria much more than both the normal and the sick. This therefore confers a selective advantage to the heterozygotes leading to consistently high frequencies of the sickle cell allele especially in such areas as the tropics where malaria is prevalent.
Explanation The carriers have both normal and sickle-shaped red blood cells, the former contain very low levels of oxygen due to abnormal hemoglobin while the latter contain high oxygen levels. This makes it difficult for the plasmodia parasites to survive in the low oxygen environments in sickle cells and to adapt to constantly changing oxygen contents. Some of them die while others are effectively eliminated by the body defense system before establishment of the disease leading to resistance.

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, its 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 n/s, 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 refers to the existence of biological factors (barriers) that impede members of the same or different species from interbreeding successfully
Within a population of one species, there are *groups of individuals which breed with one another. Each of these breeding sub units is called a* **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.
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/reproductive isolation:
This is where two groups of individuals cannot breed due to a number of reasons connected to their physiological nature.
i) The genetalia 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)***

Isolating mechanisms are classified as **prezygotic** mechanisms (Which are barriers that may lead to formation of hybrids) or **post zygotic** mechanisms (barriers that prevent hybrids from reproducing)
Post zygotic mechanism (barriers that occur after fertilization)
- ✓ ***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
- ✓ ***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)
- ✓ ***Hybrid breakdown***: The F1 hybrids are fertile but the F2 hybrids and their back crosses are infertile E.g. hybrid formed between *sp* of cotton.

"***The deep emotional conviction of the presence of a superior reasoning power, which is revealed in the incomprehensible universe, forms my idea of God" Albert Einstein.***

MOVEMENT IN AND OUT OF CELLS

The plasma membrane isolates the inside of the cell protoplasm from its extracellular environment. Materials are exchanged between the protoplasm and the extracellular environment across the plasma membrane. The plasma membrane is selectively permeable and allows transport of materials across it.

Substances move in and out of cells by the following processes:

a. Simple diffusion
b. Facilitated diffusion
c. Osmosis
d. Active transport
e. Endocytosis
   i. Phagocytosis
   ii. Pinocytosis
   iii. Receptor mediated endocytosis
f. Exocytosis

The transport of substances is important to;

a) Supply cells with oxygen for respiration and raw materials for anabolism (synthesis of biological molecules)
b) Regulate the pH and solute concentration for maintaining a stable internal environment for enzymes to function optimally
c) Excrete toxic waste substances
d) Secrete useful substances for cell activities

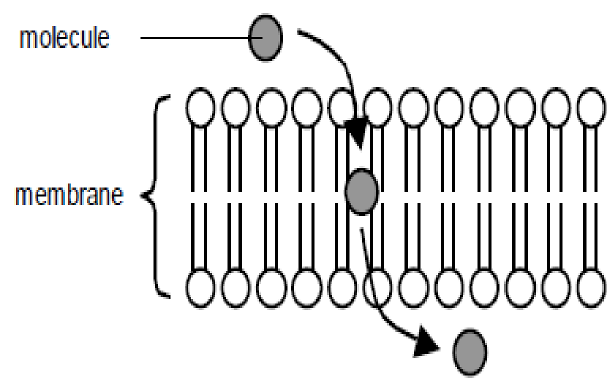
Note: the transport of substances across the cell membrane takes place by two major fundamental processes.

SIMPLE DIFFUSION

Diffusion is the random movement of ions or molecules from a region where they are at higher concentration to a region of lower concentration. That is, to move down a concentration gradient until equilibrium is reached.

The phospholipid bilayer is permeable to **very small** and **uncharged molecules** like oxygen and carbon dioxide. These molecules diffuse freely in an out of the cell through the phospholipid bilayer. **Hydrophobic substances** (lipid-soluble) e.g. steroids, can also diffuse through. These non-polar molecules do not require the aid of membrane proteins (channel or carrier) to move across the cell membrane.

Even though water is an extremely small, its **polar** therefore it does not move across the cell membrane by simple diffusion.



A charged molecule or atom and its surrounding shell of water, find the hydrophobic layer (non-polar) of the membrane more difficult to penetrate thus the lipid bilayer partly accounts for the membrane's selective permeability by preventing very large molecules and small polar molecules of ions to move across it.

The rate of diffusion depends upon;

The concentration gradient
This refers to the relative concentration on either side of the membrane or between two points. The greater the difference between the points, the faster the rate of diffusion and if the difference is less, the slower the diffusion rate. Therefore a reduced concentration gradient causes a reduced rate of diffusion and vice versa.
Temperature
When increased, temperature causes an increased rate of diffusion because the particles acquire increased kinetic energy which causes increased speed of movement hence increased rate of diffusion.
At low temperatures, the kinetic energy is very low and the speed of movement by particles is equally very low.
Surface area
The larger the surface area over which the molecules are exposed, the faster the rate of diffusion.
Distance over which diffusion takes place

This is the distance over which the molecules are to travel i.e. the surface thickness across which the molecules move. The greater the distance the lower the rate of diffusion

Size and nature of diffusing molecules

The smaller the size of the diffusing particles, the faster they diffuse i.e. smaller particles move very fats while the large ones will move slowly.

Permeability

The more porous a surface is, the greater the number of particles that diffuse through it hence the greater the rate of diffusion

Significance of diffusion

a) It's a means by gaseous exchange occurs in plants and animals e.g. in plants diffusion of gases occur through the stomata and in animals, in gills of fish, , the skin and buccal cavity of amphibians alveoli of reptiles, mammals and birds.
b) Absorption of certain digested food materials e.g. glucose in the ileum.
c) A means of exchange of materials between blood in capillaries and the tissues
d) During formation of the nerve impulse, sodium ions diffuse into the nerve cells facilitating generation of nerve impulses and ensures transmission of nerve impulses from one neurone to another i.e. diffusion facilitates synaptic transmission
e) It ensures excretion of waste products e.g. ammonia in fresh water fishes
f) It's the main means of transportation of materials within the cell's cytoplasm e.g. in unicellular organisms
g) Absorption of mineral salts by plants from the soil is effected by diffusion as one of the mechanisms

In order maximize the rate of diffusion, tissues where diffusion occu attained special adaptations. These include;

1. The lungs are ventilated by the respiratory tract (trachea, bronchus, bronchioles) which maintain a steep concentration gradient between the lung alveoli and blood in the capillaries.
2. Respiratory surfaces like the lung alveoli and intestine epithelial lining possess a rich supply of blood vessels which transport away the diffusing materials hence maintaining a steep gradient which sustains the fast diffusion
3. Diffusion surfaces e.g. lung alveoli and intestines (ileum) are covered by a thin epithelium lining which reduces the distance over which diffusion takes place.
4. The epithelial lining covering the alveoli and rumen of the ileum is very permeable to allow molecules to travel across them
5. In lungs there are numerous alveoli and in the ileum infoldings known as villi and microvilli which is coupled with a very long ileum also increases the surface area along which particles move into cells hence increase the rate of diffusion.
6. Flattened body e.g. platyhelminthes (flatworms) which increases the surface area for movement of materials by diffusion
7. Some organisms are of small size e.g. unicellular organisms which increases the surface area to volume ratio of the surface that permits increased rate of diffusion

FACILITATED DIFFUSION

This refers to the transport of molecules and ions across a membrane by specific transport proteins, carrier and channel proteins, found within the membrane in the direction of lower concentration of the ions or molecules i.e. in favour of the concentration gradient (difference) of ions.

Facilitated diffusion is a faster form of movement than simple diffusion and it involves transport of **large polar molecules** and **ions** that cannot be transported by simple diffusion.

Trans-membrane proteins form channels or act as transport proteins to facilitate and increase the rate of diffusion across the semi permeable membrane. The transport protein molecules involved in facilitated diffusion include channel and carrier proteins.

Facilitated diffusion by carrier proteins

Some small hydrophobic organic molecules e.g. amino acids and glucose pass through the cell membrane by facilitated diffusion using carrier proteins. These proteins are specific for one molecule, so substances can only cross a membrane if it contains the appropriate proteins.

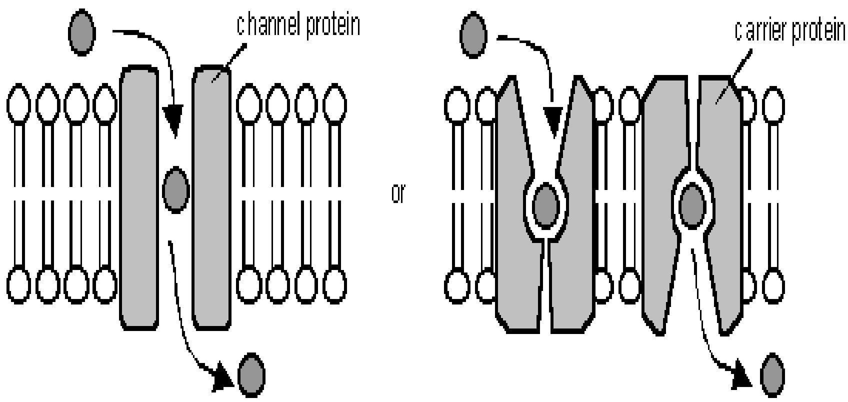
The transport of glucose across the plasma membrane of fat cells, skeletal muscle fibres, the microvilli of the ileum mucosa and across proximal convoluted tubule cells of vertebrate kidneys is brought about by a change in the shape of the carrier protein once the glucose molecule bonds to it.

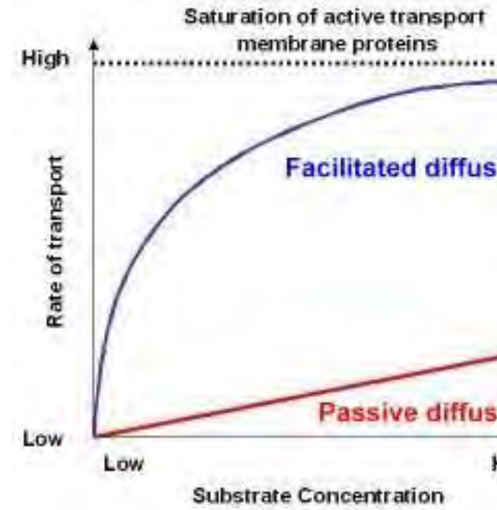
Carrier proteins alter the conformation of the carriers moving the solute across the membrane as the shape of the carrier changes. The solute molecule is released on the other side of the

Facilitated diffusion by protein channels:

These trans-membrane proteins form water-filled functional pores in the membrane. This allows charged substances, usually ions, and polar molecules to diffuse across the cell membrane. Most channels can be gated (opened or closed), allowing the cell to control the entry and exit of the ions, these include the ligand-gated and voltage gated channels. The proteins form specific water filled hydrophilic channels that permit the diffusion of various ions such as K^+, Na^+, Ca^{2+},Cl^-,HCO^-_3.

There are also specialized channels for water known as **aquaporins** found in both plant and animal cells. The aquaporins speed up the rate of diffusion of water molecules





Comparison between simple and facilitated diffusion

Differences

Simple	Facilitated
The rate of diffusion depends on the concentration gradient	The rate of diffusion does not depend on the concentration gradient
Diffusion can occur in either direction	Diffusion occurs in only one direction
Similar molecules diffuse at the same rate	Specific molecules diffuse faster than others
does not require special transport proteins	Occurs via special channels or carrier proteins

Similarities

Both move molecules from a region of high concentration to a region of low concentration through a partially permeable membrane.

ACTIVE TRANSPORT

It is the movement of molecules or ions across a cell membrane against their concentration gradient aided by the protein pump with specific binding sites, involving the expenditure of energy. Cells which carry out active transport have a high respiratory rate and a large number of mitochondria to generate a high concentration of Adenosine Tri Phosphate (ATP). The energy from ATP can be directly or indirectly used in active transport.

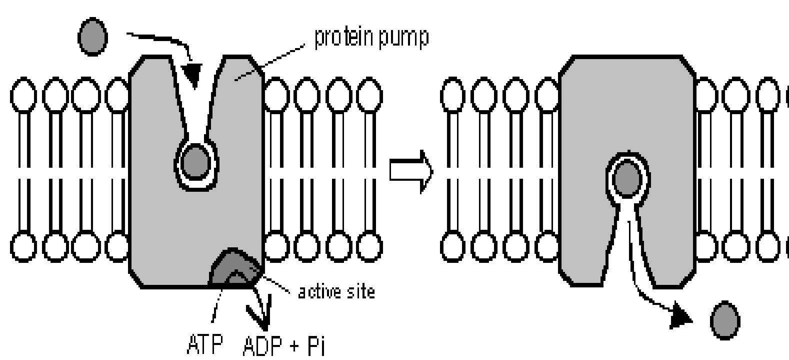
Active transport can be slowed or inhibited by respiratory poisons (inhibitors) e.g. cyanide or lack of oxygen.

Mechanism of active transport

This can be direct active transport if the energy from ATP is used directly to transport the substances, ions or molecules, or it can be indirect active transport if the energy is not directly used to transport a substance across a membrane.

a) **Direct active transport (e.g. Na^+- K^+ pump)**

ATP is hydrolysed and the binding of the phosphate group to the protein pump changes the protein conformation. The protein pump actively transports three sodium ions (3 Na^+) out of the cell for every two potassium ions ($2K^+$) pumped against their concentration gradient into the cell. This generates a difference in ionic charge on the two sides of the membrane which is important for the transmission of nerve impulses. The Na+ gradient is also used in the coupled uptake of solutes such as glucose into the cells against its concentration gradient.

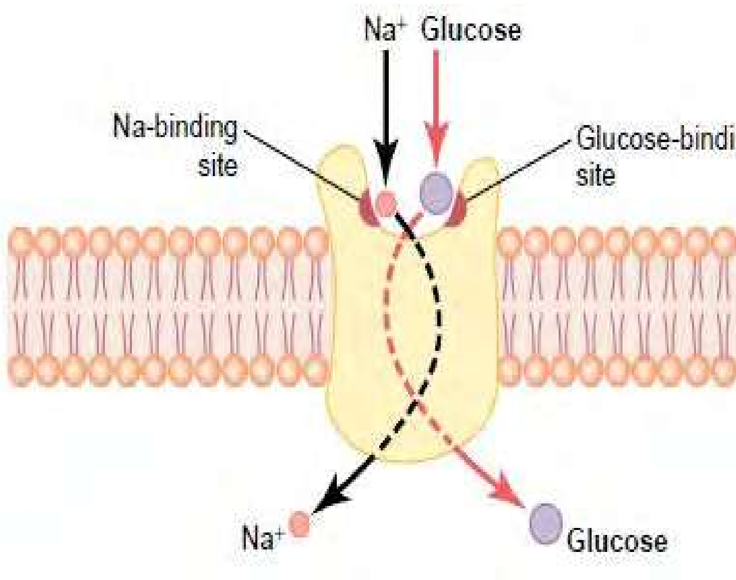


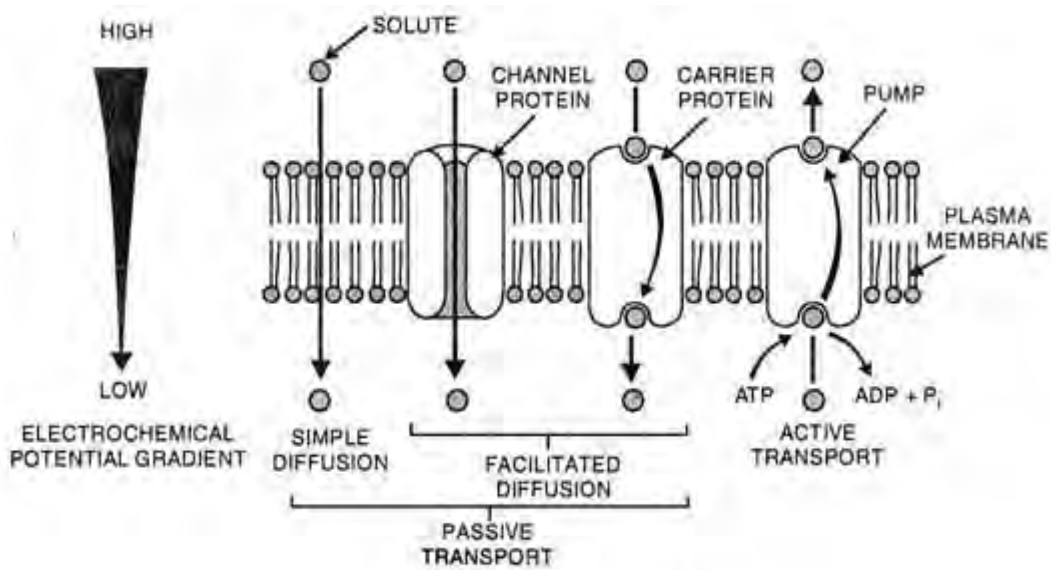
Indirect active transport mechanism (secondary active transport)

This is also known as co-transport e.g. the coupled uptake of glucose into cells lining the ileum in mammals where glucose and Na+ ions are absorbed into the cells. Sodium ions down a concentration gradient while the glucose molecules against the concentration gradient.

In co-transport of Na^+ and glucose, ATP is used by the protein pump to pump Na^+ out of the cell creating a Na^+ concentration gradient.

The Na^+ and glucose molecules then bind to trans-membrane protein (carrier protein), also called co-transport proteins/coupled transport proteins. They are then moved by the proteins inside the cells i.e. the Na^+ moves down its concentration gradient while the glucose molecules moves down against its concentration gradient.

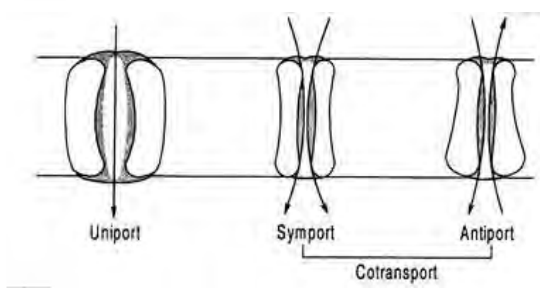




Types of membrane proteins involved in active transport

Three main types of membrane proteins exist;

a) **Uniport carriers**. They carry (transport) a single ion or molecule in a single direction.
b) **Simport carriers**. They carry two substances in the same direction.
c) **Antiport carriers**. They carry two substances in opposite directions.



The factors required for active transport to take place;

i. **Temperature**
Increase in temperature increases the rate of transport of substances by active transport, so long as the increase in not above the optimum. The increase in temperature makes respiratory enzymes more active, having their speeds of movement increased (kinetic energy) with that of substrate molecules which results into collisions of molecules at a faster rate thus forming enzyme substrate complexes that form products. In this case, ATP is required to power active transport.
At very high temperatures, above the optimum, respiratory enzymes are denatured in the carrier proteins in the membrane. This reduces the rate of active transport.
At very low temperatures, below the optimum, the respiratory enzymes together with the carrier proteins are inactive and this reduces the rate of active transport.

ii. **Availability of oxygen**
Oxygen is required for aerobic respiration to generate ATP. Increase in oxygen concentration results into increased rates of active transport as more ATP molecules are available for the process. In circumstances of very little or no oxygen, the rate of active transport is reduced since in the case of anaerobic respiration, there's very little or no ATP molecules available for active transport

iii. **Concentration of respiratory substrates e.g. glucose**
If the concentration of respiratory substrate is increased, the rate of active transport also increases and if it is lowered, the rate of active transport lowers. This is because increase in the amount of the substrate increases the rate of ATP generation during respiration. If the amount of substrate is reduced, the rate of ATP generation is also lowered.

Importance of active transport

a) It is a means of absorption of food materials in the mammalian gut
b) It is the means of absorption of mineral salts by plant root hairs and the root epidermal cells of the peliferous layer
c) It facilitates the excretion of waste materials from the cells to the extracellular fluids against a concentration gradient e.g. excretion of urea
d) It is important in muscle contractions and relaxations where there's active pumping in and out of calcium ions inside the cytoplasm (sarcoplasm) of the muscle.
e) It is used in the loading and unloading of materials in the plants phloem tissue which creates pressure differences in the phloem tissue that maintain mass flow of materials.
f) Active transport is vital in transmission of nerve impulses along nerve cells where it creates a membrane action potential using the potassium-sodium pumps.
g) It plays a part in the opening and closure of stomata where differential pumping of potassium ions between the guard cells and neighboring subsidiary cells lead to turgidity changes hence causing stomatal movements (opening/closure).

Note: metabolic poisons (inhibitors), inhibit the enzymes and carrier proteins required to bring about active transport by either changing the active sites/binding sites for the enzymes/carrier proteins for the molecules to be transported. The poisons also inhibit ATP synthesis hence cutting off the source of energy needed to affect the active transport.

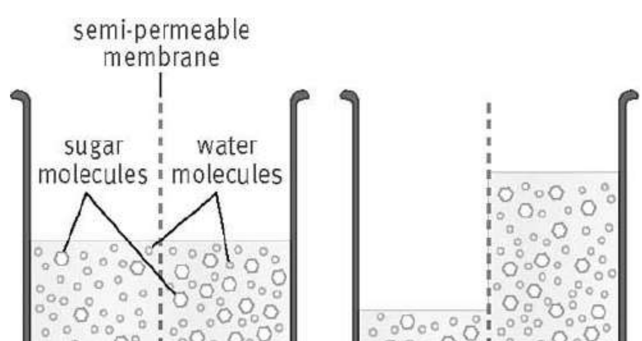
OSMOSIS

This is the passive movement of water molecules, across a partially permeable membrane, from a region of lower solute concentration to a region of higher solute concentration. It may also be defined as the passive movement of water molecules from a region of higher water potential to a region of lower water potential through a partially permeable membrane.

A selectively permeable membrane is one that allows unrestricted passage of water molecules but no passage of solute molecules.

Different concentrations of solute molecules lead to different concentrations of free water molecules on either side of the membrane. On the side of the membrane with a high concentration of free water molecules (low solute concentration), more water molecules will strike the pores in the membrane in a given interval of time, water molecules pass through the pores resulting in net diffusion of water molecules from the region of high concentration of free water molecules to the region of low concentration of free water molecules.

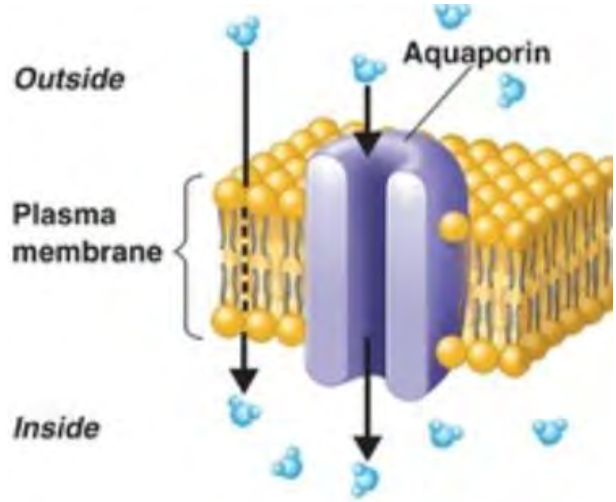
A net flow of free water molecules is maintained because in the side with more solute molecules, water forms hydrogen bonds with solutes which are charged or polar forming a hydration shell around them in



Osmosis and aquaporins

In living cells, transport of water across the cell membrane is facilitated by channel proteins called aquaporins which have specialised channels for water.

Water molecules are small but they are polar and therefore cannot interact with hydrophobic phospholipid layers easily and therefore diffusion through the lipid bilayer is extremely rare or not there at all, and water molecules can quickly enter with ease through aquaporins in the cell membrane.



(d) Osmosis through the lipid bilayer (left) and an aquaporin (right)

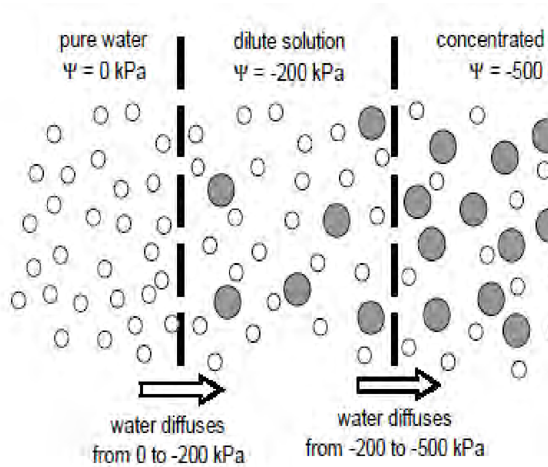
WATER POTENTIAL

This is the net tendency of any system to donate water to its surroundings. The symbol for the water potential is Ψ, the Greek l psi, and is usually measured in kilopascals (Kpa).

The water potential of pure water is zero pressure units and any addition of solute to pure water reduces its water potential and makes its value negative i.e. pure water has the highest water potential.

In pure water or dilute solution with very few solute molecules, the water molecules have a *high free kinetic energy* and can move very freely. A dilute solution therefore has a higher water potential than a concentrated solution. This is because the movement of the water molecules is restricted by the attraction between solute and water molecules i.e. there are fewer water molecules with a *high kinetic energy* to move across the membrane. The greater the concentration of solutes, the more negative is the water potential.

Water potential of a plant cell ψ_w, is the algebraic sum of its wall pressure (pressure potential) ψ_p and its osmotic (solute) potential



A concentrated solution has a low water potential and water therefore moves down a water potential gradient. The water potential of pure water Ψ_W at atmospheric pressure is arbitraily given the value of 0 Kpa.

$\Psi_W = 0$ Kpa.

The water potential of solutions is therefore less than 0 i.e $\Psi_{solution} < 0$ Kpa.

SOLUTE POTENTIAL (Ψ_S)

This is the potential or force of attraction towards water molecules caused by dissolved substances (solutes) inside the solution. That is to say, a change in water potential of a system in the presence of solute molecules.

The attraction between solute molecules and water molecules reduces the random movement of water molecules. The addition of more solute molecules lowers the water potential of a solution.

Solute potential/osmotic potential is denoted by **(**Ψ_S) and its equal to 0 for pure water and it is always negative solutes because the forces of attraction between the solute molecules and water molecules reduces the movement of water molecules.

PRESSURE POTENTIAL (Ψ_P)

This is the pressure exerted on a fluid by its surrounding. At any one time, the water potential of a plant is the sum of the solute potential and pressure potential. Pressure potential is usually, though not always, positive.

$$\Psi_W = \Psi_s + \Psi_p$$

Water potential of plant cell	Solute / osmotic potential	Pressure potential

When water enters the cell by osmosis, the pressure of the cytosol builds up, pushing out against the cell membrane. This pressure is called hydrostatic pressure. In blood cells, this pressure builds up pushing the cell membrane against the cell wall. The cell wall begins to resist the swelling caused by the influx of water. The pressure that the cell wall develops is the **pressure potential**. For plants therefore, pressure potential is the pressure exerted on the cell contents by the cell wall and cell membrane.

OSMOTIC PRESSURE AND CELL RELATIONSHIP

Osmotic pressure is the pressure needed to stop osmotic flow. If the membrane is strong enough, the cell reaches an equilibrium, a point at which the osmotic pressure drives water into the cell exactly counterbalanced by the hydrostatic pressure which tends to drive water back out of the cell. However, the plasma membrane itself cannot withstand the large internal pressures and an isolated cell under such conditions would just burst. In contrast, cells of prokaryotes, fungi, plants and many protocists are surrounded by a strong cell wall which can withstand high internal pressure without bursting.

If a cell is surrounded by pure water or solution whose concentration is lower than that of the cell contents, water will osmotically flow into the cell; such a solution with a lower osmotic pressure than that of the cell's cytoplasm is said to be **hypotonic**. If the cell is surrounded by a solution whose solute concentration exceeds that of the cell cytoplasm, water flows out of the cell. In this case the outer solution is said to be **hypertonic** to the cell cytoplasm.If the cell concentration of the cell cytoplasm and the surrounding medium are the same and there would be no net flow of water in other directions and the external solution is said to be **isotonic**.

The osmotic flow of water into the cell is **endosmosis** and the osmotic flow of water out of the cell is **exosmosis**.

OSMOSIS AND PLANT CELLS

Fig 4.5 pg 52 Roberts

A. TURGIDITY

When the external solution is hypotonic, the cell's cytosol have a lower water potential, causing an influx of water into the cells. The water enters into the cells vacuole causing an internal hydrostatic pressure developed by the cell by **osmosis**.

The pressure potential reaches its maximum when the cell wall is stretched to its maximum. At this point, the cell is described as a fully turgid or it has full turgor reached and the water potential at this point equals to 0 i.e. Ψ=0 and no more water can enter the cell.
Turgor pressure plays part in supporting plants and maintains their shape and form of herbaceous plants by being filled with fully turgid cells tightly packed together. It is also responsible for holding leaves in flat and horizontal position.

B. PLASMOLYSIS

When a plant cell is immersed in a hypertonic solution, then its cytosol, the cell decreases in volume as water moves out osmotically from its vacuole. The protoplast shrinks, pulling away from the cell wall and leaving gaps between the cell wall and plasma membrane. A cell in this condition is said to be plasmolysed and the cell is flaccid.
Plasmolysis is the shrinking of a plant cell's protoplast away from the cell wall leaving gaps between the cell wall and the plasma membrane.
When a plant cell is placed in hypertonic solution, it loses water by exosmosis. The protoplast shrinks and pulls away from the cell wall. Also on a dry and hot day, the plant cells lose their way evaporation and the turgor pressure of the plant cells is reduced with the result that the plant drops. The phenomenon is called wilting. This is the dropping of leaves and stems as a result of plant cells losing water exosmotically and becoming flaccid.

PLANT-WATER RELATION

This takes into account of three forces which include;

i. Water potential of the cell sap
ii. Solute potential
iii. Pressure potential

Considering a fully plasmolysed cell which is immersed in pure water, water enters the sap osmotically and the protoplasm begins to expand. As the osmotic influx of water continues, the protoplast goes on expanding until it comes into contact with the cell wall. When this point is reached the osmotic influx of water into the cell starts to be opposed by the inward pressure of the cell wall i.e. pressure potential. In a plasmolysed cell, the water potential of the cell now becomes less negative than the solute potential of the sap equal to/by the amount of the pressure potential.

As the cell continues to expand, the pressure potential of the cell gets steadily greater and the water potential becomes less and less negative. Eventually full turgor is reached, when the cell cannot expand anymore and at this point Ψs (osmotic potential) is exactly outbalanced by the pressure potential (Ψp).

If the solution produces no change within the volume of the cell, it has a solute concentration similar to that of the cell sap or tissue and therefore water potential of the solution equals to the water potential of the cell or tissue. When the strength of the external solution causes the cell just to plasmolyse so that the protoplast just contact the cell wall, this is called **incipient plasmolysis**.

Graphical illustration of a relationship between Ψs (osmotic potential), Ψcell and pressure potential (Ψp) of a plant cell at different stages of turgor and plasmolysis is shown below

Fig 4.6 pg 54 Roberts

In general Ψcell = Ψs (always negative) + Ψ p (always positive)

At total plasmolysis; the vacuole almost disappears, minimum hydrostatic pressure, cell membrane completely not attached to the cell wall. Cell generally small and described as **flaccid**.

At incipient plasmolysis; cell membrane begins to leave cell wall and water is lost from the cell.

At full turgidity; the cell vacuole with maximum volume and no more water can enter.

OSMOSIS AND ANIMAL CELLS

If a human red blood cell is placed in an isotonic solution i.e. 0.9% sodium chloride solution, the cell neither shrinks nor swells. If they are placed in a hypertonic solution i.e. 1.2% sodium chloride, it will shrink and appear crinkled and this is called **crenation**.

If it is placed in a hypotonic solution i.e. 0.5% sodium chloride, it will swell and even burst and this is called **haemolysis**. Haemolysis is due to red blood cells lacking cellulose cell walls which would prevent red blood cells expansion and therefore stops bursting.

ROLE OF OSMOSIS IN LIVING ORGANISMS

1. It is the main form by which root hairs and piliferous layer cells on roots absorb water from the soil
2. Kidney nephrons (tubules) re-absorb water back into the blood stream via the blood capillaries osmotically leading to water conservation in the body hence bringing about osmoregulation
3. In herbaceous plants, osmosis brings about turgidity in plant cells due to presence of cell wall leading to provision of support and shape in a whole plant body.
4. Osmosis causes plant structures (organs) like leaves and flowers to determine their form for example holding the leaf in flat and horizontal position enabling it to trap maximum sunlight.
5. Osmosis bring about opening and closure of petals of flowers and osmosis bring about the opening and closure of stomata in plant leaves when the guard cells become turgid facilitating gaseous exchange in plants.

CYTOSIS

This is a form of active transport involving infoldings or folding of secretions into vesicles or vacuoles which can be moved.

Cytosis involves the contractile proteins in cellular microfilaments and microtubules. Cytosis results in bulk transport of materials into the cell or outside the cell, thus cytosis is divided into two main types i.e.

i. Endocytosis
ii. Exocytosis

Fig 4.22 pg 70 Toole OR Fig 5.23 pg 147 Soper

ENDOCYTOSIS

This is bulk transport of materials inside the cell. It involves a small area of plasma membrane folding inwards to surround a material to be taken in and moves deeper inside the cell. There are three types of endocytosis;

i. Phagocytosis
ii. Pinocytosis
iii. Receptor-mediated endocytosis

PHAGOCYTOSIS (cellular eating)

This is called cellular eating and it involves the cell taking in large solid substances. Phagocytosis involves invagination of cell membrane surrounding of the organism or particle forming a phagocytotic vesicle or vacuole which pinches off the cell membrane and moves into the cytoplasm.

Lysosomes fuse with vacuoles and release hydrolytic enzymes into the vacuole which break down the substances in the vacuole. The protein substances are absorbed into the surrounding cytoplasm across the lining of the vacuole.

Any undigested material may be got rid of by the vesicles of vacuoles moving into the cell surface membrane and fusing with it.

Mechanism of phagocytotic killing by white blood cells

White blood cells form cytoplasmic extensions to form pseudopodia which surround and engulf micro-organisms. Micro-organisms are completely surrounded by pseudopodia to form phagocytotic vesicles or phagosomes which pinch off the cell membrane into the cytoplasm. The phagosome fuses with the lysosome to form a phagolysosome. Inside the phagolysosome are microbes which are broken down by hydrolytic enzymes.

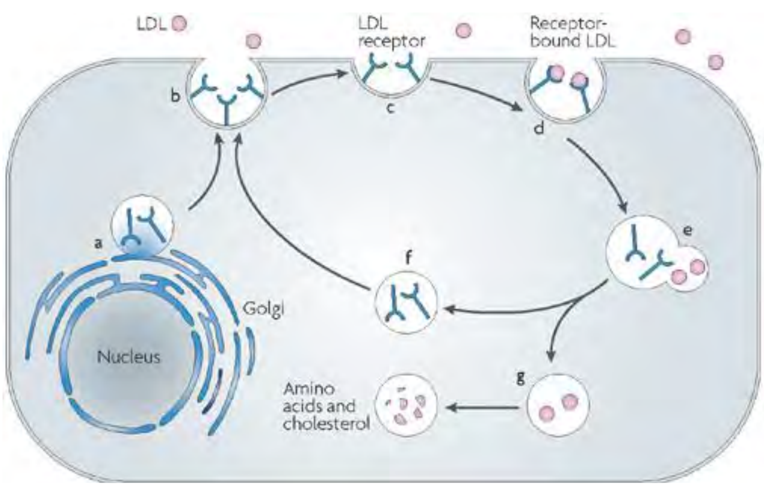
PINOCYTOSIS (cellular drinking)

This is cellular drinking, it is similar to phagocytosis only that the infoldings forming the vesicles are much smaller. Liquid and large macro molecules such as proteins are taken in via small pinocytotic vesicles. The process is highly specific involving the binding of the molecules with corresponding receptor molecules in the plasma membrane.

RECEPTOR MEDIATED ENDOCYTOSIS

This involves receptor molecules on a cell membrane which binds with specific substance from extracellular fluid as the receptor sites are filled, the surface falls inwards until the coated vesicles finally separates from the cell surface membrane.

Illustration



EXOCYTOSIS

This involves the vesicles or vacuoles moving to the cell membrane fusing with the releasing their contents to the outside of the cell.

Exocytosis provides a means by which enzymes, hormones, antibodies and cell wall precursors are released from the cell.

The vesicles are often derived from the Golgi apparatus which move along microtubules of the cytoskeleton of the plasma membrane. When the vesicles get into contact with the plasma membrane, the lipid molecules of the two bilayers rearrange and diffuse. The content of the vesicles spill to the outside of the cell and the vesicle membrane becomes part of the plasma membrane.

Importance of cytosis

1. Many secretory cells use exocytosis to release their excretory products outside themselves e.g. pancreatic cells manufacture insulin and secrete it into blood by exocytosis and many other hormones are secreted in this form by the gland cells
2. Exocytosis facilitates synaptic transmission during which neuro-transmitter substances like acetylcholine in synaptic vesicles of synaptic knobs fuse with the pre-synaptic membrane to release neuro transmitter substances into the synaptic cleft of the synapse.
3. Exocytosis delivers cell wall materials to the outside of the cell from the Golgi apparatus/body through vesicles which contain proteins and certain carbohydrates
4. Exocytosis leads to replenishment of the plasma membrane as the vesicle membrane become part of the plasma membrane become part of the plasma membrane after spilling/discharging their contents to the outside.

Summary			
Features	**Simple diffusion**	**Facilitated diffusion**	**Active transport**
Concentration gradient	Down the concentration gradient from high to low	Down the concentration gradient from high to low	Against a concentration gradient from low to high
Energy expenditure	None	None	Energy expenditure is in the form of ATP
Carrier protein/ transporter	Not required	Required	Required
Speed	Slowest mode	Fast	Fastest

UPTAKE AND TRANSPORT IN PLANTS

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.

Types of transpiration

There are three types of transpiration which include the following;

i. Stomatal transpiration
ii. Cuticular transpiration
iii. Lenticular transpiration

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 5% 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.

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

Measuring 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 the rate at which the plant takes in water (water uptake), using an instrument called a **potometer.**

Determining the rate of transpiration using

a) 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

b) the potometer

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

Total area of leaves = Number of complete squares + Number of incomplete squares x $\frac{1}{2}$

The rate of transpiration is therefore expressed in terms of the volume of water taken up by the leafy shoot per unit time per unit leaf area. The structure of a potometer is shown in the diagram below.

(Kent Fig 2 pg 276, Soper Fig 13.10 pg 439, Toole fig 22.12 pg 457)

Precautions taken when using a potometer

1. The leafy shoot used should have a significant water loss by having very many leaves
2. The stem of the leaf shoot must be cut under water to prevent air from entering and blocking the xylem vessels
3. The setup must have plenty of water
4. Ensure that only one bubble is present in the capillary tube
5. A well graduated scale must be used e.g. a ruler, so that clear readings are taken
6. The air bubble should always be reset to zero mark before the potometer is used again under different conditions
7. The water reservoir should be filled with water when setting the air bubble at the zero mark
8. The cut leafy shoot must be in contact with water in the sealed vessel

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.

The leafy area is then established by tracing the outline of the leaves on squared papers and then counting the number of complete and incomplete squares in the outline of the leaves.

The rate of transpiration is therefore expressed in terms of the volume of water taken up by the leafy shoot per unit time per leafy area.

NOTE; since most of the water taken up by the potometer is lost by transpiration, it is assumed that water uptake = water loss.

Advantages of transpiration

i. It allows the uptake of water from the roots to leaves in form of a transpiration stream. This is due to a transpiration pull created in the leaves. This ensures proper distribution of water throughout the plant to keep it alive.
ii. It facilitates the uptake of the absorbed mineral salts within the xylem vessels from roots to leaves
iii. It brings about the cooling of the plant since as water evaporates to the atmosphere, excessive heat is also lost as heat of vaporization, which results into the cooling of the plant
iv. It brings about mechanical support in non-woody or herbaceous plants, due to water uptake which provides turgidity to the parenchyma cells of the stem and leaves
v. It is important for cloud formation via evapotranspiration hence resulting into rainfall

Disadvantages of transpiration

i. It causes wilting of plants in case of excessive transpiration
ii. It may eventually cause death of the plant, when the plant looses water excessively due to excessive transpiration

NOTE: wilting is the loss of water from the plant cells. Evaporation occurs at rate greater than that at which it is absorbed, resulting into reduction in turgor pressure and dropping of the plant. It always takes place in hot and dry areas. Wilting also results into the closure of the stomata which cuts off gaseous exchange and therefore may cause death if it persists.

FACTORS AFFECTING TRANSPIRATION

The potometer may be used to investigate the effect of environmental factors on the rate of transpiration i.e. it can be moved to a windy place or a place which is dark. Transpiration is affected by both environmental and non-environmental factors.

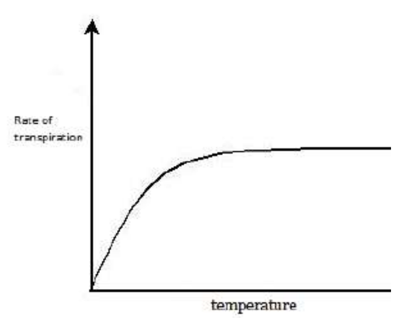
ENVIRONMENTAL FACTORS

1. 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.
In areas where humidity is too high, plants loose liquid water from their leaves via structures/glands on their leaf margins known as **hydathodes**, a process known as **guttation.** Guttation is the loss of liquid water from plant leaves through hydathodes due to excessive humidity in the atmosphere.

2. 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.



3. Air movements

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.

(Soper fig 13.9 pg 439)

4. Atmospheric pressure

Water vapour and the atmospheric pressure decreases with increasing altitude.

The lower the atmospheric pressure the greater the rate of evaporation of water 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.

5. 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.

6. Light intensity

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.

(Soper fig 13.13 pg 443)

NON-ENVIRONMENTAL FACTORS

1. Leaf area

The larger the leaf surface area on the plant, the higher the rate of water loss by transpiration. In addition, broad leaves provide a large surface area over which water vapour diffuses to the atmosphere as compared to the narrow leaves.

2. Cuticle

The thinner the cuticle, the higher the rate of water loss by transpiration and the thicker the cuticle, the lower the rate of water loss from the plant to the atmosphere by transpiration. This is because this offers a significant resistance towards the diffusion of water vapour from the plant to the atmosphere.

3. Number of stomata

The larger the number of stomata on the plant, the higher rate of water loss by transpiration and the lower the number of stomata, the lower the rate of transpiration.

However, a very large number of stomata so close to each other may instead reduce the rate of transpiration especially in still air due to the accumulation of water vapour around the whole stomata pore.

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.

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 inner cell wall of guard cells is thicker and less elastic than the outer wall. 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.

(Toole fig 22.7a pg 452)	(Toole fig 22.7b pg 452)

(Soper fig 13.15 pg 444)

Ventilation (opening and closing of stomata)

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.

Several theories have been put forward to explain how the light intensity influences the opening and closing of stomata.

1. Photosynthetic product theory	**2. Potassium ion (K^+) mechanism (mineral ion concentration)**
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 from nighbouring epidermal cells by osmosis. The result is an expansion and increase in turgidity of the guard cells containing the stomata 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 neighboring cells by osmosis. The guard cells become flaccid and the stomata close. **Note;** this theory does not explain how the low rate of glucose formation can account for the rapid opening of stomata	When guard cells are exposed to light, the light energy activates the ATPase enzyme, hence their chloroplasts manufacture ATP. The ATP drives a K^+ - pump on the cell membrane of the guard cells. This causes an active uptake of K^+ ions in the guard cells from the surrounding epidermal cells. Accumulation of K^+ in the guard cells increases the osmotic pressure of their cell sap. This causes water to move into the guard cells from neighboring epidermal cells by osmosis. The result is an expansion and increase in turgidity of the guard cells causing the stomata to open because when they become turgid, they expend but not uniformly since the inner wall is inelastic, making the guard cells curve away from each other. At the onset of darkness, ATP concentration in guard cells falls rapidly stopping the K^+ pump. K^+ migrates from the guard cells to neighboring epidermal cells by diffusion. This lowers the osmotic pressure of guard cells causing them to lose water to neighboring cells by osmosis. The guard cells become flaccid and the stomata close.

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.

(Toole fig 22.8 pg 452 OR Kent fig 3 pg 281)

The two above theories can be summarised into a single mechanism of stomata opening and closing as described below;

Stomata opening

1. Stomata opening is promoted by high light intensity and low mesophyll carbon dioxide levels. Guard cells generate ATP by photophosphorylation during photosynthesis. .
2. Blue light is absorbed by blue-light photoreceptors which activate a proton-pump (H^+-ATPase) in the cell membrane of the guard cell
3. 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.
4. In some plants the starch is converted to malate.
5. 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.
6. The outer wall of the guard cells is t hinner 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
7. The increased turgor pressure therefore causes the guard cells to curve outward and the stoma opens

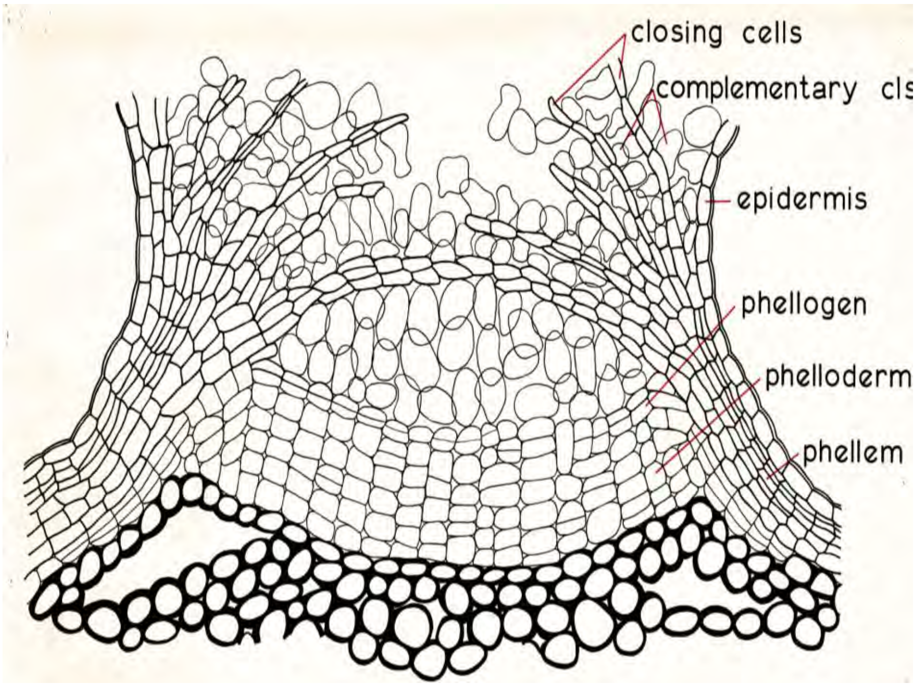
Stomata closure

1. Stomata closure can be triggered by water stress, high temperature, increasing carbon dioxide levels in the leaf mesophyll and low light intensity (night time)
2. The hormone abscisic acid (ABA) is secreted by plant cells when transpiration rate is high and soil water is low.
3. 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.
4. Potassium ions (K^+) move out of the guard cells into the subsidiary cells
5. In some plants (Cl^-)and certain organic ions e.g. malate ions also move out of the guard cells
6. 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.
7. At night the chloroplasts in the guard cells do not photosynthesise, 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.

LENTICELS

A small amount of gaseous exchange takes place in the stem through structures called lenticels. The small gaps in the stem, usually circular or oval slightly raised on the bark surface. The cells in this area are thin walled and loosely parked, leaving air spaces which communicate with air spaces in the cortex. Here oxygen for respiration is taken up and carbon dioxide is given out.

Structure of the lenticel



ROOT EPIDERMAL CELLS

Root cells can also take in oxygen for respiration and give out carbon dioxide. Gaseous exchange takes place by diffusion between the epidermal cells of roots and the air spaces in the soil. Most of the exchange takes place at the root hairs which provide a large surface area.
Water logged soils have their air spaces occupied by water, thereby reducing respiration in the roots which may subsequently die. This would obviously kill the whole plant.

Some aquatic plants, like pond weeks and multi cellular algae are completely submerged in water. These obtain their gaseous requirements by diffusion from the surrounding water. Epidermal cells of such plants have no cuticle and gasses diffuse directly across it.
Others like rice and water lilies are partially submerged in water. Their aerial parts obtain carbon dioxide and oxygen in the same manner as terrestrial plants. The submerged parts may face the problems of obtaining adequate oxygen for their respiratory requirement. However such plants have large air spaces in their stems and roots which store oxygen obtained from the aerial parts and that formed during photosynthesis. Floating leaves of such plants have stomata on the upper surfaces only.

In swampy environments, root systems give rise to breathing roots or pneumatophores. These grow out of the water and op into the air. Oxygen diffuses into them and aerates the submerged parts of the root system.

EXPERIMENT TO OBSERVE STOMATA

Obtain a leaf a leaf of comelina. Hold it in such a way that the lower surface is facing you. Slowly tear the leaf as you would tear a piece of paper by moving the right hand towards the body. This produces a thin, transparent membrane-like tissue along the edge of the tear on the part of the leaf in the left hand. This is the lower epidermis. Using forceps, remove a small section of the epidermis and mount it in a drop of water on a slide and cover it with a cover slip. Observe under low power and then under the high power of a microscope. Identify the guard cells and the normal epidermal cells. Observe a closed stoma and an open stoma under low and high power. Draw each of these.

WATER UPTAKE BY THE ROOTS

Internal structure of the root

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.

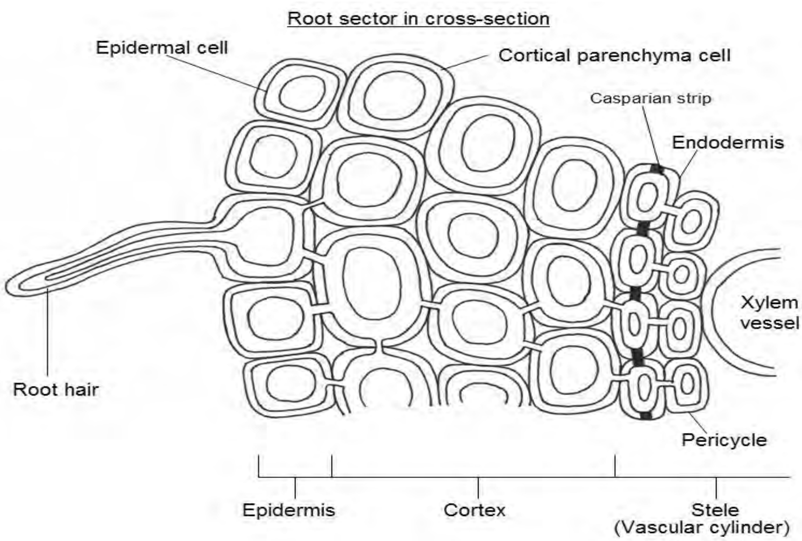
Next to the endodermis is another layer of cells known as **pericycle** from which lateral roots develop. The pericycle, that is made up of parenchyma cells which encloses the vascular bundles (xylem and phloem) in the centre of the root.

Diagram showing the internal structure of the root

(Toole fig 22.13a pg 462)

(Toole fig 22.13b pg 462)

Longitudinal section through a root



Mechanism of water uptake by the roots

For water to be transported up to the leaves through the stem, it must be absorbed from the soil by the tiny root hairs. Water absorption into the root hairs occurs by **osmosis**. This is due to the water potential of the cell sap of the root hairs being lower than that of the soil solution (water content).

When the root hair absorbs water, its water potential increases and becomes higher than that of the adjacent cells of the root. This facilitates the flow of water from the root hairs to the endodermal cells across a water potential gradient.

The water flow is also due to the root pressure developed by the cell cortex and endodermis which ensures that water flows from the root hairs to the xylem vessels and upwards to the leaves.

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

a) Apoplast (cell wall) pathway
b) Symplast (cytoplasm) pathway
c) Vacuolar pathway

Apoplast pathway

This is the pathway in which water moves through the spaces between the cellulose fibres in the cell wall of one cell to the cell wall of the adjacent cells.

However, this movement does not occur within the endodermal cells because they possess the impermeable **casparian strip** which prevents water and solutes flow through the cell walls of the endodermal cells. This means that water and solutes flow through the cell walls of the endodermal cells via the Symplast and the vacuolar pathways only.

The significance of this casparian strip is to actively pump salts (ions) from the cytoplasm to the endodermal cells into the xylem vessels which creates a high solute concentration in the xylem, thereby greatly lowering the water potential in the xylem than in the endodermis. This makes the water potential of the xylem vessels more negative (very low) and results into rapid osmotic flow of water from the endodermal cells to the xylem vessels, due to the steep water potential gradient between the endodermal cells and the xylem vessels.

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

Symplast pathway

This is the movement of water through the cytoplasm of one cell to the cytoplasm of the adjacent cell via plasmodesmata.

Water leaving the pericycle cells to enter the xylem causes the water potential of these cells to become more negative (more dilute). This facilitates the flow of water by osmosis from the adjacent cells into these cells. In this way the water potential gradient from the root hairs to the xylem is established and maintained across the root. This pathway offers a significant resistance to the flow of water unlike the apoplast pathway.

Vacuolar pathway

This is the movement of water from the sap vacuole of one cell to the sap vacuole of the adjacent cell following a water potential gradient.

This is achieved by maintaining a steep water potential gradient. However, this also offers a reasonable level of resistance towards water flow in comparison to the Symplast pathway.

Note; the apoplast is the most appropriate pathway in plants because it provides less resistance to water flow in the plant.

Diagram showing the three pathways of water in the root

(Soper fig 13.18a pg 448)

To ensure maximum absorption of water, the root hairs have the following **adaptations**

a. They are numerous in number so as to provide a large surface area for the maximum absorption of water by osmosis.
b. They are slender and flexible for easy penetration between the soil particles so as to absorb water.
c. The lack a cuticle and this enhances the passive osmotic absorption of water without any resistance
d. They have a thin and permeable membrane which allows the absorption of water by osmosis.
e. They have a water potential lower than that of the soil solution which facilitates a net osmotic flow of water from the soil

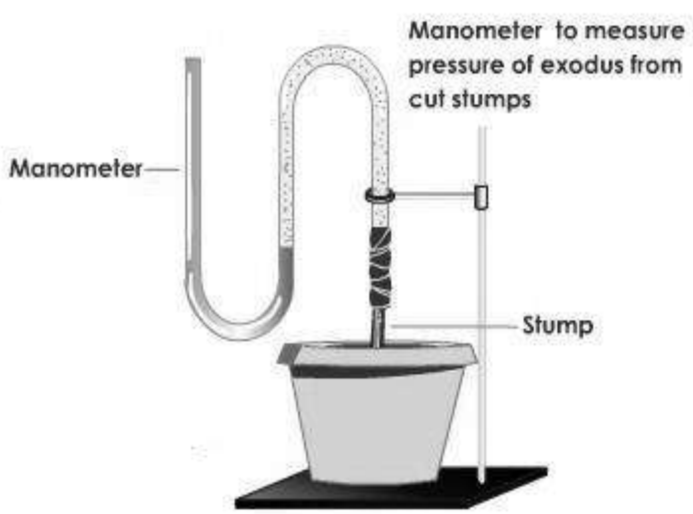
ROOT PRESSURE

Root pressure is the force developed by cells of the roots which forces water from the endodermal cells into the xylem vessels of the root and constantly forces water upwards through the stem to leaves. This process is active and involves utilization of many ATP molecules. Root pressure occurs as a result of endodermal cells actively secreting salts into the xylem sap from their cytoplasm, which greatly lowers the water potential in the xylem.
In some plants, root pressure maybe large enough to force liquid water through pores called hydathodes of the leaves in a process called guttation
The following is the **evidence to support the mechanism of water uptake from the endodermis into the xylem vessel as an active process**

a. There are numerous starch grains in endodermal cells which could act as an energy source for active transport.
b. Lowering the temperature reduces the rate of water exudation (given out) from the cut stem as it prevents root pressure, an active process.
c. Treating the roots with metabolic poisons e.g. potassium cyanide also prevents water from being exuded from the cut stems. This is because the poisons kill the cells thereby preventing aerobic respiration, a source of ATP molecules.
d. Depriving roots of oxygen prevents water from being exuded from the cut stems. This shows that water was being pushed upwards in the cut stem by root pressure, an active pressure.

The following is **the evidence to show that water moves by pressure in a plant.**
When the stem of a plant is cut water continues to exude from the xylem vessels of the plant stem. The continuous exudation of water from the xylem vessels of the cut stem is due to root pressure because the leafy shoot is cut off, meaning that water not only moves upwards by transpiration pull, but also due to pressure and other forces.

Root pressure can be measured using a mercury manometer whose diagram is shown below



Experiment to demonstrate root pressure-B

Though it is true that water moves from the roots through the stem to the leaves by transpiration pull, root pressure partly contributes towards the movement of water from the **parenchyma cells** to the xylem of the root, to the stem and eventually up to the leaves.

THE UPTAKE OF WATER FROM THE ROOTS TO THE LEAVES

The movement of water from the roots to the leaves is by combination of different forces which include the following;

A. Root pressure
B. Transpiration pull(cohesion force)
C. Capillarity

Root pressure

This enables movement of water from the parenchyma cells of the main root into the xylem tissue due to the active pumping of cells from endodermal cells into the xylem tissue.

Root pressure also ensures upward movement of water through the xylem tissues to the leaves.

Transpiration pull (cohesive force/cohesion-tension theory of water uptake)

This offers an explanation for the continuous flow of water upwards through the xylem of the plant i.e. from the root xylem to the stem xylem and finally to the leaf xylem. Water is removed from the plant leaves by transpiration which creates a tension within the leaf xylem vessels that pulls water in the xylem tubes upwards in a single unbroken column or string held together by the cohesive forces of attraction between water molecules.

According to the cohesion-tension theory, evaporation of water from the mesophyll cells of the leaf to the sub-stomatal air chamber and eventually to the atmosphere via the stomata by transpiration, is responsible for the rising of water from the roots to the leaves. This is because the evaporated water molecules get replaced by neighbouring water molecules which in turn attract their other neighbours and this attraction continues until the root is reached.

Evaporation of water results in a reduced water potential in the cells next to the leaf xylem. Water therefore enters these mesophyll cells by osmosis from the xylem sap which has the higher water potential. Once in the mesophyll cells water moves using the three pathways namely; apoplast, Symplast and vacuolar pathways from one cell to another by osmosis across a water gradient.

When water leaves the leaf xylem to the mesophyll cells by osmosis, a tension is developed within the xylem tubes of water which is transmitted to the roots by cohesive forces of water molecules. The tension develops in the xylem vessels and builds up to a force capable of pulling the whole column of water molecules upwards by means of mass flow and water enters the base of these columns from neighbouring root cells. Because such a force is due to water loss by osmosis by transpiration, it is referred to as **transpiration pull.**

The upward movement of water through the xylem tissue from the roots to leaves is also facilitated by the **cohesive forces** of attraction which holds the water molecules firmly together, due to the hydrogen bonds which exist between them. This enables water to have a high tensile strength which enables it to move upwards in a continuous stream without breaking. In addition, the upward movement of water from roots to leaves is also facilitated by cohesive forces which hold the water molecules on the xylem walls so that it continues moving upwards.

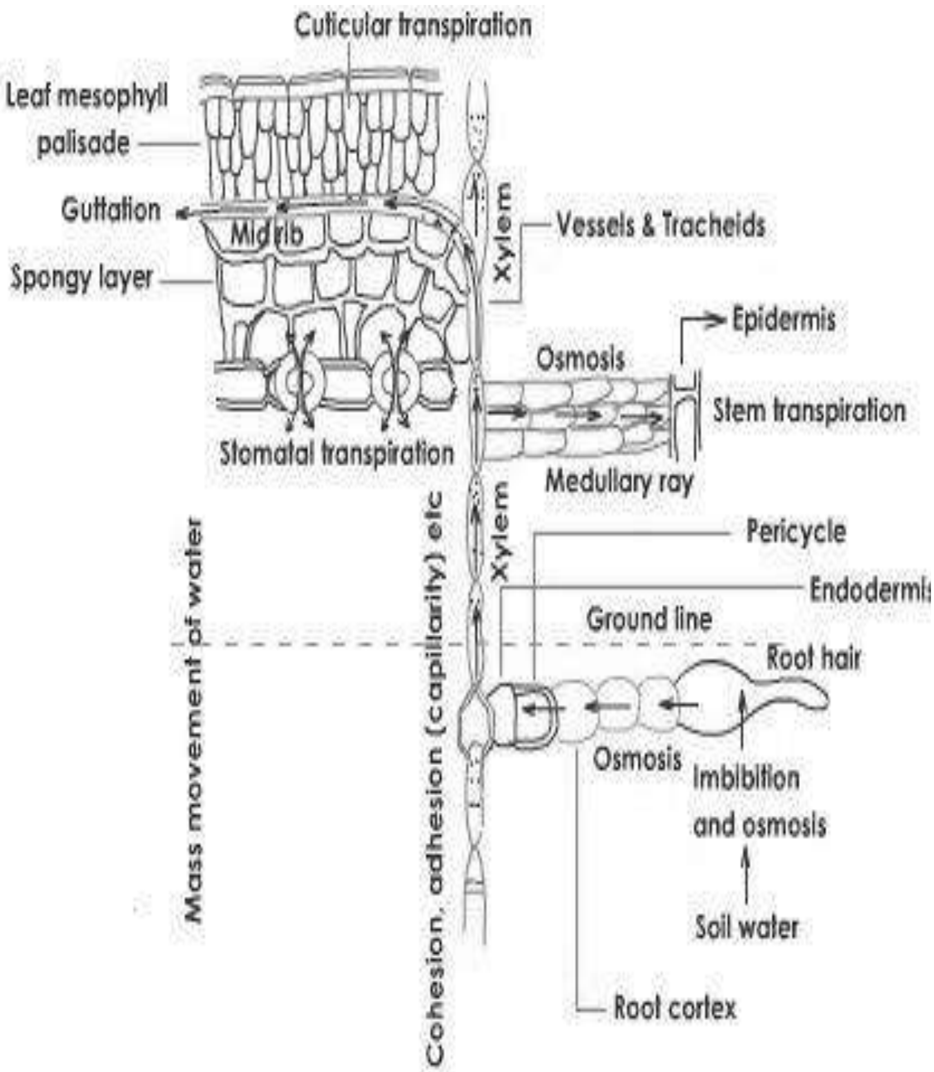
Capillarity

Since the water rises upwards through narrow leaves, it is also facilitated by capillarity through the stem. This is because the xylem vessels are too narrow and the flow of water is maintained without breaking by both the cohesive and adhesive forces.

NOTE

1. The continuous mass flow of water through the xylem vessels from the roots to the leaves in a stream without breaking, due to the transpiration pull is called the **transpiration string**
2. Adhesion is the force of attraction between molecules of different substances while cohesion is the force of attraction between molecules of the same substance

The diagram below shows the upward movement of water from the soil up to the leaves.



UPTAKE AND TRANSLOCATION OF MINERAL IONS

Translocation is the movement of mineral salts and chemical compounds within a plant.

There are two main processes of translocation which include;

a. The uptake of soluble minerals from the soil and their passage upwards from the roots to the various organs via the xylem tubes.
b. The transfer of organic compounds synthesized by the leaves both upwards and downwards to various organs via the phloem tubes

Mechanism of mineral ion uptake

Minerals such as nitrates, phosphates, sulphates e.t.c. may be absorbed either actively or passively.

1. Active absorption of minerals

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

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

(Soper Fig 13.19 pg 449)	(Soper Fig 13.20 pg 450)

2. Passive absorption

If the concentration of a mineral in a soil solution is greater than its concentration in the root hair cell, the mineral may enter the root hair cell by diffusion.

Mass flow or diffusion occurs once the minerals are absorbed by the root hairs so that they move along cell walls (apoplast pathway). In mass flow, the mineral ions are carried along in solution by water being pulled upwards in the plant in the transpiration stream, due to the transpiration pull i.e. the mineral ions dissolve in water and move within the water columns being pulled upwards.

The mineral ions can also move from one cell of the root to another against the concentration gradient by using energy inform of ATP.

The mineral ions can also move through the **Symplast pathway** i.e. from one cell cytoplasm to another. When the minerals reach the endodermis of the root, the Casparian strip prevents their further movement along the cell walls (**apoplast pathway).** Instead the mineral ions enter the cytoplasm of the cell (Symplast pathway) where they are mainly pumped by active transport into the xylem tissues and also by diffusion to the xylem tissues.

Once in the xylem, the minerals are carried up the plant by means of mass flow of the transpiration stream. From the xylem tissues, minerals reach the places where they are utilised called **sinks** by diffusion and active transport i.e. the minerals move laterally (sideways) through pits in the xylem tissue to the sinks by diffusion and active transport.

NOTE;

1. The following is the evidence to show that most mineral ions are absorbed actively by the root hairs

a. 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
b. Treating the root with respiratory inhibitors such as potassium cyanide prevents active mineral ion uptake leaving only absorption by diffusion. This is because the rate of mineral ion uptake greatly reduces when potassium cyanide is applied to the plant.
c. 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.

2. The following is the evidence for supporting the role of the xylem in transporting minerals

a. The presence of mineral ions in the xylem sap i.e. many mineral ions have been found to be present in the xylem sap.
b. 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.
c. There's evidence that other solutes e.g. the dye, eosin, when applied to the plant roots, it is carried in the xylem vessels
d. 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.
(The interpretation of these elements is that 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)

NOTE; Some plants absorb mineral salts by using mutualistic associations between their roots and other organisms e.g. the association between the fungus and the higher plant roots called **mycorrrhiza**.

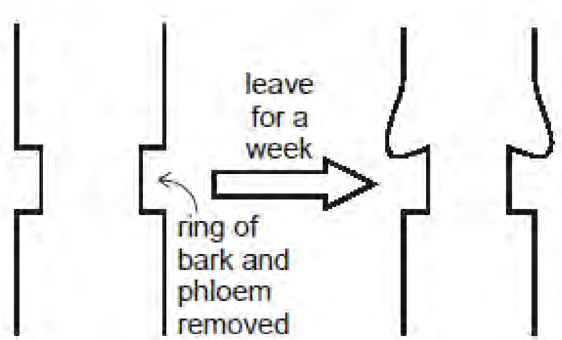
TRASLOCATION OF ORGANIC MOLECULES

(Food molecules in the phloem)

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 to support that organic molecules of photosynthesis are transported in the phloem

a. When the phloem is cut, the sap which exudes out of it is rich in organic food materials especially sucrose and amino acids.
b. 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.



c. 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.**

d. 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.

e. 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 content exudes.

When the contents of the phloem are analyzed, they are confirmed to be containing carbohydrates, amino acids, vitamins e.t.c. 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 was found out that organic materials do not move through the phloem sieve tubes by diffusion because the rate of flow of these materials is too fast for diffusion to be the cause. The mechanism of translocation of food in the phloem is explained by the following theories or hypothesis.

1. The mass flow or pressure flow hypothesis (i.e. Much's hypothesis)
2. Electro-osmosis
3. Cytoplasmic streaming

Mass flow or pressure flow hypothesis

Mass flow is the movement of large quantities of water and solutes in the same directions.

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 where food is utilized are referred to as the sink.

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

The sink and the source are linked by the phloem sieve tubes and as a result the solution flows from the leaves to other tissues (sinks) along the

A diagram showing movement of the products of photosynthesis by mass flow

(Toole fig 22.23 pg 470, Kent fig 2 pg 286)

Evidence supporting the mass flow theory

1. When the phloem is cut, the sap exudes out of it by mass flow
2. 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.
3. Most researchers have observed mass flow in microscopic sections of the sieve tube elements.
4. There's some evidence of concentration gradient of sucrose and other materials with high concentration in the leaves and lower concentration in the roots.
5. Any process that can reduce the rate of photosynthesis indirectly reduces the rate of translocation of food.
6. 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.

Criticism of mass flow

1. 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.
2. The phloem has a relatively high rate of oxygen consumption which this theory does not explain.
3. 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.
4. The mass flow hypothesis does not mention any translocation of solutes with influence of transfer cells and Indole Acetic Acid (IAA) hormone that loads the sugars or solutes into the sieve tubes and also unload it into the cells of the sink.
5. 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.
6. 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

NOTE: the mass flow theory is considered to be the most probable theory in conjunction with electro-osmosis

Electro-Osmosis

This is the passage of water across a charged membrane.

(Clegg fig 16.39b pg341)

This membrane is charged because positively charged ions e.g. K^+ ,actively pumped by the companion cells across the sieve plate into the sieve tube element using energy from ATP of the companion cells.

Potassium ions accumulate on the upper side of the sieve plate thereby making it positively charged. Negatively charged ions accumulate on the lower sides of the sieve plate thereby making it negatively charged. The positive potential above the sieve plate is further increased by hydrogen ions, actively pumped from the wall to the upper sieve tube element into its cytoplasm.

Organic solutes such as sucrose are transported across the sieve plates due to an electrical potential difference between the upper and the lower side of the sieve plate whereby the lower side is more negative than the upper side i.e. solutes move from the upper sieve tube element which is positively charged to the lower sieve element which is negatively charged.

The electrical potential difference is maintained across the plate by active pumping of positive ions, mainly potassium ions, in an upward direction. The energy used is produced by the companion cells.

The movement of K^+ ions through the pores of the sieve plates rapidly draws molecules of water and dissolved solutes through the sieve

Evidence to support the electro-osmosis theory

1. K^+ ions stimulate the loading of the phloem in the leaves with sugars during photosynthesis.
2. 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 theory

This suggests that the protoplasm circulates using energy from sieve tubes elements or companion cells through the sieve tube elements from cell to cell via the sieve pores of the sieve plates.

As the protoplasm circulates, it carries the whole range of the transported organic materials with it. The solutes are moved in both directions along the trans-cellular strands by peristaltic waves of contraction, such that they move from one sieve tube element to another using energy in from of ATP. The proteins in the strands contract in a wave form, pushing the solutes from one sieve tube element to another, using energy in form of ATP.

Diagram showing Cytoplasmic streaming

(Kent fig 3 pg 287)

Evidence supporting the cytoplasmic streaming theory

1. It has been found that the solute materials move in both directions in the phloem tissue
2. The theory explains the existence of the trans-cellular strands in the phloem tissue as well as many mitochondria in the companion cells
3. Presence of a sieve plate where a potential difference can be developed across the plate

Criticism of the Cytoplasmic Streaming Theory

1. 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

TRANSPORT IN ANIMALS

Many materials including oxygen, carbon dioxide, soluble food substances, hormones, urea e.t.c. 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 due to a small surface area to volume ratio which reduces the rate of diffusion of materials from the body surface to the cells in the middle of the organism. There are however some organisms which lack the transport system e.g. protozoa and platyhelmithes e.t.c. This is because, being small in size and being flattened in shape gives these animals a large surface area to volume ratio, this enables free and rapid diffusion of materials from one part of the body to another. Consequently large multi-cellular organisms have an elaborate transport system that carries useful substances such as oxygen and glucose to the cells and carries away the waste products of metabolism. An elaborate transport system has two major features;

i. An increased surface area of the sites of exchange of materials. Such sites include the lungs and the gills where oxygen is absorbed and the villi of the ileum where food nutrients are absorbed along the alimentary canal.
ii. A system whereby the circulating medium carries the absorbed substances at a faster rate than diffusion. In some organisms with a blood circulating system, blood flow is not confined to blood vessels but instead it flows within a blood filled cavity called ***Haemocoel*** e.g. in arthropods and molluscs. In other organisms with the blood circulatory system, blood flow is confined to blood vessels only e.g. in vertebrates and some invertebrates such as the earth worm.

IMPORTANCES OF A BLOOD CIRCULATORY SYSTEM (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

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**

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 e.t.c.

The plasma proteins are manufactured by the liver and include the following;

a. Fibrinogen. This protein is important for normal blood clotting by changing into fibrin in the presence of thrombin enzyme.

$$\text{Fibrinogen (soluble)} \longrightarrow \text{Fibrin (insoluble)}$$

b. Prothrombin. This is the inactive form of the proteoltyic enzyme, thrombin, used in converting fibrinogen to fibrin during the clotting of blood.

c. Globulin. Both Prothrombin and globulin play important roles in the homeostasis. All the plasma proteins maintain pH of the body fluids constant by acting as buffers.

d. Blood cells. There are three main types of blood cells which include;

- Erythrocytes (Red blood cells)
- Leucocytes (White blood cells)
- Platelets

ERYTHROCYTES (Red blood cells)

These are small numerous bi-concave disc shaped cells mainly important in transportation of oxygen as oxyhaemoglobin from the respiratory surfaces e.g. lungs and gives it to the tissues. Erythrocytes are manufactured by the bone marrow in adult and by the liver in the foetus.

Adaptations of erythrocytes

i. They have a bi-concave disc shape which provides a large surface area that enhances maximum diffusion of enough oxygen into them.

ii. They have a pliable membrane (flexible membrane) which can enable them change their original shape and squeeze themselves into the blood capillaries in order to allow the exchange of respiratory gases.

iii. They lack a nucleus so as to provide enough space for haemoglobin in order to carry a lot of oxygen in form of oxyhaemoglobin.

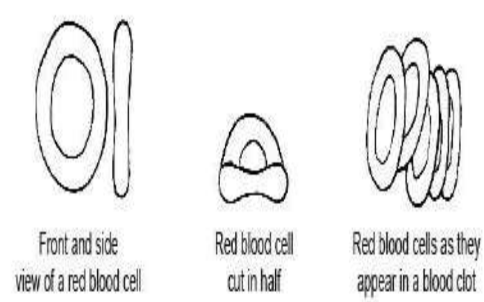
iv. They have a red pigment called haemoglobin in their cytoplasm which has a high affinity for oxygen and therefore rapidly transports oxygen.

v. They have a thin and permeable membrane which enables faster diffusion of oxygen and carbon dioxide into them.

vi. They have an enzyme known as carbonic anhydrase within their cytoplasm which enables most of the carbon dioxide to be transported in form of bicarbonate ions (HCO_3^-), by catalyzing the reactions between carbon dioxide and water to from carbonic acid.

$$CO_2 + H_2O \xrightarrow[\text{Carbonic anhydrase}]{} H_2CO_3$$

Diagram showing the shapes of erythrocytes



NOTE; Erythrocytes have a life span of 120 days.

LEUCOCYTES (white blood cells)

They are amoeboid cells having a nucleus and a colourless cytoplasm important for defense of the body against infections. They are fewer than erythrocytes i.e. they are about 7000/m^3 of blood. They are mainly manufactured by the bone marrow. They are classified into two main types which include;

Granulocytes (polymorphonuclear leucocytes)

These are leucocytes with granules in there cytoplasm and a lobed nucleus. They originate in bone marrow. There are three types of granular leucocytes which include;

i. Basophils (0.5%)
ii. Eosinophils (1.5%)
iii. Neutrophils (70%)

Basophils (0.5%) produce *heparin* and *histamine.* Heparin is an anti-coagulant which prevents blood clotting in blood vessels. Histamine is a substance that is released during allergic reactions e.g. hay fever. Histamine brings about allergic reactions by causing dilation (widening) and increased permeability of small blood vessels which results in such symptoms as itching,, localized swellings, sneezing, running nose, red eyes e.t.c.

Eosinophils (1.5%) possess anti-histamine properties and their number increases in people with allergic reactions such as high fever, asthma e.t.c. so as to combat the effects of histamine.

Neutrophils (phagocytes) (70%) engulf pathogens phagocytotically and digest them actively inside to defend the body against diseases.

Agranulocytes (mononuclear leucocytes)

These are leucocytes with no granules in there cytoplasm usually with a spherical or bean shaped nucleus. They originate in bone marrow and lymph nodes. They are divided into two types;

i. Monocytes (4%)
ii. Lymphocytes (24%)

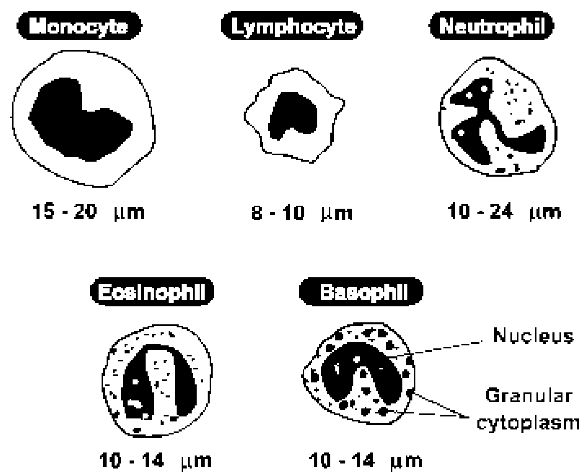
Monocytes (4%) are leucocytes which enter the tissues from which they develop into macrophages which carry out Phagocytosis to defend the body against pathogens.

They have a bean shaped nucleus.

Lymphocytes (24%) 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.

Adaptations of white blood cells to their function

1. They do not have a fixed shape and hence the amoebic movements used to engulf pathogens.
2. They are larger than the pathogens
3. They are numerous
4. Some lymphocytes produce antibodies which attack pathogens
5. They have an irregular shaped nucleus which allows them to squeeze through the narrow capillaries
6. They have a sensitive cell surface membrane that detects micro organisms
7. They have enzymes in their cytoplasm to digest the engulfed micro organisms
8. They have a large nucleus which contains many genes for the control of antibody production.



- In adults they are produced and develop in the bone marrow and lymph glands while in embryos they are produced in the thymus gland, liver and spleen.
- They have a life span of 21 days

BLOOD PLATELETS (thrombocytes)

These are irregularly shaped, membrane bound cell fragments lacking the nuclei and are formed from the bone marrow cells. They are responsible for starting up the process of blood clotting. There are abound 250,000 blood platelets per mm^3 of blood.

TRANSPORT OF OXYGEN

The equation below shows how haemoglobin combines with oxygen.

$$Hb + 4O_2 \leftrightarrow HbO_8$$

As shown by the equation above, each haem group combines with one oxygen molecule and therefore 1 haemoglobin molecule carries four oxygen molecules.

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 β-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.

Assignment;

a. Copy the extension on page 221 in Advanced biology by Michael Roberts and Monger

b. With the aid of a diagram, describe the structure of the haemoglobin molecule

c. How is haemoglobin adapted to its function

Oxygen tension and oxyhaemoglobin 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 milimetres of mercury (mmHg)

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** which is shown below.

(Toole fig 21.3 pg 414 OR Kent fig 3 pg 129)

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 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. Beyond this part of the curve any small drop in the oxygen partial pressure results into a relatively large decrease in the percentage saturation of blood with oxygen, 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; 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.

The oxygen supply can be distributed 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. For example, falling during fainting actually prevents serious damage to the brain cells as a result of inadequate blood supply. (These responses are often thwarted by well-meaning bystanders anxious to get the affected individual 'back on his feet'. In fact, holding a fainting person upright can lead to severe shock and even death).

Effect of carbon dioxide on the oxygen dissociation curve (Bohr's effect)

Within tissues there is a high concentration of carbon dioxide produced during aerobic respiration

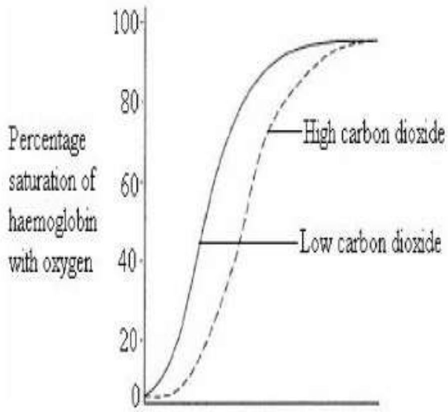
$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

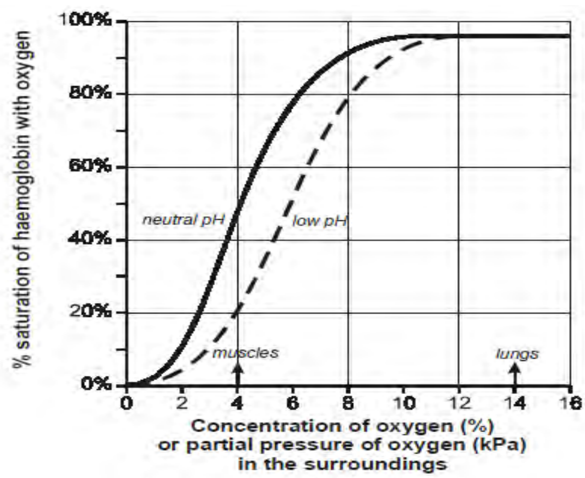
Increase in carbon dioxide concentration decreases the affinity of haemoglobin for oxygen, by making the pH of the surrounding medium more acidic (low), thereby shifting the oxygen dissociation curve to the right. This shifting of the curve to the right is known as **Bohr's effect** i.e. the shifting 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.

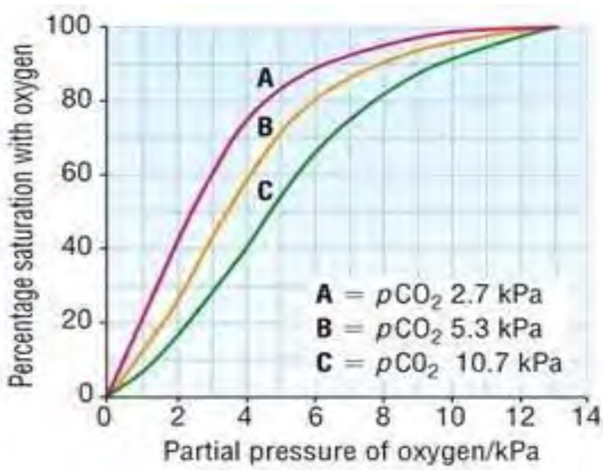
Bohr's effect may be defined as the lowering of the affinity of blood's haemoglobin for oxygen due to increased acidity caused by increase in carbon dioxide concentration.

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







Effect of carbon monoxide on the affinity of haemoglobin for oxygen

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 combines readily with carbon monoxide to form a permanent compound known as **carboxyhaemoglobin**rather than combining with oxygen.

A permanent carboxyhaemoglobin compound is formed because carbon monoxide oxidizes iron (II) to iron (III). This reduces the free haemoglobin molecules available to transport oxygen molecules to the tissues, which makes the tissues develop symptoms of **anoxia** (total lack of oxygen in the tissues).

Therefore, carbon monoxide is referred to as a respiratory poison because it can readily combine with haemoglobin much more than oxygen and the product formed i.e. carboxyhaemoglobin does not dissociate.

Note; smokers have 10% of their total haemoglobin in form of carboxyhaemoglobin.

Myoglobin and other pigments

(Kent fig 3 pg 131 OR Clegg fig 17.31 pg 360)

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 as shown in the graph

Note;

i. High affinity refers to low rate of dissociation to release oxygen and a higher rate of association of haemoglobin with oxygen.
ii. Low affinity refers to higher rate of dissociation to release oxygen and a lower rate of association of haemoglobin with oxygen.
iii. There are other respiratory pigments mostly found in the lower animals which include **haemocyanin** which consists of copper and mostly found in some snails and crustaceans
iv. Other pigments include**haemocrythrin** which contains iron and is also found in some in annelids
v. **Chlorocruorin**which also contains iron is also found in some annelids.
vi.

Comparison between the oxygen dissociation curve for Lugworms' haemoglobin and that of Man

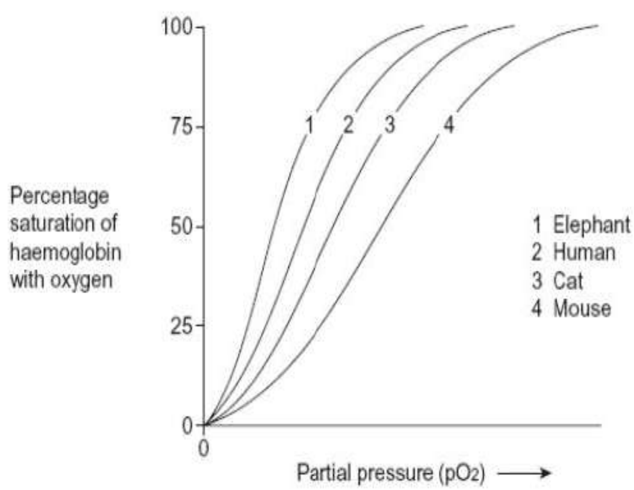
The oxygen dissociation curve of the lugworm's haemoglobin lies on the left of that of man's haemoglobin as shown in the graph besides;

(Clegg fig 17.32 pg 360 OR Toole fig 21.5 pg 416)

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.

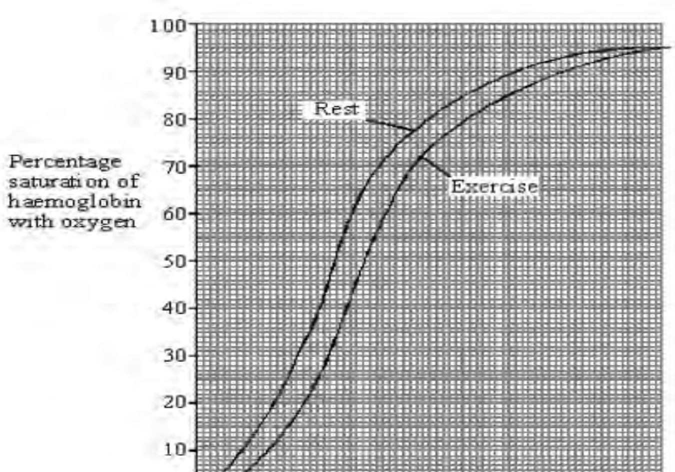
This implies that the lugworm's haemoglobin dissociates to release oxygen to its tissues compared to that of man which makes the lugworm less active than man, who releases much oxygen rapidly to the tissues.

Comparison between the oxygen dissociation curves of different sized mammals



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

Comparison between the oxygen dissociation curves at rest and during exercise



During exercise, the 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.

Comparison between the oxygen dissociation curve of maternal haemoglobin and that of the foetal haemoglobin

The oxygen dissociation curve of foetal haemoglobin lies to the left of maternal haemoglobin as shown in the diagram besides;

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.

(Clegg fig 17.36 pg 363 OR Toole fig 21.7 pg 416 OR Soper fig 14.32 pg 481)

Effect of changing altitude on oxygen carriage

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 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 (lack of oxygen) 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 heart beat. 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. Increase in the amount of haemoglobin and red blood cells together with increase in the breathing rate and heart beat increases the oxygen carrying capacity of the blood to the tissues which leads to the disappearance of the symptoms of anoxia and which also makes the individual organism to be acclimatized. 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.

The graphs below show the oxygen dissociation curves of people living at sea level and at high altitude

(Clegg fig 17.37 pg 363 OR Toole fig 21.4 pg 415 OR Soper fig 14.31 pg 481 OR Simpkins fig 8.19 pg 145)

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 e.g. the llama. This explain why the oxygen dissociation curve of the haemoglobin of the llama lies to the left of that of other mammals at sea

Describe the acclimation changes undergone by humans at high altitudes

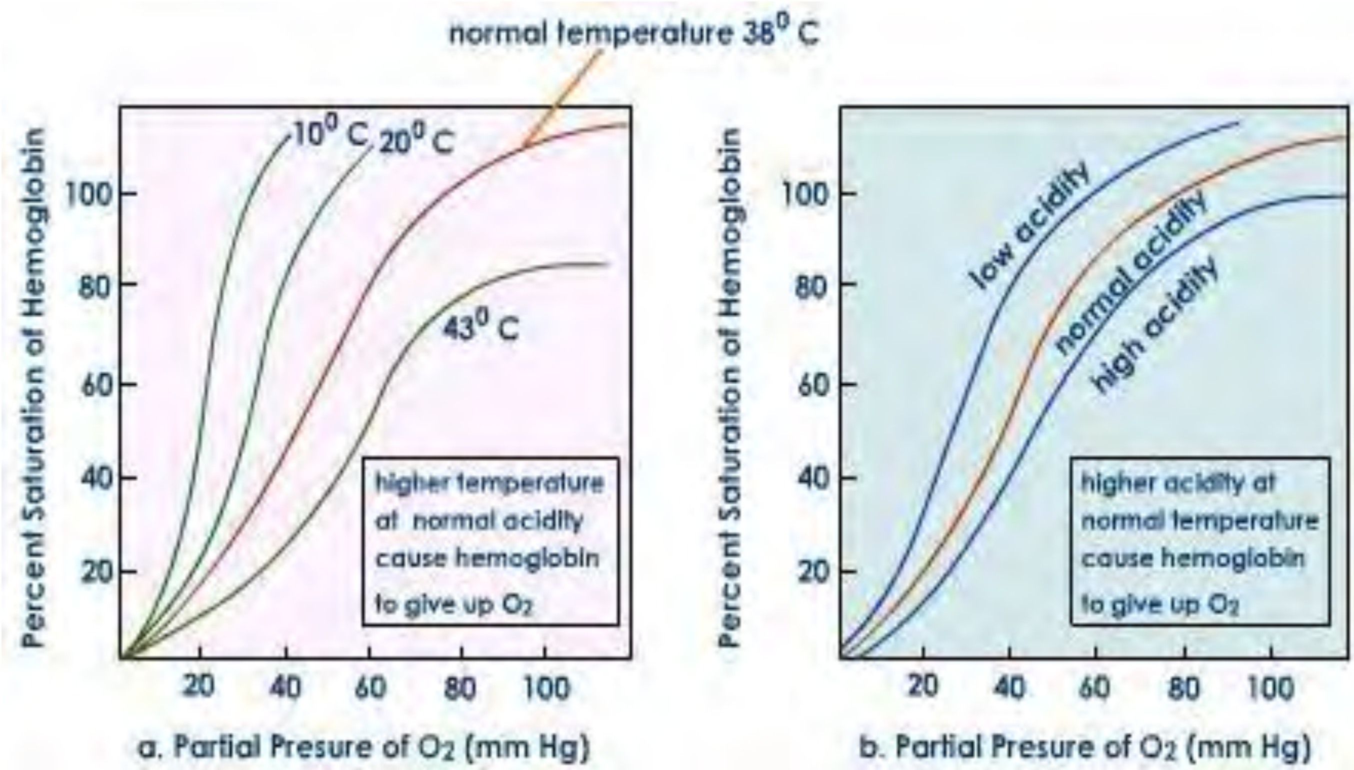
Describe the adaptations of diving mammals

Effect of temperature on haemoglobin oxygen dissociation curve

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. This is so because increase in temperature makes the bonds which combine haemoglobin with oxygen to break, resulting into the dissociation of oxyhaemoglobin.

Oxygen dissociation curve for haemoglobin at different temperatures



TRANSPORT OF CARBON DIOXIDE

Carbon dioxide is transported from the body tissues mainly inform of bi-carbonate ions in blood plasma to the lungs for removal.

Although carbon dioxide is mainly transported inform of bi-carbonate ions i.e. 85%, carbon dioxide can also be transported in the following ways;

a. About 5% of carbon dioxide is transported in solution form. Most of the carbon dioxide carried in this way is transported in physical solution. A very small amount is carried as carbonic acid. In the absence of haemoglobin, the plasma proteins buffer the hydrogen ions to form weak proteionic acids.
b. About 10% of carbon dioxide combines with the amino group of haemoglobin to form a neutral compound known as **carbamino haemoglobin ($HbCO_2$).** If less oxygen is being carried by haemoglobin molecule, then more carbon dioxide is carried in this way as $HbCO_2$.

Transportation of carbon dioxide inform of hydrogen carbonate ions

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

$$H_2CO_{3(aq)} \longrightarrow H^+ + HCO^-_{3(aq)}$$

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.

$$HbO_8 \longrightarrow Hb + 4O_{2\,(g)}$$

The free oxygen molecules diffuse into the tissues to be used in respiration. The free haemoglobin molecules buffer the hydrogen ions (H^+) inside the red blood cells into a weak acid known as **haemoglobinic acid**

$$H^+ + Hb \longrightarrow HHb$$

In case of excess H^+ plasma proteins are used to buffer them into another weak acid called **proteinic acid.**

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.

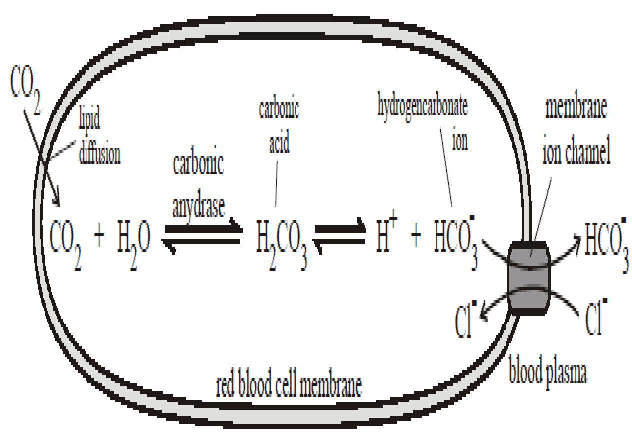
The outward movement of bicarbonate ions from the erythrocytes into the plasma results into an imbalance of positively charged and negatively charged ions within the cytoplasm. In order to maintain electrochemical neutrality, to remove this imbalance in the red blood cells, chloride ions diffuse from the plasma into the red blood cells, a phenomenon known as the **chloride shift**

When the bicarbonate ions reach the lungs, they react with H^+ to form carbonic acid which eventually dissociates into carbon dioxide and water.

$$H^+ + HCO_3^- \longrightarrow H_2CO_3$$

$$H_2CO_3^- \longrightarrow H_2O + CO_2$$

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



VASCULAR SYSTEMS IN ANIMALS

In animals, every vascular system has at least three distinct characteristics.

a. It has a circulating fluid e.g. blood
b. It has a pumping device inform of a modified blood vessel or a heart.
c. It has tubes through which the fluid can circulate e.g. blood vessels

Note; animals require a transport system because of;

- Surface area of the organism
- Surface area: volume ratio of the organism
- Activity of the organism
- The diffusion distance for the transported substances between the tissues to and from their sources.

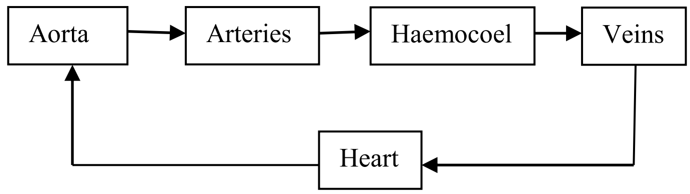
There are two types of vascular systems, the open vascular system and the closed vascular system.

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 e.t.c. 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 the ventral perivisceral cavity. 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.



Transverse section through the insect's heart

(Clegg fig 17.5b pg 344

Mechanism of open circulation

Blood flows through the heart from the posterior end to the anterior end by waves of contractions (systole) 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. The heart chambers are equipped with valves which allow blood to enter, but not to leave, the heart through them.

Closed vascular system

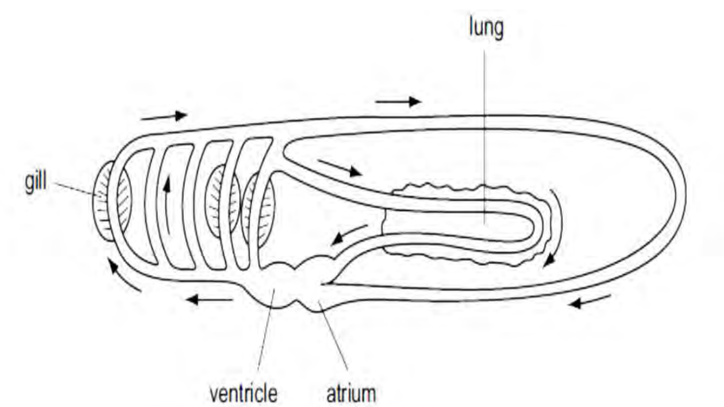
In a closed vascular system, blood flows in blood vessels or sinuses. It occurs in all vertebrates, annelids such as earthworms, cephalopods and echinoderms. The distribution of blood in this system is therefore adjustable e.g. blood from the heart is at high pressure and that to the heart is at low pressure. Closed vascular systems are further divided into single and double circulation.

A. Single and double circulation

Single circulation is the flow of blood through the heart once for every complete circulation around the body. Single circulation occurs in fish and 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.

The problem of single circulation is that blood tends to move very slowly at the venous side due to the significant drop in pressure before completing the circulation. The drop in pressure is as a result of capillaries having a considerable resistance to blood flow i.e. capillaries in the gills and body tissues. The sluggishness of blood flow at the venous side is solved by replacing the veins with large sinuses which offers minimum resistance towards blood flow.

Diagram showing single circulation in fish



Vascular system of the earthworm (annelid)

The earthworm belongs to phylum annelida. Annelids are coelomate animals i.e. they have a body cavity that separates the muscular wall of the animal from the internal organs.

T.S of the annelid vascular system

Clegg fig 17.6 pg 344

The largest vessel is the longitudinal muscular-walled dorso vessel and it is above the alimentary canal (gut). The peristaltic contraction from the posterior end of the vessel drives blood forward to the anterior end of the animal. The backflow of blood is prevented by valves. Each valve originates from a fold of an internal membrane or tissue of any blood vessel that is called an endothelium.

The dorso vessel collects and receives blood from the body wall, the gut, the nerve cord and the nephridia via capillaries. The dorso vessel connects with the smaller more contractile ventral vessel via five pairs of contractile pseudo hearts.

Each pseudo heart has four valves which permit the blood to flow towards only the ventral vessel and back to the posterior end of the animal.

Between the ventral vessel and the organs in the coelom e.g. nephridia and gut, there are a series of segmented blood vessels which run between them and they end up forming capillaries where there is exchange of materials between the organs and the blood in the capillaries. From the capillaries, blood fills its way back to the dorso vessel for its flow to the anterior side due to the peristaltic movement of the dorso vessel.

The blood is red in colour with haemoglobin.

B. Double circulation

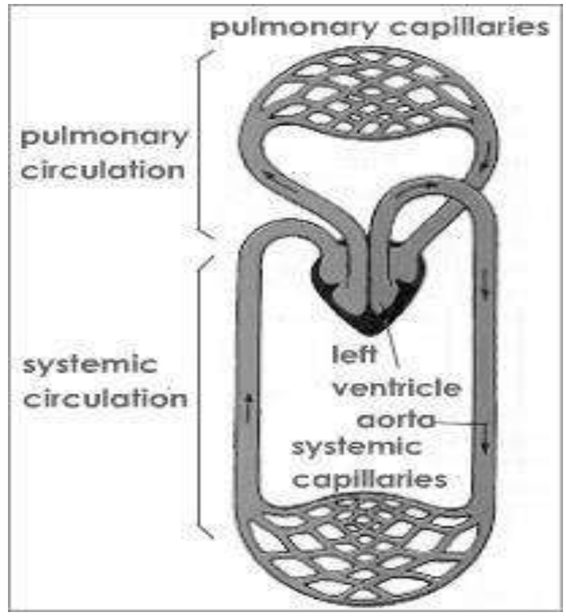
Double circulation is the flow of blood through the heart twice for every complete circulation around the body.

In double circulation deoxygenated blood from body tissues is pumped from the heart to the lungs from where it returns to the heart after being oxygenated and it is then re-pumped to the body tissues so as to supply oxygen to the body tissues. A double circulation serves as one of the solutions towards the sluggish flow of blood at the venous side in single circulation

In double circulation, the heart must be divided into the left and right chambers to prevent oxygenated blood from mixing with deoxygenated blood e.g. in reptiles, birds and mammals have a four chambered heart made up of the right atrium and ventricle and the left and atrium and ventricle.

The frog experiences double circulation although its heart has three chambers namely; one ventricle and the two atria i.e. the left and right atria. Both deoxygenated and oxygenated blood in the frog flow through the same ventricle and conus arteriosus at the same time without mixing. This is achieved due to the folding in the walls of the ventricle which enhances the separation of deoxygenated blood from oxygenated blood and this separation is also facilitated by the spinal valves in the conus arteriosus.

Diagram showing double circulation in a frog and a mammal



(Roberts fig 11.17 pg 175)

Some organisms e.g. the octopus and squids solve the problem of sluggish flow of blood of the venous side by possessing brachial hearts which pump deoxygenated blood from the body tissues of the gills and eventually back to the main heart. The main heart pumps, oxygenated blood to body tissues from the gills.

MAMMALIAN BLOOD CIRCULATION

The mammalian blood circulation is a double blood circulation which is mainly based on the heart and blood vessels,

BLOOD VESSELS

There are three main types of blood vessels; arteries, veins and capillaries. The walls of these blood vessels occur in three layers, namely;

a. Tunica externa (outer most layer)
b. Tunica media (middle layer)

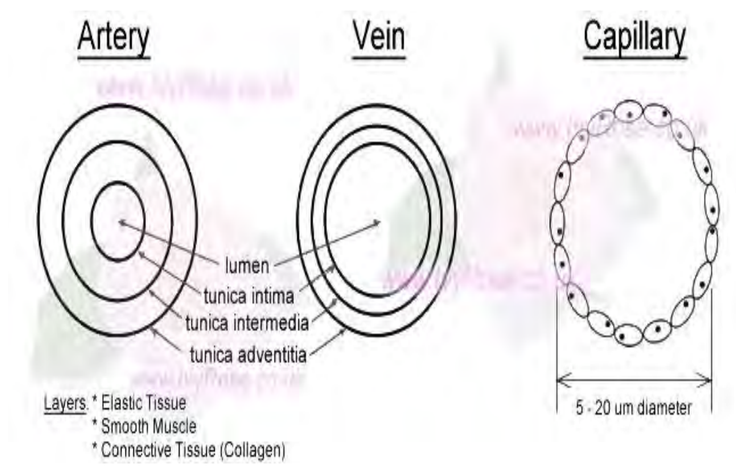
c. Tunica interna (inner most layer

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.

Diagrams showing the transverse sections of the vein, artery and capillary



Comparison 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. 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 capillaries lack both the tunica externa and the tunica interna.

In addition 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. 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. ***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. Therefore ***arteries*** can be defined as blood vessels which transport blood away from the heart and ***veins*** are defined as blood vessels which transport blood from the tissues to the heart.

Adaptations of blood capillaries

4. 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.
5. 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.
6. 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.

4. They possess the capillary sphincter muscles which contract and relax so as to regulate the amount of blood entering into the capillary network.
5. 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 e.t.c.
6. 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.

Diagram showing the capillary network

Clegg fig 17.18 pg 353

THE MAMMALIAN HEART

Structure of the mammalian heart

The heart is the muscular organ pumping blood to all body organs using its chambers. It is made up of four chambers which include the right and left atria (auricles) and the right and left ventricles. The four chambers enhance the blood flow through the heart at the same time without mixing it i.e. deoxygenated blood is separated from oxygenated blood. The oxygenated blood flows through the left atrium and ventricle while the deoxygenated blood flows through the right atrium and ventricle.

The heart is composed of the **cardiac muscles** within its walls which are **myogenic** in nature, in a way that, the initiation of their contraction is not under the control of the central nervous system but is within the muscles themselves. This enables them to contract continuously and rhythmically without fatigue and therefore enables the heart to beat and pump without stopping.

Clegg fig 17.8 pg 347

The heart consists of atrioventricular valves/ pocket valves and semi lunar valves. The atrioventricular valves include the following;

a. The three (3) flapped tricuspid valves found between the right atrium and the right ventricle
b. The two (2) flapped bicuspid valves which prevent back flow of blood from the left ventricle to the left ventricle.

The semi lunar valves are prevented from turning inside out by connective tissues called **tendinous cords**

The heart linked with four blood vessels which include the following;

i. **The venacava** which transports deoxygenated blood from body tissues through the right atrium of the heart.
ii. **The pulmonary artery** which transports deoxygenated blood from the right ventricle of the heart to the lungs.
iii. **The pulmonary vein** which transports oxygenated blood from the lungs into the left atrium of the heart.
iv. **The aorta** which is the biggest vessel and it transports oxygenated blood from the left ventricle of the heart to the body tissues.

The left ventricle is more muscular (thicker) than the right ventricle because the left ventricle has to contract more powerfully than the right ventricle in order to enable oxygenated blood with high pressure to move for a long distance to the body tissues unlike the right ventricle which pumps deoxygenated blood with low pressure for a short distance to the lungs.

Initiation of the heart beat

The cardiac muscle within the walls of the heart is myogenic in nature in a way that the initiation of its contraction is within the muscle itself, but not under the control of the central nervous system (brain and spinal cord). This enables the muscles to contract continuously and rhythmically without fatigue to enable the heart to beat continuously and rhythmically without stopping. The intrinsic initiation of the heart beat enables the heart to remain beating even it is surgically removed from the body, provided it is under ideal conditions.

The rhythmic contraction of the cardiac muscles is initiated by specialized network of fine cardiac muscles network found inside the wall of the right atrium close to the entrance of blood from venacava into the right atrium. This network of fine cardiac muscle fibre is known as Sino Atrial Node (SAN) and it serves as a pace maker by giving off a wave of electrical excitations similar to impulses, which spread out very rapidly over both atria causing them to contract and force blood into the ventricles via the open atrial ventricular valves.

When the electrical excitations reach the junction at the boundary of the atria, they excite another specialised plexus of other cardiac muscle chambers known as Atrio Ventricular Node (AVN). When excited, the AVN sends waves of electrical excitations down to another bundle of cardiac muscle of fibres formed along the inter-ventricular septum called the Purkinje tissue or Bundle of His to the apex of the heart. This conducts and spreads the excitement to both ventricles which eventually pump blood into the arteries.

Diagram showing how the waves of electrical excitations spread from the SAN

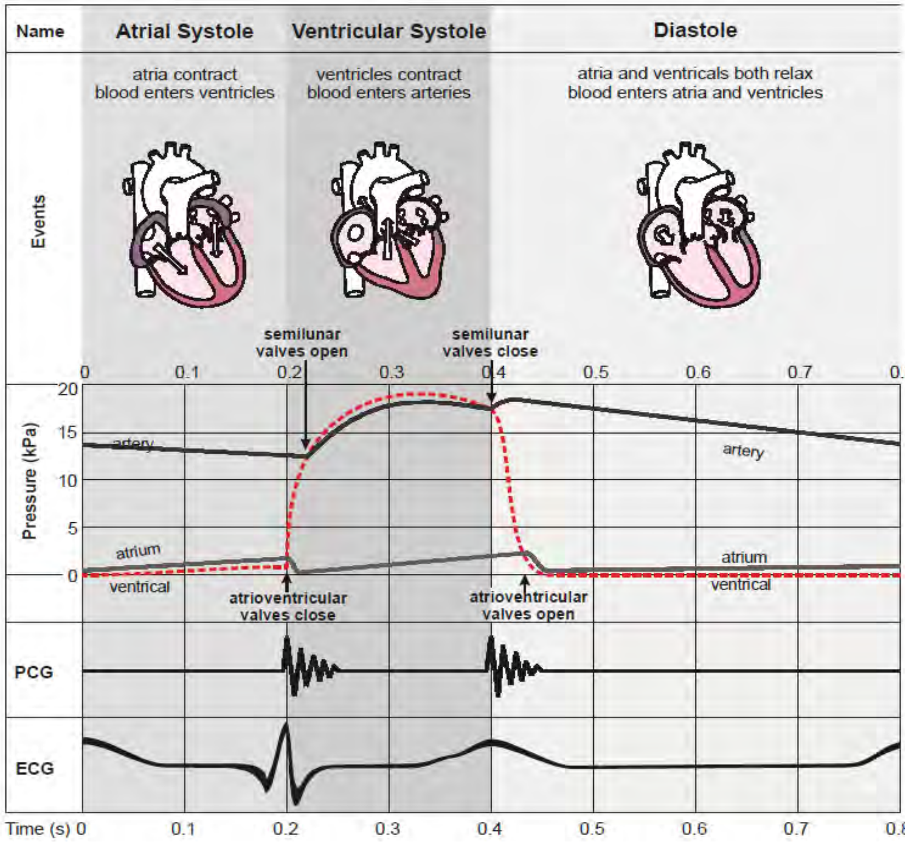
Clegg fig 17.10 pg 349

NOTE;

a. The closing of the atrioventricular 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.***
c. The pulse in the arteries is due to ventricular systole and elastic recoil of the arteries due to high pressure of blood.
d. The pulse is more pronounced in the arteries

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 atrioventricular valves closing and the second sound (dub) it is the semi lunar valves closing.

The ECG (electrocardiogram) is a recording of the electrical activity of the heart. There are characteristic waves of electrical activity marking each phase of the cardiac cycle. Changes in these ECG waves can be used to help diagnose problems with heart.



The cardiac cycle (Sequence of the heart beat)

This is the sequence of events of heart beat by which blood is pumped around the body. The pumping action of the heart consists of alternate contractions of heart muscles (cardiac muscles) called **systoles** and relaxations called **diastoles**. The term cardiac output refers to the volume of blood pumped from each ventricle.

The cardiac cycle begins with the contractions of the atria i.e. **atrial systole,** which is initiated by SAnode and it which causes the atria volume to decrease and the atria increases. As the atria contracts, the ventricles relax i.e. undergo ventricular diastole, causing the bicuspid and tricuspid valves to close. The contraction of the atria due to blood entering the atria forces the bicuspid and tricuspid valves to open so that blood moves from atria into the ventricles.

Contraction of atria walls has an effect of sealing off the venacava and pulmonary veins, thereby preventing the back flow of blood into the vessels as the blood pressure rises within the atria. It takes 0.1 seconds.

When the ventricles are filled with blood from atria, their walls contract simultaneously i.e. **ventricular systole**, and the atria relax i.e. **atrial diastole.** Ventricular systole is initiated by impulses from AVnode to the bundle of His, Purkije fibres and rapidly through the ventricle muscles. The ventricles' volume reduces while the pressure increases, forcing the bicuspid and tricuspid valves to close and prevent the back flow of blood into the atria. The increased pressure in the ventricles also forces blood to be pumped into the pulmonary artery via the open semi lunar valves from the ventricles. This enables the blood to be pumped into the lungs via the pulmonary artery and into the body tissue via the aorta.

The ventricular systole is more powerful than the atrial systole because the ventricles are more muscular than the atria and therefore generate more pressure. The powerful ventricular systole forces blood into the atria and pulmonary artery.

After ventricular systole, there's a short period of simultaneous atrial and ventricular relaxations. In the **ventricular diastole**, the high pressure developed in the ventricles causes a slight back flow of blood which closes the semi lunar valves, thereby reducing blood back flow.

Relaxation of the atrial wall and contraction of the ventricle, initiates the refilling of the atria by blood under relatively low pressure i.e. deoxygenated blood in the venacava flows into the right atrium and oxygenated blood from the lungs flows into the left atrium via the pulmonary vein.

Intrinsic control of the 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 SAnode 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-ventricluar 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 (Purkyne tissue) throughout the ventricular walls. This causes the contraction of both ventricles forcing blood into the pulmonary arteries and the aorta.

Characteristics of the cardiac muscle in relation to excitation and contraction

a. The absolute relative refractory period is longer than that of other muscles i.e. the heart cannot be fatigued easily
b. The generation of the wave from the SAN has a refractory period between contraction of the heart and relaxation of the heart i.e. the waves are not generated continuously.

Control of the rate of the heart beat

Though the initiation of the contraction of cardiac muscle and hence initiation of heart beat are not under the control of the central nervous system, the rate at which the heart beats to pump blood is under the control of the autonomic (Involuntary) 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.

(Clegg fig 17.13 pg 350 OR Soper fig 14.24 pg 475)

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.

NOTE;

Cardiac output (volume of blood going out of the heart) = **Rate of heart beat** **X** **Cardiac frequency**

Soper fig 14.25 pg 476

Internal factors affecting the heart beat

1. Body temperature
2. Blood pH
3. Carbon dioxide concentration
4. Partial pressure of oxygen
5. Hormonal balance
6. Salt balance
7. Blood pressure
8. Emotional situations
9. Impulses from the venacava and aorta

Control of blood pressure

Small receptors which are sensitive to stretching, called **baro receptors** are found in the walls of aortic arc, carotid sinuses, vena cava and the right atrium become stimulated when blood pressure increases above the norm. They fire impulses to the vasomotor centre and cardio vascular centre found in the medulla oblongata of the brain via the afferent nerves (sympathetic nerves). The cardio vascular centre sends impulses to the heart via the efferent nerves (vagus nerves), which results into reduction of the cardiac output. The vasomotor centre on receiving impulses, its sympathetic output is suppressed and this lowers the blood pressure by causing vasodilation of the arterioles

When the blood pressure lowers below the norm, the baro receptors stop being stimulated and this leads to impulses being fired from the cardio vascular centre to heart. The cardiac output is then increased. Decrease in blood pressure also increases the vasomotor centre sympathetic output which results into vasoconstriction of the arterioles hence increasing the blood pressure back to normal.

NOTE: When the arterioles constrict (vasoconstriction) blood pressure is raised and when they dilate (expand) the blood pressure decreases.

Stimulus → Receptor → Regulator → Effectors → Response

Pressure change → Barorece ptorss → Brain → Muscles, glands, arterioles & cardiac muscle → Response

The brain includes the vasomotor, cardiovascular centre and the medulla oblongata

Note:-Blood pressure depends on the following factors;

- Blood volume
- Force of the heart
- Blood vessel radius/ diameter of the lumen

Blood volume is adjusted to some extent through contraction of the spleen and liver which bring stored blood into circulation. The stored blood is due to the regulation of the fluid intake and fluid loss by organs such as the kidney and the skin during homeostasis.

Blood vessels offer resistance **(R)** to blood flow. The resistance is inversely proportional to the fourth power of the radius **(r)** of the vessel **($R \propto \frac{1}{r^4}$).** Therefore, the resistance increases as the vessel becomes narrower and since we are dealing with the fourth power of the radius, small changes in the arterioles radius will make a large difference to the resistance.

[Clegg fig 17.17 pg 352 OR Soper fig 14.26 pg 477]

Page

NOTE:

Blood is expelled from the heart only when it contracts. Blood flow through the arteries is therefore *intermittent,* the blood flowing rapidly during systole and slowly during diastole. However, by the time the blood reaches the capillaries it is flowing evenly. The gradual change from intermittent to even flow is made possible by the elasticity of the of the arterial walls which contain elastic tissue and smooth muscles

DEFENCE AGAINST DISEASES

Every mammal is equipped with a complex system of defensive mechanisms which are designed to enable it prevent the entry of microbes into it, to withstand attacks by pathogens (disease causing micro-organisms) and to remove foreign materials from the system.

The defensive mechanisms of blood include the following;

a. Clotting of blood
b. Phagocytosis
c. Immune response to infection

Clotting of blood

When a tissue is wounded, blood flows from it and eventually coagulates to form a blood clot which covers the entire wound. This prevents further blood loss and entry of pathogens. The process of blood clotting is described below.

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.

(Clegg fig 17.41 pg 365)

Note:

a) **Heparin** is an anticoagulant which inhibits the conversion of prothrombin to thrombin thereby preventing blood clotting.
b) Apart from blood clotting, the entry of microbes into the body can be prevented by the following;
    i. Using impermeable skin and its protective fluid called sebum (oily secretion in the skin)
    ii. Using mucus and cilia to trap the microbes and then remove them
    iii. By using hydrochloric acid in the stomach
    iv. By using lysozyme enzyme in the tears and nasal fluids
    v. By vomiting and sneezing

Why blood does not clot in the vessels

1. Connective tissue plus the liver produce chemical, heparin, which prevents the conversion of prothrombin to thrombin, and fibrinogen to fibrin.
2. Blood vessels are smooth to the flow of blood. Damage to the vessel's endothelium can lead to platelets breakdown which leads to clotting of blood.

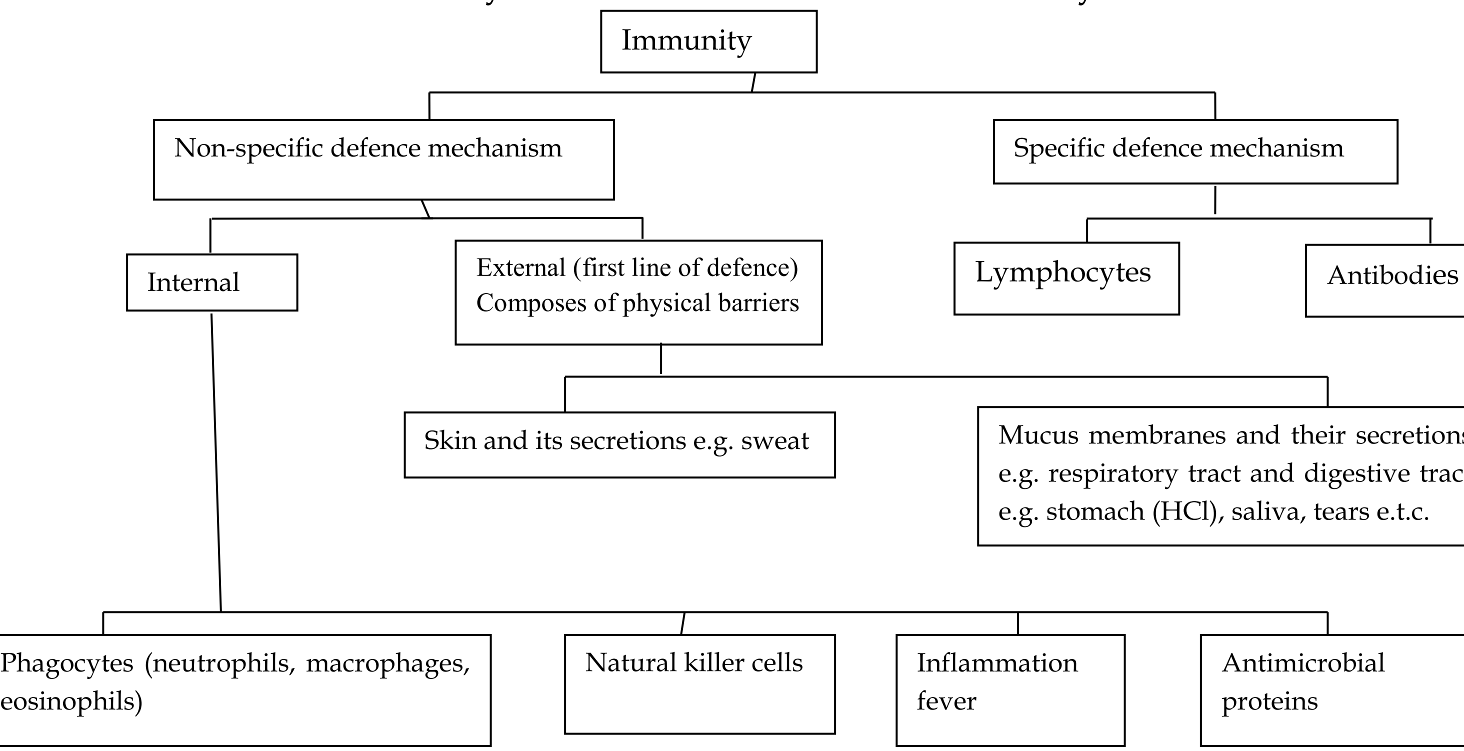
BODY DEFENCE SYSTEM AND MECHANISM IN MAMMALS (HUMANS)

An animal must defend itself against unwelcome intruders e.g. dangerous viruses and other pathogens it encounters in the air, water and food. The body also deals with abnormal cells (cancer cells) that develop periodically in the animal's body.
Two comparative defensive systems are used to fight pathogenic and abnormal cells in the body. One of the system is **non-specific** in nature i.e. it does not distinguish ones infections agent from another. The other defence system is **specific** in nature and constitutes the **immune system**. The non-specific system includes two lines of defence which an invader encounters in sequence. The first line of defence is external comprising of epithelial tissues that cover and line our bodies (skin and mucus membranes) and other secretions these tissues produce. The second line of non-specific defence is internal. It is triggered by chemical signals and uses antimicrobial proteins and phagocytic cells that indiscriminately attack any invader that penetrates the body's outer barrier (inflammation is a sign that tins second line of defence has been deployed.
The immune system constitutes a third line of defence which comes into place simultaneously with the second line of specific defence. However, the immune system responds specifically to a particular type of invader. This immune response includes

the production of specific defence proteins called **antibodies**. It also involves participation of several different types of cells that are derived from the white blood cells called **lymphocytes**.

NOTE: the non-specific defence system which involves use of phagocytes, natural killer cells and antimicrobial proteins is said to offer innate immunity (defence) which is abroad defence mechanism against infection. The immune response offers a specific defence against infection. It is also described as **acquired immunity**. Immunity is the ability of an organism to resist infection or to counter the harmful effects of toxins produced by infecting organisms.

A summary of defence mechanisms in an animal's body



NON SPECIFIC DEFENCE MECHANISM

The non-specific defence mechanism act in 6 ways i.e.

- Through physical barriers e.g. skin.
- Phagocytosis.
- Natural killer cell.
- Anti-microbial proteins.
- Inflammation.
- Fever

THE SKIN AND MEMBRANES

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.

Mucus, which is a viscous secreted by cells of the mucus membranes also traps particles that contact it. Microbes entering the upper respiratory system are caught in the mucus and are the swallowed or expelled.
The lining of the trachea has specialized epithelial cells equipped with cilia which sweep out microbes and other particles trapped by mucus, preventing them from entering the lungs.
Microbes prevent in food or trapped in swallowed mucus from the upper respiratory system pass through the highly acidic gastric juice produced by the stomach lining which destroys most of the macrobes before enter the intestinal tract.

PHAGOCYTIC DEFENCE MECHANISM

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 term macrophage means "**big eater**" and these cells 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 (*Schistosoma mansoni*) they rarely engulf such a large parasite but position themselves against the parasites body and though discharged destructive enzymes which demage the invader.

A drawing to summarize the phagocytic process affected by neutrophil, macrophage or monocytes.

NATURAL KILLER (NK) CELLS

This is a class of white blood cells which attack virus injected body cells and abnormal cells that could form tumours.
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.

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.

N.B. it is the damaged cells and certain leucocytes that produce histamine and

Prostaglandins. 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.

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 tumour cells and virus infected cells.

ANTIMICROBIAL 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

(specific defence system) interferon is one of the proteins of the complement system which provides innate defence against viral infection the interferon protein is secreted by virus infected body cells and induce neighbouring uninfected to produce other substances that inhibit viral reproduction. In this way, inteferons limit the cells spread of viruses in the body helping control of viral infections such as colds and influenza.

SPECIFIC DEFENCE SYSTEM /IMMUNE SYSTEM/ ACQUIRED IMMUNITY

The specific immune response confers immunity against specific microbes. (immunity is the capacity of an organisms body to recognize the intrusion of foreign materials in the body and mobilize cells and cell products (anti bodies) to remove a particular sort of foreign material to a greater speed and effectiveness) the specific defence system 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)

MAJOR CELLS IN THE IMMUNE SYSTEM.

1. B-CELLS (B-LYMPHOCYTES)

These are lymphocytes that produce antibodies when stimulated. They are produced and mature in the bone marrowsfrom 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-LYMPOCYTES)

The T-lymphocytes regulate the immune response (in case of T_H-cells) or kill certain types of cells (Tc-cells) the T cells are produced in the bone marrow but mature in the thymus gland where they develop specific receptors which recognise specific antigens. These are two main categories of T cell namely

- T_4 cell which have the CD4 receptor cites

- Thelper cells.
- TC/T.cytotic cells recognize and destroy cells with foreign antigens on their surface. They mainly attack virus infected cells, cancerous body cells and foreign grafted tissues

T_4 cells recognize and destroy cells with foreign antigens on their surface. They mainly attract virus infected cells, cancerous body cells and foreign grafted tissues.

T_4 cells stimulates and enhance the immune responses by both B and Tc cells. T cells include the following;

Killer T-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.

Helper T-cells

These are cells that recognize a specific antigen on an antigen-presenting cell, binds to it, and then assists a B-cell binding the same antigen to proliferate into specific antibody secreting cells.

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.

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.

MOLECULES OF THE IMMUNE SYSTEM

1. Antibody

This is a specific protein (immunoglobin) which recognizes and binds to specific antigens. Antibodies either neutralise antigens or tag cells that are antigens for easy attack by macrophages.

N.B. Macrophages are also taken to be part of the immune response i.e. involved in specific defence mechanism through indirectly since they are phagocytes which destroy microbes and alert other immune cells the infection.

2. Epitopes

These are antigens determinants with specific sequences of amino acids that confer as specific shape to the antigen molecules which is then recognized by an antibody or T-cell receptor. An antigen can have several different epitopes on its surface and different antibodies can therefore bind a single antigen.

3. Cytokines (lympokines)

These are peptides and proteins that regulate many cell activities (growth and repair) and act as signal in both the specific and non-specific immune responses

Examples of cytokines include

- Interferons
- Interleukin

4. Complement system.

This is a group of about 20 proteins found in plasma and other body fluid. These are inactive until the body is exposed to antigens e.g. histamines.

CHARACTERISTICS OF THE 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.

- Specificity.
- Diversity
- Memory
- Self/non self-recognition.

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 defences, each response the immune system targets a specific invader distinguishing it from other foreign molecules that may be very similar.

Diversity

The immune system has the ability to respond to very many kids 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.

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.

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

.TYPES OF ACQUIRED IMMUNITY

There are two types of acquired immunity namely:

- Active acquired immunity.
- Passive acquired immunity.

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.

In **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.

NB. 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.

MECHANISM OF IMMUNE RESPONSES

The immune system mounts two different types of responses to antigens namely;

- Cell-mediated response.
- Humoral response.

HUMORAL RESPONSE

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, the fluids that were once called humors.

In the cell mediated response, the immunity depends on the direct action of the T-lymphocytes rather than antibodies.

N.B: The circulating antibodies of the humoral branch of the immune response defends the body against toxins, free bacteria and viruses present in the body fluids. In contrast, lymphocytes of the cell mediated branch are active against bacteria and viruses inside the body's cells and against fungi protozoa and worms. The cell mediated immunity is also involved in attacks on transplanted tissue and cancer cells both of which are perceived as non self.

HOW ANTIBODIES WORK

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.

Neutralisation

Here the antibody blocks certain sites on an antigen or toxins making it effective. Antibodies neutrallise 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 neutralised, eventually, phagocytic cells (macrophages) destroy these antigen-antibody complexes.

Agglutination (clumping)

This is when antibodies cross link adjacent antigens. 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 licked to form immobile precipitates which are captured by phagocytes and macrophages that destroy them.

Opsonisation

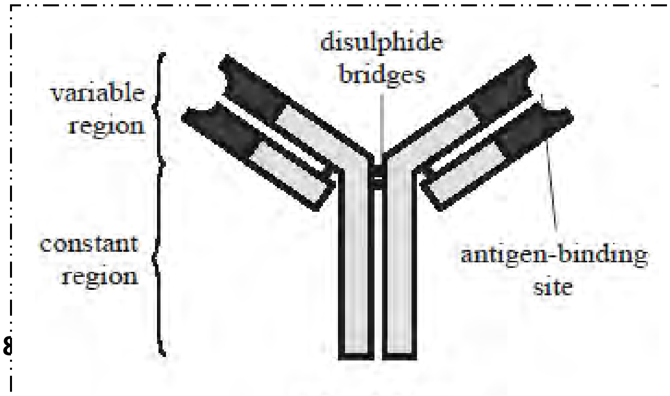
Here, the antibody molecule oats the surface of a microbe making it easier for phagocyte leucocytes to engulf it.

Complement fixation

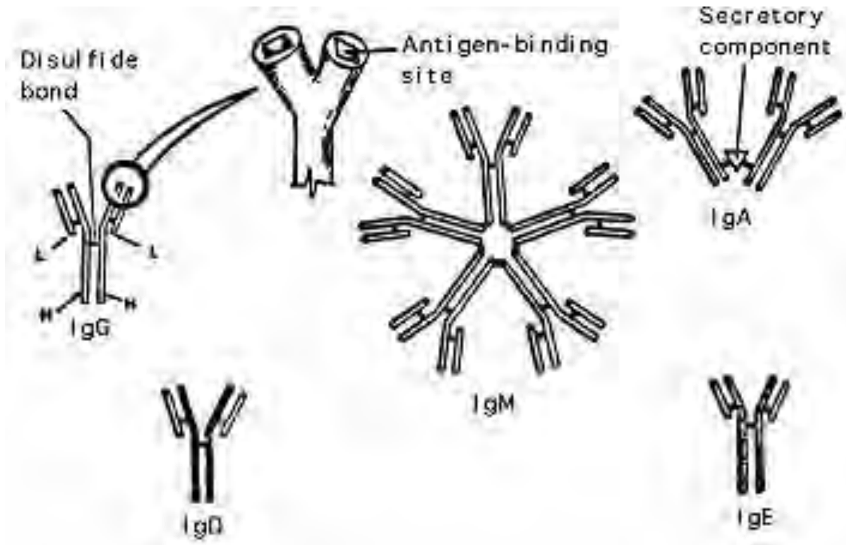
Here, the antibodies activate the complement proteins which then leads to lysis of foreign cells.

TYPES OF ANTIBODIES

Antibodies constitute a class of proteins called immunoglobulins (igs). 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 of two light and two heavy linked together by sulphide bridges (s-s) and has got a Y shaped molecule. Most of the molecule is the same for all antibodies of the same



There are 5 classes of immunoglobulins namely
- IgM (pentamer)
- IgG (monomes)
- IgA (dimes)
- IgD(monomers)
- IgE (monomes)



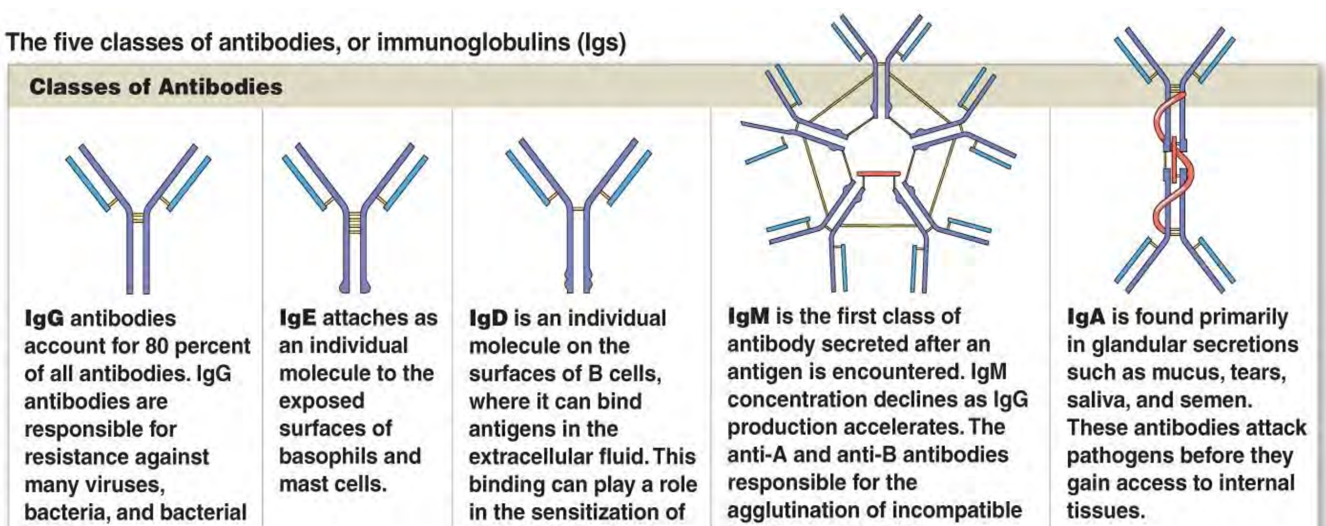
IgMs
These are the 1st circulating antibodies to appear in response to an initial exposure to an antigen. Their concentration in blood declines rapidly and this is useful diagnostically because their presence indicates a current infection by the pathogen, causing its formation. The IgM consists of 5 Y shaped monomers arranged in a pentamer structure.
Note. The numerous antigen-binding sites of an IgM make it very effective in agglutinating antigens and in reaction involving complements. However the IgM is too large to cross the placenta and does not confer material immunity

IgG
IgG is the most abundant of the circulating antibodies. It readily crosses the wall of blood vessels and enters tissue fluids. IgG crosses the placenta and confers passive immunity from the mother to the fetus. IgG protects against bacteria, viruses and toxin circulating in blood and lymph and triggers action to the complement system.

IgA
This is produced inform of 2 Y shaped monomers (it is a dimer) by cells abundant in mucus membranes. The main function of IgA is to prevent the attachment of viruses and bacteria to epithelial surfaces. IgA is also found in many body secretion such as saliva perspiration (sweat) and tears. It is also present in colostrums (1st milk of nursing mammal) it protects the infant from gastro-intestinal infections.

IgD
IgD antibodies do not activate the complement system and cannot cross the placenta. They are mostly on the surfaces of the B cells where they function as antigen receptors required for initiating the differentiation of B-cells into plasma and memory cells

IgE
These are slightly larger than IgG molecules and represent only a very function of the total antibodies in blood. The tail region attach to receptors of most cells and basophiles and when triggered by an antigen, cause the cells to release instamine and other chemicals that cause an allergic reaction.



Cell mediated immune response.

When a microphage ingests a bacteria, most of the bacteria antigens are destroyed by its enzymes. However some fragment of the foreign antigens combine with the major histo compatibility class II proteins (MHC-Class II) which are found on the macrophages cell surface membrane. In this way, the macrophage becomes an antigen presenting cell (APC). The APC interacts with helper T-cells especially those with CD4 receptors. The CD4 receptors hold the APC and TH cells together while activation occurs.

The APC is stimulated to several interleukin–I (IL-I) which then activates the TC cells to start dividing and to produce interlenkin-2 (IL-2). IL-2 stimulates the TH cell to divide more rapidly and produce even more interleukins.

IL-2 also stimulates the development of natural killer cell and B-cells. Interlenkin-2 also stimulates cytotoxic T-cell which generally have the CD8 receptors on their cell membranes. These receptors enable the TC cells to interact with the class I MHC molecule. If these cells are infected by viruses, the fragments of virus are displayed on the membrane with the aid of MHC protein. The T cell is also activated when it is in contact with the class I MHC antigen complex on an infected cell. The stimulated TC cell release perforins a protein that forms pores in the infected cell membrane. This results in the lysis of the infected cell. The pathogen e.g. a virus becomes exposed and it is destroyed by the circulating antibodies.

NB. In the same way, the T-cells attack tumour cells which display fragments of tumour antigen.

The Major Histocompatibility Complex (MHC) is a set of closely linked genes which code for a set of proteins (antigen marker) found on the surface of cells.

It is divided into two main classes i.e.

- The MHC class 1 antigens are carried by most nucleated cells and are important in self /non self-recognition.
- The MHC class-2 antigen are mostly found of B-cells, macrophages and some T-cells. However the components of the complement system are made of special class namely: the MCH class 3 proteins.

EXPLANATION OF HOW THE KEY FEATURES OF AN IMMUNE SYSTEM ARE REALIZED DURING THE SPECIFIC DEFENCE MECHANISM.

SPECIFITY AND DIVERSITY

Immunological specificity and diversity is based on clonal selection of lymphocytes if the antigen enters the body and binds to receptors on the specific lymphocytes, the nasal those lymphocytes are activated to mount an immune response. The selected cells proliferate by cell division and develop into a large number of identical effector cells known a clone. This clone of cells combat the very antigen that provoked the response e.g. plasma cells that develop from that function as the antigen receptor on the original B-cell. Which first encountered the antigen. The antigen specific selection and cloning of lymphocytes is called clonal selection.

In clonal selection, each antigen by binding to specific receptors selectively activate a tiny traction of cells from the body's diverse pool of lymphocytes. These relatively small numbers of selected cells, all dedicated to eliminating the specific antigen that stimulated the humoral or cell mediated immune response.

N.B. Antigens are molecules (usually proteins, polysaccharides or glycoproteins carried on the surface of cells which cause antibody formation. All cells have antigen makers on their cell surface membranes but the body can distinguish between its own antigen (self) and foreign antigen (non self)

Memory and secondary immune response

Memory cells function in secondary immune response. 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.

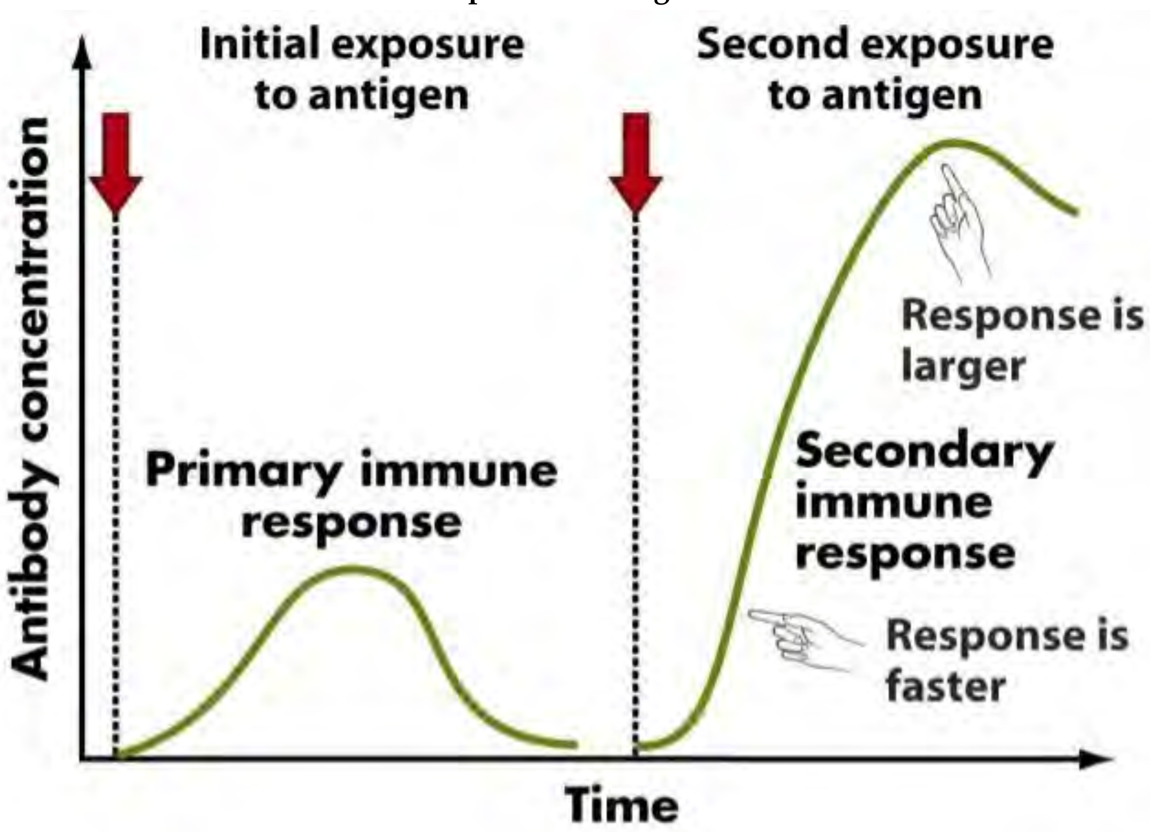
During the lag period, the lymphocytes secreted by the antigen differentiates into effector Tcells (TH and TC) and antibody producing plasma cells

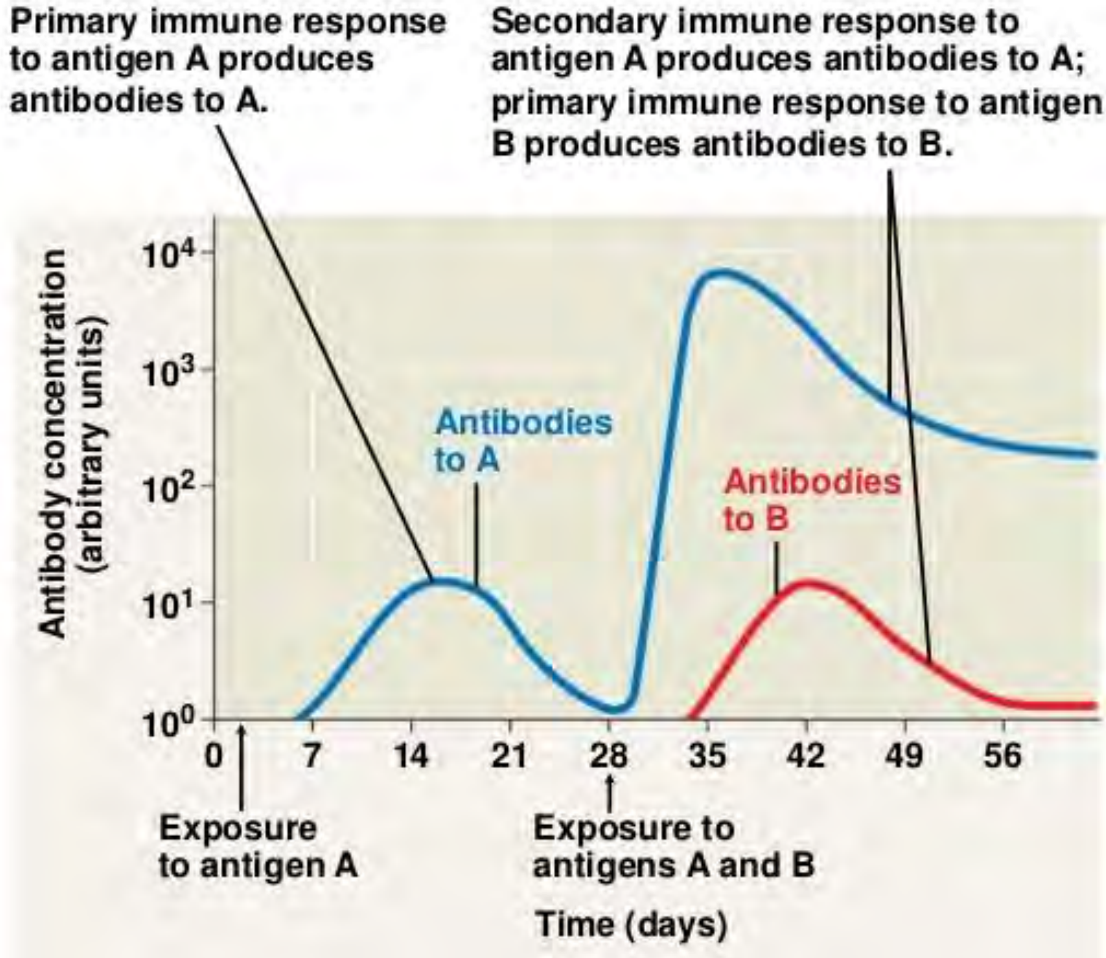
If the body is exposed to the same antigen at a later time, the response is faster one/more prolonged than the primary immune response. This is the secondary immune response.

Secondary immune response is the rapid response that results in faster production of effector Tcells 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 to illustrate changes in antibody concentration during primary and secondary immune responses to antigens





Self and non-self-recognition

Here, molecular markers on cell surface, function in self and non-self-recognition. The antigen receptors on the surface of lymphocytes are responsible for detecting molecules that enter the body. Normally, there are no lymphocytes that are reactive against the body's own molecules. Self-tolerance begins to develop as T and B lymphocytes bearing antigen receptors mature in the thymus and bone marrow and continues to develop with receptors for molecules present in the body are destroyed or rendered passive (non-functional) leaving only lymphocytes that are reactive against foreign molecules tolerated by an individual's immune system, are a collection of molecules encoded by a family of genes called the Major Histocompatibility complex (MHC) two main classes of MHC molecules mark cells as self. Class 2 MHC molecules are restricted to a few specialised cell types of the body's defence system e.g. macrophages, B-cells and activated T-cells.

NB. Class 2 MHC molecules play an important role in interaction between cells of the immune system.

ABNORMAL IMMUNE FUNCTION

Sometimes, the immune system fails to defend the animal against intruders instead turns against the components of the body which leads to certain disease. Conditions immune system abnormalities include;

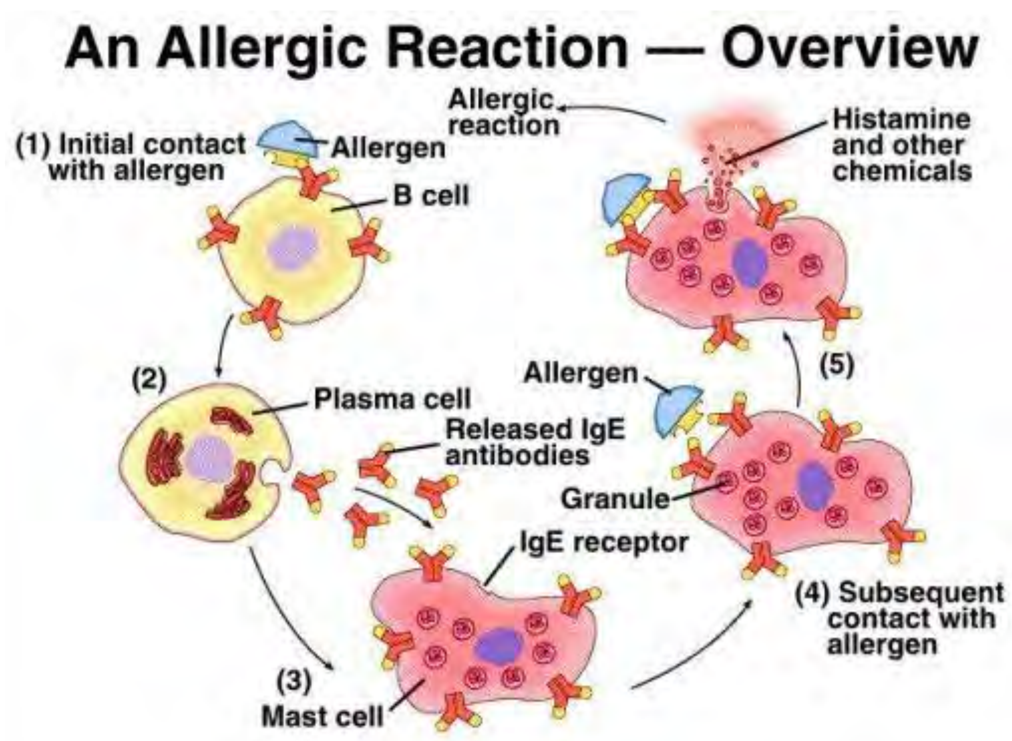
- Auto immune disease.
- Allergy.
- Immune deficiency.

AUTO IMMUNE DISEASES

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 Rheumatioal 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 infection (such as strep throat) react with heart muscles tissue damaging the heart valves. Repeated episodes of infecting results in more antibodies and more heart damage.

Allergy

Allergies are hypersensitivities of the body's defence system to certain environmental antigens called allergens. The most common allergens involve antibodies of the IgE class e.g. hay fever and other allergies caused by pollen allergens. The IgE antibodies attach by their tails to mast cells which are non-circulating cells found in connective tissue. In this way, a susceptible person become sensitized to the specific foreign antigen later.
When a pollen grain binds to the IgE and bridges the space between 2 IgE monomers, the mast cells responds with rapid reaction called degranulation releasing histamine and other chemicals.



NB.

a) Histamine causes dilation and increased permeability of the small blood vessels. In an allergy response, histamine causes symptoms like sneezing, a runny nose and smooth muscle contraction that often result into breathing difficulty.
b) Antihistamines are drugs that interfere with action of histamine
c) Upon first exposure to an allergy. The plasma cells secrete the IyE specific for the allergy. Some of these antibodies are attached by their cells to the mast cells. When upon second exposure, the allergen binds to IgE already on the mast cell. It triggers the degranulation of the cell.
d) Degranulation releases histamine leading to most of the symptoms at allergy.

IMMUNE DEFICIENCY

Certain individuals are inherently deficient (lack) in either humoral or cell medicated immune defences. In a congenital disorder, this is known as severe combined immune deficiency. For people with this genetic disease, long term survival requires a successful bone marrow transplant that will continue to supply functional lymphocytes.

Adaptation of mammals to oxygen deprivation

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 particulary occurs at relatively lower altitudes.
    i. 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.
    ii. 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.

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 subclavian 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.

N.B the lymphatic system serves to;

- Defend the body against infection.
- Maintains the level of interstitial fluid (tissue fluid).
- Transports fats from the digestive tract to the circulatory system (the lymph capillaries called lacteals) penetrate the villi of the small intestine which absorb the fatty acids and glycerol.

Whenever the interstitial fluid accumulates rather than being returned to the blood by lymphatic system, the tissues and body cavities become swollen a condition known as oedema.

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.

Note; toxins are toxic chemicals produced by microbes and therefore can work as antigens

BLOOD TRANSFUSION

This is the transfer of compatible blood from the donor to the recipient.

Blood transfusion based on the ABO system of grouping blood

Blood group A has antigen A on the surface of its red blood cells and antibody b in the blood plasma of that person. Blood group B has antigen B on the surface of its red blood cells and antibody a in the blood plasma of that person. Blood group AB has antigen B and A on the surface of its red blood cells and no antibody in the blood plasma of that person. Blood group O has no antigen on the surface of its red blood cells and both antibody b and a in the blood plasma of that person.

Blood group	Antigen on the red blood cell membrane	Antibody on plasma
A	A	b
B	B	a
AB	A and B	Lacks antibodies
O	No antigens	a and b

Blood plasma permanently contains antibodies depending on a particular blood group. However these antibodies do not correspond to a specific antigen, if they correspond then agglutination occurs (precipitation of blood). That is why an individual with blood A having antigen A cannot donate blood to an individual with blood group B having antibody a in the plasma which corresponds to antigen A to cause agglutination. Similarly, blood groups A and B cannot donate blood to an individual of blood group O because antigen A will be attacked by antibody a in blood group O and antigenB will be attacked by antibody b in blood group O to precipitate the recipient's blood. The table below summarizes the possible blood transfusions and the impossible ones.

Blood group compatibilities

Recipient		**Donor's blood group**			
Blood group	**Antibody in plasma**	**A**	**B**	**AB**	**O**
A	B	✓	X	X	✓
B	A	X	✓	X	✓
AB	None	✓	✓	✓	✓
O	a and b	X	X	X	✓

✓ = compatible with recipients blood

X = Incompatible with recipient i.e. agglutination ocurs

Individuals with blood group AB posses antigen B which stimulates blood group B of the recipient to produce antibody a that reacts with antigen A in the donor's blood to cause agglutination and therefore this transfusion from AB to B is impossible. Similarly blood group O individuals can donate blood to blood group A because the donor's blood has no antigens which would react with antigen A in the recipient's blood and therefore agglutination is impossible.

Individuals with blood group O are called **universal donors** because they lack antigens which would react with the corresponding antibodies in the recipient's blood. Individuals with blood group AB are called **universal recipients** because they lack antibodies in their blood plasma which would have reacted with the corresponding antigens in the donor's blood.

NOTE; the recipient's antibody is the one expected to attack and react with the corresponding antigen in the donor's blood. Whenever the antigen of the donor corresponds with the antibody of the recipient's blood group, an antibody-antigen reaction occurs, leading to agglutination (precipitation or clotting of blood)

RHESUS FACTOR (D-Antigens)

These are antigens which were first observed in the bodies of the Rhesus monkeys. These antigens are also carried on the surface of the erythrocytes of some human beings. Those people with D-antigens on the surface of their red blood cells are called Rhesus positive (Rh^+) while individuals missing such D-antigens are called Rhesus negative (Rh^-).

The bodies of individuals do not have already manufactured antibodies against the D-antigens. When an expectant mother who is Rh^- bears the foetus with which is Rh^+, some foetal erythrocytes with D-antigens will cross the placenta and enter into the blood circulation of the Rh^- mother towards the end of the gestation period (pregnancy). It is also possible for the blood of the foetus to mix with that of the mother during birth so that the mother gets Rh^+ by getting the D-antigens from the child.

The D-antigens that have entered the mother's blood circulation stimulate the maternal body to manufacture corresponding antibodies (antibody-d or anti-D antibodies) which attack and react with the D-antigens in the mother. Some formed antibodies-d can also pass via the placenta and enter the foetal blood circulation where they attack and react with the D-antigens which results into clumping together and bursting of the foetal red blood cells, a condition called **erythroblastosisfoetalis** (Haemolytic disease of the new born). This disease results into acute anaemia which can lead to death of the feotus.

The first born rarely dies because the time is too short for the mother to produce enough antibodies that can pass to the foetus to cause death but subsequent Rh^+foetus can die due to the many antibodies of the mother entering its circulation to cause agglutination.

To prevent this disease, pregnant mothers are always given anti-D chemicals 72hours to delivery, to render her immune system insensitive towards the D-antigen i.e. the mother may be infected with antibody-d within 70-72hours to delivery or within 72 hours after her first born. Also the blood of the foetus can be transfused with normal blood to dilute antibody-D so as to save the child.

NOTE: if a rhesus negative mother of blood group O is carrying a rhesus positive child of any blood group other than O, the problem will not arise. This is because if fetal cells enter the mother's circulation, the mother's **a** and**b** antibodies will destroy the blood cells before the mother has time to manufacture anti-rhesus antibodies.

SAMPLE QUESTIONS

1. (a) State any two theories which have been put forward to explain stomatal movement?

(b) Describe the mechanism of stomatal movement basing on each of the theories stated above?

© State any weaknesses for the two theories described above

2. (a) Describe the structure of the phloem tissue

(b) Describe the mass flow theory of food transport in plants

3. The table below shows data obtained from a study of leaves of a tree

Time	**Percentage of open stomata**	**Relative amount of starch in guard cells**	**Relative intensity of light**
8:00 am	42	70	0
10:00 am	100	30	5
12:00 noon	100	13	50
02:00 pm	100	18	61
04:00 pm	80	30	76
06:00 pm	28	68	20
08:00 pm	0	100	0

a. Using the same axes, plot graphs for this data (13 marks)

b. Describe the nature of the graphs (08 marks)

c. What are the interrelationships between;

i. Stomata opening and relative amount of starch in guard cells (01 mark)

ii. Stomata opening and relative intensity of sunlight (01 mark)

iii. Percentage of open stomata and time of the day (01 mark)

d. Explain these interrelationships? (16 marks)

4. a) Differentiate between Natural active immunity and Artificial active immunity (02 marks)

5. b) State the different ways in which the mammalian body naturally prevents pathogens from accessing its internal environment (11 marks)

c) What is the significance of the high body temperature experienced when the mammalian body is attacked by *Plasmodium Spp?* (07 marks)

6. Explain how water moves from;

a) From soil into the xylem (10 marks)

b) Through the stem xylem to the leaf (10 marks)

7. a) What is meant by the term chloride shift? (03 marks)

b)Account for the relative position of the oxygen dissociation curves of the human and rat haemoglobin

c) Explain the rapid dissociation of oxyhaemoglobin of a rat during a vigorous activity (07 marks)

8.) Describe the events which occur during the heart beat (16 marks)

b) Outline the features which ensure efficient flow of blood within the mammalian body (04 marks)

9. a) Describe the mechanism of stomatal movement based on osmotic pressure (08 marks)

10. Explain how each of the following affect the rate of transpiration

i. Temperature (07 marks)

ii. Sunken stomata (05 marks)

11. An experiment was carried out with cells of the carrot tissue which was first thoroughly washed in pure water. The slices of carrot tissue were immersed in an aerated potassium chloride solution of known concentration at varying temperatures. The results are shown in the table below. At the fourth hour, the carrot tissue at 25^0C was treated with potassium cyanide. Absorption of potassium ions is given in micrograms of potassium per gram of fresh mass of carrot tissue.

Time in minutes	Potassium ion uptake in $\mu g\ g^{-1}$ fresh mass	
	At temperature of 2^0C	At temperature of 25^0C
0	0	0
60	90	170
120	105	300
240	130	480
300	130	500
360	130	500

a. Represent the above data graphically (10 marks)

b. Describe the changes in the rate of potassium ions absorption within the first four hours at temperature of 250C. (02 marks)

c. During the first hour, some potassium ions enter the carrot cells passively. Suggest any two passive means of their movement and any two conditions needed for one of them to occur. (04 marks)

d. (i) calculate the mean rate of absorption of potassium ions at 25^0C, between the 2nd and 6th hour (03 mark)

(ii) Compare the rates of absorption of potassium ions at 2^0C and 25^0C during the experiment (06 marks)

(iii) Suggest an explanation for the differences in the rates of absorption of potassium ions at the two temperatures. (05 marks)

a) Explain the effects of treating the carrot cells with potassium cyanide on the rate of their absorption of potassium ions. (03 marks)

b) Suggest;

i. The aim of the experiment (01 mark)

ii. Why the carrot tissue was first washed pure water (01 mark)

iii. Why the potassium chloride solution was aerated (02 marks)

12. (a) What is the physiological significance of the Bohr effect in animals? (08 marks)

(b) Discuss the factors that may alter the rate of heart beat in mammals (12 marks)

13. a) What are the essential features of the immune system in mammals?

b) (i) Give an account of the ABO blood group system in humans, and explain how certain ABO group donations cause agglutinations with the recipients, while others do not.
(ii) Besides blood, other tissues can be transplanted from one individual to another. Mention problems associated with them, and steps taken to minimize the transplant failures

14. b) Define the term **facilitated diffusion**
c) State **three** ways how facilitated diffusion differs from simple diffusion
d) Describe **one** way how facilitated diffusion occurs across membranes
e) State **two** ways how the action of carrier proteins is similar to that of enzymes

15. (a) What is meant by pressure potential? (03 marks)

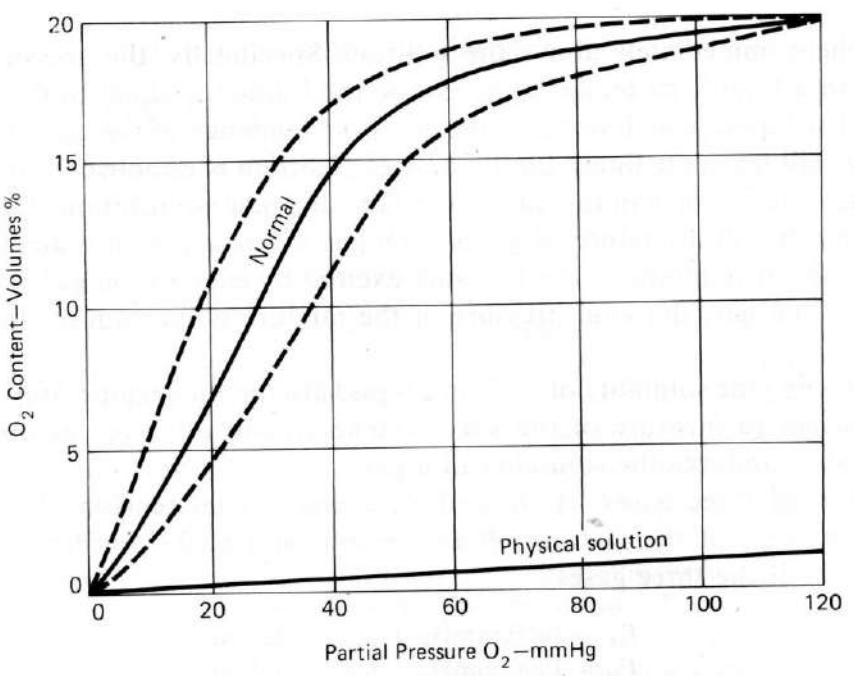
(b) What is the effect of lowering solute potential on the

i. Water potential of a plant tissue (03 marks)
ii. Mechanical support in herbaceous plants (04 marks

(c) Explain how organisms benefit from the possession of well developed transport systems (10 marks)

16. Briefly explain the significance of the existence of the Casparian strip within the endodermal cells of the root

17. Figure 3 shows the union of oxygen and haemoglobin in three different physiological conditions



The straight line near the bottom of the graph shows the uptake of oxygen by a solution when hemoglobin is not present while the dotted curves on either side of the solid curve shows the formation of oxyhaemoglobin under two different levels of carbon dioxide

a) Label the curves of blood in

(i) veins and muscles and
(ii) (ii) arteries and lungs (02 marks).

b) Explain the importance of the positions suggested above in the physiology of the animal (04 marks).

c) Explain the difference in the variation of the oxygen content of normal and physiological solutions(03 ma

17. (a) Describe the distribution of vascular and parenchyma tissues in plants
(b) Discuss the theories of stomatal opening in plants
(c) Discuss the theories of food transport in plants

18. (a) Describe the mechanism of mineral salt up take from the soil by the plant.

(b) Describe mass flow of organic food in plants

(c) What are the evidences and weaknesses of mass flow in plants?

19. (a) Give an account of the structures involved in the translocation of organic solutes between the different parts of a flowering plant.

(b) Briefly describe how dissolved blood carbon dioxide is expelled in gaseous form by the lungs.

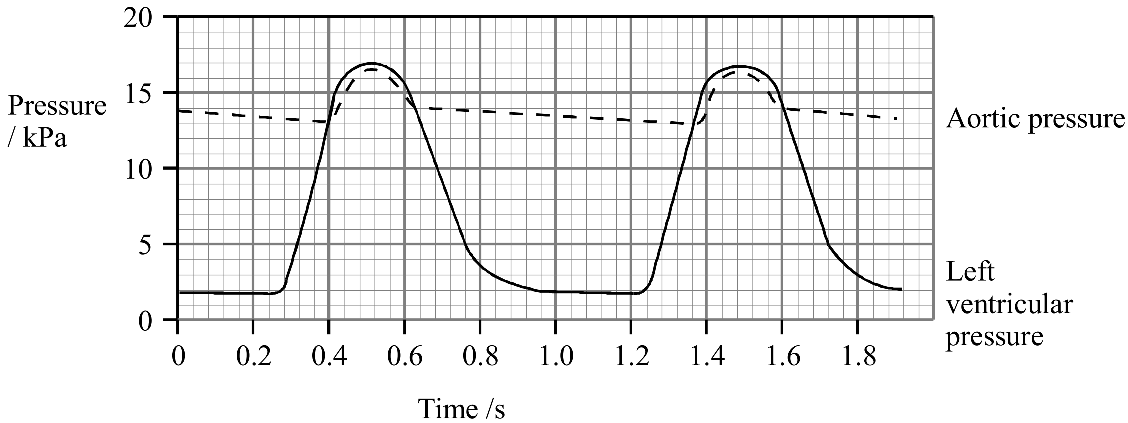
20. In fish, oxygen is transported in the blood in the form of oxyhaemoglobin. The table below shows the percentage saturation of blood with oxygen of a teleost (bony) fish after equilibrating with oxygen of different partial pressures. The experiment was carried out at two different partial pressures of carbon dioxide.

Partial pressure of oxygen in Pa	Percentage saturation of blood with oxygen	
	Partial pressure of carbon dioxide at 500 Pa	Partial pressure of carbon dioxide at 2600 Pa
500	30	5
1000	70	13
2000	90	24
3000	96	33
4000	98	41
5000	99	48
7000	100	60
9000	100	69
11000	100	76
13000	100	81

a) Present the data in a suitable graphical form.
b) Calculate the difference of percentage saturation of blood with oxygen at the two different partial pressures of carbon dioxide at oxygen partial pressures of 500 Pa.
c) With reference to the graph, describe the effects of different partial pressure of carbon dioxide on the percentage saturation of blood with oxygen.
d) Explain how changes in oxygen content of blood at different partial pressure of carbon dioxide are important in the release of oxygen to the tissues of fish.
e) What information do such experiments give about the environmental conditions in which fish would maintain a high level of growth as required in commercial fish farming?
f) Explain how the properties of haemoglobin molecule are affected by changes in the oxygen and carbon dioxide partial pressures.

21. (a) Distinguish between the terms **immunity** and **autoimmunity** (02 marks)
(b) Suggest **three** key roles played by the body's immune system (03 marks)
(c) State **three** ways body openings are protected from entry of pathogens (03 marks)
(d) State **two** human diseases resulting from autoimmune disorders (02 marks).

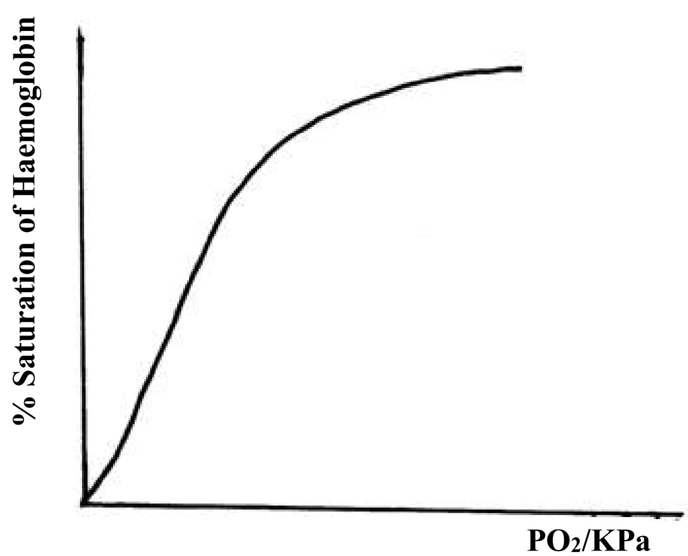
22. Figure below shows changes in the blood pressure in the aorta and the left ventricle during two complete cardiac cycles.



(a) On the graph, draw an arrow to show when the left atrioventricular (mitral) valve closes.(01 mark
(b) Use the information in the graph to calculate the heart rate. Show your working. (02 marks)

(b) During the cardiac cycle, the pressure in the left ventricle falls to a much lower level than in the aorta. Suggest an explanation for this difference. (03 marks)
(c) During the cardiac cycle, the pressure in the right ventricle rises to a maximum of about 3.3 KPa. Suggest reasons for the difference between this pressure and the maximum pressure in the left ventricle.(03 marks)

23. Blood that is fully saturated with oxygen carries 105cm^3 of oxygen in 1 dm^3(liter) of blood
(a) Calculate the volume of oxygen released from 1 dm^3 of blood when blood that has become 90% saturated at 38^{0}C reaches a part of the body where the partial pressure is 18% (03 marks)
(b) The figure below shows the oxygen dissociation curve of hemoglobin from a mammal at 38^{0}C.



(i) Draw the curve of hemoglobin when the body temperature is raised to 43^{0}C(01 mark)

(ii) Name one change in the conditions in the tissues which has the same effect on the oxygen dissociation curve as change in temperature (01 mark)

(iii) Explain the effect of increased body temperature on the oxygen dissociation curve for hemoglobin in mammals(03 marks)

(c) State how this effect of temperature on the oxygen dissociation curve of hemoglobin might be advantageous to the mammal (03 marks)

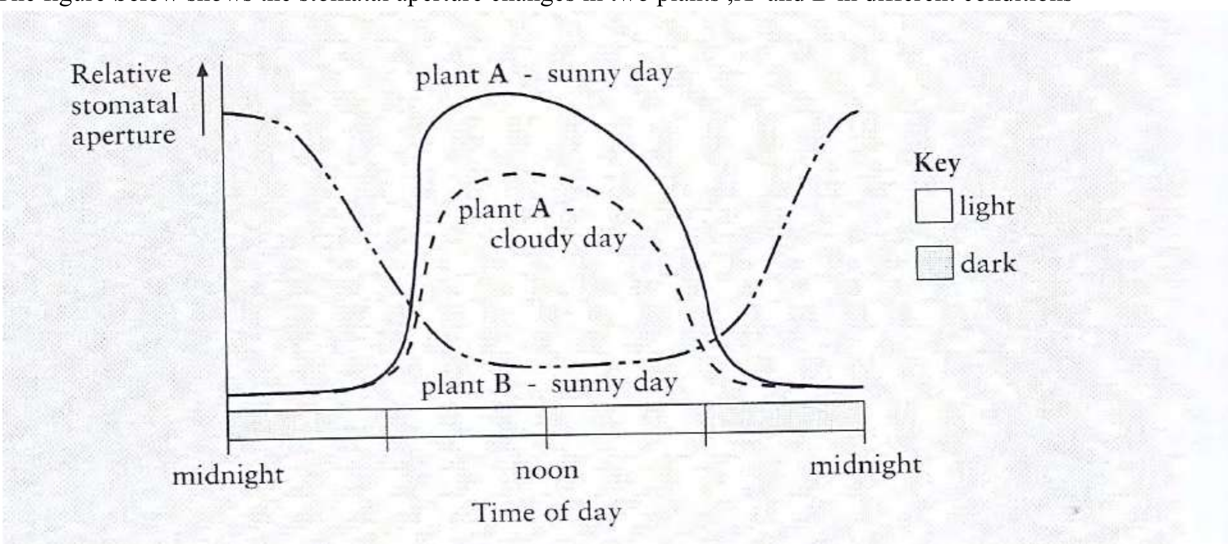
24.

a) State the parameters listed in **Fick's law** of diffusion (03 marks)

b) Explain how each parameter in **Fick's law** of diffusion is reflected in the structure of the mammalian lung (03 marks)

c) Explain the changes in oxygen delivery to the tissues that occur as a person proceeds from a resting state to intense exercise (04 marks)

25. The figure **below** shows the stomatal aperture changes in two plants ,**A** and **B** in different conditions



a) stomata open when guard cells absorb water because of a change in the water potential of their cell contents

b) Give **one** explanation for the mechanism that results in

i) a change in water potential of the guard cells in plant **A** between 06.00 and noon *(03 marks)*

ii) the stomata of plant **A** not operating as widely on the cloudy day as on the sunny day*(03 marks)*

b) Plant **B** is a succulent plant that lives in dry conditions

i) Give **one** advantage to plant **B** of the different behavior of its stomata *(03 marks)*

ii) Give **one** disadvantage to plant **B** of the different behavior of its stomata *(02 marks)*

26. The table below shows the results of an experiment on the rate of absorption of sugars by a mammalian intestine. Study it carefully and answer the questions that follow.

Sugar		Relative rates of absorption taking normal glucose uptake as 100	
		By living intestine	By intestine poisoned with cyanide
Hexose sugars	Glucose	100	30
	Galactose	106	35
Pentose sugars	Xylose	32	32
	Arabinose	30	31

a) Suggest a reason for the difference between the rates of absorption of hexose and pentose sugars in the living intestines (03 marks)

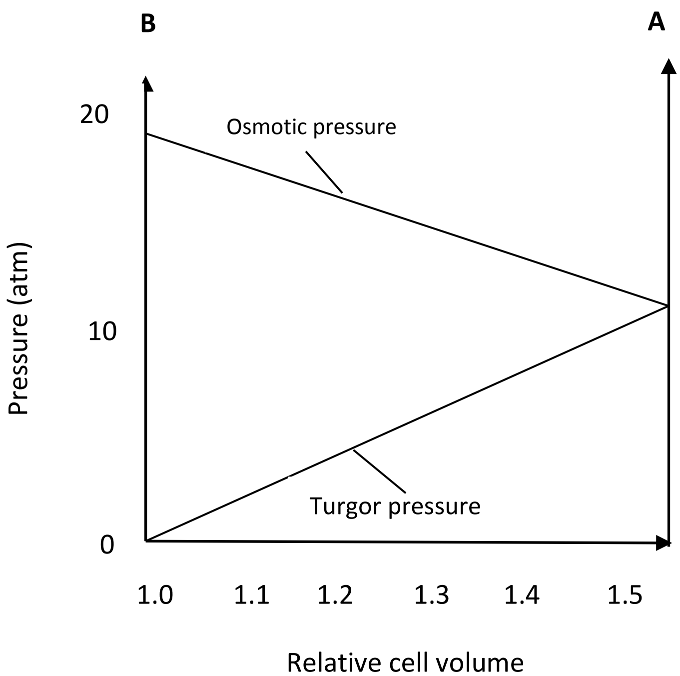
b) (i) Mention the mechanism by which hexose sugars are absorbed by living intestines ($0\frac{1}{2}$ mark)

ii) What is the advantage to the individual of having hexose sugars absorbed in the way mentioned above?

c) What could be the effect of cyanide on the mechanism of hexose absorption? (02 marks)

d) In an intact mammal, absorption of fatty acids is drastically curtailed by any clinical condition which leads to a reduction in bile salt excretion or release. Explain why this is so. (03 marks)

27. The figure below shows the relationship between pressure and cell volume of plant leaves. Study it and carefully and answer the questions that follow.



a. What is the condition of the cell at point (01 mark)
   i. A ii. B

b. State any effects of a cell at (04 marks)
   i. A ii. B

c. Explain why the osmotic pressure falls when the turgor pressure increases (05 marks)

28. (a) Explain why simple organisms do **not** have a transport system (02 marks)

(b) State three differences between vascular systems in higher plants and circulatory systems in higher plants and circulatory systems in mammals (03marks)

(c) Describe what happens in the following pathways during transport in plants

i. The apoplast (02 marks)

ii. The symplast (03 marks)

29. (a) What is meant by the term **Bohr's effect**? (02 marks)

(b) Briefly explain the following observations;

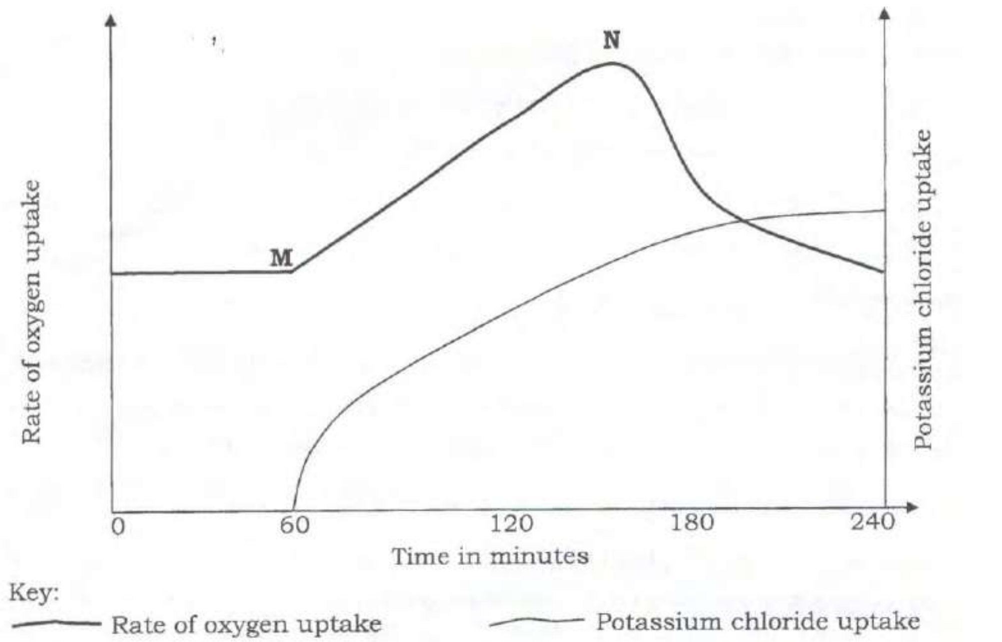
The oxygen dissociation curve of,

i. man shifts to the right during exercise (03 marks)

ii. the elephant is on th e left of the oxygen dissociation curve of a mouse? (03 marks)

iii. thelungworm is on the left of that of man? (03 marks)

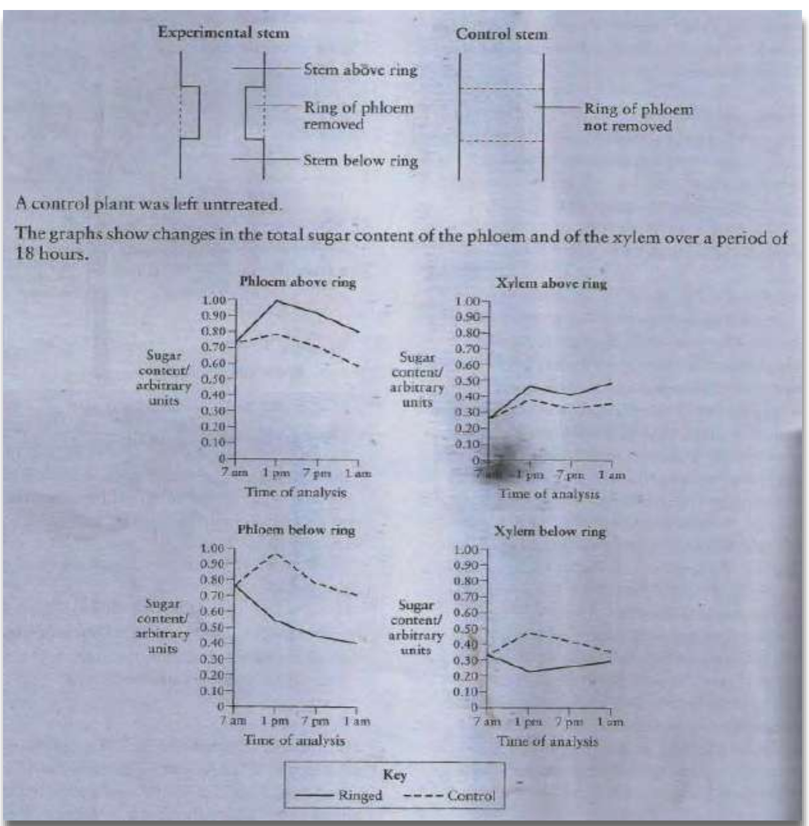
30. In an experiment a set of young cereal roots were washed thoroughly in pure water and transferred into culture solutions containing potassium chloride solution under varying oxygen concentrations (at point **M** on the graph below). After 160 minutes solution of unknown substance was introduced (at point **N** on the graph below). The rate of oxygen uptake and potassium chloride uptake were measured and recorded graphically as shown in the figure below.



a) Compare the rate of oxygen uptake with the rate of chloride uptake between 60 and 240 minutes.

b) Explain the rate of oxygen and potassium chloride uptake as shown in the graph above? (06 marks)

31. The figure **below** shows the effect of ringing the stem of a cotton plant with time



a) Explain the variation in the sugar content of the phloem of the plant over the period shown

i) above the ring *(03 marks)*

ii) below the ring *(02 marks)*

b) What evidence from the graphs supports the hypothesis that sugars can move laterally but not downwards in the stem ? *(02 marks)*

c) Explain why

i) both plants survive in the short run*(01 mark)*

ii) one of the plants eventually dies*(02 marks)*

32. **T**he relationship between potassium ion concentration in the roots and sugar consumption at different oxygen concentration was investigated.

The table below shows the concentration of potassium ions in $mgcm^{-3}$ and the rate of sugar consumption in $mghr^{-1}$ by roots of a freshly uprooted plant when inserted in a bathing fluid at different oxygen concentration.

Oxygen concentration (%)	0	2	5	10	20	30	50	70
Potassium ion concentration in gcm^{-3}	7	10	21	49	52	51	48	44
Rate of sugar consumption in $mghr^{-1}$	14	16	20	27	33	34	35	36

a) Represent the information above on the graph paper.(9 marks)

b) Compare the effect of oxygen concentration on potassium ion concentration in the roots and rate of sugar consumption from the graph.(3 marks)

c) Explain the:

i) Prescence of potassium ion concentration in the root wihout oxygen.(4 marks)

ii) Relationship between potassium ion concentration and oxygen concentration. (5 marks)

iii) Increase in the rate of sugar consumption with oxygen concentration (4 marks)

d) State two factors other than oxygen concentration that could affect the rate of potassium ion uptake by roots (2 marks)

e) Predict what would happen if the oxygen concentration was increased up to 98%. Explain your answer. (3 mar

f) State two main mechanisms of uptake of mineral salts by plants and give three differences between them

g) Outline two factors that can influence the process of potassium ion uptake investigated in this experiment other than sugar and oxygen concentration (02 mks)

33. 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

34. The table below shows the difference in percentage saturation in blood with oxygen at varying partial pressure of oxygen between a pregnant woman and that of the fetus developing in her uterus.

Partial pressure of oxygen /mmHg	Percentage saturation of blood with oxygen	
	mother	Fetus
1.3	8	10
2.7	20	30
3.9	40	60
5.3	65	77
6.6	77	85
8.0	84	90
9.3	90	92
10.6	92	92

i) Plot the results in a suitable graphical form. (08 marks)

ii) Compare the percentage saturation of blood for the mother and that of the fetus.(04 marks)

iii) State and explain the shape of the curve for the mother. (07 marks)

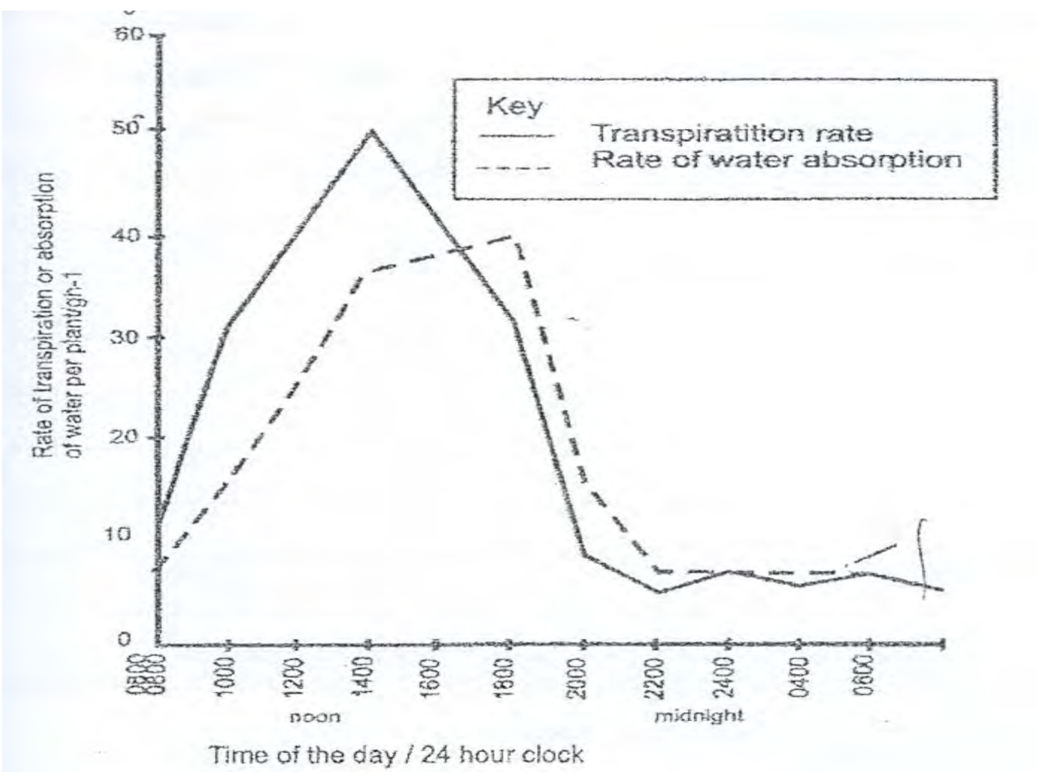
iv) Explain the physiological significance of the position of the fetal curve (05 marks)

b) Explain what is meant by: (06 Marks)

i) Bohr's effect ii) Loading tension iii) Un loading tension

c) Explain three factors that influence the affinity of haemoglobin for oxygen (06 marks)

35. An investigation was carried out to establish the relationship between the rate of water absorption and its rate of transpiration in sunflower plants at various times of the day. The results are shown in figure 1 below.



ai) Describe the changes in the rate of transpiration that took place during the experiment (10 marks)

ii) Suggest why these changes occurred (05 marks)

b) Comment on the relationship between the rate of transpiration and the rate of water absorption during the experiment. (04 m arks)

c) Why is transpiration a necessary evil? (06 marks)

d) Describe fully the passage of water from the soil to the xylem tissue of plant roots (10 marks)

e) Explain why according to pressure flow hypothesis, translocation can only take place in living phloem.

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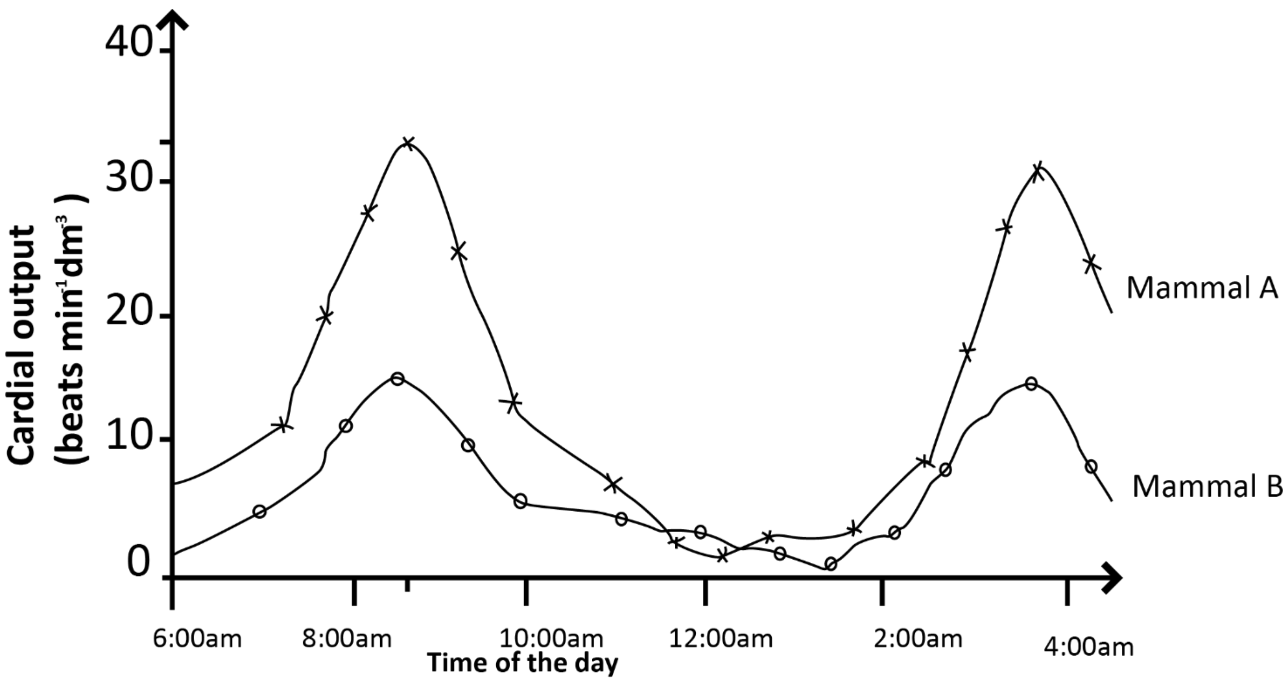
36. a) The figure shows the changes in the cardiac output of two individual Mammals and A and B of different sizes, determined from 6:00a.m up to 4:00p.m in the evening when the mammals were given a hot drink.



(i) Compare the cardiac output of both mammals. (04marks)

(ii) Explain the effect of day time on the cardiac output of both mammals. (08marks)

(iii) Comment on the difference in the cardiac output both mammals. (04marks)

(iv) Suggest factors that are likely to affect the cardiac output of a mammal. (03marks)

b) The table below shows the volume of blood flowing from the left vertical side of the heart of various parts of the body in one minute at rest and during a heavy exercise.

Organ	Volume of blood/cm^3	
	Rest	**Exercise**
Brain	750	750
Hear Muscle	250	750
Skeletal muscle	1,200	1,250
Skin	500	1,900
Kidney	1,100	600
Other organs	2,000	1,000

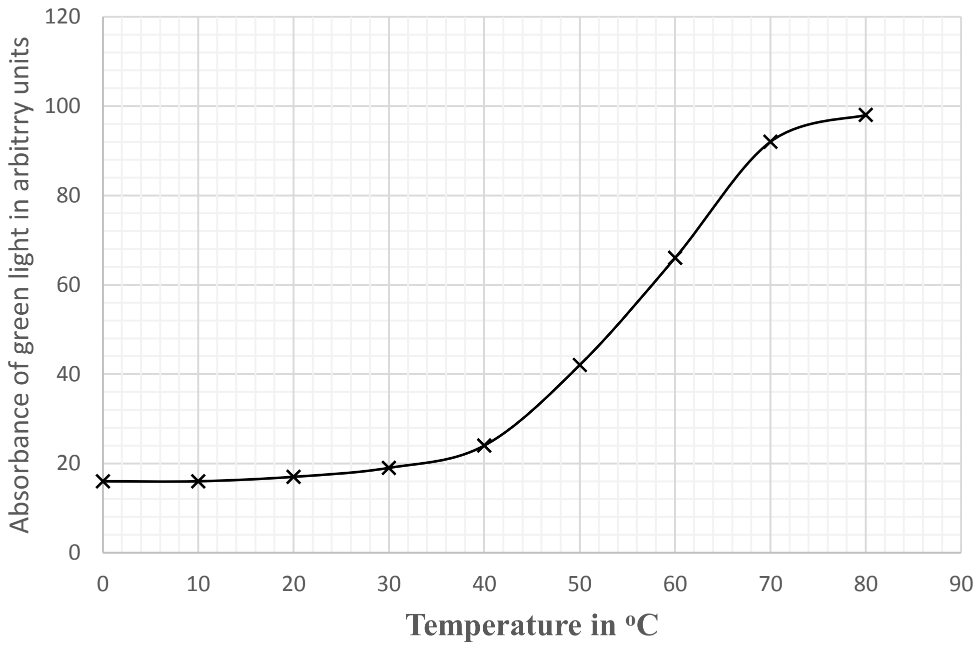
(i) Calculate the percentage increase in blood flow from rest to exercise in skeletal muscle. (03 marks)

(ii) Give three ways in which the increase in b(i) is achieved. (03 marks)

(iii) Explain the changes in volume of blood flow rest to exercise to various parts of the body. (11 marks)

(iv) Suggest with reasons the likely changes in composition of blood as it flows through the kidney. (04 marks)

37. Beet root cells contain a pigment that cannot normally escape from the cells through the cell surface membrane. The graph below shows the results of an investigation into the effect of temperature on the permeability of the cell surface membrane of beet root cells. The permeability was measured by using a calorimeter to measure the absorbance of green light by the solution in which samples of beet root had been immersed. The greater the absorbance, the more red pigment had leaved out of the beet root cells.



(a) Describe the changes in the absorbance of green light with temperature. (4 marks)
(b) What is the general effect of temperature on the absorbance of light? (1 mark)
(c) With reference to the structure of cell membranes, explain the effect of temperature on absorbance. (4 marks)
(d) State one other way in which membrane permeability could be altered. (1 mark)

38. An experiment was carried out with cells of the carrot tissue which was first thoroughly washed in pure water. The slices of carrot tissue were immersed in an aerated potassium chloride solution of known concentration at varying temperatures. The results are shown in the table below. At the fourth hour, the carrot tissue at 25^{0}C was treated with potassium cyanide. Absorption of potassium ions is given in micrograms of potassium per gram of fresh mass of carrot tissue.

Time in minutes	Potassium ion uptake in μg g^{-1} fresh mass	
	At temperature of 2^{0}C	At temperature of 25^{0}C
0	0	0
60	90	170
120	105	300
240	130	480
300	130	500
360	130	500

a. Represent the above data graphically
b. Describe the changes in the rate of potassium ions absorption within the first four hours at temperature of 25^{0}C.
c. During the first hour, some potassium ions enter the carrot cells passively. Suggest any two passive means of their movement and any two conditions needed for one of them to occur.
d. (i) calculate the mean rate of absorption of potassium ions at 25^{0}C, between the 2nd and 6th hour
(iii) Compare the rates of absorption of potassium ions at 2^{0}C and 25^{0}C during the experiment

(iii) Suggest an explanation for the differences in the rates of absorption of potassium ions at the two temperatures.

e) Explain the effects of treating the carrot cells with potassium cyanide on the rate of their absorption of potassium ions. Suggest;

iv. The aim of the experiment
v. Why the carrot tissue was first washed pure water
vi. Why the potassium chloride solution was aerated P

f) Briefly explain the significance of the existence of the **Casparian strip** within the endodermal cells of the root 8

39. Two investigations concerning movement of substances in and out of cells were carried out in 2 different organisms and results were summarized in tables 1 and 2 as indicated below.
The first investigation had 2 experiments. In the first experiment the marine ciliate *corthurnia* was placed in a series of dilutions of sea water and the output of its contractile vacuole was measured. In another experiment, the change in volume of the organism in different dilution of sea water was recorded.

Added fresh water/%	0	10	20	30	40	50	60	70	80	90
Contractile vacuole out put/dm^3s^{-1}	0.7	0.6	1.1	1.0	1.5	2.4	6.3	18.2	35.1	9.5
Relative body volume	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.1	2.0

In the second investigation, the relative rate of uptake of glucose and xylose (a pentose) from living intestine and from intestine which had been poisoned with cyanide, was determined and results recorded in table 2

Sugar	Without cyanide	With cyanide
Glucose	100	28
xylose	18	18

a) Represent graphically the results in table 1 using a single set of axes (06 marks)
bi) Explain the effects of dilutions on the activity of the contractile vacuole(04 arks)
ii) what do changes in relative body volume indicate about the effect of the contractile vacuole activity?
c) Some species of marine protozoa form contractile vacuoles only the protozoan begins to feed . Suggest an explanation for this observation. (03 marks)
d) How is active transport:
i) similar to facilitated diffusion (02 marks)
ii) different from facilitated diffusion (03 marks)
e) Explain the relative uptake of the sugars by the intestines (05 marks)
f) How do the following factors affect the rate of diffusion across a membrane
i) concentration difference, (02 marks)
ii) the size of the molecules(02 marks)
iii) temperature (02 marks)
iv) polarity of the molecules(02 marks)
h) state the composition and major function of the animal's cell surface.(03 marks)

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END

HETEROTROPHIC NUTRITION
This is the type of nutrition in which organisms take in ready made organic food substances made by autotrophs (producers).

TYPES OF HETEROTROPHIC NUTRITION
(a) Holozoic nutrition
(b) Saprotrophic nutrition (Saprophytic nutrition)
(c) Symbiosis: **(i)** Parasitism **(ii)** Mutualism **(iii)** 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.

BASIC PROCESSES INVOLVED IN HOLOZOIC NUTRITION
1. ***Obtaining food:*** May involve movements to capture or find new food sources from the environment.
2. ***Ingestion***: The intake of food into the body (feeding mechanisms).
3. ***Digestion***: Chemical breakdown (by enzymes) and physical breakdown (by teeth, gizzard, mandibles, radula) of large insoluble molecules of food into small soluble molecules.
4. ***Absorption***: The uptake of nutrient molecules into the cells of the digestive tract and, from there, into the bloodstream
5. ***Defecation (Egestion)***: elimination of undigested residue.
6. ***Assimilation:*** The utilization of the absorbed soluble food substances to form energy or materials which are incorporated into the body tissues.

FEEDING MECHANISMS OF ANIMALS

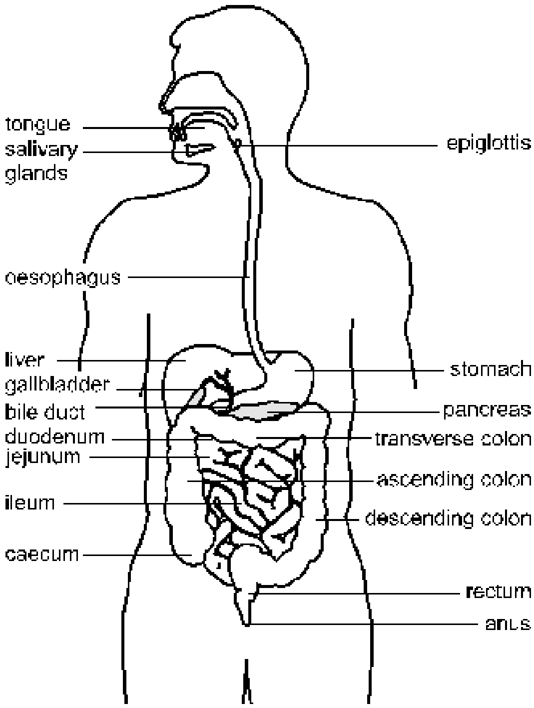
Nature of food	***Mechanism***	***Organisms***	***Description***
Small particles	filter feeding / microphagous feeding;	Whales, sharks, flamingo, herring;	Body appendages (gills/beaks/keratinous plates) filter planktons/blue green algae suspended in water into body cavity /mouth then digestion occurs.
	Pseudopodial feeding	Amoeba	Pseudopodia enclose the food particle to form **food vacuoles** which on associating with **primary lysosomes** form **secondary lysosomes,** and after digestion, soluble products simply/facilitatively diffuse /actively move into the cytoplasm while undigested wastes are egested by **exocytosis**.
	Flagellate feeding	Euglena, sponges	Flagellar beating directs microscopic food particles to the region of ingestion, then intracellular digestion occurs.
	Ciliary feeding	Paramecium, *Amphioxus*	Cilia beating directs microscopic food particles to the region of ingestion, then intracellular digestion occurs.
	Tentacular feeding	Sea cucumber	Mucus on tentacles traps food particles
	Setous feeding	Water flea (*Daphnia)*, culex mosquito larvae	Setae on appendages trap and direct small food particles into the digestive system.
	Mucoid feeding	Some molluscs	Mucus layer traps food particles, later swallowed and new layer formed.
Fluids or soft tissues	Fluid feeding;	Aphids, leeches, fleas, lice, mosquitoes, housefly, vampire bats/ Tapeworm, *Trypanosoma*;	Nutrient-rich fluid from the living host; is sucked by modified mouth parts; Already digested food is absorbed across the integument;
Large particles	Substrate feeding / deposit feeding;	Insect larvae / earthworms;	Non-selective swallowing of mud, silt, sand, etc after burrowing their way through the food / organic material;
	Bulk feeding / macrophagous feeding;	Land snail, caterpillar, termites, snakes, birds, seals, squids, many mammals, spiders, blowfly larvae, crabs, dragonfly, etc.	May involve scraping and boring (termites, snails) / Capturing and swallowing (snakes, birds, dogfish, seals) / Capturing, chewing and swallowing (squid, mammals) / Capturing, digesting externally and ingesting (spider, starfish, blowfly); using appendages like tentacles/pincers, claws/ poisonous fangs and jaws/ mandibles;

THE HUMAN DIGESTIVE SYSTEM

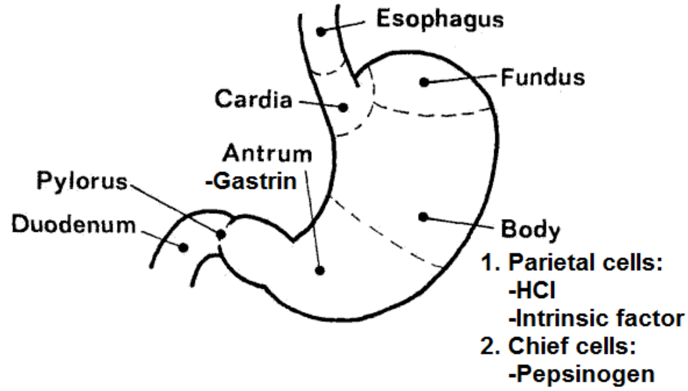
The human digestive system consists of:

1. Alimentary canal: Mouth, throat, oesophagus, stomach, small intestine (duodenum, jejunum and ileum), large intestine (colon, caecum and appendix), rectum and anus.

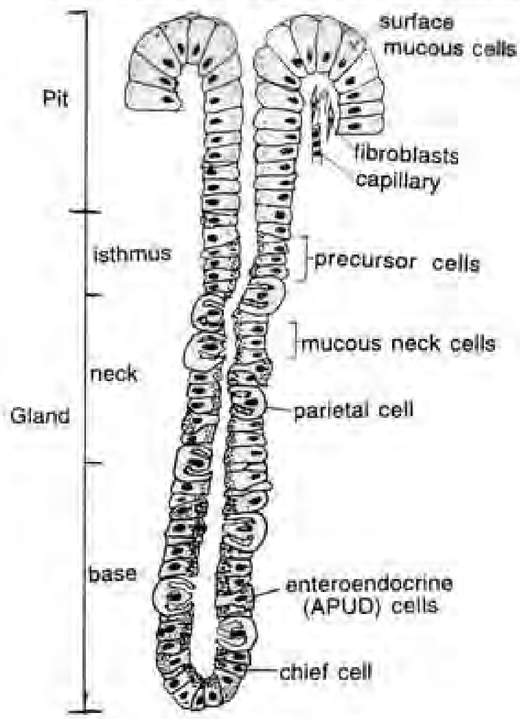
2. Accessory structures: Teeth, tongue, salivary glands, liver, gall balder and pancreas. These are organs, glands, and tissues that enable digestive processes, e.g. by secreting fluids /chemicals, but the food does not actually pass through them.



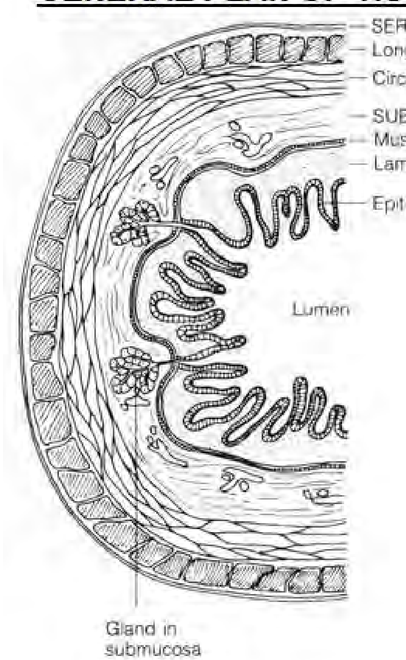
Details of the stomach region



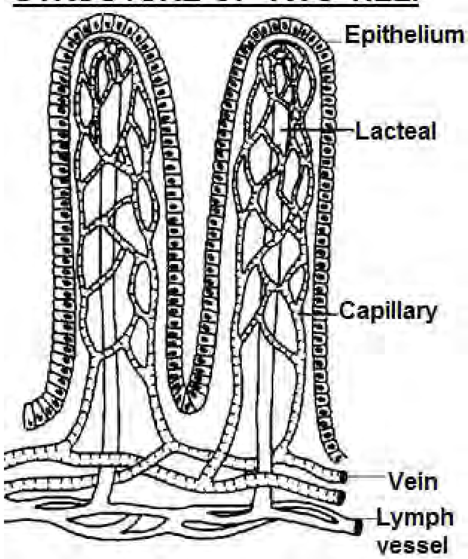
Structure of Gastric gland



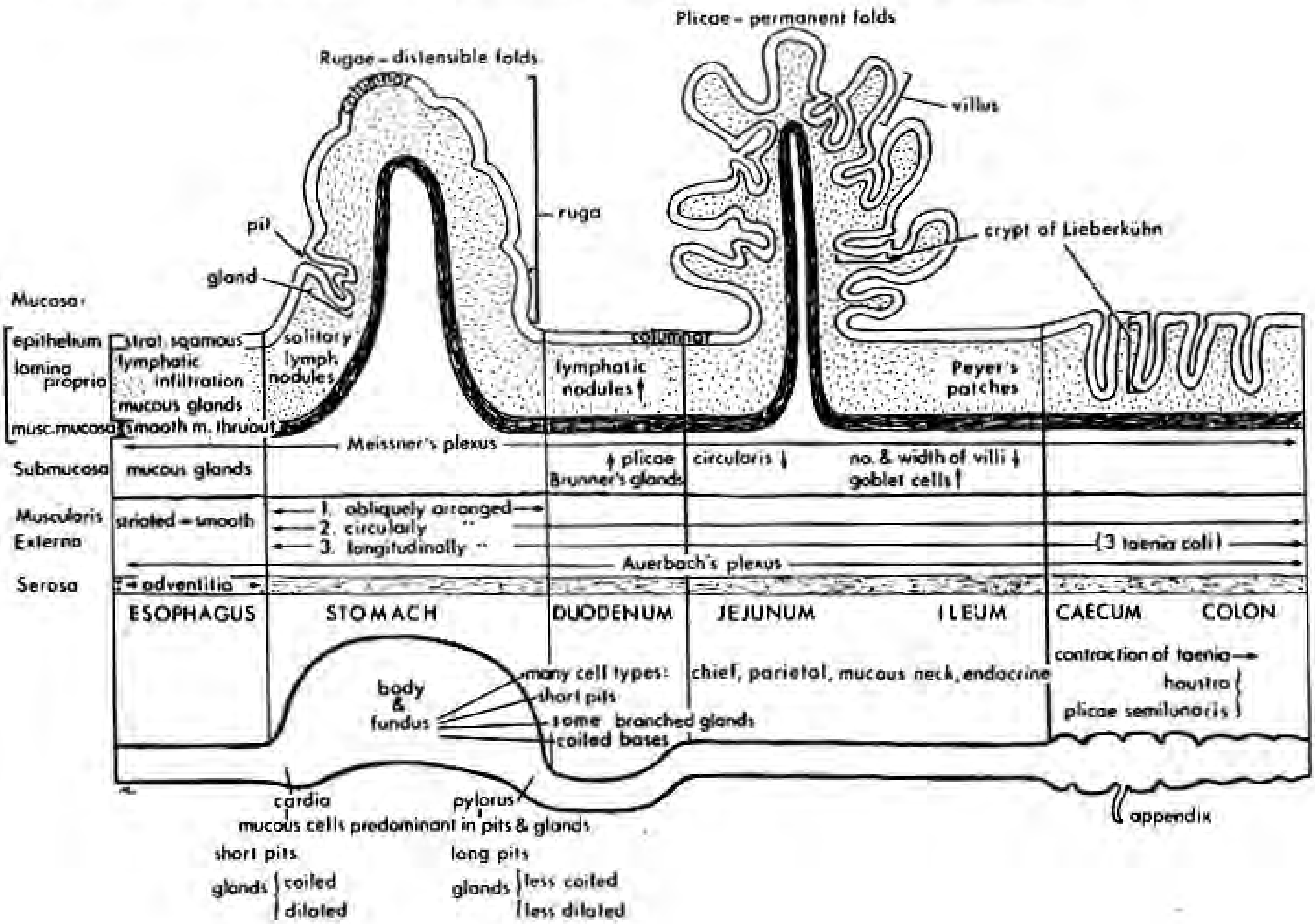
GENERAL PLAN OF T.S OF ALIMENTARY CANAL



STRUCTURE OF TWO VILLI



VERTICAL SECTION THROUGH THE ALIMENTARY CANAL



COMPARISON OF HISTOLOGY OF GASTROINTESTINAL TRACT REGIONS

WALL LAYER	STOMACH	DUODENUM	ILEUM	COLON
Serosa (Adventitia)	● Areolar connective tissue, same composition as mesenteries ● It is called **serosa** when the outermost layer lies adjacent to the peritoneal cavity. ● It is called **adventitia** when the outermost layer is attached to surrounding tissue.			
Muscularis externa	● Consists of three muscle layers: **(i)** inner oblique layer **(ii)** middle circular layer **(iii)** outer longitudinal layer			
Auerbach's plexus (Myenteric plexus)	● Network of **unmyelinated** nerve fibers and ganglia between Muscularis externa longitudinal and circular muscles ● Brings about **peristalsis** when stimulated by pressure of food in the gut. ● Receives impulses from the **vagus nerve** ● Control of nerve impulses is **involuntary** ● Promotes secretion of intestinal juices ● Causes sphincter muscles to open, thus permitting food to pass from one part of the digestive system to another			
Submucosa	● Consists of loose connective tissue, collagen, large arteries and veins, lymph vessels and nerves			
	● **Brunner's glands** absent. ● No **goblet cells**	● **Brunner's glands** present ● Brunner's glands secrete alkaline mucus to neutralize acidic chyme from the stomach ● Brunner's glands are compound, tubular, mucous ● **Goblet cells** present	● **Brunner's glands** absent. ● **Goblet cells** present	● **Brunner's glands** absent.
Meissner's plexus (Submucosal plexus)	● Nerve network of unmyelinated nerve fibres and associated ganglia located with the submucosa ● It is believed to work against the myenteric plexus to control the muscular contractions more finely. ● In intestines, it works with Auerbach's plexus in producing peristaltic waves and increasing digestive secretions.			

WALL LAYER	STOMACH	DUODENUM	ILEUM	COLON
Mucosa	***1. Muscularis mucosa:*** ● Thin layer of smooth muscle at the boundary between mucosa and submucosa. ● Contains both circular and longitudinal muscles ● Functionally, the ***Muscularis mucosa*** presumably causes stirring at mucosal surface for increased secretion and nutrient absorption			
	2. Lamina propria: ● Formed by a very cell-rich loose connective tissue (fibroblasts, lymphocytes, plasma cells, macrophages, eosinophilic leucocytes and mast cells). ● Lamina propria contains numerous cells with **immune function** to provide an effective **secondary line of defense** e.g. **Peyer's patches** which are lymphoid structures located in the ileum. ● Lamina propria of **villi** includes **lacteals** (**lymphatic capillaries**). ● Lamina propria of **intestinal villi** may include smooth muscle fibers. ● In **oral cavity** and **oesophagus**, lamina propria is located immediately beneath a stratified squamous epithelium			
	3. Surface epithelium: ● Mucosal epithelium is highly differentiated along the several regions of the GI tract. ● At the **upper** and **lower** ends of the tract, the epithelium is protective, ***stratified squamous***. ● Along the **lining of the stomach, small intestine, and colon**, the epithelium is ***simple columnar*** ● In the stomach, surface epithelium contains mucous cells that secrete protective, alkaline mucus **(a)** P**licae** of the small intestine are permanent folds in the mucosa supported by a core of submucosa. Plicae increase the absorptive surface area of the mucosa. **(b) Gastric pits** are shallow indentations in surface epithelium of stomach mucosa into which gastric glands open. **(c) Intestinal crypts** (**crypts of Lieberkühn**) contain secretory **Paneth cells** at the deep end, which secrete lysosomal enzymes that contribute to protecting cells in the crypt lining. **(d) Villi** are very small, typically densely-packed, invaginations of a mucosa that increase the surface area for absorption. In the **stomach** – no villi, **duodenum** – many, leaf-like villi, **ileum** – few, finger-like villi. **(e) Rugae** are distensible folds in the **gastric** mucosa.			

SECRETIONS FROM CELLS LOCATED IN THE GASTRIC WALL

The secretions of the mucous cells, chief cells, and parietal cells are known collectively as ***gastric juice***, whose components include: ***mucus***, ***pepsinogen***, ***hydrochloric acid*** and ***intrinsic factor***

Type of Cell	Secretion	Stimulus for secretion	Function
Mucous Cells (i) Mucous surface cells (ii) Mucous neck cells	Mucus	Tonic secretion, with irritation of mucosa	Physical barrier between lumen and stomach lining.
	Bicarbonate	Secreted with mucus	Buffers gastric acid to prevent damage to epithelium
Chief / Peptic / zymogenic cells	Pepsinogen	Acetylcholine, acid secretion.	Pepsin digests protein, including **collagen**
	Gastric lipase		Digests lipids
	Prochymosin (Prorennin)		Rennin curdles soluble Caseinogen (milk protein) into insoluble casein whose slow flow enables digestion
Parietal / oxyntic cells	Hydrochloric acid	Acetylcholine, gastrin, histamine	(i) Activates pepsinogen to pepsin, Prorennin to rennin (ii) Kills bacteria. Only ***Helicobacter pylori***, that cause ***gastritis*** and **gastric ulcers** survive in the stomach
	Intrinsic factor		● Complexes with vitamin B_{12} to enable absorption of Vitamin B_{12} necessary for red blood cell formation ● Vitamin B12 is a cofactor of enzymes which synthesise tetrahydrofolic acid, which, in turn, is needed for the synthesis of DNA components ● Little ***intrinsic factor*** causes **pernicious anemia**
Enteroendocrine cells (APUD-cells: amine precursor uptake and decarboxylation cells)			
(a) G cells (Gastrin-producing cells)	Gastrin hormone	Acetylcholine, peptides, and amino acids	(i) Stimulates secretion of gastric juice (ii) Increases contractions of gastro-intestinal tract (iii) Relaxes the pyloric sphincter.
(b) D cells (Somatostatin-producing cells)	Somatostatin hormone	Acid in stomach	(i) **Inhibits** stomach secretion of **gastrin** and **HCl** (ii) **Inhibits** duodenal secretion of **secretin** and **cholecystokinin** (iii) **Inhibits** pancreas secretion of **glucagon**
(c)VIP-producing cells (vasoactive intestinal peptide)	Vasoactive intestinal peptide	Distension of the stomach wall	(i) Induces smooth muscle relaxation (ii) Inhibits gastric acid secretion (iii) Stimulates pepsinogen secretion by chief cells
(d) Enterochromaffin cells (Serotonin-containing cells)	Histamine	Acetylcholine, gastrin	Stimulates gastric acid secretion

DIGESTION

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 includes two types of processes:

Mechanical 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.

Chemical processes: which include hydrolysis action of digestive enzymes, bile, acids.

DIGESTION IN THE MOUTH

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:

(i) **Salivary amylase (ptyalin)** enzyme catalyses the breakdown of **amylose** of cooked **starch** into **maltose**.

(ii) **Water** moistens food and binding it together for swallowing

(iii) **Mucin** binds and lubricates food; to enable swallowing.

(iv) **Chloride ions** activate salivary amylase

(v) **Lysozymes** kill bacteria in the buccal cavity.

NOTE:

- Amount of **amylase** secreted in saliva depends on **amount of starch** the animal regularly feeds on in diet.

1. Amylase is usually absent in the saliva of carnivores because of absence of cooked starch in the diet.
2. In separate human groups, the relative amounts of amylase (in arbitrary units) produced in saliva were as follows: **Tswana: 248, Bushmen 22, European: 101**. Which human group's diet is largely made of flesh?

SWALLOWING

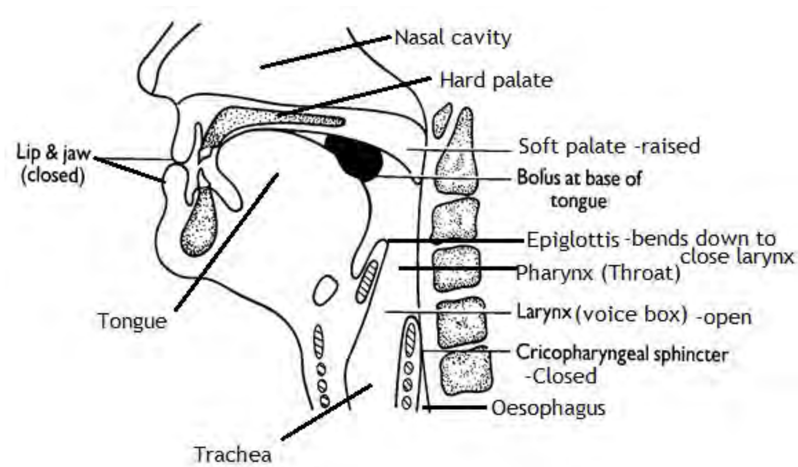
This is a reflex action, which lasts less than 10 seconds.

STAGES OF SWALLOWING

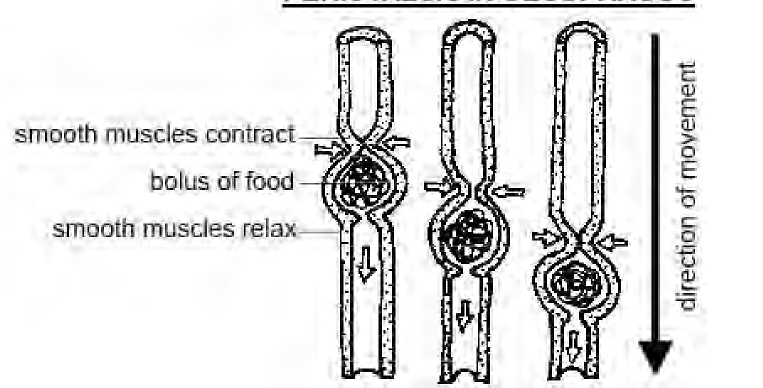
- **Tongue** contracts to push the bolus towards the throat, forcing the **soft palate** upwards to close the **nasopharynx**
- **Larynx** and **hyoid bone** move anteriorly and upwards.
- **Epiglottis** bends downwards to close **larynx** (trachea entrance) to prevent food from entering the trachea.

***NB:** 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** (Cricopharyngeal 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.



PERISTALSIS IN OESOPHAGUS



TYPICAL EXAMINATION QUESTION

(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 marks)

DIGESTION IN THE STOMACH

●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:

Type of Cell	Secretion	Function
Mucous cells (i) Mucous surface cells (ii) Mucous neck cells	Mucus	Forms a barrier at the stomach lining, to prevent tissue digestion.
	Bicarbonate	Buffers gastric acid to prevent damage to epithelium
Chief / Peptic / zymogenic cells	Pepsinogen	Pepsinogen on activation to pepsin digests protein to polypeptides
	Gastric lipase	Digests lipids to fatty acids and glycerol
	Prochymosin (Prorennin)	Rennin coagulates soluble milk protein **Caseinogen** into insoluble **casein** in babies, whose slowed flow enables digestion by **pepsin**.
	Gastric lipase	Gastric lipase **weakly** hydrolyses **fats** to **fatty acids** and **glycerol**
Parietal / oxyntic cells	Hydrochloric acid	(i) Activates pepsinogen to pepsin, Prorennin to rennin (ii) Kills most bacteria in the stomach. (iii) Provides optimum acidic pH for pepsin to hydrolyse proteins into polypeptides. (v) Stops the working of salivary amylase enzyme
	Intrinsic factor	●Forms a complex which enables absorption of vitamin B_{12} that is necessary in red blood cell formation ●Little *intrinsic factor* causes **pernicious anemia**

MECHANISM OF HYDROCHLORIC ACID SECRETION IN PARIETAL CELLS

●Hydrochloric acid is produced by **parietal** cells through a complex series of reactions.

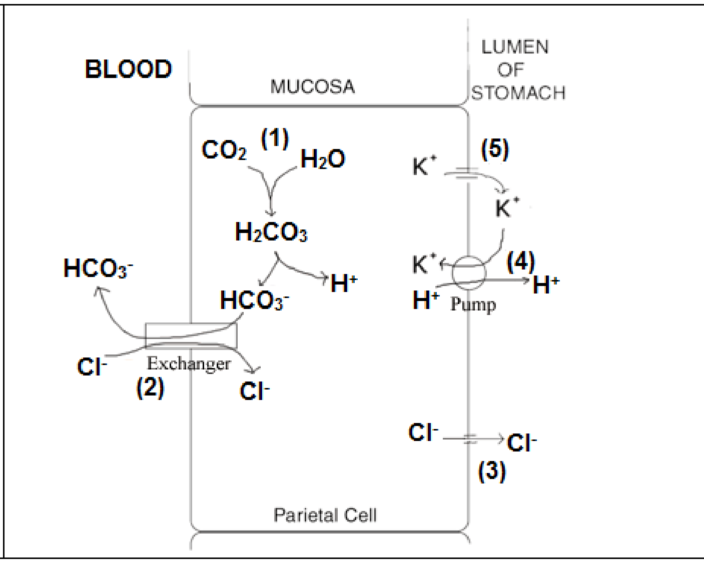
●Catalysed by the enzyme **carbonic anhydrase**, **carbon dioxide** (which diffused from capillaries) reacts with **water** to form **carbonic acid**, which dissociates into **bicarbonate ion** and **hydrogen ion**.

●**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**.

●The net result is production of hydrochloric acid in the **parietal cells** and its secretion into the **duct** of **gastric gland**.



●Due to churning by the stomach wall (alternate contractions and relaxations), **VIP-producing cells** are stimulated to secrete the hormone called **vasoactive intestinal peptide**, which causes relaxation of **pyloric sphincter muscle** to allow the semi solid **chyme** flow from the stomach into the duodenum, after a maximum of about **four hours**.

DIGESTION IN THE DUODENUM

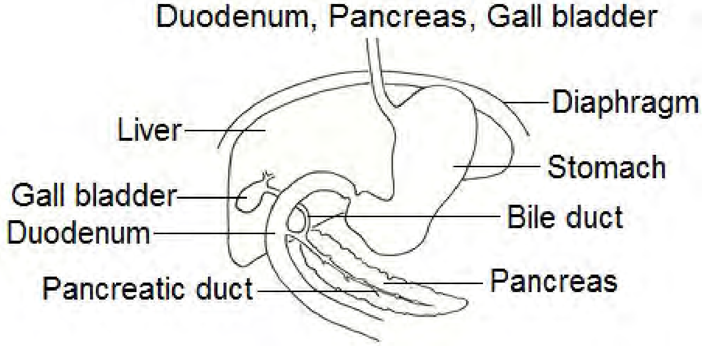
Arrival of **partially digested, acid food** mixture in the duodenum stimulates **endocrine cells** in duodenal walls to secrete the hormones: **Secretin, Enterogastrone, Cholecystokinin (CCK)** formerly **Cholecystokinin-Pancreozymin (CCK-PZ), Villikinin** and **Enterocrinin**. These hormones coordinate activities of the stomach, pancreas, gall bladder and ileum as follows:

Hormone	Stimulus for secretion	Effect
Secretin hormone	Acid chyme in duodenum	●Stimulates the **liver** to secrete **bile** into the **gall bladder**. ●Stimulates pancreatic secretion of **non-enzymatic** substances (**hydrogen carbonate ions)** from **acinar cells.** HCO_3^- neutralise the acid from the stomach to provide an alkaline pH optimum for pancreatic enzymes. ●Inhibits secretion of **HCl** by **oxyntic cells** as chyme leaves the stomach.
Enterogastrone hormone	Acid and fat in the duodenum	●Reduces stomach motility ●Inhibits oxyntic cells from secreting hydrochloric acid in order to provide an optimum pH for pancreatic enzymes. ●Signals the stomach to empty slowly when fat is present, allowing much time for digestion of fat already emptied. **NOTE**: High fat diets stimulate enterogastrone production, which prolongs food stay in the stomach, and is therefore useful in treating duodenal ulcer.
Cholecystokinin hormone (CCK) formerly called **Cholecystokinin**	Partially digested **fat** and **protein** in the duodenum	●Stimulates contraction of **gall bladder** to release **bile** into **duodenum**. **(i)** Bile salts (sodium glycocholate) emulsify fats i.e. fats physically break into droplets due to reduced surface tension, which increases their surface area ●Stimulates the pancreas to secrete **pancreatic enzymes**: (i) **Pancreatic amylase** which catalyses the hydrolysis of **starch** into **maltose** (ii) **Enterokinase**, a non-digestive enzyme which activates **Trypsinogen** to **Trypsin.** (iii) **Trypsinogen**, which is activated by **enterokinase** to **Trypsin.** **Trypsin:** **(1)** Catalyses hydrolysis of **polypeptides** to **peptides.** **(2)** Activates **chymotrypsinogen** to **chymotrypsin**. (iii) **Chymotrypsinogen,** which is activated to **chymotrypsin** by **Trypsin.** **Chymotrypsin** catalyses hydrolysis of **casein** / **polypeptides** into **peptides**.
Villikinin (Motilin)	**Alkaline pH** in the duodenum	●Increases peristalsis in the small intestine and ileum villi movements, in preparation for incoming food.

NOTE:
1. Some sources indicate that **enterogastrone** refers to any of the hormones secreted by the mucosa of the duodenum in the lower gastrointestinal tract in response to dietary lipids to inhibit churning e.g. **(i)** Secretin **(ii)** Cholecystokinin
2. All **proteolytic** (protein digesting) enzymes along the gut are secreted in **inactive (precursor)** form to prevent **autolysis** (self-digestion) of gut tissues, which are protein in nature.

The churning action of duodenal walls turns the semi-solid **Chyme** into a thin, milky-looking alkaline fluid called **Chyle**.

Anatomical relationship between Duodenum, Pancreas, Gall bladder



DIGESTION IN THE ILEUM

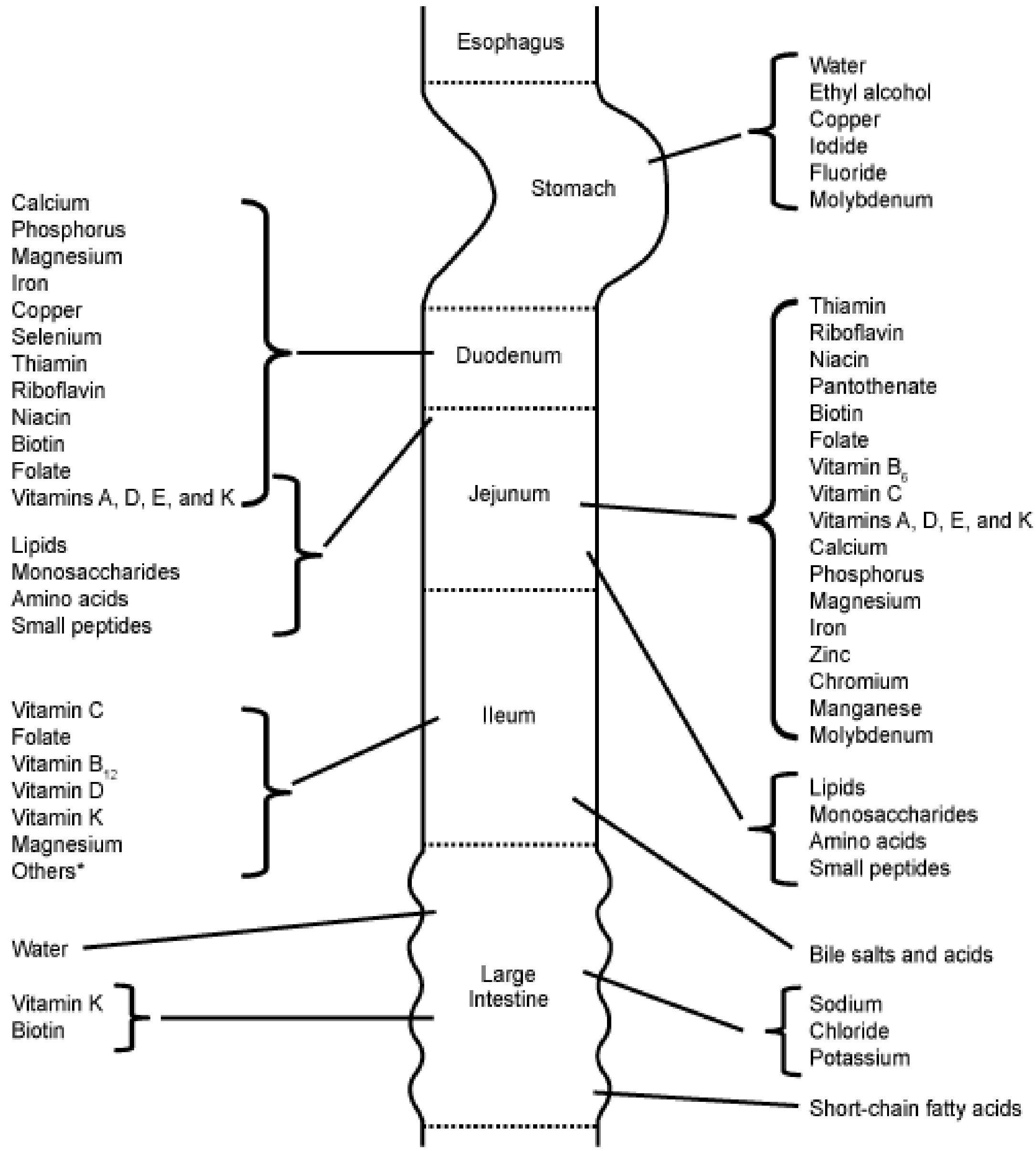
Distention of the small intestine by food / **tactile stimulus** / **irritating stimulus** stimulates the secretion of **intestinal juice** (**Succus entericus**), which consists of a mixture of substances from **crypts of Lieberkühn** and **Brunner's glands**. Some of the components of **Succus entericus** include the following enzymes:

●***Peptidases***: catalyse hydrolysis of **peptides** into **amino acids**, thereby completing the digestion of proteins.
●***Nucleotidases***: catalyse hydrolysis of **nucleotides** into **phosphoric acid, nitrogenous bases** and **pentose sugars**.
●**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 **lactose** into **glucose** and **galactose** molecules.
●***Intestinal lipase***: catalyses hydrolysis of **lipids** into **fatty acids** and **glycerol**.
●***Intestinal amylase***: catalyses hydrolysis of **starch** into **maltose**.

FOOD ABSORPTION
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.
During absorption, substances move as follows:
(i) From **intestinal lumen** across the free end / **apical** end / **mucosal** end of the absorbing cell.
(ii) Across the base / **basilar** end / **serosal** end of absorbing cell into the **subcellular space**, and finally into **blood circulatory system** or **lymphatic system**.

NOTE: Substances entering at the apical surface may be metabolized or within the cell or may appear at the basilar surface when changed into another form.

MAIN SITES OF NUTRIENT ABSORPTION



*Many additional nutrients may be absorbed from the ileum depending on transit time.

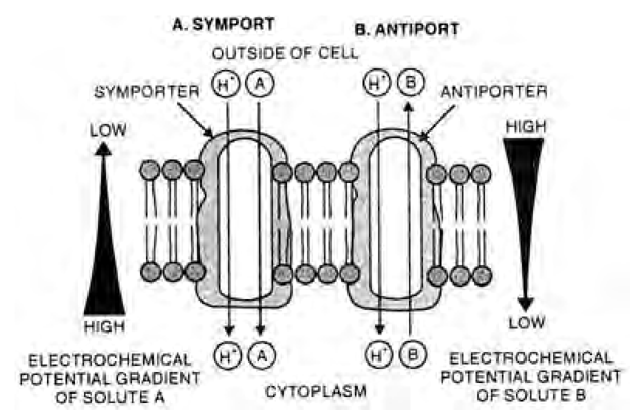
PROCESSES INVOLVED IN ABSORBING DIGESTED FOOD
(1) Simple diffusion **(2)** Facilitated diffusion **(3)** Active transport**: Direct** active transport and **Secondary** active transport

SECONDARY ACTIVE TRANSPORT
A form of active transport across a biological membrane in which a transporter protein couples the movement of an ion (e.g. Na^+ or H^+) **down** its electrochemical gradient to the **uphill** movement of another molecule or ion **against** a concentration/electrochemical gradient. Thus, energy stored in the electrochemical gradient of an ion is used to drive the transport of another solute against a concentration or electrochemical gradient.

TYPES OF SECONDARY ACTIVE TRANSPORT
1. Cotransport (also known as **Symport**) **2. Exchange** (also known as **Antiport**)

1. COTRANSPORT: The direction of transport is the same for both the driving ion and driven ion/molecule.
Examples:
(i) The Na^+/glucose cotransporter in **enterocytes** (small intestine epithelial cell) and kidney proximal tubule epithelial cells simultaneously transports 2 Na^+ ions and 1 glucose molecule into the cell across the plasma membrane.
(ii) The H^+/dipeptide or tripeptide cotransporter in epithelial cells of small intestine couples the downhill movement of H^+ across the plasma membrane to the uphill transport of dipeptides and tripeptides into the cell against a concentration gradient.

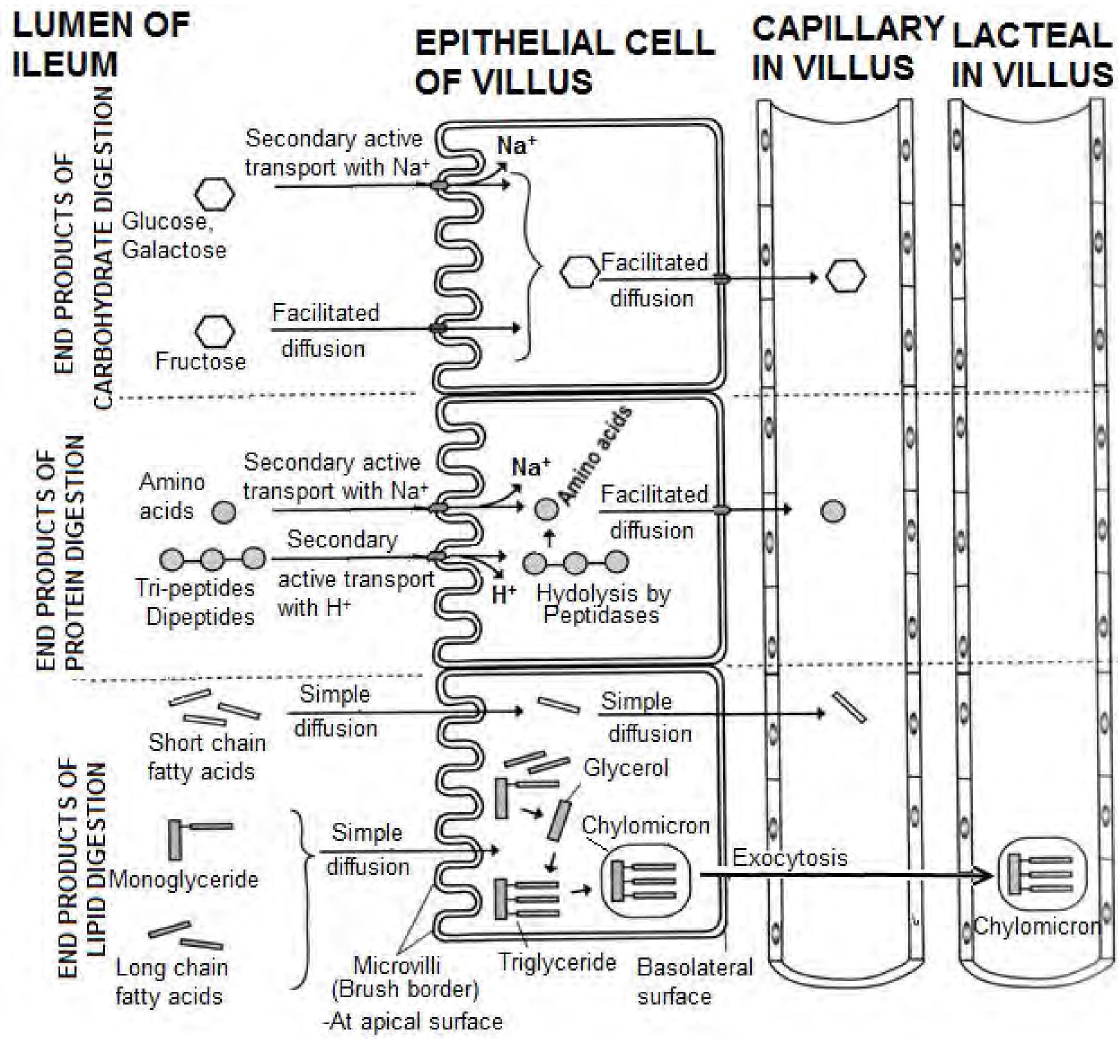
2. EXCHANGE: The driving ion and driven ion/molecule move in opposite directions.
Example:
The Na^+/Ca^{2+} exchanger in cardiac muscle cells transports 3 Na^+ ions into the cell in exchange for 1 Ca^{2+} ion transported out of the cell.



MECHANISMS OF ABSORBING DIGESTED FOOD IN THE ILEUM

Digested food	Mechanism	Description of the mechanism
Glucose and galactose	Secondary **active transport** with Na^+ (**Cotransport with Na^+**)	Glucose and galactose are **cotransported** into epithelial cells of villi with **Na^+** ions, then exported into blood capillaries by **facilitated diffusion**.
Fructose	Facilitated diffusion	Fructose moves into epithelial cells of villi by **facilitated diffusion**, then exported into blood capillaries by **facilitated diffusion**.
Amino acids	Secondary **active transport** with Na^+ (**Cotransport with Na^+**)	Amino acids are **cotransported** from intestinal lumen into small intestinal epithelial cells with **Na^+** ions, then exported to capillaries by **facilitated diffusion**.
Dipeptides and Tripeptides (Oligopeptides)	Secondary **active transport** with H^+ (**Cotransport with H^+**)	Oligopeptides (dipeptides and tripeptides) are **cotransported** from intestinal lumen into villi epithelial cells with **protons (H+)** Oligopeptides are then **hydrolysed by cytoplasmic peptidases** into **amino acids**, which are exported from the villi epithelial cells into blood capillaries by **facilitated diffusion**.
Short chain fatty acids	Simple diffusion	Short chain fatty acids move into epithelial cells of villi by **simple diffusion**, then are exported into blood capillaries by **simple diffusion**.
Monoglycerides and Long chain fatty acids	Simple diffusion	Monoglycerides and long chain fatty acids **diffuse** into columnar epithelia of villi, **recombine** to form **lipids**, then combine with **proteins** to form water soluble **lipoproteins** called **chylomicrons**, which are exported by **exocytosis** to lacteals.

NOTE:
1. Absorption of **whole proteins** occurs only in a few circumstances e.g. **newborns** when suckling absorb **antibodies** (**immunoglobulins**) from the mother's milk (colostral milk) to acquire **passive immunity**.
2. In adults, absorption of whole protein can cause **allergic reaction** due to presence of **foreign protein** in blood.



ILEUM – THE MAJOR SITE FOR ABSORPTION

Adaptations of the ileum to absorption of food

(i) Ileum is **long** and **highly folded** for **increased surface area** in **absorption** of soluble food substances.

(ii) Ileum has **numerous** finger-like projections called **villi** which **increase** the **surface area** for **absorption** of soluble food.

(iii) Ileum epithelial cells have **microvilli** which further **increase** the **surface area** for efficient food absorption.

(iv) Ileum **epithelium** is **thin** to **reduce diffusion distance** for soluble food substances to allow **fast rate** of **diffusion**.

(v) Ileum **epithelium** is **permeable** to allow **movement** of soluble food substances **across** with **minimum resistance**.

(vi) Ileum villi have **dense network of blood capillaries** to **rapidly carry away digested food** from the absorption area which **maintains** a **steep diffusion gradient**.

(vii) Ileum villi have **permeable lacteal**, a branch of the lymphatic system for **carrying away** fats

(viii) Ileum **epithelial cells** have **numerous mitochondria** to generate ATP energy for active transport of some ions.

(ix) Ileum **inner surface** is lined with **a lot** of **mucus** to **prevent autolysis (self-digestion)** by **proteolytic** enzymes.

TYPICAL EXAMINATION QUESTIONS

1. (a) Explain how the structure of villi in the small intestine is related to absorption of digested 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.
- Numerous mitochondria provide much ATP for active uptake of some nutrients like glucose and salts.
- Blood capillaries close to epithelium/ surface to reduce diffusion distance during absorption of glucose/ amino acids
- Lacteal / lymphatic vessel is permeable/has large surface area at centre to absorb fatty acids and glycerol.
- Tight junctions between adjacent villi enable controlling absorption of substances

(b) The table below shows experimental results of the rate of absorption of hexose sugars (Glucose, galactose and fructose), and pentose sugars (xylose and arabinose) by pieces of living intestine and by pieces of intestine poisoned with cyanide. The results are shown as relative to the rate for glucose.

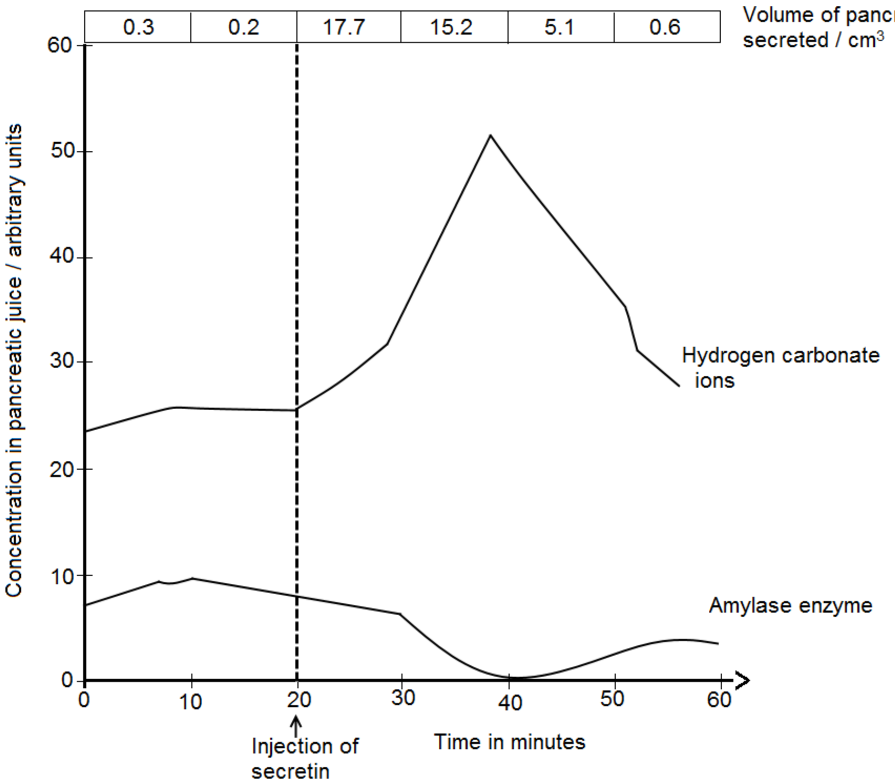
	Rate of absorption	
	By living intestine	By poisoned intestine
Glucose	1.00	0.33
Galactose	1.10	0.53
Fructose	0.43	0.37
Xylose	0.31	0.31
Arabinose	0.29	0.29

(i) Explain the observed rates of sugar absorption shown by the two tissues.

●The rate of absorption of glucose and galactose is faster in living intestine**;** but much slower in poisoned intestine**; because** absorption of these sugars is **active transport** requiring ATP whose formation depends on enzymes**;** which are **inhibited** by respiratory inhibitor **cyanide;** To a small extent, the two sugars are absorbed **passively;**

●Rate of absorption of fructose, xylose and arabinose is the same or relatively the same in living intestine and in poisoned intestine**; because** absorption of these sugars is **facilitated diffusion** which **does not** require ATP; therefore **not inhibited** by respiratory poison **cyanide;**

2. The graph below shows how an injection of secretin affects the secretion of pancreatic juice by the pancreas.



(a) Use the graph to explain the effect of secretin on pancreatic secretion.

(b) (i) From the graph, comment on the composition of pancreatic juice.

(ii) State any other digestive secretion stimulated by secretin.

(c) 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 atrophine.

PROBABLE SOLUTIONS

(a) ●Secretin injection causes a rapid increase in the volume of **pancreatic juice** from 20 minutes to 30 minutes**;** followed by gradual decrease to 40 minutes**;** then a rapid decrease to 60 minutes**;**

●Secretin injection causes gradual increase in the concentration of bicarbonate ions from 20 minutes to 30 minutes**;** followed by rapid increase to a peak at 40 minutes**;** then rapid decrease until 60 minutes**;**

●Secretin injection causes gradual decrease in concentration of amylase from 20 minutes to 30 minutes**;** followed by rapid decrease to a minimum at 40 minutes**;** then gradual increase until 55 minutes and thereafter remains constant until 60 minutes**;**

●Upon injection into blood, secretin hormone circulates to reach the pancreas and liver, first in **low concentration** from 20 minutes to 30 minutes**;** gradually stimulating pancreatic secretion of **watery hydrogen carbonate ions** from **acinar cells** and **gradually stimulating** secretion of **somatostatin hormone** which **gradually inhibits** secretion of pancreatic amylase enzyme**.**

●From 30 minutes to 40 minutes, there is now **much secretin concentration** in blood circulation; which rapidly stimulates pancreatic acinar cells to rapidly secrete **hydrogen carbonate ions** and **also** greatly stimulates secretion of **somatostatin hormone** which **rapidly inhibits** secretion of pancreatic amylase enzyme**;**

●From 40 minutes to 60 minutes, high PH (alkalinity) due to **hydrogen carbonate ions** inhibits the working of secretin hormone; causing less stimulation of acinar cells hence rapid decrease in secretion of hydrogen carbonate ions. **Somatostatin hormone** secretion decreases hence decreasing the inhibition of pancreatic exocrine cells causing increased amylase enzyme secretion;

(b) (i) Pancreatic juice is mainly composed of **substances** (like water), **hydrogen carbonate ions,** and small amounts of enzymes like **amylase**.

(ii) Secretion of **bile** in liver cells, stored in the gall bladder which when released in the duodenum emulsifies fats into droplets, which is physical digestion.

(c) (i) Conditioned reflexes from vagal centre in the brain fail to stimulate secretion of acetylcholine, no secretion of gastrin hormone, no secretion of gastric juice (HCl) during the cephalic phase (before food reaches the stomach) hence the stomach wall will be less irritated.

(ii) Blocking the action of acetylcholine using atrophine **inhibits** the secretion of **gastrin hormone**; hence secretion of gastric juice (HCl) is inhibited.

COLON

●In the colon, there is mainly absorption of:
(i) Water into the blood capillaries by **osmosis.**
(ii) Vitamins Biotin (B_7) and K, which is synthesised by *Escherichia coli* bacteria that live in the colon.
(iii) Na^+, Cl^- and K^+

NOTE: The colon wall contains mucus secreting cells for lubricating the movement of undigested food through the colon.

APPENDIX AND CAECUM

●In ruminants like cattle and in non-ruminants like rabbits, **mutualistic bacteria** secrete **cellulase enzyme** which digests **cellulose** to **glucose,** which is lost along with faeces. In the process described as **coprophagy (coprophagia)**, rabbits eat own faecal pellets while dung beetles feed on cow dung to enable absorption of glucose at the ileum.
●In humans, appendix and caecum have no obvious role.

RECTUM

●In the rectum, food is stored temporarily to enable osmotic absorption of water into blood capillaries.

CONTROL OF DIGESTION IN HUMANS

A combination of **hormonal** and **nervous stimulations** and **inhibitions** of the gut that **regulate** the secretion of digestive juices in the gut.

IMPORTANCE OF CONTROL OF DIGESTION

(i) Secretion of digestive juices depends on respiratory energy, therefore unnecessary secretion must be prevented to avoid wastage of respiratory substrates.
(ii) Secretion of **proteolytic enzymes** in inactive form prevents **autolysis** (self-digestion of tissues).

MECHANISMS OF CONTROLLING DIGESTION IN HUMANS

●Involves a combination of **hormonal** and **nervous; stimulations** and **inhibitions** of the gut; that **regulate** the secretion of digestive juices in the gut;
●The digestive juices secreted include **saliva** in the buccal cavity; **gastric** juice in the stomach; **pancreatic** juice and **bile** in the duodenum; **intestinal** juice in the ileum;

CONTROL IN THE MOUTH

●Sight / smell / thought of food **stimulate** conditioned reflexes involving the **cerebral cortex, hypothalamus** and **medulla oblongata;** which **stimulate** salivary glands to secrete saliva.
●Contact of food with tongue taste receptors **stimulates** nerve impulses via sensory neurons to the **hypothalamus** and **medulla oblongata;** relayed along motor neurons to **stimulate** salivary glands to secrete saliva.
-Salivary amylase in saliva causes hydrolysis of starch to maltose.
●Loss of appetite / depression **inhibit** cerebral cortex**;** parasympathetic centre is **not stimulated**, no secretion of saliva**;**

CONTROL IN THE STOMACH

Occurs in 3 phases: **cephalic; gastric;** and **intestinal** phases;

Cephalic phase / Nervous phase:

It occurs before food enters the stomach;
●Sight / smell / 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 **hormone gastrin**; whose effects are:
(i) Stimulates secretion of gastric juice.
(ii) Increases contractions of gastro-intestinal tract
(iii) Relaxes the pyloric sphincter to let in bolus of food from the gullet;
●Loss of appetite / depression **inhibit** cerebral cortex**;** parasympathetic centre is **not stimulated**, no gastric secretion**;**

NOTE:
Secretion of nervous phase lasts for about one hour during which gastric juice secretion reaches a maximum, after which there is a rapid decrease from 1 hour to 1.5 hours.
Therefore, nervous secretion is: **(i)** short lasting and **(ii)** rapid as compared to the hormonal phase.

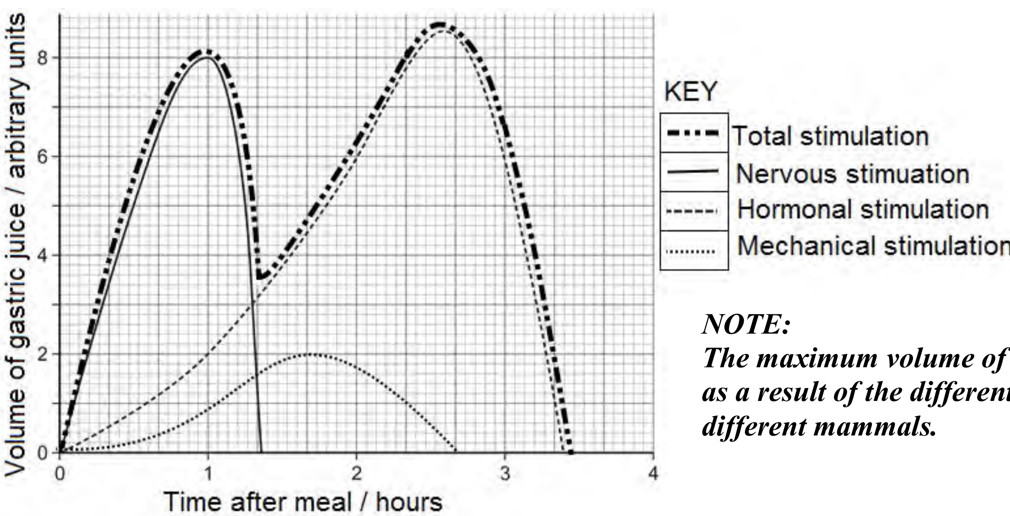
Gastric phase:
● Arrival of food bolus distends / stretches the stomach wall which activates **stretch receptors** to fire impulses to the **Meissner's plexus** in the stomach wall to cause the following effects:
(i) Stimulate local secretory reflexes in the stomach wall to activate gastric glands secrete **pepsinogen** and **HCl**;
(ii) Stimulate reflexes in the medulla, via the **vagus nerve** to activate gastric glands wall to secrete **pepsinogen** and **HCl**;
(iii) Stimulate **enteroendocrine** cells / G-cells to secrete **gastrin hormone;** which stimulates secretion of **gastric juice;**
(iv**)** Stimulate **enteroendocrine /enterochromaffin** cells to secrete **histamine;** which activates secretion of **gastric juice;**
● Partially digested proteins especially peptides / decrease in pH activates **chemoreceptors**, which stimulate G-cells to secrete **gastrin hormone;** which stimulates secretion of **gastric juice;**
● Excessive acidity (PH of less than 2) **inhibits G-cells** hence **gastric juice** secretion reduces;
● Emotional upset activates **sympathetic nervous system** whose effects override the **parasympathetic nervous system**;

NOTE:
The gastric glands are stimulated by hormones to secrete gastric juice for about four hours.
Therefore, hormonal secretion is: **(i)** longer lasting and **(ii)** gradual as compared to the cephalic phase.

Intestinal phase:
● Distension of duodenum / presence of acid chyme / partially digested food stimulates the secretion of **intestinal** (**enteric**) **gastrin hormone**; which stimulates secretion of **gastric juice** in the stomach**;**
● Distension of duodenum / presence of acid chyme / fatty acids / irritants / in the duodenum stimulates the secretion of Intestinal hormones:
(i) **Secretin**; which stimulates the release of **bile** from the liver and **hydrogen bicarbonate ions** in pancreatic juice;
(ii) **Cholecystokinin**; which stimulates the pancreas to secrete its enzymes;
(iii) **Enterogastrone**; which inhibits/suppresses gastric activity (any further secretion of acid by the stomach);
(iv) **Vasoactive intestinal peptide** inhibits gastric acid secretion.
● Distension of duodenum / presence of acid chyme / fatty acids / irritants / in the duodenum initiates gastric-inhibitory impulses in the enterogastric reflex causing suppression of gastric activity; and emptying of stomach;

CONTROL IN THE 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;

Variations in volume of gastric juice produced by nervous, hormonal and mechanical stimulations with time after eating food

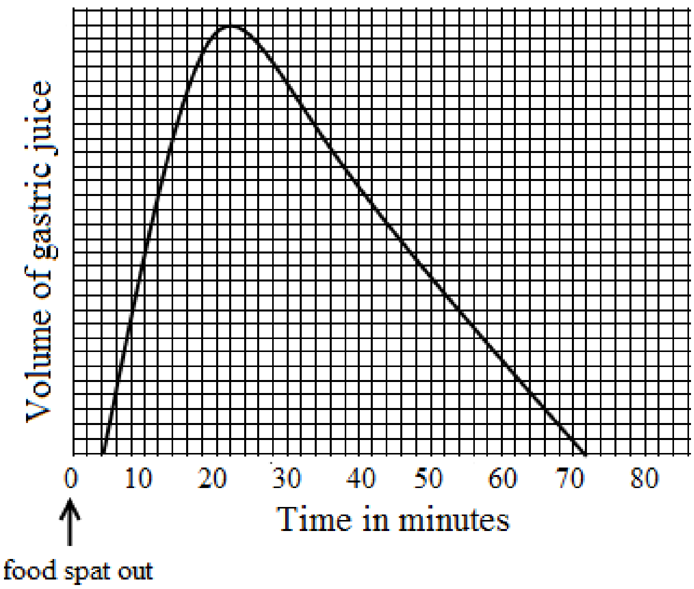


NOTE:
The maximum volume of gastric juice produced as a result of the different stimulations varies in different mammals.

OBSERVATIONS / DESCRIPTION
1. Volume of gastric juice produced during nervous stimulation increases rapidly from 0 hour to a maximum at 1 hour, then decreases rapidly and ceases at 1.5 hours. Nervous secretion is: (i) shorter lasting (ii) instantly rapid as compared to hormonal and mechanical phases.
2. Volume of gastric juice produced during hormonal stimulation increases gradually from 0 hour to 1 hour, then increases rapidly to a maximum at about 2.5 hours, then decreases rapidly and ceases at about 3.3 hours.
Therefore, hormonal secretion is: **(i)** longer lasting and **(ii)** initially gradual as compared to the cephalic phase.
3. Volume of gastric juice produced during **mechanical stimulation (food stretching stomach and duodenal wall)** increases gradually from 0 hour to 0.7 hour, then increases rapidly to a maximum at about 1.6 hours, then decreases rapidly and ceases at about 2.6 hours

TYPICAL EXAMINATION QUESTION

The graph below shows the amount of gastric juice produced by the stomach of an individual who had just chewed some food. **The food was spat out after being chewed, and none was swallowed.**



(a) Name two constituents of gastric juice

(b) Assuming that no traces of food got down into the stomach, explain how the secretion of gastric juice was brought about.

(c) (i) How much time elapsed between the moment the food was spat out and the moment gastric juice started to be produced?

(ii) Account for the delay in (c) (i) above.

(d) If the stomach of an adult person is surgically removed through an operation, suggest with reasons, the more suitable diet for such a person after recovery from the operation.

ASSIMLIATION OF FOOD

Assimilation: The process by which simple soluble food substances are absorbed and used by body cells in the various ways. The products of digestion are brought directly through the hepatic portal vein to liver, which controls the amount of nutrients released into the mainstream blood circulatory system.

Assimilation supports growth, development, body renewal, and storing up of reserves used as a source of energy.

Metabolism: Chemical processes within cells of an organism.

It involves:

(i) Catabolism: Break down of complex molecules into simpler molecules, with release of energy.

(ii) Anabolism: Assembly / building up of complex molecules from simple molecules using energy.

FOOD	HOW ABSORBED FOOD IS USED IN THE BODY	HOW BODY DEALS WITH EXCESS
Glucose	● ATP synthesis in respiration ● Formation of glycoproteins involved in cell to cell recognition mechanisms. ● For production of mucus ● Excess carbohydrates are stored in the form of glycogen in the liver and muscles.	● Stored in the liver as glycogen. ● Excess carbohydrates may be converted into fats for storage.
Amino acids	● Formation of protoplasm of cells during growth ● Production of enzymes and antibodies ● Formation of body structures such as hairs, nails, hooves, cell membranes ● Oxidised to release ATP energy during severe starvation i.e. in the absence of glucose and fats. ● Formation of hormones e.g. insulin ● Formation of plasma membrane components e.g. glycoproteins, channel proteins	● Deaminated in the liver to form urea, which is expelled by kidneys. ● Some amino acids are **transaminated** to produce a different amino acid
Fatty acids and glycerol	● The long chain fatty acids are desaturated in the liver and are then broken down to carbon dioxide and water by successive oxidations. ● Some of it can be converted into glucose ● Some used to form various structures which are components of cells e.g. phospholipids	● Stored as fat under the skin

TYPICAL EAMINATION QUESTION
(a) 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?

	Digestion	Metabolism of absorbed products
Pancreas	On stimulation by **cholecystokinin hormone**, the pancreas secretes enzymes whose effects are as follows: (i) Amylase catalyses hydrolysis of starch into maltose (ii) Enterokinase enzyme which activates Trypsinogen to Trypsin. (iii) Trypsin: (1) Catalyses hydrolysis of polypeptides to peptides. (2) Activates chymotrypsinogen to chymotrypsin. (iii) Chymotrypsin catalyses hydrolysis of casein / polypeptides into peptides. (iv) Lipase hydrolyses fats to fatty acids and glycerol (v) Nuclease hydrolyses nucleic acids to nucleotides (vi) Polypeptidase hydrolyses polypeptides to amino acids. On stimulation by secretin hormone, the pancreas secretes hydrogen carbonate ions from acinar cells, which neutralise the acid chyme from the stomach to provide an alkaline pH optimum for pancreatic enzymes.	(i) If in excess (above 90mg/100cm^3), the pancreas is stimulated to secrete insulin hormone which causes conversion of glucose to glycogen for storage, fat or metabolizing it to energy and CO_2. (ii) If little (below 90mg/100cm^3), the pancreas is stimulated to secrete glucagon hormone which causes conversion of glucagon to glucose hence increasing the blood glucose level.
Liver	On stimulation by secretin hormone, the liver secretes **bile** into the **gall bladder**. On stimulation by CCK hormone, **gall bladder** contracts to release bile salts which emulsify fats i.e. fats physically break into droplets due to reduced surface tension, which increases their surface area	**1. The Liver regulates blood glucose:** (i) If in excess (above 90mg/100cm^3), glucose is converted into glycogen for storage. (ii) If little (below 90mg/100cm^3), glycogen is converted into glucose for use. **2. The liver regulates amino acids in the body:** Excess amino acids are not stored in the body, but undergo deamination process. i.e. the amino group (-NH_2) from the amino acid is removed to form ammonia, which later forms urea that is carried in blood to kidneys for excretion. **3. The liver regulates lipids (fats) in the body:** It synthesizes and degrades phospholipids and cholesterol. 4. The liver forms red blood cells in foetus and breaks down worn out red blood cells in adults. 5. The liver forms plasma proteins from amino acids 6. The liver stores fat soluble vitamins A, D, E, K and water soluble vitamins B_{12} and C 7. The liver stores minerals like Iron, potassium, copper, zinc and trace elements. 8. The liver detoxifies poisonous substances i.e. toxic substances are turned harmless by the liver cells e.g. alcohol, cholesterol and hydrogen peroxide.

(b) Raw liver is rich in vitamin B_{12} which is essential for formation of red blood cells (erythrocytes), whose absence causes pernicious anaemia characterised by paleness, slowness and death.

FOOD AND DIET IN HUMANS

Food: Any substance taken in to nourish the body and sustain life. Food provides energy and nutrients.
Nutrient: is a substance which is needed for **growth**, **repair** and **metabolism**.
The three main nutrients are: **(1)** carbohydrates **(2)** proteins **(3)** lipids (fats and oils)

MEASURING FOOD ENERGY CONTENT

The energy content in a food sample can be measured by **simple calorimetry.**
Calorimetry: Measuring the amount of heat given out or taken in by a process, such as the combustion of a fuel.

PROCEDURE OF CALORIMETRY

(i) Pour cold water into a boiling tube / small beaker / metal can
(ii) Record the starting temperature of the water
(iii) Measure accurately the mass of the food sample in a crucible
(iv) Heat the food until it catches fire.
(v) Heat the water using the flame from the burning food
(vi) Record the final temperature of the water and calculate the temperature difference.

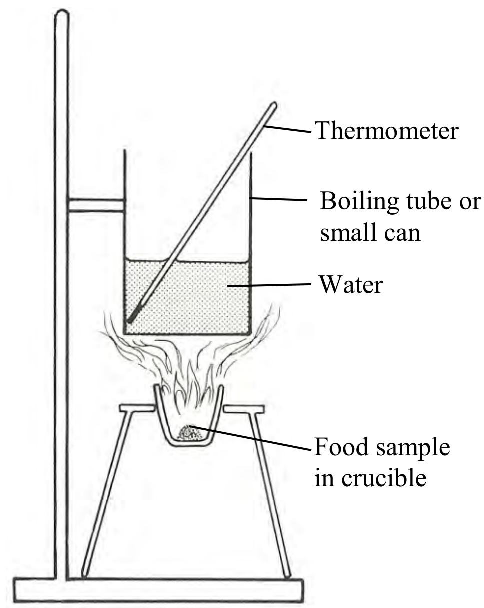
NB: The experiment above can be done more accurately using a **food calorimeter,** though it costs more money to purchase.

Calculations
Work out the energy transferred to the water in joules or in calories
Energy transferred (J) =
Mass of water (g) × 4.2 (J/g°C) × temperature increase (°C)

Note: 4.2kJ (1 cal.) of energy are required to raise the temperature of 1 kg of water through 1^0C

Worked example
When 0.5 g of food is burned, 10 cm^3 of water warms up by 20°C. What is the energy content of the food in J/g?

Solution
1 cm^3 of water has a mass of 1 g
Energy transferred to water = 10 × 4.2 × 20 = 840 J
Energy content of food = 840 ÷ 0.5 = 1680 J/g
To find the energy value of sugar, 1g of sugar is burnt in a crucible, the flame produced is used to heat 100 g water in a metal can and the rise in temperature of the water measured.



COMPARISON OF ENERGY VALUES

Carbohydrate: 1 gram contains 17 kJ
Fat: 1 gram contains 39 kJ
Protein: 1 gram contains 18 Kj

ENERGY UNITS

Energy units are joules, no longer calories
4.18 joules = 1 calorie
1000 calories = 1 kilocalorie (kcal.) = 1 Cal
1000 joule = 1 kJ (kilojoule) = 1 joule
1000 kJ = MJ (megajoule)

PRECAUTIONS

When comparing different foods, it is important to carry out a fair test by keeping other variables constant:
(1) Starting temperature of water **(2)** temperature increase **(3)** distance of the flame from the boiling tube
● More reliable results can be obtained by repeating the experiment.

SOURCES OF ERROR IN CALORIMETRY

(a) Inaccurate weighing of sugar
(b) Incomplete combustion of the sugar
(c) Inability to measure the temperature difference accurately enough
(d) Heat from the burning sugar escaping without heating the water.

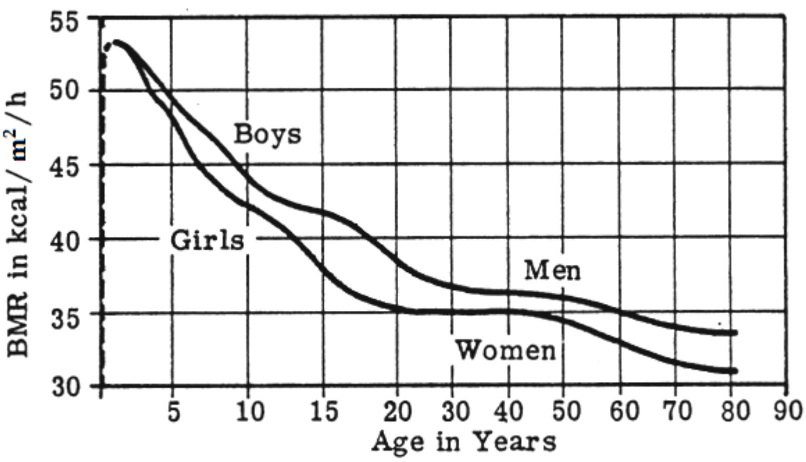
ENERGY-FOOD INTAKE AND CONSUMPTION

The body needs energy for **three main** reasons:
(i) Maintain the **basal metabolic rate** (**BMR**) – 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.
(ii) Sustain body activities like muscle contraction during movement, locomotion, etc.
(iii) Generation of heat to maintain body temperature at about 37^0C

NOTE: BMR accounts for about 65% of the energy used in the body each day.

FACTORS WHICH DETERMINE BASAL METABOLIC RATE

Age, Sex, Body mass, Nature of physical activity engaged in, Muscle mass, Diet, Drugs, Environmental factors e.g. temperature, Hormonal factors e.g. during pregnancy and lactation, Genetics.



(a) (i) Factors shown in the graph, which affect BMR: Age and sex

(ii) Other factors not shown in the graph, which affect BMR:
Muscle mass, Body size, level of physical activity, and Pregnancy and lactation, Diet, Drugs, Environmental factors e.g. temperature, Hormonal factors e.g. during pregnancy and lactation, Genetics

Explanation of variation in BMR with the factors in (a) (i) above.

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.

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Explanation of variation in BMR with the factors in (a) (ii) above.

- **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.

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, water is a solvent while roughage stimulates peristalsis to prevent constipation.
- An unbalanced diet can lead to **deficiency diseases**.

EFFECTS OF UNDERFEEDING AND OVERFEEDING

- 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).

Disadvantages of obesity: (1) the extra mass causes a person to get tired quickly **(2)** increases chances of stroke/heart attack.
How an obese person can lose weight: (1) Eating less energy food **(2)** Taking more exercises to increase energy output

BODY MASS INDEX (BMI)

This is one of the ways of determining whether a person is **underweight** or **overweight**.
BMI can be calculated using the formula:

$$\text{BMI} = \frac{\text{Mass in kg}}{(\text{Height in m})^2}$$

Qn. Calculate the BMI of a female of mass 69 kg and height of 1.67m
Another way of determining whether a person is underweight or overweight is to use a graph showing the relationship between height and body mass.

CHANGES IN BODY ENERGY RESERVES DURING STARVATION

- **Starvation** results from the inadequate intake of nutrients or the inability to metabolize or absorb nutrients.

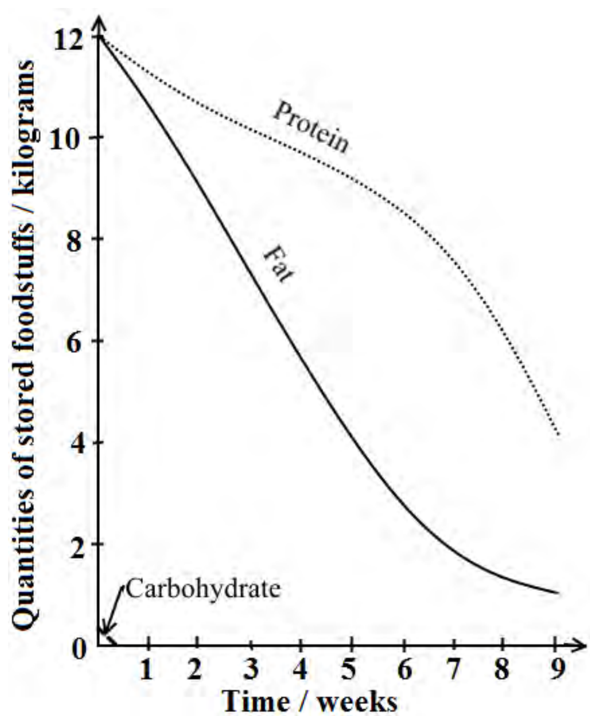
CAUSES OF STARVATION
Prolonged fasting, anorexia, deprivation, or disease
SYMPTOMS OF STARVATION
Weight loss, dehydration, apathy, listlessness, withdrawal, increased susceptibility to infectious disease, discoloured hair color, flaky skin, and massive edema in abdomen and lower limbs causing the abdomen to appear bloated.

ADVERSE EFFECTS OF STARVATION
(i) Marasmus: occurs on account of extreme energy deficiency, typically from inadequate amounts of protein and calories.
(ii) Kwashiorkor: is related to marasmus, affects children who are protein-energy deficient, and can result in edema (fluidic inflammation) and an enlarged fatty liver — resulting in the counterintuitive distending of bellies, giving the illusory impression that starving children are well fed.

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

DESCRIPTION OF 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.



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 characterised 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.

TYPICAL EXAMINATION QUESTIONS

A group of rats were encouraged to over eat by feeding them with unlimited supplies of processed foods such as chocolate and cakes over a three week period. These rats were called **cafetarian rats**. Over the same period, another group of control rats fed on unlimited supplies of their natural food.

	AVERAGE OVER 21 DAYS	
	Cafetarian rats	**Control rats**
Energy content of food eaten (kj)	11670	6480
Gain in the body mass (g)	131	103
Gain in body fat (g)	66	40
Energy used (kj)	9440	4690

(i) What was the effect of feeding the rats on food other than their natural food? (1½ marks)
They gained more body mass, fat and energy

(ii) Determine the average gain in mass of the cafetarian rats over the control rats during the 21 days
Average gain in mass = gain in body mass of cafeterian – gain in body mass of control rats = 131 – 103 = 28g

(iii) State three features of the two groups of rats which should be kept the same: Age, sex, species **(1½ marks)**

(iv) Which chemical of life in the rats would have been responsible for most of the gain in mass? Body fat **(½ marks)**

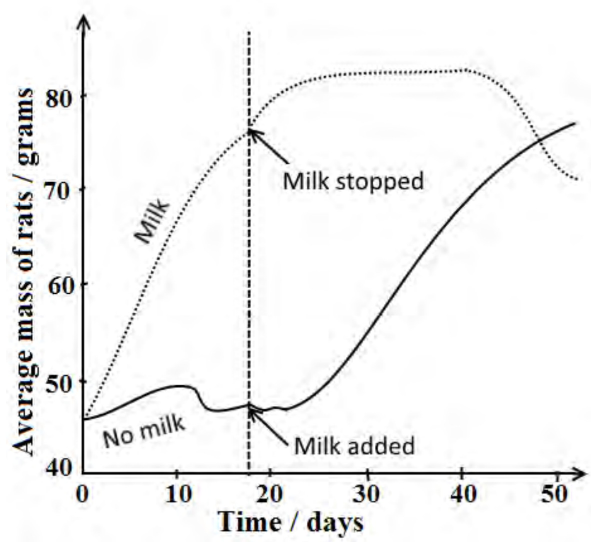
(c) Explain the observation that some people eat enormous amounts of foods without putting on weight where as others become over-weight on quite small food intake: Weight gain does not only depend on food intake, but on other factors like genetic makeup.

(d) Using evidence from the data, explain why cafetarian rats were able to gain more weight than control rats. (2 marks)
The difference between the energy content of food and energy used is higher in cafetarian rats; so unused food had to be converted to fat

(e) Why were control rats necessary in this experiment? For comparison of results **(1 mark)**

FEEDING EXPERIMENTS ILLUSTRATING THE IMPORTANCE OF VITAMINS IN NORMAL DIETARIES

In his investigations exploring the relationship between diet and growth in rats, **Frederick Gowland Hopkins** found that a diet consisting of protein, salts, fats, and carbohydrates **could not alone** support growth.



EXPERIMENT

Two groups of young rats were used.
Group A were fed on a diet of purified casein, starch, glucose, lard, minerals and water only for the first 18 days.
Group B were fed on a diet of purified casein, starch, glucose, lard, minerals and water **plus** an extra of 3cm^3 of milk daily for the first 18 days.
After 18 days milk was given to group A rats and removed from group B's diet.

OBSERVATIONS

Group A rats increased in mass gradually from 0 day to 10 days, mass decreased gradually until about 12 days, mass remained relatively constant up to 22 days, then mass increased rapidly from about 22 days to 50 days

Group B rats increased rapidly in mass from 0 day to 18 days, then gradually increased in mass from 18 days to about 23 days, stopped growing from about 23 days to 40 days and gradually decreased in mass/lost weight thereafter.

CONCLUSION: Hopkins's experiments revealed that, to grow, animals needed small amounts of other substances he called **"accessory food factors"**- now known as **vitamins**.

EXPLANATION
Group A rats resumed growth and increased in weight after 18 days while **group B** rats stopped growing and lost weight after 18 days. While the 3cm^3 of milk had an insignificant food value in terms of carbohydrate, fat, protein and minerals, the milk contains an extra nutrient which the rats needed to be able to grow and develop.

Why it was necessary to transfer milk from group B to group A half way through the experiment?
To ensure that all groups of rats are subjected to identical conditions e.g. feeding them on identical food so as to establish the effect of milk on growth while eliminating the possibility of other factors being responsible the observed differences in results e.g. choice of rats in one group (group A) may have been more sickly than those in group B etc.

Why feeding rats on one type of protein (casein), not a variety is ruled out as a possible cause of growth stoppage and weight loss?
Although proteins are essential for growth and there are different types, proteins are hydrolysed in the body into different amino acids, and the body is able to make some amino acids for itself. Therefore even though the rats were only getting casein this was enough to not have an effect on growth.

Why while a diet of protein alone is sufficient for young animals, it is inadequate for adults?
Much as milk contains all the nutritional requirements like protein, carbohydrates (lactose), lipids, mineral salts, vitamins and water, some amounts may be nutritionally insufficient to meet the metabolic demands of adults.
Some people who are lactose intolerant can't digest the main sugar (lactose) in milk. In normal humans, production of lactase enzyme that digests lactose stops between ages of two and five years, which would result in insufficient ATP production.

NUTRITION IN CARNIVORES AND HERBIVORES
(a) Carnivorous animals: are either **predators** or **scavengers** whose diet consists of mainly flesh obtained from **preys**.
(i) Predator: An animal that hunts and kills animals for food.
(ii) Prey: An animal that is hunted and killed for food.
(iii) Scavenger: An animal that eats dead animals, but doesn't kill them.
(b) Herbivore: An animal whose diet is mainly vegetation
(i) Grazers: Mainly feed on grass
(ii) Browsers: Mainly feed on leaves of shrubs and trees

	Carnivore	**Herbivore**
Adaptations for finding and capturing prey (**carnivores**) or grazing / browsing (**herbivores**)	●Well-developed sense of smell for locating prey ●Fast moving to outpace and capture prey ●Well-built body to manipulate and capture prey. ●Very sharp claws for gripping and killing prey. ●Keen eye sight for locating prey from a distance ●Foot pads enable stealth movement to ambush prey. ●Long, sticky tongue for reaching distant prey e.g. toads. ●Elongated canines for digging up prey e.g. walrus	●Upper jaw lacks incisors to provide a hard pad against which lower incisors press and cut grass. ●Tongue is highly muscular for manipulating food during chewing.
Adaptations for ingesting the food	●Sharp pointed canines for tearing the fresh of prey ●Flat molars to crush prey ●Incisors pointed for nipping and biting. ●Carnassial teeth present for shearing flesh. ●Upper jaw wider than lower jaw to facilitate shearing. ●Up-and-down jaw action only prevents lateral movement hence reducing the danger of dislocation ●Powerful jaw muscles provide much force for chewing	●Molars and premolars are ridged for maximum grinding of hard cellulose materials. ●Molars and premolars have large surface area for maximum grinding of the hard cellulose materials. ●Articulation of lower jaw permits lateral movement to enable maximum grinding of food. ●Well-developed jaw muscles provide much grinding power for crushing cellulose materials. ●Between the front and cheek teeth, there's a gap called diastema for separating crushed grass from uncrushed grass for effective chewing.
Adaptations for digesting the food	●No cellulose in diet hence less developed caecum and appendix to reduce on body weight to enable fast running. ●Relatively short alimentary canal reduces weight, since diet is entirely protein.	●Ruminant stomachs are four chambered to derive maximum nourishment from grass. ●Mutualistic bacteria in caecum and appendix enable chemical digestion of cellulose into glucose. ●Relatively long alimentary canal to digest vegetation

DIFFERENCES BETWEEN CARNIVORES AND HERBIVORES RELATED TO NUTRITION

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 caecum

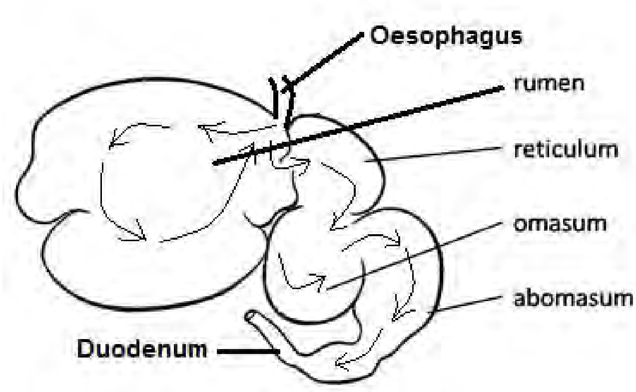
EXAMPLES OF SYMBIOTIC ASSOCIATIONS IN ANIMALS

- **Symbiosis:** Ecological relationship between two or more organisms living together with some form of feeding relationship.
- **Mutualism:** Close relationship where two organisms of different species depend on each other for reciprocal benefit, without any harm e.g. pollination flowers by insects, **Trichonympha** and **termites,** cellulase producing bacteria and herbivores, etc.
- **Commensalism:** Loose relationship in which two organisms of different species live together, only one organism benefits while the other remains unharmed e.g. sea anemone and clown fish.
- **Parasitism:** Close relationship between organisms of different species in which one organism called **parasite** obtains nutrients from and harms a larger living organism called host.

DIGESTION IN RUMINANT MAMMALS

Ruminants: are the mammals, which have a 4-chambered stomach for the digestion of plant based food.
Rumination involves regurgitation of fermented grass known as cud, chewing and re-chewing it again to further break down plant matter and stimulate digestion.
Ruminating mammals include cattle, goats, sheep, giraffes, deer, camels, antelope, etc.

Four-chambered stomach showing food movement during feeding



1. Rumen (Paunch): 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 **ethane**. The fermentation process produces heat that keeps ruminants warm.

2. Reticulum (Honeycomb bag): Here any foreign objects that may have been accidentally swallowed with food settle out in the **honeycomb** structure of the reticulum's walls. Reticulum is sometimes called **"hardware stomach".**

3. Omasum (Psalterium / Manyplies): Absorbs water from food and also absorbs more nutrients called volatile fatty acids that supply ruminants with energy.

4. Abomasum (Reed / 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.

CELLULOSE DIGESTION IN TERMITES

Guts of wood-eating termites contain a micro-organism called **Trichonympha,** which secretes **cellulase enzyme** to digest cellulose in wood. The termite absorbs some of the products of digestion (**glucose**), while **Trichonympha** gets sheltered.

CELLULOSE DIGESTION IN RABBITS (NON RUMINANTS)

The caecum and appendix of a rabbit 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 **coprophagy (coprophagia)**, rabbits eat own faecal pellets while dung beetles feed on cow dung to enable absorption of glucose at the ileum.

PARASITISM

Close relationship between organisms of different species in which one organism called **parasite** obtains nutrients from and harms a larger living organism called host.

Challenges / Dangers faced by ectoparasites	Challenges / Dangers faced by endoparasites
●Failure to cling on the host to avoid being dislodged. ●Failure to obtain nutritive molecules from the host. ●Failure to find the right host for dispersal to their final host	●Failure to penetrate the host ●Failure to obtain nutritive molecules from the host. ●Destruction by the digestive enzymes and immune responses of the hosts. ●Complete elimination or extinction. ●Fluctuating environment e.g. low oxygen tensions, excess heat, solute concentration, darkness etc. ●Failure to find the right host for dispersal to their final host

GENERAL ADAPTATIONS OF PARASITES

Structural adaptations	Physiological adaptations	Reproductive adaptations
●Possession of penetrative devices for host entry e.g. fungal haustoria, cutting teeth in hook worms *Ancylostoma duodenale*) ●Possession of nutrient suckers e.g. leech ●Development of digestive-resistant outer covering to avoid host's enzyme attack e.g. *Ascaris* and *Taenia* etc. ●Camouflaging morphology to increase survival chances e.g. brown ticks on brown cattle. ●Possession of specialised mouth parts in some ecto-parasites to suck hosts e.g. sharp stylets in aphids and tsetse flies. ●Possession of specialised haustorial structures in Cuscuta (Dodder plants) for obtaining nutrients from the host ●Degeneration of non-essential organs e.g. no feeding organs, no locomotory organs, no alimentary canal to reduce body size and fit in intestines /blood vessels and for reducing energy expenditure on such organs for example *Fasciola hepatica* (liver fluke), tape worm, hook worm etc.	●Production of enzymes to digest the host's tissues during penetration into the host e.g. fungi and plasmodium ●Production of anticoagulants by blood feeding parasitic animals such as mosquitoes and ticks to avoid blood clotting during feeding. ●Highly tolerant to fluctuating environment e.g. anaerobic respiration in areas of low oxygen tensions, high temperatures, darkness and pH changes in places where they live e.g. most endoparasites. ●Rapid means of escape which increases their chances of survival e.g. fleas and mosquitoes. ●Production of much mucus for resisting digestion by host's enzymes. ●Some endoparasites produce chemicals to protect themselves against the immune response of the host.	●Some are hermaphrodites with the ability to carry out self fertilisation to increase the rate of reproduction e.g. *Fasciola*, *Taenia*. ●Some asexually reproduce for high rate of reproduction to avoid extinction. ●Release of sexually mature forms of the parasites as free living organisms e.g. in some parasitic animals such as the horse hair worms ●Production of large number of infective agents such as eggs, cysts, and spores which increase survival chances to avoid extinction e.g. tape worms. ●Development of reproductive bodies that are highly resistant when out of the host to survive adverse conditions e.g. cysts in amoeba, fungal spores, etc. ●Use of intermediate host (vector) for their transfer to primary host e.g. plasmodium in female anopheles mosquito to man. ●Some parasites localise the strategic points for propagation to the next host e.g. HIV which causes AIDS is localised in the sex organs. ●Some use hereditary transmission for increased spreading i.e. some parasites infect the ovary of primary host which lays parasite infected eggs.

COMMON PARASITES

Definitive host (final host / primary host): a host in which a parasite attains sexual maturity.
Intermediate host (secondary host): a host in which a parasite passes one or more of its asexual stages; usually designated first and second, if there is more than one.

Phylum/division	Parasite	**Host**		**Effect on primary host**
		Primary	**Secondary**	
Platyhelminthes	*Fasciola hepatica* (liver Fluke)	Sheep, cattle	Pond snails	Liver rot
	Schistosoma mansoni (blood fluke)	Humans	Pigs	*Schistosomiasis* (Bilharzia)
	Taenia solium (Pork tape worm)	Humans	Pigs	**Taeniasis;** Anaemia, Weight loss Abdominal (intestinal) pain
	Taenia saginata (Cattle tapeworm)	Humans	Cattle	
Nematoda	*Ascaris lumbricoides (*roundworm*)*	Humans	None	*Ascariasis,* Intestinal obstruction
Spermatophyta (Seed plants)	Dodder plant (Cuscuta)	Nettle, clover, tomato, potato	None	Damages tissues causing secondary infections
Spermatophyta (Seed plants)	*Striga* sp. (witch weeds)	Maize, millet, groundnut, etc.	None	Stunted growth, wilting, and chlorosis
Heterokontophyta	*Phytophthora infestans*	Tomato leaves	None	Late blight of potato and tomato (Black leaf spots, tuber rot)
Arthropoda	*Plasmodiun*	Female Anopheles	Humans	Malaria fever

LIFECYCLES OF SELECTED PARASITES

Lifecycle of *Ascaris lumbricoides (*roundworm*)*	Adaptations of *Ascaris* to parasitic life
●Adult female in lumen of ileum lays about 200,000 eggs daily, which are passed out in faeces. ●Fertile eggs **embryonate** and become infective after about **three** weeks, (***optimum conditions:*** moist, warm, shaded soil). ●On being swallowed by humans, eggs hatch into larvae, which invade intestinal wall, and are carried via the portal, then systemic circulation to lungs. ●Larvae mature further in lungs (10 to 14 days), penetrate alveolar walls, ascend the bronchi to the throat, and are swallowed into gut. ●Upon reaching the ileum, they develop into adult worms. ●Between 2 and 3 months are required from ingestion of the infective eggs to **oviposition** by the adult female. ●Adult worms can live 1 to 2 years.	●Degeneration of structures reduces space occupied. ●Possession of digestive-resistant cuticle resists destruction by the host's enzymes. ●Ability to position itself in a habitat where it gains maximum nourishment. ●Eggs have protective/resistant shell which is their main ineffective and resistant stage. ●Tolerance to oxygen deficient environment ●Ability to copulate within the intestines followed by the laying of very many eggs increases survival chances.

Lifecycle of *Taenia sp. (*Tapeworm*)*	Adaptations of *Taenia* to parasitism
●Humans are the definitive hosts for *T. saginata* and *T. solium*. ●Eggs or **gravid proglottids** are passed out in faeces; ●Cattle (*T. saginata*) and pigs (*T. solium*) become infected by ingesting vegetation contaminated with eggs or gravid proglottids. ●In the animal's 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. ●Humans become infected by ingesting raw or undercooked infected meat. ●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 in the stool (approx 6 per day). ●The eggs contained in the gravid proglottids are released after the proglottids are passed with the feces.	●Has hooks and suckers for holding tightly onto ileum wall. ●Flattened body increases surface area for absorbing its host's digested food ●Degeneration of structures reduces on space occupied. ●Lays many eggs to increase survival chances. ●Hooks for boring through the gut of the host ●Eggs have a thick shell for resisting enzyme destruction. ●Being hermaphrodite increases reproductive rate

Hygienic practices for controlling 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.

PLASMODIUM – THE MALARIA CAUSING PARASITE

There are approximately 156 named species of *Plasmodium* which infect various species of vertebrates. Four species are considered true parasites of humans, as they utilize humans almost exclusively as a natural intermediate host: *P. falciparum, P. vivax, P. ovale* and *P. malariae*.

LIFE CYCLE OF *PLASMODIUM*

- Malaria parasite life cycle involves **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**.
- After this initial replication in the liver (**exo-erythrocytic schizogony**), the parasites undergo asexual multiplication in the erythrocytes (**erythrocytic schizogony**).
- **Merozoites** infect red blood cells, the ring stage **trophozoites** mature into **schizonts**, which rupture releasing **merozoites**.
- Some parasites differentiate into sexual **erythrocytic** stages (**gametocytes**).
- Blood stage parasites are responsible for the clinical manifestations of the disease.
- The gametocytes, male (**microgametocytes**) and female (**macrogametocytes**), are ingested by an *Anopheles* mosquito during a blood meal.
- The parasites' multiplication in the mosquito is known as the **sporogonic cycle**.

- While in the mosquito's stomach, the **microgametes** penetrate the **macrogametes-generating zygotes**.
- **Zygotes** become motile and elongated (ookinetes), invade the midgut 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 perpetuates the malaria life cycle.

LIFE CYCLE OF *PHYTOPHTHORA INFESTANS*

- *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* spores (**oospores** or **chlamydospores**) germinate to form hyphae or directly produce sporangia.
- Sporangia release free swimming **biflagellated 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.

TYPICAL EXAMINATION QUESTION

1. The blood fluke, *Schistosoma mansoni* is an important helminth parasite that resides within the mesenteric veins of its definite host. Experiments were done and the graphs in figures 1, 2 and 3 below show the effect of temperature, light and salinity on the hatching of the eggs of *Schistosoma mansoni.* At hourly intervals, the number of eggs hatching was determined and expressed as a percentage of total hatch.

Figure 1 shows the effect of temperature on hatching. After 4 hours of treatment at the temperatures shown, the samples were incubated for a further two hours at 28^0C at constant light and salinity.

Figure 2 shows the effect of light on hatching. One sample was kept in light for 6 hours while a second sample was first kept in the dark for 3 hours, then transferred to light for 3 hours at constant temperature and salinity.

Figure 3 shows the effect of salinity on hatching after treatment for 6 hours at constant temperature and light (percentage of total hatch is expressed as a % of number of eggs hatching in 0% saline).

Figure 1

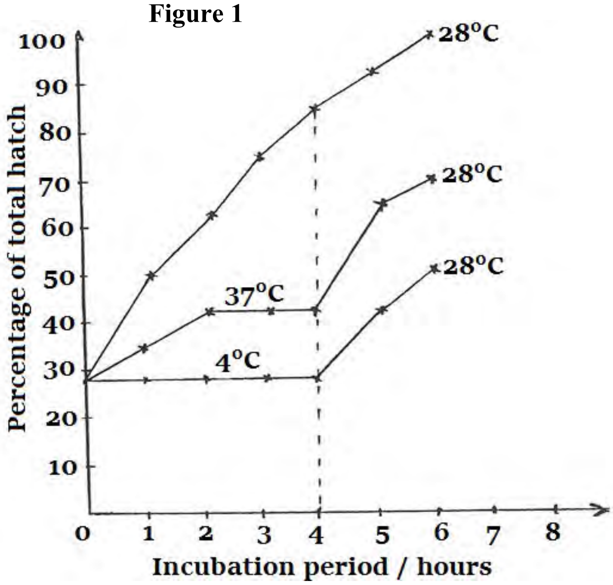
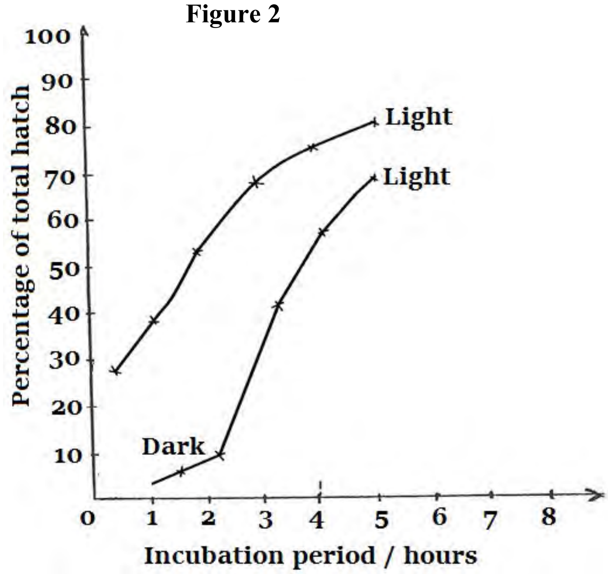


Figure 2



The eggs kept in 0.8% saline for 6 hours as in figure 3 above were removed, divided equally into four lots and placed in a range of saline solutions for a further 6 hours. The results are as shown in **table 1** below:

Figure 3

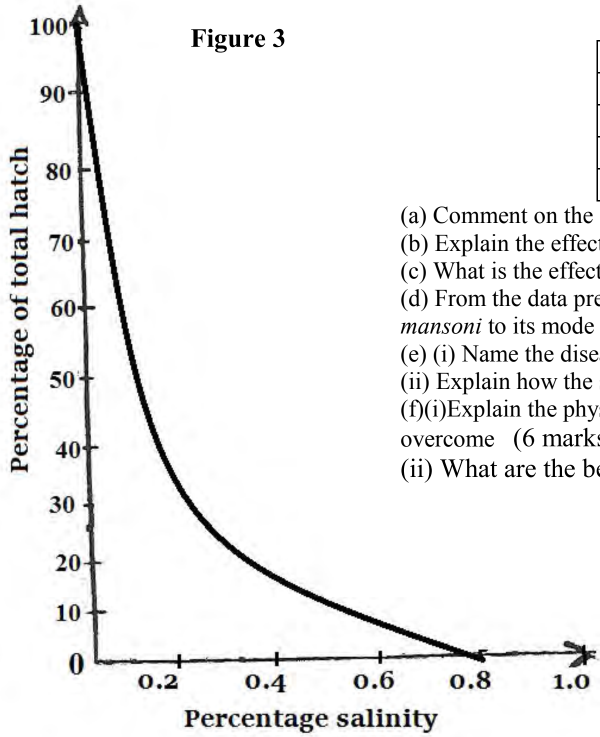


Table 1

Salinity (%)	Total hatch after 6 hours (%)
0.0	100
0.2	40
0.4	20
0.6	8

(a) Comment on the effect of temperature on hatching of *Schistosoma mansoni* eggs. (7 marks)
(b) Explain the effect of light on percentage hatch of eggs. (6 marks)
(c) What is the effect of salinity on percentage hatch of the eggs? (4 marks)
(d) From the data presented and restricting yourself to egg stage only, discuss adaptations of *S. mansoni* to its mode of life. (10 marks)
(e) (i) Name the disease caused by this blood fluke to man (1 mark)
(ii) Explain how the spread of disease can be controlled (4 marks)
(f)(i)Explain the physiological challenges facing human endo-parasites and how they are overcome (6 marks)
(ii) What are the benefits of parasitic nutrition to organisms that exhibit it? (2 marks)

PROBABLE SOLUTIONS

(a) Comment on the effect of temperature on the hatching of the eggs of *Schistosoma mansoni.* (7 marks)
- At constant light, salinity and temperature of 28^{0}C; ✓ eggs hatched rapidly; ✓ to completion; ✓
- At higher temperature of 37^{0}C and lower temperature of 4^{0}C; ✓hatching is just slightly stimulated (greatly inhibited); ✓
- Restoring temperature from 37^{0}C and 4^{0}C to 28^{0}C; ✓stimulates rapid hatching; ✓

(b) Explain the effect of light on the percentage of the total hatch of the eggs. (6 marks)
- The lot of eggs exposed to light hatch rapidly to completion; ✓ because light stimulates / activates a hatching substance/enzyme; ✓ which digests/breaks down the egg membranes to enable emergence of larvae; ✓
- Darkness generally inhibits hatching; ✓ because the hatching substance is inactive; ✓ however in this case a little hatching occurred in the dark probably due to experimental errors which resulted in some illumination of eggs;✓

(c) What is the effect of salinity on the percentage of total hatch of the eggs? (4 marks)
- In fresh water (at 0% salinity) all eggs hatched; ✓ at 0.8% salinity no eggs hatched (hatching was inhibited); ✓ increase in salinity; ✓ causes a rapid decrease in hatching; ✓

(d) From the data presented and restricting yourself to the egg stage only, discuss the adaptation of *S. mansoni*
(For more information, see MBV Roberts; functional approach, pg. 552-553)
- In the mesenteric veins of the main host of *Schistosoma mansoni*; ✓ there is total darkness and temperature is about 37^{0}C; ✓both of which prevent hatching of eggs into miracidia (larvae) in man; ✓because they would die; ✓
- When faeces with eggs reach fresh water bodies; ✓where there is much illumination (light), lower temperature and very low salinity; ✓ all of which favour rapid hatching of eggs; ✓ many larvae (miracidia) are formed; ✓ which infect water snails; ✓ (intermediate host) and form more larvae (cercariae) that infect man; ✓

(e) (i) Name the disease caused by this blood fluke to man (1 mark)
Bilharzia (Schistosomiasis); ✓

(ii) Explain how the spread of the disease can be controlled (method and its purpose = 01 mark x 4)
- Disposal of faeces in latrines/toilets to avoid their contact with fresh water bodies; ✓
- Deworming to kill adult worms in humans; ✓
- Wearing gear (boots/shoes) that shield/protect feet from larvae (cercaria) infection; ✓
- Use molluscides to kill larvae’s (miracidia) intermediate hosts (adult snails) in water; ✓
- Biological control in which some fish and ducks are introduced in water to feed on larvae /snails; ✓

(f)(i) Explain the physiological challenges facing human endo-parasites and how they are overcome
(Any 3, @ challenge – 1 mark, how overcome – 1 mark = 06 marks)

Challenge	How it is overcome
• Digestion by the host's enzymes; ✓	• Development of thick cuticle/secretion of inhibitory substances /mucus✓
• Osmotic changes in the habitat; ✓	• Increased chemosensitivity in order to equilibrate with host✓
• Inhibitory chemical environment; ✓	• Secretion of anti-inhibitory substances; ✓
• Anaerobic conditions; ✓	• Ability to respire anaerobically; ✓
• Attack by host's immune system; ✓	• Development of protective structures against the host's immune attack✓

(ii) Importance of parasitic nutrition (2 marks)
- A variety of nutrients required for growth, development and body maintenance may be obtained from one meal

Less development of digestive system since most nutrients obtained are fully /partially digested.

SAPROTROPHISM (SAPROTROPHIC NUTRITION)
The process of obtaining soluble organic substances from extracellular digestion of dead or decayed organic matter.
Saprotroph: An organism that absorbs soluble nutrients from extracellular digestion of dead/decaying organic matter.

EXAMPLES OF SAPROTROPHS
(i) Saprobes: fungi like mushrooms, yeasts and moulds
(ii) Saprophytes: **saprotrophic plants** e.g. sugar stick, gnome plant, Indian-pipe and **putrefying bacteria** which convert complex organic substances into simpler compounds e.g. **Zygomonas** bacterium ferments **glucose** producing **alcohol, lactic acid and carbon dioxide**, **Clostridium aceto-butylicum** forms **butyl alcohol** from **carbohydrates**, **Lactobacillus** converts **sugars** into **lactic acid**.
(iii) Saprophages: Animal scavengers, such as dung beetles and vultures

DESCRIPTION OF SAPROTROPHISM IN FUNGAL MOULD LIKE MUCOR/RHIZOPUS
●Under suitable conditions (moisture / water, oxygen, neutral / mildly acidic pH, temperature of about 25 °C) the saprotroph secretes different enzymes into the dead animal/plant body; proteases, lipases, carbohydrases e.g. amylase which break down insoluble complex organic substances into simple soluble substances as follows:
-**Proteases** break down **proteins** into **amino acids**
-**Lipases** break down **lipids** into **fatty acids** and **glycerol**
-**Carbohydrases** e.g. **Amylases** break down **starch** into **maltose/simple disaccharides**
●The end products of extra-cellular digestion such as **fatty acids** and **glycerol, glucose, amino acids** plus other nutrients like **vitamins** e.g. **thiamine** and **ions** e.g. **potassium, phosphorus, and magnesium** are re-absorbed into the hypha through the cell wall by **endocytosis / simple diffusion / facilitated diffusion / active transport** and passed on throughout the mycelium complex to enable growth and repair.

COMPARISON OF SAPROPHYTES WITH PARASITES
Similarities
Both: **(1)** are heterotrophs **(2)** absorb soluble food **(3)** have simple digestive systems **(4)** have sexual and asexual phases in their reproduction **(5)** produce large numbers of offspring.

Differences

Parasites	Saprophytes
●Energy derived from living organisms	●Energy derived from dead organisms
●Many stages in lifecycle	●Usually a single adult stage, with spores inclusive
●Very specific to their host	●Use a variety of food sources
●Nutritionally highly adapted	●Simple methods of nutrition
●Most plant and animal groups have representatives	●Almost totally fungi and bacteria
●Most are aerobic	●Anaerobic and aerobic

IMPORTANCE OF SAPROPHYTES
●Recycling of materials e.g. carbon, nitrogen, phosphorus
●Brewing and baking e.g. yeast (*Saccharomyces*)
●Making antibiotics e.g. Penicillin
●Decomposition of wastes e.g. sewage
●Production of yoghurt and cheese
●Food source e.g. mushrooms
●Industrial applications e.g. leather tanning, production of vitamins, etc.

AUTOTROPHIC NUTRITION

Autotrophic (Greek: *auto* – 'self'; *trophic* – 'feeding') organisms take in inorganic carbon e.g. carbon dioxide and energy, to form complex organic compounds.

Types of Autotrophs
(1) ***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.*
(2) C***hemotrophs -*** organisms which synthesize organic compounds using energy extracted from oxidation of inorganic chemicals by the process called **chemosynthesis** e.g. *Nitrosomonas* and *Nitrobacter*

CHEMOSYNTHESIS

Chemosynthesis: chemical process in which inorganic chemicals are oxidized to provide energy to living organisms for the synthesis of organic compounds.

Chemosynthetic bacteria	***Substrate***	***Main product***	***Habitat***
Nitrosomonas and Nitrococcus	Ammonium (NH_4^+)	Nitrite (NO_2^-)	Soil
Nitrobacter	Nitrite (NO_2^-)	Nitrate ((NO_3^-)	Soil
Thiobacillus	Sulphur (H_2S)	Sulphate (SO_4^{2-})	Decaying organic matter
Ferrobacillus / Iron bacteria	Ferrous (Fe^{2+})	Ferric (Fe^{3+})	Streams flowing over iron rocks
Hydrogenomonas	Hydrogen (H_2)	Water (H_2O)	Soil

Importance of chemosynthesis
The chemical activities of the organisms involved bring about nutrient cycling; for example:
- *Nitrosomonas* and *Nitrobacter* bacteria are involved in nitrification in plants.
- *Thiobacillus* catalyse the conversion of sulphur containing compounds to sulphates which are directly useful to plants.

Mechanism of chemosynthesis in some bacteria

$$NH_3 + 3O_2 \xrightarrow{\textit{Nitrosomonas}} HNO_2 + H_2O + \text{energy (79 kcals)}$$

$$HNO_2 + O_2 \xrightarrow{\textit{Nitrobacter}} HNO_3 + \text{energy (22 kcals)}$$

$$H_2S + 2O_2 \xrightarrow{\textit{Thiobacillus}} SO_4^{2-} + 2H^+ + \text{Energy}$$

The chemosynthetic bacteria utilize the energy from the chemical oxidation of inorganic chemicals to synthesize organic compounds, some of which are subsequently oxidized in respiration to yield energy for metabolism.

$$6CO_2 + 12H_2S \longrightarrow C_6H_{12}O_6 + 6H_2O + 12S$$

PHOTOSYNTHESIS

It is the formation of complex organic substances inside the cell containing chlorophyll from carbon dioxide and water using sunlight energy.

Importance of photosynthesis
1. It is the means by which the sun's energy is captured by plants for use by all organisms.
2. It provides a source of complex organic molecules for heterotrophic organisms.
3. It releases oxygen for use by aerobic organisms.
4. It reduces on gaseous carbon dioxide, which would accumulate in the atmosphere to cause green house effect.

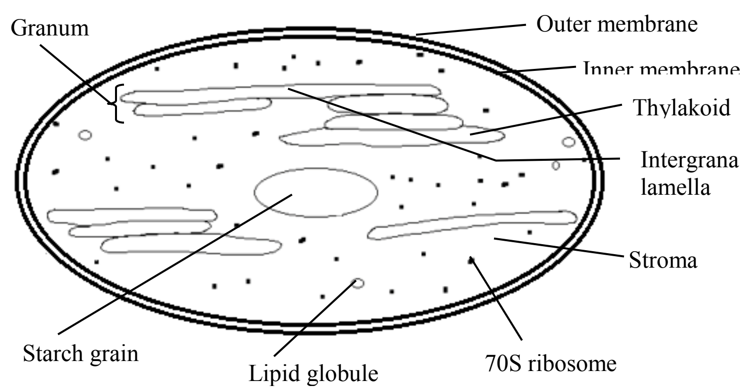
GENERAL ADAPTATIONS OF LEAVES FOR PHOTOSYNTHESIS

Adaptations for obtaining sunlight
1. ***Phototropism*** causes shoots to grow towards light in order to obtain energy. **2.*Etiolation*** causes rapid elongation of shaded shoots to enable access to light. **3.** The ***mosaic*** leaf arrangement minimizes leaf overlap and reduces leaves shading each other. **4.** Leaf ***large*** surface area enables capturing maximum sunlight. **5.** Thinness of leaves enables maximum light penetration. **6.** The ***transparence*** of leaf cuticle and epidermis allow light penetration into the photosynthetic mesophyll. **7.** The palisade mesophyll cells are densely packed with chloroplasts to trap much light. **8.** ***Cyclosis*** (movement of chloroplasts within the mesophyll cells) allows repositioning in the direction of light. **9.** 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. **10.** Multiple cell layers in the palisade mesophyll of sun plants increases photosynthetic efficiency.

Adaptations for gas entry and exit	*Adaptations for liquid entry and exit*
1. Numerous stomata are present in the epidermis of leaves to enable entry and exit of gases. **2.** The guard cells bordering stomata pores can be opened and closed to regulate the uptake of carbon dioxide and the loss of water. **3.** Spongy mesophyll possesses many airspaces to enable faster and uninterrupted diffusion of gases between the atmosphere and the palisade mesophyll which wouldn't happen if the gases were to diffuse through the cells themselves, a process which would be much slower.	**1.** A large central midrib containing a large vascular bundle comprising xylem and phloem tissue is possessed by most dicotyledonous leaves for the entry and transport of water and mineral salts, and the phloem for carrying away sugar solution, usually in the form of sucrose. **2.** A network of small veins is found throughout the leaf to ensure that every cell is close to xylem vessel or phloem sieve tube for constant supply of water for photosynthesis and a means of removing the sugars they produce.

CHLOROPLAST STRUCTURE

- 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.
- Intermembrane space is narrow, ~10 nm-20 nm in between the outer and inner membranes.
- Stroma is semi-gel-like fluid, alkaline, rich in protein (e.g. enzymes), with chloroplast DNA, 70S ribosomes, starch granules, lipid globules and thylakoid membrane system.
- Thylakoids are interconnected, membranous sacs, with chlorophyll in the membranes.
- At intervals, thylakoids form piles (~10-20) known as **grana**.



Adaptations of chloroplast for its functions
- 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 catalyse photosynthetic reactions in the stroma.
- Extensive network of thylakoid membranes increase surface area for photosynthesis.
- Narrow intermembrane space enables H^+ ion concentration gradient to be rapidly established for chemiosmosis to occur
- Inner membrane contains molecules for electron transport pathway
- DNA presence codes for protein synthesis, including enzymes.
- Many ribosomes for protein synthesis to reduce on importing proteins from cytoplasm.
- Outer membrane is permeable to gases like carbon dioxide which is a raw material for photosynthesis.

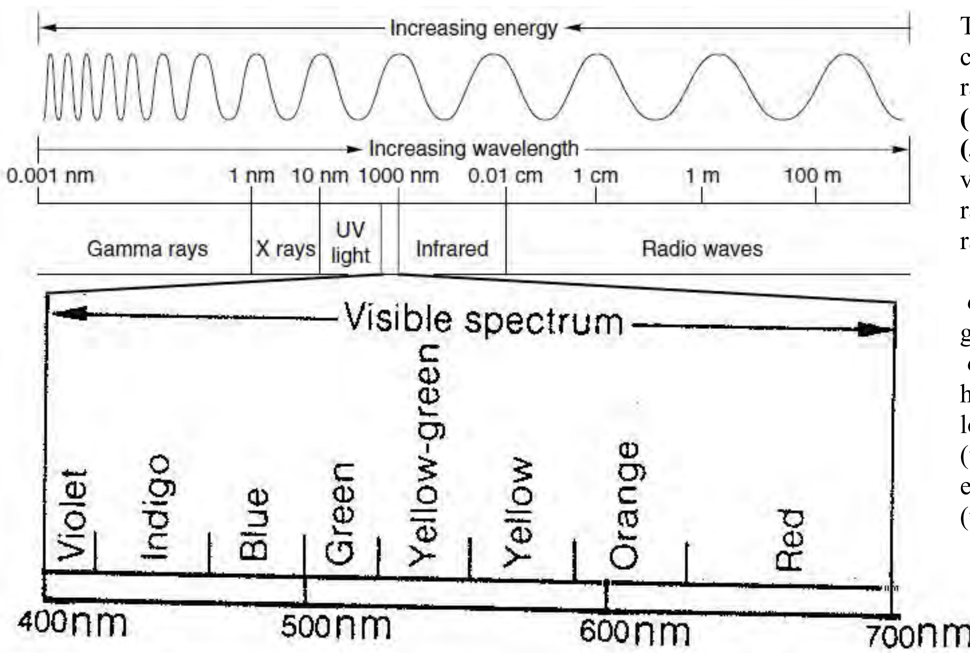
CONDITIONS NECESSARY FOR PHOTOSYNTHESIS

1. Carbon dioxide, 2. Water, 3. Light, 4. Photosynthetic pigments

Condition	Explanatory notes
1. Carbon Dioxide	●Land plants obtain CO_2 **(1)** by diffusion via stomata **(2)** by absorbing CO_3^{2-} from soil via roots. ●Aquatic plants absorb dissolved bicarbonates through their general surface to carbon dioxide. ●Air contains about 0.04% (400 ppm) by volume carbon dioxide while it is variable in water
2. Water	Water provides the H^+ ions (protons) and electrons for the reduction of carbon dioxide. $2H_2O \longrightarrow O_2 + 4(H)$ $4(H) + CO_2 \longrightarrow CH_2O + H_2O$
3. Light	Three important properties of light: **(i) quality**/colour **(ii) intensity**/brightness **(iii) duration**/time. Light is **electromagnetic** energy propagated in discrete particles called **photons or quanta**

ELECTROMAGNETIC RADIATION

Electromagnetic radiation is a form of energy transmitted through a vacuum (empty space) or a medium (such as glass) in which electric and magnetic fields are propagated as waves.



The electromagnetic spectrum consists of ***eight types*** of radiations:
(1) Cosmic rays **(2)** gamma rays **(3)** x-rays **(4)** ultra-violet rays **(5)** visible light spectrum **(6)** infrared rays **(7)** electric rays and **(8)** radio rays.

●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).

ORIGINS OF PHOTOSYNTHETIC LIGHT

1. 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.
2. 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.

NATURE OF LIGHT

Visible light is the part of the electromagnetic spectrum between the wavelengths of 400 nm and 740 nm, known as the **photosynthetically active radiation (PAR)**.

FATE OF LIGHT THAT HITS A LEAF

Light interacts with a leaf in three ways:
1. Reflection (Reflectance): light can simply rebound off the leaf surface and hence never utilized in leaf photosynthesis.
2. Transmission (Transmittance) through the leaf, exiting from the underside.
3. Absorbance 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.
●Transmission depends on the thickness of the leaf; thin leaves transmit more light than thick leaves.

LIGHT IN A FOREST (SHADY ENVIRONMENT)

● The amount of **sunlight decreases** as light penetrates down the vegetation layers because the amount of **leaf area** increases. **Leaf area index** is the one-sided leaf area per unit area of ground.

● The leaf area index (LAI): **LAI = m^2 leaf area/m^2 ground area**

E.g.: 3 m^2 leaf area/m^2 ground area means there are 3 square meters of leaf area over each square meter of ground area.

● The greater the leaf area over a surface, the lower the quantity of light reaching that surface.

FATE OF LIGHT IN A FOREST (SHADY ENVIRONMENT)

The graph beside shows the energy in light of different wavelengths reaching the ground in a forest.

Energy was measured in:

(1) Direct sunlight that passed through canopy gaps.

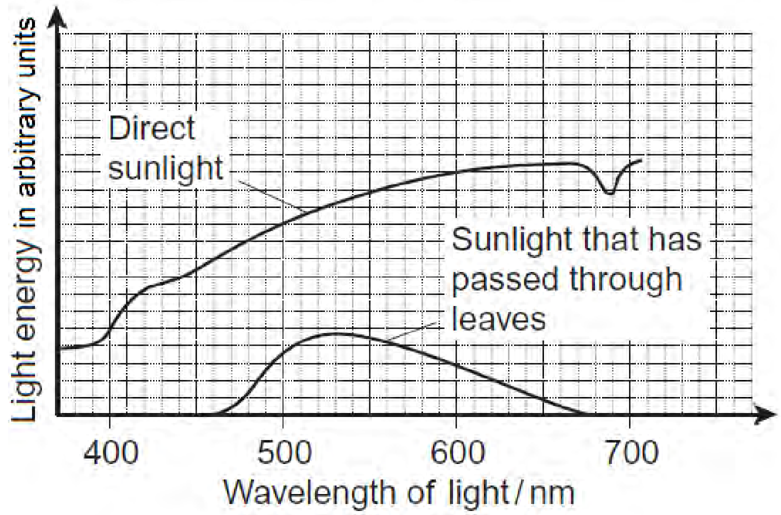
(2) Sunlight that had passed through tree leaves.

● As light penetrates the canopy, different wavelengths are filtered out – **light becomes attenuated (reduced)**:

(i) The denser (thicker) the canopy, the more weakening of light occurs.

(ii) Leaves with whitish hairs and cuticle reflect more light than deep green leaves

(iii) The smaller the size of gaps in the canopy, the more weakening of light.



Observations

1. All the wavelengths of direct light reach the ground because this light passes through gaps left by leaves hence no wavelength is filtered out.
2. Of the light that passes through leaves, only wavelengths in the range 460 nm – 670 nm reach the ground (high transmittance to the ground) because of low/no absorption by chlorophylls in the leaves.
3. Wavelengths of visible light below 460 nm and above 670 nm do not reach the ground after passing through leaves (no transmittance) because of much absorption by photosynthetic pigments e.g. chlorophylls.
4. Of the light that passes through leaves, wavelength 525 nm reaches the ground with most energy because it is least absorbed by photosynthetic pigments.

4. PHOTOSYNTHETIC PIGMENTS

● **Chlorophylls** and **carotenoids** absorb light energy required in photosynthesis.

● **Carotenoids** also protect chlorophyll from photo damage.

Photosynthetic Pigment	*Distribution (occurrence)*	*Properties*
Chlorophyll ***a***	All photosynthetic plants i.e. It is the most abundant	●Bluish green in pure state ●Very soluble in ether, and also soluble in lipid solvents e.g. chloroform, carbon tetrachloride, alcohols, etc
Chlorophyll ***b***	Higher plants	●Olive green (yellow green) in pure state. ●Very soluble in methyl alcohol and also soluble in lipid solvents e.g. chloroform, carbon tetrachloride, etc
Bacteriochlorophyll	(1) Purple sulphur Bacteria, (3) Green sulfur bacteria	● Are related to chlorophylls ●Conduct photosynthesis, but do not produce oxygen. ●Absorbs wavelengths of light not absorbed by plants
CAROTENOIDS (a) ***xanthophylls*** e.g. lutein (b) ***carotenes*** e.g. α-carotene, lycopene	Occur in chloroplasts of plants, algae, some bacteria, and some types of fungi	●Xanthophylls are often yellow, Carotenes vary in colour: pale yellow, bright orange, deep red. ● Are soluble in fat solvents e.g. ether, chloroform, acetone. ●Carotenes are closely related to the vitamin A

● Chlorophyll ***b*** and carotenoids are **accessory** pigments i.e. they hand over energy absorbed to chlorophyll ***a***.

● Chlorophyll belongs to a class of organic compounds called **porphyrins** which have 4 **pyrrole** rings.

● Other **porphyrins** are **haem** and the **cytochromes**.

● However, Chlorophyll contains **magnesium atom** instead of **iron**.

SUN AND SHADE LEAVES

- Sun leaves are those that grow on branches exposed to direct sunlight while shade leaves grow on branches exposed to light that has passed through leaves.
- In **low light**, plants need to maximise light absorption for photosynthesis to exceed respiration if they are to survive.
- In **high light** environment, plants maximise their capacity for utilising abundant light energy, while at the same time dealing with excess sunlight which can bleach chlorophyll.

ADAPTATIONS TO PHOTOSYNTHESIZE IN SUN AND SHADE

Adaptation: a genetically determined capability to acclimate to environmental condition.

Shade plant	Sun plants
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 maximise light trapping; 4. Leaf orientation horizontal to maximise 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. 6. Stomatal density low to avoid over cooling; 7. Thin leaves to maximise light penetration; 8. Stomatal size large to allow loss of excess water; 9. Elongated internodes for increased access to light; 10. Chloroplast size large to increase the surface area for storage of photosynthetic pigments.	1. Abundant chlorophyll ***a*** (high chlorophyll *a* to chlorophyll *b* ratio) to increase light absorption; 2. Palisade/ spongy mesophyll ratio high to minimise light penetration; 3. Mesophyll cell surface / leaf area ratio high to minimise excessive light and transpiration; 4. Leaf orientation erect to minimise light trapping; 5. Stomatal density high to avoid over heating; 6. Much carotenoids to prevent damage to chlorophyll from very bright light. 7. Thick leaves to minimise light penetration; 8. Stomatal size small to minimise water loss; ***Other features*** (i) RuBISCO and soluble protein content /mass higher (ii) Chlorophyll / soluble protein ratio high (iii) Chloroplast size small

PHOTOSYNTHETIC PIGMENTS IN SUN LEAVES AND SHADE LEAVES OF BEECH TREE

Photosynthetic pigment	**Mean mass of each pigment per m^2 of leaf area / µg**	
	Sun leaves	**Shade leaves**
Chlorophyll ***a***	299.3	288.9
Chlorophyll ***b***	90.7	111.1
Carotenoids	0.10	0.07

Graphically, the data can be reflected by a **bar graph**.

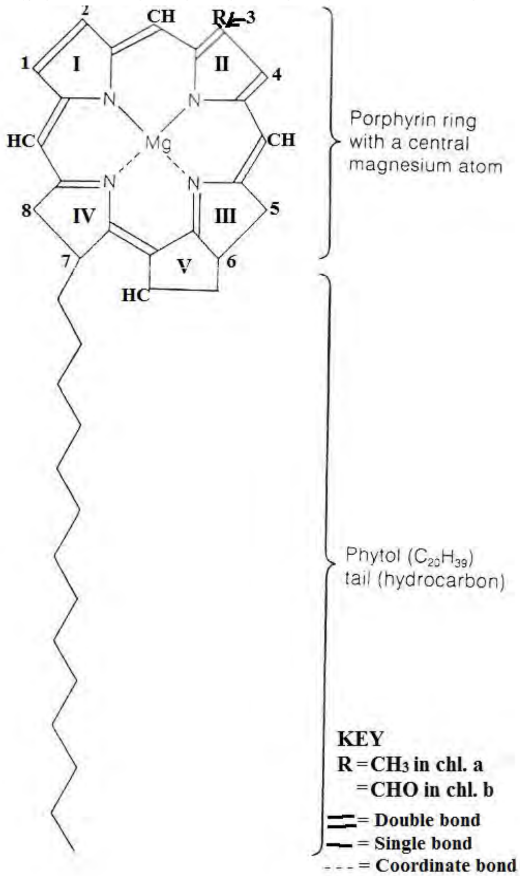
COMPARISON OF DISTRIBUTION OF PHOTOSYNTHETIC PIGMENTS

- 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.

Why few species of plant can survive under shady habitats.

- Less direct light reaches ground via gaps in the canopy hence minimum energy is available for effective photosynthesis.
- Of the light that passes through leaves, only a small range of wavelengths reaches the ground, which is not effective for photosynthesis.
- Therefore, under shady habitats little light energy is available for chlorophyll to absorb and hence photosynthesise is insufficient for growth.

DESCRIPTION OF CHLOROPHYLL MOLECULE STRUCTURE



- 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**.
- The ***flattened*** head is made up of ***four nitrogen*** containing ***pyrrole*** rings (labelled I-IV) which are linked by methine bridges (-CH=).
- 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 ($-CH_3$) at position **R** (carbon 3).

NB: The phytol tail ***anchors*** and ***orients*** the chlorophyll molecule in the chloroplast's thylakoid membrane

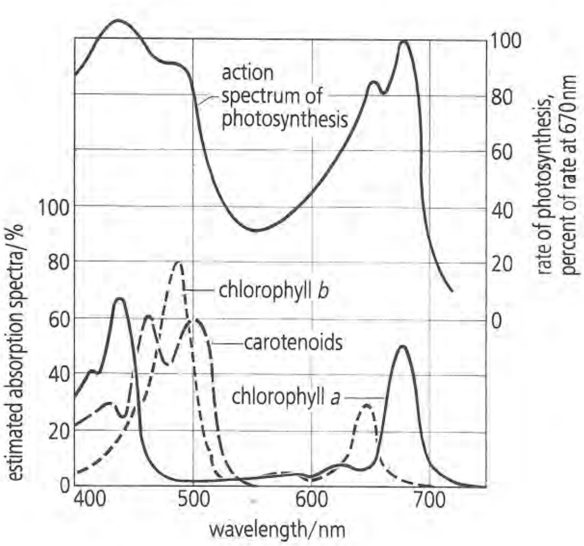
ABSORPTION SPECTRUM OF PHOTOSYNTHETIC PIGMENTS

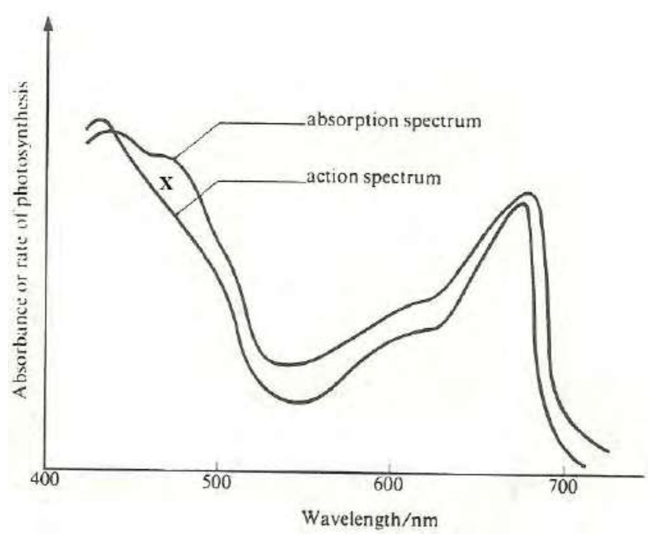
It is a graph of the relative absorption of different wavelength of light by a pigments like chlorophyll. It is measured by a **spectrophotometer**

ACTION SPECTRUM OF PHOTOSYNTHESIS

A graph of the effectiveness of different wavelengths of light in stimulating the photosynthetic process. It represents the actual rate of photosynthesis in living cells.

Absorption spectra of chlorophylls a & b, and carotenoids and the action spectrum of photosynthesis





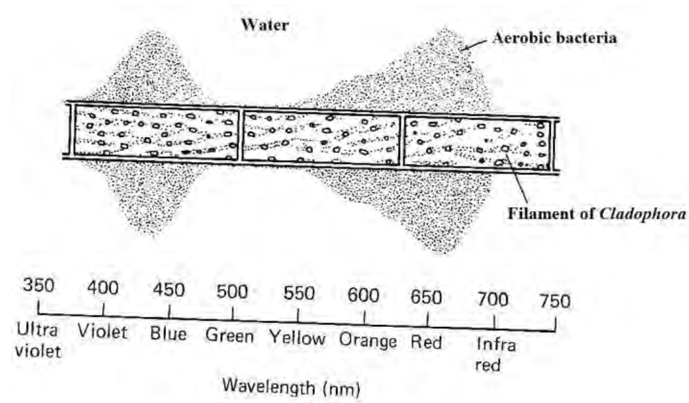
Observations	*Explanation*
● The action spectrum of photosynthesis corresponds closely to the absorption spectra of chlorophyll **a** and **b**.	● This indicates that most of the wavelengths of light absorbed by chlorophyll are used in photosynthesis.
● There is non-correspondence of action spectrum of photosynthesis with absorption spectra at point marked **'X'**	● This is because it is at **'X'** where there is maximum absorption by carotenoids, which are not used in photosynthesis.
● The wave lengths of about 550 nm to 620 nm have the lowest absorption and action spectra for all the photosynthetic pigments.	● The unabsorbed (reflected light) appears green, thus making chlorophyll, the chloroplasts and the leaves that contain it appear green to our eye.
● There are two absorption maxima of *lambda* = 430 nm and *lambda* = 662 nm for chlorophyll **a**, and 453 nm and 642 nm for chlorophyll **b**, but only one maximum for carotenoids at about 510 nm.	● This shows that chlorophyll a as well as b are the main photosynthetic pigments, however, photosynthesis also occurs in the mid part of light spectrum where carotenoids are active.
● The action spectrum peaks within the blue-violet and red regions of the light spectrum.	● This shows that maximum photosynthesis occurs in red part and blue-violet part of visible light.

OTHER OBSERVATIONS

● ***Chlorophyll a*** absorption in red light is about twice that of ***chlorophyll b*** and the absorption peak is at a slightly longer wavelength (lower energy)

● Absorption of chlorophyll a in the blue is lower and shifted to a slightly shorter wavelength (higher energy).

ENGELMANN'S EXPERIMENT ON ACTION SPECTRUM OF PHOTOSYNTHESIS

Description of Engelmann's experiment	*Results of Engelmann's experiment*
●Filaments of the green alga ***Cladophora*** *of the genus* ***Pseudomonas*** are placed in a drop of water on a slide, then illuminated with light of different wavelengths and observed under the microscope. ●The control experiment involves mounting the alga on a slide in water with aerobic bacteria in total darkness and thereafter exposing the slide to light. ● ***Observation 1:*** The motile aerobic bacteria cluster near to the filaments in the region of blue light (450 nm) and red light (650 nm). ● ***Deduction 1:*** Since the distribution of aerobic bacteria is in response to the concentration of oxygen which is a by-product of photosynthesis, then red and blue light are the most effective for photosynthesis. ● ***Observation 2:*** Motile aerobic bacteria cluster around the edge of the cells adjacent to the chloroplast. ● ***Deduction 2:*** Oxygen is more concentrated near the chloroplast which shows that the chloroplast is the sight of photosynthesis. ● ***Observation 3:*** The aerobic bacteria of the slide previously in the dark are immobile but later cluster around the alga filament on exposure to light.	 ● ***Deduction 3:*** Darkness prevents photosynthesis, which stops evolution of oxygen resulting in anaerobic conditions that **donot** favour aerobic bacterial activity ● ***Observation 4:*** There is hardly any aerobic bacteria in the ultra-violet, green and infra-red regions of the spectrum. ● ***Deduction 4:*** Light from ultra-violet, green and infra-red regions of the spectrum is hardly absorbed by chlorophylls hence least used in photosynthesis, with no / little evolution of oxygen.

MECHANISM OF PHOTOSYNTHESIS

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

PHASES OF PHOTOSYNTHESIS

[1] Light stage (**Photochemical** reactions or **Hill** reaction)   **[2]** Dark stage (**Biochemical** reactions**)**.

LIGHT DEPENDENT PHASE

● It takes place in the thylakoid membranes of chloroplasts.

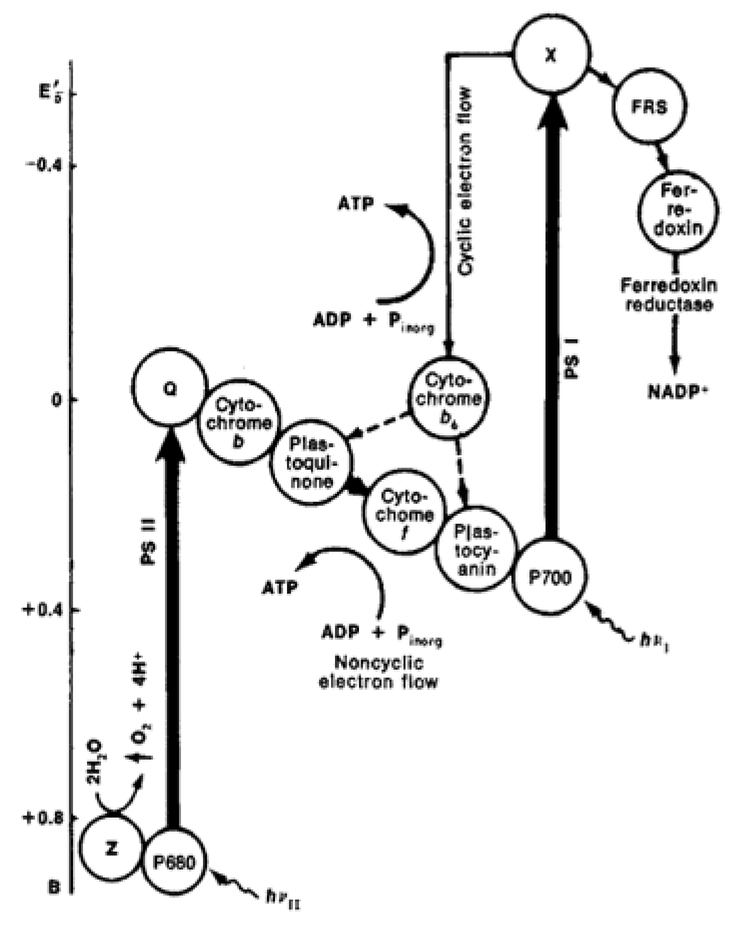
The main functions are:

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

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

DESCRIPTION OF LIGHT STAGE OF PHOTOSYNTHESIS

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

THE Z-SCHEME SUMMARISING LIGHT STAGE	OPERATIONS OF PHOTOSYSTEMS I AND II
	● Chlorophyll molecules of PSII and PSI are excited by light of wavelength 680 nm and 700 nm respectively; causing the loss of electrons to a chain of electron carriers in a series of reduction-oxidation reactions as follows: **(i)** From PSI, some electrons may flow: **(1) Cyclically** to iron-protein complex, cytochromes b_6, plastoquinone, cytochrome-**f,** plastocyanin and back to P-700, during which electrons lose energy to form ATP from ADP and P*i*. **(2) Non-cyclically (Unidirectionally)** to unknown molecule A, iron-protein complex, Ferrodoxin, Flavin-Adenine Dinucleotide (FAD) which becomes reduced (FADH), finally to NADP to form reduced NADP (NADPH). **(ii)** From PSII to the unknown molecule Q, substance B, plastoquinone (PQ), cytochrome f, plastocyanin, (a copper enzyme), and finally to PSI, to replace the electrons earlier lost. During this flow, electrons lose energy to **phosphorylate** ADP to form ATP. ● The flow of electrons through carriers in the thylakoid membranes releases energy for active pumping of hydrogen ions (H^+) from the stroma into the thylakoid space. ● ***At the same time, photolysis of water:*** **(1)** Causes accumulation of H^+ **inside the thylakoid space.** **(2)** Provides electrons to replace those lost from PSII, with evolution of oxygen molecule. ● ***Chemiosmosis*** occurs i.e. the highly concentrated H^+ inside the thylakoid space **diffuse** along the steep electrochemical gradient from the thylakoid space via the stalked particles into the stoma, thereby providing: **(1)** energy to form ATP in the presence of ATPase enzyme **(2)** H^+ for reducing NADP to form NADPH, which together with the ATP formed enter the dark stage.

NOTE

The loss of 2 electrons by the chlorophylls in the photosystems **bleaches** the chlorophyll molecule. In this state, it can no longer absorb light energy effectively. Therefore, the electrons lost to the electron transfer chain must be replaced.

WHAT IS MEANT BY?

Chemiosmosis: It is the movement of ions across a selectively permeable membrane down an electrochemical gradient.

Z-Scheme: It is a diagrammatic representation of electron flow in cyclic phosphorylation and non-cyclic phosphorylation, showing the change in energy potential of the electrons.

COMPARISON OF CYCLIC AND NON-CYCLIC PHOTOPHORYLATION

Similarities

In both:

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

Differences

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

ROLE OF WATER IN PHOTOSYNTHESIS

- Catalytic photolysis / splitting / breaking of water produces electrons (e^-) and protons (H^+).
- Water is a source of electrons to replace those lost by chlorophyll / photosystem II
- Water is a source of H^+ needed to produce NADPH + H
- Water is a source of H^+ which when flowing from thylakoid space into stroma via ATPase, ATP forms.
- Water is a substrate / reactant / raw material / for photosynthesis
- Water is transparent so photosynthesis can take place underwater / light can penetrate to chloroplasts

DARK REACTION [BIOSYNTHETIC PHASE OR BLACKMAN'S REACTION]

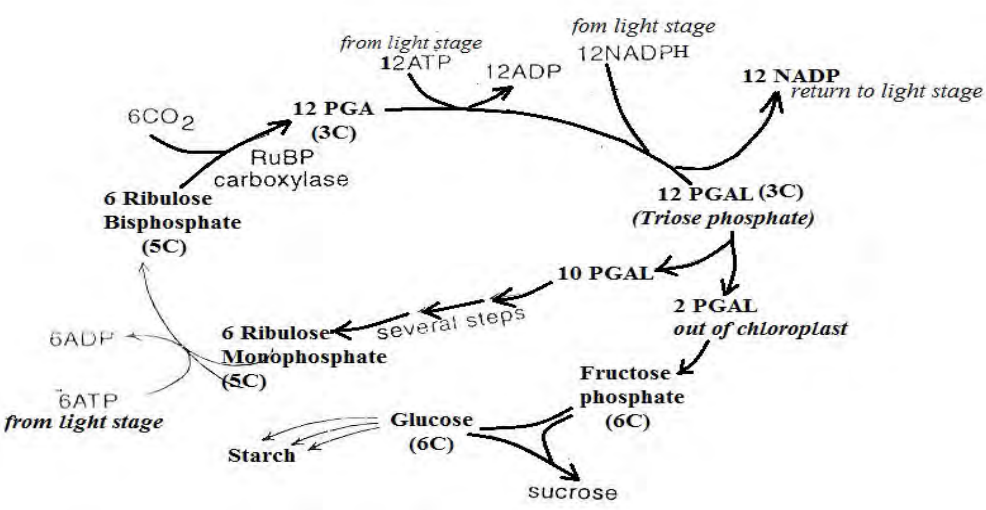
It's called **dark reaction** because does not require light, although can take place in light also. It occurs in the stroma of chloroplasts.

THE MAIN PATHWAYS FOR THE DARK REACTION

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

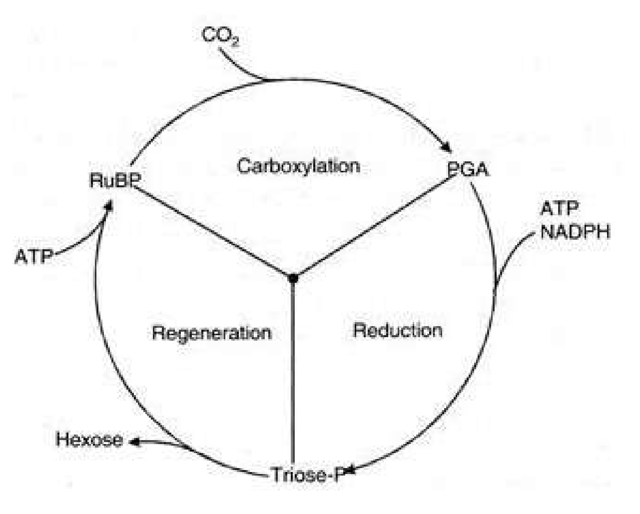
MAIN STAGES OF CALVIN-BENSON CYCLE (C_3 CYCLE)

C_3 Plants: Plants whose first stable product of photosynthesis is a 3-carbon organic compound called **glycerate-3-phosphate**



Triose phosphate (glyceraldehydes 3-phosphate) is the **end product** of the Calvin cycle / photosynthesis because all subsequent reactions can also occur in no-photosynthetic organisms like animals and fungi . **(Soper R. et al (1997). *Biological Science* p210:7.7)**

THREE MAIN STAGES OF THE CALVIN CYCLE



1. CARBOXYLATION

● Catalysed by RuBP carboxylase, 6 molecules of RuBP react with 6 molecules of CO_2, and 6 molecules of water forming 12 molecules of 3-phosphoglyceric acid (PGA), which is the **first carbohydrate made by C_3 plants.**

2. PHOSPHORYLATION AND REDUCTION

● 12 molecules of PGA react with 12 molecules of ATP forming 12 molecules of 1, 3-diphosphoglyceric acid and 12 molecules of ADP.

● 12 molecules of NADPH (formed in light stage) reduce 12 molecules of-1, 3-diphosphoglyceric acid to form 12 molecules each of 3-phosphoglyceraldehyde (PGAL) / triose phosphate (TP), NADP and phosphoric acid.

● Out of these 12 molecules of PGAL, only 2 molecules undergo **isomerization** and several reactions to form hexose sugar, sucrose or starch and 10 molecules are recycled to produce 6 molecules of ribulose monophosphate.

3. REGENERATION: ● The remaining 10 molecules of PGAL regenerate 6 molecules of ribulose-6-phosphate when 6 molecules of a 5-carbon sugar **ribulose monophosphate** react with 6 molecules of ATP (formed during light stage) to form 6 molecules of Ribulose-1,5-bisphosphate (RuBP) and 6 molecules of ADP.

Metabolism of Glycerate phosphate (GP) and Glyceraldehyde phosphate (TP / PGAL)

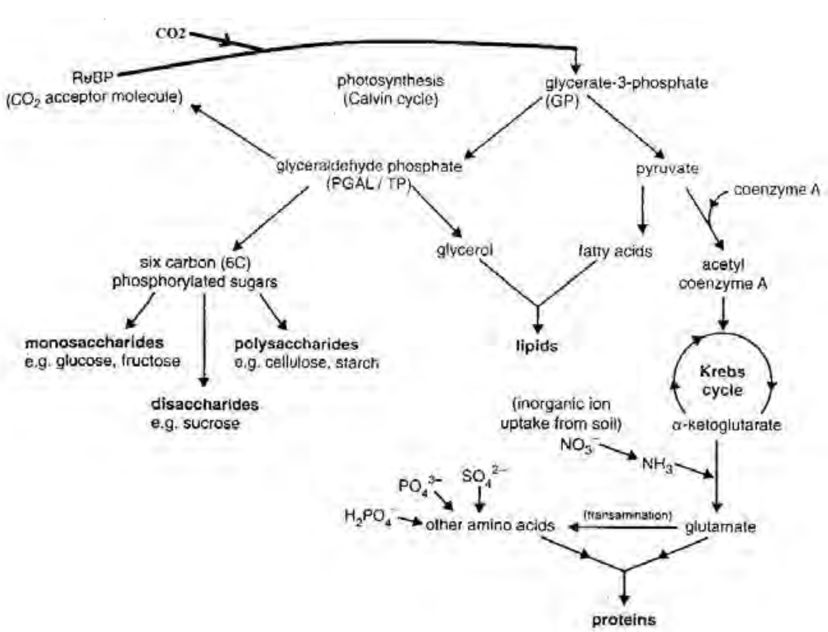
(a) Synthesis of carbohydrates: Glyceraldehyde-phosphate molecules are converted to form monosaccharides e.g. glucose, which may combine with fructose to form **sucrose**, transported in phloem sieve tubes or can be polymerized into starch for storage or cellulose.

(b) Synthesis of lipids: (i) Glycerate-phosphate enters glycolysis pathway and is converted to pyruvate, which can be converted into acetyl group, which combines with coenzyme A to form acetyl coenzyme A. This can be used to form a variety of fatty acids in th cytoplasm and chloroplast.

(ii) Glycerate-phosphate can also be converted to glycerol. Lipids such as triglycerides are esters of fatty acids and glycerol, which are important components of cell membranes.

(c) Synthesis of proteins: Glycerate-phosphate is converted into acetyl coenzyme A and enters into the Krebs cycle. Some of its intermediates can produce different amino acids by transamination reactions. The amino acids are then polymerized into proteins which are required for growth and development, synthesis of enzymes and structural components of the cell.

RELATIONSHIP BETWEEN PHOTOSYNTHESIS AND SYNTHESIS OF FOOD IN GREEN LANTS



QUESTION:

The enzyme RUBISCO, in spite of being the most common enzyme in the world, is very inefficient in photosynthesis. Explain this statement.

1. 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, with it composing 50% of the protein in a chloroplast.
2. 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, rather than carbon dioxide fixation.

WHAT IS PHOTORESPIRATION?

Oxygenation of RuBP by RuBP oxygenase (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, thereby preventing carbon fixation in C3 plants.

HOW PHOTORESPIRATION AFFECTS PLANTS

When C3 plants are exposed to low carbondioxide concentration (or high oxygen concentration) e.g. 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 carbondioxide. Yet when the carbondioxide concentration is high, RUBISCO enzyme catalyses the reaction between RuBP and carbondioxide to form a 3-carbon compound; 3-**phosphoglyceric acid,** which undergoes several reactions to form sugar useful to the plant. It is estimated that Photorespiration **therefore reduces the potential yield of photosynthesis by 30-40%.**

THE HATCH-SLACK CYCLE OR C_4 PATHWAY

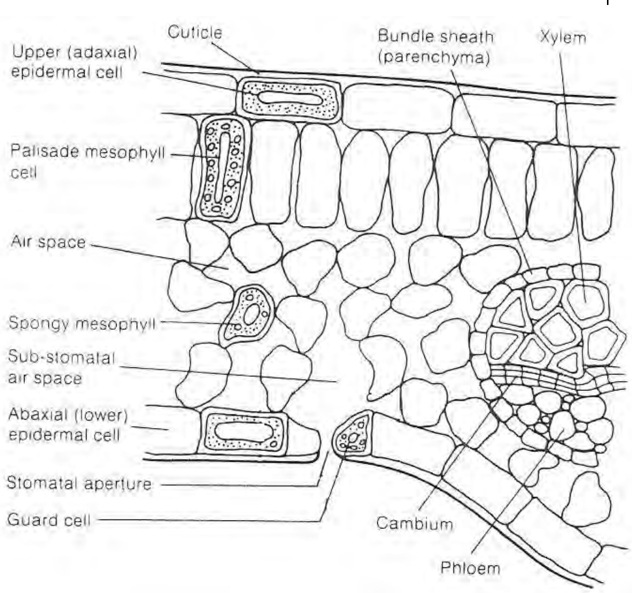
- ***C4 photosynthesis:*** type of photosynthesis in which the first stable product of CO_2 fixation is a four carbon compound called **oxaloacetate** (OAA) inside mesophyll cells, which is later reduced and exported into bundle sheath cells for further metabolism.
- ***Carbon 4 plants:*** plants in which the first 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 C_4 plants***: maize, sorghum, *Amaranthus*, *Sugar cane*, paspalum, Bermuda grass, rhodes grass, nut grass.
- ***Fact:*** C_4 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.
- ***Habitats:*** hot / arid / saline tropical habitats.
- ***Description of leaf anatomy:*** **Kranz**.

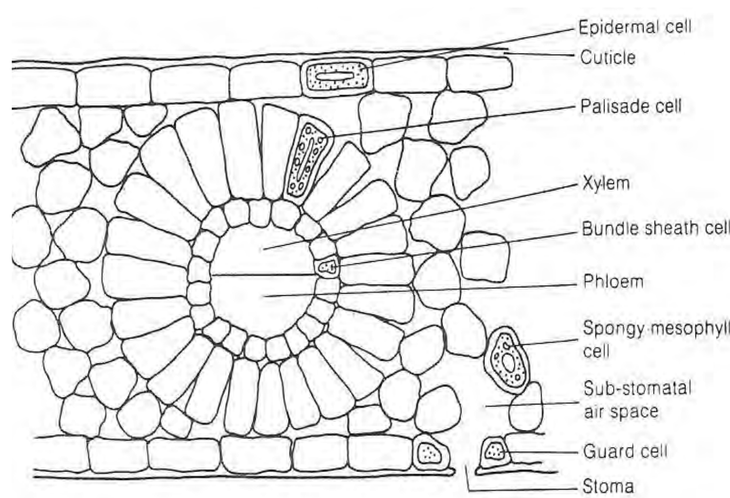
WHAT IS KRANZ LEAF ANATOMY?

A condition in which bundle sheath cells and palisade cells of the mesophyll form two concentric layers (rings) around each vascular bundle of leaves.

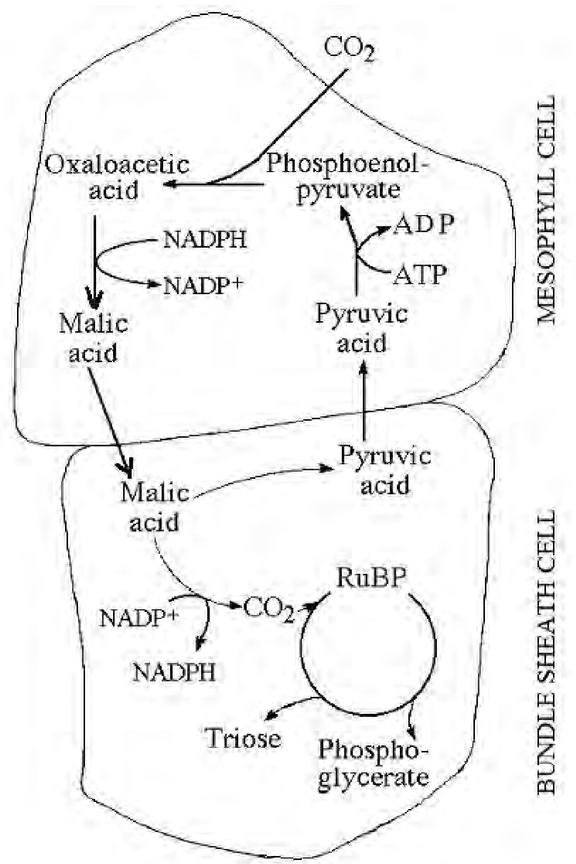
COMPARISON OF LEAF ANATOMY IN C_3 AND KRANZ ANATOMY IN C_4 PLANTS

Leaf anatomy in C_3 plants	***Kranz anatomy in C_4 plants***





DESCRIPTION OF C_4 CYCLE IN CO_2 FIXATION



1. In the presence of ***phosphenol pyruvic acid carboxylase*** enzyme, ***Phosphenol pyruvic acid*** is carboxylated inside the chloroplasts of mesophyll cells to form ***oxaloacetic acid***.
2. ***Oxaloacetic acid*** is reduced by NADPH to ***malic acid*** in the presence of ***malate dehydrogenase*** enzyme.
3. From chloroplasts of mesophyll cells, malic acid is translocated (shunted) to chloroplasts of bundle sheath cells where it is decarboxylated by NADP to form ***pyruvic acid*** and ***carbon dioxide***. The pyruvic acid produced returns to mesophyll cells for phosphorylation by ATP to regenerate **PEP;** the CO_2 acceptor.
4. Now the second carboxylation occurs in the chloroplasts of bundle sheath cells through Calvin cycle.

●RuBP of Calvin cycle is called ***final*** or ***secondary*** CO2 acceptor in C_4 plants.

●Ribulose bisphosphate accepts CO_2 produced in step 3 and to yield 3-phosphoglyceric acid as given in Calvin cycle.

●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.

●In the Calvin cycle 3 ATP molecules are required for the C_4 plants, 5 ATP molecules are required for the fixation of CO_2. For the formation of a glucose molecules, C_4 plants require 30 ATP while C_3 plants utilize only 18 ATP.

ADVANTAGES AND DISADVANTAGE OF C4 PATHWAY

Advantages	***Disadvantage***
●C_4 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. ●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. ●**Photorespiration,** which inhibits growth in C_3 plants is **avoided / reduced** in C_4 because **(1)** the CO_2 fixing enzyme PEP carboxylase does not accept oxygen **(2)** RUBISCO enzyme inside the bundle sheath cells is shielded from high oxygen concentration by the ring of palisade cells. ● The CO_2 fixing enzymes in C_4 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 C_3 plants. ●The productivity of C_4 almost ***four times*** greater than in C_3 ***because:*** **(1)** of the increased rate of CO_2 uptake caused by **(i)** large internal leaf surface area **(ii)** short CO_2 diffusion distance **(iii)** CO_2 steep diffusion gradients **(2)** 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***. **(3)** the Palisade cells in which light reactions occur have large grana to increase the photosynthetic surface area.	● The CO_2 fixing enzymes in C_4 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. ***NB:*** *C4 plants grow better under hot, dry conditions when plants must close their stomata to conserve water – with stomata closed, CO2 levels in the interior of the leaf fall, and O2 levels rise*

QUESTION:

In spite of the higher productivity of C_4, which is almost four times greater than in C_3, majority of plants perform C3 photosynthesis. Explain this statement fully.

- CO_2 concentration is a major factor determining the pathway of carbon dioxide fixation.
- While C_4 plants are more productive at low CO_2 concentration, C_3 plants form the dominant plant life because they are effective at high CO_2, whose concentration is high in most environments and steadily increases due to increasing combustion of fossil fuels.
- Also considering that C_4 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, C_3 dominate since C3 photosynthesis is more effective.

COMPARISON OF C_3 AND C_4 PLANTS

Similarities

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

Differences	**C_3 PLANTS**	**C_4 PLANTS**
Structural	●Lack Kranz anatomy ●All chloroplasts have identical structure	●Exhibit Kranz anatomy ●Chloroplasts are dimorphic (are in two forms) e.g. those of palisade cells have grana yet are lacking bundle sheath cells.
Physiological	● CO_2 acceptor is a 5-Carbon RuBP ● CO_2 fixation occurs once ●Photorespiration occurs ●Lesss photosynthetically efficient ●GP is the first stable organic product ●Enzymes are more efficient at lower temperatures ● RUBISCO enzyme is used ● Compensation point is attained at higher CO_2 concentration	● CO_2 acceptor is a 3-Carbon PEP ● CO_2 fixation occurs twice ●No photorespiration ●More photosynthetically efficient ●OAA is the first stable organic product ●Enzymes are more efficient at high temperatures ● PEP carboxylase enzyme is used ● Compensation point is attained at lower CO_2 concentration

CRASSULACEAN ACID METABOLISM (CAM) PHOTOSYNTHESIS

Definition:

A type of photosynthesis in which CO_2 is taken in at night via open stomata, fixed by phosphoenolpyruvate carboxylase (PEPC) into OAA, stored as organic acid (mainly malate) which is **later** decarboxylated during daytime, refixed and CO_2 is assimilated in the Calvin-cycle when stomata are closed.

CAM is a modified form of C_3 photosynthesis adopted by approximately 6% of vascular plant species as an adaptation to water deficit in terrestrial and epiphytic plants, with exceptions exhibited by submerged freshwater plants for other reasons.

Examples of CAM plants: Cacti, sisal, Opuntia, *Kalanchoe* (*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.

Example: Mesembryanthemum crystallinum usually uses C3 photosynthesis but during water or salt stressed it switches to CAM photosynthesis.

PHASES OF CAM THROUGH THE DIURNAL COURSE

Phase I: nocturnal CO_2 fixation (atmospheric + respiratory sources) mediated by PEPC and accumulation of malic acid within the vacuole.

Phase II: atmospheric CO_2 fixation at dawn which marks the transition between C_4 and C_3 activity.

Phase III: decarboxylation of malic acid and fixation of the regenerated CO_2 by Rubisco.

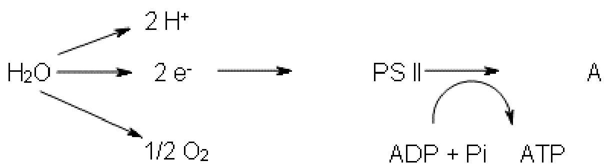
Phase IV: a period of atmospheric CO_2 fixation from the end of Phase III to dusk which latterly incorporates the shift from Rubisco to PEPC activity.

INVESTIGATING HILL REACTION OF PHOTOSYNTHESIS IN ISOLATED CHLOROPLASTS

Hill reaction: The photoreduction of an electron acceptor by the hydrogens of water, with the evolution of oxygen.

$$H_2O + A \xrightarrow[\textbf{\textit{Chloroplasts}}]{\textbf{\textit{Light}}} AH_2 + \tfrac{1}{2}O_2$$

This experiment investigates electron transfer in isolated chloroplasts using artificial electron acceptor, such as DCPIP, which intercepts electrons after Photosystem II (PS II) but before they reach Photosystem I (PS I). The path of electrons from water to the artificial acceptor (A) is, thus:



In this experiment, DCPIP (2,6-dichlorophenol-indophenol), a **blue** dye in oxidised form, acts as **an electron acceptor** and becomes **colourless** when **reduced**, allowing any **reducing agent produced by the chloroplasts** to be detected.

Procedure

(i) Small pieces of green spinach, lettuce or cabbage leaves (veins removed) are homogenated vigorously by grounding in a cold mortar or blended in cold blender containing 20 cm^3 of ice cold, isotonic buffered medium. The ice cold solution deactivated enzymes to prevent reactions. The **isotonic** solution prevents **rupturing** of chloroplasts which can result from osmotic influx or efflux of water. **Buffered** solution maintains pH to mimic chloroplast pH that's suitable for photosynthetic enzyme.
(ii) Filter into the beaker and pour the filtrate into pre-cooled centrifuge tubes supported in ice-water-salt bath.
(iii) Centrifuge the tubes for sufficient time to get a small pellet of chloroplasts. (e.g. 10 minutes at high speed).
(iv) Pour off the liquid (supernatant) into a boiling tube being careful not to lose the pellet.

Cuvettes are set up with the contents as listed below and monitored by a spectrophotometer
Cuvette 1 (leaf extract + DCPIP covered by aluminium foil)
Cuvette 2 (no leaf extract / boiled leaf extract + DCPIP + exposure to light)
Cuvette 3 (leaf extract + exposure to light + no DCPIP).
Cuvette 4 (leaf extract + DCPIP + Exposure to light).
(vi)When the DCPIP is added to the extracts, shake the Cuvette and note the time.
(vii)Time how long it takes to decolourise the DCPIP in each tube.

Sample results

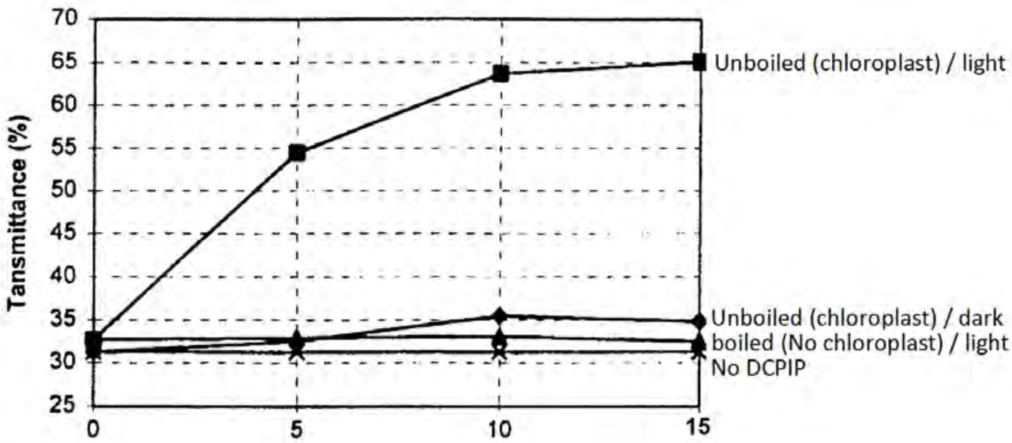
Time (sec)	Absorbance (arbitrary units)			
	Cuvette 1 (**Dark**)	Cuvette 2 (**No chloroplasts**)	Cuvette 3 (**No DCPIP**)	Cuvette 4 **(All conditions)**
0	1.08	1.37	0.80	1.07
20	1.06	1.37	0.80	0.90
40	1.06	1.37	0.80	0.81
60	1.06	1.37	0.80	0.71
80	1.05	1.37	0.80	0.57
100	1.05	1.37	0.80	0.47

On same axes, the results in the table above can be reflected graphically.

EXPLANATION FOR RESULTS IN THE TABLE ABOVE

Cuvettes	Observation / Description	Explanation
1	Absorbance decreases slightly from 0 second to 20 seconds, remains constant from 20 second to 60 seconds, decreases slightly from 60 seconds to 80 seconds, then remains constant thereafter.	There was no light hence no DCPIP reduction. The gradual decrease in the first 20 seconds is due to DCPIP being reduced when light hit the chloroplasts in the brief moment before the cuvette was wrapped by aluminium foil.
2	Absorbance remains constant from 0 seconds to 100 seconds	No reduction of DCPIP occurred, due to absence of chloroplasts.
3	Absorbance remains constant from 0 seconds to 100 seconds.	No reduction was detected without DCPIP hence the mixture didn't change from its original colour.
4	Absorbance of the reaction mixture decreases fast from 0 seconds to 100 seconds.	Presence of light enables the live chloroplasts to release electrons that were accepted by DCPIP to become reduced, which was shown by the colour change from blue to colourless hence enabling absorbance.

CONCLUSIONS
Cuvette 1: Light is necessary for DCPIP reduction.
Cuvette 2: Chloroplasts are necessary for reduction of DCPIP.
Cuvette 3: Chloroplasts do not affect the changes in absorption of the DCPIP solution.
Cuvette 4: Light is necessary for the release of electrons from live chloroplasts.
Cuvettes 1, 2, 3 work as control experiments.
If transmittance is used, the results can be reflected graphically as shown below

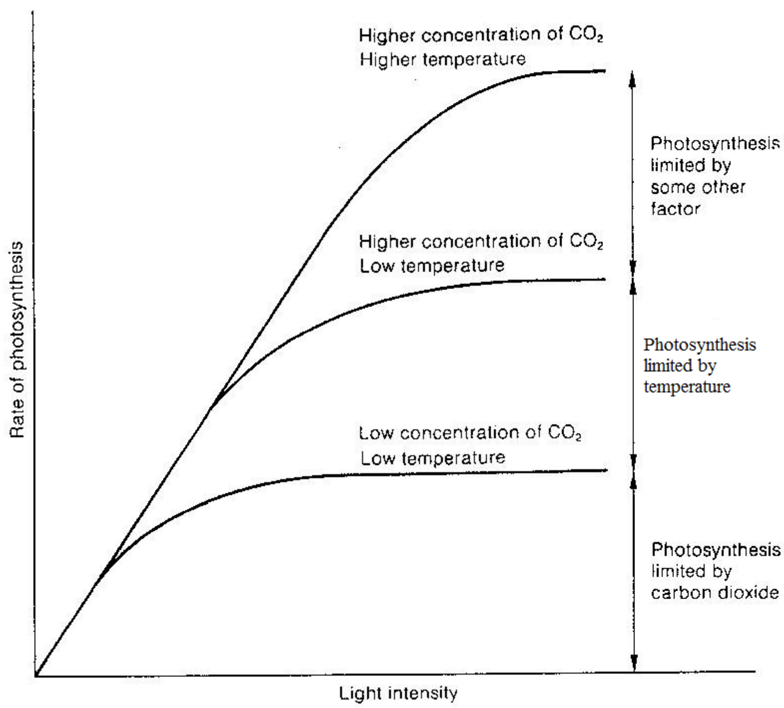


UNDERWATER PHOTOSYNTHESIS

Major photosynthetic challenges under water
(i) reduced carbon dioxide diffusion rate, which is overcome by supplementary use of HCO_3^- (bicarbonate ions)
(ii) low light penetration with depth.
● The rate of light penetration in a body of water depends on suspended substances and the turbidity of the water.

FACTORS WHICH AFFECT PHOTOSYNTHESIS
(1) carbondioxide concentration **(2)** Light intensity **(3)** Temperature **(4)** Chlorophyll concentration **(5)** oxygen concentration **(6)** Water and dissolved nutrients **(7)** Enzyme inhibitors e.g. cyanide, dichlorophenyl dimethyl urea – DCMU **(8)** Some air pollutants e.g. Sulphur dioxide **(9)** Altitude **(10)** Salinity

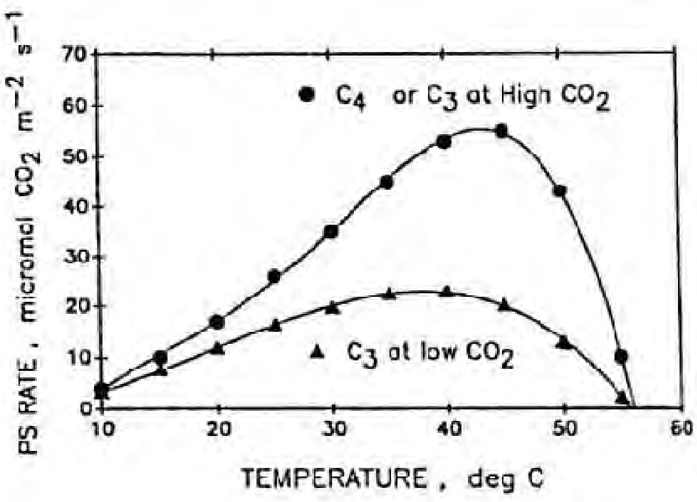
THE PRINCIPLE OF LIMITING FACTORS
It states that: ***'At any given moment, the rate of a chemical process is limited by the one factor which is nearest its minimum value, and by that factor alone'***
Graph illustrating the concept of limiting factors on the rate of photosynthesis



Salinity
One of the major effects of salinity is osmotic stress, and hence there are intimate relationships to drought stress or 'water stress'. This results in stomata closure in an effort to avoid desiccation, which reduces photosynthesis because uptake of CO_2 reduces.

Effect of carbon dioxide

In the atmosphere, the concentration of carbon dioxide ranges from 0.03 to 0.04 %



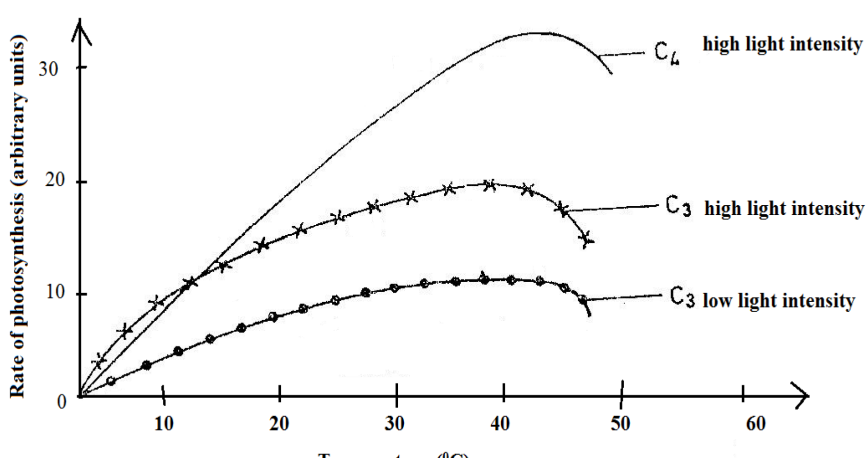
Observation / description	*Explanation*
● Generally, the rate of photosynthesis increases rapidly with increasing CO_2 concentration to a maximum at 30 Pa in C4 plants and 90 Pa in C3 plants and thereafter remains constant.	● RuBISCO attaches carbon dioxide instead of oxygen, because the CO_2 concentration is higher than the oxygen concentration. ●More cells photosynthesize because of the increased carbon dioxide molecules available.
● The rate of photosynthesis is faster in C4 than C3.	PEPC of C_4 has a higher affinity for carbondioxide than RuBISCO of C_3 and hence acts faster.
● The overall photosynthetic products are greater in C3 than in C4	C4 needs more ATP than C3 which generally reduces photosynthetic out put
● The C4 plants are more efficient at lower CO_2 concentration while C3 more efficient at higher CO_2	● At lower CO_2 concentration in C3 photorespiration reduces the photosynthesis efficiency yet PEPC has a high affinity for CO_2
● C_3 plant has a higher compensation point than C_4	PEPC has a high affinity for carbon dioxide
After attaining the maximum, the rate of photosynthesis remains constant in both	It is because other factors limit the process e.g. temperature, light intensity etc.
● At the CO_2 concentration of about 70 Pa, the rate of photosynthesis is equivalent in both plants	

Chlorophyll Concentration

The concentration of chlorophyll affects the rate of reaction as they absorb the light energy without which the reactions cannot proceed.

Temperature

An optimum temperature ranging from 25°C to 35°C is required. At temperatures around 0°C the enzymes stop working and at very high temperatures the enzymes are denatured.

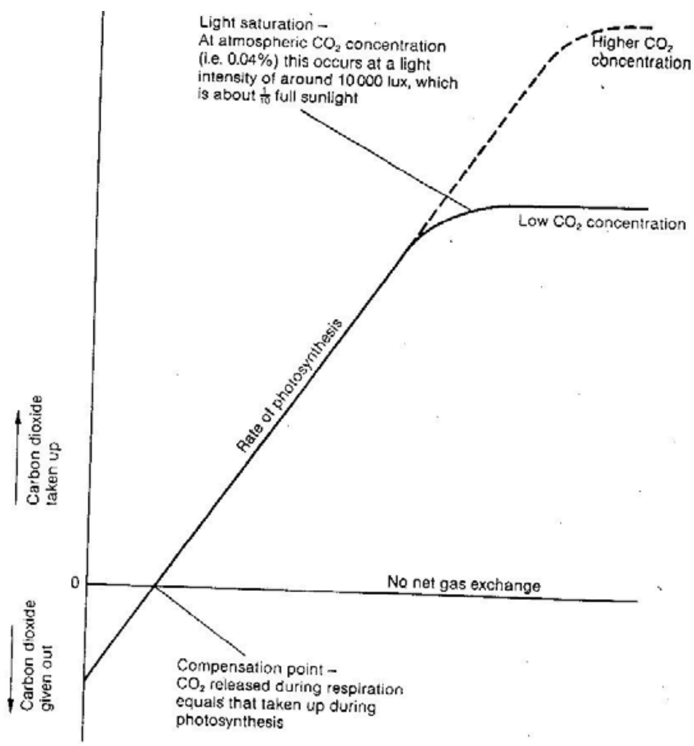


Observation / description	*Explanation*
●Below 10^0C, C_3 rate of photosynthesis is higher than in C_4 above 10^0C.	●C_4 photosynthetic enzymes are less active in the cold but become more active with increase in temperature.
●The maximum rate of photosynthesis attained in C_4 is much higher than in C_3	●The optimum temperature for enzymes involved in the C_4 cycle is higher than in the C_3 cycle
●At about 45^0C, the rate of photosynthesis decreases	●Enzymes controlling photosynthesis are denatured
There is an initial increase in photosynthetic rate to a maximum at about 40-42^0C, inspite of further increase in temperature	●Light intensity becomes a limiting factor in each of the three cases
●There is increase in the rate of photosynthesis with increase in temperature until up to at about 40^0C	●Increase in temperature activates enzymes to a level beyond which enzyme denaturation occurs.

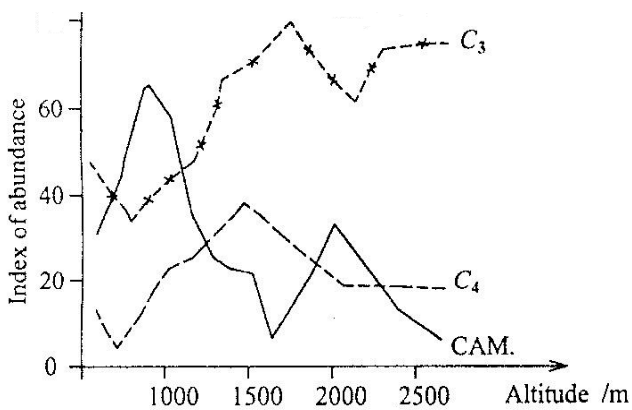
Water: In response to drying, leaves close their stomata to conserve water being lost as water vapour through them.
Pollution: Soot blocks stomata and reduce the transparency of the leaves, which reduces photosynthesis.

Light intensity and Compensation Point

Low light intensity lowers the rate of photosynthesis. As the intensity is increased the rate also increases. At maximum intensity there is no effect on the rate. Very high intensity may, in fact, slow down the rate as it bleaches the chlorophyll.
Compensation point: The light intensity at which the photosynthetic intake of carbon dioxide is equal to the respiratory output of carbon dioxide. It occurs during early morning or late evenings



Effect of altitude (and oxygen)



Effect of altitude explained

Observation / description	*Explanation*
●C3 plants are more abundant at high altitude/elevation	●The decrease in atmospheric pressure at higher altitude decreases the partial pressure of oxygen enables more productivity since photorespiration reduces
●CAM plants are more abundant at low altitude	●Even when temperature is high, nocturnal stomatal opening and closure in day light enables them to reduce transpiration. ●CAM plants that store a lot of malate and due to the thus high osmotic value also a lot of water, are usually less frost resistant than C_3 plants.
●C4 plants are widely distributed at low altitude and slight elevation	●Enzymes are tolerant to high temperatures and the Kranz mesophyll anatomy shields RuBISCO in bundle sheath cells from much O_2 to avoid photorespiration.

RESPONSE OF LEAF DISCS FROM SUN AND SHADE PLANTS TO GREEN LIGHT

- Several leaf discs from a sun plant and a shade plant are put in two separate 10 cm^3 capacity syringes containing sodium hydrogen carbonate solution (**source of carbon dioxide**).
- The air is sucked out of them so that they sink, then they are illuminated with white light.
- As they photosynthesise, the oxygen produced makes them re-float, while the time taken to rise is noted.

Calculate the average time for the leaf discs to float

- The experiment is repeated, this time covering the syringes with a green filter, so that the discs are illuminated with green light and the time taken for leaf discs to rise is noted again.
- Calculate the average time for the leaf discs to float as before.

OBSERVATION:

(1) Leaf discs from **shade plants** eventually float, an indicator that they are able to use green light for photosynthesis.
(2) Leaf discs from sun plants sink at bottom of the container which indicates that they cannot use green light to photosynthesise.

NOTE

1. Time taken for leaf discs to float can thus be used as an indirect measure of the rate of photosynthesis i.e. the more quickly flotation occurs, the faster the rate of photosynthesis.
2. The experimental results mimic the conditions in the plant's **natural habitat** i.e. the sun plant in the canopy receives white light and absorb the blue and red light from it in order to photosynthesise while the shade plant receives light that has already passed through the canopy, . In order to photosynthesise it absorbs many other wavelengths of light, including **green**.

MEASUREMENT OF RATE OF PHOTOSYNTHESIS

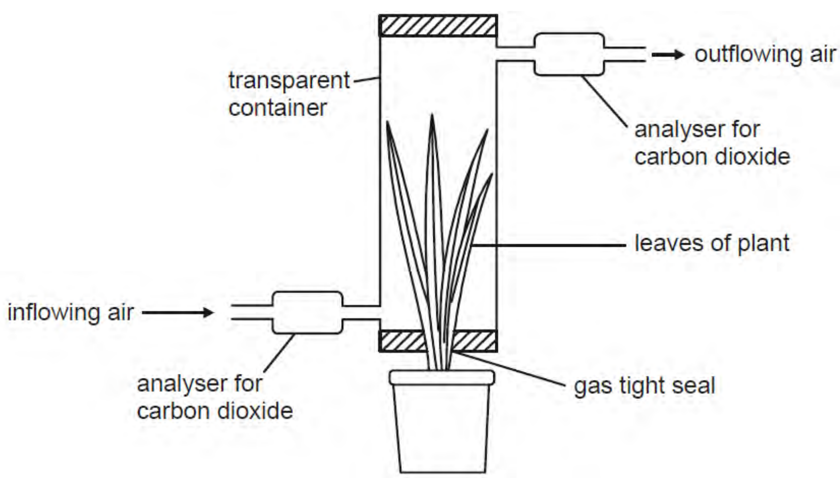
(i) Measure the uptake of CO_2 **(ii)** Measure the production of O_2 **(iii)** Measure the production of carbohydrates
(iv) Measure increase in dry mass

MEASURING THE UPTAKE OF CO_2

Uptake of CO_2 can be measured with the means of an Infra-Red Gas Analyser (IRGA) which can compare the CO_2 concentration in gas passing into a chamber surrounding a leaf / plant and the CO_2 leaving the chamber. **The soil and roots must NOT be in the bag to avoid CO_2 production from respiration**

EXAMPLE

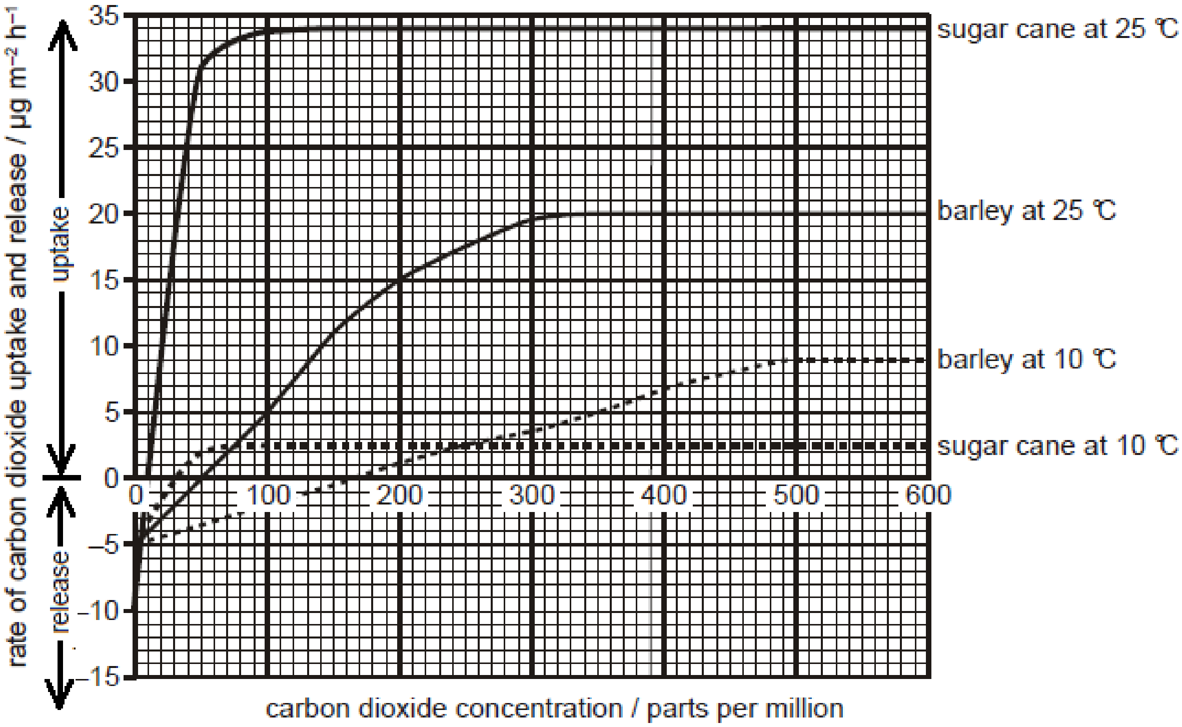
In an investigation of photosynthesis, the rate of carbon dioxide absorption by leaves of two plants, barley and sugar cane, was measured. The leaves were provided with air, moving at a constant rate, through an apparatus shown below:



EXPERMENTAL CONDITIONS

- Light intensity was kept constant and high, equivalent to full sunlight.
- Concentration of CO_2 in air entering the apparatus could be varied.
- The carbon dioxide taken up or given out by the leaves was determined by calculating the **difference** between the concentration in the inflowing and outflowing air.
- Leaves remained attached to the plants during the investigation.
- Two different temperatures, 10 °C and 25 °C, were used for each type of plant.

The results of the investigation



(a) For each plant species, describe the observed carbon dioxide uptake / release at the different temperatures (11 marks)
(b) Explain the observed carbon dioxide uptake / release in the two species at the different temperatures. (08 marks)
(c) Explain why all the measurements were made at the same light intensity.
(d) Suggest why it was important that the leaves remained attached to the plants while the measurements were made.
(e) Compare the response of the two species, sugar cane and barley, to differences in carbon dioxide concentration and temperature.

NOTE: CO_2 uptake can also be measured by following the uptake of carbon dioxide labelled with 14C

● ***Production of carbohydrates***

This is a **crude** method where a disc is cut out of one side of a leaf (using a cork borer against a rubber bung) and weighed after drying. Some weeks later, a disk is cut out of the other half of the leaf, dried and weighed. Increase in mass of the disc is an indication of the extra mass that has been stored in the leaf.

However, you can probably think of several inaccuracies in this method.

● ***Measuring the increase in dry mass***

Dry mass is often monitored by the technique of 'serial harvests' where several plants are harvested, dried to constant weight and weighed - this is repeated over the duration of the experiment so as to have an accurate measure of the surplus photosynthesis over and above the respiration that has taken place. As with most methods, several plants are needed to have replicate measurements which are used to calculate the average and a standard deviation if necessary.

● ***Measuring the production of O_2***

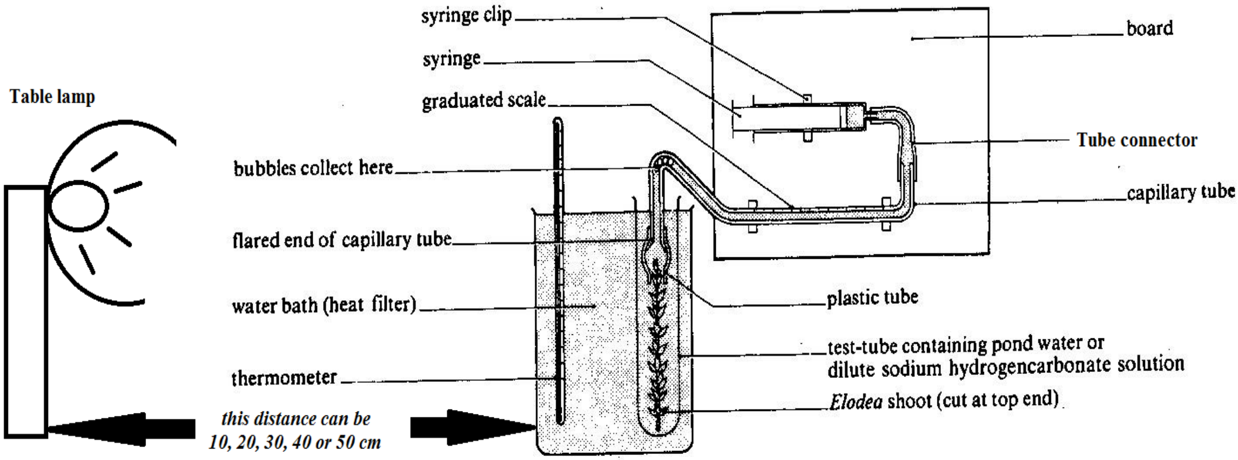
Oxygen can be measured by (a) counting bubbles evolved from pond weed with the Audus apparatus

Requirements

(1) Previously well illuminated aquatic plant e.g. *Elodea* or *Cabomba* **(2)** Test tube **(3)** Watch **(4)** Water at room temperature **(5)** bench lamp to provide light (6) Knife **(7)** Ruler **(8)** 0.2 % sodium bicarbonate solution **(9)** plastic Syringe **(10)** 500 cm^3 glass beaker **(11)** capillary tube **(12)** plastic tube connector **(13)** graduated scale **(14)** retort stand **(15)** soft board **(16)** thermometer

Procedure:

Set up the apparatus as below in TOTAL DARKNESS



(1) A light source is placed 50 cm away facing the test tube, is powered on and a 5 minutes lapse is allowed to enable the plant adjust to the light intensity.
(2) The length of gas bubble evolved in 10 second, 30 second, and 1 minute intervals is measured by pulling the syringe plunger to draw the bubble slowly along the capillary tube.
(3) Steps **1** and **2** are repeated with the light source placed at 40 cm from the test tube with the plant, then 30 cm, 20 cm, and finally 10 cm.
(4) Lastly the control experiment involves using natural room lighting and repeating the above steps.

Observation / results	***Explanation***
● A colorless gas which relights a glowing splint evolves from the cut end of the plant.	● The gas is oxygen released from Photosynthetic reactions.
● The rate of gas evolution is directly proportional to light intensity up to a certain illumination i.e. the closer the light source is to the plant, the more oxygen bubbles evolve up to a certain light intensity then remains relatively constant and may decrease. **<u>Determination of amount of gas released</u>** a) if scale is marked in mm^3 or cm^3: read volume directly b) if scale is marked in mm: calculate volume from $\pi r^2 h$ π=3.14, r=capillary tube radius, h=distance bubble covers	●This is because of the increased light intensity which provides more energy for photo-activation of electron flow. ● Increased illumination may not cause any further evolution of oxygen because **(1)** of light saturation **(2)** other factors limit the process ● Increased illumination may cause a decrease in bubble evolution because chlorophyll gets **bleached** with increased illumination.

Precautions to avoid experimental inaccuracies / errors	***Explanation / Remedy***
● Temperature fluctuation of the water in the beaker	● Thermostatically controlled bath should be used to maintain temperature constant since it affect photosynthetic activity.
● The experiment must be conducted in total darkness	● To avoid effects of external light fluctuations on photosynthesis
● There must be periodical refilling of HCO_3^- solution	● To avoid depletion of carbondioxide
● The water should be aerated first.	● To saturate the water with oxygen such that the oxygen evolved does not dissolve into water.
● Each time the light position is adjusted, a 5 minute lapse must be allowed before bubble counting	● To allow the plant equilibrate (adjust) to the new light intensity.
●Light intensity fluaction	●Use voltage that gives constant light for a long time
●Trapped gas bubbles	●Swirl the water weed to release them
● Expel gas before taking another reading	●

NOTE:

● Instead of measuring the length of bubble, bubbles can be counted, but this has several disadvantages **(1)** Some bubbles may not be seen due to variations in size, which can be avoided by adding a little detergent to lower the surface tension **(2)** Bubbles may evolve very fast to be counted, especially in much illumination.

●The percentage of oxygen in the evolved gas is **only about 40%** because of dilution by **(1)** dissolved N_2 or other gases released from solution and **(2)** CO_2 which had accumulated from respiration, and is first displaced into the capillary tubing, especially if the plant had been kept in the dark

RELATIONSHIP BETWEEN PHOTOSYNTHESIS AND RESPIRATION

There is a close relationship between the activities of respiration and photosynthesis in living things. These two activities counteract each other in many ways, and a balance of the processes are necessary to maintain the favourable O_2/CO_2 ratio in the atmosphere.

- In the presence of light, plants respire aerobically to release carbon dioxide while consuming oxygen, and at the same time photosynthesise to release oxygen while consuming carbon dioxide, although photosynthesis far exceeds respiration.
- In darkness, plants respire aerobically to release carbon dioxide but photosynthesis is inhibited by absence of light.

SAMPLE QUESTIONS

1. Five small discs cut from spinach leaves were floated on a small volume of buffered hydrogen carbonate solution in a flask attached to a respirometer. The discs were first exposed to bright light, then to dim light and finally left in the dark. Oxygen release was recorded as positive values and oxygen uptake as negative values as given in the table below.

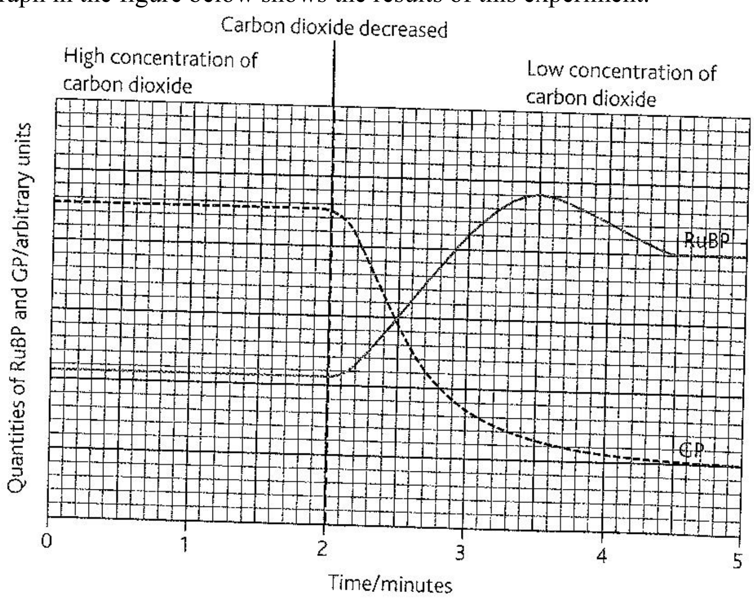
Light intensity	Time interval in minutes	Oxygen uptake or release in mm^3
Bright light	0 – 3	+57
	3 – 6	+64
	6 – 9	+58
	9 – 12	+60
Dim light	12 – 15	+16
	15 – 18	+3
Dark	18 – 21	- 16
	21 – 24	- 12
	24 – 27	- 15
	27 – 30	- 14

(a) Present the data in a suitable graphical form

(b) (i) Calculate the mean rate of oxygen release in bright light
(ii) Explain the significance of the results obtained from this experiment.

(c) Explain the use of the following in the experiment above:
(i) Five small leaf discs, not one.
(ii) Hydrogen carbonate solution
(iii) Buffered hydrogen carbonate solution

2. In an experiment, samples of algae were collected at 1-minute intervals over a period of 5 minutes. The quantities of glycerate-3-phosphate (GP) and ribulose bisphosphate (RuBP) were measured. At the beginning of the experiment, the concentration of carbondioxide supplied was high. After 2 minutes, the concentration of carbondioxide was reduced. The graph in the figure below shows the results of this experiment.



Describe the effects of the decrease in carbondioxide after 2 minutes on:
(i) Glycerate 3-phosphate (GP)
(ii) Ribulose bisphosphate (RuBP)
(b) Suggest explanation for these changes to the levels of glycerate 3-phosphate (GP) and RuBP

3. 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

4. The rate of photosynthesis of *Digitaria bipartite*, a C4 plant and *Astropa belladonna*, a C3 plant was investigated under different intracellular carbon dioxide concentrations. The results are shown in the table below

Carbon dioxide concentration (ml per dm^3)	Rate of photosynthesis (mol of CO_2 assimilated per m^2 of leaf area per second)	
	Digitaria bipartite	*Digitaria bipartite*
0	0.0	0.0
25	12.5	0.0
50	35.0	5.0
75	37.5	14.0
100	37.5	25.0
150	37.5	40.0
200	37.5	47.5

(a) Present the data in the table above graphically
(b) Compare the rates of photosynthesis of two plants at the carbon dioxide concentrations shown in (a) above
(c) Explain your answer in (b) above
(d) Explain, in biochemical terms, the distribution of C_3, C_4 and CAM plants at their environments

5. The table below shows how the rate of photosynthesis of C4 and C3 plants vary with the temperature at different light intensities. The rate is in arbitrary unit.

Temperature/^{0}C	0	5	10	20	30	35	40
C_4 plants at high light intensity	0	5	12	25	28	32	38
C_3 plants at high light intensity	0	10	12	15	18	20	10
C_3 plants at low light intensity (Arbitrary units)	0	2	5	8	10	10	6

(a)Represent the above results graphically on the same axes.
(b) Explain how differently temperature affects photosynthesis in C_3 plants and C_4 plants.
(c) Explain the pattern of the graph obtained for C_3 plants under low light intensity.
(d) Explain the effect of light intensity on the following.
(i) Leaf colour (ii) Leaf size (iii) Internode length
(e) State three other factors that may limit the rate of photosynthesis.

6. 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) Plot the data on a graph paper (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
(ii) Explain the physiological significance of the mechanism described in (e) (i) above.

6. (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.

7. (a) Outline the light-independent reactions of photosynthesis.
(b) (i) 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.

8. (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.

9. (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.
(c) Explain the concept of limiting factors in photosynthesis, with reference to light intensity, temperature and concentration of carbon dioxide.

WHAT IS CELLULAR RESPIRATION?

A series of enzyme catalysed reactions in living cells during which complex organic substances are broken down to release energy in form of **adenosine triphosphate (ATP).**

OR A series of enzyme catalysed reactions in living cells during which the chemical-bond energy of complex organic substances is released and converted into the usable form called **adenosine triphosphate (ATP).**

STORAGE OF CHEMICAL ENERGY IN FOOD

The C-H covalent bonds in organic substances (e.g. carbohydrates and lipids) form by sharing pairs of fast-moving energetic electrons, and therefore contain potential energy. The catalytic breakage of the C-H bonds releases energy, some of which powers the formation of ATP – a compound that can readily hydrolyse to provide energy that powers cellular activities. **The higher the C-H bonds, the more the energy yields. This explains why lipids yield twice more energy than carbohydrates of same mass.**

The Fate of High Energy Electrons and Hydrogen ions released from breaking C-H Bonds

To avoid fatality, the electrons lost from compounds are prevented from joining other molecules by joining electron carrier molecules which pass them along the **electron transport chain** until they get attached to oxygen, which becomes negatively charged, O^{2-}. As the electrons are transferred along the transport chain, energy is gradually extracted from them to power ATP formation. To avoid PH becoming acidic, which would be fatal, hydrogen ions, H^+ combine with O^{2-} to form neutral water.

STRUCTURE OF ADENOSINE TRIPHOSPHATE (ATP)

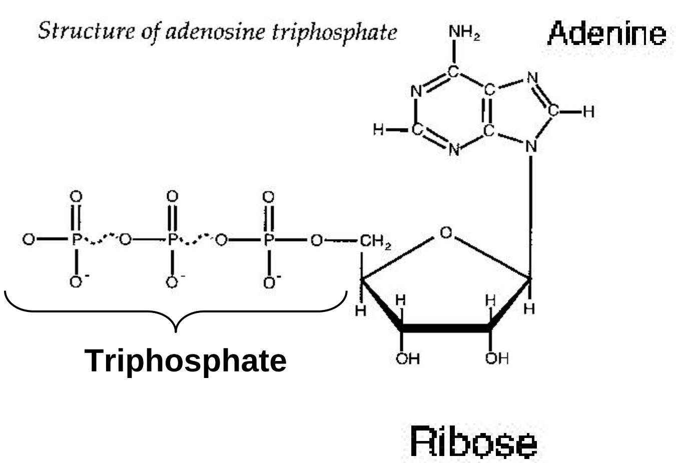
ATP is a compound made up of a molecule of **adenine** – a nitrogenous base, a molecule of **ribose sugar**, and **three phosphate molecules**.

WHY ATP IS CONSIDERED TO BE AN 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. Hydrolysis of ATP to form **adenosine diphosphate (ADP)** releases 30.6kJmol^{-1} of free energy, and further hydrolysis of the terminal phosphate bond of ADP to form **adenosine monophosphate (AMP)** yields another 30.6kJmol^{-1} of free energy, but hydrolysis of the phosphate-ribose bond in AMP is not feasible because releases very little energy.

WHY THE TWO ATP TERMINAL PHOSPHATE BONDS ARE HIGH-ENERGY BONDS

It is because their hydrolysis proceeds with the release of an unusually large amount of free energy (about 7.3kcal/mol or 30.6kJ per mol from each phosphate bond)



NOTE:

(1) Phosphorylation of AMP (addition of phosphate molecules to AMP) forms ADP, while Phosphorylation of ADP yields ATP.

(2) Addition of each phosphate molecule requires 30.6kJ, and therefore energy released from any chemical reaction if less than 30.6kJ cannot be stored as ATP but is lost as heat.

(3) High-energy bonds are symbolized by the **squiggle (~)** i.e. solid curved line.

(4) Potential energy increases whenever things experiencing a repulsive force are pushed together such as adding the 3rd phosphate to an ADP molecule. Potential energy also increases whenever things that attract each other are pulled apart as in the separating of protons from the electrons.

PHOSPHORYLATION IN CELLS

ATP is formed in cells by three types of phosphorylation:

1. Directly by **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: **Phosphoenolpyruvate, 1, 3-Bisphosphoglycerate, acetyl phosphate and phosphocreatine.**

2. Indirectly by **oxidative Phosphorylation *i.e.*** use of energy supplied by transmembrane proton gradients across the inner mitochondrial membrane during electron transport system to form ATP.

3. Indirectly by **Photophosphorylation *i.e.*** use of energy supplied by transmembrane proton gradients across thylakoid membranes in chloroplasts during photosynthesis to form ATP.

EXAMPLES OF OTHER HIGH-ENERGY COMPOUND IN CELLS

Phosphoenolpyruvate, 1, 3-Bisphosphoglycerate, acetyl phosphate and phosphocreatine

Apart from ATP, there are other compounds with even higher energy than ATP, but ATP is commonly used because:

(i) ATP releases just the right amount of energy for cellular needs when hydrolysed.

(ii) ATP releases energy at the right time

(iii) ATP and can be moved to any place when need arises.

Example: In muscles and nerve cells where ATP is continually hydrolysed at a rate faster than respiration can provide due to high metabolic activity, **phosphocreatine** provides the phosphate for regeneration of ATP from ADP.

Standard Free Energies of Phosphate hydrolysis of some compounds in cells

Compound	*$\Delta G^{0'}$ (kJ/mol)*
Phosphoenolpyruvate	-61.9
1, 3-Bisphosphoglycerate	-49.4
Acetyl phosphate	-43.1
Phosphocreatine	-43.1
ATP (+ $H_2O \Leftrightarrow$ ADP + P_i)	**-30.6**
Glucose-1-phosphate	-20.9
Fructose-6-phosphate	-13.8
Glucose-6-phosphate	-13.8
Glycerol-3-phosphate	-9.2

1. ATP has an intermediate phosphate-group transfer potential. Under standard conditions, the compounds above ATP in the table on the left can spontaneously transfer a phosphate group to ADP to form ATP, which can in turn spontaneously transfer a phosphate group to the appropriate groups to form the compounds listed below it.

2. The negatives of the values listed in the table are often referred to as **phosphate group-transfer potentials;** compounds with large negative values readily transfer their phosphate group to form compounds with small negative values by first forming ATP

WHY ATP IS REFERRED TO AS "THE UNIVERSAL ENERGY CURRENCY"

It is because the structure and functioning of ATP in providing energy is the same in all living cells.

DURATION OF ATP STORAGE IN CELLS

ATP is continually hydrolysed and regenerated. The metabolic half-life of an ATP molecule varies from seconds to a few minutes depending on the cell type and its metabolic activity.

Examples:

(i) Brain cells have only a few seconds' supply of ATP – which partly explains why brain tissue deteriorates rapidly if deprived of oxygen.

(ii) Muscle cells can store phosphocreatine for some minutes to act as a reservoir of phosphate groups that can be used to produce ATP. **This ATP/PCr store although small, is important in providing instant energy e.g. during sprinting.**

HYDROLYSIS OF ATP TO ADP AND INORGANIC PHOSPHATE (P_i)

Hydrolysis of ATP to ADP + P*i* releases more potential energy than hydrolysis of ADP to AMP + P*i* because:

(1) The three phosphate molecules in ATP have four negative charges with great electrical repulsion, raising the potential energy of the electrons.

(2) The negative charges on ADP and P_i are stablised by much more efficiently by interactions with the partial positive charges on surrounding water molecules. For these and other reasons, ADP and P_i have lower potential energy than does ATP.

USES OF ENERGY OF ATP IN CELLS
(1) Enables transport of materials in phloem of plants.
(2) Enables movement of cilia or flagella and muscle contraction
(3) Allows active transport to be carried out (movement of substances against concentration gradient) e.g. ion pumps
(4) Drives endergonic reactions e.g. assembly of amino acids into proteins, synthesis of polysaccharides from monosaccharides, and DNA replication
(5) Activates chemicals to become more reactive e.g. phosphorylation of sugar during Glycolysis
(6) Enables formation of vesicles during secretion of cell products.
(7) Contraction of microfilaments during cell division

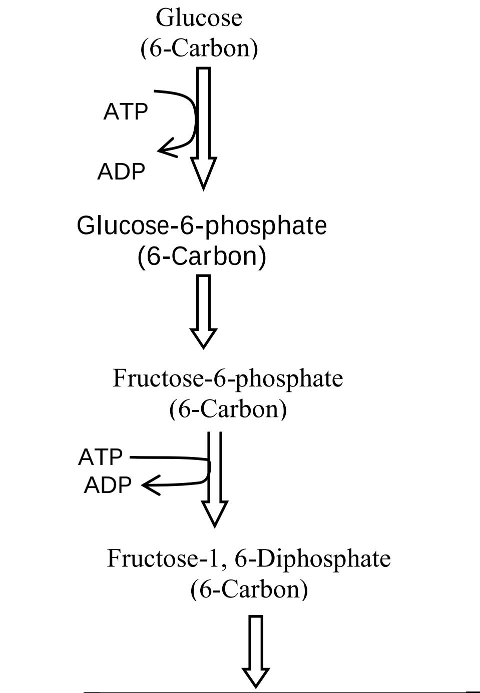
LOCATION OF RESPIRATION IN CELLS

Cell type	Location of pathway in cell
All prokaryotic cells	Infoldings of cell membrane (mesosomes) and in cytoplasm
All eukaryotic cells	Cytoplasm ***(Glycolysis)***, Mitochondrial matrix ***(Krebs cycle)*** and inner membrane of mitochondria ***(Electron transport system)***

STAGES OF CELLULAR RESPIRATION
(1) Glycolysis **(2)** Krebs cycle **(3)** Electron transfer system
Each step will be discussed individually, but remember that each is part of the whole process.

GLYCOLYSIS (*glyco* = carbohydrate; *lys* = splitting; *sis* = the process of)
Definition:
A series of enzymatically controlled reactions in the cytoplasm of cells during which one molecule of a six-carbon sugar glucose, is split into two molecules of the three-carbon compound Pyruvate, with a net out put of two ATP molecules.

DESCRIPTION OF GLYCOLYSIS



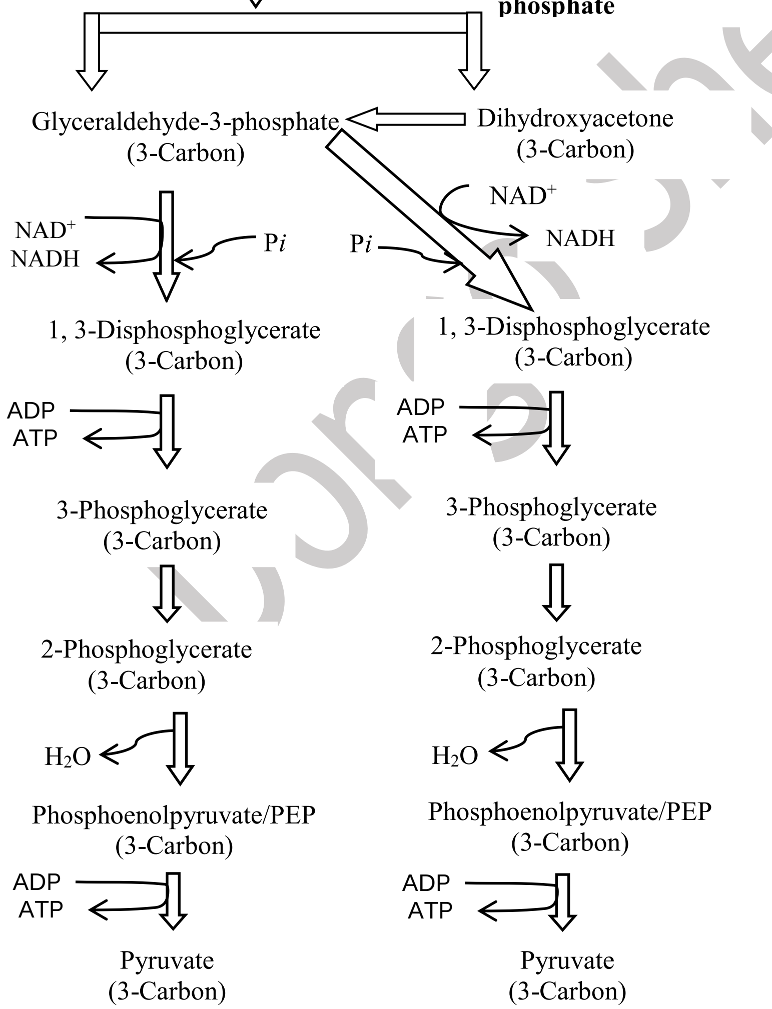
Glycolysis starts with **phosphorylation** of glucose by ATP to form **glucose-6-phosphate**.
This process **(1)** chemically reactivates glucose **(2)** traps glucose in the cell because the phosphate group bears a negative charge yet the cell membrane is impermeable to ions.

Glucose-6-phosphate **isomerizes** to form **fructose-6-phosphate** to ease another Phosphorylation.

Fructose-6-phosphate is **phosphorylated** by ATP to form **fructose-1, 6-bisphosphate *(Fructose-1, 6-diphosphate)***

Fructose-1, 6-bisphosphate **splits / cleavages** at once into two molecules each with three-carbons:

- **Glyceraldehyde-3-phosphates** (3-phosphoglyceraldehyde / PGAL)
- **Dihydroxyacetone**, which **isomerizes** into **Glyceraldehyde 3-phosphate**



- Each PGAL is **dehydrogenated** by nicotinamide adenine dinucleotide (NAD^+) to form **reduced nicotinamide adenine dinucleotide** (NADH)
- Each 3-PGAL molecule is **phosphorylated** by phosphates present in the cytoplasm to form **1, 3-diphosphoglycerate**, which later donates the phosphate to ADP to form ATP and **3-phosphoglycerate**, which has 3-carbons.

Each 3-phosphoglycerate **isomerizes** to form **2-phosphoglycerate**

Each 2-phosphoglycerate loses a water molecule (**dehydrated**) to form **3-phosphoenolpyruvate** (PEP).

Each 3-phosphoenolpyruvate (PEP) loses a phosphate to ADP (**dephosphorylated**) to form ATP and **pyruvate** which has three-carbons

SIGNIFICANCE OF GLYCOLYSIS

Glycolysis forms:

(1) ATP which is used to power cell activities

(2) NADH and Pyruvate which may be further oxidized to generate additional ATP.

However in oxygen deficiency, both NADH and pyruvate undergo fermentation to regenerate NAD^+.

NOTE:

The breakdown of Glucose in glycolysis into two molecules of pyruvate yields about 5.2% of the total energy that can be released from glucose by complete oxidation.

EVOLUTIONARY SIGNIFICANCE OF GLYCOLYSIS

The role of glycolysis in both fermentation and respiration suggests that ancient prokaryotes probably used glycolysis to make ATP long before oxygen was present in the atmosphere.

This conclusion is based on the following observations:

(1) The oldest bacterial fossils date back 3.5 billion years, yet oxygen accumulated about 2.7 billion years ago. Therefore early prokaryotes may have generated ATP exclusively from glycolysis, which does not require oxygen.

(2) Glycolysis occurs in all organisms, which suggests that it evolved very early in the history of life.

(3) Glycolysis is located in the cytoplasm where no membrane-bounded organelles are required in eukaryotic cells, which evolved approximately 1 billion years after the prokaryotic cell.

ELECTRON CARRIER MOLECULES

1. NAD^+ (Nicotinamide Adenine Dinucleotide): A coenzyme containing the B-vitamin, **niacin**.

NAD^+ accepts 2 e^- and one H^+ (a hydride) in going to the reduced state, as $NAD^+ + 2e^- + H^+ \rightarrow NADH$.

It may also be written as: $NAD^+ + 2e^- + 2H^+ \rightarrow NADH + H^+$

NAD^+ is a **coenzyme**, that reversibly binds to enzymes.

2. FAD (Flavin Adenine Dinucleotide): is derived from the vitamin riboflavin (B2). The protein to which it is attached is termed a **flavoprotein (FP).**

FAD normally accepts 2 e^- and 2 H^+ in going to its reduced state: $FAD + 2e^- + 2H^+ \rightarrow FADH_2$

FAD is an electron-carrier coenzyme like NAD+. However, unlike NAD+, FAD always occurs as a **prosthetic group**, tightly bound at the active site of an enzyme, never as a free carrier.

3. FMN (Flavin Mono Nucleotide): is a prosthetic group of some flavoproteins. It is similar in structure to FAD, but lacking the adenine nucleotide.

ROLE OF VITAMIN B COMPLEX IN CELLULAR RESPIRATION

Vitamin	**Role in cellular respiration**
B_1 (Thiamine)	Involved in formation of some Krebs cycle enzymes Forms part of acetyl coenzyme A
B_2 (Riboflavin)	Forms part of the hydrogen carrier Flavine Adenine Dinucleotide (FAD)
B_3 (Niacin or Nicotinic acid)	Forms part of coenzymes NAD and NADP Forms part of acetyl coenzyme A
B_5 (Pantothenic acid)	Forms part of acetyl coenzyme A

FATE OF THE PRODUCTS OF GLYCOLYSIS

1. ATP: It is hydrolysed to release energy to power the cell's needs.

2. NADH:

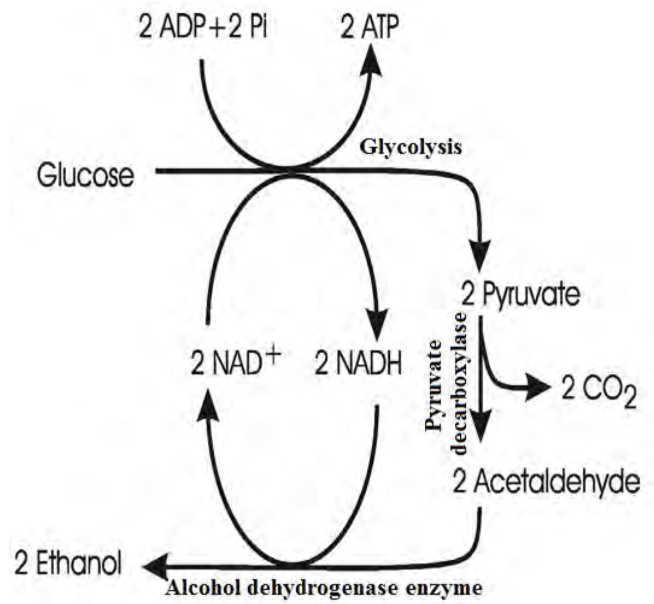
Under **aerobic conditions (in the presence of oxygen),** NADH is converted into $FADH_2$ which is then shuttled into the mitochondria where it donates electrons to a series of electron carriers until they reach the final oxidizing agent oxygen in a process called electron transport system. During this process, the free energy of electron transport drives the synthesis of ATP from ADP and NAD+ is regenerated such that it can participate in further catalysis.

Under **anaerobic conditions,** NADH must be re-oxidised by other means to supply glycolysis with NAD+

3. PYRUVATE:

- Under **aerobic conditions**, pyruvate is completely oxidised via the **citric acid cycle** to carbon dioxide and water.
- Under **anaerobic conditions** in the cytoplasm, pyruvate undergoes **fermentation**.

TYPES OF FERMENTATION (ANAEROBIC RESPIRATION)
There are many types of fermentation, but the two common types are given below:

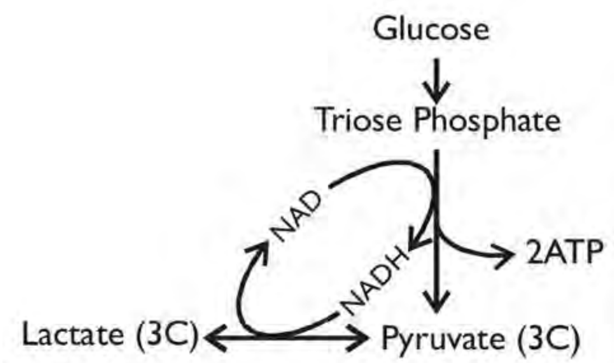


(a) Alcoholic fermentation:
Pyruvate is decarboxylated to form a 2-carbon compound **acetaldehyde** and carbon dioxide

Acetaldehyde is then reduced by NADH to form **ethanol** and NAD^+

NAD^+ enables the continuation of glycolysis.

Alcoholic fermentation occurs in some bacteria and yeasts.



(b) Lactic acid fermentation:
Pyruvate is reduced directly by NADH to form **lactic acid** as the end product. No carbon dioxide is released.
Lactic acid fermentation:
(1) Is carried out by **certain fungi and bacteria** during the formation of **yoghurt** and **cheese**
(2) Occurs during oxygen scarcity in human skeletal muscle cells during sprinting.

The lactic acid is gradually carried away by blood to the liver and converted back to **pyruvate** by **liver cells**. ***If ATP is abundant, pyruvate and lactate can be used as a substrate in the synthesis of glucose.***

EXPERIMENTS ON ALCOHOLIC FERMENTATION IN YEAST
Investigations have been carried out using a Biology gas pressure sensor and Methylene blue dye to determine:
(i) The type of sugar best metabolized by yeast (***Maltose*** or ***glucose*** or ***fructose*** or ***sucrose, galactose*** or ***lactose***)
(ii) The effect of yeast fermentation of polysaccharides.

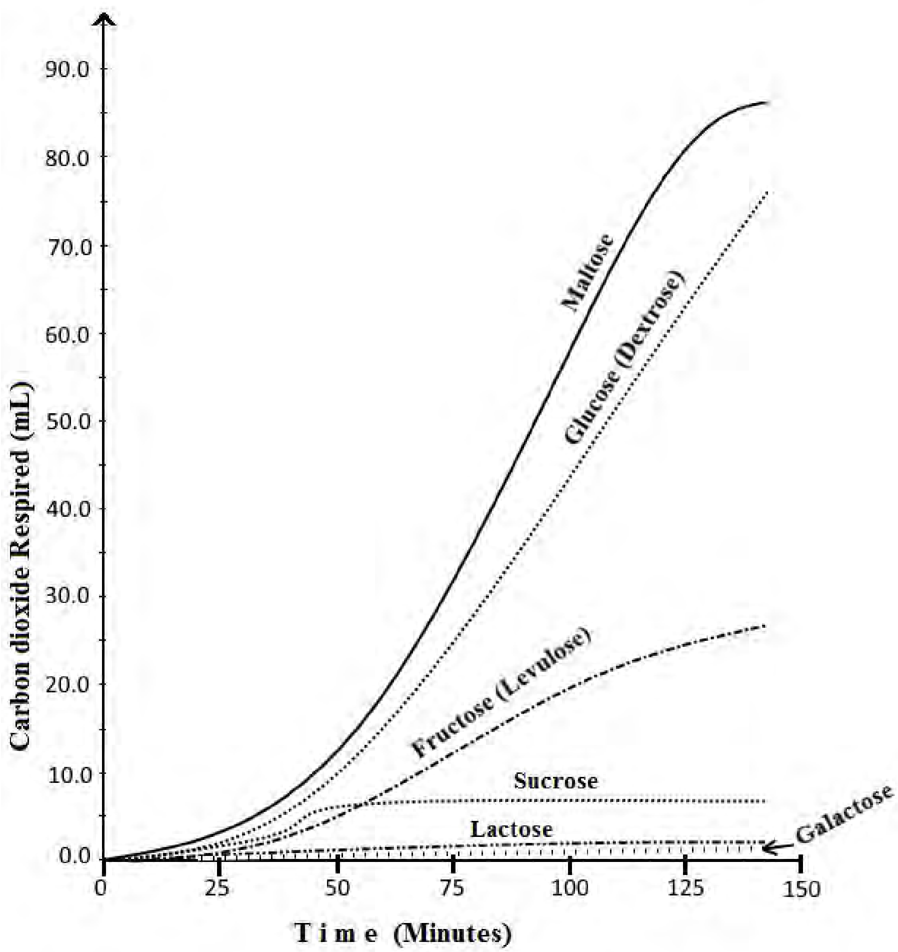
Using Gas pressure sensor
- A gas pressure sensor is used to monitor anaerobic fermentation of sugar because CO_2 produced causes a change in the pressure of a closed test tube, since no oxygen being consumed.
- Aerobic respiration of yeast consumes oxygen gas at the same rate that CO_2 gas is produced, hence no change in the gas pressure in the test tube. The rate of CO_2 evolution is an indication of the rate of breakdown of sugar.

Using Methylene blue or DCPIP dye
- In the **oxidised state**, the colour of indicator / dye is **blue** but on accepting **electrons released by breakdown of sugar** goes into **reduced state** and turns **colourless**. The rate of dye colour change from blue to colourless is an indication of the rate of breakdown of sugar to release electrons.

EXPERIMENT TO DETERMINE THE TYPE OF SUGAR BEST METABOLIZED BY YEAST

Independent variable	Dependent variable	Control variables	Series
Time (minutes)	Carbon Dioxide Production	Sugar concentration, Yeast, Water, Temperature	**Monosaccharides:** Dextrose (Glucose), Levulose (Fructose) and Galactose **Disaccharides:** Sucrose, Maltose, Lactose

Graphs of carbon dioxide evolved with time during anaerobic respiration of yeast in different sugar solutions. A gas pressure sensor was used to monitor anaerobic fermentation of sugar as the CO_2 produced caused a change in the pressure of a closed test tube. The data was collected until no more gas could be detected. All control variables were managed to enable accuracy of results.



EXPLANATION (12 marks)

- From 0 minute to about 38 minutes, CO_2 evolution was slow by almost all sugars; **because** enzyme secretion was still slow / low;
- From about 38 minutes to about 148 minutes, CO_2 evolution was rapid in both maltose and glucose; but more rapid in maltose**; because** yeast enzymes for maltose and glucose breakdown are rapid; but enzymes for maltose breakdown are more rapid;
- From about 38 minutes to about 148 minutes, CO_2 evolution was slow in fructose**; because** yeast enzymes for fructose break down are slow;
- From about 38 minutes to about 148 minutes, CO_2 evolution was low and constant in sucrose; **because** yeast enzymes for sucrose breakdown are in low concentration;
- From about 0 minute to about 148 minutes, CO_2 evolution was very low and remained constant in Lactose and galactose; **because** enzymes for lactose and galactose may be present in very low concentration;

How control variables were managed to enable obtaining accurate results **(08 marks)**

- In such experiment involving enzyme work in various substrates, the key control variables that affect results of the experiment include: sugar concentration; yeast (enzyme concentration); volume of water; temperature;
- All the control variables must be kept constant in all the experiments;
- Concentrations of sugars and yeast in fixed volume of water must be high enough to generate detectable volume of carbon dioxide; for a relatively long period of time;
- Temperature should be optimum for enzyme work;

Explain the differences in results observed from Maltose and Sucrose, which are both common disaccharides and Glucose and Fructose, which are both common monosaccharides. **(05 marks)**

- Yeast breaks down maltose faster than sucrose yet both are disaccharides; and also breaks down glucose faster than fructose yet both are monosaccharide;
- This is because among monosaccharides and disaccharides are many different configurations of atoms (isomers); requiring different enzymes; to be used in utilizing the energy in the different isomers;

Briefly describe the essential stages in the anaerobic breakdown of glucose by yeast (08 marks)
Phosphorylation of glucose by ATP; second phosphorylation of hexose sugar by ATP; cleavage of hexose into two triose molecules; dehydrogenation and dephosphorylation of triose molecules to form pyruvate; and a net of two ATP molecules; decarboxylation of Pyruvate to form acetaldehyde; and carbon dioxide; reduction of acetaldehyde by NADH to form ethanol;

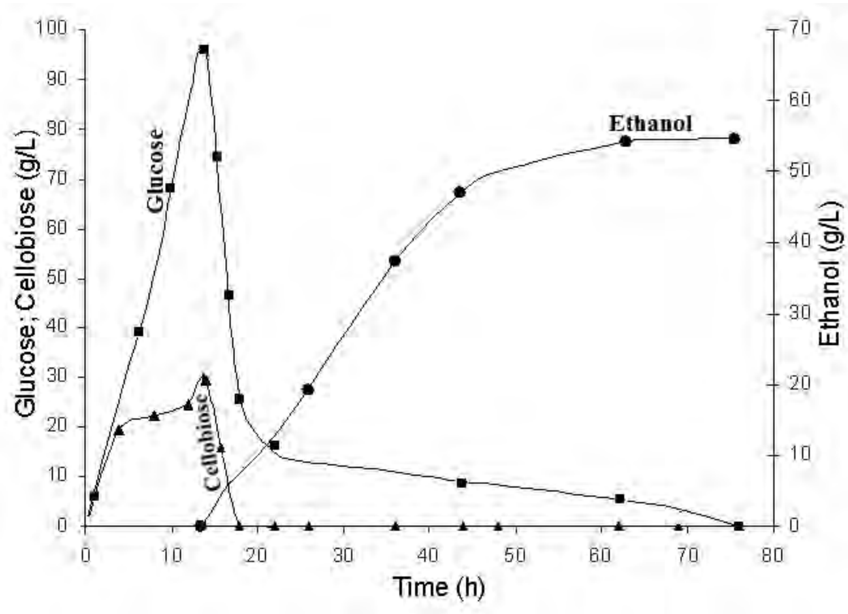
(i) State the commercial applications of fermentation (04 marks)

- In breweries, fermentation of sugars forms alcoholic drinks like wine, beer and spirits.
- In bakeries, fermentation of starch by yeast is used in leavening of bread i.e. production of raised bread
- Applied in the manufacture of milk products like sour milk, yoghurt and cheese
- Applied in food industries for the manufacture of organic acids e.g. citric acid, oxalic acid and butyric acid.
- In sewage treatment, sewage is digested by enzymes secreted by bacteria to reduce the bulk and odour of sewage

(ii) From the results, comment on the suitability of maltose and sucrose in any named commercial application (03 marks)

In breweries in the manufacture of ethanol; maltose is a better substrate / raw material than sucrose; on the basis of the faster rate of breakdown of maltose to form ethanol than it occurs in glucose;

EXPERIMENT TO DETERMINE EFFECT OF YEAST FERMENTATION OF CARBOHYDRATES



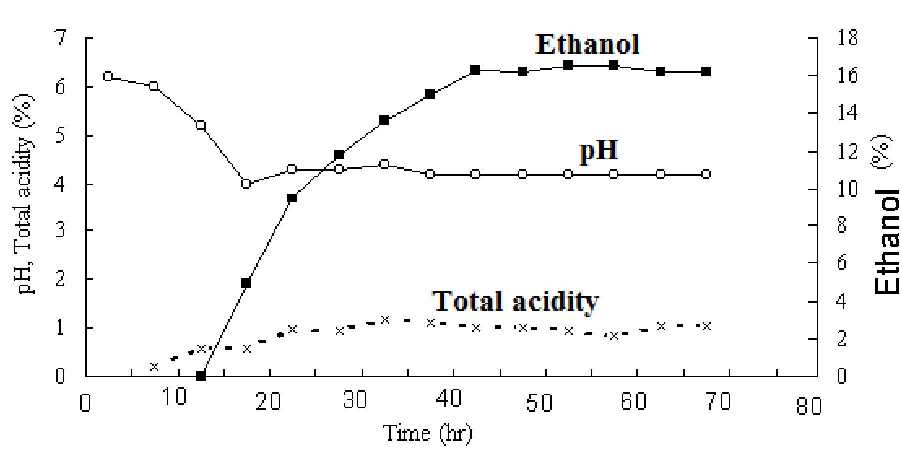


Figure I shows results from the experiment of simultaneous saccharification and fermentation of steam-pretreated sugarcane (*Saccharum officinarum*) bagasse by ***Saccharomyces cerevisiae,*** a strain of yeast.

Bagasse, the fibrous residue obtained after extracting juice from sugar cane consists approximately of 50% cellulose, 25% hemicellulose, and 25% lignin.

During the experiment, temperature of the medium was maintained at 37^0C, and initial pH adjusted to 6.1.
Nitrogen was flushed into the reaction vessels at the beginning of the experiment.

Figure II shows changes in pH and total acidity during the same period of time.

(a) From figure I:

(i) Describe the changes in the concentration of sugars and ethanol. (10 marks)

From 0 hour to about 15 hours, the concentration of glucose increased rapidly;
From about 15 hours to about 19 hours the concentration of glucose decreased rapidly;
From about 19 hours to about 76 hours the concentration of glucose decreased gradually to complete disappearance;

From 0 hour to about 4 hours the concentration of Cellobiose increased rapidly;
From about 4 hours to about 15 hours, the concentration of Cellobiose increased gradually;
From about 13 hours to about 15 hours the concentration of Cellobiose increased rapidly;
From about 15 hours to about 18 hours the concentration of Cellobiose decreased rapidly to complete disappearance;

From 13 hours to about 45 hours the concentration of ethanol increased rapidly;
From about 45 hours to about 62 hours, the concentration of ethanol increased gradually;
From about 62 hours to about 76 hours the concentration of ethanol was relatively constant;

(ii) Explain the changes in the concentration of sugars and ethanol. (10 marks)

From about 0 hour to about 15 hours cellulosic hydrolyzing enzymes secreted by yeast rapidly hydrolysed cellulose to form glucose and Cellobiose / **there was rapid saccharification;**
From about 15 hours to about 19 hours yeast respired the sugars glucose and Cellobiose rapidly under anaerobic conditions to form ethanol;
From about 19 hours to about 76 hours there was gradual breakdown of cellulosic material to form glucose; yet there was rapid anaerobic respiration to form ethanol;
From 13 hours to about 45 hours rapid alcoholic fermentation of sugars formed ethanol rapidly;
From about 45 hours to about 62 hours gradual alcoholic fermentation of sugars formed ethanol gradually due to little inhibition of enzymes; by some of the products of saccharification and fermentation;
From about 62 hours to about 76 hours alcoholic fermentation of sugars had ceased / stopped due to much inhibition of enzymes by some of the products of saccharification and fermentation;

(b) Explain the necessity of the following in the experiment:

(i) Steam-pretreatment of sugarcane bagasse (05 marks)

Steam-pretreatment **separates / loosens / disentangles** lignin from cellulose in the sugarcane residue (bagasse); which exposes cellulose molecules to yeast's hydrolytic enzymes / cellulase and hemicellulase; for conversion into glucose and Cellobiose sugars;
Steam-pretreatment also sterilizes the bagasse; to avoid interference by any other microorganisms except yeast;

(ii) Adjustment of pH to 6.1 (02 marks)

Creates an optimum weakly acidic medium; in which yeast's hydrolytic enzymes work best;

(iii) Flushing nitrogen into the reaction vessel. (02 marks)

To reduce the partial pressure of oxygen within the vessel; so as to create anaerobic conditions for fermentation to occur;

(c) Explain the observed changes in pH and total acidity of the medium during the experiment. (07 marks)

From about 1 hour to about 15 hours the pH of the medium decreased gradually to become more acidic; and thereafter remained relatively constant; **because** anaerobic respiration of glucose produced carbon dioxide; which reacted with water in the solution to form a weakly acidic medium;
From about 1 hour to about 15 hours glucose was still much in the medium; hence providing much substrate for anaerobic respiration of yeast;
After 15 hours to 70 hours the concentration of glucose in the medium decreased gradually; hence little carbon dioxide was generated from anaerobic respiration; whose effect on pH was minimal;

(d) From figure II, suggest one reason for the observed efficiency of the experiment. (04 marks)

Experiment was inefficient; since only about 16% of the total yielded of ethanol was realised; probably because cellulose and hemicellulose in bagasse could not be easily hydrolysed / digested into sugars; by enzymes in yeast;

COMPARISON OF CELLULAR RESPIRATION AND FERMENTATION

Similarities: Both

(i) Form ATP

(ii) Use glycolysis to oxidise glucose to pyruvate

(iii) Use NAD+ as the oxidizing agent that accepts electrons from food during glycolysis

(iv) May be carried out by same cells (e.g. muscle cells) or same organisms (e.g. yeasts and bacteria).

Differences:

Cellular respiration / Aerobic respiration	Fermentation / Anaerobic respiration
● Uses oxygen for releasing energy	● Occurs in absence of oxygen
● Efficient i.e. up to **38 ATPs** formed per glucose molecule.	● Inefficient i.e. **2 ATPs** formed per glucose molecule
● Occurs in cytosol and mitochondria.	● Occurs in cytoplasm (cytosol) only.
● End products are CO_2 and water	● End products are Ethanol or 2 Lactate and CO_2
● Complete oxidation of respiratory substrate occurs	● Incomplete oxidation of respiratory substrate occurs

FATE OF PYRUVATE UNDER AEROBIC CONDITIONS

In the presence of oxygen, each pyruvate molecule produced by glycolysis in the cell cytoplasm is **actively transported** across the mitochondrial envelope (since it is a charged molecule) into the matrix, where it is transformed in what is called **link reaction** as follows:

First, pyruvate is decarboxylated, then oxidised (dehydrogenated) to form a **2-C compound called acetate**, **carbon dioxide** and **NADH**.

Carbon dioxide, a waste product is eventually excreted while NAD+ serves as a hydrogen carrier.

Finally, **Acetate** is attached to **Coenzyme A** to form **acetyl coenzyme A**, making the **acetyl group very reactive**.

Acetyl coenzyme A now enters citric acid cycle for further oxidation. (A–stands for acetylation)

Note: the transition from pyruvate to acetyl coenzyme A is not usually considered as a separate phase and is included with the first step of Krebs cycle.

THE ROLE OF CoA IN RESPIRATION

(1) Within the active centre of the enzyme **citrate synthetase,** CoA transfers the 2-carbon **acetyl group** to a 4-carbon molecule of **oxalocetate** to make a molecule of **citrate** which enters the Krebs cycle.

(2) It serves as a link between many different pathways of metabolism to provide a wide range of carbon compounds needed in the cell

(3) During energy deficiency, amino acids from proteins and fatty acids from lipids can be broken down to provide acetyl CoA for use in respiration.

Acetyl- Coenzyme A: *a central metabolic intermediate*

All proteins, lipids, and carbohydrates must be converted to **Acetyl- Coenzyme A** prior to participation in cellular respiration.

The fate of *acetyl-CoA* is dependent upon ATP needs. When ATP is prevalent, *acetyl-CoA* serves as the basis for fatty acid synthesis, which forms the basis of your body's long-term energy storage: triglycerides (i.e., fat). ***Acetyl-CoA* is the starting point for anabolic pathways that result in the synthesis of fatty acids.**

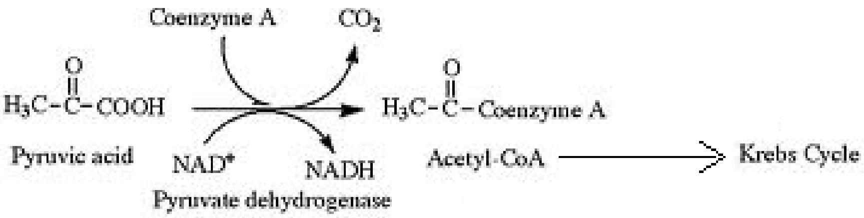
Alternatively, *acetyl-CoA* may enter the Kreb's citric acid cycle.

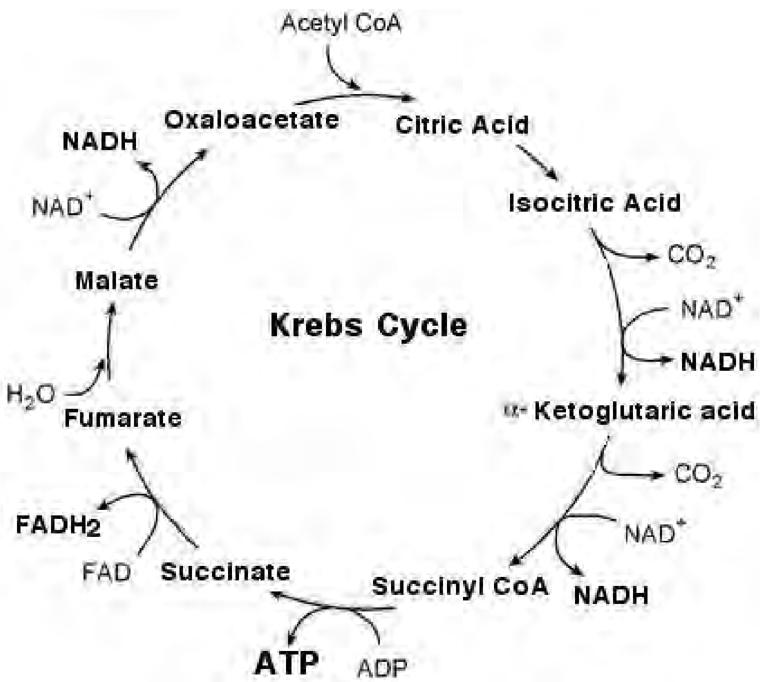
KREBS CYCLE/ TRICARBOXYLIC ACID CYCLE / CITRIC ACID CYCLE

It is a multi-step reaction in the mitochondrial matrix during which an acetyl group is completely oxidized to CO_2 with the generation of ATP and reducing hydrogens in the form of NADH and $FADH_2$.

It is named:

1. Krebs cycle after the formulator Hans Krebs
2. Citric acid because citric acid is the first compound formed.
3. Tricarboxylic acid because citric acid which is the first compound formed has 3 carboxyl (-COOH) groups





1st Reaction: Prior to entering the Krebs cycle, pyruvate must be converted into acetyl CoA. Acetyl CoA adds its 2-C acetyl group to a 4-C oxaloacetate to form a 6-C citrate molecule.

2nd reaction: citrate isomerizes to a more reactive isocitrate by both removal and addition of one water molecule.

3rd reaction: isocitrate is decarboxylated (loses a carbon dioxide) and then oxidized (loses hydrogen to NAD+ to form NADH) to form α-ketoglutarate.

4th reaction: α-ketoglutarate loses a carbon dioxide (is decarboxylated) and is oxidised (loses hydrogen to NAD+ to form NADH) and attached to coenzyme A to form succinyl-CoA.

5th step: succinyl-CoA causes phosphorylation of ADP to ATP and the formation of succinate.

6th reaction: a 4-C succinate loses two hydrogens to FAD (is dehydrogenated), forming $FADH_2$ and a 4-C fumarate.

7th reaction: fumarate is hydrated (a water molecule is added) and rearranged to form malate.

8th reaction: finally, malate loses hydrogen to NAD+ to form NADH (is oxidised) regenerating oxaloacetate.

NOTE:

(1) Carboxylic acids are represented in their ionized forms as $–COO^-$ because the ionized forms prevail at the PH within the mitochondrion. E.g. **citrate** is the ionized form of **citric acid**.

(2) The regeneration of oxalocetate makes the process a cycle

(3) For each acetyl group that enters the cycle, 3 NAD+ are reduced to NADH (reactions 3, 4, and 8)

(4) Most of the ATP output of respiration results from oxidative phosphorylation, when the NADH and FADH2 produced by the citric acid cycle relay the electrons extracted from food to the electron transport chain.

COMPARISON OF KREBS CYCLE AND GLYCOLYSIS

Similarities: In both:

(1) NADH forms

(2) ATP is generated

(3) There is a reduction in number of carbon atoms of organic compounds

(4) Pyruvate participates

(5) Both occur in living cells

***Differences*:**

Glycolysis	Krebs cycle
• The electron acceptor FAD is **not** involved	• The electron acceptor FAD is involved
• Carbon dioxide doesn't form	• Carbon dioxide is liberated
• Occurs in cell cytoplasm	• Occurs in mitochondrial matrix
• Doesn't necessarily depend on oxygen	• Depends on oxygen availability to occur

ELECTRON TRANSPORT SYSTEM, CHEMIOSMOSIS AND OXIDATIVE PHOSPHORYLATION

●Electron transport system:

A sequence of oxidation-reduction (redox) reactions whereby the transfer of electrons between protein complexes in inner mitochondrial membrane is coupled with the transport of protons into intermembrane space to create a proton gradient that drives synthesis of about 34 ATP molecules.

●Chemiosmosis:

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.

●Oxidative Phosphorylation:

Use of energy supplied by transmembrane proton gradients across the inner mitochondrial membrane during electron transport system to form ATP.

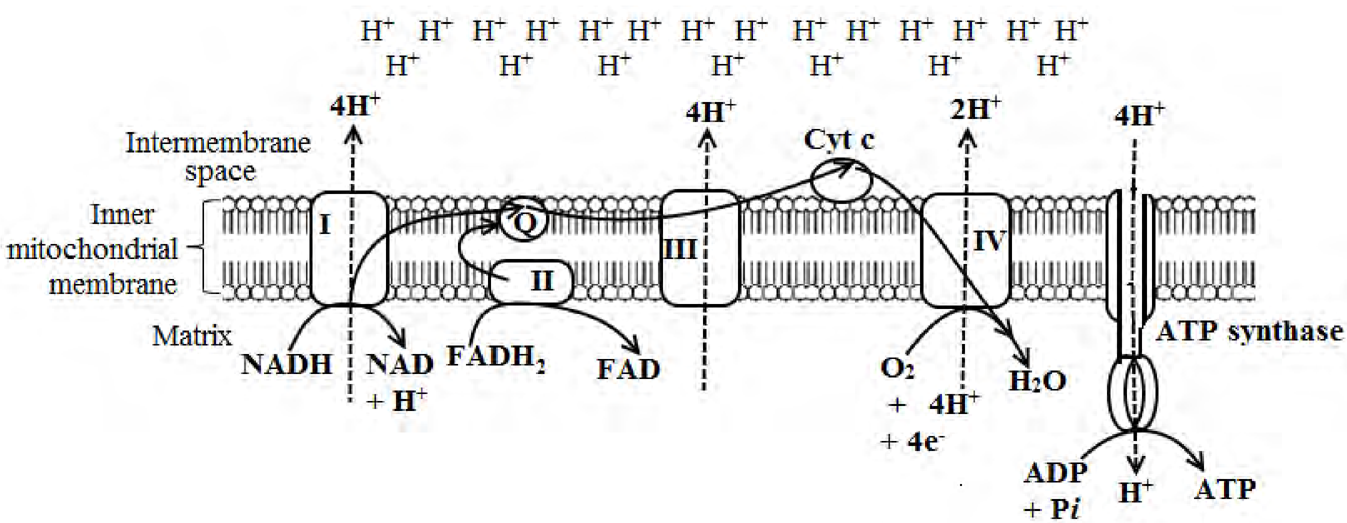
Components of electron transport chain

Complex	Name	Prosthetic Groups
Complex I	NADH Dehydrogenase	FMN, 9 Iron-Sulphur (Fe-S) centres
Complex II	Succinate-Coenzyme Q Reductase	FAD, cyt b_{560}, 3 Fe-S centers
	Coenzyme Q (CoQ) (also called ubiquinone)	cyt b_H, cyt b_L, cyt c_1, Fe-S
Complex III	Cytochrome bc1 complex	Cytochrome b_1 heme, b_2 heme
	Cytochrome c	cyt c
Complex IV	Cytochrome Oxidase	cyt a, cyt a_3, copper (Cu_A)and (Cu_B)

Cytochromes: are proteins with **haem** prosthetic groups. **Haem** contains an iron atom embedded in a porphyrin ring system. They absorb light at characteristic wavelengths.

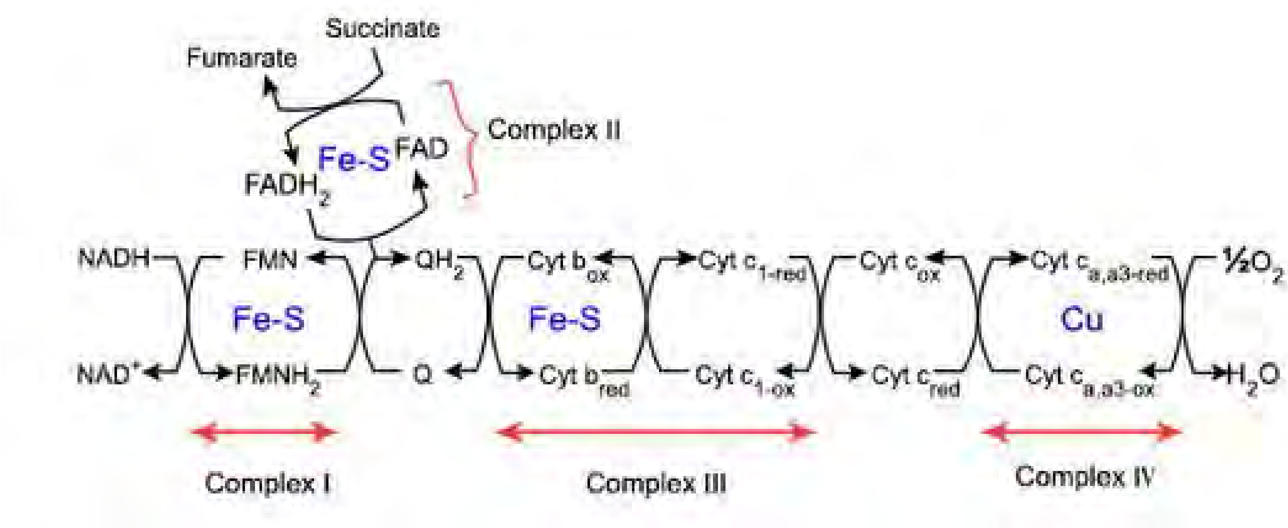
Iron-sulfur centers (Fe-S): are prosthetic groups containing **2, 3, 4, or 8 iron atoms**, complexed to a combination of elemental and cysteine **sulfur atoms**.

LOCATION OF CONSTITUENTS OF ELECTRON TRANSPORT CHAIN



The production of ATP during electron transport involves two separate but connected processes i.e. Chemiosmosis and oxidative phosphorylation

DESCRIPTION OF ELECTRON TRANSPORT SYSTEM



The electrons released during glycolysis and carried by NADH are converted to $FADH_2$ in order to shuttle them from the cytoplasm into the mitochondrial matrix.

In Complex I (also called **NADH reductase)**, reduced nicotinamide adenine dinucleotide **(**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 $FMNH_2$ 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.

In **complex II (succinate dehydrogenase),** electrons from $FADH_2$ are passed on to Fe-S proteins then to Coenzyme Q which transfers them to **complex III**. **$FADH_2$** becomes oxidised to **FAD+.** During this process, four protons (H^+) are translocated across the inner mitochondrial membrane, from the matrix to the intermembrane space. This creates a proton gradient that will be later used to generate ATP through oxidative phosphorylation. During oxidation of $FADH_2$ complex I is bypassed because complex II has only enough reducing potential to pass electrons to Coenzyme Q.

Reduced coenzyme Q ($CoQH_2$) transfers electrons to **Complex III** 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 **Complex IV (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, complex IV moves protons (H+) across the membrane into the intermembrane space, producing a proton gradient.

Energy lost by electrons in complex I, III and IV, is used to pump protons into the intermembrane space producing a proton gradient.
Complex II (succinate dehydrogenase) is not a proton pump. It only serves to funnel additional electrons into coenzyme Q. Electron transfers involving Coenzyme Q and Cytochrome c do not release enough free energy to pump any protons.
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.

Note: If the oxygen supply is cut off, the electrons and hydrogen protons cease to flow through the electron transport system. If this happens, the proton concentration gradient will not be sufficient to power the synthesis of ATP. This is why we, and other species, are not able to survive for long without oxygen!

IS THE E.T.S A SEQUENCE?
No! The complexes move in the fluid membrane independently of one another, and exchange electrons when they are in mutual proximity. Although textbooks show the ETS as a physical sequence, the complexes and carriers are not locked in place.

CHEMIOSMOTIC COUPLING HYPOTHESIS AND OXIDATIVE PHOSPHORYLATION

As proposed by Peter D. Mitchell, the chemiosmotic coupling hypothesis explains that the electron transport chain and oxidative phosphorylation are coupled by a proton gradient across the inner mitochondrial membrane.

The efflux of protons into the intermembrane space creates both a **pH gradient** and an **electrochemical gradient**. This proton gradient is used by the ATP synthase complex to make ATP via **oxidative phosphorylation**. The stalk component of ATP synthase complex works as an ion channel for return of protons back to mitochondrial matrix during which the free energy produced during the generation of the oxidized forms of the electron carriers (NAD^+) is released and used to drive ATP synthesis, catalyzed by the head component of the ATP synthase complex.

ACCOUNTING FOR ELECTRONS IN EUKARYOTIC ORGANISMS

Oxidation of NADH to NAD^+ pumps 3 protons from the mitochondrial matrix into the intermembrane space, which charges the electrochemical gradient with enough potential to generate 3 ATP. Oxidation of $FADH_2$ to FAD^+ pumps 2 protons into the intermembrane space, which charges the electrochemical gradient with enough potential to generate 2 ATP.

However, information from recent sources suggests that 1NADH generates 2.5 ATP and 1$FADH_2$ generates 1.5 ATP. The reason for this is that not all of the energy stored in the proton gradient is used to generate ATP. Some of the energy is used to power transport of ions in and out of the mitochondria.

A total of 12 pairs of electrons and hydrogens are transported to the electron transport system from glycolysis and Krebs cycle for each glucose molecule that enters the process:

- 4 pairs are carried by NADH and were generated during glycolysis in the cytoplasm, 8 pairs are carried as NADH and were generated within the mitochondrial matrix and 2 pairs are carried by $FADH_2$ and were generated within the mitochondrial matrix.
- For each of the 8 NADHs generated within the mitochondrial matrix, enough energy is released to produce 3 ATP molecules; therefore, 24 ATP molecules are released from these electrons carried by NADH.
- The electrons carried by FADH2 are lower in energy, so during the oxidation-reduction reactions, they release energy to produce only 8 ATP molecules.
- Therefore, a grand total of 32 ATP molecules are produced from hydrogen electrons that enter the electron transport system.

WHAT QUANTITY OF ATP IS GENERATED BY CHEMIOSMOSIS FROM ONE MOLECULE OF GLUCOSE DURING THE ELECTRON TRANSPORT CHAIN?

The chemiosmotic model suggests that one ATP molecule is generated for each H^+ pump activated by the electron transport chain. Since the electrons from NADH activate **three pumps** and those from $FADH_2$ activate **two**, it would be expected that the numbers of ATP molecules generated by each molecule of NADH and $FADH_2$ are t**hree** and **two** respectively.

However, since the transportation of the **two** molecules of NADH produced during Glycolysis into the mitochondrion requires **two ATPs**, the theoretical yield from aerobic respiration = 36 molecules of ATP i.e. 4 (from substrate-level Phosphorylation) + 30 (3 from each of 10 molecules of NADH) + 4 (2 from each of 2 molecules of $FADH_2$) – 2 (for transport of glycolytic NADH).

The actual yield is less than 36 because:

(1) The inner mitochondrial membrane allows some H^+ to re-enter the matrix without passing though ATP-generating channels

(2) Mitochondria often use the proton gradient generated by chemiosmosis for purposes other than ATP synthesis e.g. transporting Pyruvate into the matrix. As a result, the measured values of ATP generated are closer to 2.5 for each NADH and 1.5 for each $FADH_2$.

The molecules of ATPs formed from one molecule of glucose = 30 i.e. 4 (from substrate-level Phosphorylation) + 25 (2.5 from each of 10 molecules of NADH) + 3 (2 from each of 2 molecules of $FADH_2$) – 2 (for transport of glycolytic NADH)

SUMMARY OF ENERGY YIELD DURING AEROBIC RESPIRATION OF ONE GLUCOSE MOLECULE

Pyruvate $\longrightarrow$ **Acetyl CoA** = 6 ATP (2 Molecules of reduced NAD each yielding 3 ATP)

Krebs cycle = 24 ATP (6 Molecules of reduced NAD each yielding:

3 ATP + 2 Molecules of reduced FAD yielding

2 ATP + 2 Molecules of ATP formed directly)

Total ATP yield = 38 Molecules of ATP

INHIBITORS OF ELECTRON TRANSPORT

• **Inhibitors**	• **Action**
• Cyanide and Carbon monoxide	• Block cytochrome oxidase enzyme in complex IV
• Rotenone	• Blocks complex I. It's a common rat poison
• Antimycin	• Blocks electron transfer in complex III
• Oligomycin	• Blocks the proton channel in ATP synthase

Inhibitors bind to the components of the electron transport chain and block electron transfer. All components before the block are stuck in a reduced state and all components after in an oxidised state. No electron transfer is possible and proton pumping stops. The proton gradient is quickly run down and ATP synthesis stops. Inhibitors may also block the proton channel of ATP synthase.

EFFICIENCY OF RESPIRATION

Not all the energy present in the high-energy hydrogen atoms is conserved as ATP. Part of the energy is released as heat used for the maintenance of body temperature, but if it is in excess then it can be dissipated to the external environment. The efficiency of energy conserved in aerobic respiration, alcoholic fermentation and lactic acid fermentation are thus as follows:

Aerobic respiration	Alcoholic fermentation	Lactic acid fermentation
A total of 38 molecules of ATP are formed while the amount of energy released is 2880KJ. To form 1 molecule of ATP requires 30.6kj. Thus the amount of energy used to form 38 molecules of ATP is equal to 38 x 30.6 = 1162.8KJ.	Alcohol fermentation releases 210KJ with the formation of 2ATP. To form 1 molecule of ATP requires 30.6kj. Thus the amount of energy used to form 2 molecules of ATP is equal to 2 x 30.6 = 61.2KJ.	Lactic acid fermentation releases 150KJ with the formation of 2ATP. To form 1 molecule of ATP requires 30.6kj. Thus the amount of energy used to form 2 molecules of ATP is equal to 2 x 30.6 = 61.2KJ.
Efficiency of energy conserved= $\frac{38ATP \times 30.6KJ}{2880} \times 100$ = 40.375 ≈ 40.4%	*Efficiency of energy conserved* = $\frac{2ATP \times 30.6KJ}{210} \times 100$ = 29.1%	*Efficiency of energy conserved* = $\frac{2ATP \times 30.6KJ}{150} \times 100$ = 40.8%
The remaining 1717.2KJ (59.6%) is released as heat	The remaining 148.8KJ (70.9%) is released as heat	The remaining 88.8KJ (59.2%) is released as heat
However, considering that glucose on complete oxidation releases 2880KJ of energy, the yield from anaerobic respiration is given by: $\frac{2ATP \times 30.6KJ}{2880} \times 100 = 2.1\%$ Therefore, on a whole anaerobic respiration is 2% efficient.		

ENERGY FROM NON-GLUCOSE SUBSTRATES

1. ENERGY FROM LIPIDS (FAT AND OIL)

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.

Carbohydrates versus Fats in energy release

Aspect	Explanation
Amount of energy released	Gram for gram, fats provide more energy than carbohydrates. The reason for this is the amount of oxidation that takes place as these compounds are converted to carbon dioxide and water. Carbon for carbon, fats require more oxidation to become CO2 and H2O than do carbohydrates. Roughly, carbohydrates already have one oxygen for every carbon atom, thus each carbon atom needs only one more oxygen and each pair of hydrogen atoms needs one more oxygen. However, almost every carbon atom in a fat molecule needs two oxygens instead of just one additional one, and each pair of hydrogen atoms still needs one more oxygen. So, just from counting the number of oxygens needed to be added, fats require about half again as much oxygen for the same number of carbon atoms. Because of this, the oxidation of fats takes longer, but it also gives off more energy. When comparing gram to gram, instead of carbon to carbon, the effect is exaggerated. When you weigh a carbohydrate, more oxygen is included in that weight. When you weigh a fat, you get more carbon atoms per gram and therefore, gram for gram, the fats will give even more energy (over twice as much) than will the carbohydrates.
Time spent	**Carbohydrates** enter into the oxidation process much more quickly and **provide energy more rapidly than fats.** This is because **fats** go through several more steps than do carbohydrates to become acetyl CoA and enter the citric acid cycle.

ENERGY FROM OTHER HEXOSES

In most organisms, hexoses other than glucose can undergo glycolysis after conversion to a phosphorylated derivative.

1. 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.

2. GALACTOSE: is a product of hydrolysis of the disaccharide lactose (milk sugar). Galactose is first phosphorylated by ATP to galactose-1-phosphate and then converted to glucose-1-phosphate through a series of reactions.
Galactosemia is a human genetic disease that results from disordered galactose metabolism in which the overall conversion of galactose to glucose prevented.

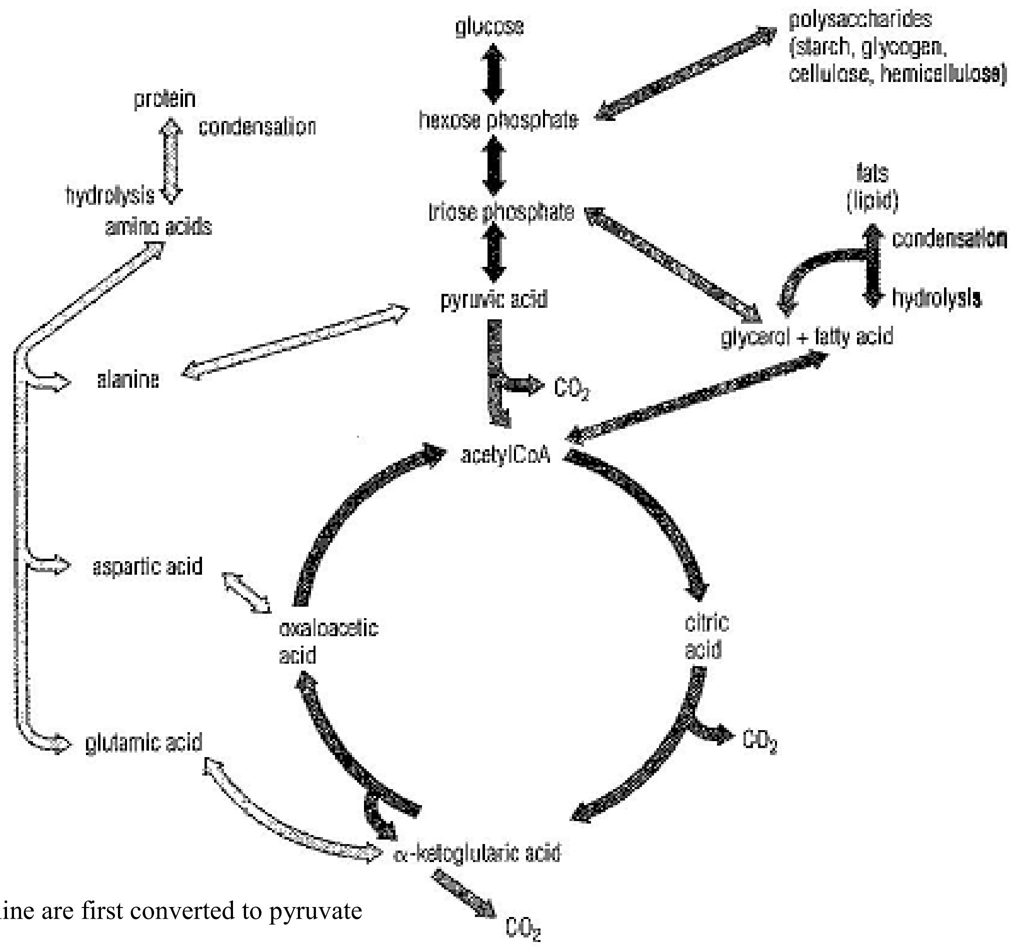
3. MANNOSE, which is released in the digestion of various polysaccharides and glycoproteins of foods, can be phosphorylated at C-6 by hexokinase:
Mannose + ATP → mannose 6-phosphate + ADP
Mannose 6-phosphate then isomerizes to fructose 6-phosphate, an intermediate of glycolysis.

Tissue respiration and its connections with the rest of metabolism

ENERGY FROM PROTEIN

- 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 (-NH2) are removed and converted to ammonia, urea or uric acid for excretion. The residual carbon compound (a keto acid) then enters the respiratory pathway at a number of points depending on their number of carbon atoms:

(i) 5-C amino acids like glutamate are converted to α-ketoglutarate,
(ii) 4-C amino acid like aspartate are converted to oxaloacetate. α-ketoglutarate and oxaloacetate enter Krebs cycle.



(iii) 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.

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:

1. At cellular level, the rate at which respiration occurs is regulated mainly by the energy state of the cell (i.e. 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. Highly active cells utilize ATP very fast breaking it to ADP. This has the effect of enhancing the rate of respiration. Such cells include **liver cells, striated muscle cells, spermatozoa** and **nerve cells**. They are characterized by presence of numerous mitochondria. Less active cells utilize ATP slowly and hence respiration in them is slow e.g. **fat cells**.

2. At the level of the whole organism, the respiratory rate is influenced by **environmental factors** e.g. temperature, **structural factors** e.g. body size and **physiological factors** such as level of activity, growth and dormancy.

***(a) Temperature*:**

Generally, 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. *This partly explains why mosquitoes and tsetse flies are only found in the tropics where environmental temperature is close to their optimal temperature.* High temperature slows down the respiration rate in homoiotherms. This explains why such animals tend to be sluggish during hot weather. However, excessively high temperatures trigger increased respiration rate and finally stop as a response by enzymes to temperature.

(b) Body size:
Small organisms with a large surface area to volume ratio lose heat faster and therefore respire faster than large organisms.
(c) Level of activity:
Animals engaging in vigorous physical exercise require much energy and so experience faster respiration rate e.g. sprinting, flying, etc
(d) Growth:
Actively growing organisms e.g. young animals and germinating seeds respire faster to generate much energy required to drive metabolic processes involved in cell division.
(e) Dormancy during extreme cold and hot seasons:
Respiration rate is always slow to avoid depleting food reserves before the unfavourable season ends.

RESPIRATORY QUOTIENT (RQ)
RQ is the ratio of the volume of Carbon dioxide produced to the volume of oxygen used in respiration during the same period of time

$$RQ = \frac{\text{Volume of Carbon dioxide given out}}{\text{Volume of oxygen taken in}}$$

Importance of RQ values
(1) Can indicate the kind of substrate being respired by the cell or organism
(2) Can indicate whether the respiration is aerobic or anaerobic.

RQ can be measured using a **spirometer** or **respirometer.**

RQ FOR HEXOSE SUGAR
Like glucose, the equation for its complete oxidation is:

$$C_6H12O_6 + 6O2 \longrightarrow 6CO_2 + 6H_2O$$

Hence RQ is: $\frac{6CO_2}{6O_2}$ = 1.0 (one)

R.Q FOR FATS
For lipids like tripalmitin and tristearin, the equation for its complete oxidation is:

$$\underset{\text{Tripalmitin}}{2\,(C_{51}H_{98}O_6)} + 145\,O_2 \longrightarrow 102\,CO_2 + 98H_2O + \text{energy}$$

RQ is: $\frac{102CO_2}{145O_2}$ = 0.7 (less than one)

$2\ C_{57}H_{110}O_6 + 163\ O_2 \rightarrow 110\ H_2O + 114\ CO_2$
RQ is: $\frac{114CO_2}{145O_2}$ = 0.69 (less than one)

NB: The R.Qs for different fats show slight variations because of differences in molecular composition.

R.Q FOR PROTEINS
No concrete value can be calculated since:
(i) Proteins vary so much in composition
(ii) Proteins are difficult to separate in the pure state.
RQ estimates for protein vary between 0.5 and 0.8 on complete oxidation.

SUMMARY OF THE POSSIBLE INTERPRETATIONS OF R.Q VALUES:

Subject	R.Q.	Possible interpretations
Germinating starchy seeds Leaves rich in carbohydrate	1.0 1.0	Complete oxidation of a carbohydrate substrate
Wheat seedlings in nitrogen	∞	Anaerobic respiration
Germinating seeds	0.64	Oxidation of a fatty substance
Germinating peas (testa intact)	3.0 to 4.0	Slow entry oxygen causing some anaerobic respiration
Germinating peas (testa removed)	1.5 to 2.5	More rapid entry of oxygen, but some anaerobic respiration
Man (average)	0.8 to 0.85	Mixed fat and carbohydrates substrate
Lumbricus terrestris	0.75	Mainly fat substrate
Drosophila (at rest)	1.23	Conversion of carbohydrate to fat / organic acids : excess CO_2 produced by decarboxylation
Drosophila (flying)	1.0	Complete oxidation carbohydrate
Nerve tissue (resting)	0.77	Possibly mainly fat substrate
Nerve tissue (active)	0.97	Almost entirely carbohydrate substrate

COMPARISON OF RESPIRATION WITH PHOTOSYNTHESIS

Similarities Both:

(i) Involve converting energy from one form to another
(ii) Occur in living cells
(iii) Form adenosine triphosphate (ATP)
(iv) Require energy to occur
(v) Involve a series of multi-enzyme catalysed reactions
(vi) Involve flow of electrons along electron carriers.

Differences

Photosynthesis	Respiration
Occurs in cells with chlorophyll	Occurs in all cells
Occurs in the presence of light	Occurs all the time
Raw materials are Carbon dioxide and water	Raw materials are reduced carbon compounds and oxygen
Forms Reduced carbon compounds, oxygen, and water	Forms Carbon dioxide and water
Light is a source of energy	Chemical bonds are the source of
Energy stored	Energy released
Reactions involve reduction of carbon compounds	Reactions involve oxidation of carbon compounds
Energy carrier is NADP	Energy carriers are NAD and FAD

ECONOMIC / COMMERCIAL IMPORTANCE OF ANAEROBIC RESPIRATION

(i) In breweries, fermentation of sugars forms alcoholic drinks like wine, beer and spirits.
(ii) In bakeries, fermentation of starch by yeast is used in leavening of bread i.e. production of raised bread
(iii) Applied in the manufacture of milk products like sour milk, yoghurt and cheese
(iv) Applied in food industries for the manufacture of organic acids e.g. citric acid, oxalic acid and butyric acid.

CIRCUMSTANCES THAT MAY LEAD TO ANAEROBIC RESPIRATION

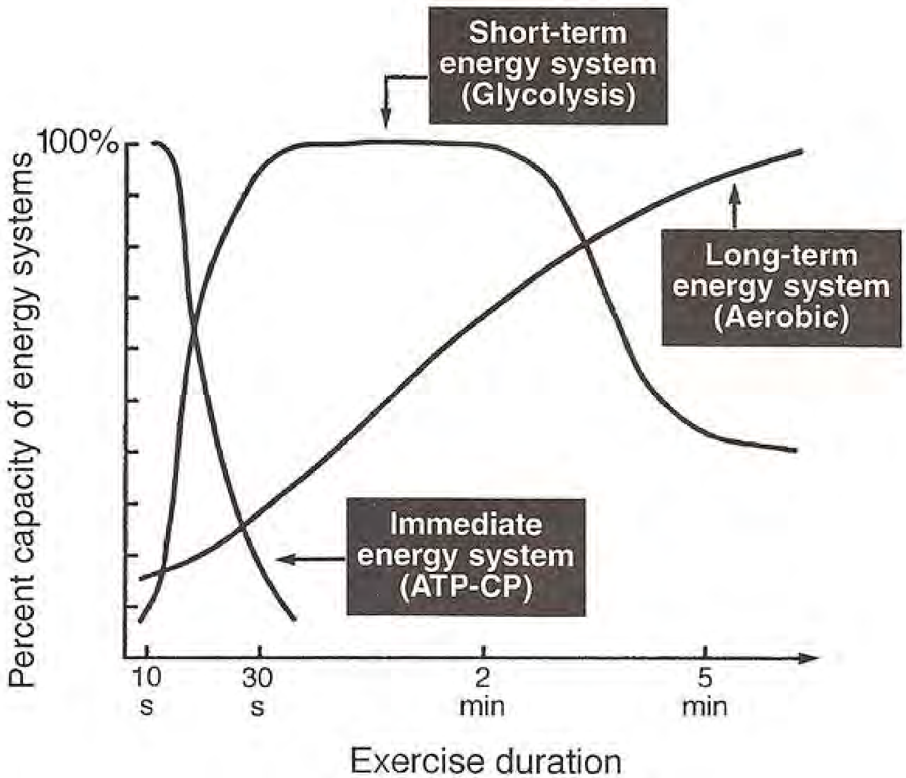
In Yeast	In flowering plant	In a mammal
● Stagnant solutions ● Centre of decomposing fruits and other organic matter	● Young seeds ● Seeds at centre of fruits and other organic matter ● In roots growing in water logged soils ● In aquatic plants growing in stagnant ponds	● Inefficiency of lungs e.g. emphysema ● Decrease in blood pressure e.g. haemorrhage, pressure on artery ● Low oxygen carrying capacity of blood e.g. anaemia, bone marrow disease. ● Low cardiac output e.g. slow heart rate, coronary thrombosis. ● Capillary network inadequate e.g. angina. ● High oxygen demands e.g. strenuous exercise, pregnancy. ● **Others:** Hibernation, Sperm in oviduct, High altitude

ATP PRODUCTION DURING EXERCISE

- On average, a muscle contains only enough ATP to sustain about 15 seconds of intense exercise. For muscle contractions to continue, massive amounts of ATP are required.
- Depending on intensity and duration of activity, exercising muscles may produce the ATP aerobically or anaerobically.
- Sustained periods of sub-maximal activity like jogging are powered by aerobic respiration, but in contrast short periods of intense activity like sprinting are powered by a combination of aerobic and anaerobic respiration.

"Anaerobic" here means a combination of glycolysis and stored ATP/Phosphocreatine release.

The graph below shows the three systems of energy transfer and their percentage contribution to total energy output during all-out exercise of different durations.



Observations / Description:

(1) From 10 seconds to about 35 seconds, % capacity of energy from **ATP / Phosphocreatine** decreases rapidly and stops.

(2) From 10 seconds to about 15 seconds, % capacity of energy from **Glycolysis** increases gradually, then increases rapidly to the maximum at 32 seconds, then remains constant from about 32 seconds to about 2 minutes, then decreases rapidly to about 3 minutes and finally decreases gradually.

(3) From 10 seconds to about 30 seconds, % capacity of energy from **Aerobic respiration** increases gradually, then increases rapidly thereafter.

Explanation:

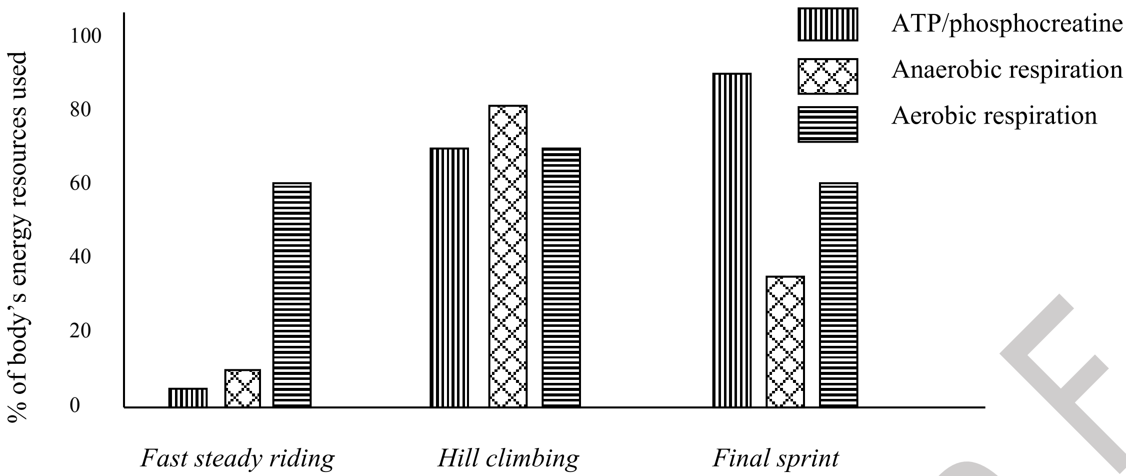
During the first 30 seconds, the small amounts of ATP and phosphocreatine stored in cells provide instant energy for muscle contraction and get depleted.
During the first 15 seconds, glycolysis provides a proportionally smaller contribution, and a smaller contribution yet comes from aerobic respiration.
From about 15 seconds to about 2 minutes, muscles largely rely on glycolysis to generate ATP for contraction.
From about 30 seconds to 2 minutes, aerobic respiration supplements glycolysis in providing ATP, but after 2 minutes, muscle contraction mainly relies on aerobic respiration for ATP.

NOTE:

- Phosphocreatine (also called creatine phosphate), **stores ~P bonds in** nerve and muscle cells.
- Creatine Kinase catalyzes: **phosphocreatine + ADP $\Leftrightarrow$ ATP + creatine**
- This is a reversible reaction, though the equilibrium constant slightly favors phosphocreatine formation.

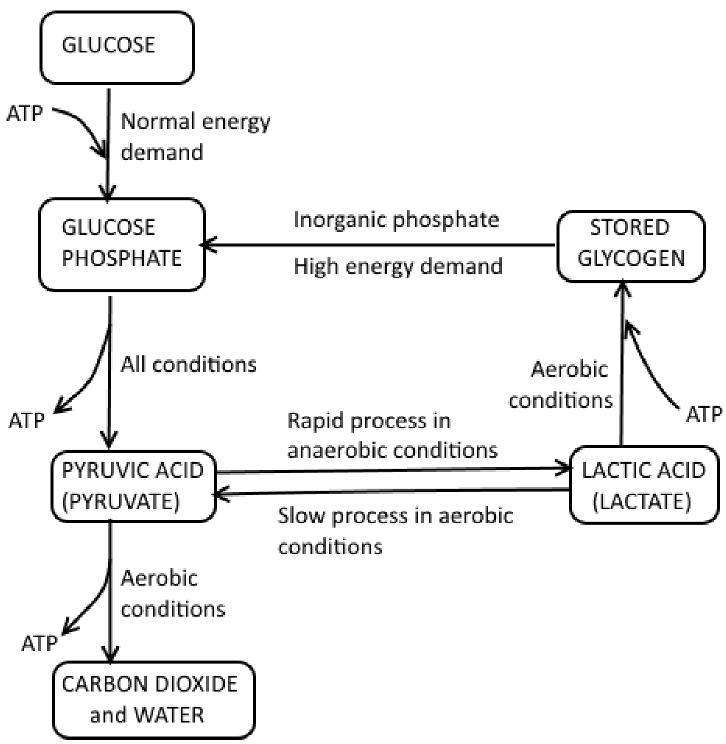
Phosphocreatine is produced when ATP levels are high. When ATP is depleted during exercise in muscle, phosphate is transferred from phosphocreatine to ADP, to replenish ATP.

The figure below shows how the different energy sources are used at different stages in a bicycle race.



Observations:
(1) During the fast steady riding, there is an overriding contribution of aerobic respiration, but very little from ATP/phosphocreatine and anaerobic respiration.
(2) In the stretches of hill climbing, glycolysis predominates over ATP/phosphocreatine and aerobic respiration in providing energy. The latter two make equal contribution, which follows closely.
(3) In the final sprint, ATP/phosphocreatine takes the leading role in providing energy, followed by aerobic respiration and leastly by anaerobic respiration. This is because during the steady riding, ATP/phosphocreatine reservoirs replenished and therefore provides energy fast to the cells.

TYPICAL EXAMINATION QUESTION
The figure below summarises the metabolic processes involved in the release of energy in the muscles during and after running in a 200-metre sprint. During the race, the rate of oxygen consumption rose above the resting level while after the race, oxygen consumption did not drop to the resting level for some time. Blood sample tests after the race revealed a significant increase in lactic acid (lactate).



(a) (i) Explain why, although oxygen consumption rises during the race, more lactic acid (lactate) is present in the blood at the end of the race.
(ii) Why is the athlete's oxygen consumption still higher than normal sometime after the race.
(iii) After the race ATP is used to convert most lactic acid (lactate) to glycogen. With the help of information in the diagram, explain why this is efficient use of lactic acid.
(iv) For every molecule of glucose, 38 molecules of ATP are produced during aerobic respiration but only 2 molecules of ATP are produced during anaerobic respiration. Explain how this difference occurs.
(v) From the information in the figure above, explain why it is advantageous to respire glycogen rather than glucose during strenuous exercise.
(b) Suggest three ways in which exercise may improve an athlete's subsequent performance.

SUGGESTED ANSWERS

(i) During the race, oxygen supplied by ventilation and gaseous exchange is not sufficient to meet the ATP demands of the body, causing muscles to resort to anaerobic for ATP generation, with formation of lactic acid.

(ii) All the lactic acid formed during the race is transported to the liver for degradation, which requires oxygen uptake shortly after the race. This is what is called paying the **"Oxygen debt".**

(iii) Immediately after the race, skeletal muscles have low ATP requirements. Since lactic acid can later be converted to pyruvate, conversion of lactic acid to glycogen therefore stores energy for later use rather than oxidise all the lactic acid to form ATP which has no immediate use.

(iv) In the absence of oxygen, Krebs cycle and electron transport system are inhibited, so glucose is only partially broken down by glycolysis to yield a net of 2 ATP molecules. Under aerobic conditions, Glycolysis, Krebs cycle and electron transport system all occur to yield about 38 ATP molecules.

(v) Conversion of glucose to glucose phosphate requires ATP, which reduces the total ATP produced. Conversion of glycogen to glucose phosphate does not require ATP, therefore more ATP is available to the organism to power muscle contraction during exercise.

(b)

- Build up and improved functioning of the muscles.
- Improvements in blood circulation, efficient cardiac output (more blood pumped per unit time)
- Improved oxygen carrying capacity of the body e.g. through a greater concentration of red blood cells with more haemoglobin in each one.
- Greater lung capacity permitting more air and therefore oxygen to be inspired per unit time.

CO-ORDINATION

All organisms have the ability to detect and respond to changes in the external and internal environment. Plants and animals have developed control systems that receive stimuli, process them and initiate appropriate responses.

CONCEPT OF RESPONSE AND RECEPTION IN PLANTS

Coordination and control in plants is carried out by hormones. Plants lack the nervous system and information is carried by hormones especially ***auxins.***

Plants do not move from one place to another. Their response involves growth movements of part of the plant and turgor changes within cells. Parts of the plant move towards or away from a stimulus due to changes in auxins concentration in the parts concerned.

PLANT RESPONSES

1. Tactic responses (taxes)

A taxis is the movement of a freely motile organism, or a freely motile part of an organism, in response to a directional stimulus. The direction of the response is related to that of the stimulus. Taxes occur in both plants and animals. In plants, it is common in lower plants such as green algae, antherozooids (sperm) of mosses, liverworts and ferns are attracted to chemicals produced by the archegonium.

Examples of taxis

- Unicellular organisms e.g. Euglena swim towards light hence positively tactic (phototactic)
- Earth worms, wood lice and cockroaches move away from light hence negative phototactic.
- Sperms swim towards the chemical produced by the ovum hence positively chemotactic.
- White blood cell moves towards harmful bacteria in the body hence positively chemotactic.

2. Nastic response

This is the movement of part of the plant in response to a non-directional stimulus. Nastic responses involve changes in turgidity and growth to some extent. This can be observed in the folding of the leaves of the sensitive plant (*Mimosa pudica)* when touched (thigmonasty). The touching of the plant causes water to be quickly withdrawn from the leaf cells into the pulvinus cells which have large air spaces, therefore causing the leaf or petiole to collapse due to change in turgidity.

Nastic response are named depending on the type of stimulus i.e. Photonastic if the stimulus is light, hydronasty if the stimulus is water and thigmonastic if the stimulus is touch.

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.

Examples of nastic responses

- Opening and closing of flowers in response to light e.g. morning glory.
- Sudden folding of the sensitive plant's (*Mimosa pudica*) leaves in response to touch.
- Closure of leaves of insectivorous plants e.g. butter walt and pitcher plant when the insect lands on the leaf. Such plants are found in nitrogen deficient soils.

3. Tropic response (tropism)

Tropism is a growth movement of part of the plant organ in response to an external unidirectional stimulus. Growth movement towards a stimulus is referred to as ***positive tropism*** while growth movement away from a stimulus is referred to as ***negative tropism***.

Characteristics of a tropic response

- 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.

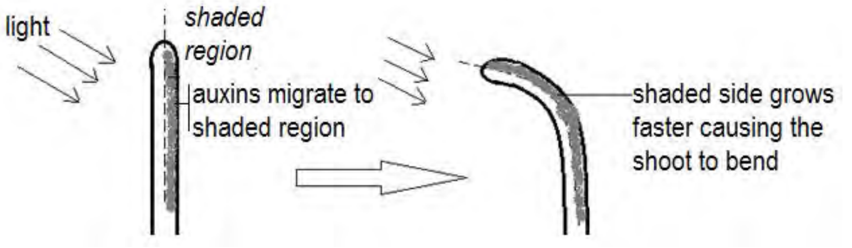
Examples of tropisms

Example of tropism (response)	Stimulus
1. Hydrotropism	Water
2. Thigmotropism / haptotropism	Touch
3. Chemotropism	Chemicals
4. Geotropism	Gravity
5. Phototropism	Light

Phototropism:

This is the growth movement of part of the plant in response to unidirectional light. Plant shoots are positively phototropic that is, they grow towards the direction of light while the roots are negatively phototropic (they grow away from the direction of light).

The shoot apex detects a light stimulus. When a shoot apex is exposed to a unilateral source of light causes ***auxins***, which are plant growth hormones produced at the shoot apex to migrate to the shaded side. The higher concentration of auxins on the shaded side causes faster growth than on the illuminated side, hence the shoot curves towards the source of light.



Importance of phototropism

- The shoot grows towards light hence the leaves are able to absorb light to carry out photosynthesis.
- Roots grow away from light into the ground from which water and mineral salts are absorbed and also provide support.

Assignment:

1. *Compare tropisms and nastic responses.*
2. *Explain what you understand by the terms irritability, stimulus and response.*
3. *a) Distinguish between a tactic and a tropic response.*
   b) Explain the survival values of tactic and tropic responses.
   c) What type of response would you expect in roots of a plant that are subjected to dry conditions on one side of the soil while the other side is moist?
4. *a) Name three plant hormones.*
   b) In which parts of a seedling are hormones produced?

Photoperiodism

The relative length of day and night varies with the time of the year and is called the photoperiod. The response of a plant to changes in day length or night length is called Photoperiodism. One of the most studied examples is flowering.

Photoperiodic control of flowering

Plants whose flowering is triggered by the photoperiod are often placed into three basic categories:

1) **Long day plants (LDP):** These only flower when the period of daylight exceeds a critical minimum length. Examples of LDP include clover, barley, lettuce and wheat.
2) **Short day plants (SDP):** These only flower when the period of day light is shorter than a critical maximum length. Examples include tobacco and straw berries.
3) **Day neutral plants:** These plants flower regardless of the length of day light. Examples include cucumber, carrot, tomato and garden peas.

Characteristics of long day plants

- They require long days and short nights to flower.
- They flower only when the light period exceeds the critical length of the day (12 hours).
- Short nights are more essential than the length of the day. Thus they are commonly known as short night plants.
- They flower even when the short night is interrupted by flashes of light and do not need an interrupted short night. They also show flowering even when the long day is interrupted by short dark periods.
- They flower during summer when the days are longer than the night, like wheat.

Characteristics of short day plants

- They require short days and long nights for them to flower.
- They flower only when day length become shorter than the critical day length.
- They need an uninterrupted period of darkness.
- They do not flower if given short days and long nights interrupted by flashes of light. On the contrary, if the short days are interrupted by intervals of darkness but left with an interrupted long night they flower.
- Such plants flower during autumn and winter.

Characteristics of day neutral plants

- They are independent of day length.
- They flower after a period of vegetative growth regardless of the photoperiod.

Phytochrome and the detection of night length

Photoperiodism requires a mechanism for detecting the length of darkness. One of the important ways in which light exerts its influence on living organisms is through variations in day length (photoperiod).

The pigment that is responsible for this is ***Phytochrome.*** Phytochrome exists in two inter-convertible forms:

i) Phytochrome 660 (P_R) which absorbs red light.
ii) Phytochrome 730 (P_{FR}) which absorbs light in the far-red region of the spectrum.

Phytochrome is synthesized in its P_R (P_{660}) form. Absorption or exposure to the appropriate light wavelength causes the conversion of one form into the other form within a second.

P_R is converted into P_{FR} when exposed to red light, and that P_{FR} is converted back into P_R when exposed to far-red light or when in darkness.

$$P_{660} \underset{\text{far-red light}}{\overset{\text{red light}}{\rightleftharpoons}} P_{730}$$

During day, there is more P_{FR} than P_R bacause sunlight has a higher proportion of red light than far-red light. P_{FR} form is the physiologically active form, but converts slowly to the more stable, but inactive, P_R form during the darkness of night.

$$P_{660} \underset{\text{darkness (slow conversion)}}{\overset{\text{day light}}{\rightleftharpoons}} P_{730}$$

Therefore the relative amounts of the two forms of phytochrome controls flowering in short-day and long-day plants. ***Accumulation of Pfr stimulate flowering in long-day plants, whereas in short-day plants, Pfr inhibits flowering***. (Note that P_R does not have any effect on flowering). Phytochrome is distributed throughout the plant in minute quantities, being most concentrated in growing tips.

The physiological processes affected by light through the phytochromic effects include;

- Germination of small seeds
- Elongation of internodes
- Chlorophyll development
- Leaf expansion
- Control of flowering in long day and short day plants.
- Leaf fall.

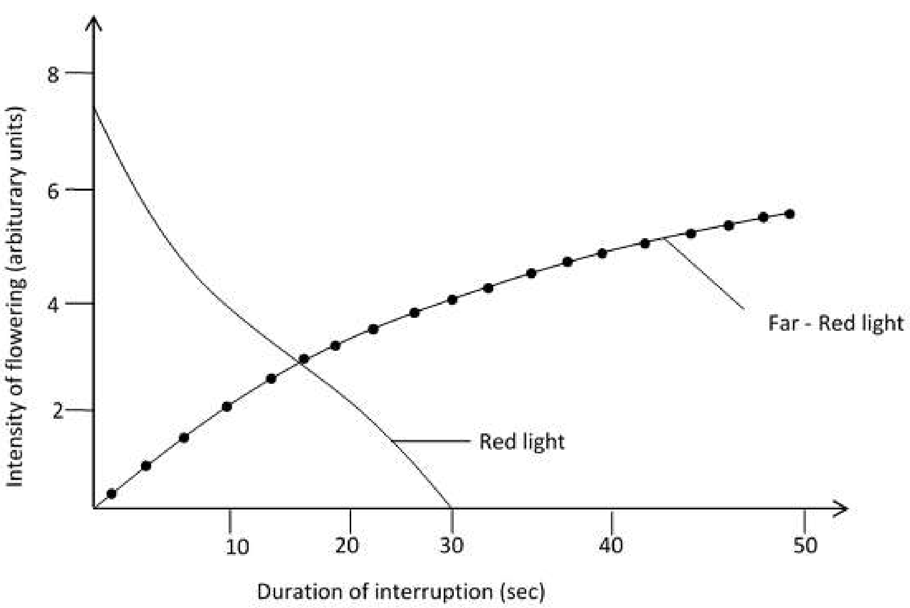
Role of florigen hormones in flowering

These are hormones that control flowering in long day plants. The light stimulus is detected by the leaves. In some cases even a single leaf needs to be subjected to the appropriate stimulus to induce flowering. A high concentration of Phytochrome far red is required for inducing the leaves to produce florigen hormone that travels through the phloem to the buds to cause flowering.

Note: Vernalisation is the exposure of seeds/plant to low temperature requirements for the initiation of germination/flowering.

Typical examination question:

1. **The figure below shows the effect of red light and far red light interruption of the night period on flowering of a plant.**



a) What is the effect of interruption of light 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 treatment as shown in figure above.

c) How can the knowledge of the effect of red light and far red light and far red light on flowering be utilized in the commercial growing of flowers?

Note:

If the whole plant is covered with light proof material except the leaves, flowering occurs proving that the point of perception is in the leaves. Flowering has been induced to occur in short day plants kept in long days by keeping one of the leaves in short days i.e. covering it with light proof material for a period longer than critical point of light.

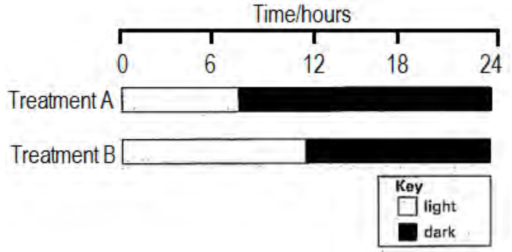
Possible solution:

a) *i) The interruption by red light lowers the intensity of flowering. The longer the duration of interruption, the lower the intensity of flowering up to duration of 30s when no flowering occurs. This is because it leads to accumulation of P_{FR}, which inhibits flowering.*
ii) The interruption by far-red light increases the intensity of flowering. The longer the duration of interruption, the higher the intensity of flowering up to a maximum of 50s when no further increase in the intensity of flowering is achieved. This is because of conversion of P_{FR} to P_R, thus stimulating flowering.

b) *Short day plant.*

c) *Plants can be induced to flower at the required time by interruption of dark period by far red light or red light at the right time and duration.*

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 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***

PLANT HORMONES

1. Indole Ascetic Acid (IAA)

Auxins are a group of plant growth hormones responsible for processes like growth, root formation and apical dominance. Auxins produced in plants include the ***Indoleacetic acid (IAA).***

Auxins are produced in small amounts in seeds, germinating embryos, buds, leaves and apices of roots, shoots and buds.

Effects of auxins on plant growth

- Promote elongation of young leaves.
- High auxin concentration stimulates the growth of the shoot but inhibits the growth of the root.
- They cause tropisms.
- They promote formation and growth of adventitious roots.
- They retard lateral buds in shoots.
- They promote apical dominance.

Commercial applications and uses of synthetic auxins

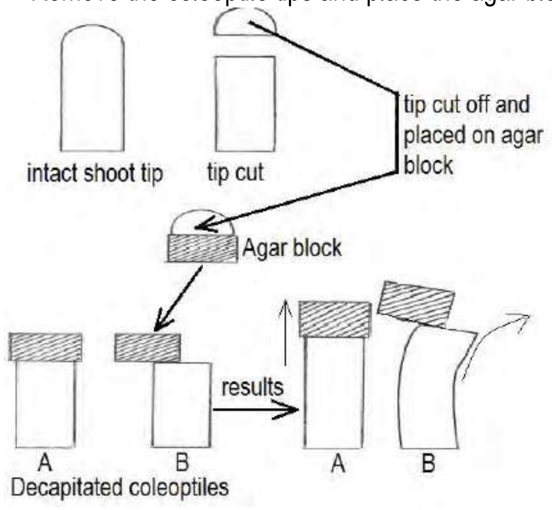
- Auxins are used to initiate rooting in stem cuttings.
- They are used to inhibit leaf fall when the leaf matures.
- They inhibit fruit fall, leaf fall and flower fall (abscission) by maintaining the structure of cell walls.
- They inhibit the development of lateral buds hence reducing branching in plants. Removal of the apical buds therefore leads to branching.
- Synthetic auxins kill broad leaf plants by disrupting their growth hence used as selective weed-killers.
- Synthetic auxins stimulate fruit growth and parthenocarpic fruit development. Parthenocarpy is fruit development without fertilization.

Experiment to show the effect of unequal distribution of auxins and to show that auxins are diffusible

Apparatus/Material: Maize seedlings with coleoptiles, agar block (gelatinous substance through which auxins diffuse) and razor blade.

Procedure:

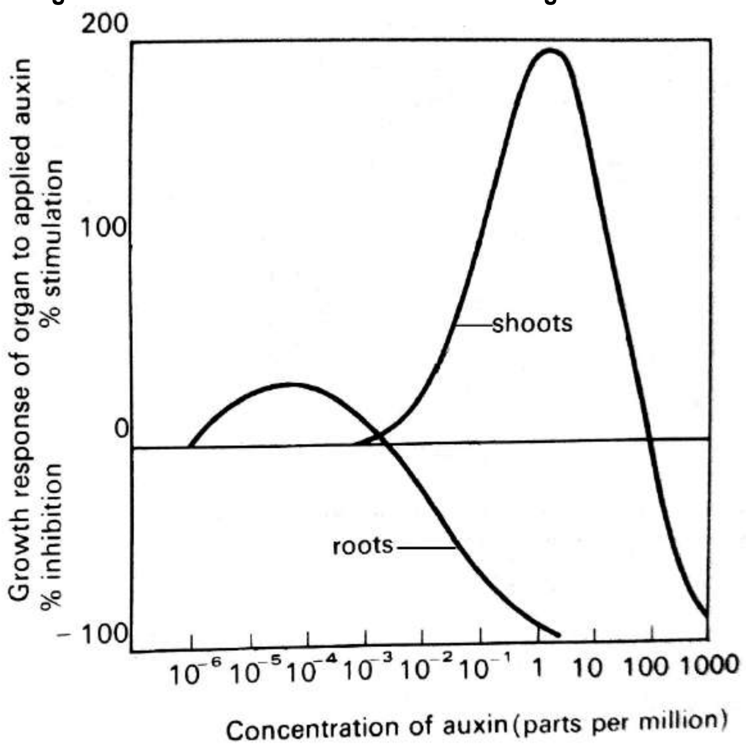
- Two maize seedlings with coleoptiles at least 2cm long are exposed to light for at least 4 hours.
- Cut the coleoptiles tips and transfer each on to an agar block and leave them for 24 hours.
- Remove the coleoptile tips and place the agar blocks on fresh decapitated shoot tips as shown below.



Observation:
Shoot A grew straight upright while shoot B grew bending away from the side with agar block.

Explanation:
Auxins diffused from the coleoptile tips into the agar block. Thus auxins are evenly distributed on the agar block.
In shoot A- Auxins diffuse from the agar block into the decapitated shoot. All sides receive same concentrations of auxins. Cell elongation occurred and growth took place evenly with the shoot growing up right.
In shoot B- Auxins diffused on one side of the shoot. I.e. the side covered with agar block. There was faster cell elongation and hence faster growth on the side compared to the uncovered side. This resulted to the growth curvature observed.

Graph showing the effect of auxins concentration on the growth of roots and shoots.



Observations:

Very low concentrations of auxins do not stimulate shoot growth. However, an increase in the amount of auxins brings about a rapid increase in the rate of growth of the shoot. If the amount of auxin in the shoot continues to increase, there comes a stage where the growth rate begins to slow down until at very high auxin concentration where growth is inhibited.

Roots are stimulated and inhibited by much lower concentrations of auxins than the shoots. Concentration of auxins which stimulate shoot growth inhibit root growth.

Very low concentrations of auxins stimulate root growth and high concentrations inhibit root growth.

Higher concentration of auxins stimulates growth of the shoot but inhibits growth of the root.

2. Gibberellins

They are produced by plants in varying amounts in seeds and young leaves and roots.

- They promote cell elongation of plant stems.
- They promote germination of seeds.
- Application of synthetic gibberellins to genetically dwarf plants causes bolting hence making dwarf plants grow taller.
- End dormancy of buds.
- They also induce flowering in some plants.
- They remove the need for cold treatment in vernalization.

3. Abscisc acid (ABA)

It's made in leaves, stems, fruits and seeds. It has the following effects:

- Inhibits growth.
- Promotes bud and seed dormancy.
- Promotes abscission and leaf senescence.

Commercially, ABA is sprayed on tree crops to regulate fruit drop at the end of the season.

4. Cytokinins

Cytokinins are most abundant where rapid cell division is occurring, particularly in fruits and seeds where they are associated with embryo growth. They have the following effects:

- They increase the rate of cell division (in the presence of auxins).
- They stimulate bud development.
- Promote leaf growth and fruit growth.
- Promote apical dominancy.
- Promote stomatal opening.
- Break dormancy

Commercially they prolong the life of fresh leaf crops such as cabbages by delaying leaf senescence as well as keeping flowers fresh.

5. Ethene (ethylene)

It's made by almost all plant organs. It is a product of plant metabolism. It has the following effects:

- Inhibits stem growth and root growth.
- Promotes flowering e.g. in pine apples.
- Ripens fruits.

Commercially it induces flowering in pine apple and stimulates ripening of tomatoes and citrus fruits.

Note:

Synergism is where the combined effect of growth substances is much greater than the sum of their separate effects.

Antagonism is where the two substances have opposite effects on the same process, one promoting and the other inhibiting.

Examples of synergism are:

- The effect of gibberellins on elongation of stems, petioles, leaves is dependent on the presence of auxins.
- Cytokinins promote cell division only in presence of auxins.

HORMONAL COORDINATION IN ANIMALS

Animals unlike plants have two different but related systems of coordination; the nervous and endocrine system. The nervous system is fast acting, its effects are localized and it involves electrical and chemical transmission whereas the endocrine system is slower in acting, its effects are adverse and it relies on chemical transmission through the circulatory system.

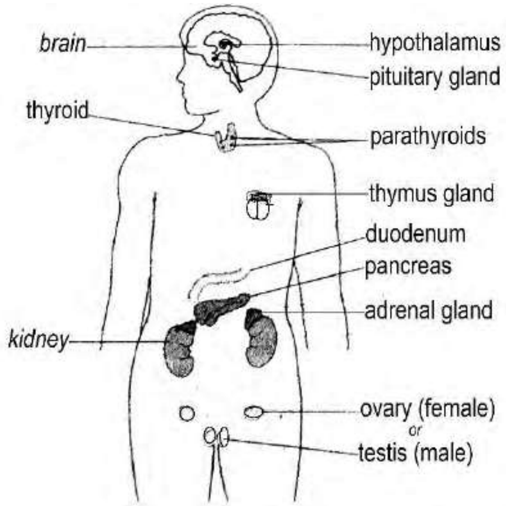
THE ENDOCRINE SYSTEM

This is the endocrine system of glands that secrete chemical substances called hormones.

This system is under the control of ***pituitary gland*** which is therefore known as the **MASTER GLAND** in the body because it controls the activities of all the glands in the body through the hormones it secretes.

*A hormone is a specific chemical substance produced by glands and is transported to a **target organ** to regulate physiological activities in the body.*

In animals, two types of glands are recognized: exocrine glands which convey their secretions to the site of action by special ducts, and endocrine glands, which lack ducts and transport their secretions instead by the blood.
Endocrine glands are stimulated to secrete hormones either by impulses from motor nerves or by hormones from other glands.
The endocrine system is linked to the nervous system by the hypothalamus which exerts a major control over the pituitary gland of the endocrine system.
The positions of the major endocrine organs in humans are shown below:



Mechanisms controlling the release of hormones

1) The presence of a specific metabolite in the blood for example glucose in the blood causes the release of insulin from the islets of the Langerhans of the pancreas which lowers the glucose level.
2) The presence of another hormone in blood. Such hormones are called stimulating hormones and most of them are produced by the anterior pituitary gland like thyroid stimulating hormone.
3) Stimulation by neurons from the autonomic nervous system like adrenaline and noradrenaline are released from the cells of the adrenal medulla by the arrival of the nerve impulse in situations of anxiety and danger.

The cascade effect

This is the release of hormones by the presence of another circulating hormone usually under the control of the hypothalamus and pituitary gland. The cascade effect is significant because it enables the effect of the release of a small amount of initial hormone to become amplified (magnified) at each stage in the pathway.
An example of the cascade effect in the control of the conversion of glucose to glycogen as a result of the release of adrenocorticotrophic releasing factor. (***Fig 17.47 BS page 601)***

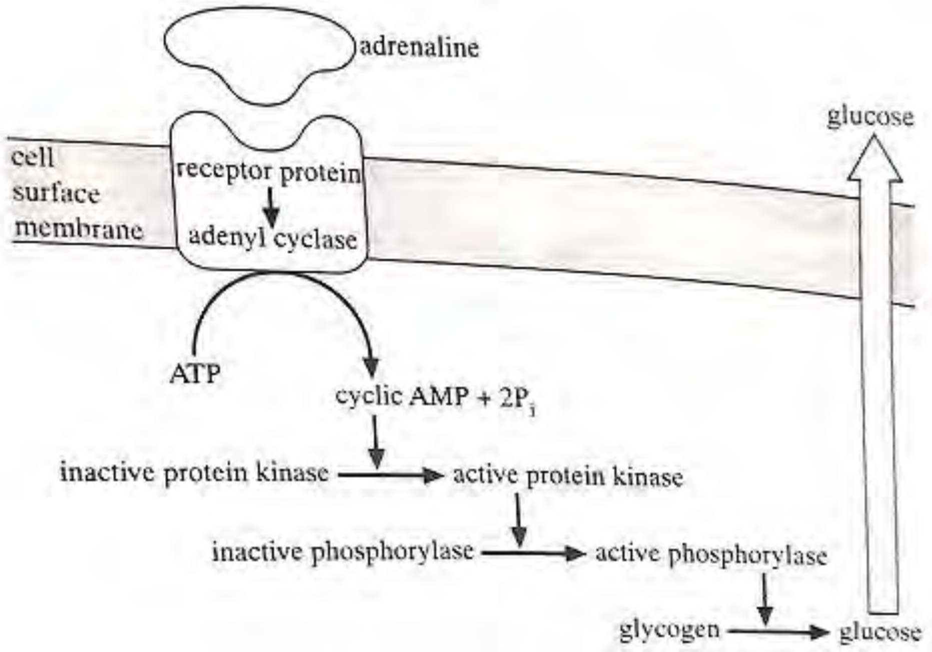
Effects of hormones on target cells

Hormones are very specific and only exert their effects on target cells which possess the particular protein receptors that recognize the hormone. Non target cells lack these receptors and therefore do not respond to the circulating hormone. Once attached to a receptor, the hormone may exert its effect in a number of ways. Three of the most important are through effects on:

1) The cell membrane:
Insulin exerts one of the effects by increasing the uptake of glucose into cells. It binds with a receptor site and alters the permeability of the membrane to glucose. 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) **Enzymes located in the cell membrane** (second messenger mechanism):
Adrenaline and many peptide hormones bind to receptor sites on the cell membrane but cannot enter the cells themselves. Instead they cause the release of a 'second messenger' which triggers a series of enzyme-controlled reactions. These eventually bring about the hormonal response. In many cases this second messenger is the nucleotide cyclic AMP (cyclic adenosine monophosphate).

An example is how adrenaline causes the release of glucose from a liver cell. The activation of membrane bound adenyl cyclase produces cyclic AMP which activates enzyme systems leading to the breakdown of glycogen to glucose. Glucose then diffuses out of the cell into the bloodstream. At each stage in the process an amplification occurs because only a few molecules of adenyl cyclase are needed to activate many molecules of protein kinase, and so on. This is the cascade effect.



3) Genes:

Steroid hormones (sex hormones and other hormones secreted by the adrenal cortex) pass through the cell surface membrane and bond to a receptor protein in the cytoplasm. The complex formed passes to the cell nucleus where the hormones exert a direct effect upon the chromosomes by switching on genes and stimulating transcription. The messenger RNA enters the cytoplasm and is translated into new proteins, such as enzymes, which carry out a particular function. For example, the hormone thyroxine passes through the surface membrane and binds directly to receptor proteins in the chromosomes, switching on certain genes,

Typical examination question:

1. a) What are target cells?

They are cells that respond to specific hormones.

b) Explain any two mechanisms by which hormones bring about cellular response in target cells.

- *The hormone binds onto its receptor in the cell membrane forming a hormone-receptor complex which activates a G-protein in the membrane.*
  The G-protein activates adenylcyclase which catalyzes conversion of ATP to cAMP. The cAMP activates a specific enzyme that catalyzes reactions which end with activation of another enzyme.
  The enzyme produced brings about change in the structure or function of the cell.
- *Some hormones pass through the cell membrane and bind with specific receptor protein in the cytoplasm to form a hormone-receptor complex.*
  The receptor then carries it into the nucleus where it then activates specific genes in a specific section of DNA triggering synthesis of mRNA which initiates enzyme synthesis in the cytoplasm bringing change in the function of the target cell.

c) Explain how a very small amount of hormone is able to exert a large effect on a target cell.

By use of a two messenger system where a very small amount of hormone can lead to the synthesis of a comparatively large amount of cyclic AMP which in turn evoke a correspondingly large response - the cascade effect.

THE ENDOCRINE GLANDS

1. The hypothalamus

It performs the following functions:

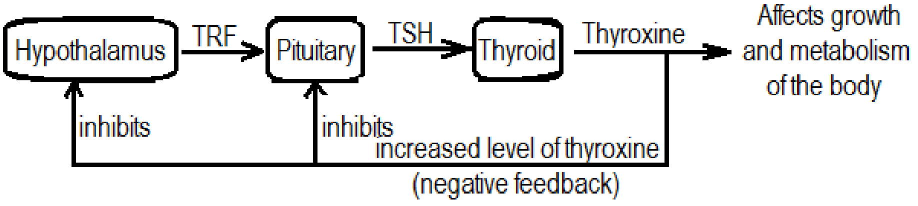
- It regulates activities such as thirst, sleep and temperature control.

- It monitors the level of hormones and other chemicals in blood passing through it.
- It controls the functioning of the anterior pituitary gland.
- It produces antidiuretic hormone and oxytocin which are stored in the posterior pituitary gland.

The hypothalamus is the link between the nervous and endocrine systems.
By monitoring the level of hormones in the blood, the hypothalamus is able to exercise homeostatic control of them. For example, the control of thyroxine production by the thyroid gland is achieved by this means:

i) The hypothalamus produces thyrotrophin releasing factors (TRF) which passes to the pituitary along blood vessels.
ii) TRF stimulates the anterior pituitary gland to produce thyroid stimulating hormone (TSH).
iii) TSH stimulates the thyroid gland to produce thyroxine.
iv) As the level of thyroxine builds up in the blood it suppresses TRF production from the hypothalamus and TSH production by the anterior pituitary gland. By this form of negative feedback the levels of thyroxine in the blood is maintained at a constant level.

Homeostatic control of thyroxine production



2. The pituitary gland

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.
It's connected to the brain by the pituitary stalk. The two lobes of the pituitary gland are the anterior and posterior pituitary lobes.

Anterior pituitary:

It produces and secretes six hormones. Most have other endocrine glands as their target organs. These hormones called trophic hormones, stimulate the activity of their respective endocrine glands. The only non-trophic hormone is growth hormone which directly affects body tissues in general. The secretion of the six hormones is triggered off by specific chemical substances from the hypothalamus called releasing factors.
The hormones secreted include;

Hypothalamus hormone	Anterior pituitary hormones	Function
Growth hormone releasing factor	Growth hormones	• Promotes growth of skeletal muscles. • Control protein synthesis and general body metabolism.
Thyrotrophin releasing factors	Thyroid stimulating hormones (Thyrophic hormones)	• Stimulates growth of thyroid glands. • Stimulates the Thyroid gland to secrete thyroxine hormone
Adrenocorticotrophic releasing factor (C.R.F)	Adrenocorticotrophic hormone	• Regulates growth of adrenal cortex
Prolactin releasing factor (P.R.F)	Prolactin hormones (Luteotrophin)	• Induces milk production in pregnant women. • Maintains progesterone production in corpus luteum.
Luteinizing hormone releasing factor	Luteinizing hormone	• Causes the release of ovum from the ovary. • Stimulates ovary to produce progesterone or corpus luteum.
Follicle stimulating factors	Follicle stimulating hormones	• Initiates cyclic changes in ovary causing development of the graafian follicle. • Stimulates the secretion of oestrogen in the ovary. • Initiates sperm formation in the testis.

Posterior pituitary lobe:

The posterior lobe communicates to the hypothalamus by means of nerve fibres. It does not synthesize any hormone but stores two hormones i.e. antidiuretic hormone (ADH) or vasopressin and oxytocin.
Antidiuretic hormone is released in response to fall in the water content of the plasma and leads to an increase in the permeability to water of the distal convoluted tubule and collecting ducts of the nephron so that water is retained in the blood plasma. It also rises the blood pressure by constricting arterioles.
Oxytocin causes the contraction of uterine walls during birth. It also causes the release of milk from the nipples.

3. Thyroid glands

It produces 3 hormones i.e. Triiodothyronin, thyroxine and calcitonin hormones.

Triiodothyronin and thyroxin hormones are chemically and functionally similar (both contain iodine), however thyroxin contain 4 iodine molecules while triiodothyronin 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 thyroxin work in conjunction with adrenaline and insulin.

In conditions of low iodine levels, triiodothyronin is produced instead of thyroxin in order to maximize the use of limited iodine. If the thyroid gland is unable to make adequate supply of this hormone, it results into under activity of the gland.

Abnormalities of thyroid gland

1) Hypothyroidism (under activity):

In young ones, it brings about sluggishness, physical and mental retardation. In adults, it results in mental and physical sluggishness, reduced metabolic rates, reduced heart beat rates, lowered body temperature and obesity (over weight). Such a condition is called myxoedema. This results into a swelling of the neck called Goitre. Hypothyroidism is caused by insufficient supply of thyroid stimulating hormones and can be cured by taking in thyroxin orally.

2) Hyperthyroidism (over activity):

It leads to increased metabolic rates, increased heart beat rate and ventilation rate, raised body temperature, nervousness i.e. restless. It brings about wasting of muscles where one fails to grow fat.

Extreme cases of hypothyroidism results into heart failure. The main cause of over activity is a blood protein that stimulates thyroid gland to produce triiodothyronin and thyroxin.

Role of calcitonin and parathormone in Ca^{2+} regulation

Calcitonin is concerned with calcium ion regulation in conjunction with parathormone secreted by the parathyroid gland. **Calcitonin** (secreted by the thyroid gland) lowers levels of calcium ion concentration in blood while **Parathormone** (secreted by the parathyroid gland) rises the level of the Calcium ions.

When the concentration of calcium ions rises to high levels in blood, the thyroid gland secretes calcitonin hormone which lowers the calcium ions in the blood stream by:

- Stimulating greater calcium ion loss through the kidneys. Over production causes excess calcium ions to be removed from the kidney causing kidney stones.
- Reducing calcium ion absorption in the gut.
- Increasing calcium ion storage in the bones.

When the concentration of calcium ions in the blood reduces significantly, the parathyroid gland secretes parathormone which rises the level of calcium ions in 3 ways:

- Increases calcium ion absorption from the gut.
- Increases calcium ion reabsorption by the kidney at the expense of phosphate ions.
- Causes release of calcium ion from the bones into the blood stream. Over production of parathormone leads to excess removal of calcium ions from bones making them brittle and reliable to fracture.

Under production of these hormones results into low levels of calcium ions in blood leading to nervous disorder and uncontrolled contraction of muscles.

4. Adrenal glands

They are of two parts, i.e.

- Adrenal cortex: consisting of the outer region of the gland.
- Adrenal medulla: consisting of the inner region of the gland.

Adrenal cortex

All the hormones produced by the cortex are steroid hormones formed from cholesterol. Hormones from this cortex are collectively called corticoids and are of two types:

- Gluco-corticoids which is concerned with glucose metabolism.
- Mineral corticoid that is concerned with mineral metabolism.

i) Gluco-corticoids:

Such hormones include cortisol hormone which is produced in response to stressful situation like pain, stroke, emotion and extreme cold infection.

The hypothalamus stimulates the anterior pituitary gland to secrete the adrenocorticotropic hormone (corticotrophin). Corticotrophin stimulates the adrenal cortex to synthesize and secrete cortisol hormone. When stress is prolonged, the size of adrenal glands increase. Cortisol fight stress in the following ways:

- Inhibits glycogenesis (stops formation of glycogen).
- Rises the blood sugar level by inhibiting insulin and hence lead to the formation of glucose (glucogenesis).
- Increases the uptake of amino acids by the liver. These are deaminated to form more glucose.

ii) Mineral corticoids:

This is a group of hormones including Aldosterone which regulate water retained in the body. It does this by controlling the distribution of Na^+ and other minerals in the tissues. Aldosterone increases the re-absorption of Na^+ and Cl^- ions by the kidney and K^+ lost in urine.

The reduction of Na^+ concentration in the total blood volume causes special kidney cells to produce renin which activates the plasma proteins and angiotensin that stimulates the release of aldosterone from adrenal cortex. This causes the kidney to conserve both water and sodium ions.

Angiotensin also creates a sensation of thirst that drives the organism to drink water thus helping to restore the blood volume.

Over production of aldosterone often results into excessive Na^+ retention by tissues, high blood pressure and headache. Retention of sodium ions in the body leads to a fall in potassium ions level in the blood leading to muscle weakness.

Under production of aldosterone leads to the fall in the amount of sodium ions in blood.

Adrenal medulla

It produces adrenalin and noradrenalin hormones.

Both are important in preparing organisms for emergence or action. The cells producing them are modified neurons of sympathetic nerve system. Therefore, they act as a link between the nervous and endocrine system. They are sometimes known as 'fight or flight' hormones as they prepare an organism to either take off or face the enemy.

The effect of both hormones is to prepare a body for danger and to fasten its response to stimulus. In some cases adrenaline dilates blood vessels while noradrenaline constricts them. This explains why blood vessels around the gut constrict while those supplying the muscles, lungs and liver dilates.

Effects of adrenalin and noradrenalin in the body

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 respiration.
Heart beat rate increases and the volume of blood pumped per beat increase.	Increases the rate at 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 blood to muscles, liver and lungs that need more energy.
Sensory perception increases.	It produces rapid reaction to stimulus.
Increased mental awareness.	To allow quick response to stimuli.
Pupil of the eye dilates.	Increases the range of vision and perception of visual stimulus.
Erector muscles of hair contract, hairs on skin stand.	Gives an impression of increased body size to scare the enemy.

PANCREAS

It is an exocrine as well as endocrine gland with special cells called islets of Langerhans. Within them are the beta cells which produce insulin and alpha cells which secret glucagon hormones.

Glucagon increases blood sugar levels by stimulating the breakdown of glycogen to glucose and its release from the liver cells.

Insulin reduces the blood sugar levels by stimulating the conversion of glucose to glycogen in the process called glycogenesis.

Insufficient levels of insulin in blood leads to disorders called ***diabetes mellitus***. As a result, the blood sugar levels rises to dangerous levels causing blindness and kidney failure.

In case the kidney is unable to reabsorb all glucose passing through it, it results into the symptom of the presence of glucose in urine. Treatment involves administering insulin.

Summary of endocrine glands and their functions

Gland	Hormone	Function
Pituitary gland		
Thyroid gland	Tri-iodothyroxine Iodine Calcitonin	Regulates growth and development by affecting metabolism.
Parathyroid	Parathormone	Raise calcium levels as it lowers phosphate levels
Adrenal gland i) Adrenal cortex ii) Adrenal medulla	Cortisol hormone	Helps in combating stress by rising blood sugar levels and pressure.
	Aldosterone	Increases reabsorption of Na^+ by kidney tubules.
	Adrenaline and noradrenaline	They prepare the body for fright or fight/emergency or stressful situations.
Pancreas	Insulin	Lowers blood sugar levels
	Glucagon	Increases blood sugar levels
Duodenum	Secretin	Stimulates secretion of minerals and pancreatic juice by pancreas. Stimulates the secretion of bile by the liver into the gall bladder.
	Cholecystokinin	Causes contraction of gall bladder to release bile. Stimulates the pancreas to release its enzymes.
Ovary	Oestrogen	Stimulates the pituitary gland to produce luteinizing hormone. Causes repair of uterine lining after menstruation.
	Progesterone	Causes the uterus lining to be maintained in readiness for the embryo to be implanted. Inhibits production of FSH and luteinizing hormone thus inhibiting ovulation and maintaining pregnancy.
Testis	Testosterone	Produces male sex secondary characteristics.
Placenta	Progesterone	Maintains pregnancy after corpus luteum has degenerated.
	Chorionic gonadotrophin hormone	Maintains the presence of corpus luteum in the ovary.
Kidney	Renin	Activates plasma proteins and angiotensin.
Stomach walls	Gastrin	Initiates secretion of gastric juice.

INSECT HORMONES

Most invertebrate hormones are nerve secretory hormones. In insects their important in controlling ecdysis/molting. The process involves two hormones; ecdysin and juvenile/neotenin hormones.

In holometabolous (complete metamorphosis), all moults require ecdysin hormones. If however a high concentration of juvenile hormone is present the larva moults to another larva stage. As growth proceeds, the level of juvenile decreases. At less levels of juvenile, the larva moults to give rise to pupa. In absence of juvenile hormone, ecdysin causes the pupa to molt to an adult.

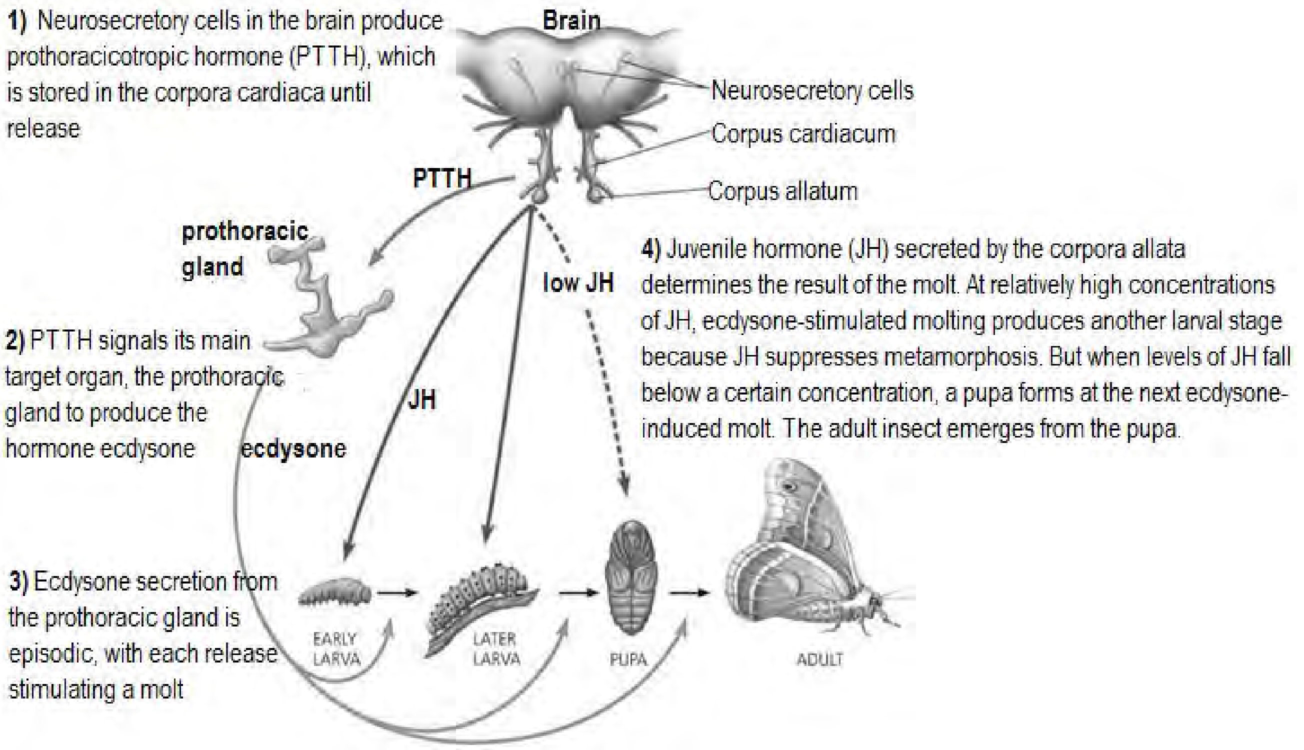
Production of two hormones is controlled by the insect brain as follows:

The brain produces a hormone prothoracic-trophic hormone which passes to a pair of bodies called corpora cardiaca which lies next to the brain where it's stored. In response to external stimulus like day length, temperature and food supply, the brain sends impulses to corpora cardiaca to release the formed prothoracic trophic hormones.

Juvenile/neotenin is produced by the region behind the brain called corpora allatum. The production of the juvenile hormone decreases as the insect develops and resumes in adults because it is important in the production of eggs in female insects stimulation of the male accessory glands to produce seminal fluid in male adult insects.

Therefore the main role of JH in immature insects is to inhibit the genes that promote development of adult characteristics, causing the insect to remain as nymph or larva.

In adult insects, the neurosecretory cells of the brain release a brain hormone that reactivates the corpora allatum, stimulating the production of juvenile hormone.



Other hormone-like substances

Pheromones:

These are chemicals capable of acting like hormones outside the body of the secreting individual to impact the behaviour of the receiving individuals.

They include alarm pheromones, food trail pheromones, sex pheromones, and many others that affect behavior or physiology. Some species like female silk moth produce sweet smell that attract male sex moth.

Pheromones attract individuals from far distance thus these pheromones are used to control population of the same species. Ants, termites and bees all produce chemicals which aid others in their social groups to go for food resource.

Prostaglandins:

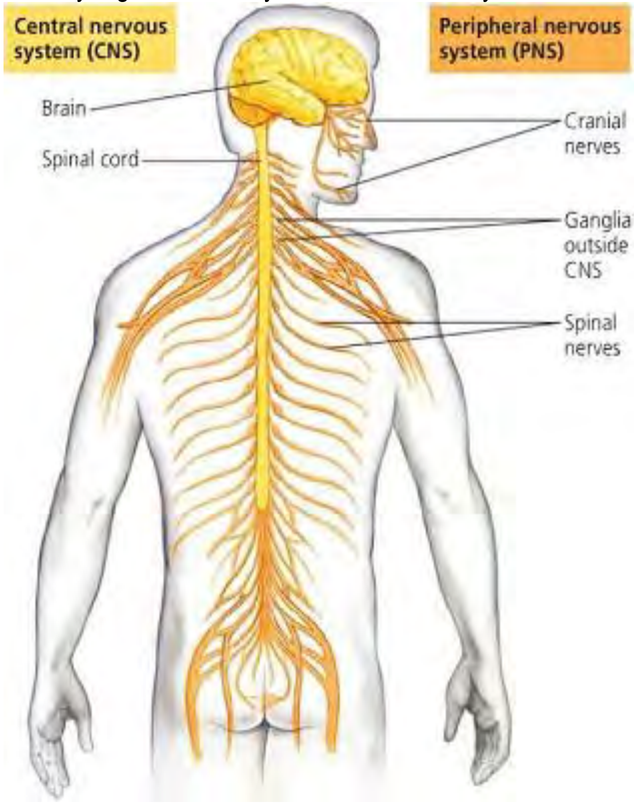
They are produced throughout the body and are found in the semen. They bring about contraction of smooth muscles, contraction of the uterus to push the sperm up to the oviduct.

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.

NERVOUS COORDINATION IN ANIMALS

This is a system of nerve cells and sensory organs that carry out co-ordination by transfer of impulses.



The nervous system consists of;

Receptors: These are the organs that detect ***stimuli*** to which the animals respond. E.g. sensory endings in the skin, nose, tongue, eyes and ears.

Impulses: these are electrical transmissions or chemical stimuli sent from the receptors to the coordinating center. The coordinating center interprets the impulses before a response is made.

Effectors: These are organs that respond to the stimuli and carry out the response.

The central nervous system (CNS): This interprets and determines the nature of the response. The CNS consists of the brain and spinal cord.

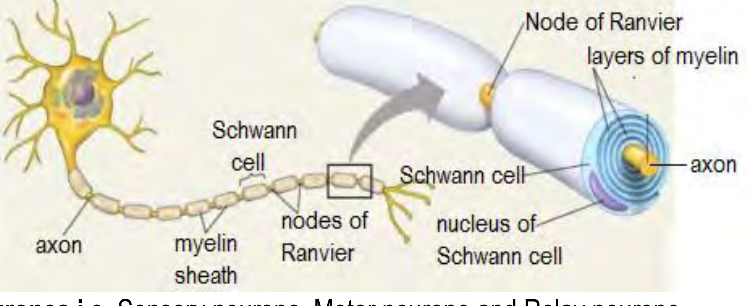
Peripheral nervous system: This consists of the vast network of spinal and cranial nerves linking the body to the brain and spinal cord.

Functions of the nervous system

1. It receives impulses from all sensory organs of the body.
2. It stores information.
3. It correlates various stimuli from different sensory organs.
4. It sends messages to all parts of the body making them function accordingly.
5. It's involved in temperature regulation.

STRUCTURE AND FUNCTIONS OF THE NEURONE

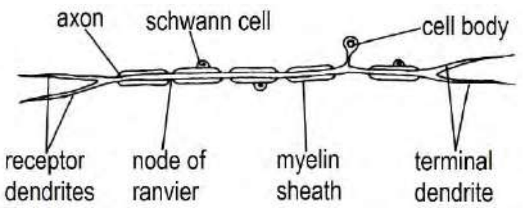
A neurone is made up of a small mass of cytoplasm, a nucleus in a structure called the cell body, branching cytoplasmic filaments called dendrites and a single long fiber called axon.



There are three types of neurones i.e. Sensory neurone, Motor neurone and Relay neurone

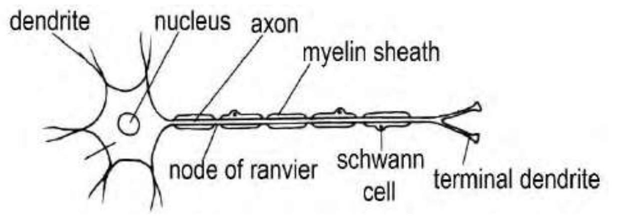
Sensory neurone

Sensory neurones are cells that transmit impulses from the receptor cells to the central nervous system.



Motor neurone

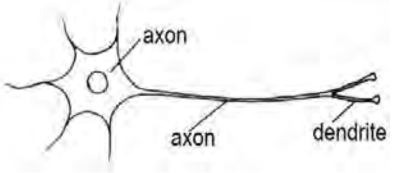
This is a neurone that transmits impulses from the central nervous system to the effector organs such as muscles and glands, where a response is made. The muscles respond by contracting while glands respond by secreting substances.



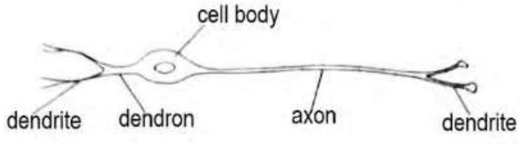
Relay neurone

This is a neuron located in the central nervous system and transmits impulses from the sensory neurone to the motor neurone. The axon extends towards the motor neurone. It is also referred to as an intermediate neurone. A relay neurone is either unipolar, bipolar or multipolar.

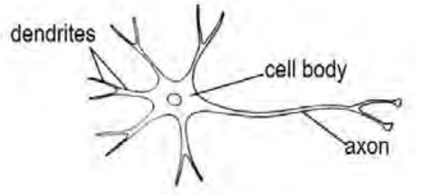
Unipolar neurone:



Bipolar neurone:



Multipolar neurone:



Functions of the parts of a neurone

Cell body: This consists of a nucleus surrounded by a mass of cytoplasm. The nucleus controls all activities of the neuron.
Axon: Transmits impulses over long distances in the body. Each axon is filled with cytoplasm called axoplasm.
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 the transmission of impulses.
Dendrites: These are hair-like structures surrounding the cell body. They conduct incoming signals.
Node of Ranvier: This is the space on the axon between two adjacent myelin sheaths. It speeds up nervous transmission.
Dendron: It is a branch through which impulses are transmitted to the body.
Schwann cell; this is a cell which secretes the myelin sheath.
Nissl's granules; these are groups of ribosomes responsible for protein synthesis.

Differences between motor and sensory neurons

Motor neuron	Sensory neuron
Has a long axon.	Has a short axon.
It has a cell body at the terminal end of the axon.	Has a cell body located on the axon branch.
It has a short dendrons.	It has a long dendron.
It carries impulses from the central nervous system to the effector organ.	It carries impulses from the receptor cells to the central nervous system.
It has several dendrons.	It has one dendron.
Terminal dendrites connect with effector organ.	Terminal dendrites connect to relay neurones.

How the motor neurone is suited for functioning

- The nucleus is **relatively large** to coordinate the metabolic activities all over the large cytoplasm of the cell.
- There are very many rows of rough endoplasmic reticula (**Nissl's granules**) for massive production of proteins and neurotransmitters.
- The dendrites are **numerously branched** to increase the surface area for synapting with several other neurones.
- Axon is **long** to carry impulses to the target parts.
- The axon membrane is wrapped with a myelin sheath for electrical **insulation.**
- The axon membrane is wrapped with a **thick** myelin sheath for **protection** against damage.
- The axon membrane is wrapped with a myelin sheath at intervals around the axon which **increases speed** of impulse transmission through salutatory conduction.

THE FUNCTIONING OF NEURONES

Neurones are electrically excitable cells i.e. they can change their membrane potential and are capable of transmitting electrical nerve impulses. The impulses are due to events in their cell membrane.

Polarization of the neuron's membrane:

Cell membranes surround neurons just as any other cell in the body has a membrane. When a neuron is not stimulated — it's just sitting 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 excess sodium ions (Na+); the inside of the cell contains excess potassium ions (K+**).

You're probably wondering: ***How can the charge inside the cell be negative if the cell contains positive ions?*** Good question. The answer is that in addition to the K+, negatively charged protein and nucleic acid molecules also inhabit the cell; therefore, the inside is negative as compared to the outside.

Then, if cell membranes allow ions to cross, **how does the Na+ stay outside and the K+ stay inside**? If this thought crossed your mind, you deserve a huge gold star! The answer is that the Na+ and K+ do, in fact, move back and forth across the membrane. However, Mother Nature thought of everything. There are Na+/K+ pumps on the membrane that pump the Na+ back outside and the K+ back inside. The charge of an ion inhibits membrane permeability (that is, makes it difficult for other things to cross the membrane).

Resting potential

This *gives the neuron a break.* When the neuron is inactive and polarized, it's said to be at its resting potential. It remains this way until a stimulus comes along.

Action potential

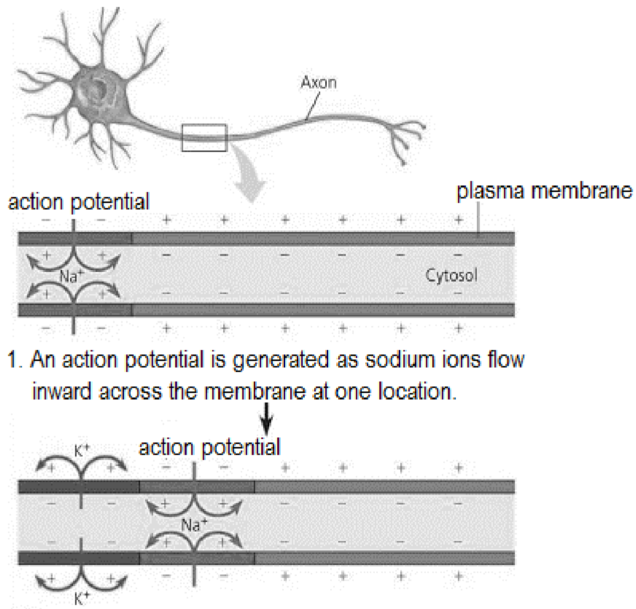
This begins when sodium ions move into the inside the membrane**.**

When a stimulus reaches a resting neuron, the gated ion channels on the resting neuron's membrane open suddenly and allow the Na+ that was on the outside of the membrane to go rushing into the cell. As this happens, the neuron goes from being polarized to being depolarized.

Remember that when the neuron was polarized, the outside of the membrane was positive, and the inside of the membrane was negative. Well, after more positive ions go charging inside the membrane, the inside becomes positive, as well; polarization is removed and the **threshold** is reached.

Each neuron has a threshold level — ***the point at which there's no turning back***. After the stimulus goes above the threshold level, more gated ion channels open and allow more Na+ inside the cell. This causes complete depolarization of the neuron and an action potential is created. In this state, the neuron continues to open Na+ channels all along the membrane. When this occurs, it's an ***all-or-nothing*** phenomenon. "***All-or-nothing"*** *means that if a stimulus doesn't exceed the threshold level to cause **all** the gates to open, no action potential results*; however, after the threshold is crossed, there's no turning back: Complete depolarization occurs and the impulse will be transmitted.

When an impulse travels down an axon covered by a myelin sheath, the impulse must move between the uninsulated gaps called nodes of Ranvier that exist between each Schwann cell – *this is referred to as the **saltatory effect.***



1. An action potential is generated as sodium ions flow inward across the membrane at one location.
2. The depolarization of the action potential spreads to the neighbouring region of the membrane, reinitiating the action potential there. To the left of this region, the membrane is repolarizing as potassium ions flows outward.
3. The depolarization-repolarization process is repeated in the next region of the membrane. In this way, local currents of ions across the plasma membrane cause the action potential to be propagated along the length of the axon.

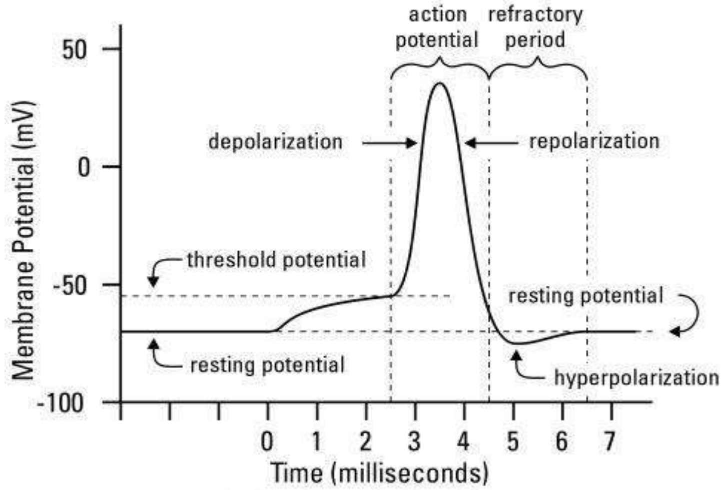
Repolarization

Potassium ions move outside, and sodium ions stay inside the membrane. After the inside of the cell becomes flooded with Na^+, the gated ion channels on the inside of the membrane open to allow the K^+ to move to the outside of the membrane. With K^+ moving to the outside, the membrane's repolarization restores electrical balance, although it's opposite of the initial polarized membrane that had Na^+ on the outside and K+ on the inside. Just after the K+ gates open, the Na+ gates close; otherwise, the membrane couldn't repolarize.

Hyperpolarization

More potassium ions are on the outside than there are sodium ions on the inside. 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, and the membrane is said to be hyperpolarized because it has a very low membrane potential. (Because when the membrane's potential is lower, it has more room to "grow."). This period doesn't last long, though (well, none of these steps take long!). After the impulse has traveled through the neuron, the action potential is over, and the cell membrane returns to normal (that is, the resting potential).

A graph showing the changes in membrane potential inside a neuron



Therefore in summary: The membrane is more permeable to outward diffusion of K^+ than inward diffusion of Na^+. This will leave a surplus negative charges inside and positive charges outside hence resting potential.

When an impulse is passing, the membrane suddenly become permeable to Na^+ and they diffuse into the axon rapidly and reverse the resting potential by making the inside positive and leaving the outside negative hence an action potential which is propagated along the axon as a current of propagation.

As sodium ions enter the axon, potassium ions leave to the outside and this restores the negative charges inside. The sodium ions are later expelled from the inside by Na-K pump and return the potassium ions hence restoring the distribution of ions as they normally exist when an axon is at rest.

Refractory period

This puts everything back to normal. Potassium returns inside, sodium returns outside.

The refractory period is 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.

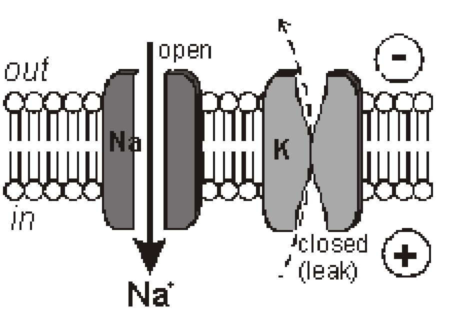
WORKED OUT EXAMINATION QUESTIONS

a) **State the 'All-or-nothing law' in the transmission of nerve impulses.**

It states that if the strength of the stimulus is below certain threshold intensity, no action potential is evoked. If however the stimulus is above the threshold, a full sized potential is evoked and remain the same however-much intensity the stimulus becomes.

b) Describe how a nerve impulse is initiated and propagated in a neurone

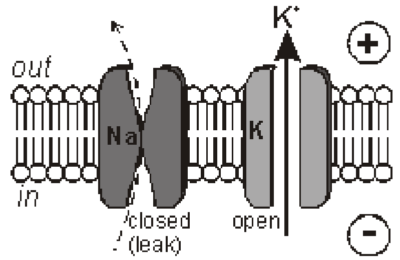
Depolarization:



- A stimulus from sensory cell or another neurone can cause the membrane potential of a target neurone to change a little.
- The voltage-gated ion channels can detect this change, and when stimulated past threshold (about –30mV in humans), the sodium channels open for 0.5ms.
- This causes Na^+ to rush in, making the inside of the cell more positive.
- This phase is referred to as a **depolarization** since the normal voltage polarity (negative inside) is reversed (becomes positive inside).

Repolarization:

- The region of positive charge causes nearby voltage gated sodium channels to close.



- Just after the sodium channels close, the potassium channels open wide for 0.5ms, causing potassium ions to rush out, making the inside more negative again, so the charge across the membrane is brought back to its resting potential.
- This is called **repolarization.** As the polarity becomes restored, there is a slight 'overshoot' in the movement of potassium ions (called **hyperpolarization**).
- This process continues as a chain-reaction along the axon in one direction.
- The influx of sodium depolarizes the axon, and the outflow of potassium **repolarizes** the axon.
- The resting membrane potential is restored by the Na-K pump.

c) What is meant by a resting potential?

A resting potential is a negative potential difference existing across a membrane of an axon when the outside of the membrane is more positive while the inside of the membrane is more negative or membrane is polarized, when there exists no stimulus.

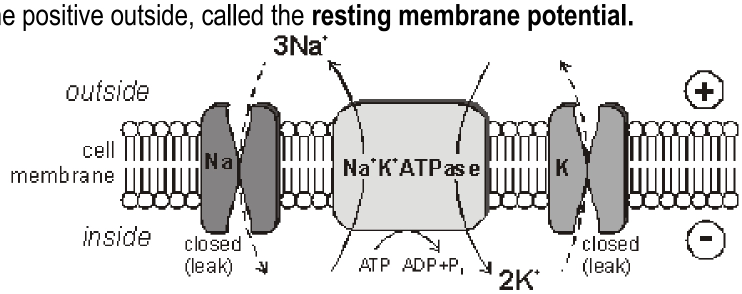
d) Explain how a resting potential is maintained across the membrane of a resting axon.

It is maintained by the activity of sodium-potassium pump mechanism; which actively pumps 3 sodium ions outside; the membrane and two potassium ions inside the membrane; The membrane remain permeable to potassium ions but impermeable to sodium ions; and outward flow of negative ions such as chloride ions, potassium ions freely diffuse outside the membrane while the negative ions are retained; inside the membrane causing the inside of the membrane more negative and outside of the membrane more positive;

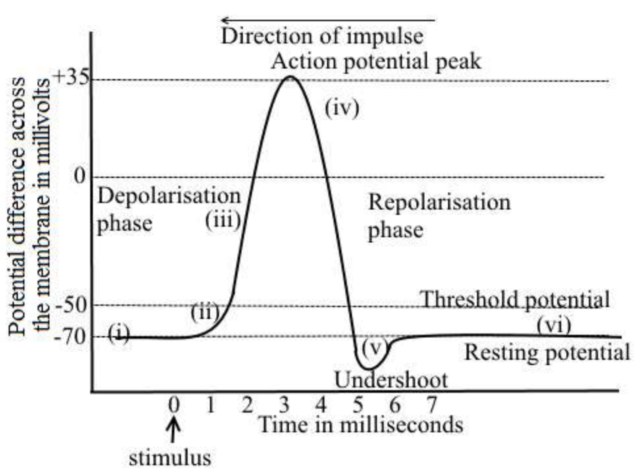
e) Explain how the resting membrane potential is created

The protein pump called the sodium-potassium pump in all animal cell membranes actively pumps **simultaneously** 3 Na^+ out of the cell and 2 K^+ in, causing a higher concentration of Na^+ outside the membrane than in the cytoplasm, and more K^+ in the cytoplasm than outside thus creating a chemical gradient.

Although Na^+ and K^+ later leak by diffusion along their gradients, the axon membrane is more permeable to potassium ions which therefore leak out of the cytoplasm faster than the sodium ions leak in because most of the potassium gates are open while most of those of sodium are closed, resulting in a potential difference (difference in charge) between the negative inside of the neurone and the positive outside, called the **resting membrane potential.**



Changes in potential difference across a neuron membrane during the passage of an impulse



Note: Nerve impulses can only travel in one direction. Action potential can only depolarize the membrane in front while the membrane behind is recovering from refractory period (previous action potential)

Resting membrane potential

At (i): Both the voltage-gated sodium and potassium channels are closed. The membrane's resting potential is maintained by the Na+/K+ pump and the permeability of the membrane which permits facilitated diffusion of more K+ ions out and less Na+ ions into the inside.

At (ii): A stimulus triggers the opening of some sodium voltage-gated channels. When the influx of Na+ ions exceeds threshold potential, more sodium voltage-gated channels open

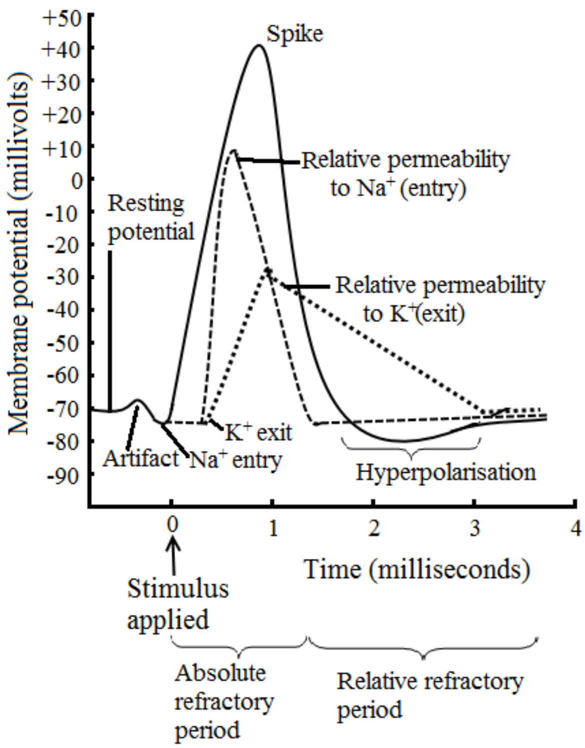
Depolarization phase of the action potential at (iii): The activation gates of the voltage-gated sodium channels open. There is influx of Na+ ions into the axon as the cell becomes more positive inside. The voltage-gated potassium channels remain closed.

Repolarization phase of the action potential at (iv): Inactivation gates close voltage-gated sodium channels. Voltage-gated potassium channels open and K+ ions diffuse out of the cell. The loss of positive K+ ions cause the inside of the cell to become more negative than the outside.

Hyperpolarization / Undershoot at (v): Both gates of the voltage-gated sodium channels are closed. The voltage-gated potassium channels remain open because their gates close slowly. Within one or two milliseconds, voltage-gated channels close.

Re-establishing resting potential at (vi): The resting potential is re-established by the Na+/K+ pump and facilitated diffusion through ion channels.

Axon membrane permeability to Na^+ and K^+



Comparison of membrane permeability to Na^+ and K^+

Similarities:

Axon membrane permeability: is **constant** from 0ms to about 0.3ms and 3ms to 3.5ms**; increases** from about 0.3ms to 0.5ms**; equivalent** at about 1ms**; decreases** between 1ms and 1.3ms;

Differences:

Axon permeability to Na+	Axon permeability to K+
Increases rapidly from 0.3ms to about 0.5ms	Increases gradually from 0.3ms to about 0.5ms
Attains much higher peak	Attains much lower peak
Constant from about 1.5ms to 3ms	Decreases from about 1.5ms to 3.5ms

Neurone excitability during and after an impulse

Refractory period: Represents a time during which the membrane cannot be depolarised again.

- Occurs during repolarization and hyperpolarization.
- Membrane is impermeable to Na^+ ions / sodium ion channels are closed.
- Sodium ions cannot enter axon.
- K^+ ions move out as membrane is more permeable to K^+ ions.
- Membrane becomes more negative than resting potential.

Nerve impulses can only travel in one direction.

- Action potential can only depolarize the membrane in front.
- Membrane behind is recovering from refractory period (previous action potential)

Refractory period limits frequency with which neurones can transmit impulses

- **Absolute refractory period:** is when it is not possible to elicit another action potential despite the size of the stimulus. Na+ channels are recovering and no matter what stimulus is applied, they cannot activate to allow Na+ in and depolarize the membrane to the threshold of an action potential.
- **Relative refractory period**: is when it is more difficult to elicit an action potential, but still possible if a greater stimulus is used than is needed at rest.

In relative refractory period some of the Na+ channels have re-opened but the threshold is higher than normal making it more difficult for the activated Na+ channels to raise the membrane potential to the threshold of excitation.

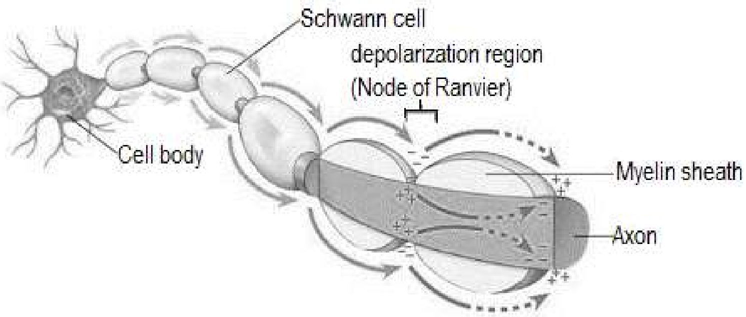
Importance of refractory period

- Determines the maximum frequency at which an axon can transmit an impulse.
- Ensures separation of action potential and specify the stimulus causing the excitation.
- Prevents spreading of action potential and makes it flow in one direction.

Factors that affect nerve conduction speed

1) **Axon diameter:**
Impulses are faster in an axon with larger diameter because longitudinal resistance of axoplasm decreases with increasing diameter of axon, which increases the length of the membrane influenced by local circuit as the distance between adjacent depolarization increases; causing increased conduction velocity.
Small cells or cells with large surface area to volume ratio or ion leakage weakens membrane.
Myelin sheath stops ion leakage; therefore large diameter only important for unmyelinated neurons.
2) **Temperature:**
Homoiotherms with steady body temperature have faster impulse propagation than poikilotherms which have fluctuating body temperature.
3) **Myelination and saltatory conduction:**
Myelination speeds up conduction. In a myelinated neuron, the conduction velocity is directly proportional to the fiber diameter. Schwann cells prevent diffusion of ions; flow of current occurs only between adjacent nodes of Ranvier. Therefore, depolarization only at nodes of Ranvier because action potential 'jumps' from node to node.

Transmission of an impulse along a myelinated neuron

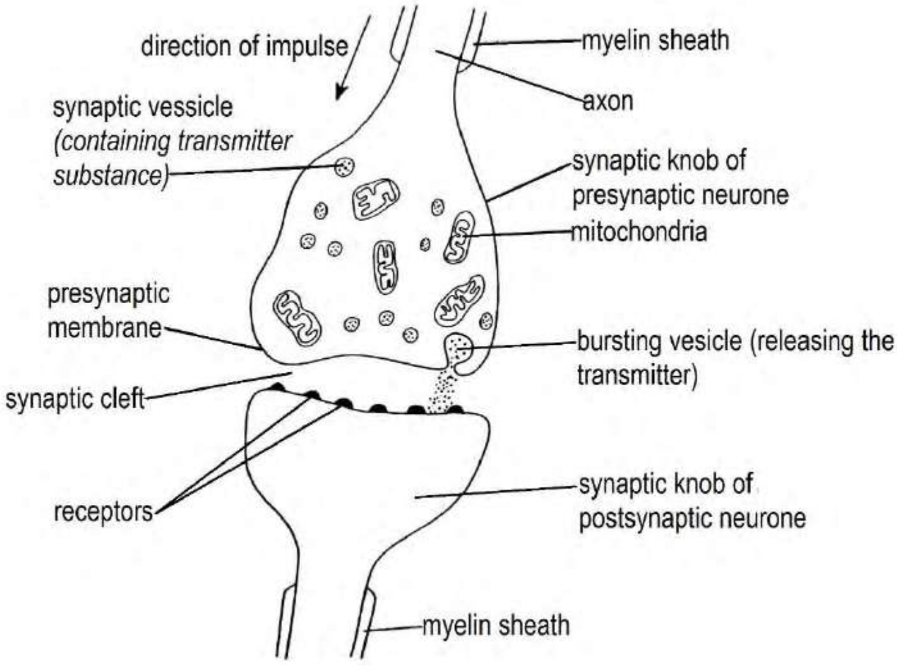


Note: Properties of nerves and nerve impulses are based on stimulation, the all or nothing law, transmission speed, and myelin sheath and axon diameter

SYNAPSE

This is the point where the axon of one neuron meets and joins with the dendrite or cell body of another neuron. This allows information to cross from one neuron to another neuron.

Structure of the synapse



Synapses can be:

Inhibitory i.e. neurotransmitter opens Cl^- ion or K+ ion-gated channels in the post-synaptic membrane, causing hyperpolarization which makes it difficult to generate an action potential

Excitatory i.e. neurotransmitter opens Na+ channels to cause depolarization in the post-synaptic membrane.

Transmission of the impulse across a synapse

When an impulse arrives on the presynaptic knob, the calcium ion channels in the presynaptic membrane are opened. Calcium ions from the synaptic cleft enter the knob and cause the vesicles to move close to the presynaptic membrane.

When these vesicles reach the membrane, they discharge/release the transmitter substances through the membrane to the cleft.

The released neurotransmitter substances then diffuse across the synaptic cleft attaches to specific receptor sites on the postsynaptic membrane.

What follows depends on whether the synapse is either excitatory or inhibitory.

At excitatory synapse, the reception of neurotransmitter substance (acetyl choline) on the receptor sites changes their configuration such that the membrane channels in them are opened up thus allowing sodium ions to diffuse into the postsynaptic membrane.

The potential difference of the membrane therefore changes and an **excitatory postsynaptic potential (EPSP**) results. This fills up until the threshold is reached which results into an action potential being fired in the post synaptic neuron. At that point the impulse has crossed the synapse.

At an inhibitory synapse, release of transmitter substances (noradrenaline) into the synaptic cleft leads to the opening up of chloride ion channels in the post synaptic membrane resulting into chloride ions entering and potassium ions leaving.

As a result, the interior of the post synaptic membrane becomes more negative. This is known as **inhibitory postsynaptic potential (IPSP)** and makes it difficult to generate an action potential in the post-synaptic cell.

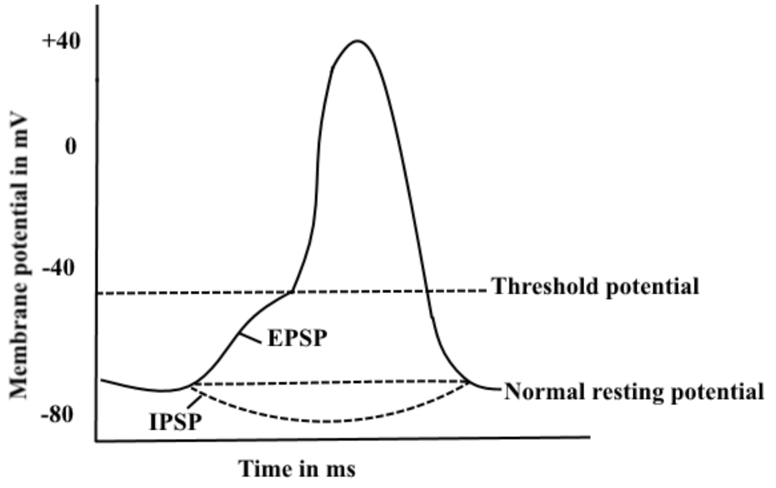
Note:

After neurotransmitter substance has performed its function, it does not stay because if it was to stay it would continue to stimulate the post synaptic neuron.

Acetyl choline is normally hydrolyzed by an enzyme, acetyl cholinesterase to choline and acetyl. These two products then diffuse back and re-enter the presynaptic knob and combine back to form the transmitter substance which is packed into vesicles ready for reuse.

Because this process is energy demanding, it explains why the synaptic knob has many mitochondria.

Graph showing membrane potential changes during synaptic transmission



Action of drugs and poison

The fact that transmission of impulse is as a result of chemicals, it provides explanations that drugs and poisons have an effect on the synapse:

Cocaine blocks reuptake of neurotransmitter e.g. **dopamine**

Curare blocks action of **acetylcholine** by binding to receptors on the post synaptic membrane.

Organophosphate insecticides and nerve gases block **acetylcholinesterase**, thus acetylcholine remains active for longer periods.

Being an antagonist of **acetylcholine-receptors** and **adrenaline-receptors** on membrane of muscle cells in heart, **curare** in small doses is used as a general muscle relaxant in patients undergoing major surgery.

Curare is commonly applied on tips of hunting arrows to paralyze animals.

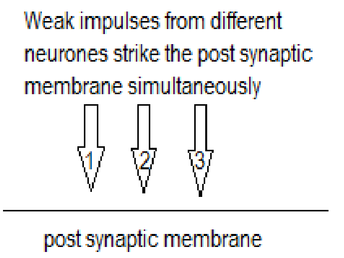
Other terms used in impulse transmission

1. **Summation:** This is a phenomena used to describe how the depolarizing effect of several excitatory post synaptic potential is additive. There are two types i.e.

Spatial summation:

This is the addition of transmitter substances from two synaptic knobs so that it can be enough to excite the post synaptic membrane.

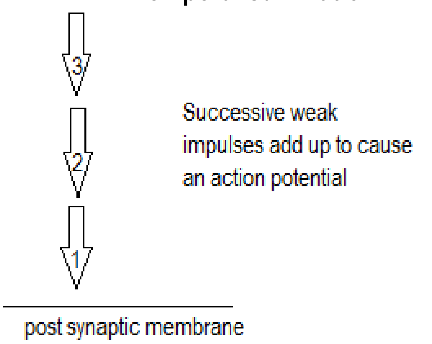
Spatial summation



Temporal summation:

This involves the facilitation process i.e. the first impulse transmission is insufficient to trigger off an impulse in the post synaptic membrane but cause an effect, therefore the second faster stimulation will add to the former and generate an impulse at the post synaptic membrane. The rapid repeated release of transmitter substance from several synaptic vesicles by the same synaptic knob as a result of an intense stimulus produces individual excitatory post synaptic potentials (epsp) which are so close together that they summate and give rise to an action potential in the post synaptic membrane.

Temporal summation



2. **Accommodation:**

If a synapse has had a persistent high frequency impulse for a long time than usual, the post synaptic nerve cell may fail to respond and impulses are no longer generated. This means supply of transmitter substance is exhausted and its re-synthesis can't keep pace with the rate at which the impulse are reaching the synapse therefore the synapse is said to be fatigued or accommodate.

Functions 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 also act as 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.

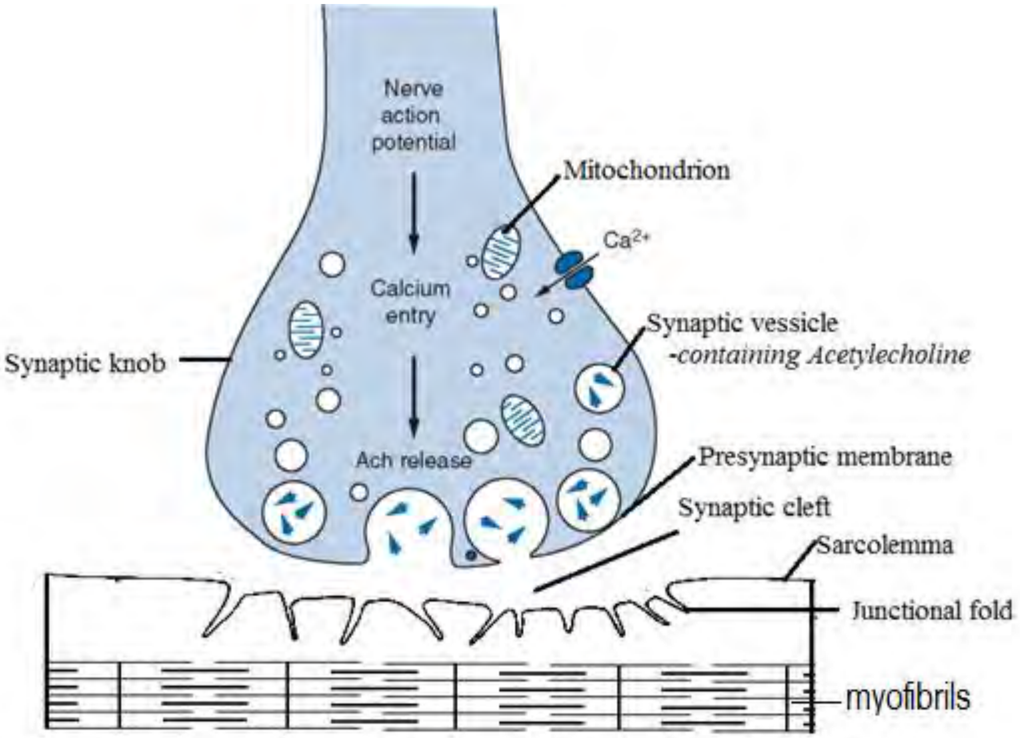
Disadvantages of synapse

- Slows down the speed of transmission.
- Are highly prone to drugs and fatigue which may inhibit impulse transmission.

Neuromuscular junction

This is a single synapse or junction made between one motor neuron and one muscle fiber

Structure of a neuromuscular junction



Functioning of the neuromuscular junction

Arrival of an action potential at the synaptic terminal of motor neuron causes the influx of Ca^{2+} ions from the extracellular fluid into the presynaptic neuron's cytosol followed by exocytosis of synaptic vesicles containing acetylcholine.

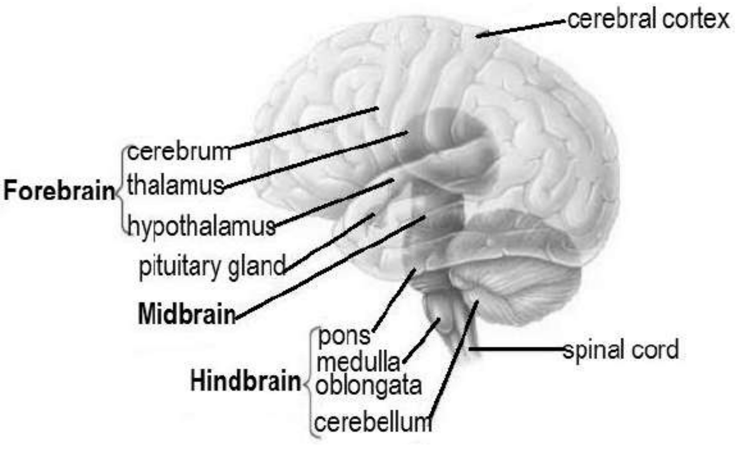
Acetylcholine diffuses across the synaptic cleft of neuromuscular junction to depolarize the sarcolemma and trigger an action potential that brings about contraction and relaxation of the muscle.

THE CENTRAL NERVOUS SYSTEM

This is made up of the brain and spinal cord and it coordinates all the neutral functions.

THE BRAIN

The brain is covered and protected externally by the skull (cranium) and internally by membranes called meninges. It is made up of three distinct areas namely the forebrain, midbrain and hindbrain.



Functions of the parts of the brain

1. **The fore brain**

It consists of:

i) The cerebrum (cerebral hemisphere):

It consists of right and left cerebral hemispheres which are interconnected by the corpus callosum. It is covered by a thin layer of cerebral cortex.

The right hemisphere sends and receives impulses from the left side of the body while the left hemisphere receives impulses from the right side of the body.

It coordinates learning, memory, reasoning, conscience and personality. It is responsible for intelligence.

ii) Thalamus: It transmits impulses of sensations received from sense organs to the cerebral cortex.

iii) Hypothalamus:

It controls activities of the pituitary gland.

It also coordinates and controls the autonomous nervous system.

2. **The mid brain**

It relays audio and visual information.

It is also responsible for movement of the head and the trunk.

3. **Hind brain:** It is made up of:

i) **Cerebellum:** It is responsible for balance and muscular coordination.

ii) **Medulla oblongata:** It controls heartbeat, blood pressure, breathing rate, coughing and sneezing.

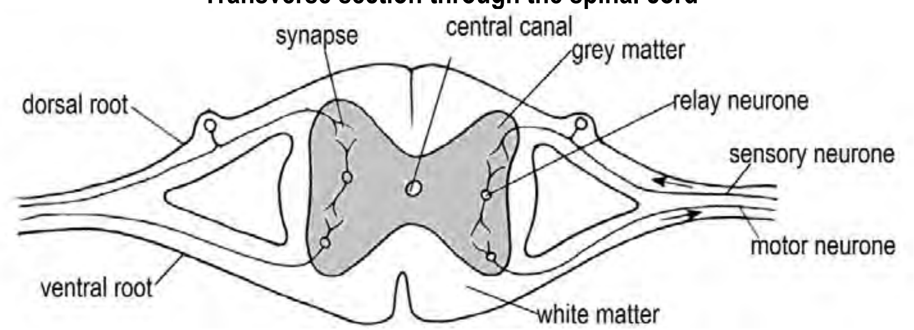
Functions of the brain

- It receives impulses from all receptors and sends back impulses to the effectors.
- It integrates and coordinates all activities in the body such that the body works efficiently.
- It stores information.
- It is involved in cranial reflex actions but it does not initiate them.

THE SPINAL CORD

This is part of the central nervous system that runs from the brain through to the tail and protected by the vertebral column.

Transverse section through the spinal cord



Functions of the spinal cord

- It connects the peripheral nervous system to the brain.
- It is a center for simple spinal reflex actions.
- Receives impulses from receptors.
- Interprets messages especially in reflex arc.
- Sends impulses to the effectors.

THE PERIPHERAL NERVOUS SYSTEM

It is made up of neurones that link the brain and spinal cord to muscles and organs such as the eyes and ears.

It is divided into autonomic nervous system and somatic nervous system. The autonomic nervous system is responsible for the ***involuntary*** control of internal organs, blood vessels, smooth muscles and cardiac muscles.

The somatic nervous system is responsible for the ***voluntary*** control of skin, bones, joints and skeletal muscles.

Voluntary and involuntary actions

A voluntary action *is one initiated consciously under the direct control of the brain i.e. they are actions one does at will e.g. dancing, laughing, stealing, etc.* These actions are performed consciously by an animal. In such actions the animal chooses to do or not to do something.

Involuntary actions *are the ones that occur without conscious thoughts e.g. breathing, etc.*

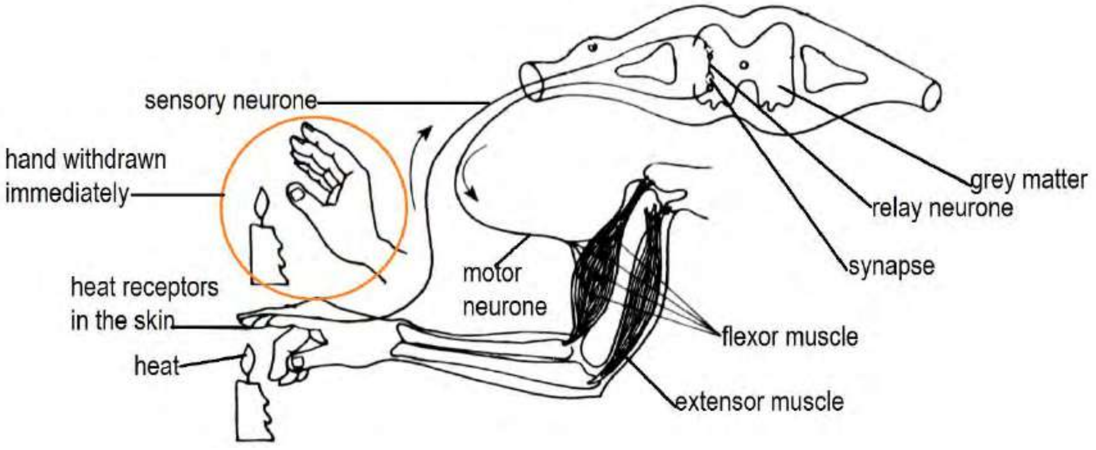
THE REFLEX ACTION

A reflex action is an automatic (involuntary) response to a particular stimuli. Reflex actions take place without the awareness of the individual. A reflex action occurs as a result of impulses travelling along neurons in a path called a ***reflex arc***. A reflex action can either be **simple** or **conditioned reflex**

Simple reflex action

This is an involuntary quick response to a stimulus without conscious thought. It is also known as an ***instinctive reflex*** which does not have to be learnt. They include sneezing, coughing, salivating, the knee jerk and removal of a hand from a hot flame. For instance, when one steps on a sharp object, the knee jerk enables the removal of the foot thus avoiding further injury.

Reflex arc of a hand being withdrawn from a hot flame



The stimulus is perceived by the receptors, which change it into nervous impulse (transduction). The impulse travels along the sensory neurone to the spinal cord. In the grey matter of the spinal cord, the sensory neurone makes synaptic connections to the relay neurone and impulses move from the sensory neurone to the relay neurone across synapses. The relay neurone in turn transmits the impulse to the motor neurone across a synapse. The impulse then moves from the spinal cord to the effector muscles through the motor neurone. The impulse causes the muscles to contract or relax depending on the stimulus.

Characteristics of a simple reflex action

- ✓ It occurs rapidly i.e. the action occurs very fast.
- ✓ It is inborn (innate) but not learnt.
- ✓ It is coordinated by either the brain or spinal cord but usually initiated by spinal cord.
- ✓ It occurs without one's will.
- ✓ It is a repeated response to a similar stimulus.
- ✓ Three neurons are involved.

Examples of simple reflex actions

1) Blinking when a foreign body falls on the eye.
2) Withdraw of the arm when someone accidentally touches a hot body.
3) Sneezing.
4) Knee jerk i.e. a relaxed leg gives a forward kick when tapped slightly below the patella.
5) With draw of the foot from a sharp object.

How a hand is withdrawn from a hot object (an example of a simple reflex action)

When one accidentally touches a hot body using a finger, the receptors in the finger receive the stimulus and change it into nervous impulses that travel along the sensory neurone to the spinal cord and then cross the synapse.
The impulse is then handed over to the relay neurone in the spinal cord (grey matter) and then cross another synapse.
The relay neurone in turn hands over the impulse to the motor neuron.
The motor neuron then carries the impulse from the spinal cord to the effector muscles of the hand. This causes the muscles to contract and the hand is removed from the hot body.
At the same time, the original message is sent to the brain which then interprets it as pain or heat.
Note; these processes occur rapidly in the body without the awareness of the individual

Importance of simple reflex actions to animals

- They help animals to 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.

Conditioned reflex action

This is the type of reflex action which involves learning. Organisms learn to respond to strange or meaningless stimuli by associating it with other meaningful/familiar stimuli, e.g. ***the Ivan Pavlov's experiment.***

A scientist called Ivan Pavlov performed an experiment to demonstrate a conditioned reflex action in a dog.

In his experiment he noticed that the sight or smell of food triggers off salivation reflex in a dog.

When Pavlov gave his dog food, the taste made the dog salivate. He later modified the experiment by ringing a bell each time he fed the dog. The two unrelated stimuli, that is sound and taste, were sensed simultaneously.

After several presentations of the two stimuli, he discovered that the dog salivated when the bell was rang even without the presentation of food. The dog had learned to associate the ringing of the bell to food, to a point whereby ringing the bell alone caused salivation.

Characteristics of a conditioned reflex action

- It is a temporary reflex
- It involves learning
- It is coordinated in the brain
- It involves more than one stimuli
- It involves association of stimuli
- It is reinforced by repetition
- Responses are involuntary

Similarities between simple and conditioned reflex actions

- They both involve the central nervous system particularly the brain.
- Both are autonomic responses
- Both are associated with a stimulus.
- Both involve neurons for the transmission of impulses

Differences between simple and conditioned reflexes

Conditioned reflex action	Simple reflex action
Stimulus and responses are not directly related	Stimulus and response are related
More than one stimulus is required to cause a response	Only one stimulus is needed to cause a response
It involves learning	No learning but in born
Takes time	Takes a very short time
It is coordinated in the brain only	Co-ordinated in either the brain or spinal cord
Responses occur as a result of repetition and practice.	Responses occur instantly after a stimulus.
Is an inborn, automatic response	Is a learned, automatic response
It is always constant	Can be reinforced through rewards or punishment.

Similarities between the nervous and endocrine system

- Both are affected by change in stimulus.
- Both cause a response.
- They provide a means of co-ordination in the body.
- Both systems transmit messages.

Differences:

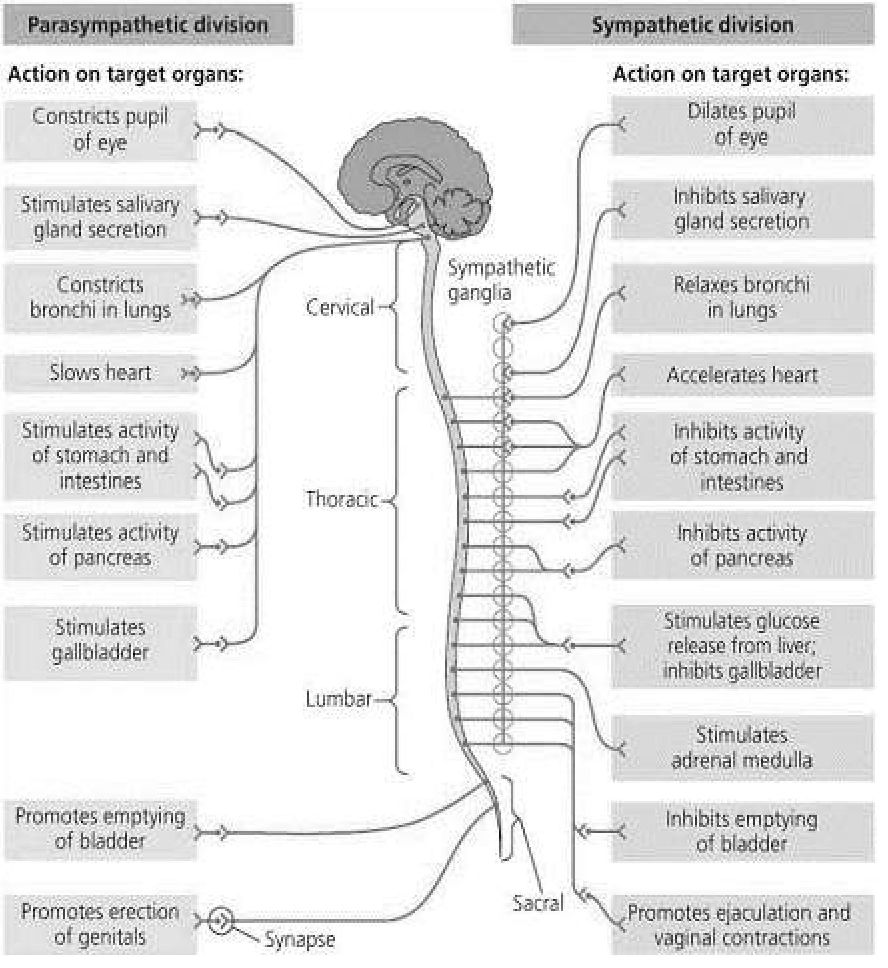
Nervous system	Endocrine system
Nerve impulses are electrical	Impulses are chemical
Responses are fast as the impulses are carried fast.	Responses are slow but long lasting.
Impulses go along nerve fibres.	Hormones are carried in blood.
This effect is more localized (specific).	Effect is wide spread in the whole body.
Stimulus arises from any part of the body where sensory receptors are located.	Stimulus arises from specific places only e.g. endocrine glands.

AUTONOMIC NERVOUS SYSTEM

This is subdivided into two parts all controlling involuntary activities. These are the sympathetic nervous system and parasympathetic nervous system.

Most pathways in each division consist of preganglionic neurons (having cell bodies in the CNS) and postganglionic neurons (having cell bodies in ganglia in the PNS).

The parasympathetic and sympathetic divisions of the autonomic nervous system



SENSE ORGANS (RECEPTOR ORGANS)

A receptor is a cell or tissue which can transform an impulse into action potential in neurones. It informs the CNS of external and internal changes.

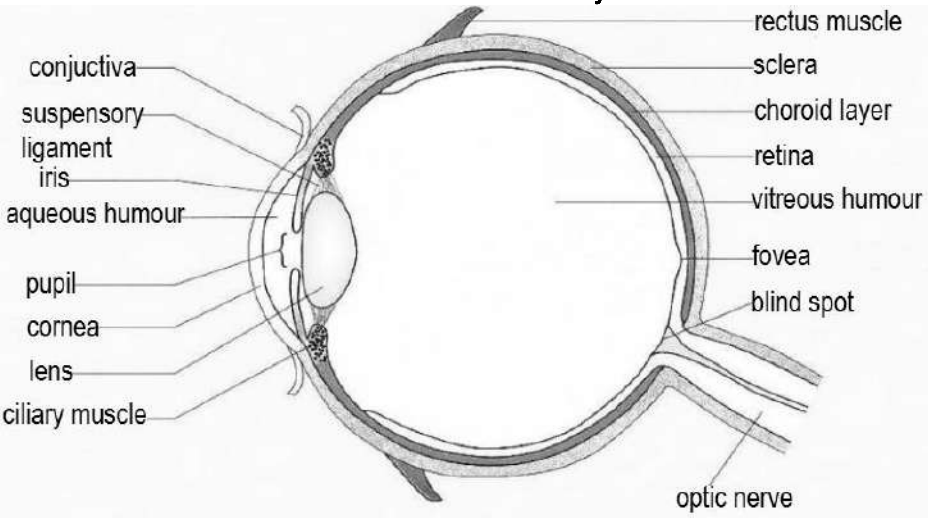
Characteristics (properties) of receptor cells

1) **Transduction**: Receptor cells are capable of changing physical stimuli into an electrical impulse.
2) **Sensitivity**: Receptor cells are able to detect the slightest change in their environment (stimulus).
3) **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. For example, the inability to hear a clock's ticking in a room after prolonged exposure to its ticking. Receptors however vary in the speed with which they become adapted, thus phasic receptors are those which adapt rapidly while tonic receptors are those which adapt slowly. Adaptation is advantageous in the following ways:
   - It provides animals with precise information about changes in the environment.
   - It enables the nervous system ignore unchanging environmental conditions and concentrate on monitoring those of survival value.
   - It prevents overloading of the nervous system with irrelevant information which reduces energy wastage.
4) **Inhibition:** Receptor cells can be stopped from firing impulses by special synaptic connections. As a result, certain impulses are transmitted only when required.
5) **Precision:** Receptors are able to transmit the information precisely without alteration.
6) Receptors are sensitive to low intensity stimulation. E.g. in some insects, tactile receptors can respond to airborne sounds when stimulated just 3.6 nm. In rod cells of human eyes, high sensitivity results from retinal convergence.
7) They are specialized in structure and position.

Therefore receptors have the following properties: *transforms energy to action potentials; Specialized in structure and function; Creates generator potentials; Has a threshold value of stimulation; Becomes adapted; Sensitive to low intensity stimulation*

THE HUMAN EYE

Structure of the human eye



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.

Functions of different parts

Sclera: It maintains the shape of the eyeball and protects the inner layer of the eye.

Conjunctiva: It is a thin and transparent layer over the cornea and is continuous with skin over the eye. It protects the cornea.

Choroid layer: It's a pigment layer present beneath the sclera and contains numerous blood vessels that nourish the retina. The pigmentation prevents unnecessary reflection within the eye.

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.

Suspensory ligaments: These are thread-like ligaments that attach the ciliary body to lens hence holding the lens in position.

The aqueous humour:

- It is a solution of sugar, salts and proteins.
- The aqueous humor is a watery fluid which maintains the shape of the eye.
- It also refracts light into the pupil and the lens.

The vitreous humour:

- It is a jelly-like substance that fills the inner cavity of the eye.
- It is transparent and maintains the shape of the eye.
- It refracts light to the retina.

The ciliary body: This contains ciliary muscles, which control the size of the lens during viewing nearby or distant objects.

The lens.

- It is transparent and held by suspensory ligaments.
- It refracts light to make an image on the retina.

The iris

- This is made up of an opaque tissue the center of which is a hole called pupil that allows in light to form an image on the retina.
- The contraction of the muscles of the iris increases the size of the pupil and relaxation decreases the size of the pupil.
- It is therefore responsible for controlling the amount of light entering the eye.

The retina: This is a layer containing photoreceptor cells (light sensitive cells). It is where the image is formed in the eye.

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. When an image falls on this point, it is not taken to the brain thus blind spot.

The fovea: This is a small depression in the center of the retina. It has only cones in a high concentration. It is therefore a region on the retina that contains the largest number of sensory cells. Due to this, it produces the most accurate images in the eye.

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.
Eye lashes: They prevent dust particles and other objects from entering the eye.

Working of the eye

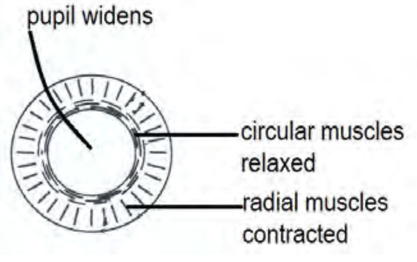
The camera and the eye work on the basic principles which include;
i) Control the amount of light entering the structure.
ii) Focuses the images of the external world by the lens system
iii) Registering images on sensitive surface
iv) Processing a captured image to produce a pattern which can be seen.

All the working principles of the eye and the camera are the same only that the lens of the human eye does not move forward or backward like that of the camera but it adjusts the distance of focus by undergoing changing of its shape.

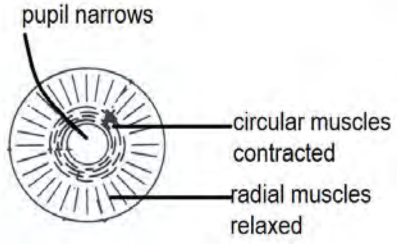
Control of light amount entering the eye

The iris controls the amount of light entering the eye. It is made up of circular and radial muscles. This is done to protect the retina from damage by bright light and the wide size of the pupil during dim light allows in enough light of low intensity.

Control of amount of light entering the eye in dim light
- In dim light, radial muscles contract,
- Circular muscles relax,
- Pupil widens and more light is admitted into the eye.

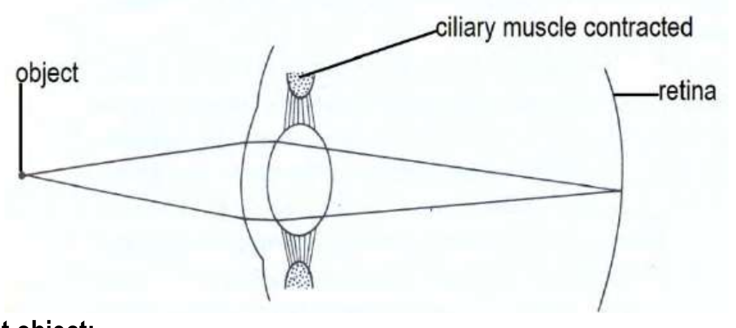


Control of amount of light entering the eye in bright light
- Circular muscles of the iris contract,
- Radial muscles relax,
- Pupil becomes smaller and narrower hence less light is admitted into the eye.

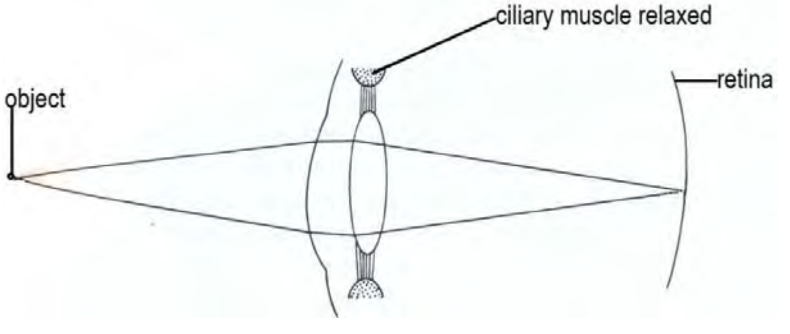


Accommodation of the eye

Accommodation is the ability of the eye to change the focal length of the lens when viewing distant or nearby objects.
Accommodation for a nearby object:
When looking at a nearby object, the ciliary muscles in the ciliary body contract, the suspensory ligaments slacken. This makes the lens short and thick. This increases the ability of the lens to refract light and reduces the focal length of the lens for the nearby object to be seen clearly.



Accommodation for a distant object:
When viewing a distant object, the ciliary muscles in the ciliary body relax. This causes tension in the suspensory ligaments. The suspensory ligaments pull the lens apart making the lens thin and long. This makes the lens to refract less and increase the focal length of the lens.



Summary of accommodation

Nearby object	Distant object
Diverging light rays from a nearby object are refracted by cornea.	Parallel light rays from a distant object are refracted by the cornea.
Ciliary muscles in the ciliary body contract.	Ciliary muscles in the ciliary body relax.
Suspensory ligament slacken.	Suspensory ligaments develop tension.
The lens become short and thick.	The lens becomes thin and long.
The focal length of the lens decreases	The focal length of the lens increases.
Light rays are refracted to the retina.	Light rays are refracted to the retina.

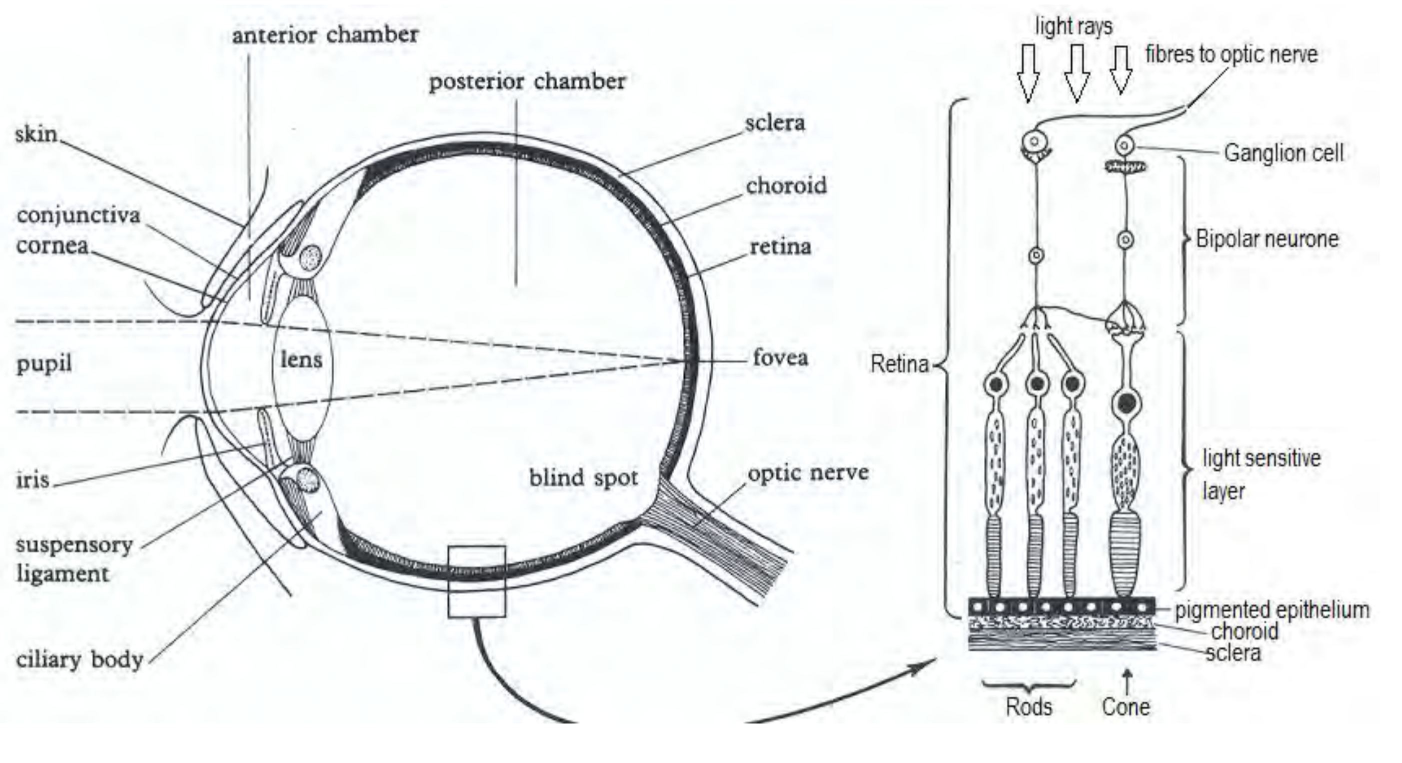
THE RETINA

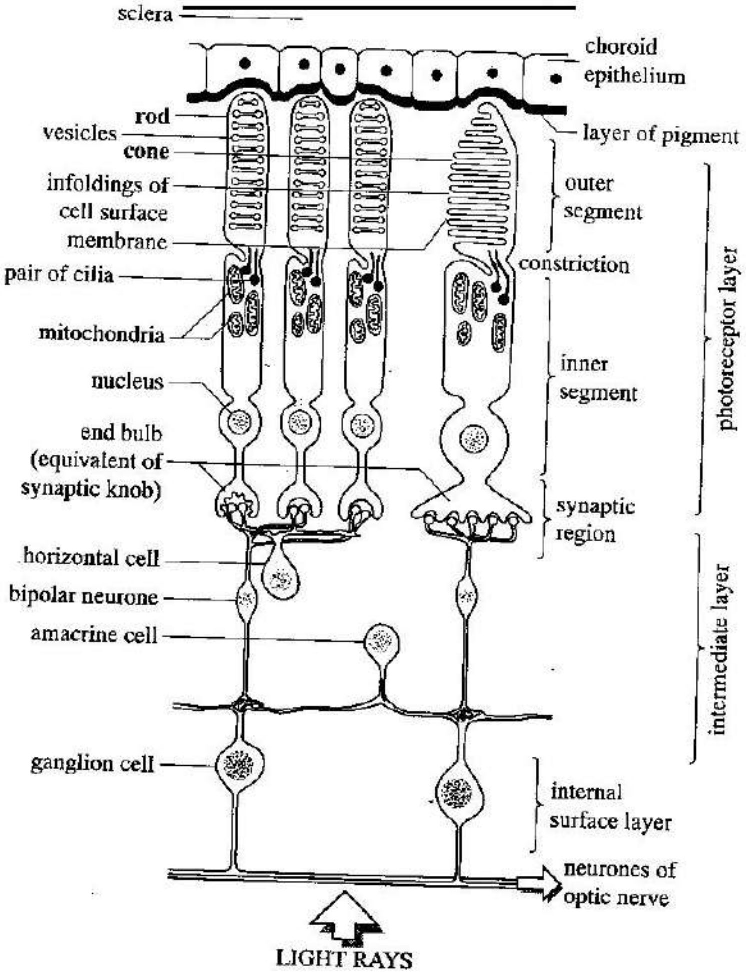
The human retina contains **rods** and **cones,** two types of photoreceptors that differ in shape and in function.
Rods are more sensitive to light but do not distinguish colours; they enable us to see at night, but only in black and white.
Cones provide colour vision, but, being less sensitive, contribute 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 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 human retina

The retina is composed of 3 layers of cells containing a characteristic type of cells, i.e.

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.





Horizontal cells and ***amacrine cells*** function in neural pathways that integrate visual information before it is sent to the brain. *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.

The structure and composition of cones and rods

Rods and cones have an essentially similar structure and their photosensitive pigments are attached to the outer surface of the membrane in the outer segment. They have four similar regions where structure and function are shown below;

i) Outer segment:

This is the photosensitive region where light energy is converted into a generator potential. The entire outer segment is composed of flattened membranous vesicles containing the photosensitive pigments.

ii) 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.

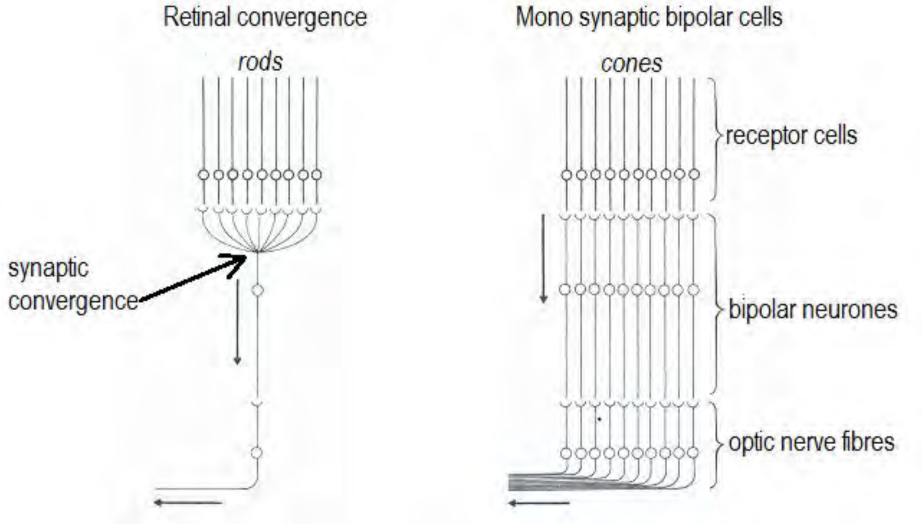
iii) Internal/inner segment:

This is an actively metabolic region. It's packed with mitochondria producing energy for visual processes and polysomes for synthesis of proteins involved in the production of membranous vesicles and visual pigments. The nucleus is located in this region.

iv) Synaptic region:

Here the cells form synapses with bipolar cells. Different bipolar cells may have synapses with several rods; this is called **synaptic convergence** and it increases visual sensitivity.

Mono synaptic bipolar cells link one cone to one ganglion cell and this gives the cone greater visual acuity than the rods.

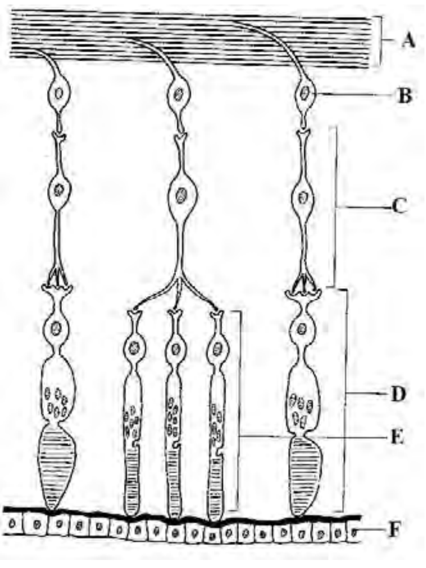


The high visual acuity in the cones is also because they are highly packed at fovea with direct connection to the optical nerves.

Visual acuity is the amount of detail that can be seen (image sharpness). Although there are far more rods than cones, we use cones most of the time because they have fine discrimination and can resolve colours. This is because one cone cell synapses to one bipolar cell which in turn synapses onto one ganglion cell as the information is relayed to the visual cortex. The more densely-packed the cone cells, the better the visual acuity. In the fovea of human eyes there are 160 000 cones per mm^2, while hawks have 1 million cones per mm^2, so they really do have far better acuity.

Differences between rods and cones

Rods	Cones
Photochemical pigment is readily regenerated when bleached.	Pigment take long to be regenerated once bleached.
Poor colour vision	High ability of recognizing colours.
Have retinal convergence.	Lack retinal convergence.
The photosensitive pigment is rhodopsin.	The photosensitive pigment is iodopsin.
Outer segment is rod shaped	Outer segment is cone shaped
Greater numbers (about 10^9 cells per eye)	Fewer numbers (about 10^6 cells per eye).
Distributed more at the periphery of the retina (absent at fovea), so used for peripheral vision.	Concentrated in the fovea, so can only detect images in centre of retina.
Sensitive to low light intensity – can detect a single photon of light, so are used for night vision.	Not sensitive to low light intensity – need bright light, so only work in the day.
Only 1 type, so only give monochromatic vision.	3 types (red green and blue), so are responsible for colour vision.
Many rods usually connected to one bipolar cell, so poor acuity (i.e. rods are not good at resolving fine detail).	Each cone usually connected to one bipolar cell, so good acuity (i.e. cones are used for resolving fine detail such as reading).



WORKED OUT EXAMINATION QUESTIONS

(a) (i) Name the structures labelled A to F

A – Optic nerve fibres; B - ganglion cell; C – bipolar neurone;
D – cone cell; E – rod cell; F – choroid epithelium / layer [pigment epithelium / layer] ;

(b) What is the significance of the fact that:

(i) Several cells of type labelled E connect to one cell in layer C?

Retinal convergence increases the eye's sensitivity. Light which activates one rod cell (cell E) may be insufficient to generate an action potential in the bipolar neuron (cell C) connected to it yet several rods when hit by light simultaneously may activate action potential the bipolar neuron (cell C) due to summation of generator potentials. Impulse propagation to the CNS results in image formation.

(ii) One cell of type labeled D connects to one cell in layer C?

It improves visual acuity / precision / resolving power of the eye because light from two objects close together stimulate two cones (cell D), the brain receives two impulses and interprets this as two separate objects rather than when different impulses summate into a single message received by the brain]

MECHANISM OF PHOTORECEPTION

Light reception in the rods

Each rod or cone in the vertebrate retina contains visual pigments that consist of a light absorbing molecule called **retinal** (a derivative of vitamin A) bound to a membrane protein called an **opsin.** The opsin present in rods, when combined with retinal, makes up the visual pigment **rhodopsin.**
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. Because it changes the color of rhodopsin from purple to yellow, light activation of rhodopsin is called "bleaching."
When this potential difference is large enough, it results into an impulse being generated into an optic nerve leading to the brain.
Rhodopsin returns to its inactive state when enzymes convert retinal back to the *cis* form for it to be stimulated again (dark adaptation). In very bright light, however, rhodopsin remains bleached, and the response in the rods becomes saturated. If the amount of light entering eyes decreases abruptly, the bleached rods do not regain full responsiveness for some time. This is why you are temporarily blinded if you pass abruptly from the bright sunshine into a dark place.

Rods are more sensitive than the cones because:

i) 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.
ii) They show retinal convergence where separate rods add up or summate to build a generator potential upto a threshold.

Qn. How is a rod cell suited for photoreception?
Qn. How are rod cells suited for photoreception?

WORKED OUT EXAMINATION QUESTIONS

1) Suggest why convergence of rod cells in the retina of human eyes reduces the ability to read small print in dim light.
Light falling on groups of rods is transduced into an impulse in only one receptor neurone so the power of resolution is low
2) Suggest a chemical explanation of convergence
Only when many synaptic knobs release their neural transmitter simultaneously does its concentration reach a threshold at which depolarization of the post-synaptic membrane occurs.
3) Why should pilots waiting to fly at night not be exposed to bright lights?
Even a short exposure to bright light would cause the rhodopsin in the rods to break down so destroying the pilot's night vision.
4) Many nocturnal mammals like cats have a reflective layer – the tapetum lining the back of the eye rather than a pigmented layer. Suggest the value of this arrangement
Light will be reflected back off the tapetum so that it passes twice through the light-sensitive cells, thereby increasing the size of the generator potential developed in the cells
5) Explain why when sitting in a dimly lit room, objects often appear slightly fuzzy and colours are more difficult to distinguish.

Seeing objects using rod cells leads to lower visual acuity; rod cells are insensitive to colour

6) ***Explain why brightly coloured objects often appear grey in dim light***

Only rods are stimulated by low-intensity (dim) light. Rods cannot distinguish between wavelengths / colours of light, therefore the object is perceived only in a mixture of black and white i.e. grey.

7) ***At night, it is easier to see a star in the sky by looking slightly to the side of it rather than directly at it. Suggest why this is so.***

Light reaching the earth from a star is of low intensity. Looking directly at a star focuses light on to the fovea, where there are only cone cells. Cone cells respond only to bright light, so they are not stimulated by dim light from the star and it cannot be seen. Looking to one side of the star ensures that light from the star is focused to the periphery of the retina, where there are mostly rod cells. These are stimulated by low light intensity and therefore the star is seen.

8) ***What is the role of:***
   - ***i) Horizontal cells?*** They cause lateral inhibition which increases sensitivity and visual acuity i.e. they inhibit (cancel out) equal intensity stimuli if received from two adjacent rods thereby increasing contrast between weakly stimulated and strongly stimulated areas. E.g. edges of objects stand out more clearly.
   - ***ii) Amacrine cells?*** After partial processing, they transmit information about changes in the level of illumination

9) **Explain the following phenomena:**
   - **a) When a person moves from bright sunlight into a dimly-lit room; objects in the room cannot at first be seen but they gradually become visible.**

   In bright light, the circular muscles contract to narrow the pupil; and reduce on over-stimulation of the retinal cells by entry of light into the eye. In dim light, radial muscles contract to dilate the pupil slowly to allow entry of light; whose threshold at first is low to stimulate the rods for objects to be seen; but later improves to enable vision as the pupil dilates fully;
   - **b) In the dimly-lit room, objects are only visible in black and white.**

   Rods which are sensitive to light of low intensity do not respond to light of various wavelengths; causing images to appear black and white;
   - **c) Some nocturnal animals like cats close their pupils to a vertical slit and also squint in bright light**

   The retina of nocturnal animals is almost entirely composed of rods; with rhodopsin which is particularly sensitive to low levels of light and breaks down so rapidly in bright light; The slit pupil and squinted eyes reduce the amount of light entering the eye to enable rhodopsin form faster than it breaks down for vision to occur;
   - **d) When trying to see a faint star in the sky, it is better to look slightly to one side of it rather than directly at it.**

   When you look directly at an object, its image forms on the retina's *Fovea centralis* (yellow spot) which is packed with cone cells yet these are only activated by bright light, hence can't see in dim light. Looking slightly away from a faint star moves the image off the fovea and onto parts of the retina that have more rod cells, which are more light-sensitive than the cones.
   - **e) If both your eyes are open and you press the side of one of your eyeballs, you see double.**

   Pressing of eye ball distorts the eye position such that the two eyes are unable to look directly at an object in the same direction, hence the brain fails to blend together the images from the two eyes, causing double vision to be perceived

Colour perception in the cones

There are three different kinds of cone cell, each with a different form of opsin (they have the same retinal). These three forms of iodopsin are sensitive to different parts of the spectrum, so there are red cones (10%), green cones (45%) and blue cones (45%).

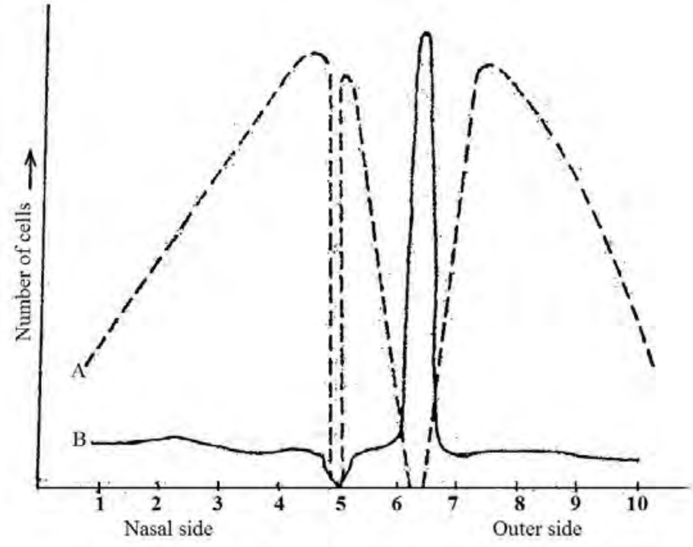
Trichromatic theory of colour vision:

It suggests that different colours are produced by the degree of stimulation of the different types of cone.

When viewing an object, the three types of cone are stimulated to various degrees depending on the wavelength of light the object reflects. By comparing the nerve impulses from the three kinds of cone, the brain can interpret any colour. For example, when the red/blue/green receptors are stimulated in the ratio of 10:86:15, the color of an object is interpreted by the brain to be blue. When the ratio is 13:14:86, the color is interpreted as green, and when it is 100:20:99 the color is yellow.

Question:

The figure below shows the number of receptor cells (types A and B) in the human retina along a horizontal line from the nasal side of the eye to the outer side. Distances are expressed in arbitrary units.



The table below shows the absorption of different wavelengths of light by three varieties of the light sensitive pigment **iodopsin** as suggested by the trichromatic theory of colour vision in man.

Light wavelength (nm)	Amount of light absorbed as a percentage of maximum		
	Red iodopsin	***Green iodopsin***	***Blue iodopsin***
660	5	0	0
600	75	15	0
570	100	15	0
550	85	85	0
530	60	100	10
500	35	75	30
460	0	20	75
430	0	0	100
400	0	0	30

a) From the graph;
   i) With a reason in each case, identify the types of receptor cells represented by letters A and B
   ii) Explain why there are no receptor cells at position 5
   iii) What is the name of the region of the retina at position 6?
   iv) Explain how position 6 is suited for functioning

b) From the table;
   i) Plot a suitable graph to represent the data.
   ii) Using the data in the table, comment on perception of the wavelength of light as colour.

c) From your knowledge of the retina explain why small objects close together can be more easily distinguished by cones than by rods.

Colour blindness

It is the inability to distinguish between colours. Red-green colour blindness is the commonest, although other forms of colour blindness are also possible, but are much rarer.

The red, green and blue opsin proteins are made by three different genes. The green and red genes are on the X chromosome, which means that males have only one copy of these genes (i.e. they're haploid for these genes). About 8% of males have a defect in one or other of these genes, leading to red-green colour 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 compesated for by the other e.g. it cancels the effect of the blind spot and provides the basis of stereoscopic vision.

Stereosccopic vision depends upon the eyes simultaneously producing slight different retinal images which the brain resolve as one image.
Binocular and stereoscopic vision enables predator animals e.g. hawks and lions to accurately judge the distance to catch prey. Their eyes are set in front.
The animals with eyes on the sides of their head e.g. a rabbit (a common prey) rely on:

- The relative size of an object.
- The shadow it creates.
- The movement of it relative to distant non-moving objects, to judge distance because they have poor stereoscopic vision due to little overlapping of visual field results.

However, they have wide overall visual field, which is good for detecting movements.

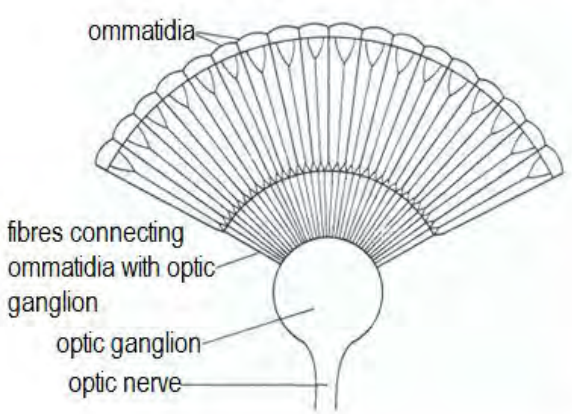
Eye defects

An eye defect is a condition where the eye fails to focus an object well unless aided by external lenses. The common eye defects include:
Myopia results from eyeball being too long, so that the image is brought to a focus in front of the retina; this is corrected by a concave lens.
Hyperopia results from eyeball being too short, so that the image is brought to a focus behind the retina; this is corrected by a convex lens.
Astigmatism is the condition in which asymmetry of the cornea and or lens causes uneven refraction of light around 360 degrees of a circle, resulting in an image that is not sharply focused on the retina.

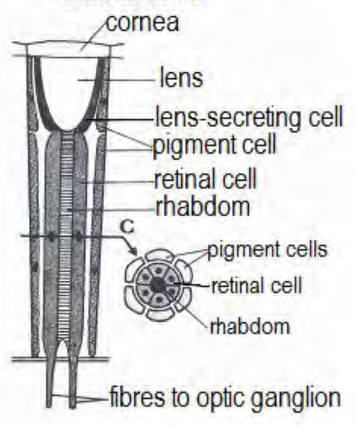
COMPOUND EYE

Arthropods have compound eyes and some have simple eyes.
Simple eyes consist of a single lens able to distinguish between light and dark, unable to produce an image.
A compound eye consists of up to thousand light detectors called ommatidia, each with its own light focusing lens. Each ommatidium detects light from a tiny portion of the visual field.
A compound eye is very effective at detecting movement, an important adaptation for flying insects and small animals constantly threatened with predation.
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.
Insects have an excellent colour vision, and some (including bees) can see into the ultra-violet (UV) range of the electromagnetic spectrum. Because UV light is invisible to us, we miss seeing differences in the environment that bees and other insects detect.

Structure of the compound eye



Longitudinal section through an ommatidium



Note: C - *shows the cross section through ommatidium*

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 ommatidium from its neighbor.
The ***rhabdom*** is the light sensitive part of the ommatidium where photochemical stimulation occurs leading to depolarization of the membrane of the retinal cells.
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.

Differences between compound eye and mammalian eye

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 and very elastic.	Lens is membranous and elastic.
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.

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.

Question:

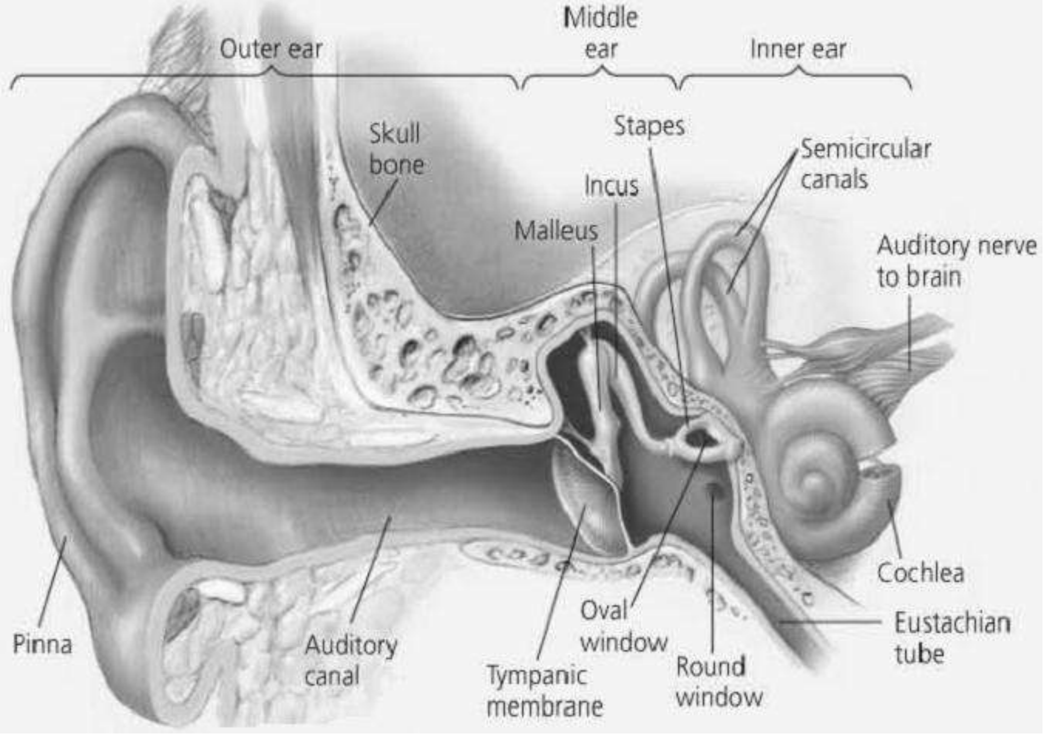
Why do insects generally have very low visual acuity compared with the vertebrates?
How have insects overcome the above problem?

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:

1) Sound (hearing)
2) Head movements
3) Changes in gravity (balance or posture)

Structure of the ear



The ear is made up of three areas i.e. the outer ear, middle ear and inner ear.

1. **The outer ear:** This is the tube opening to the side of the head and inwards stopping at the eardrum. It consists of the pinna, auditory canal and the ear drum.

The outer projecting portion of the outer ear is known as the ***pinna (auricle).*** Its function is to receive and concentrate sound waves.

The ***auditory canal*** has hairs and wax that trap foreign bodies. It transmits sound waves to the eardrum (tympanum).

The ***ear drum*** is a thin membrane. The eardrum transmits sound waves to the middle ear.

2. **The middle ear:**

This is a cavity in the skull filled with air. It is comprised of three small bones called ***ossicles****, i.e.* ***hammer*** *(****malleus****),* ***anvil*** *(****incus****) and* ***stapes*** *(****stirrup****).* They transmit sound vibrations from the eardrum to the ***oval window*** *(****fenestra ovalis****) that* transmits sound vibrations to the inner ear.

It communicates with the mouth cavity through the ***Eustachian tube*** (a slender canal that connects the middle ear to the pharynx). It equalizes the air pressure on the two sides of the eardrum.

3. **The inner ear:**

The inner ear is filled with a fluid and consists of mainly a coiled tube known as the cochlea. The cochlea has sensory ***auditory nerve*** that transmits impulses to the brain.

The ***semi-circular canals***, ***utriculus*** and ***sacculus*** form the ***vestibular apparatus***, which controls body balance and orientation.

The ***round window*** *(****fenestra rotunda****)* equalizes pressure in the cochlea.

The process of hearing in mammals

The pinna receives and concentrates the sound waves.

They are transmitted to the eardrum, which vibrates.

The vibrations of the eardrum are transmitted to the ossicles that vibrate and transmit the vibrations to the oval window at the entrance of the **vestibular canal** of the cochlea.

The **perilymph** (fluid in the vestibular canal) vibrates and causes **Reissner's membrane** to be displaced.

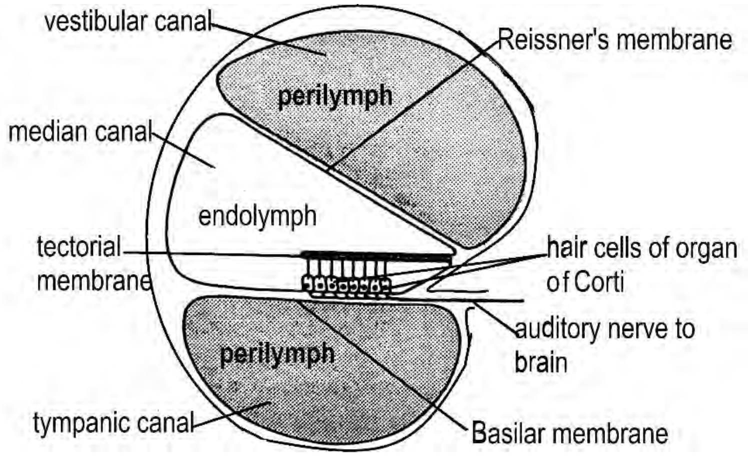
The displacement of Reissner's membrane causes the **endolymph** in the **median canal** to vibrate, which in turn causes the **basilar membrane** to vibrate.

The vibration of the basilar membrane stimulates sensory cells (in the **organ of Corti**), which generate impulses.

The impulses are transmitted by the auditory nerve to the brain, which interprets them into sounds.

The vibrations of the basilar membrane disturb the perilymph in the **tympanic canal**. The round window takes up these vibrations.

Transverse section of the cochlea



Qn: Explain why even though the head is not moved, the direction from which a sound comes may be determined?

Deafness

Deafness is the inability to hear. It may be brought about by a defect in the nerves or the conduction of waves.

Causes of deafness

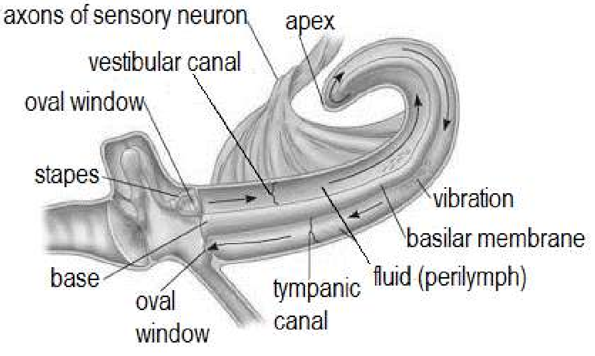
1) ***Accumulation and hardening of wax in the outer auditory canal*** that presses against the eardrum. This can be controlled by use of cotton buds to remove excess wax after the wax has been softened using warm water.
2) ***Blocking of the Eustachian tube*** as a result of accidents and certain infections such as the common cold, etc. This can be treated by use of antibiotics to kill the bacteria that caused the infection.
3) Some individuals are born with ***thick eardrums*** that do not easily vibrate. This can be solved by use of hearing aids.
4) ***Ruptured eardrum*** due to accidents and infections. Sometimes the eardrums heal on their own or a hearing aid can also be used.

5) Damage to the cochlea as a result of ***exposure to loud noise over a long period of time***. This can be prevented by keeping sound volume low because once the cells of organ of Corti in the cochlea are damaged, they cannot be repaired.
6) ***Fused ossicles*** due to infections that cause inflammation in the middle ear. Some individuals are born with fused ossicles. The ossicles do not hit each other when they vibrate. This can be treated by medication to kill the microorganisms that caused the infection or surgical operation to replace the ossicles.
7) ***Damage to the hearing centre of the brain*** also causes deafness.

Worked out question:

What prevents pressure waves from reverberating within the ear and causing prolonged sensation?

Once pressure waves travel through the vestibular canal, they pass around the apex (tip) of the cochlea. The waves then continue through the tympanic canal, dissipating as they strike the round window. This damping of sound waves resets the apparatus for the next vibrations that arrive.



Discrimination of sound intensity

The human brain is able to discriminate the sound quality in terms of pitch and intensity.

The pitch of sound (frequency) depends on its wave length.

High tones are as a result of sound of high frequency (short wave length) while low tones are as a result of sound of low frequency (long wave length).

The basilar membrane is about 2-5 times wider at the apex than at its base between the oval and round window. Sound of short wave length (high frequency) vibrates relatively a short portion of basilar membrane. Only the hair cells nearest the oval window will be stimulated. The impulses fired from these few cells and arriving at the brain are interpreted as a high pitched sound.

On the other hand, sound of a longer wave length (low frequency) causes a larger portion of the basilar membrane to vibrate, therefore the sensory hair cells that are stimulated further along this membrane are stimulated. The impulses fired from these cells when they reach the brain are interpreted as sound of low pitch.

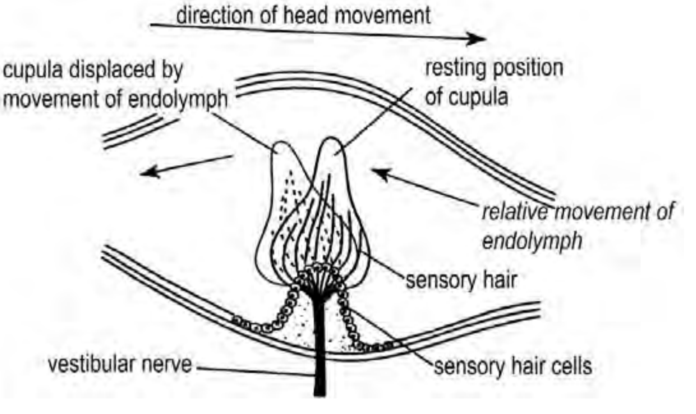
In this way, the brain is therefore able to determine the pitch of each sound according to the source of impulse from the cochlea.

The role of the semi-circular canals and utriculus and sacculus in maintaining body balance

i) Semi-circular canals:

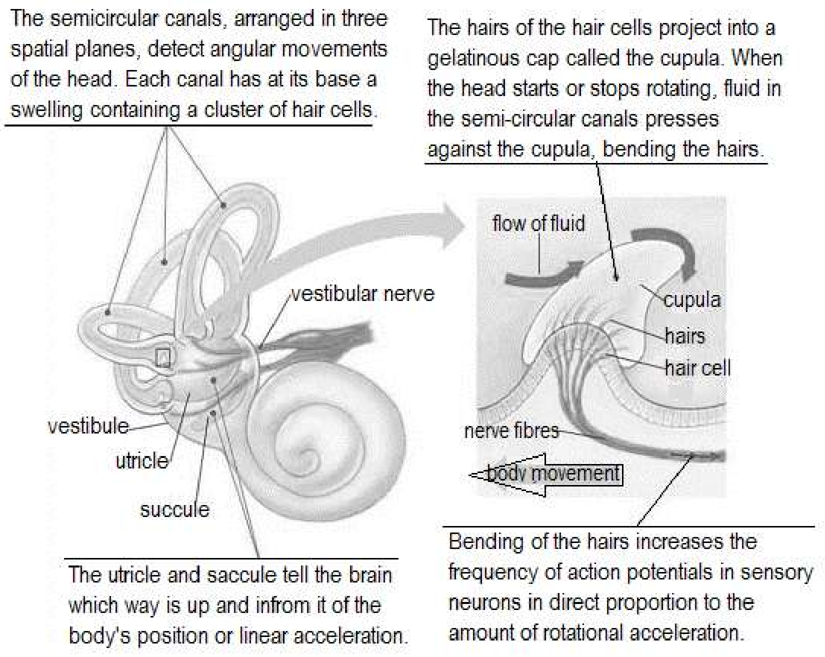
The semi-circular canals are important in in dynamic equilibrium. Each semi-circular canal terminates in a swelling known as the **ampulla**, which contains the **cupula** (dome-shaped, gelatinous structure). The cupula is in contact with sensory hairs.

The canals are filled with fluid and are three in number, arranged in three planes; vertical canals detect movement in upward direction, horizontal canals detect backward and forward motion while lateral canals detect sidewise movements of the head.



When the head moves, the endolymph in the ampulla of one of the canals moves in the opposite direction and deflects the cupula. This stimulates the **cristae** (sensory cells), which generate impulses. The impulses are transmitted by the **vestibular neurones** to the brain.

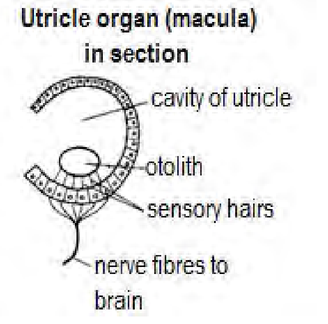
The pattern of impulses is interpreted by the brain which detects the direction and speed of movement and sends instructions to relevant organs that maintain dynamic balance.



ii) Utriculus and sacculus:

The utriculus and sacculus contain structures called **maculae** which maintain body posture (static equilibrium).

Each macula consists of a patch of sensory cells with the free ends embedded in the **otolith** (gelatinous granule of calcium carbonate). The otolith detects the position of the head with respect to the force of gravity. By varying the position of the head, the pull of gravity over the hairs on the otolith tilts them accordingly.



The different influences of the pull of gravity result in a pattern of impulses to the brain.

The impulses are interpreted thus providing information about the position of the head and accordingly sends instructions to relevant muscles to restore balance. When the head is upright, the otolith is positioned on top of the sensory cells and no stimulation occurs.

Deafness

Deafness is the inability to hear. It may be brought about by a defect in the nerves or the conduction of waves.

Causes of deafness

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9) ***Blocking of the Eustachian tube*** as a result of accidents and certain infections such as the common cold, etc. This can be treated by use of antibiotics to kill the bacteria that caused the infection.
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14) ***Damage to the hearing centre of the brain*** also causes deafness.

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

1) The sound vibrations do not spread so wide and their echoes are so refined that they pin point the obstacle on which they are correctly reflected.
2) The echoes allow location of even small objects since these sounds have short wave lengths.

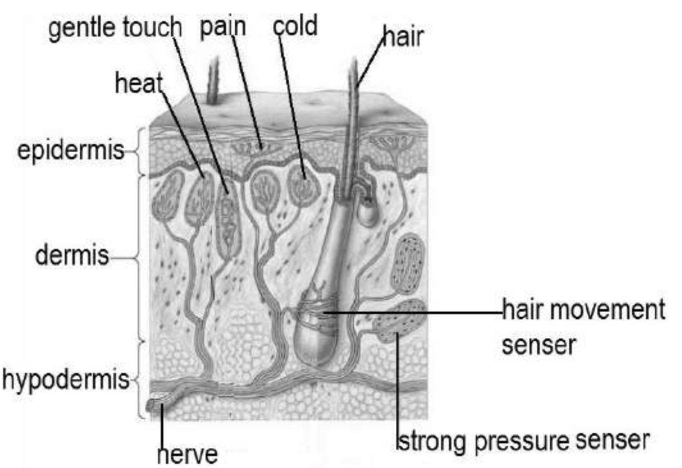
Differences between hearing in bats and man

Bat	Man
Depend on sound produced and deflected by object.	Depend mainly on sound produced by vibrating objects in the environment.
Have the ability to eliminate noise in their echoes.	Have the ability to discriminate between sounds.
Able to detect sounds of very high frequency.	Can perceive sounds of low frequency.

THE SKIN

The skin is a sense organ responsible for the senses of pain, touch, pressure and temperature. The skin has mechanoreceptors, pain receptors and thermo receptors.
Mechanoreceptors sense physical deformation caused by forms of mechanical energy such as pressure, touch, stretch and motion. The sense of touch relies on mechanoreceptors that are dendrites of sensory neurons. Touch receptors are often embedded in layers of the skin. Other receptors sense movement of hairs. For example, cats and many rodents have extremely sensitive mechanoreceptors at the base of their whiskers which help them to detect the size of the tunnel and also get information about nearby objects.
Pain receptors detect stimuli that reflect harmful conditions like extreme pressure and temperature hence triggering defensive reactions such as withdrawal from danger.
Thermo receptors in the skin and hypothalamus detect heat and cold. (***Note:*** *in essence, we describe spicy foods as 'hot' because they activate the same sensory receptors as do hot things).*

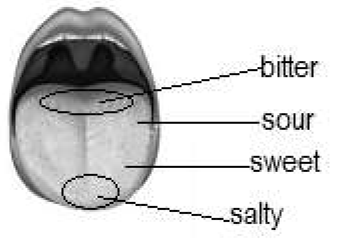
Structure of the skin as a sense organ showing the sense receptors



THE TONGUE

The tongue is a chemoreceptor organ for taste. It changes chemical stimuli in the mouth into nervous impulses. It contains chemo-receptors which carry out this function. The tongue contains taste buds, which contain the chemo-receptor cells. The tongue distinguishes between four different kinds of taste, i.e. *sweet, sour, salty and bitter*.
When a chemical is placed in the mouth, it dissolves in the moisture (saliva) in the buccal cavity. The dissolved chemicals then stimulate the taste buds in the different parts of the tongue depending on the type of taste. Impulses are then sent from the tongue through a sensory neuron to the brain and the brain interprets the type of taste.

Structure of the tongue showing the taste regions



THE NOSE

The nose is the receptor organ for smell. It is also made up of chemo-receptor cells and it is stimulated by chemicals in air. This helps the organism to respond to chemical stimuli at a distance. When air containing a chemical enters the nose, it dissolves in the moisture (mucus) in the nasal cavity. In this form, it stimulates the chemo-receptor cells in the nose. These cells send nervous impulses through a sensory neuron to the olfactory lobe of the brain where interpretation occurs.

"You will experience a painful sharpening from time to time, but this is required if you are to become a better pencil"

SUPPORT IN TERRESTRIAL PLANTS

Importance of support in terrestrial plants
1. Enables holding leaves to receive maximum sunlight for photosynthesis
2. Enables exposing flowers in the most suitable position for pollination
3. Allows holding fruits and seeds in the possible favourable position for dispersal
4. Maintains plant shape.

SUPPORT MECHANISMS IN DICOTYLEDONOUS PLANTS

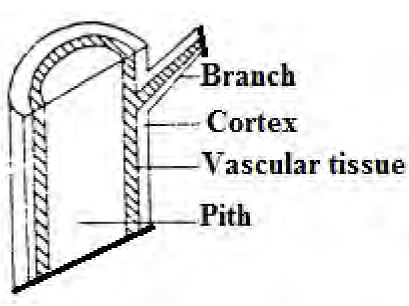
1. Turgidity of cells
Turgor pressure: outward pressure from the inside of a fully turgid cell.
When fully turgid, the close packing of parenchyma cells in cortex and pith of the stem causes them to press against one another to keep herbaceous plants and young woody plants erect. Absence / insufficient 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.
(i) Collenchyma tissue provide flexible support (a mechanical function) to stems and leaves, enabling withstanding the lateral force of the wind.
(ii) 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

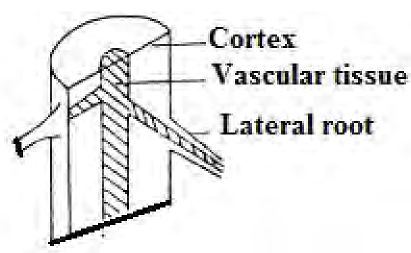
(b) Sclerenchyma fibres and sclereids have lignified cell walls and are dead when mature.
(i) The tough and elastic cell wall of elongated fibres allow the cell to be deformed but can snap back to their original size and shape when the pressure or tension is released.
(ii) Provides great tensile or compressional strength in plants parts, such as in the vascular tissues of stems and roots and the bundle sheath of leaves
(iii) 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 tissue 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



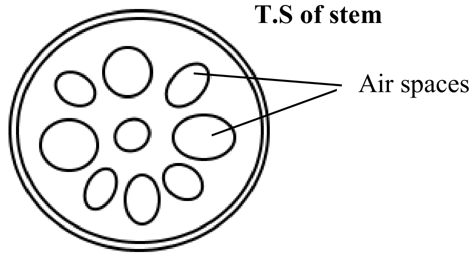
(iv) In leaves, vascular tissue is located at the upper side of midrib and lateral veins, and it extends throughout the leaf surface. This enables resisting tearing forces acting on the leaves blade by the wind.
(v) In woody stems, the lignified secondary xylem tissues (known as wood) occupy most part of the woody stem, which makes the stem very hard and rigid to avoid depending on cell turgidity for support

SUPPORT IN AQUATIC PLANTS (HYDROPHYTES)

Support from buoyancy is provided by:
1. Surrounding water, whose density is much higher than that of air, hence providing a larger upthrust force.
2. Presence of numerous large air spaces (intercellular spaces) in stems and leaves, which form air-filled cavities extending through the tissues, inside to give buoyancy.

Note: When removed from water, most hydrophytes collapse quickly because of having poorly developed (some lack) mechanical tissues (i.e. collenchyma and sclerenchyma) and xylem tissue is reduced, since it is unnecessary (no need to transport water within the body and buoyancy is provided by water for support).

COMPARISON OF SUPPORT IN TERRESTRIAL PLANTS AND HYDROPHYTES

Terrestrial Plants	Aquatic Plants
Require mechanical support because air will not hold up plant structures in the same way that water does.	Density of water is much higher than air, hence providing a larger upthrust force
The presence of collenchyma cells, sclerenchyma cells and the abundant highly lignified thick-walled xylem vessels in terrestrial plants implies that support depends on these specialized thick-walled cells.	No collenchyma and sclerenchyma cells are found in aquatic plants, and the poorly developed xylem vessels indicate that aquatic plants do not depend on these cells for mechanical support.
Small air spaces in stem since air with low density only provides limited support to plants.	There are numerous large air spaces in the stem and the leaf of aquatic plants suggest that aquatic plants depend on the buoyancy **T.S of stem** 

LOCOMOTION AND MOVEMENT

Locomotion: The act of changing position by the **entire** body.
Movement: The act of displacing body parts while maintaining the whole body in one position.

The study of movements is called **kinesiology.**

THE BASIC TYPES OF MOVEMENTS

Movement involves these basic mechanisms.

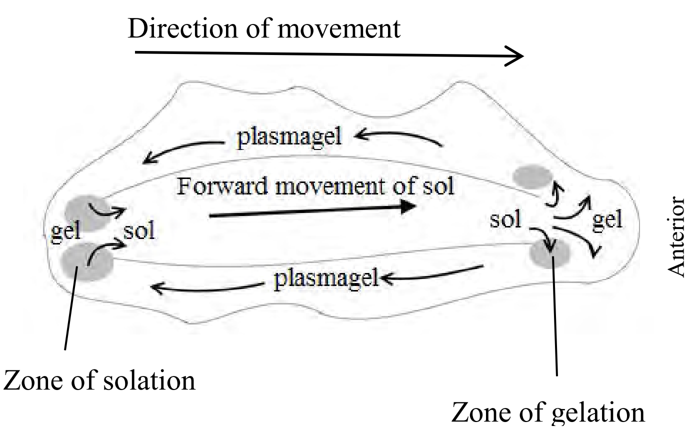
Mechanism	*Importance of the process to organisms involved*
Amoeboid movement	a) Enables amoeba to move about to **(i)** obtain food **(ii)** avoid dangers **(iii)** escape from energy. **b)** Enables white blood cells (Leucocytes) like phagocytes, macrophages of the lymph and Kupffer cells of liver to **(i)** engulf antigen or microbes **(ii)** immigrate in the circulatory fluid.

Ciliary and flagellar movement	**a)** Ciliary movement enables paramecium to **(i)** avoid danger **(ii)** drive water and food into their gullet. **b)** In certain molluscs Ciliary movement facilitates gaseous exchange by passing water currents over the gills **c)** In echinoderms Ciliary movement enables locomotion by driving water through the water vascular system. **d)** Ciliary movement of the cells lining the respiratory tract of humans drives away the microbes and dust particles towards the nose or mouth. **f)** Ciliary movement in the oviduct or fallopian tubes of human female moves ova towards the uterus. **g)** Ciliary movement in nephridia of annelids e.g. earthworms moves wastes **h)** Flagellum of sperms enables their swimming movement. **i)** Flagellum enables the movement in certain protozoans like euglena
Muscular movement	Muscular movements enable **(i)** animals to find food, mate up, avoid predators and unsuitable environmental conditions **(ii)** flow of contents in the gut and arteries **(iii)** positioning of eyes and external ears for effective functioning in some animals

AMOEBOID MOVEMENT

Definition: is a crawling-like type of movement characterised by protoplasmic protrusion to form temporary feet-like structures called pseudopodia.

●Several theories (about 8) have been advanced about the formation of pseudopodia, but the most accepted now-a-days is the **sol-gel-sol** transformation of the cytoplasm as given by ***Mast*** (1925).



Description of amoeboid movement according to the sol-gel-sol theory

● The plasmalemma attaches to the substratum

●Stimulation of the ectoplasm (plasmagel) 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.

●The movement is sustained by contraction of the outer gel layer which squeezes inwards, causing cytoplasmic streaming towards the tip of the pseudopodium.

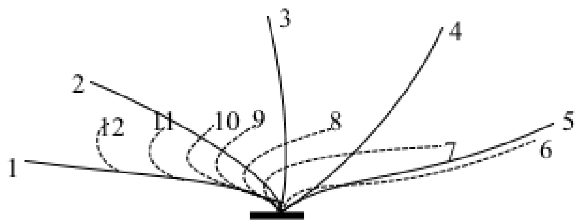
●Within the advancing tip at the **fountain zone**, plasmasol is converted to plasmagel which is then deposited on the sides of the pseudopodium. At the temporary posterior (rear/hind) end of the cell the plasma gel is converted to plasmasol, which then flows forwards into the newly formed pseudopodium so much so that the whole of body 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.

DESCRIPTION OF CILIARY MOVEMENT

Definition: the rhythmic beating of fine hair-like processes projecting from the cell membrane of certain cells (cilia).

Description by diagrammatic illustration



Description in words

●A ciliary beat cycle consists of an **effective (power) stroke phase** and a **passive recovery stroke phase.**

●During the **effective stroke phase** the fully extended cilium makes an oar-like movement towards one side exerting maximum force on the surrounding fluid. The cilia beat in reverse when the power stroke is directed toward the anterior end of the organism so as to propel it backwards while beating towards the posterior end causes the cell or organism to swim forward.

●In the **passive recovery stroke phase** which follows the effective stroke, the cilium moves back by propagating a bend from base to tip in an unrolling motion to reduce drag.

●The cycles of adjacent cilia are slightly out of phase so that they do not bend at exactly the same moment, resulting in **metachronal rhythm** in which waves of ciliary activity pass along the organism from front to rear.

Metachronal rhythm*:* movements produced by the sequential action of structures such as cilia, segments of worms or many legs, producing the appearance of a travelling wave.

MUSCULAR MOVEMENT

In this compilation, muscular movement has been limited to a few vertebrates, insects and earthworms.

The unique properties of muscles which enable their functionality include:
(a) Excitability (b) Contractibility (c) Extensibility and (d) Elasticity
Muscular movement is dependent on skeletal systems.

TYPES OF SKELETONS

Type of skeleton and example of animal having it	*Definitions of the skeletons and extra notes*
Hydrostatic skeleton or Hydroskeleton *It's the most widespread type of skeleton found in:* **a) Organisms** like annelids (e.g. earthworms), cnidarians (e.g. jellyfish, sea anemones), nematodes (e.g. round worms) **b) Structures** like mammalian eyes (the aqueous and vitreous humour), spinal cord (cerebrospinal fluid), extra embryonic membranes (amniotic fluid), hearts (move blood), and intestines (move food).	**Hydroskeleton:** a high-pressured fluid in a cavity (coelom), surrounded by muscle layers at different orientations. **(i)** The **main principle** on which the hydroskeleton operates is the low compressibility of liquid water (often assumed incompressible). Muscle contractions exert pressure on the coelomic fluid causing stiffening of the outer structures to form a strong rigid skeletal unit that provides a base against which movements can occur. **(ii)** The optimal volume of fluid for a particular system must remain constant for effective contraction and expansion of the antagonistic muscles. Too much loss of fluid causes limpness of tissues and pressure loss, and too much gain causes over swelling, both of which fail muscle stretching and hence movement fails. This explains why snails and earthworms are restricted in their activity to moist conditions.

Type of skeleton and example of animal having it	*Definitions of the skeletons and extra notes*
Exoskeleton ●***Chitinous exoskeleton*** is in: arthropods like insects, arachnids (e.g. spiders) crustaceans (e.g. crabs, lobsters), some fungi and bacteria ●***Calcified exoskeleton*** is in: shelled mollusks (e.g. snails, clams), some polychaetes like lugworms. ●***Silicated exoskeleton*** is in diatoms. ●***Bone, cartilage, or dentine*** make up the exoskeletons of turtles and primitive fish	**Exoskeleton:** a non living external body structure that supports and protects an organism. **(i)** Exoskeletons are secreted by **ectoderm** **(ii) Chitinous exoskeleton** has complex muscular system which enables insects to lift or pull an object 20 or more times heavier than their body weights! Grasshoppers have about 900 muscles, caterpillars up to 4,000 yet human beings have fewer than 700 muscles ***(The World Book Encyclopedia).*** **(iii)** Exoskeletons do not grow with the body so in arthropods they must be periodically shed to allow growth; mollusks e.g. snails continually enlarge their shells as they grow. **(iv)** In insects and spiders the epicuticle is waterproof.
Endoskeleton *Found in:* **a) Chordates:** birds, mammals, reptiles etc. **b) Echinoderms:** starfish, brittle stars, sea urchins, sea cucumbers **c) Poriferans:** sponges **d) Molluscs** (class Cephalopoda) e.g. cuttlefish **Note:** Some animals, such as the tortoise, have both an endoskeleton and an exoskeleton.	**Endoskeleton:** a living internal support structure of an animal, usually composed of mineralized tissue which develops within the skin or in the deeper body tissues. (i) The vertebrate endoskeleton is made up of bone and cartilage tissues. (ii) In sponges, the endoskeleton is purely for support, but in vertebrates and echinoderms it's also for attachment of muscle and locomotion. (iii) Echinoderms and chordates have a true endoskeleton derived from **mesodermal tissue**

ADVANTAGES / FUNCTIONS AND LIMITATIONS OF THE SKELETONS

	Advantages / Functions	**Limitations / Disadvantages**
Hydroskeleton	●Hydroskeleton is elastic and can bend accordingly when a muscle contracts enabling fitting in narrow burrows.	● Coelenterates that use a hydroskeleton regularly face a loss of pressure because their skeleton is also their gut. ● Due to lack of a strong supportive system, majority of the **invertebrates** are small ●The slow motion due to lack of effective ways to support a large body compromises the animals' escape response from predators. ●The organisms are limited to moist habitats because of the need to minimise water loss by evaporation

	Advantages / Functions	**Limitations / Disadvantages**
Exoskeleton	● Exoskeletons contain rigid and resistant components that offer protection against predators, bacterial attack and desiccation while on land. ●Exoskeletons contain rigid components that offer support enabling maintaining 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 more rapid locomotion than the hydroskeleton ● The arthropod exoskeleton contains various folds, flaps and parts modified for feeding and structures for respiration. ● Exoskeletons are often highly coloured for camouflage	● Since exoskeletons are rigid and do not grow with the body, in arthropods they disrupt smooth and steady growth and so must be periodically shed to allow growth, which makes the animal temporarily vulnerable for predation and water loss by evaporation until hardening. **NB:** Snails and many other mollusks solve that problem by continually enlarging their shells as they grow. ● An exoskeleton cannot support large sized animals because of their large volume and body mass in proportion to the cube of their linear dimensions, necessitating an impossibly heavy and thick exoskeleton. ●It requires modifications in movement. Many individual muscles are attached to the outer shell in order to create movement. In the appendages,

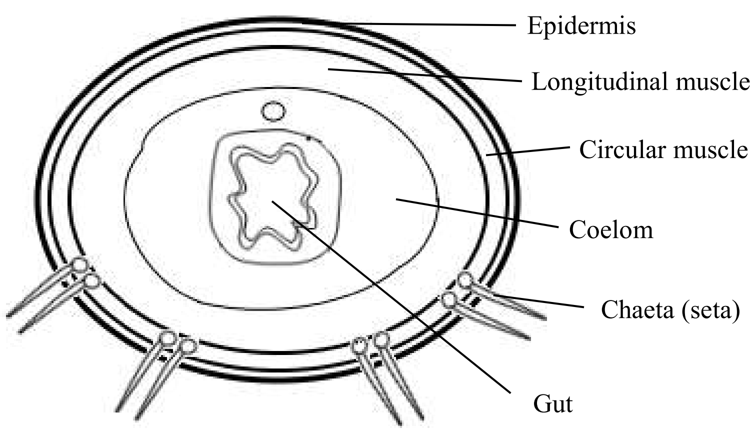
from predators, recognition by mates, and warning to scare off predators.
●The arthropod exoskeleton is jointed enabling flexibility in locomotion.

these muscles are set up within multiple hinge joints, as these allow a wide range of motions.

	Advantages / Functions	Limitations / Disadvantages
Endoskeleton	●Vertebrates have a versatile support system and as a result, they develop faster and bigger bodies than invertebrates. ● It's jointed for flexibility to allow diverse range of locomotory patterns: swimming, digging, running, climbing, and flying, feeding (jaws). ●Endoskeleton does not limit space available for internal organs and can support greater weight. ●Bone are hard for protecting delicate parts like the brain, lungs, heart, spinal cord, etc. ●Bone tissue is mineralized and hence acts as mineral reserve for the body's' physiological processes. ●Mammalian bones manufacture the defensive leucocytes	●Endoskeletons are enclosed in other tissues do not offer much protection from predators in some animals. ● Endoskeletons do not contribute to minimizing water loss from the body by evaporation

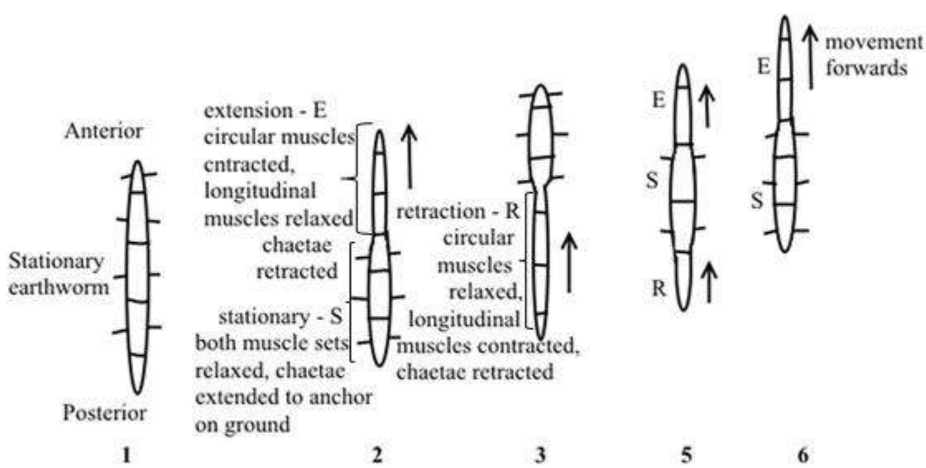
DESCRIPTION OF HYDROSKELETON OF THE EARTHWORM

Only the structures that make up the skeleton are required, not description of the whole body.



The body 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.
NB: segmental partitioning prevents backflow of the coelomic fluid which would provide little elongation

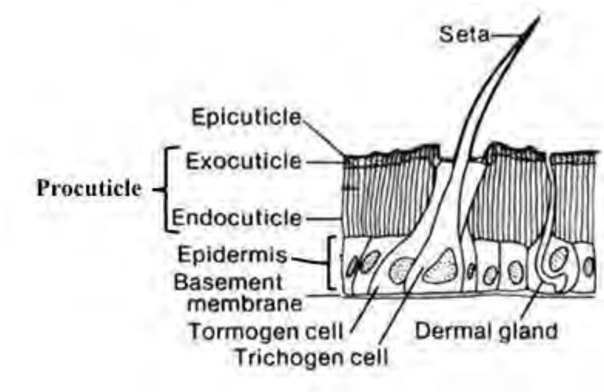
DESCRIPTION OF THE EARTHWORM'S LOCOMOTION



●Crawling 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 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 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 intrasegmental neurones

LOCOMOTION WITH AN EXOSKELETON

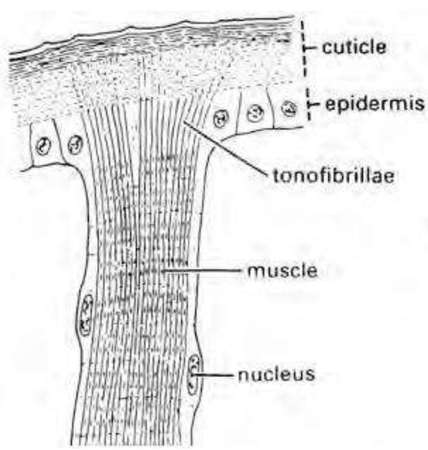
DESCRIPTION OF A TYPICAL ARTHROPOD EXOSKELETON

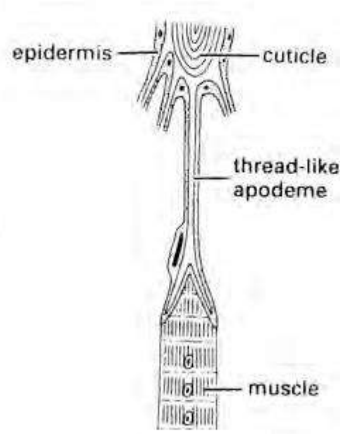


● It is a **multi-layered** structure with **4 main regions;** from out - inwards: ***epicuticle, procuticle, epidermis and basement membrane.***
●**Epicuticle:** a multi-layered external barrier made of lipoproteins, fatty acids, wax and some times cement. It prevents water loss (desiccation) and bacterial invasion.
●**Procuticle:** lies immediately below the epicuticle, is secreted by the epidermis, contains **chitin** surrounded by a matrix of protein. At times procuticle stratifies into a **sclerotized** exocuticle and a soft, inner endocuticle.
*(**Sclerotization** involves linking protein molecules together by quinone compounds into a solidified protein matrix, creating rigid "plates" of exoskeleton known as **sclerites)***
●**Epidermis:** made up of a single layer of epithelial cells, secretes the basement membrane and all of the overlying layers of cuticle.
●**Basement membrane:** a supportive bilayer of mucopolysaccharides and collagen fibers, it is where epidermal cells rest.

Types of insect muscles
1. Skeletal muscles – attacked to exoskeleton
2. Visceral muscles – found in the gut / alimentary canal.

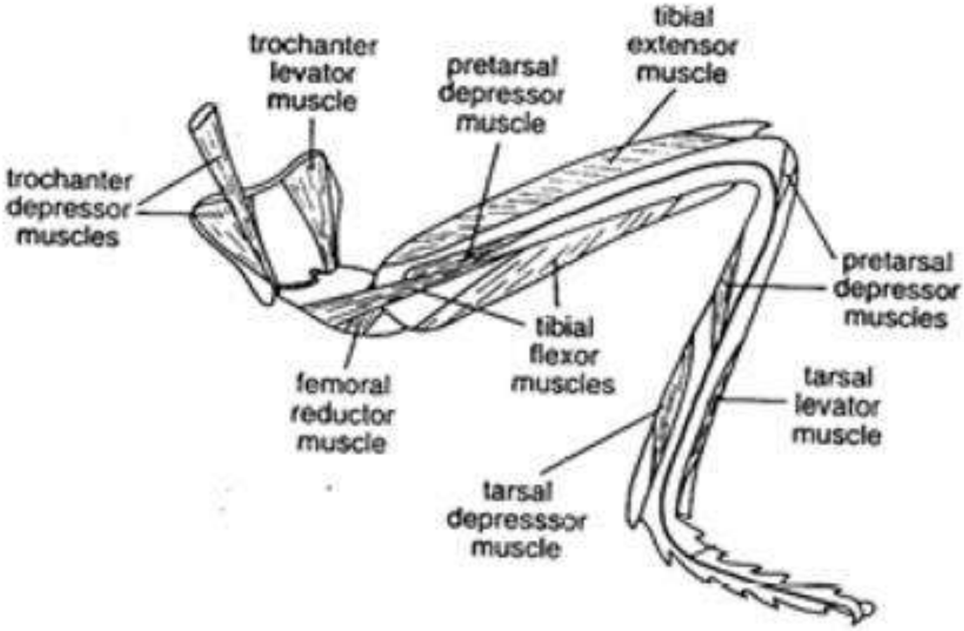
Attachment of insect muscles
(a) Some skeletal muscles using **tonofibrillae** attach on ectoderm (cuticle) through the epidermis.
(b) Other skeletal muscles attach on internal ridge-like cuticle called **Apodemes** and **Apophyses**
(c) Flight muscles attach on platelike invaginations called **phragma** in the thorax.



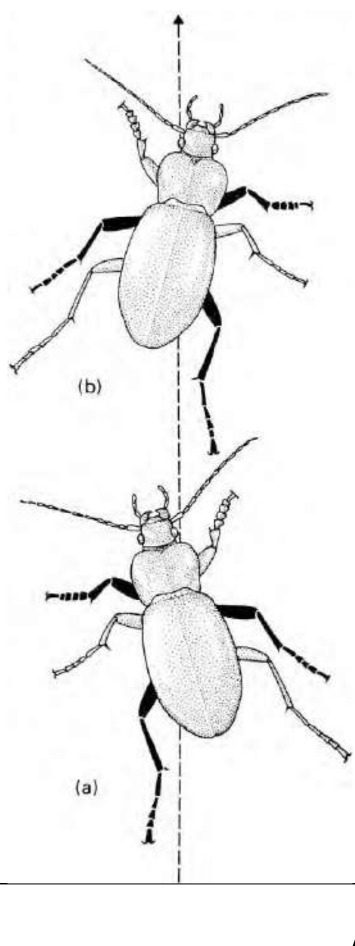


ANTAGONISTIC MUSCLES FOR INSECT LOCOMOTION

(a) Levator vs. depressor muscles for wings
(b) Flexor vs extensor muscles in legs



A. DESCRIPTION OF WALKING IN INSECTS



●Walking is achieved by the coordinated activity of 6 legs all attached on the thorax.

● Bending and straightening of limbs is brought about by the **reciprocal innervation** of flexor and extensor muscles attached to the inner surface of the exoskeleton on either side of a joint.
Reciprocal innervation: **Same time excitation of one muscle with the inhibition of its antagonist.**

●A limb bends (folds) by contraction of flexor muscle and relaxation of extensor muscle simultaneously (at the same time).

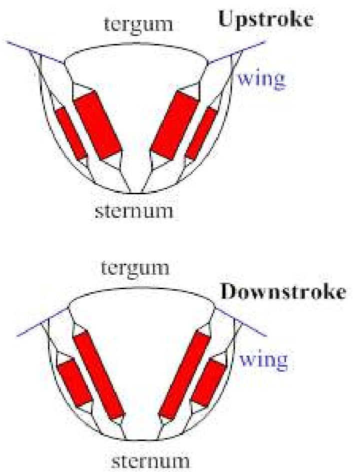
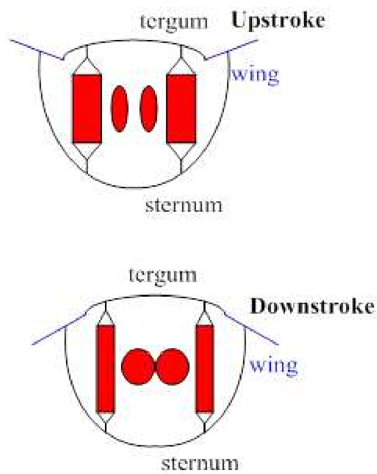
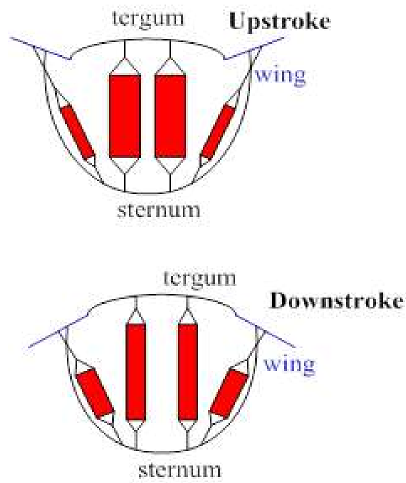
●A limb straightens (extends) by contraction of extensor muscle and relaxation of flexor muscle simultaneously.

●When the insect starts to walk, the 2nd leg on one side and the 1st and 3rd legs on the other side support the body off the ground while the other 3 move forward.

●The 1st leg on the side where the 2nd leg is stationary pulls the insect, while the 3rd leg of the same side and the 2nd leg on the other side push.

●The process is then repeated but with the role of each trio of limbs reversed.

INSECT FLIGHT MUSCLES

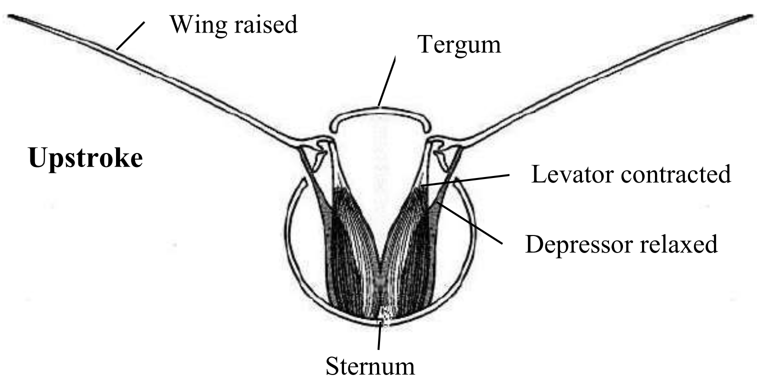
Direct muscles – directly attach to wings e.g. dragon flies, mayflies	**Indirect muscles** - attach to interior of thorax (NOT directly to wings) e.g. houseflies, honey bees, midges, etc	**Direct and indirect muscles** (mixed)
		

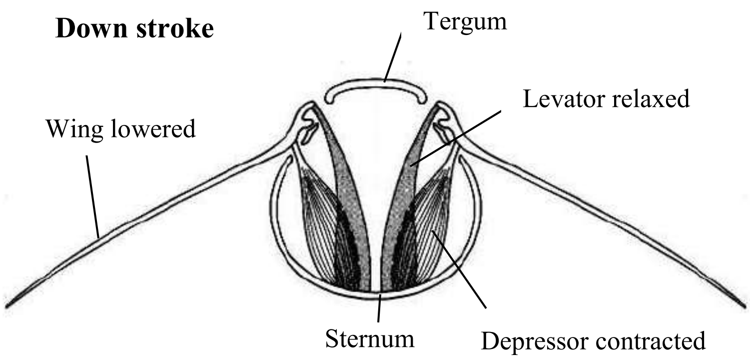
COMPARISON OF DIRECT AND INDIRECT FLIGHT MUSCLES

Direct muscles	**Indirect muscles**
1. Directly attach to wing bases e.g. dragon flies, mayflies 2. Are **Synchronous muscles i.e.** - One nerve impulse = one muscle contraction = one wing beat – One contraction and relaxation per 1 neural impulse. 3. Frequency of wing beat corresponds to the rate at which the nervous system can send impulses 4. Wing beat is slower (about 5-50 times/second)	1. Attach to interior of thorax (NOT directly to wings) e.g. houseflies, honey bees, midges, etc 2. Are **Asynchronous muscles i.e.** – More than 1 contraction and relaxation per 1 neural impulse. 3. Single nerve impulse required to initiate muscle contraction, single impulse to stop. - The muscles exhibit **stretch reflex** i.e. automatic contraction in response to being stretched. 4. Energy is conserved because the elasticity of the thorax restores its shape 5. Frequency of wing beat exceeds the rate at which the nervous system can send impulses (about 120-200 beats in house flies to 1000 beats /second in midges).

B. DESCRIPTION OF FLIGHT IN INSECTS

ACTION OF DIRECT FLIGHT MUSCLES
e.g. dragonflies, butterflies and grasshoppers.





1. Using Direct flight muscles

● During the ***upstroke***, the **elevator muscles** contract, the **depressor muscles** relax at the same time, the wings are elevated.

● During the ***downstroke***, the depressor muscles contract, the elevator muscles relax at the same time, the wings are depressed down.

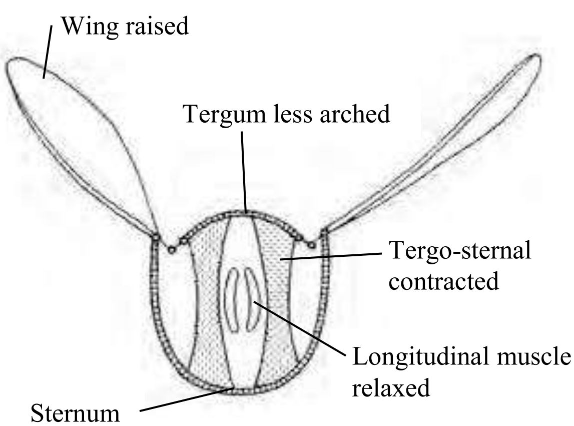
2. Using Indirect flight muscles

●During the ***downstroke***, the **longitudinal muscles** (depressor muscles) contract, the **tergo-sternal muscles** (dorso-ventral muscles) relax at the same time, the thorax is compressed, its dorsal surface (notum) arches (bulges / bows upward), the wings flip downward (depress).

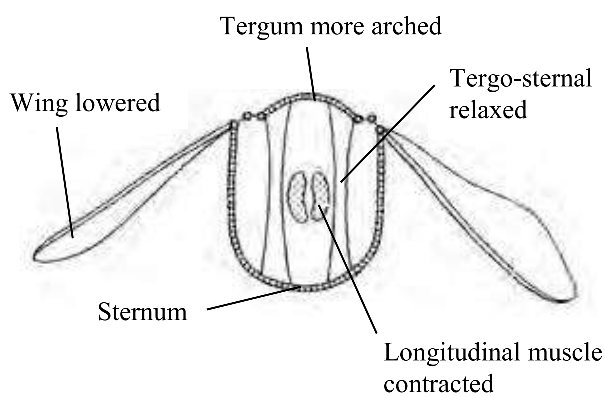
● During the ***upstroke***, the **tergo-sternal muscles** (elevator muscles) contract, the **longitudinal muscles** (depressor muscles) relax at the same time, the notum is pulled downward (flattens), causing the wings to flip upward (elevate).

ACTION OF INDIRECT FLIGHT MUSCLES e.g. houseflies, bees and wasps, etc.

Upstroke (wings raised / elevated)



Down stroke (wings lowered / depressed)

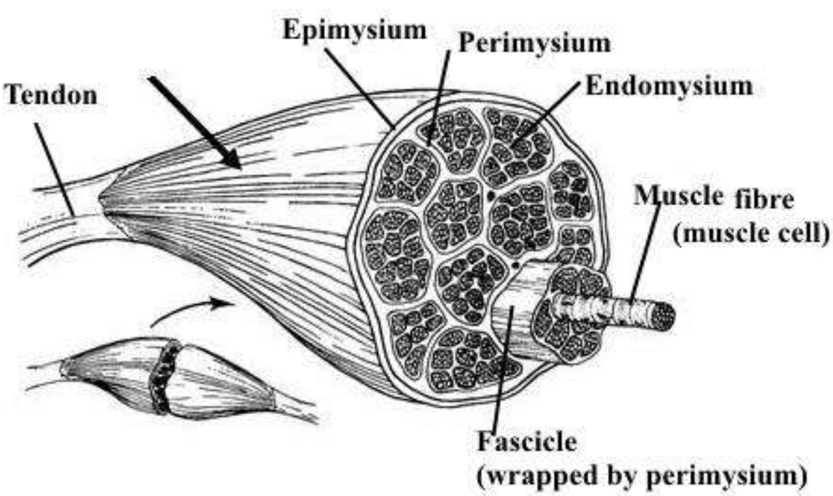


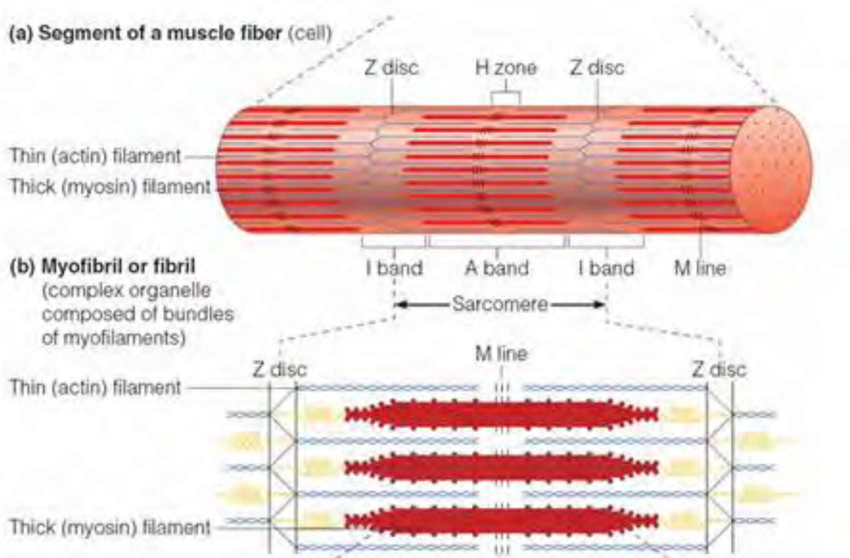
ENDOSKELETON
The vertebrate skeletal tissue is composed either of **cartilage only** like in elasmobranch fishes e.g. dogfish and sharks or **both cartilage and bone** covered by a muscular system.

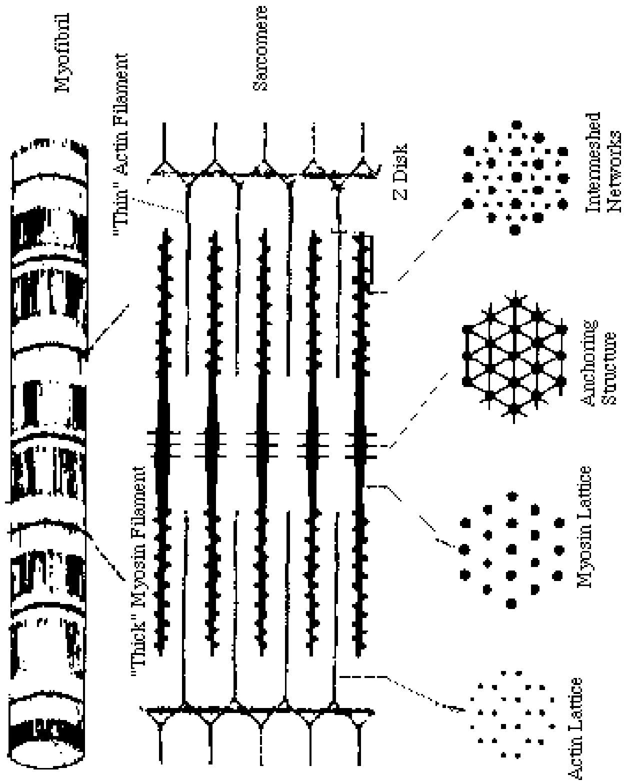
MUSCULAR TISSUE
Muscular tissue is derived from the mesoderm and is specialised for contraction. It is made up of contractile units called muscle fibres bound in a framework f vascular connective tissue which also provides an anchorage to the skeleton or skin.

TYPES OF MUSCLE
●**Smooth (Involuntary / visceral) muscle;**
Location: walls of blood vessels; ciliary muscle; erector (arrector) pili muscle; gastrointestinal, urinogenital and respiratory tracts
●**Skeletal (voluntary) muscle;**
Location: attached to bones; abdominal wall; diaphragm; rectus muscle; under skin; middle ear.
●**Cardiac (heart) muscle; *Location:*** found in the heart only.

GROSS AND MICROSCOPIC STRUCTURE OF SKELETAL MUSCLE







As seen under the light microscope

●Skeletal muscle is highly compartmentalized, and each compartment is treated as a separate entity (such as the biceps muscle).

●The entire muscle is a collection of several muscle fibre 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 **endomysium,** a meshwork of collagen fibres and fibroblasts**.**

●Each striated muscle cell (**muscle fiber**) has a fluidy **sarcoplasm** (cytoplasm); bound by the sarcolemma (plasma membrane); is multinucleate (is a **syncytium)**; the nuclei are at the periphery of the cell; is long; cylindrical; with longitudinally oriented threadlike structures-**myofibrils** exhibiting periodic cross striations repeatedly.

●**The sarcoplasm** contains Golgi apparatus, many mitochondria, ribosomes, sarcoplasmic reticulum (endoplasmic reticulum), glycogen, lipid droplets, and myoglobin.

Syncytium*: A multinucleated mass of cytoplasm that is not separated into individual cells.*

Details of myofibril (fine structure)

● One myofibril shows alternating cross striations; which are light (**isotropic**) and dark (**anisotropic**) bands.
● One myofibril is made of filamentous proteins; **myosin** (thick) and **actin** (thin) overlapping to give the striated appearance.
● Actin filaments are anchored at their midpoints to a structure called the **Z-line.**
●The region from one z-line to the next is called a **sarcomere,** which is the functional unit of muscle contractions.
● **Sarcomeres** are sections of **myofibril** that are separated from each other by areas of dense material called **"Z discs".**
● **"A band"** is the relatively darker area within the sarcomere that extends along the total length of the **thick filaments**.
●**"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 **sarcomere**.
The **"I band"** is the region between adjacent **A bands**, in which there are only **thin filaments**, and no **thick filaments**. (Each **I band** extends across two adjacent sarcomeres)

SLOW-TWITCH AND FAST-TWITCH MUSCLE FIBRES

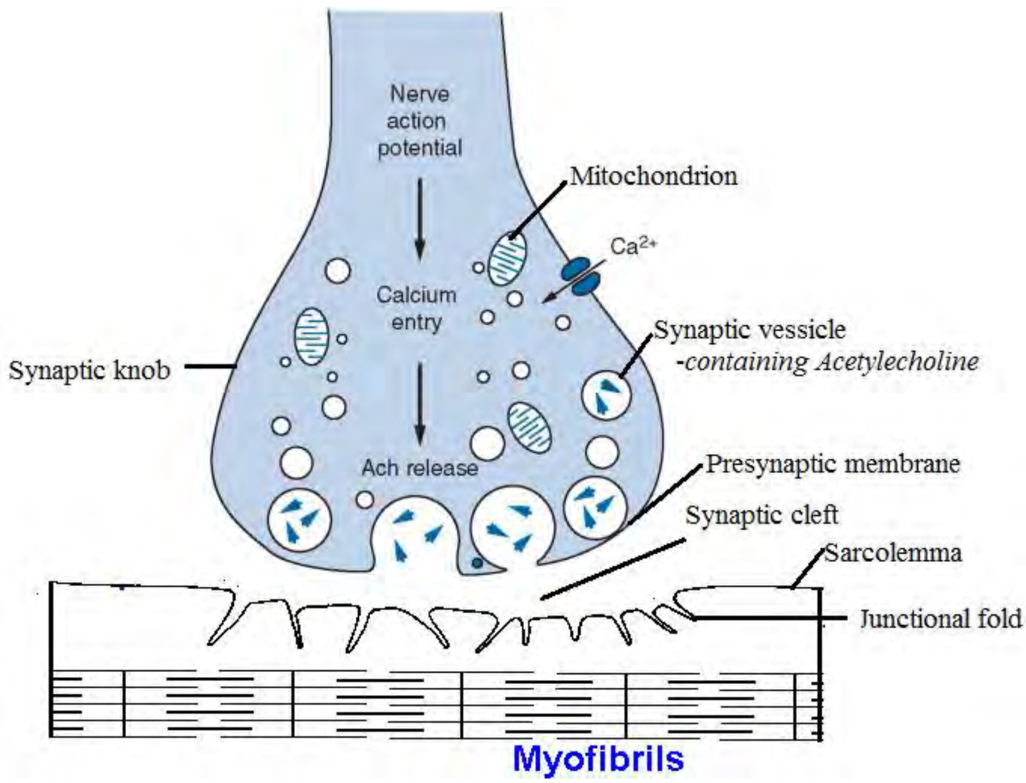
1. Slow-twitch fibres – e.g. calf muscle	**2. Fast-twitch fibres** – e.g. biceps muscle
Contract more slowly, less powerfully, over a longer period hence suited to endurance work e.g. marathon running. ***Adaptations:*** (i) Large reservoir of myoglobin for storage of oxygen which facilitate aerobic respiration to avoid accumulation of lactic acid which would make them less effective. (ii) Much glycogen to provide a source of metabolic energy. (iii) A rich supply of blood vessels to deliver oxygen and glucose needed in aerobic respiration to provide ATP. (iv) Numerous mitochondria to produce ATP that maintains muscle contraction.	Contract more rapidly, more powerfully, only for a short period hence suited to intense exercise e.g. weight lifting. ***Adaptations:*** (i) Thicker and more numerous myosin filaments. (ii) High concentration of enzymes involved in anaerobic respiration. (iii) Store of phosphocreatine, a molecule that can rapidly generate ATP from ADP in anaerobic conditions and so provide energy for muscle contraction.

HOW SKELETAL MUSCLE STRUCTURE RELATES TO FUNCTIONING

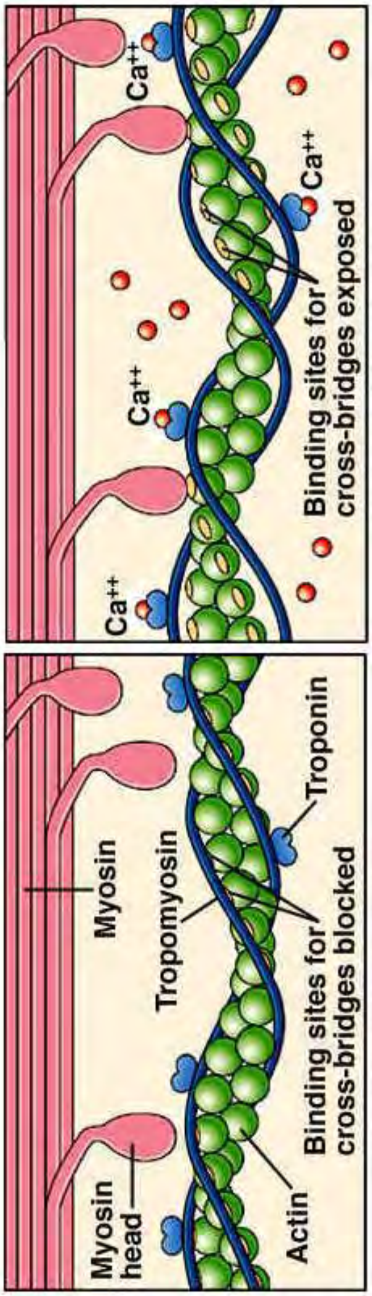
●Each muscle cell is long to allow considerable contractile effect.
●The fibres are parallel to each other so that contractile effect is transmitted along same axis.
●Muscle fibres taper at both ends for interweaving to improve muscle strength.
●Muscle fibres have very many mitochondria to provide much ATP needed in muscle contraction.
●Cross bridges enable actin and myosin to fit into each other to allow sliding during muscle contraction.
●There is a rich supply of blood vessels to supply nutrients to and drain wastes away from cells.
●There is much myoglobin for storage of oxygen needed very much in aerobic respiration during exercising.
●There are motor end plates to allow innervation that result 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

WHAT IS A NEUROMUSCULAR JUNCTION (NMJ) / MOTOR END PLATE?

●A single synapse or junction made between one motor neuron and one muscle fiber.



MECHANISM OF MUSCLE CONTRACTION AND RELAXATION



The sliding filament theory / Ratchet mechanism

Excitation-Contraction coupling *(see next page for definition)*

●Arrival of an **action potential** at the synaptic terminal of motor neuron causes the influx of Ca^{2+} ions from the extracellular fluid into the presynaptic neuron's cytosol followed by exocytosis of synaptic vesicles containing acetylcholine.

●**Acetylcholine** diffuses across the synaptic cleft of neuromuscular junction to depolarize the sarcolemma and trigger an action potential that spreads through the **transverse tubules,** causing the sarcoplasmic reticulum to release Ca^{2+} into the sarcoplasm.

●Ca^{2+} bind to troponin of actin to cause cooperative conformational changes in troponin-tropomyosin system, releasing the inhibition of actin and myosin interaction.

●Myosin hydrolyses ATP and undergoes a conformational change into a high-energy state.

●The myosin head binds to actin forming a cross-bridge between the thick and thin filaments.

●This is accompanied by energy release, ADP and inorganic phosphate dissociation from myosin.

●The resulting relaxation entails rotation of myosin head, which flexes the cross bridge to move **actin** a small distance pulling the 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 in muscle contraction.

Relaxation

● Ca^{2+} are pumped back into sarcoplasmic reticulum.

●Again **ATP** binds to myosin head, detaching it from actin as the myosin head "recharges" or "cocks".

●Troponin-tropomyosin regulated inhibition of actin and myosin interaction is restored

● Finally, active tension disappears and the rest length is restored. This completes the contraction-relaxation cycle.

NB: high concentration of Ca^{2+} in the sarcoplasm coupled with lack of ATP results in Rigor mortis (see below for details on this phenomenon)

EVIDENCE OF SLIDING FILAMENT THEORY (OBSERVATIONS) IN A CONTRACTING MUSCLE FIBRE

● Each **sarcomere shortens** / Z lines come closer

●**I Band shortens**

●**H zone** shortens greatly (usually **disappears)**.

●**A Band remains** unchanged in length during contraction or relaxation

●Cross bridges are visible between actin and myosin in photomicrographs.

CHANGES DURING MUSCLE PASSIVE STRETCHING

●Sarcomere lengthens

● **I Band** elongates.

WHAT IS RIGOR MORTIS?

●The progressive stiffening of the body that occurs several hours after death as a result of failure of contracted muscles to relax.

WHAT CAUSES RIGOR MORTIS?

●Upon death, there's increased permeability of sarcoplasmic membrane to Ca^{2+}, allowing Ca^{2+} influx into the sarcoplasm hence promoting the cross-bridge formation between actin and myosin (muscle contraction).
●However efflux of Ca^{2+} from the sarcoplasm into the sarcoplasmic reticulum fails because of lack of ATP since respiration would have ceased. This causes the muscle to remain contracted, relaxing only when decomposition starts.
NB: Interestingly, meat is generally considered to be tenderer if it is consumed after expiry of **rigor mortis.**

WHAT IS EXCITATION-CONTRACTION COUPLING?

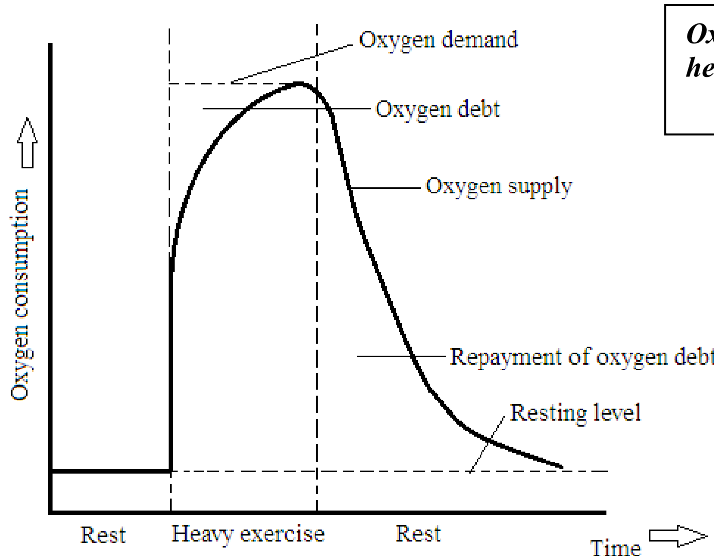
●The sequence of events by which an action potential in the plasma membrane of the muscle fibre leads to force production via an increase in intracellular calcium and cross bridge formation and turn-over ***(see previous page for explanation)***

ATP PRODUCTION DURING MUSCLE CONTRACTION

1. Phosphorylation of ADP by creatine phosphate provides a very rapid means of forming ATP at the onset of contractile activity. **Phosphocreatine + ADP ⇔ ATP + creatine**
In a resting muscle fiber, the concentration of ATP is always greater than ADP leading to the reformation of creatine phosphate.
2. Oxidative phosphorylation of ADP in mitochondria during aerobic respiration (need myoglobin for oxygen transfer)
3. Substrate phosphorylation of ADP in glycolysis during anaerobic respiration to form lactic acid in the process. The accumulation of lactic acid is associated with muscle fatigue, which is broken down later in the liver using oxygen to constitute what is called **oxygen debt.**

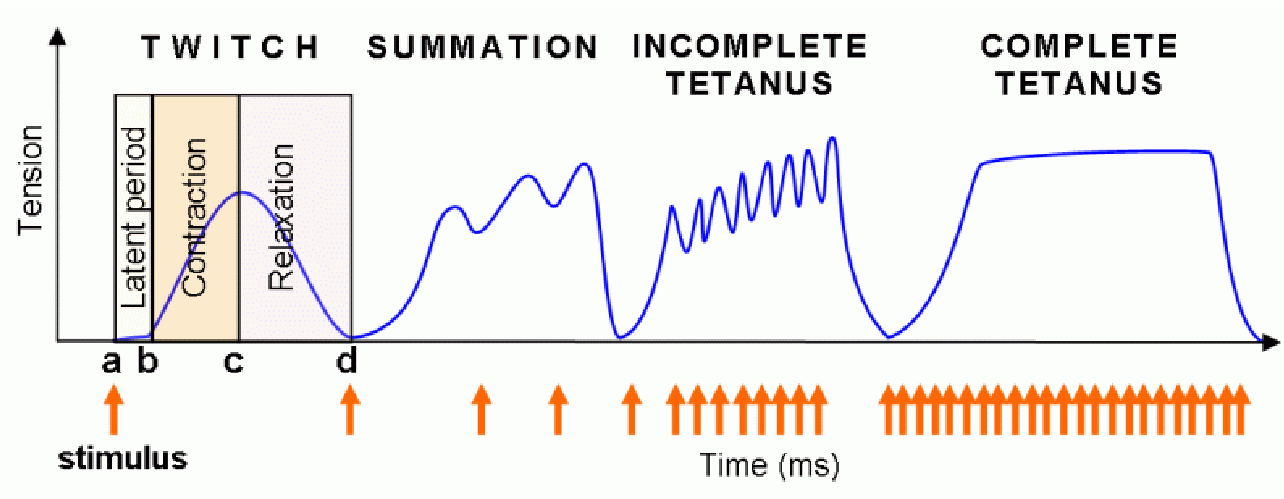
WHAT IS THE OXYGEN DEBT?

The amount of extra oxygen required by muscle tissue to oxidize lactic acid and replenish depleted ATP and phosphocreatine following vigorous exercise.



Oxygen uptake at rest, in heavy exercise and in recovery

MUSCLE STIMULATION FREQUENCY AND THE LENGTH-TENSION RELATIONSHIP



MUSCLE TWITCH
This is the rapid muscle contraction in response to a single stimulation

LATENT PERIOD
A very brief interval between stimulus application and onset of muscle fibre contraction. During latent period, excitation of muscle fibre followed by contraction occur

ALL-OR-NOTHING LAW OF THE MUSCLE
The response of one muscle fiber is independent of the intensity of the stimulus, provided the stimulus is of threshold strength.
The **entire skeletal muscle doesnot** obey the all-or-none law because the total amount of contraction depends on the number of muscle fibres that are contracted at a time.
NB: the all-or-none law holds only for the unit of tissue; i.e. the nerve cell (for nervous tissue), one muscle fiber (for skeletal muscle) and the entire auricles or the entire ventricles (for the heart).

THRESHOLD
The electrical potential (less negative than the resting potential) at which an action potential is triggered.
If the frequency of stimulation progressively increases such that it gives **first, little time** and **later no time** for complete relaxation, the graph below shows what can be observed.

MECHANICHAL SUMMATION / UNFUSED TETANY
The condition whereby multiple stimulation of a muscle or nerve before full relaxation results in a series of twitches added together to produce a more sustained contraction.

TETANY
●Smooth, sustained maximal contraction of a muscle in response to rapid firing by its motor neuron.
NB: The ability of a muscle to undergo tetany depends upon its **refractory period.**

REFRACTORY PERIOD
●A short period of inexcitability in a nerve or muscle cell following stimulation.
●The amount of time it takes for an excitable membrane to be ready for a second stimulus once it returns to its resting state following excitation.

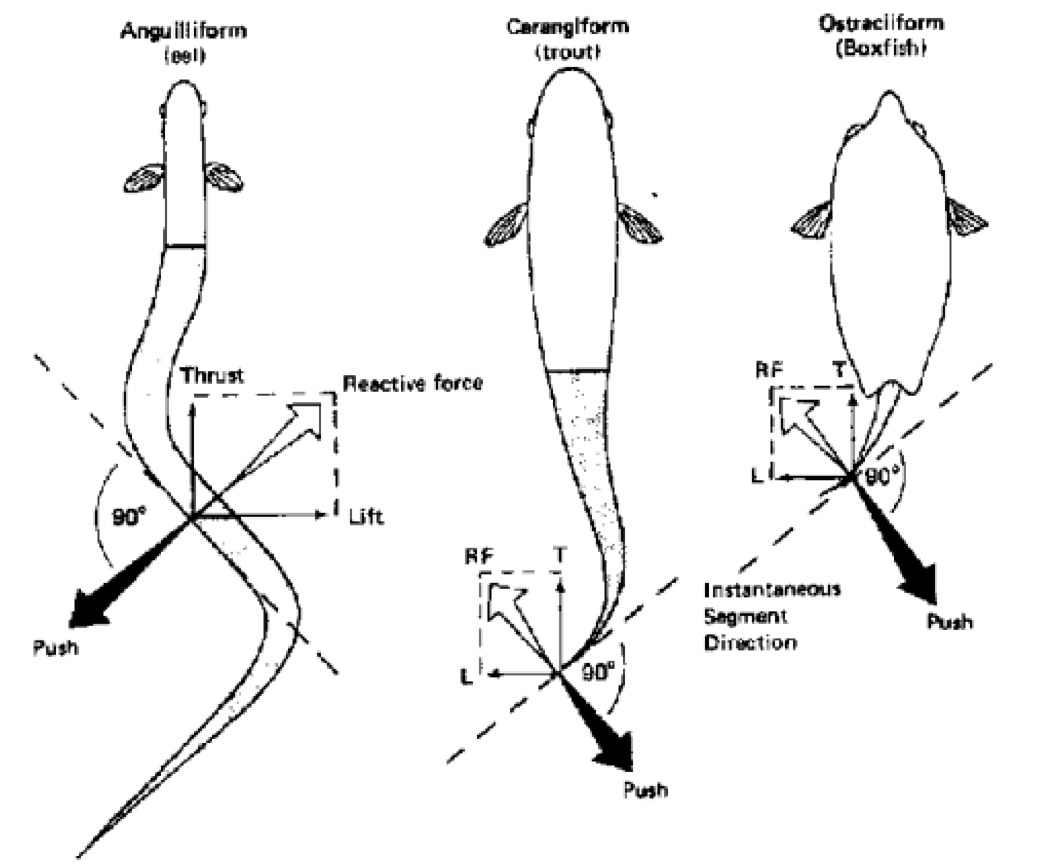
MUSCLE FATIGUE
●A condition of the muscle in which its capacity to produce maximum voluntary action, or to perform a series of repetitive actions, is reduced.
Muscle fatigue results when there is tissue oxygen deprivation, glycogen or Phosphocreatine depletion, and increased level of blood and muscle lactic acid in an exercised muscle.

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.

TYPES OF LOCOMOTION IN FISH

Anguilliform e.g. eel	*Carangiform e.g. dog fish, perch*	*Ostraciform e.g.* Ostracium (trunk fish)



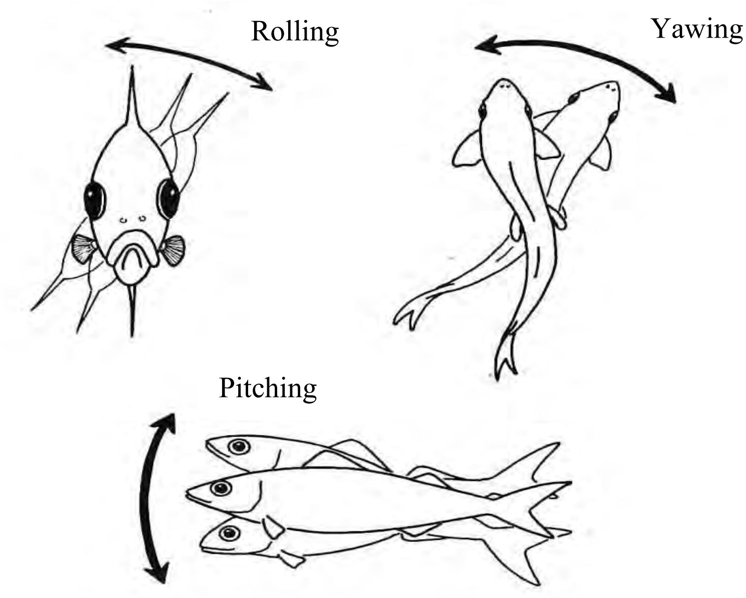
●When myotomes on one side of body contract; those of the opposite side relax at the same time; the tail pushes against the water towards the contracted side; generating a thrust that can be resolved into 3 forces:
(a) The reaction force which is the reaction of the water against the pushing action of the water and is equal and opposite to the thrust.
(b) The forward (propulsive) force that pushes the fish forward.
(c) 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:
(i) Pressure of the water against the head
(ii) 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.

NOTE
Many invertebrates like round worms and some flagellated cells including spermatozoa exhibit the principles involved in propulsion as in the above fishes.

SUPPORT (BUOYANCY) IN FISH

Elasmobranchs like dog fish sharks, skates and rays.	**Teleosts like perch**
●Support is provided by **constant swimming** using **fins.** ●These fish's density is slightly greater than that of water and must swim continuously to avoid sinking. ●How they are adapted to this: **(1)** possession of large pectoral and pelvic fins which direct swimming upwards **(2)** possession of **heterocercal** tail i.e. a tail with smaller upper and 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 body, generating a force which can be resolved into upward and backward components. ●The upward component force lifts the anterior end up in the water while the backward component force called **backward drag** being small only slightly impedes motion and is easily suppressed.	●Support is provided by adjusting air in the **swim bladder** which may be **(1)** a closed swim bladder filled with gaseous mixture of oxygen, nitrogen and carbondioxide – all secreted from blood vessels in its wall. ***The closed type is the most common in bony fish.*** **(2)** 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. 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 gravity so that the body weight equals the weight of water displaced. **NB:** Unlike in elasmobranchs, the teleost's pectoral fins are only moved at will e.g. during braking and steering but do not act as main support structures.

INSTABILITY IN FISH



Rolling: rotation of the body about its longitudinal axis. It's **counteracted** by dorsal, ventral (vertical) and pectoral (horizontal) fins acting like stabilizers on a ship.

Pitching: tendency of the fish's anterior end to plunge vertically downwards (transverse axis rotation). It's **counteracted** by **(i)** pectoral fins and to a lesser extent pelvic fins **(ii)** dorsal-ventral flattening of the body in the dogfish.

Yawing: lateral side to side deflection of the anterior part of body resulting from the propulsive action of the tail (vertical axis rotation). It's **counteracted** by **(i)** general massiveness of anterior part of body **(ii)** water's pressure against the body side **(iii)** water's pressure against the vertical fins (dorsal, anal, ventral fins) **(iv)** lateral flattening (compression) of the body

ADAPTATIONS FOR LOCOMOTION IN FISH

●Fish's body is fusiform-shaped (spindle shaped) and laterally compressed to reduce water resistance during swimming
●The slippery layer of mucus on the skin reduces water resistance during swimming
●The presence of many rayed-fins enables the fish to swim and also maintain its balance / stability in water
●The lateral line enables sensitivity of fish and also functions as an echo location process for the fish to identify its surroundings while in water
●Scales are arranged in a head to tail direction to reduce water resistance during swimming
●The swim bladder in bony fish maintains buoyancy
●Extensive blood vascular system supplies oxygen and nutrients to the muscle tissues for contraction and drain away wastes
●Body is highly muscular to generate great propulsive force against water resistance
●The neuromuscular activity is highly coordinated resulting in **reciprocal innervation.**

LOCOMOTION IN BIRDS

EXTERNAL AND INTERNAL FEATURES THAT ADAPT BIRDS TO LOCOMOTION

●Birds' bodies are streamlined (spindle shaped) during flight for overcoming air-resistance during flight.
●The endoskeleton is hollow **(pneumatized)** to reduce weight, and many unnecessary bones are fused into a single structure e.g. some vertebrae, pelvic girdle, finger and leg bones.
●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.
●The sternum bone is extended into a large keel, for the attachment of large powerful flight muscles.
●The vanes of the feathers have hooklets called **barbules** that zip them together, giving the feathers the strength needed to hold the airfoil.
●The major wing bones have internal **strut-like reinforcements** to prevent buckling during stress.
●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.
●The forelimbs have become modified into wings which act as aerofoil, generating lift when passed into air.
●They have high body temperature which maintains the high metabolic rate for generating much energy.

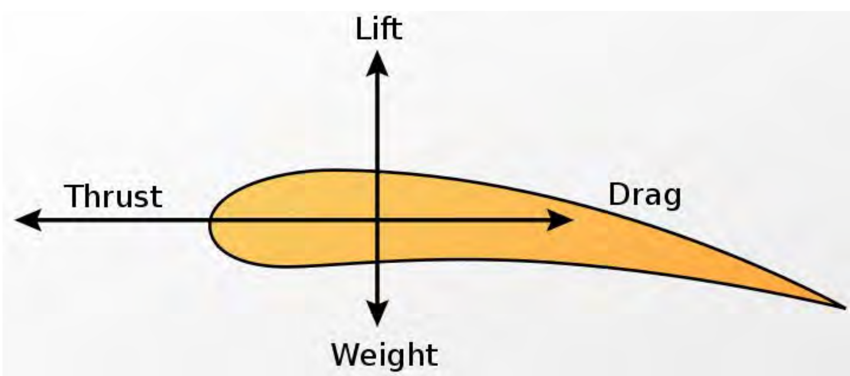
FLIGHT BIOMECHANICS (FLIGHT BIOPHYSICS)

THE BIRD'S WING AS AN AEROFOIL / AIRFOIL

Aerofoil / Airfoil: A structure whose shape and orientation provides lift, propulsion, stability, or directional control in a flying object.
An airfoil-shaped body moved through a fluid (air or liquid) produces an **aerodynamic force,** which is the resultant forces exerted on a body by the air in which the body is immersed, and is due to the relative motion between the body and the fluid.

PRINCIPLES OF THE AEROFOIL

The **four** basic forces at work when a bird is in flight are: **Lift, Thrust, Gravity (weight)** and **Drag** of which only **gravity** is **constant** (unchanging), the remaining three forces can be altered.
NB: Weight is a body force, not an aerodynamic force.



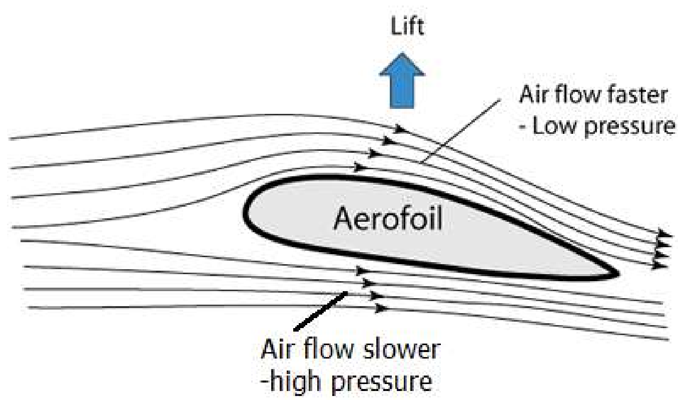
In a bird flying level at a constant speed, all four of these forces are in balance or equilibrium.
Weight: a continuous downward force (force of gravity) that flying objects must constantly overcome to stay in the air (aloft). The opposing force of gravity is lift.
Thrust: the force generated by flapping the wings which moves the bird forward and opposes drag. To move forward the flying bird must overcome drag. Drag can be reduced by streamlined shapes.
Drag (air resistance): is the friction between the moving object and the air, opposing thrust. The more streamlined or aerodynamic an object is, the less air resistance the object generates.

Drag is higher when
(i) The surface area of the object exposed to the fluid flow is higher (the reason why birds spread out their wings to slow down or land)
(ii) The object is moving faster (or the relative fluid flow is faster)
(iii) The fluid has more momentum, or inertia (high fluid viscosity and density e.g. at low altitudes)
Note that air at lower altitudes has more oxygen to facilitate muscle contraction of wings, but is thicker and therefore increases drag.

Lift: the mechanical aerodynamic force generated by the wings which directly opposes the (gravity) weight of a bird. Lift is higher when
(i) The area of the bottom of the wing is larger
(ii) The animal is moving faster
(iii) Fluid viscosity and density are higher.
Thicker air increases thrust by supplying the wings with more mass to move.

BERNOULLI'S PRINCIPLE AND AEROFOIL OPERATION

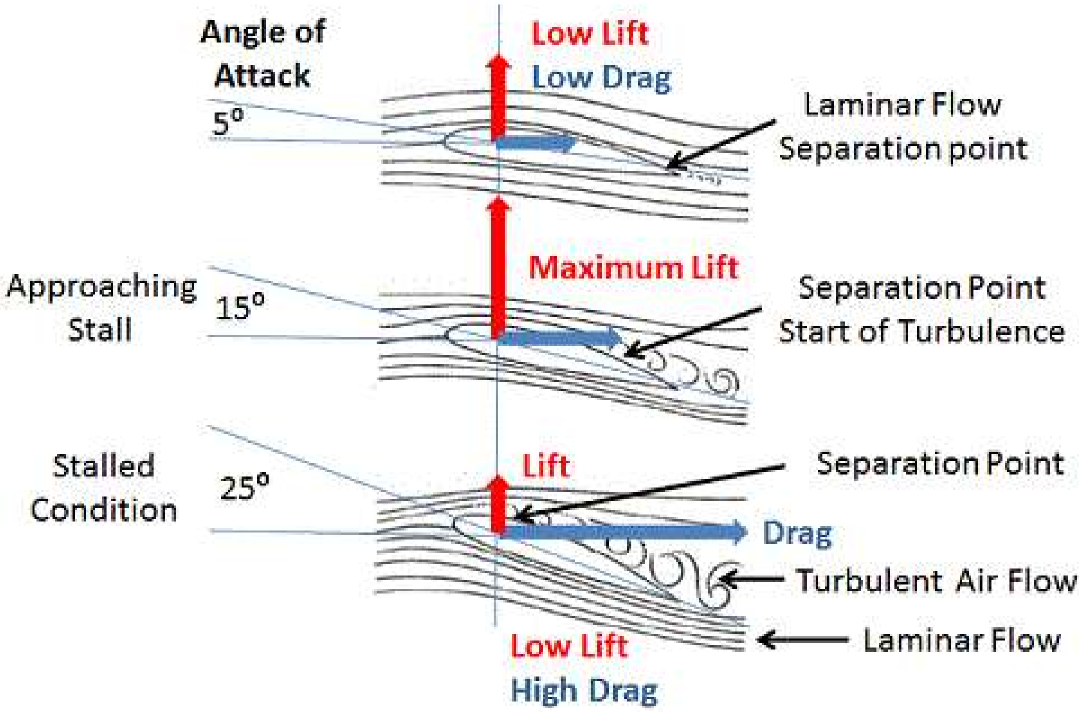
Daniel Bernoulli's theorem: an increase in the speed of a fluid produces a decrease in pressure and a decrease in the speed produces an increase in pressure.



As the bird flies, the air splitting at the front of the wing must rejoin at the back of the wing so as not to create a vacuum. The curved top surface being longer forces the air to move faster across the top than the bottom. Faster moving fluids create less pressure, so the bottom of the wing creates greater pressure than the pressure exerted downward above the wing, resulting in a net **upward force,** or **lift.**
The faster air moves across the wing the more lift the wing will produce, so moving it through the air by flapping increases this airflow and thus increases lift. The bird doesn't propel air underneath its wing; instead it cuts into the air with the leading edge to obtain the flow over the surface that it requires.

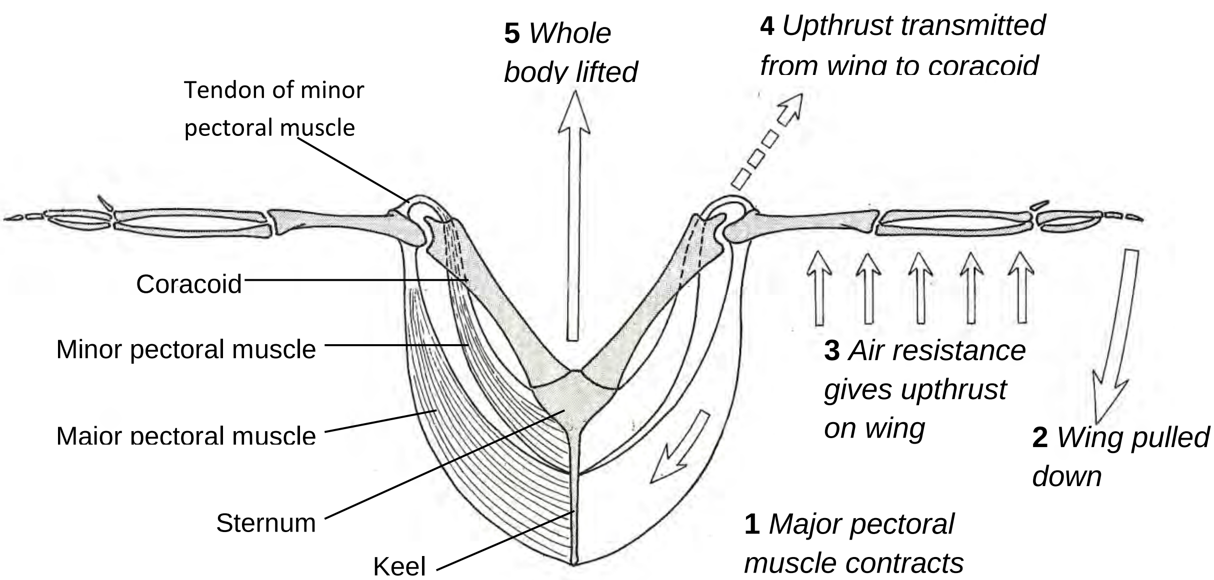
EFFECT OF ANGLE OF ATTACK ON LIFT

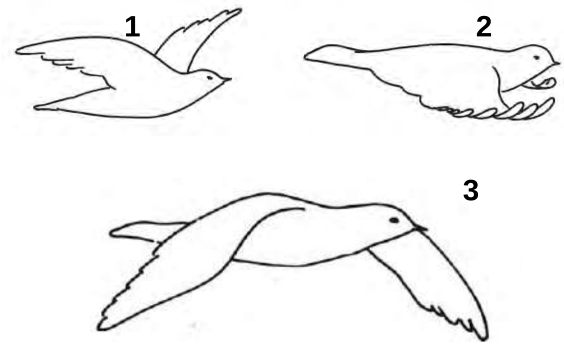
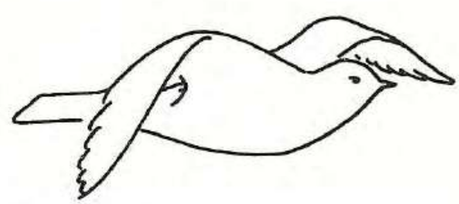
The angle of attack (AoA): the angle at which the leading edge of wing cuts into the forward airflow.
NB: It is erroneously thought that **AoA** is the angle of the aerofoil relative to the ground, yet it's the angle of the **wing** relative to **airflow**
●Increasing the angle of attack increases the 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 **AoA** results in air turbulence / interruption of airflow **(eddy)** above the wing which causes a flight stall e.g., when taking off or landing.
● Air turbulence above the wing in birds is prevented by **(1)** the **alula** (bastard wings) and **(2)** end-feathers, both of which serve as sloths to smoothen the airflow above the wings. The alula is formed by 3 or 4 feathers attached to the first digit. **NB: Angle of attack decreases with increasing speed**



MECHANISM OF FLAPPING FLIGHT

Attachment of flight muscles in a bird's thoracic region



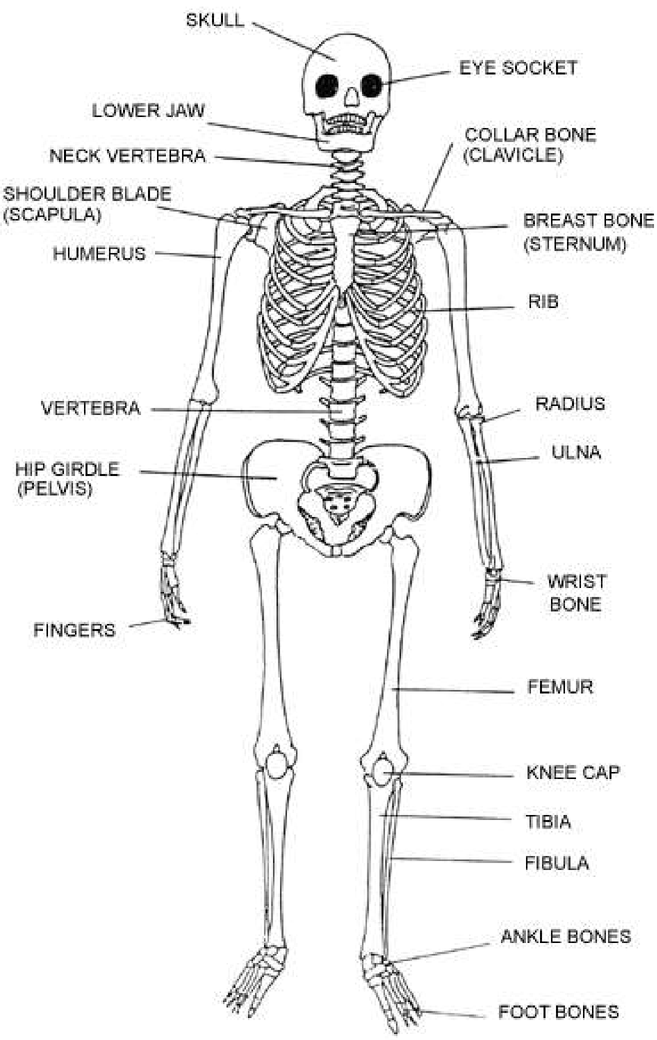
Downstroke  **1, 2** and **3** are successive stages of down stroke.	●**Downstroke** is marked by contraction of **pectoralis major** muscle and relaxation of **pectoralis minor** muscle (supracoracoideus) at the same time; abduction (elevation / raising) of humerus to a nearly vertical position and also retraction (pulling back) of wings to a horizontal position backwards; full extension of the elbow and wrist joints; **pronation** (dropping of leading edge relative to the trailing edge) and slight protraction (stretching out) slightly of humerus. This is followed by the downwards and forwards movement of wings until they lie parallel to and in front of the body. This is accomplished in part by protraction (stretching out) of the humerus.
Upstroke Flexed wrist reduces air resistance. 	The up-stroke of the wing is much more rapid than the down-stroke. ●During upstroke the pectoralis minor muscles (supracoracoideus) contract; the **pectoralis major** muscles relax at same time; the wings are first adducted(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. **NB: The secondary feathers provide much of the lifting force and the primaries most of the forward thrust.**

Why does the slower moving air generate more pressure on the wing than the faster moving air?
In calm air, the molecules are moving randomly in all directions. However, when air begins to move, most (but not all) molecules are moving in the same direction. The faster the air moves, the greater the number of air molecules moving in the same direction. So, air moving a bit slower will have more molecules moving in other directions. In the case of a wing, because air under the wing is moving a bit slower than air over the wing, more air molecules will be striking the bottom of the wing than will be striking the top of the wing.

QUESTIONS TO EXPLORE
(a) Compare gliding and flapping flights
(b) Compare the flight mechanism of insects and birds

Please read and summarise notes about joints of the mammalian skeleton

THE HUMAN SKELETON



HIGHLIGHTS OF THE HUMAN SKELETON

●Consists of **206 bones** at adulthood, about **300** at childhood.
●The **longest bone** in the human body is the **femur**; the **smallest** is **stirrup in the ear.**
● Males have slightly thicker and longer legs and arms; females have a wider pelvis and a larger space within the pelvis.
●It is divided into **axial** and **appendicular skeletons**

Axial skeleton is composed of **80 bones** divided into **five parts**; the **human skull,** the **ossicles** of the middle ear, the **hyoid bone** of the throat, the **rib cage,** and the **vertebral column.**
The word **Axial,** taken from the word axis refers to the fact that the bones are located close to or along the central axis of the body.

Appendicular skeleton is composed of **126 bones** divided into **six major** regions:
●Pectoral Girdles (4 bones) - Left and right **Clavicle** (2) and **Scapula** (2).
●Arm and Forearm (6 bones) - Left and right **Humerus** (2) (Arm), **Ulna** (2) and **Radius** (2) (Fore Arm).
●Hands (58 bones) - Left and right **Carpal** (16) (wrist), **Metacarpal** (10), Proximal phalanges (10), Middle phalanges (8), distal phalanges (10), and sesamoid (4).
●Pelvis (2 bones) - Left and right os coxae (2) (ilium).
●Thigh and leg (8 bones) **- Femur** (2) (thigh), **Tibia** (2), **Patella** (2) (knee), and **Fibula** (2) (leg).
●Feet (56 bones) - **Tarsals** (14) (ankle), **Metatarsals** (10), Proximal phalanges (10), middle phalanges (8), distal phalanges (10), and sesamoid (4).
The word **appendicular** is the adjective of the noun **appendage**, which itself means a part that is joined to something large.

FEATURES OF THE MAIN FORE AND HIND LIMB BONES

Main fore limb bones	*Hind limb bone*
HUMERUS ●It upper end bears a head which articulates with the **glenoid cavity** of the scapula to form **a ball and socket joint** at the shoulder. ●At its lower end is the **trochlea** which articulates with the fore arm to form **a hinge joint** at the elbow. **ULNA** ●Its upper end bears the **olecranon process** just after the elbow joint which when the arm is straightened prevents any further backward movement of the fore arm hence dislocation doesn't occur. **Therefore the olecranon process is considered to be the most important structure on the ulna bone.** ●It also bears a notch, the **sigmoid notch** close to the upper end which articulates with the **trochlea** of the humerus.	**FEMUR** ●At its upper end is a round head which articulates with the **acetabulum** of pelvic girdle to form a ball and socket joint at the hip. ●Three (3) **trochanter processes** protrude below the head and provide points of attachment for the thigh muscles. ●The lower end bears two (2) processes called **condyles** which articulate with tibia to form a **hinge joint** at the knee. A **patella groove** (where the **knee cap** is located) separates the femur's 2 condyles.

HIND LIMB OF A TYPICAL MAMMAL *Draw from:* **Michael Roberts, Pg. 423 fig. 24.8** *left or* **M.B.V. Roberts, functional approach**	**ILLUSTRATION OF THE HIND LIMB ACTION IN PROPULSION** *Draw from:* **Michael Roberts, Pg. 424 fig. 24.9A** *left or* **M.B.V. Roberts, functional approach**

BIPEDALISM [PROPULSION USING 2 REAR LEGS]

Bipedal locomotion is **walking, running,** and **standing** on two rear limbs.

●During walking, **the calf muscle** of the right limb c**ontracts** to raise the right heel; causing the **ball of foot** to exert a contact force on the ground; generating the **ground reaction force** (**GRF**) 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.

●As the right leg bears the body weight, the left heel is raised and the whole sequence repeats.

●This sequence in which the right leg alternates with the left, heel-and-toe action continues until walking ceases.

●The **GRF** is composed of the lift force which thrusts the body off the ground and the forward force that propels the body forward - the magnitude of which depends on the angle between the ground and the main axis of the limb.

●A large angle between the ground and the main axis of the limb (e.g. 90^0) results in large lift force which thrusts the body vertically upwards with no forward force, a small angle causes a relatively bigger forward force and small upward lift.

NB: The ball of the foot is where the toes join with the rest of the foot.

WHY MAN STANDS ON SOLES BUT GENERALLY SPRINTS ON TOES

●Standing on soles increases the surface area for supporting the body weight in a balanced posture.

●Sprinting on toes increases the effective length of limbs; enabling taking longer strides that propel the body forward over a greater distance and at a faster pace even if the speed of limb movement remains the same.

WHY SPRINTERS CROUCH (BEND DOWN) BEFORE TAKEOFF

Crouching creates a small angle between the ground and the main axis of the limb; resulting in maximum forward thrust rather than upward lift; hence propelling the body a greater distance forward.

QUADRUPEDALISM [PROPULSION USING FOUR LEGS]

Quadruped: an animal especially a mammal, having four limbs all specialized for walking, except humans and the birds.	**Tetrapod:** a vertebrate animal having four limbs e.g. amphibians, reptiles, birds and mammals. **NB:** A Tetrapod may use only two limbs for walking

●**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 and opposite force called **reaction force** is transmitted along the length of the limb against the body while **contraction of flexor muscle** pulls the limb forward and lifts it off the ground.

●During **walking**, only one limb is raised at a time; the other three remain anchored to the ground to provide tripod support / stability in a sequence of leg movement as follows**: left forelimb; right hindlimb; right forelimb; left hindlimb** *[N.P.O. Green; etal, Biol Sc]* **or LH; LF; RH; RF** *[Michael Roberts Pg 426& FA]*

●During **slow running**, tripod support is lost because the two forelimbs are moved together followed by the two hind limbs in the sequence of: **left forelimb; right forelimb; right hindlimb; left hindlimb.**

● 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 feet extension behind the rear feet, and full extension of the vertebral column coupled with full extension of front legs forward and rear legs rearward to increase stride length.

SUCCESSIVE STAGES IN THE DIAGONAL LOCOMOTORY PATTERN OF A WALKING TETRAPOD
Draw from: **Michael Roberts, etal Page 426 fig. 24.11B (walking)** ***or* M.B.V. Roberts, functional approach**

TASK
Summarize the importance of centre of gravity
Check: **Michael Roberts,** etal Page 426

PLANTIGRADE, DIGITIGRADE AND UNGULIGRADE LOCOMOTION

●**Plantigrade locomotion:** walking with the podials and metatarsals flat on the ground e.g. humans, raccoons, opossums, bears, rabbits, kangaroo, mice, pandas, rats and hedgehogs.

●**Digitigrade locomotion:** walking on the toes with the heel and wrist permanently raised e.g. birds, wolf, dog, coyote, cat, lion, elephant (semi-digitigrade)

●**Unguligrade locomotion:** walking on the nail or nails of the toes (the hoof) with the heel/wrist and the digits permanently raised. **Ungulates** include horse, zebra, donkey, cattle, bison, rhinoceros, camel, hippopotamus, goat, pig, sheep, giraffe, okapi, moose, deer, antelope, and gazelle.

Advantage of a plantigrade foot: because of a large surface area, it offers stability and able to bear much weight.
Disadvantage of a plantigrade foot: locomotion is
of slow speed because of many bones and joints in the foot making the leg heavier at the far end.
Advantage of digitigrades: They are generally faster and quieter than other types of animals

QUESTION
Explain why in terrestrial tetrapods it is advantageous to have limbs below and parallel to the sides of the body e.g. in mammals rather than lateral to the body e.g. in amphibians
Consult with: **Clegg and Mackean,** Adv. Biol Princ. & Applic. Page 495

VERTEBRATE REPRODUCTIVE TERMINOLOGY

a) Oviparity: animals deposit fertilized eggs in the external environment for development e.g. in all birds some reptiles and some fish.
b) 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
c) 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
d) Internal fertilization: is where fusion of male and female gametes occurs inside the body of the female animal.
e) External fertilization: is where fusion of male and female gametes occurs outside the body of the female animal.
f) Isolecithal eggs (Gr. *Isos*, equal, + *lekithos*, yolk): eggs with very little yolk that is evenly distributed in the egg e.g. human eggs.
g) Mesolecithal eggs (Gr. *mesos*, middle, + *lekithos*, yolk): eggs with moderate amount of yolk concentrated in the vegetal pole e.g. in amphibians.
h) Telolecithal eggs (Gr. *telos*, end, + *lekithos*, yolk): eggs contain an abundance of yolk that is densely concentrated at the vegetal pole of the egg. E.g. in birds, reptiles, most fishes.
i) Cleidoic eggs: shelled eggs e.g. eggs of birds, reptiles
j) Gametogenesis: the series of transformations that result into the formation of mature gametes.
k) Spermatogenesis: the series of transformations that result into the formation of male gametes.
l) Oogenesis: the series of transformations that result into the formation of female gametes.
m) Menopause: a period when ovulation and menstruation cease in human females.

SEXUAL REPRODUCTION IN HUMANS

Mechanisms leading to fertilization and subsequent development in mammals are of evolutionary advantage to their success. Describe some of the mechanisms you consider are of evolutionary advantage.
-Fertilisation 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.

Main features of sexual reproduction in mammals
-Fertilisation 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

PRIMARY AND SECONDARY SEX ORGANS

Primary sex organs: organs, which produce gametes and secrete sex hormones i.e. the gonads (testes in males and ovaries in females)

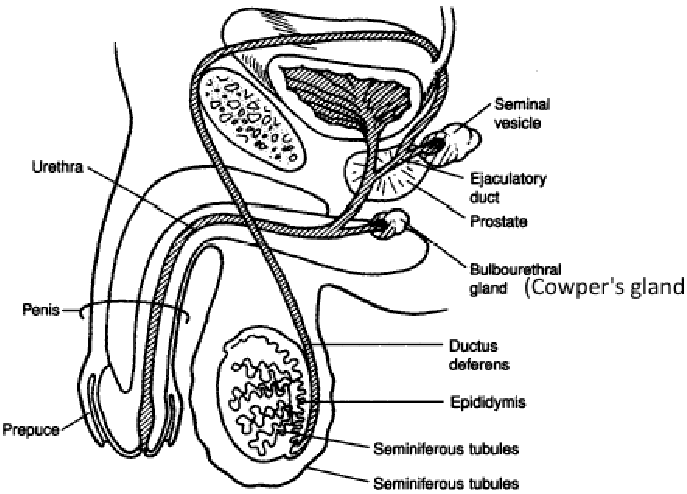
Secondary sex organs (accessory organs): organs associated with testes or ovaries which play some roles in reproduction but other than gamete production and hormone secretion. E.g. penis, prostate, seminal vesicles, sperm duct in males, and fallopian tubes, uterus, vagina, mammary glands in females.

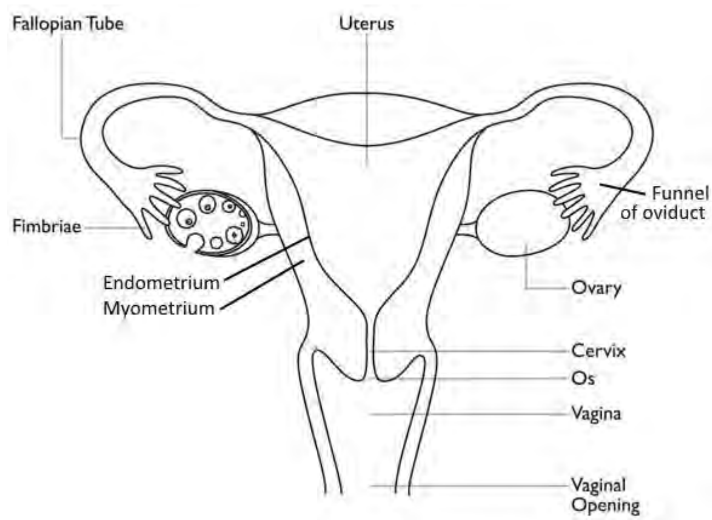
Primary sex organs	Secondary sex organs
-Produce gametes -Secrete sex hormones -Development is under the control of FSH and LH	-Do not produce gametes - Do not secrete sex hormones -Development is under the control of Oestrogen and progesterone in females and testosterone in males

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)

a) Describe the structure of the human reproductive systems.

b) State the functions of the different parts of human reproductive systems.

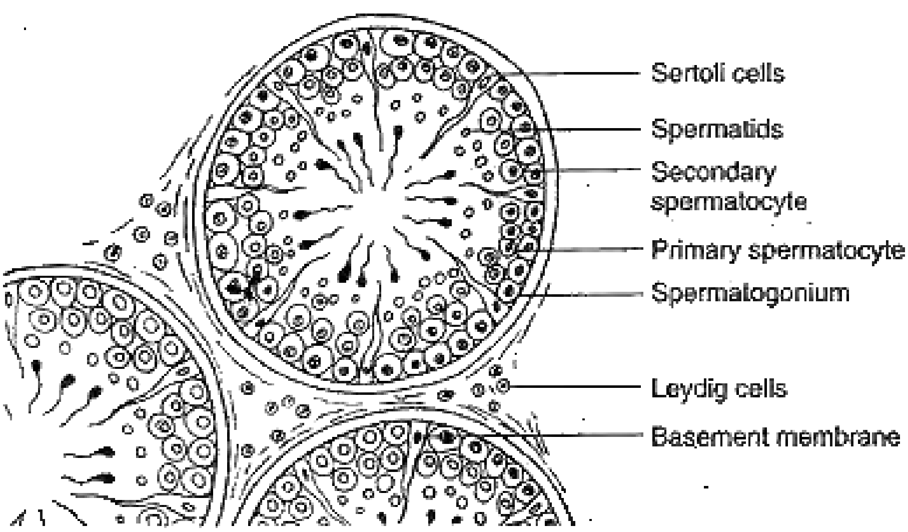


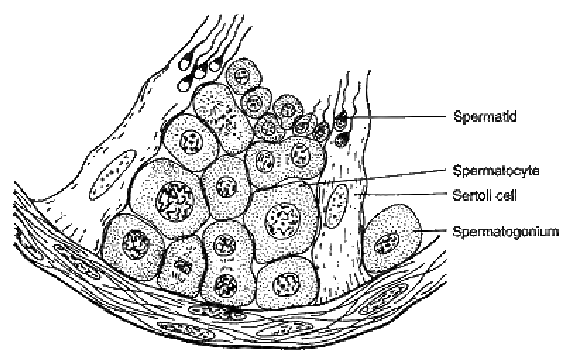


b) Functions of parts of the human reproductive systems

Male reproductive system		*Female reproductive system*	
Part	**Function**	**Part**	**Function**
Penis	-Delivers sperm to the neck of the cervix, as close to the site of ovulation as possible.	**Ovaries**	-Are sites for egg production. -Secrete the hormones oestrogen and progesterone.
Scrotum	-Regulates teste's temperature at 3^0C lower than body temperature for proper sperm formation. When cold, the cremaster muscle elevates the testes to absorb heat from the body, this's reversed at high temperature.	**Funnel of oviduct** **Oviducts (Fallopian tubes)**	-The finger-like projections sweep the egg into oviduct. -Walls are muscular and lined with ciliated epithelium for moving egg from ovary towards uterus.
Testes	-Contain seminiferous tubules that produce sperm. -Produce the male sex hormone testosterone.	**Uterus**	-Site of implantation of fertilized egg, development of foetus during pregnancy and origin of muscular contractions that precede parturition.

Prostate gland	-Secretes an alkaline fluid that neutralizes the acidic vaginal secretions to avoid reduction in sperm motility at low PH.	**Vagina**	-Passage for menstrual flow, receptacle for penis during coitus and lower part of birth canal.
Seminal vesicles	-Secrete an alkaline mucous fluid rich in fructose – the respiratory substrate for sperm motility.	**Clitoris**	-Tactile stimulation excites the female sexually during intercourse.
Cowper's (bulbourethral) gland	-Produces a mucous secretion for lubricating the penis during intercourse and neutralizing the acidity of any remaining urine.	***Labia minora* and *Labia majora***	-Produce a lubricant mucus secretion during intercourse and protect the clitoris from abrasion.
Epididymis	-Sperm maturation site (1-10 days). -Stores spermatozoa (up to 4wks)		
Vas deferens	-Stores sperm (up to many months) before ejaculation.		
Note: *Semen is 1% sperm, 20% fluid from prostate gland, 60% fluid from seminal vesicles and the rest other substances*		***Note:*** *The clitoris contains erectile tissue and nerves, and is homologous to the glans penis of males*	





Describe the main events during Spermatogenesis and development of ova in humans

Spermatogenesis:
The process by which spermatogonia in seminiferous tubules of testes develop into sperm that can leave the male's body.

Phases	**Processes**
Multiplication phase	At puberty, diploid germinal epithelial cells (primordial germ cells) of seminiferous tubules undergo repeated mitotic divisions to form a number of diploid **spermatogonia**.
Growth phase	Each **spermatogonium** increases in size and becomes a **primary spermatocyte**.
Maturation phase	Each primary spermatocyte undergoes the **first meiotic division** to form two **haploid secondary spermatocytes**, which undergo **second meiotic division** to form four **haploid spermatids**, connected to each other by cytoplasm.
Spermiogenesis	The spermatids get embedded into **sertoli cells** (loosely called "**nurse cells**") to be transformed into sperm by: (i) Losing part of cytoplasm (ii) Condensation of nucleus into head. (iii) Formation of flagellated tail. The mature spermatozoa (sperms) finally detach from sertoli cells and are released into the lumen of seminiferous tubules.

Functions of sertoli (sustentacular) cells:

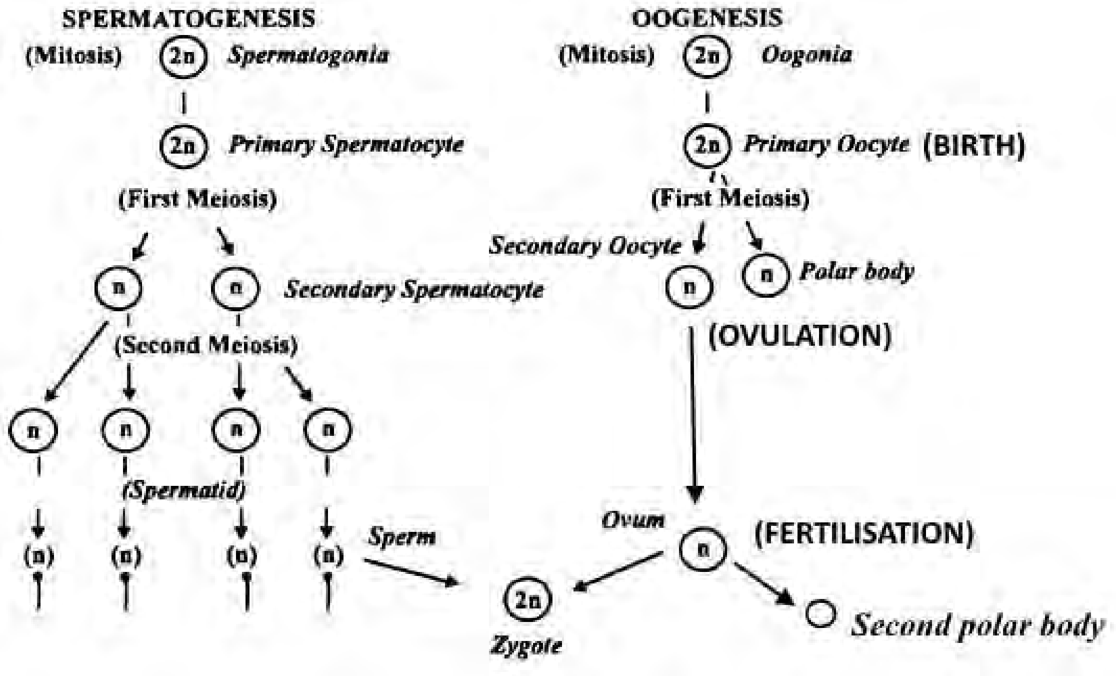
i) Provide nourishment to developing spermatids.
ii) Phagocytise (eat off) the cytoplasm of spermatids.
iii) Secrete a fluid that carries spermids through the tubules.
iv) Phagocytise foreign particles that invade the tubules.

Oogenesis:

Production of eggs in the ovary of females

Phases	**Processes**
Multiplication phase	During embryonic development, diploid oogonia (germinal epithelial cells of ovary) undergo repeated mitotic divisions to increase in number.
Growth phase	Some oogonia undergo mitosis to form **primary oocytes**, which remain at prophase I of meiosis, while the rest (now called **follicle cells/granulosa cells**) enclose the primary oocytes.
Maturation phase	-At puberty, granulosa cells multiply to form **primary follicle** & other cell layers around the primary oocyte. -The primary oocyte undergoes meiosis up to metaphase II only to form a **secondary oocyte** and 1st **polar body** -The primary follicle develops to form fluid filled **secondary follicle** and later **Graafian follicle,** which enclose **secondary oocyte & 1st polar body.** -At fertilization, the secondary oocyte completes meiosis II to form a large <u>**ootid (ovum)**</u> and <u>**second polar body.**</u> -The first polar body also undergoes meiosis at the same time to form two small polar bodies. -All the three polar bodies degenerate and only one functional egg remains

<u>Note:</u> The egg released from the Graafian follicle during ovulation is a secondary oocyte, which has undergone meiosis up to metaphase II only. Meiosis II is completed at the time of fertilization and turns the secondary oocyte into an egg.



Explain the significance of formation polar bodies during oogenesis.

- Polar bodies take the extra chromosomes resulting from meiosis in order for the ovum to carry haploid number of chromosomes.
- The unequal cytoplasmic division results into the formation of a large egg with the cytoplasm containing sufficient yolk for the development of the embryo.

Compare spermatogenesis and oogenesis in humans

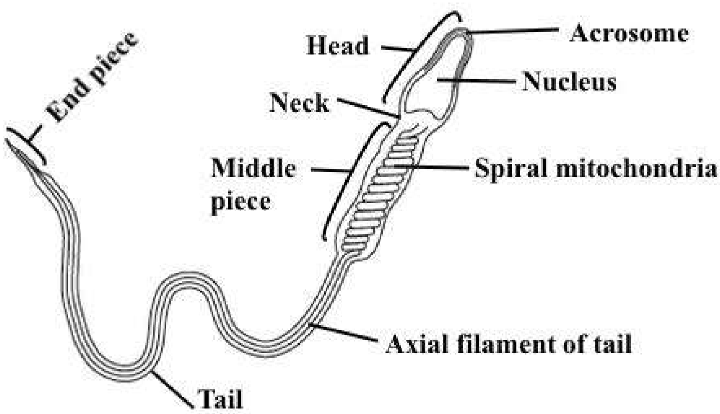
Similarities:

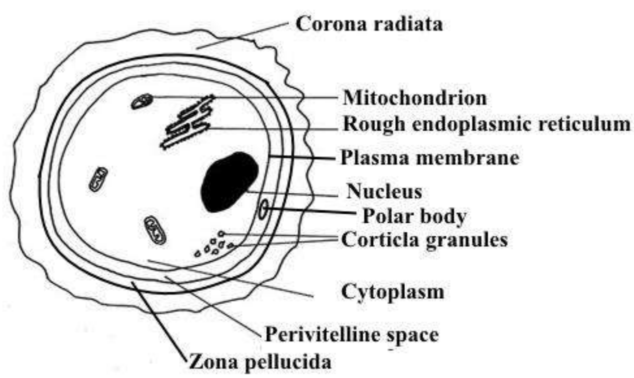
- Both begin with diploid germinal epithelial cells
- Mitosis and meiosis are involved in both
- Both yield haploid gametes
- Both occur in gonads

Differences:

Spermatogenesis	***Oogenesis***
• Occurs in seminiferous tubules in testes of males.	• Occurs in ovaries of females
• Begins only at puberty.	• Begins during embryonic development. A baby girl is born with the set number of primary oocytes already in prophase stage of 1st meiotic division.
• It is a continuous process and occurs all the time	• It is a discontinuous process, only one egg matures in about 28 days.
• During growth phase, primary spermatocyte shows only double the increase	• Primary oocyte may show the increase of about four to eight times.
• Four spermatids are formed from one primary spermatophyte	• Only one ovum is formed from one primary oocyte.
• Equal cytoplasmic divisions during meiosis I and meiosis II and no formation of polar bodies.	• There is unequal cytoplasmic division during meiosis I and meiosis II and resulting into formation of polar bodies.
• All stages are completed and sperms are formed in the testes only	• The secondary oocyte leaves the ovary and final second meiotic division at fertilization in the fallopian tube.
• Male gamete or sperm is comparatively very small.	• Female gamete is very large comparatively.
• Spermatid undergoes spermiogenesis to become sperm.	• No such stage after the formation of ootid or ovum
• Takes a longer time to complete	• Takes a shorter time to complete

a) Describe the structure of human male and female gametes
b) State the functions of the parts of gametes
c) Compare male and female gametes in humans





b) Functions of the parts of gametes

Human spermatozoon			*Human ovum*	
Part	**Function**		**Part**	**Function**
Acrosome	-Contains hydrolytic enzymes which facilitate the penetration of the egg membranes prior to fertilization.		**Yolky cytoplasm**	Contains fat and protein which nourish the developing embryo.
Nucleus	Contain a haploid set of chromosomes, which on fusion with the egg restores the diploid state of organisms.		**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.
Mitochondria	They complete aerobic to release ATP required for contraction of filaments during the sperm's movement.		**vitelline membrane**	Undergoes structural changes that prevent polyspermy at fertilisation
Tail piece (Flagellum)	Enables motility of the sperm.		**Nucleus**	Contains 23 chromosomes that complete meiosis II at fertilization to provide female haploid nucleus
Centriole	-One of a pair produces microtubules that form the axial filament of flagellum. -The function of the other centriole is not clearly known.		**Polar body**	Contains 23 chromosomes, but is non-functional and degenerate

Outline the hormonal control of spermatogenesis in humans.
-Interaction of hormones from the hypothalamus and anterior pituitary gland working together controls spermatogenesis.
-From the hypothalamus, **gonadotrophin-releasing hormone (GnRH)** stimulates the anterior pituitary gland to secrete two gonadotrophins (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.**

- The general name for male sex hormones is **androgens** (e.g. testosterone), while **oestrogens** 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.

a) (i) Distinguish between oestrous and menstrual cycles.
ii) Outline the four main phases of the menstrual cycle
b) Describe the hormonal, physiological and structural changes that occur during the human menstrual cycle.(hormonal control of menstrual cycle)

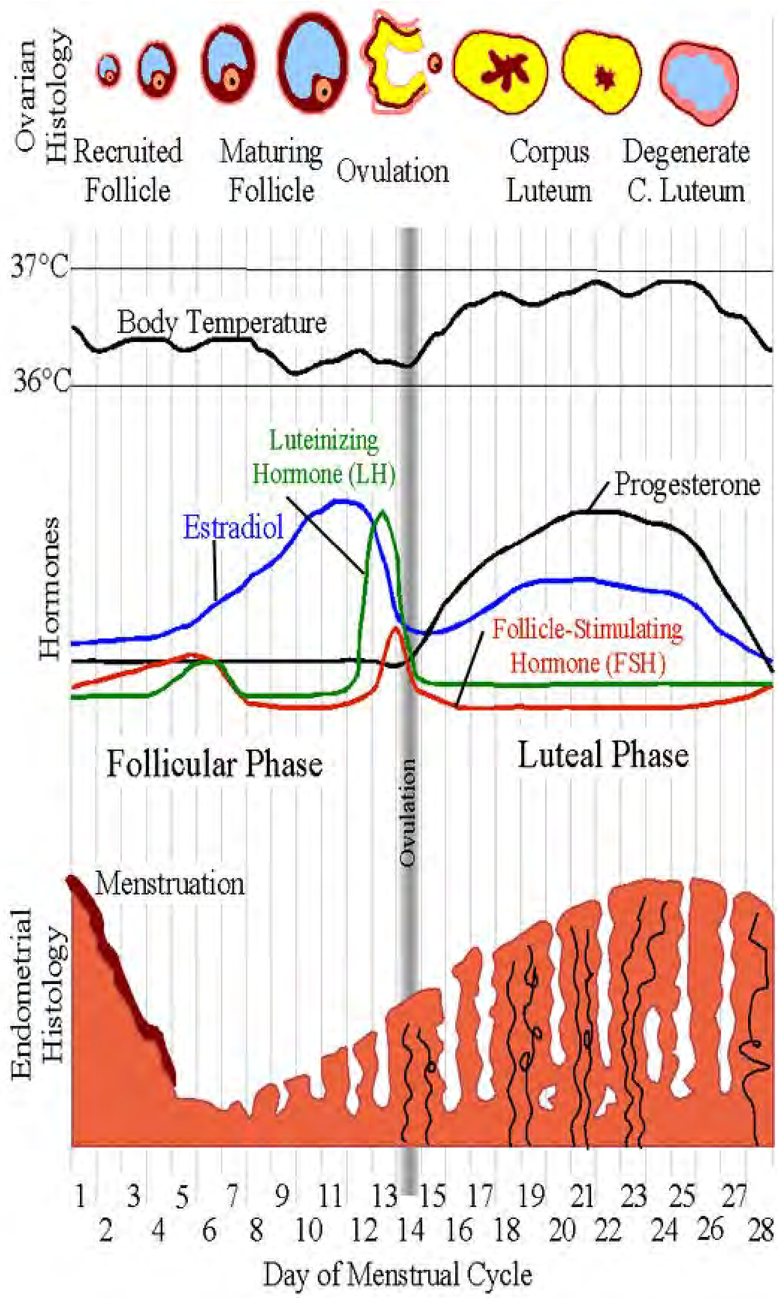
a) (i) **Oestrous cycle:** series of hormone controlled changes in the non-primate reproductive cycle characterized by females experiencing a period of heightened sexual excitement just before ovulation.

Menstrual cycle: series of hormone controlled changes in the primate female reproductive system that result in monthly discharge of blood and uterine materials when fertilization fails.

ii) **The four main phases of the menstrual cycle:**
–Follicular phase
-Ovulation
-Luteal phase
-Menstruation

b) **HORMONAL CONTROL OF MENSTRUAL CYCLE**

The hormonal, physiological and structural changes that occur during the menstrual cycle are as follows:	
Phase	*Changes*
Follicular phase	**-**At puberty (about 12 years) the hypothalamus: **1.** Secretes **Gonadotrophin-releasing hormone (GnRH)** which stimulates the anterior pituitary to secrete **follicle stimulating hormone (FSH).** **2. FSH** stimulates: (i) The development of primary follicles in the ovary (ii) The secretion of **oestrogen.** **3. Oestrogen:**
Ovulation	(i) Causes the repair and healing of the uterine wall following menstruation. (ii) Inhibits the secretion of **FSH.** (iii) Causes the secretion of **LH** from the anterior pituitary.
Luteal phase	**4. LH** stimulates: (i) **Ovulation** i.e. Meiosis I resumes in the primary oocyte to form polar body and secondary oocyte, which is released by rupturing of Graafian follicle. (ii) The remains of Graafian follicle to develop into **corpus luteum** (yellow body), (iii) The **corpus luteum** to secrete **progesterone** and o**estrogen**.
Menstruation	**5. Progesterone:** (i) Causes increased thickness (muscularisation) and vascularization of the uterus. (ii) Inhibits the release of **LH** and **FSH** by negative feedback. -**Decreased** level of **FSH** prevents development of Graafian follicles, hence secretion of **oestrogen** stops. -**Decreased** level of **LH** prevents ovulation, hence the corpus luteum degenerates and **progesterone** decreases. -The sudden decrease of progesterone level in blood completes menstrual cycle, as the hypothalamus resumes the secretion of **GnRH**. - **GnRH** stimulates the anterior pituitary to secrete **FSH** as menstruation occurs, characterized by breakdown and shedding of endometrial materials.



Briefly explain the following processes and state the significance of each.
(a) Sperm capacitation (b) Acrosome reaction (c) Fast block (d) Cortical reaction

Process	***Explanation***	***Significance of the process***
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 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**	Formation of fertilization membrane prevents multiple sperm entry into the egg (polyspermy) that would upset the diploid state to cause death of mammalian embryo.

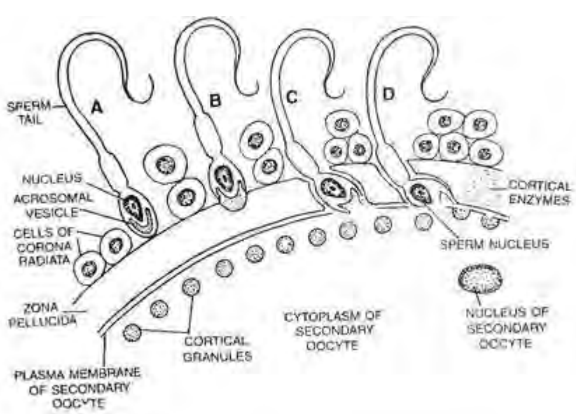
Outline the events which lead to fertilization of an egg by a sperm.

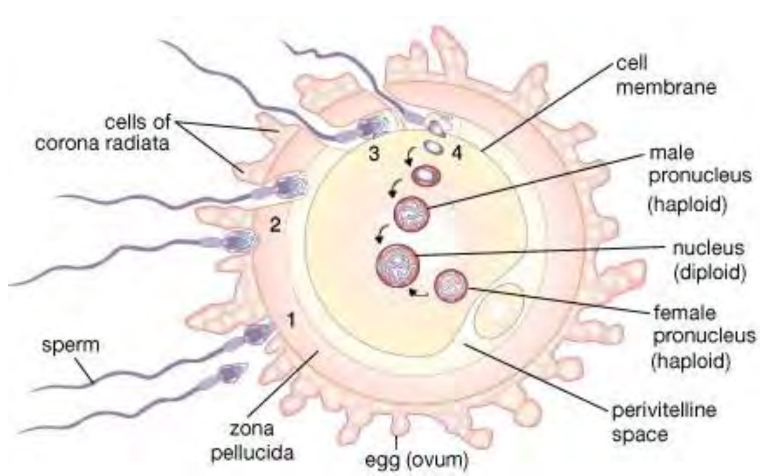
Fertilization is the fusion of sperm and egg nuclei to form a diploid zygote.

- 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 hydrolyse 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.

After their release, how long do sperm and secondary oocyte remain viable for fertilization?

Approximately 48 hours for sperm and about 10-15 hours for secondary oocyte. Therefore to result in pregnancy, sexual intercourse must occur no more than 48 hours before or 15 hours after ovulation





Outline the events that occur in the egg immediately following the entry of the spermatozoon.

- Sperm acrosome membrane ruptures to release hydrolytic enzymes 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 followed by fusion of cortical granules with plasma membrane to discharge their contents 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 to block polyspermy.
- While the sperm tail is lost and disintegrates, the nucleus expands and is now known as **pronucleus.**
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- The haploid **male and female pronuclei** fuse to form a **diploid zygote**, which divides immediately by mitosis to form two diploid cells.

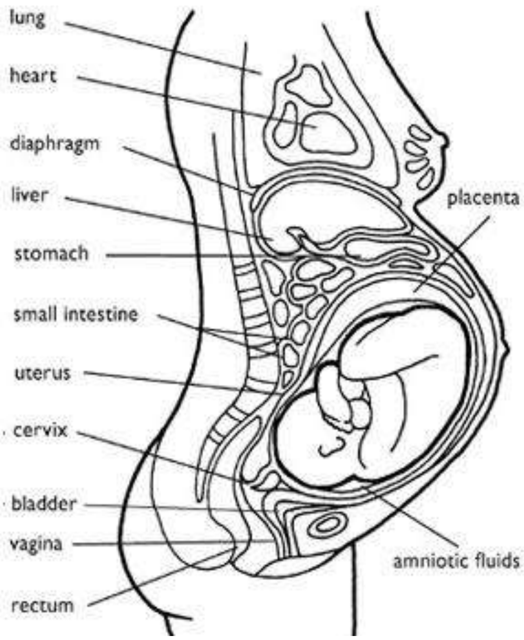
a) What is meant by negative feed back
b) Briefly explain how negative feed back operates in the control of:
i) Testicular hormone secretion
ii) The menstrual cycle
c) What hormonal controlled changes occur in the endometrium during the menstrual cycle?
(Effect of ovarian hormones on the endometrium during the menstrual cycle)

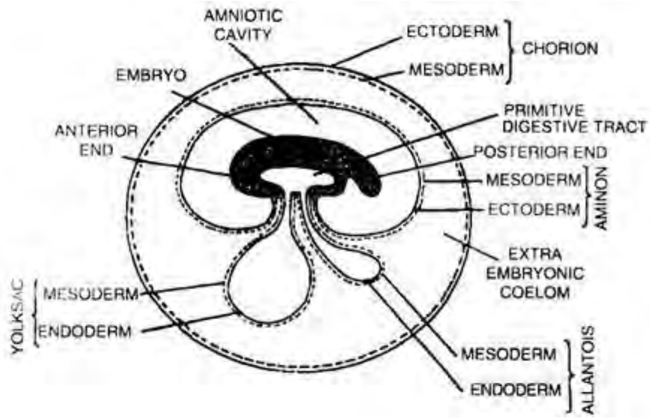
a) A mechanism in which the effect of deviation from the normal condition triggers a response that eliminates its deviation in order to reduce further corrective action of the control system once the set point value has been reached.

b) (i)-The hypothalamic hormone, **gonadotrophin-releasing hormone (GnRH)** stimulates the anterior pituitary gland to secrete both **follicle stimulating hormone (FSH)** and **luteinising hormone (LH).**
-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 stimulates leydig cells of the testes to secrete **testosterone.**
- Testosterone stimulates the growth and development of spermatogonia to form sperm, also inhibits the secretion of **LH** by feeding back, both directly at the anterior pituitary gland and indirectly by reducing **GnRH** release**.**
ii) -The hypothalamic **Gonadotrophin-releasing hormone (GnRH)** stimulates the anterior pituitary to both **FSH** and **LH.**
-FSH stimulates the secretion of **oestrogen** in the ovary.
-Oestrogen in increased levels inhibits **FSH** secretion and causes secretion of **LH** from the anterior pituitary.
-LH stimulates ovulation and development of **corpus luteum,** which secretes **progesterone** and also continues to secrete o**estrogen**.
-Progesterone inhibits the release of **LH** and **FSH** thus arresting development of any further follicles**.**

c) Hormonal control of changes in the endometrium during the menstrual cycle
-During the follicular phase, oestrogen (estradiol) from the ovary causes the uterine endometrium to repair and heal.
-During the luteal phase, progesterone secreted by the corpus luteum in the ovary causes the endometrium to become highly muscular and vascular.
-As the corpus luteum degenerates, the rapid fall in oestrogen and progesterone levels at the end of the cycle causes the endometrium to be sloughed off in menstruation.

PREGNANCY (GRAVIDITY OR GESTATION): The period between conception (fertilisation) and birth.





HIGHLIGHTS OF HUMAN PREGNANCY

30 hours after fertilisation – first cleavege

3-4 Days after Conception:

(i) The zygote, now called **morula** arrives at the uterus after a 4 inch journey through the fallopian tube.

(ii) In the uterus the morula burrows itself into the endometrium (inner lining of uterus).

(iii) The outside cells of the morula eventually grow to form the placenta.

6-7 Days after Conception

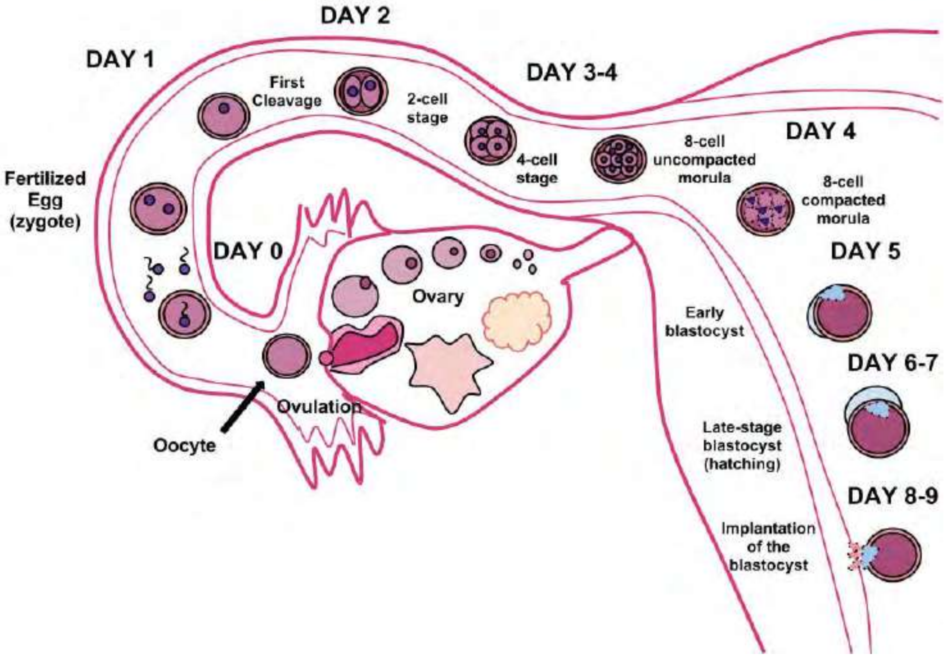
The morula, now called **blastocyst** attaches to the uterus, causing some women to feel **implantation cramps.**

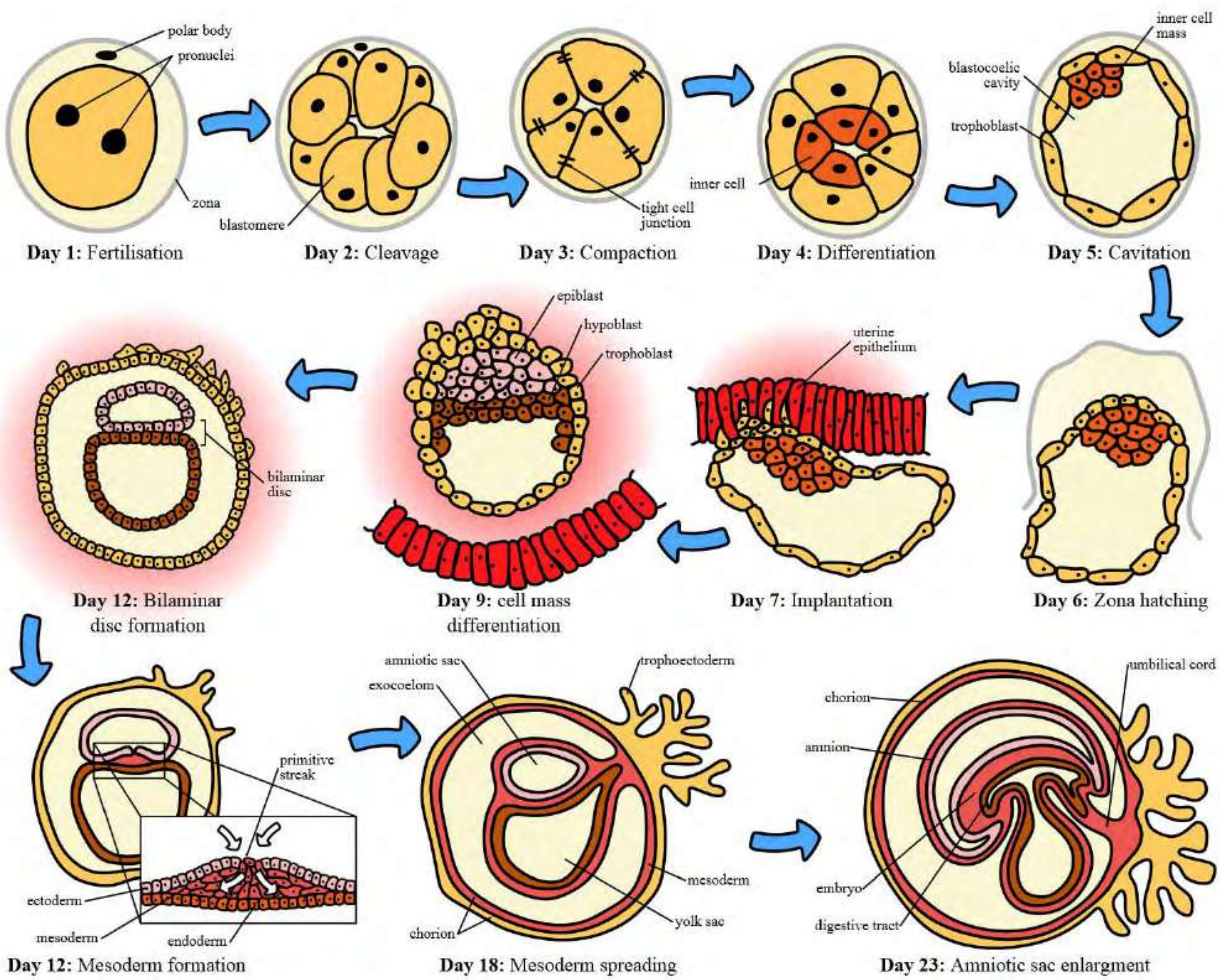
7-9 Days After Conception

(i) **Pregnancy** tests can detect the levels of **HCG** (human Chorionic Gonadotropin) hormone in the body.

(ii) **HCG**, a protein hormone, is first produced in the second week of gestation to prevent menstruation and is most concentrated at 8 weeks gestation. Levels gradually decline after the 8th week.

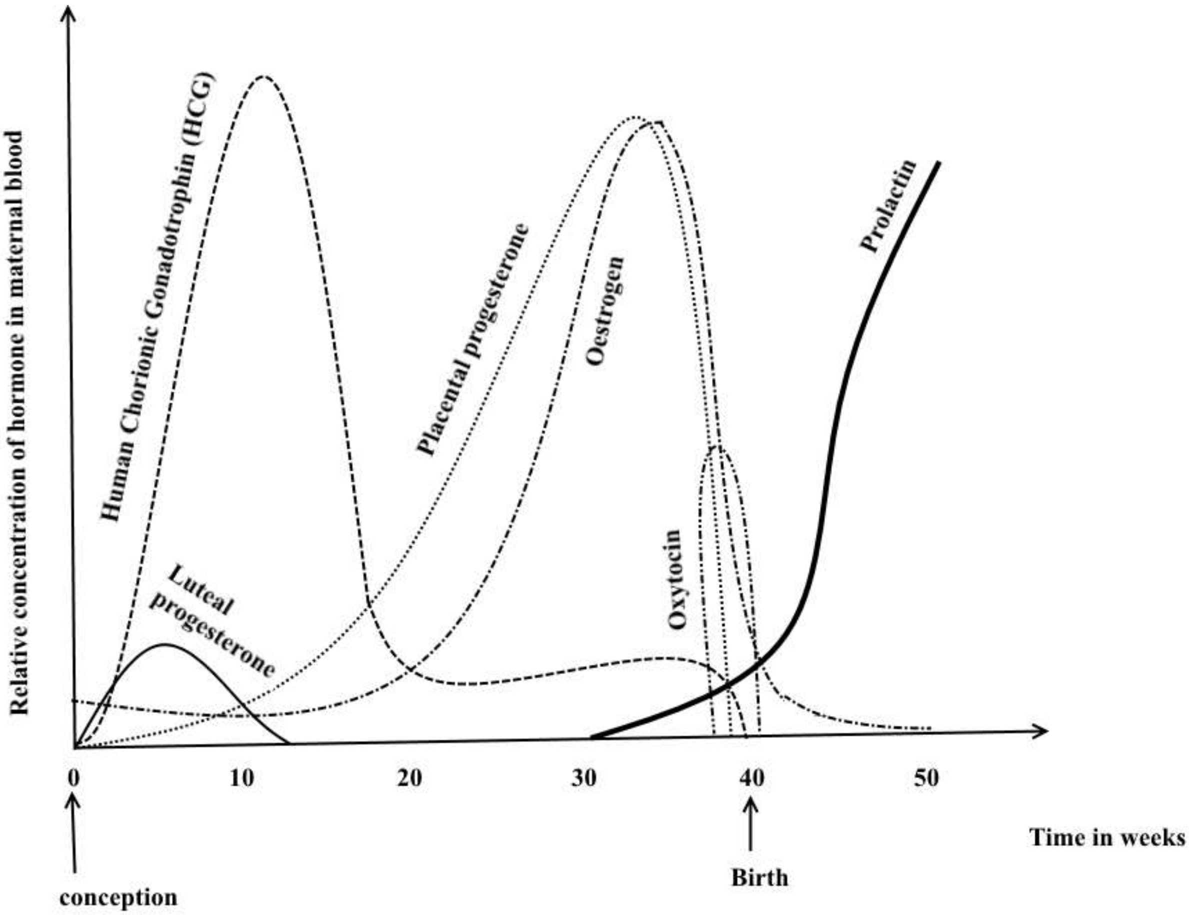
Duration	**Major events**
2 weeks	Most women can test positive for HCG urine pregnancy tests, at 95% accuracy.
3 weeks	Baby-in-the-making is a ball of cells called a **blastocyst. Gastrulation** occurs.
4 weeks	Organogenesis
5 weeks	Heart begins to beat – at twice the rate of adults.
6 weeks	Facial features (e.g. **eyes and nostrils**) begin to form, and little buds appear where arms and legs will develop
8 weeks	Arms and legs are growing, as well as a **nose** and **upper lip** are formed. Notochord degenerates.
9 weeks	**Eyes** have developed, though eyelids are still fused and shut.
10 weeks	The embryo has become a **foetus**. Vital organs – such as **kidneys, intestines, brain, and liver** – are starting to function. Tiny **fingernails** and **toenails** are forming.
11 week	Foetus is almost fully formed. **Bone templates** are formed, **external genitalia** are developing.
12 week	Baby's heartbeat can be felt.
14 week	Kidneys can release urine into the amniotic fluid.
15 weeks	Baby can see light that filters in from outside the womb, even though the eyelids are still shut
16 weeks	Baby's sex can be detected.
19 weeks	Baby can hear mother's heartbeat and sounds that come from outside the body, such as father's voice.
23 weeks	Baby's sense of movement has developed, so s/he can feel the motion if mother dances.
27 weeks	Baby can "practice breathing" by inhaling and exhaling amniotic fluid, and also open and close eyes.
34 weeks	Baby is now considered full-term, lungs can work fine if born now.
40 weeks	Baby is due and fully ready for life outside the womb.


DAY 2
DAY 1
First Cleavage
2-cell stage
DAY 3-4
4-cell stage
8-cell uncompacted morula
DAY 4
8-cell compacted morula
Fertilized Egg (zygote)
DAY 0
Ovary
DAY 5
Early blastocyst
DAY 6-7
Ovulation
Oocyte
Late-stage blastocyst (hatching)
DAY 8-9
Implantation of the blastocyst


polar body
pronuclei
zona
blastomere
tight cell junction
inner cell
inner cell mass
blastocoelic cavity
trophoblast
Day 1: Fertilisation
Day 2: Cleavage
Day 3: Compaction
Day 4: Differentiation
Day 5: Cavitation
epiblast
hypoblast
trophoblast
uterine epithelium
bilaminar disc
Day 12: Bilaminar disc formation
Day 9: cell mass differentiation
Day 7: Implantation
Day 6: Zona hatching
primitive streak
ectoderm
mesoderm
endoderm
amniotic sac
exocoelom
trophoectoderm
mesoderm
yolk sac
chorion
chorion
amnion
umbilical cord
embryo
digestive tract
Day 12: Mesoderm formation
Day 18: Mesoderm spreading
Day 23: Amniotic sac enlargment

HORMONAL CONTROL OF PREGNANCY

Changes in hormonal concentration during pregnancy



EXPLANATION FOR OBSERVATIONS

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. (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.	(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 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 weeks to a maximum just before birth.	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. (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.

a) Give an account of the role of the placenta as an endocrine organ in mammals.
b) How is a placenta suited for providing the developing foetus with nutrients?
c) Outline the transport mechanisms involved in the exchange of substances between mother and developing foetus.

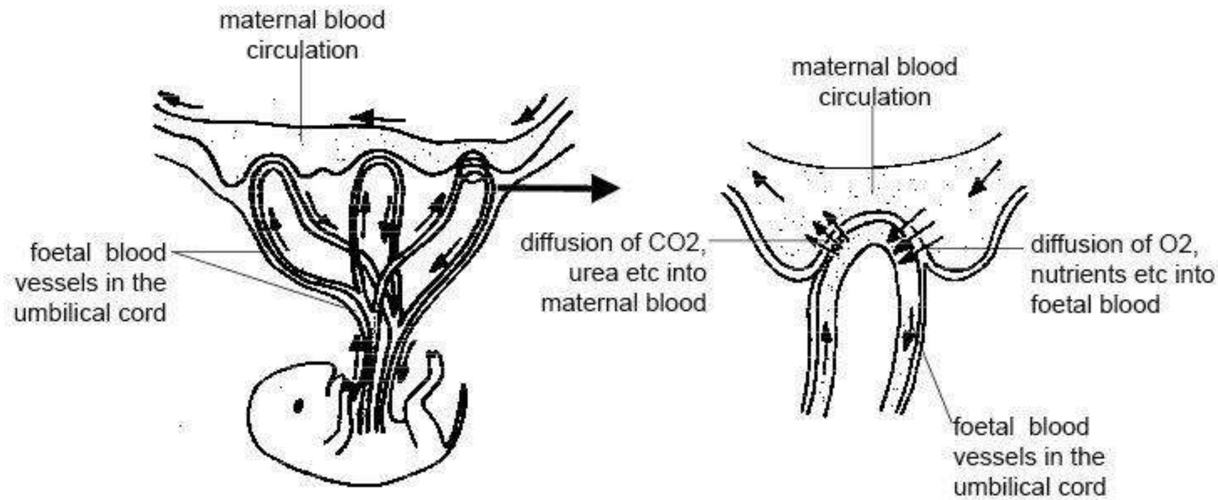
a) The role of the placenta

As an endocrine organ	*Non-endocrine role*
It secretes various hormones which control development of the foetus: • **HCG (human chorionic gonadotrophin)** causes the corpus luteum to continue secreting progesterone and oestrogen necessary for endometrial development for the first 3-4 months of pregnancy. • **Oestrogen** prevents ovulation and menstruation, stimulates growth of mammary glands and increase in uterine muscle cells, and increases myometrium sensitivity to oxytocin • **Progesterone** also stimulates growth of mammary glands, inhibits the contraction of uterine muscles and inhibits the release of **prolactin** (a hormone that stimulates milk production). • **Relaxin hormone** relaxes the connective tissue in pelvic girdle to enlarge the cervix in preparation for birth.	• Digested food and other nutrients are transported through umbilical vein to link up with the foetal blood • Waste foetal products diffuse from umbilical artery to maternal blood. • Oxygen diffuses from umbilical vein to the foetal blood while carbondioxide moves in opposite direction. • Antibodies cross the placenta from mother to foetus hence providing means by which **passive immunity** is acquired. • It serves as a barrier to the transfer of solutes and blood components from maternal to foetal circulation. • It prevents direct contact of maternal and foetal blood systems enabling them to operate at different pressures

b) How placenta is suited for providing the developing foetus with nutrients:
-The finger-like projections which grow into the endometrium increase the surface area for exchange of substances.
-Closeness of maternal and foetal blood vessels facilitates faster diffusion of substances.
-Continuous flow of blood at the placenta ensures replacement of substances to maintain diffusion gradients for easy diffusion of these materials.
-Chorionic villi cells contain numerous mitochondria to provide energy required for active transport

c) Transport mechanisms involved in the exchange of substances between mother and foetus

Mechanism	*Substances moving*
Osmosis	Water
Simple diffusion	-Respiratory gases (oxygen and carbondioxide) -Nitrogenous wastes (urea) from the foetus -Ions (of sodium, potassium, calcium) to a small extent diffuse.
Facilitated diffusion	-Glucose
Active transport	-Ions (of sodium, potassium, calcium) largely move by active transport -Amino acids -Iron -Vitamins



The BIRTHING PROCESS (PARTURITION)
The time leading up to the normal birthing process is generally 266 days (38 weeks) - from conception to birth. However, only about 5% of births occur on the actual due date.

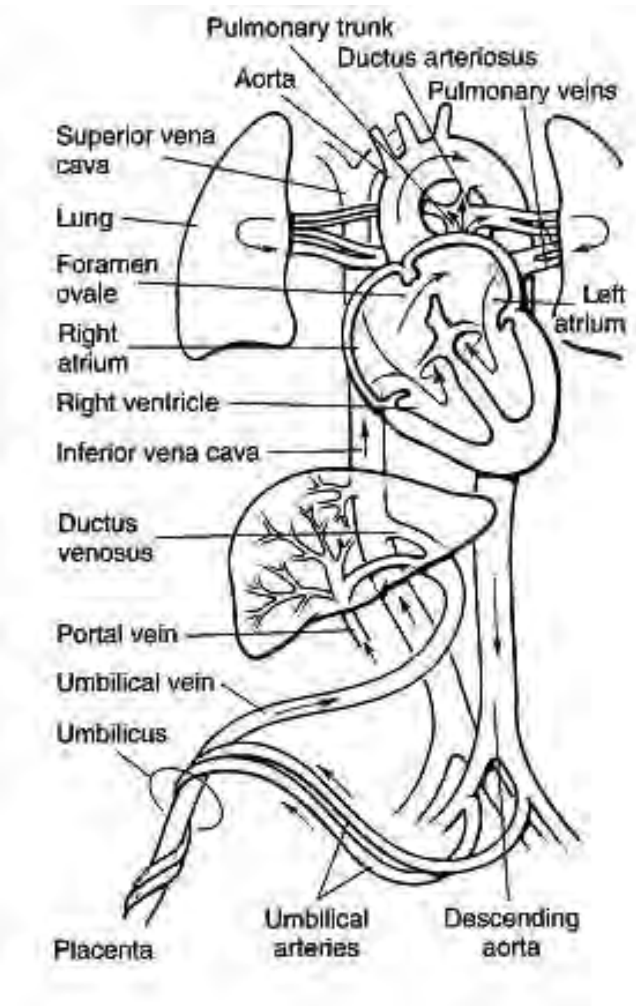
Outline the stages in the process of parturition (birth)
-The onset of birth is triggered by decreased progesterone and increased oestrogen levels during the last stages of pregnancy.
-The posterior pituitary produces **Oxytocin,** which causes contraction of the uterus that increase in force and frequency.
-Cervix dilates to allow passage of baby's head into the vagina while embryonic membranes rupture.
-Foetus is expelled in down face position, followed by afterbirth (umbilical cord and placenta) expulsion.

a) Distinguish between contraception and birth control.
b) Give an outline of birth control methods in man
Contraception: use of methods which act to prevent fertilization of an egg by sperm
Birth control: a wide range of methods that prevent development of egg into foetus, whether it is already fertilized or not.

Birth control methods

Method	***How it works***
1. Barriers preventing sperm from reaching egg cell	
a) Condom (for males and females)	-Inserted on erect penis or into vagina before sexual intercourse
b) Diaphragm (cap)	-Inserted into vagina before sexual intercourse
c) Spermicide	-Cream, foam or gel placed into vagina to kill sperm
2. Hormones that interfere with ovulation or implantation	
a) Pill	-Combination of oestrogen and progesterone prevents ovulation and implantation
b) Morning after pill (emergency pill)	-Used within 48 hours after sex.
3. Behavioural	
a) Rhythm method	-Sex is avoided during ovulation period
b) Penis withdrawal (coitus interruptus)	- Penis is withdrawn from vagina before ejaculation occurs
4. Surgical	
a) Vasectomy (males)	-Sperm duct is cut and tied permanently
b) Ligation of oviducts	-Both oviducts are cut and tied permanently
5. Other e.g. intra-uterine device (IUD), plastic or copper device	-Prevents implantation

CHANGES THAT OCCUR IN BLOOD AND FOETAL CIRCULATION AT BIRTH



INFERTILITY

Infertility: the failure of a couple to conceive a pregnancy after trying to do so for at least one full year.

(i) Primary infertility: pregnancy has never occurred.

(ii) Secondary infertility: one or both members of the couple have previously conceived, but are unable to conceive again after a full year of trying.

MAIN CAUSES OF INFERTILITY

(a) Male problems: 35% **(b)** Ovulation problems: 20%
(c) Tubal problems: 20% **(d)** Endometriosis: 10% [abnormal location of uterine tissue outside of the uterus] **(e)** Cervical factors: 5%.

1. 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.

2. 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.

3. Excessive overweight or **underweight** can disrupt the pattern of secretion of FSH and LH and affect ovulation.

4. Auto-immune response - the body mistakenly attacks ovarian tissues.

5. 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.

6. Too much prolactin secretion which reduces oestrogen production and may cause infertility due to pituitary malfunction or medications taken for another disease.

7. 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.

8. Implantation failure due to fibroids/tumors, inflammation, abnormally shaped uterus, cervical narrowing.

9. Sometimes the cervix can't produce the best **type of mucus** to allow the sperm to travel through the cervix into the uterus.

10. Low sperm count: less than 5 million sperm per ml of semen

11. Impotence: failure of the penis to erect or ejaculate

BEFORE BIRTH

-Foetal haemoglobin has a higher affinity for oxygen than adult haemoglobin to facilitate diffusion of oxygen from the mother.

- In the foetus, blood bypasses the lungs via the **ductus arteriosus**, which connects the pulmonary artery to the aorta.
- Blood also bypasses the lungs, which are functionless by going through the **foramen ovale** connecting the two atria of the foetal heart.
-Blood from the left atrium passes into the left ventricle and into the aorta, which supplies blood to the body and the umbilical artery. Pressure in the foetal circulatory system is greatest in the pulmonary artery and this determines the direction of blood flow through the foetus and placenta.

AFTER 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.

Note: sometimes the mechanism which results in the closure of foramen ovale fails. This is the reason why some children called **blue babies** bear a hole in the heart, where a portion of blood continues to bypass the lungs resulting in inadequate oxygenation of the tissues.

What major change would occur in the foetal circulation if blood pressure were highest in the aorta?
Blood would flow in the reverse direction along the ductus arteriosus.

EXTRA EMBRYONIC MEMBRANES ASSOCIATED WITH THE HUMAN FOETUS

1. Chorion: It completely surrounds the foetus and is the foetal contribution to the placenta.
2. Amnion: Forms a fluid filled **amniotic cavity** that cushions the foetus from shock and mechanical damage.
3. Yolk sac: Contains little or no yolk, it is a temporary site for **red blood cell** formation.
4. Allantois: Derived from embryonic hind gut, it contributes blood vessels that form the umbilical cord.

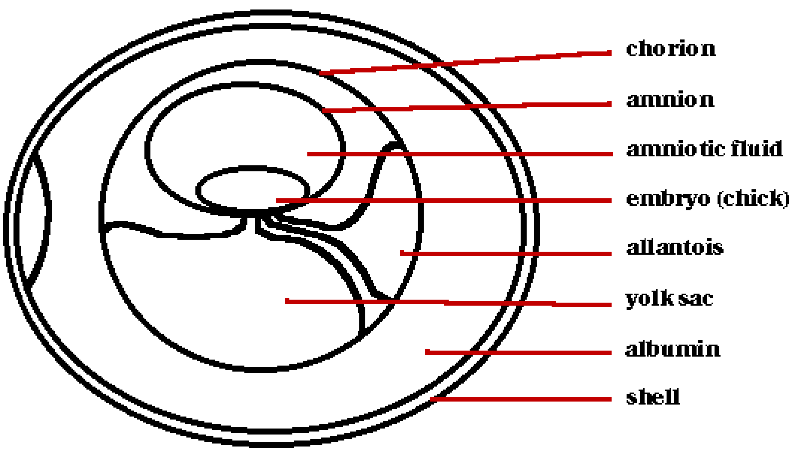
a) What are the main features of reproduction in birds?
b) How are birds suited for reproduction on land?
c) Compare embryo development in birds and mammals.
d) State the forms of parental care provided by mammals.

a) Some of the main features of reproduction in birds

(i) Fertilization is internal **(ii)** Mating is preceded by elaborate courtship displays **(iii)** Hard shelled eggs **(cleidoic/amniotic eggs)** are laid in the external environment **(iv)** Eggs are incubated usually by the mother as the embryo develops **(v)** Newly hatched young ones are fed and cared for by the parents

b) How birds are suited for reproduction on land

(i) Production of hard-shelled eggs for protection from mechanical damage **(ii)** Fertilization is internal to avoid drying up of eggs and wastage of gametes **(iii)** Newly hatched young ones are fed and cared for by the parents e.g. nest building, brooding e.t.c. **(iv)** Zygote develops within the **amniote (cleidoic egg),** which provides the embryo with a fluid-filled cavity in which it can develop on land.



c) Comparison of embryo development in birds and mammals.

Similarities:

(i) Both contain yolk sac (ii) In both the embryo is surrounded by **extra-embryonic membranes,** which develop from tissues outside the embryo (iii) In both the embryo is cushioned in the fluid-filled amniotic cavity (iv) Embryo development is preceded by internal fertilization in both (v) Allantois is involved in gaseous exchange.

Embryo development in birds	*Embryo development in mammals.*
• Yolk sac is well developed nourish the foetus	• Yolk sac is poorly developed since the foetus derives nourishment from the mother.
• Allantois is a depository organ for nitrogenous wastes e.g. uric acid.	• Nitrogenous wastes e.g. urea diffuse into maternal blood.
• Embryo is protected from damage by an outer shell.	• Outer shell is lacking around the developing embryo.
• Yolk sac transfers digested food to the embryo.	• Digested food is transferred by placenta.
• Allanto-chorion is lacking.	• There is a developed allanto-chorion

c) Forms of parental care provided by mammals:

(i) Protection from predators (ii) Feeding (iii) Provision of shelter (v) Training of offspring.

What is meant by the term reproduction?

- 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

Types of reproduction: Sexual and Asexual

Distinguish between sexual and asexual reproduction

- **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.

- **Sexual reproduction** is the production of offspring by the fusion of haploid male and female gametes (fertilization) to form a diploid zygote, which develops into the mature organism.

Compare sexual and asexual reproduction

Similarities:
- In both mitosis is involved
- Both produce offspring
- In both 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; i.e. 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

Give an account of the various forms of asexual reproduction

The five major ways by which asexual reproduction occurs are:

a) Fission:

It is the division of the cell by mitosis into two or more equal sized daughter cells identical to the parent cell. **Binary fission** ('splitting into two') occurs in bacteria, amoeba, paramecium while **multiple fission** (**schizogony**) - 'splitting into many' occurs in plasmodium (a malaria parasite) immediately after infection as the parasite (merozoites) enters the liver and again as they invade the red blood cells.

b) Sporulation (spore formation):

Is the formation of small unicellular bodies called spores by cell divisions in organisms, which detach from the parent plant and grow into new organisms under favourable conditions. It occurs in fungi e.g. *rhizopus*, bacteria, mosses, ferns, Liverworts, algae and amoeba.

What is a spore?
A haploid reproductive cell, usually unicellular, capable of developing into an adult without fusion with another cell.

c) 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, flatworms.

d) Budding:
This involves the parent cell forming an out growth (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, bryophyllum.

e) Vegetative propagation:
This is asexual reproduction in which a part of flowering plant other than the flower detaches itself 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 may also act as **organs of perennation.**

i)What are perennating organs?
ii) Explain the role played by perennating organs to the plants.
i) These are parts of flowering plants specialised for vegetative propagation as well as food storage, enabling plants bearing them to survive adverse (unfavourable) environmental conditions e.g. cold or dry periods. The food manufactured by photosynthesis in aerial green leaves is translocated and subsequently stored *as starch* in rhizomes, corms, stem and root tubers, *or as glucose* in onion bulb.

ii) During unfavourable conditions, the plant remains dormant but when conditions normalise, starch 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.

Distinguish between organs of vegetative propagation and organs of perennation in plants.
Organs of vegetative progation 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 (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*

Organs of perennation are plant parts specialised for storing the 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.
Summarily, organs of perennation also double as organs of vegetative propagation, **but not all** *organs of vegetative propagation function as perennating organs.*

Specialised organs of vegetative propagation must have buds, which only occur on stems. Explain why root tubers (swollen adventitious roots) e.g. sweet potato, dahlia and cassava, and swollen taproots e.g. carrot and turnip are used as organs of vegetative propagation yet roots lack buds.

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.

Artificial propagation methods in plants

- **Cutting:**

A piece of root *e.g. of lemon and tamarind*, or stem *e.g. sugarcane and cassava*, or a complete leaf is dipped in rooting mixture composed of plant hormones, and allowed to grow in a rooting composite or soil.

- **Layering:**

Involves pegging down of stem of runners *e.g. strawberry* into the soil to induce development of adventitious roots, after which the new daughter plants are detached from the parent plants by cutting.

- **Grafting and budding:**

It is the insertion of a stem or bud of one plant, the **scion** onto another closely related plant, the **stock,** ensuring that vascular tissues are in contact. It propagates lemons, apples, roses, hibiscus, and oranges.
Grafting in plants is not hampered by rejection, as is the case in animals.

Comparison of advantages and disadvantages of natural vegetative propagation

Advantages	Disadvantages
-It is a rapid means of reproduction and spread -Offspring are genetically identical, preserving good strains. -Perrenating 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	-Leads to overcrowding and competition for nutrients, unless separated artificially. -New varieties cannot be produced, except by mutation resulting into reduced vigour & strength -Diseases typical of a species are rapidly transmitted and can decimate a crop -

Outline the process of 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.

What is parthenogenesis?

Parthenogenesis (“virgin origin”) is:

- The development of an embryo from an unfertilized egg or one in which the male and female nuclei fail to unite following fertilisation

What is the exact meaning of the following? Give an example in each case.

a) Diploid parthenogenesis / ameoitic parthenogenesis:

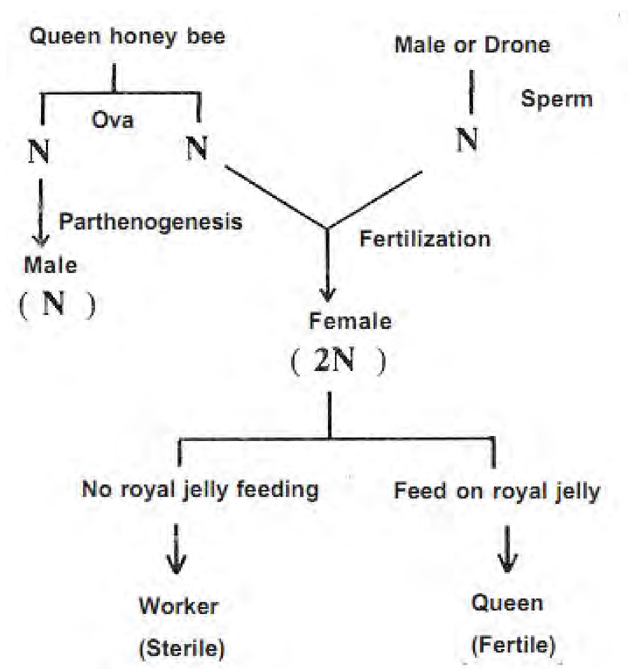
This is the development of embryo from unfertilized diploid eggs that formed by mitosis instead of meiosis, resulting into diploid offspring, which are clones of the parent. It occurs in Aphids, during which large numbers of wingless females are formed without necessitating the presence of males, in flatworms, rotifers, crustaceans.

b) Haploid parthenogenesis / meiotic parthenogenesis:

This is the development of embryo from unfertilized haploid eggs that 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 unfertilised. Fertilised eggs become diploid females (fertile queens or sterile workers), and unfertilised eggs develop to become fertile haploid males (drones). In whiptail lizards of American southwest, meiosis is severely modified to yield a clone of only females

Summary of parthenogenesis in honeybees



c) Apomixis:

It is the formation of plant embryo from an unfertilised haploid egg cell or from a diploid embryo sac mother cell or from a diploid cell in the ovule without fertilisation. It occurs in potatoes and citruses.

d) Parthenocarpy:

This is fruit development without fertilisation, usually induced by auxins e.g. in apples

Give the major advantages of parthenogenesis

- 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

Major disadvantage of parthenogenesis:

-During sudden environmental changes, parthenogenetic species have limited capacity to shift gene combinations to adapt to the new conditions

SEXUAL REPRODUCTION

The role of sexual reproduction compared

Advantages	Disadvantages
- 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	- 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

Out line the ways through which variation can arise in a population

i) During fertilization when male and female gametes with different genotypes fuse to form a zygote.
ii) Mutations during which there is alteration in gene structure and sequence.
iii) During meiosis by crossover during prophase I and also during random segregation of chromosomes on the metaphase plate
iv) By the effects of the environment where the organisms live.

What are the main characteristics / 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. Some species exhibit **oogamy**, the gametes greatly differ in size and activity
-It involves fertilisation (syngamy), the union of male and female gametes
-Bacteria reproduce by conjugation.

Define the term life cycle.

It is the progressive sequence of changes an organism goes through from fertilization till death.

What is meant by alternation of generations?

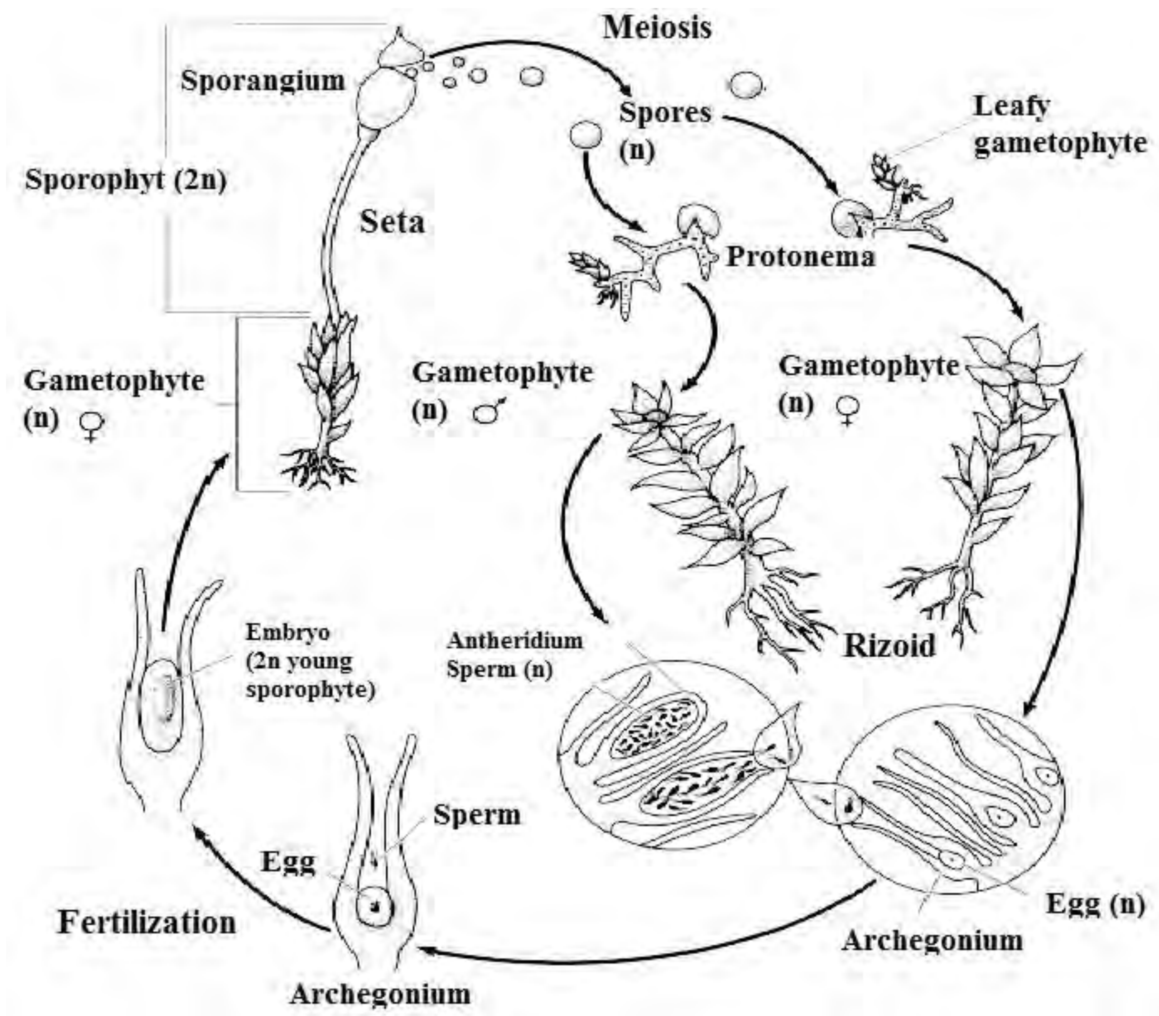
It is the occurrence within the life cycle of an organism two or more distinct forms (generations), a haploid gametophyte and diploid sporophyte generations, which differ from each other in appearance, method of reproduction and genetic constitution.

a) Give an account of alternation of generations in a named bryophyte or pteridophyte/Filicinophyte
b) Compare alternation of generations in a named bryophyte and pteridophyte.
c) Discuss the significance of alternation of generations to the life cycle of plants.

a) **<u>Alternation of generations (lifecycle) of a moss e.g. *Funaria*</u>** <u>– a bryophyte:</u>

- A moss e.g. *Funaria* consists of two distinct forms in its life cycle, the haploid gametophyte, which is the <u>dominant</u> and <u>sexual</u> stage, and the diploid sporophyte, which is the <u>asexual</u> and less conspicuous stage.
- A gametophyte may bear both sex organs, the <u>antheridia</u> (sperm producing) and <u>archegonia</u> (egg producing) or they may be borne on separate gametophyte plants.
- On maturing, the antheridia shed sperms, antherozoids that are aided by rain-splash to reach the open neck of archegonia, and the attracted by <u>chemicals</u> e.g. sucrose enables them to reach the archegonia.
- The haploid antherozoids fuse with the haploid eggs (ospheres) to form diploid zygotes (oospores).
- The zygotes develop into diploid sporophytes, which remain attached and surviving on the gametophytes.
- At maturity the sporophyte produces haploid spores by meiosis within a spore capsule, which splits open when dry and the spores are dispersed by wind.
- On landing on moist soil;, each spore germinates into a green filamentous <u>protonema</u> which produces buds that grow into new haploid gametophyte.

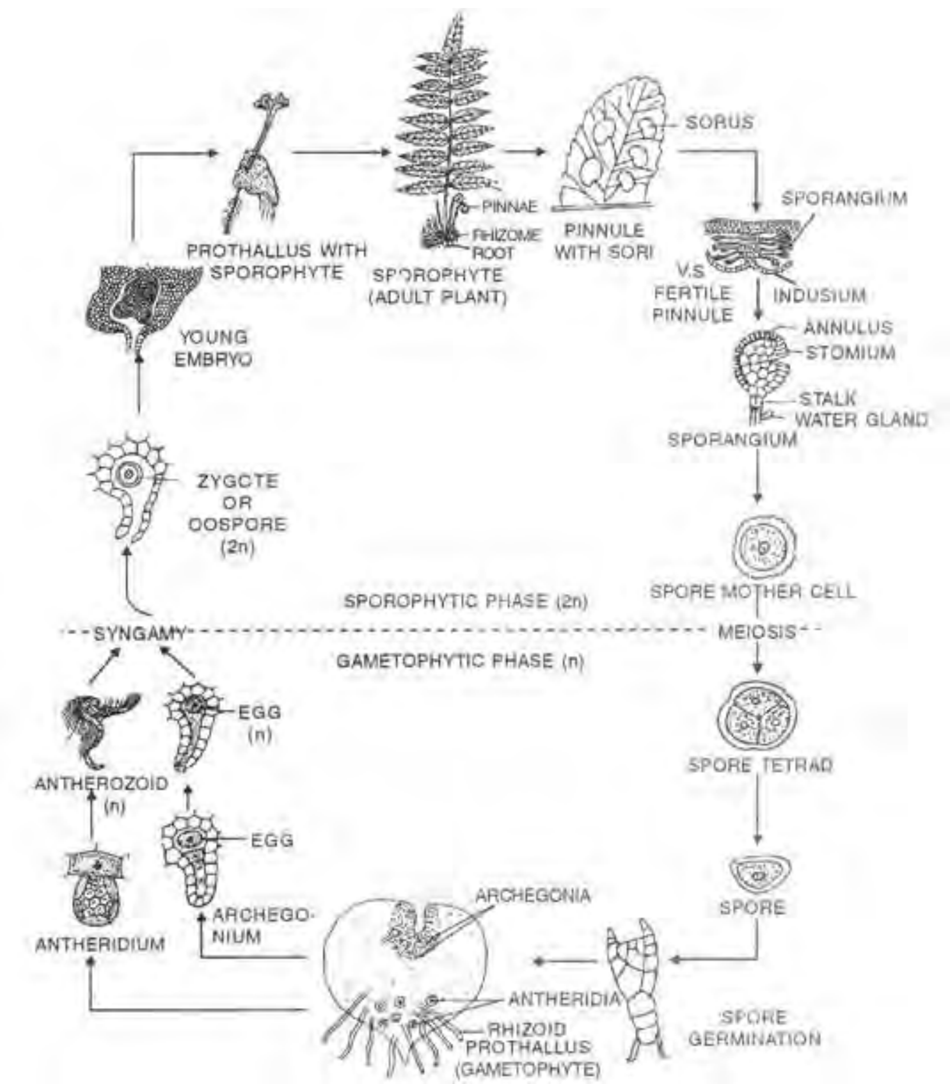
Lifecycle of Funaria



Alternation of generations (lifecycle) of a common fern - a Pteridophyte / Filicinophyte:

- A common fern (*Dryopteris)* consists of two distinct forms in its life cycle, the diploid sporophyte, which is the dominant and asexual stage, and the haploid gametophyte, which is the sexual and less conspicuous stage.
- Diploid spore mother cells inside sporangia divide by meiosis to produce haploid spores
- When mature, the protective covering (indusium) shrinks and the exposed sporangium wall begins to dry out.
- The walls rupture and the spores are discharged from the sporangium.
- If moisture is present, each spore germinates into heart-shaped prothallus (gametophyte), anchored to the soil by rhizoids.
- At the underside, the prothallus bears antheridia and archegonia that produce haploid sperms and eggs by mitosis respectively.
- After rupture of antheridia, the ciliated sperms swim through water to fertilise eggs at the base of archegonia, and the diploid zygotes formed grow into young sporophytes, which remain supported on the prothallus till self-supporting.

Lifecycle of Dryopteris



b) **Comparison of alternation of generations in a moss e.g. *Funaria* and common fern**

<u>Similarities:</u>

In both:

-There is one dominant stage and the other stage is relatively inconspicuous.
-A moist or aquatic environment is required.
-Male gametes from the antheridia are brought into contact with eggs by some mechanisms.
-The gametophytes bear sperm producing antheridia and egg producing archegonia.
-Cases the spores are formed in specialized spore-bearing sporangia.
-There is a dispersal mechanism for scattering spores.
-Sporophytes are diploid and gametophytes are haploid.
-Spores are produced by meiosis and gametes by mitosis
-There is sexual and asexual reproduction
-Male gametes are motile while eggs are non-motile

Differences between alternation of generations in a moss and common fern

Alternation of generations in a moss e.g. *Funaria*	Alternation of generations in a Common fern
- Sporophyte is dependent upon the gametophyte nutritionally	- Sporophyte is a self supporting plant
-Each spore germinates first into protonema, which transforms into gametophyte	-Each spore germinates directly into gametophyte
- Gametophyte is the dominant generation	-Sporophyte is the dominant generation
- Both male and female reproductive organs may be borne on same or separate gametophyte plants	- Both male and female reproductive organs are borne on the same gametophyte (prothallus)
-Majorly depends on water for plant growth, transference of sperms, support and spore dispersal and spore germination	- Dependence on water is less, mainly for swimming of sperms and germination of spores

c) ***The significance of alternation of generations to the life cycle of plants***

- It enable exploitation of different habitats in the ecosystem by the different generations
- Promotes rapid multiplication of species since spores are enormously produced
- Enables plants to cope better with adverse environmental conditions for survival
- It reduces chances of extinction of a species since the different generations are interdependent
- Brings abut genetic variability by meiosis during spore formation
- Mitosis during gamete formation maintains the plant genome by producing haploid gametes

Figure 1 shows the life cycle of a moss or fern and figure 2 the life cycle of most organisms e.g. humans

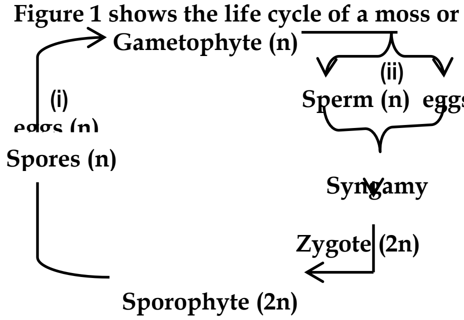
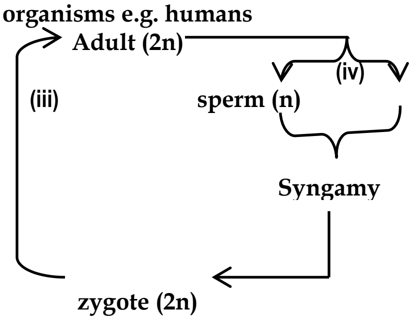


Figure 1

Figure 2



Which processes shown by arrows represent meiosis in both cycles?

A. (i) and (iii)
B. (ii) and (iv)
C. (i) and (iv)
D. (ii) and (iii)

COMPARISON OF PLANT FEATURES IN DIFFERENT PHYLA

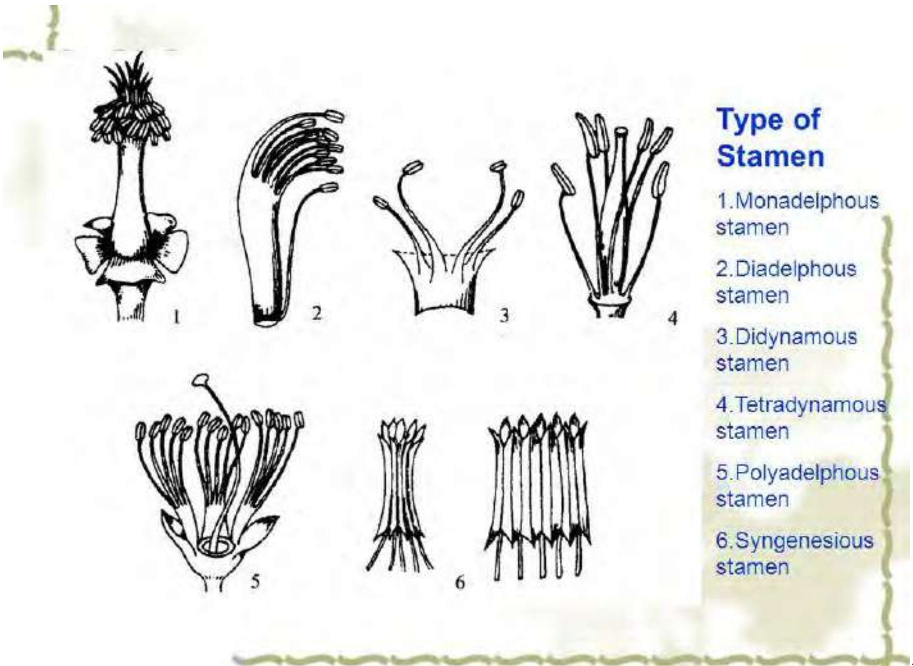
Features	Bryophyta	Pteridophyta	Gymnosperms	Angiosperms
Dominnant phase	Gametophyte	Sporophyte	Sporophyte	Sporophyte
Ploidy of main plant body	Haploid	Diploid	Diploid	Diploid
Differentiation of body	Thallus and rhizoids	Roots, stem and leaves	Roots , stem and leaves	Roots, stem and leaves
Vascular bundles	Absent	Present	Present	Present
Nature of spores	Homospores	Homospores or heterospores	Heterospores	Heterospore
Seed and its coverings	Seed absent	Seed absent	Seed naked without covering	Seed with coverings
Flower	Absent	Absent	Absent	Present

GENERALIZED DESCRIPTION OF THE ESSENTIAL ORGANS OF FLOWERS

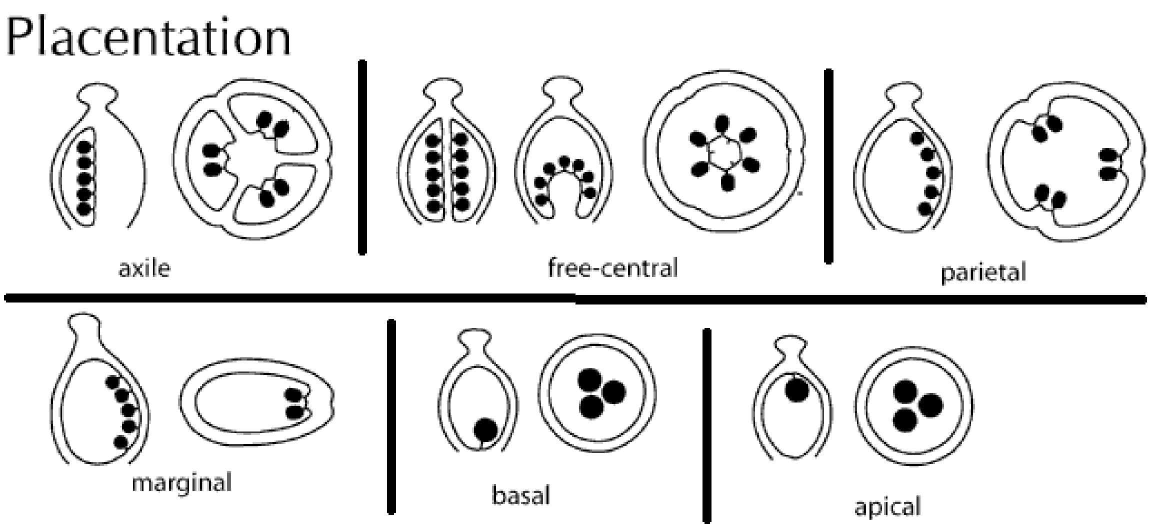
Essential organs are those which directly take part in reproduction i.e. androecium and gynoecium while the **accessory/non-essential organs** are those which assist but do not directly take part in reproduction i.e. corolla and calyx.

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.

i) Gynandrous – stamens attached to pistils
ii) 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*
iii) Adnate – anthers placed on filament along lengthwise direction of filament *e.g. michelia*
iv) Basifixed – filament attached to the base of the anther e.g. radish
v) Dorsifixed – the tip of the filament is attached to the back of the anther (about the middle region) e.g. passionflower.
vi) Staminode - infertile / sterile stamens
vii) Epipetalous – stamens attached on corolla
viii) Syngeneceous – a condition in which filaments free, but all anthers are fused
ix) Synandrous – stamens are united completely by both filaments and anthers *e.g. cucumber*
x) Adelphous – anthers free, filaments united
xi) Monoadelphous - anthers free, filaments united but in just one bundle *e.g. hibiscus*
xii) Diadelphous - anthers free, filaments fused to form two bundles *e.g. sweet pea, bean*
xiii) Polyadelphous - anthers free, filaments united to form many bundles.



b he carpels, each of which consists of the ovary, which is a swollen base, stigma, at the top and style, which links stigma to ovary. 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*



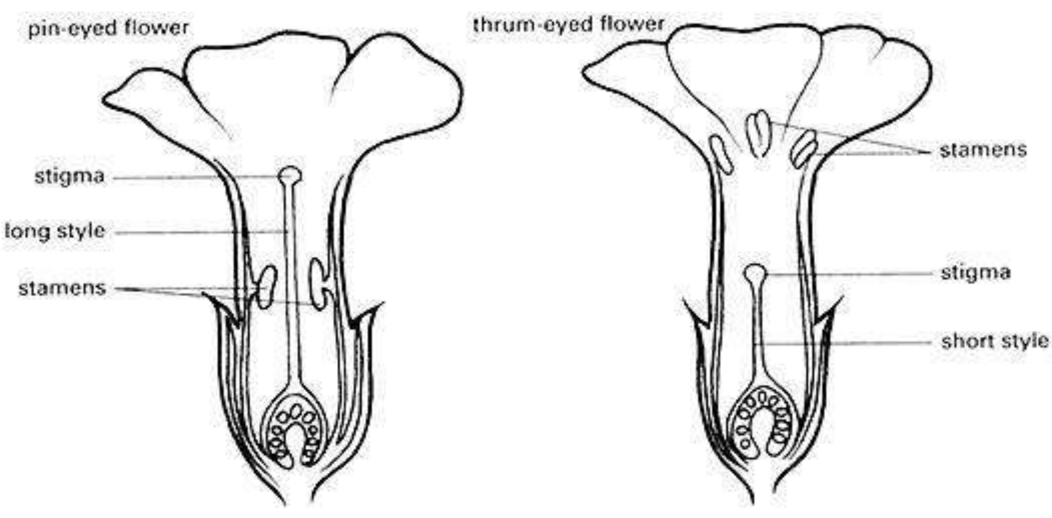
A carpel is described as:
i) Monocarpous – if it consists of only one carpel
ii) Apocarpous – if there are many carpels that are entirely separate from one another e.g. in rose.
iii) Syncarpous – when all its carpels or at least their ovaries are fused e.g. in hibiscus.

With reference to plants, distinguish between the following, giving examples.
Monoecious, dioecious, and polygamous species
Dichogamy, Protandry and Protogyny
Heterostyly and self-sterility

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
Dioecious species: 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.
Polygamous species: are species in which individual plants bear three types of flowers: bisexual, male and female e.g. mango
Dichogamy: failure of the stamens and pistil to ripen at the same time in a hermaphrodite flower.
Protandry: it is the ripening of the stamens before the carpel in a hermaphrodite flower e.g. in sunflower, white deadnettle, salvia, and dandelion *(mainly insect pollinated flowers)*.
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). NB: protandrous flowers are more common than protogynous ones.*
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/genetic self-incompatibility: 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.
In 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.
In 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.

Drawings showing Heterostyly in primrose



In a species, self-sterility is controlled by multiple alleles S_1, S_2 and S_3.
a) Assuming that self-sterility occurs if the pollen grain and the style tissue have an allele in common, what proportion of the pollen grains from a plant with the genotype S_1S_2 would be capable of successfully germinating on a plant with:
i) Genotype S_2S_3? ii) Genotype S_1S_2?
Explain your answers in (i) and (ii) above.
b) What type of self-incompatibility is exhibited in (a) above?
c) Give three other factors which promote outcrossing in plants.

a) (i) Only ½ or 50% of the pollen grains (those with the allele S_1) would be capable of germinating
A plant of genotype S_1S_2 produces ½ of its pollen with allele S_1 that does not match with either of the alleles S_2 and S_3 of the style tissue, hence would germinate, while the rest of pollen are of allele S_2 which matches with allele S_2 of the style tissue, germination would be inhibited.
ii) 0% or none of the pollen grains germinates. Both alleles S_1 and S_2 would match with those of the style tissue and germination would be inhibited.
c) Dioeciousness (Dioecism), Monoeciousness (Monoecism), Dichogamy and Heterostyly

a) State the physiological adaptations of flowers to pollination
b) Explain the mechanisms which limit inbreeding/promote outcrossing in plants
c) What are the consequences of self pollination and cross pollination

Pollination is the transfer of pollen grains from the anthers to the stigma of the flower.

Self-pollination – pollen from the anthers is transferred to the stigma of the flower on the same plant.
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, wind pollination is categorized as follows:

i) Anemophily (wind pollination). Anemophilous flowers exhibit many features (check page 12)
ii) Entomophily (insect pollination). Characteristics of entomophilous flowers are given on page 12.
iii) Hydrophily (water pollination). In hydrophilous flowers, pollen grains have same specific gravity as that of water to enable floating in water at any depth.
iv) Ornithophily (bird pollination). Ornithophilous flowers are tubular shaped, brightly coloured, with plenty of nectar, and generally odourless.
v) Chiropterophily (bat pollination). Chiropterophilous flowers emit strong scent and open after dusk, have long stalks and produce large quantities of nectar.

*a) **Adaptations of flowers to self-pollination:***

Physiological	Morphological
-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	-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	Morphological
-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.	-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.

*b) **Mechanisms which limit inbreeding (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

*c) **Consequences/effects of self-pollination (inbreeding) and cross-pollination (out breeding)***

Consequences of self-pollination (inbreeding)	*Consequences of cross-pollination (out breeding)*
It promotes homozygosity i.e. 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.	It promotes genetic diversity, resulting into hybrid vigour, causing increased resistance to diseases, high yield, and earlier maturity, thereby providing greater evolutionary potential.

Comparison of the advantages and disadvantages of self and cross pollination:

Advantages	*Type of pollination*	*Disadvantages*
-It is reliable especially where members of a species are rare and far apart -It is the only means where pollinating agents are unreliable e.g. mountain tops lack insects, and during harsh climate. -It is not wasteful of pollen grains	*Self-pollination*	It promotes homozygosity i.e. transmission of genotype in the population, resulting into decreased fertility and reduced resistance to disease
It encourages genetic variation, increasing the hybrid vigour	*Cross-pollination*	It is wasteful of pollen grains since pollinating agents are not very efficient

a) Give one ecological importance of each of the following structural arrangements in plants.

i) Monoeciousness

-It allows self-fertilization for continuity of species where plants of that species are few or separated by long distance

ii) Dioeciousness

- It encourages genetic variation, thereby increasing the hybrid vigour since it allows cross-pollination

b) Explain why
i) In dioecious plants, male plants are usually associated with dry soils while female plants are associated with moist soils.
-Pollen production does not require much water, while seed formation and fruit ripening require much water.

ii) Nearly all dioecious plants are wind pollinated
It may not be possible to have animal pollinators bring in pollen from the same plant species, which would reduce chances of fertilization.
OR: It is therefore much easier for wind to bring in pollen from same plant species to increase chances of fertlisation
c) Suggest two reasons why dioecious plants (those with separate sexes)are rarer than monoecious plants, despite the advantages of cross-pollination.
-Half of the individuals in dioecious plants do not produce seeds, whereas all individuals in monoecious plants bear seeds.
-A lot of pollen is wasted in dioecious plants because the male and female plants are not necessarily together.

d) Why is dioecism (separate sexes) common in animals than in plants?
-There is less wastage of gametes in animals than in plants because males and females can move about.

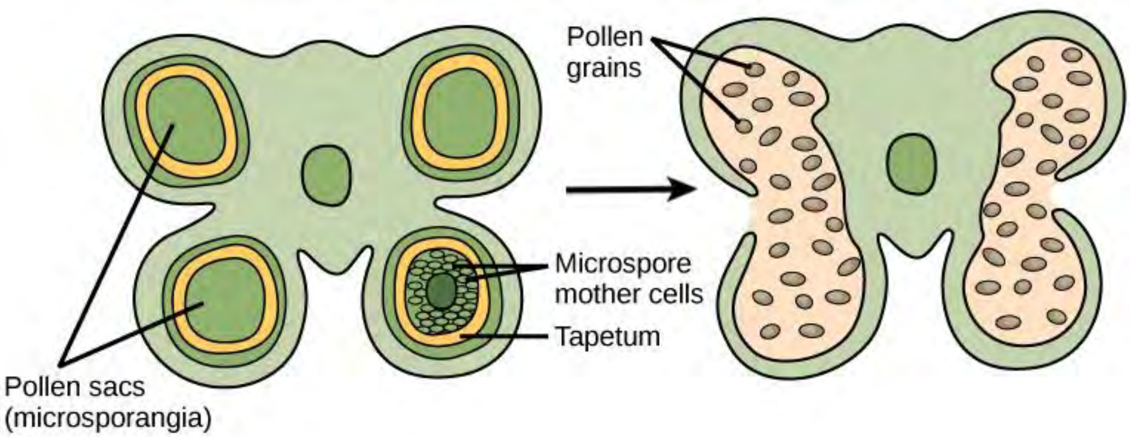
Comparison of wind pollinated (anemophilous) and insect pollinated (entomophilous) flowers

Wind pollinated flowers e.g. guinea grass, maize, rice	*Insect pollinated flowers e.g. crotalaria, sunflower, coffee, etc*
-Inconspicuous flowers, small and reduced in size. Petals may be absent or dull coloured if present. -No nectar and not scented -Pollen produced in large quantity, light, smooth, small and may have wing-like extensions. -Anthers are large and versatilily attached to filament. -Stamens hang outside the flower to release pollen. -stigmas are large, feathery or branched to trap pollen. -Stigmas hang out side the flower. -Flowers often unisexual, having male and female reproductive parts on separate flowers.	-Conspicuous flowers, large with brightly coloured petals, and often held in inflorescence if they are tiny and inconspicuous. -Produce nectar and or scent to attract insects. -Less in quantity, sticky, relatively heavy, and large pollen is produced. -Anthers are small and basifixedly or dorsifixedly attached to filament. -Stamens are confined within the flower. -Stigma relatively small, glandular, and sticky. -Stigma lies inside the corolla. -Flowers bisexual, enclosing reproductive organs e.g. stamens and carpels.

Describe the significant events that lead to the production and release of gametes in flowering plants.

- Gamete formation in plants occurs in the anther (male gametes) and ovary (female gametes).
- The pollen grains, formed in the anthers, contain and transport the male gamete while the ovules, formed in the ovary contain the female gamete (egg/ovum).

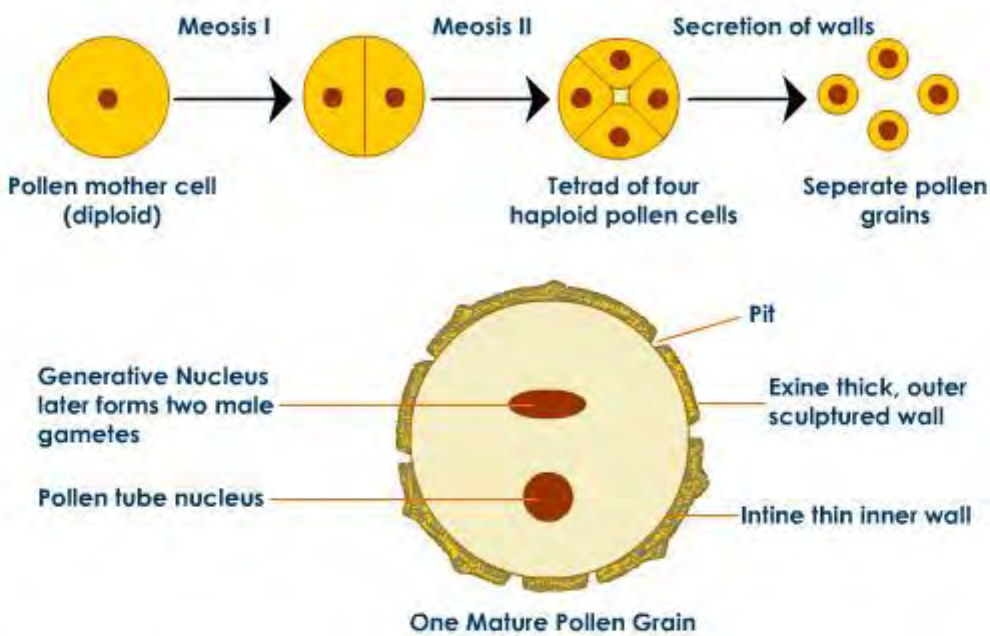
Transverse section of male gamete producing organs in flowering plants



Production and release of male gametes:

- Repeated mitotic divisions occur within the sporogenous tissue, producing a mass of swollen cells, the microspore mother cells.
- Mitosis stops and each micro spore mother cell divides by meiosis to form a tetrad of haploid microspores, each of which gives rise to a pollen grain.
- Each pollen grain develops a hard resistant, sculptured outer wall, the exine and an inner cellulose wall, the intine.
- The single haploid pollen grain nucleus divides by mitosis form a pollen tube nucleus and the generative nucleus.
- When the pollen grains mature, the walls between each pair of pollen sacs breakdown and the anther lobe rupture longitudinally along the line of weakness to release pollen grains.

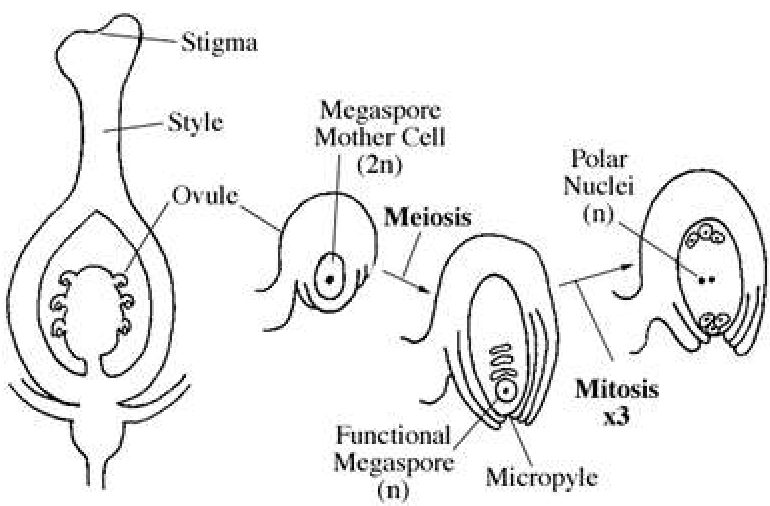
Diagrams illustrating the production of male gametes in plants



Production of female gametes:

- Each ovary develops one or more ovules, which contain a mass of cells, the nucellus, which is 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, only one of which develops to form the embryo sac while the three degenerate. *(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 divides mitotically to form four haploid nuclei at each pole.
- One nucleus from either end of the sac move to the centre and fuse to form a diploid primary endosperm nucleus.
- The remaining six nuclei each gets enclosed in a thin cell wall, and one of the three nuclei near the micropyle 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.
- Thus, a mature embryo sac contains a total of 7 nuclei, comprised of: two synergids, three antipodal cells, and diploid primary endosperm nucleus.

Diagrams illustrating the production of female gametes in plants



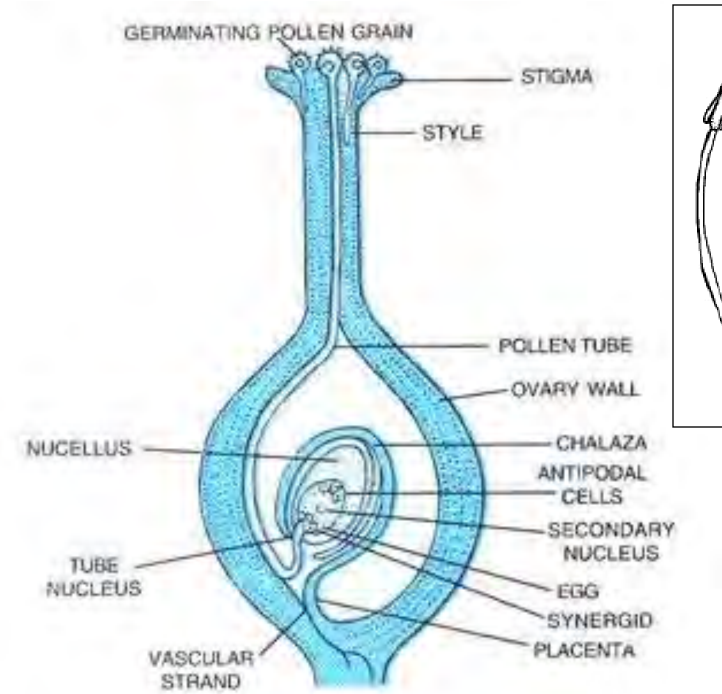
State the main features of embryo sac development in flowering plants

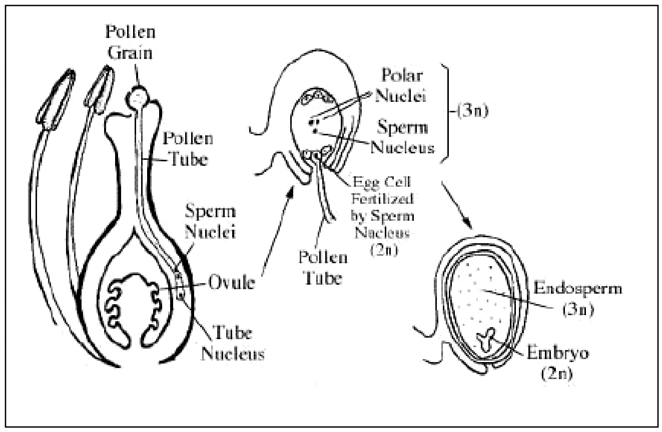
- Mitosis occurs three times
- There is formation of diploid nucleus by fusion of two male nuclei
- Produces six haploid cells
- Forms antipodal, synergid and egg cells.

a) Describe the events, which occur in the flower from pollination to fertilization.
b) What are the results of fertilization in a flower?
c) Explain what is meant by double fertilisation in relation to flowers.

a) -When a ripe pollen grain lands on the right stigma, it absorbs water, the outer wall (exine) breaks open and the inner wall (intine) germinates to form a pollen tube.
-The tube nucleus is positioned at the tip of the growing pollen tube controlling growth while the 2 male nuclei (2 sperms) formed by mitosis from the generative nucleus follow closely behind.
-The pollen tube tip pierces the stigmatic surface and penetrates the style tissue via intercellular spaces.
-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.
-The pollen tube then penetrates the embryo sac, bursts open and the tube nucleus degenerates.
-The first fertilization occurs when one sperm fuses with the egg to form a diploid zygote, while the second fertilization occurs when another sperm fuses with the diploid secondary nucleus to form a triploid primary endosperm nucleus. This double fertilization is unique to only flowering plants.

Diagrams illustrating fertilisation in flowering plants





b) Summary of the results of fertilization in a flowering plant

Before fertilisation	*After fertilisation the parts become*	*Function of part formed after fertilisation*
Zygote	Embryo	
Ovule	Seed	Protects embryo
Ovary	Fruit	Protects seeds and enables their dispersal
Integuments: (a) outer (b) inner	Testa/seed coat Tegmen	Offer protection to the seed
Ovary wall	Fruit wall/pericarp	Offers protection to fruit contents
Triploid primary endosperm nucleus	Endosperm	Acts as food store in some seeds e.g. cereals like maize, wheat, castor oil
Micropyle	Micropyle	For entry of water and oxygen at germination
Nucellus	Disappears	
Calyx	Wither away or may persist	

Petals, stigma, style & stamens	They dry and fall off	

c) 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 while another male nucleus fuses with the diploid secondary nucleus to form a triploid primary endosperm nucleus simultaneously.

a) What are the advantages and disadvantages of propagation by seed?
b) Explain how the science of palynology (pollen analysis) can provide information about past climate and human activities of a particular period of time.

a) Advantages:
- 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:
- 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

b) -The highly sculptured pattern of the exine (outer wall) of pollen grain is specific to plant species or genus.

-Since the exine has a waterproof lining resistant to decay, pollen grains last for a longtime in the sediments.

-The pollen from successive layers of sediments can be extracted and analysed by radiocarbon dating to establish the climatic history e.g. past temperature. Human interference with the natural vegetation is also reflected in the pollen record e.g. absence of pollen from trees in some areas would indicate forest clearance.

GENETICS

Genetics is the scientific study of heredity and variation among organisms. It is the branch of science that accounts for the occurrence of similarities and differences among organisms of the same species; as well as explaining how traits are transmitted to off springs from their parents.

Inheritance refers to the process by which characters/traits are passed from parents to off springs.

The importance of genetics

- It is applied in genetic engineering to produce better breeds and varieties of plants and animals by altering their genetic constitution.
- It is important in courts of law to determine the paternity of the child.
- Genetics forms the basis of blood transfusion to determine compatible blood groups.
- Genetic counselling is important in preventing transmission of genetically determined diseases among married couples. This will help to relieve the families and community of the costs on treatment as well as the suffering of the sick and their families.
- It can be used in identification of criminals by use of finger prints and DNA profiling.
- It is used in molecular biology to manufacture artificial enzymes, hormones and vaccines by manipulating responsive genes from organisms.
- Forms the basis of cloning to increase the number of genetically important plants and animals.

DEFNITION OF TERMS USED IN GENETICS

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.

Alleles; Are alternative forms of the same gene.

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

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.

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

- Consider the gene controlling height in garden peas, the allele **T** for tallness is dominant over the allele **t** for shortness. A plant with dominant genes **(TT)** is tall and the one with recessive genes **(tt)** is short while a plant with one of each genes **(Tt)** is also tall

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.

An organism with similar copies of alleles for a given gene is said to have a **homozygous genotype** e.g. TT, AA, rr etc. while an organism with different copies of alleles for a given gene is said to have a **heterozygous genotype.** E.g. Tt, Aa, Rr etc.

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.

A pea plant which is homozygous tall (represented as TT) but growing on nutrient-poor soils will become stunted and appear short. Such a plant is genotypically tall but the environment in which it grows modified it into a phenotypically short/dwarf plant.

Locus (plural loci). This is the position on the chromosome where the genes are located.

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

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

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.

First filial generation (F_1); this refers to the set of offsprings obtained from crossing two pure breeding parents with contrasting characteristics. These individuals are therefore heterozygous hybrids

Second filial generation (F_2); this refers to the set of off springsthat are obtained from crossing mature F_1hybrids.

Selfing: This refers to the crossing of offsprings of the same parents.

Test cross is a cross between an organism with an unknown genotype with a homozygous recessive organism so as to determine the unknown genotype.

This is because phenotypically dominant organisms may ether be homozygous or heterozygous. In such a cross if all hybrids show the dominant trait then the unknown is homozygous dominant. A heterozygous individual will result into a mixture of hybrids in a ratio of 1:1 of dominant to recessive trait.

Back cross. This is the mating of an offspring with one of its parent so as to prove the genotype of the parents.

Reciprocal cross; this is a cross in which the genotypes of the parents have been reversed

MENDEL'S GENETIC EXPERIMENTS AND

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 Gregor 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 F_1off springs were tall.

He then selfed the F_1 pea plants to get F_2. This generation comprised of a mixture of tall and short pea plants in a ratio of 3 tall: 1short plants.

NB: The **3:1** ratio is known as Mendel's monohybrid ratio of the dominant and recessive characters respectively in the F_2 generation.

Observation;

Mendel was able to observe that neither of the F_1 nor F_2 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

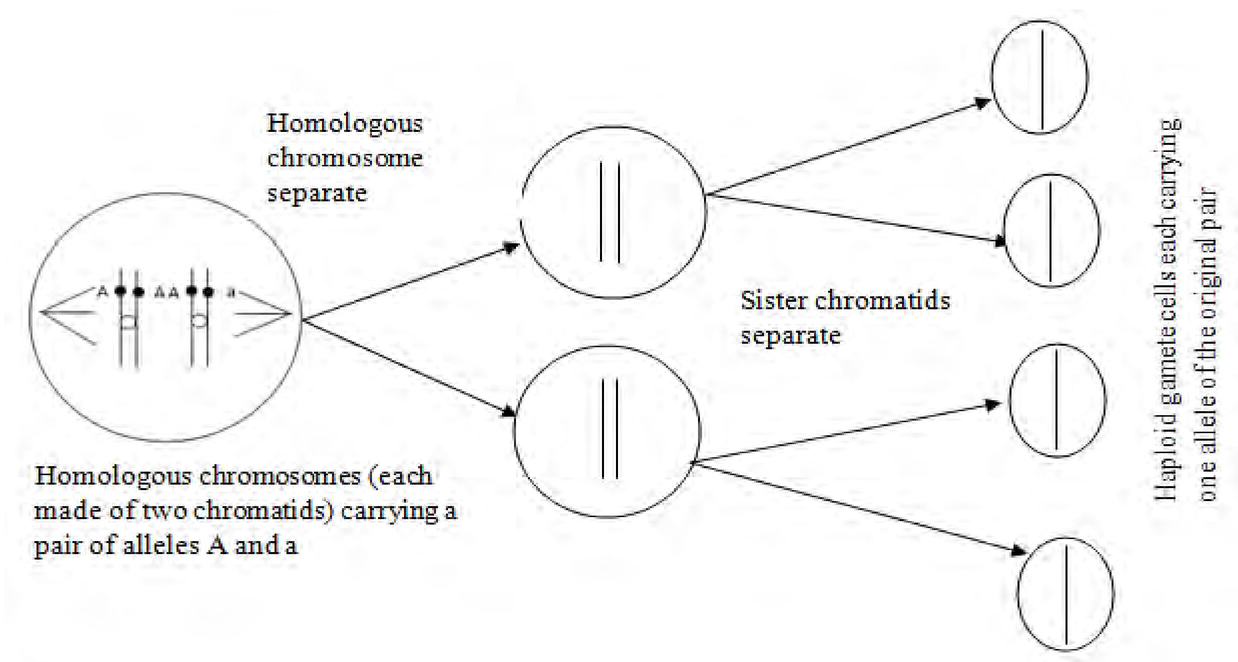
LAW1 states that **"*The characteristics of an organism are controlled by internal factors which occur in pairs but only one can be carried in a single gamete".***

Later with advancements in technology and microscopy, internal factors later came to be known as **genes** and Mendel's first law was modified. It can **modernly** be stated as follows. "The characteristics of a diploid organism are controlled by alleles which occur in pairs but singly in gametes".

Meiosis explains:

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:



A full genetic explanation of Mendel's first law and the 3:1 ratio

Let;

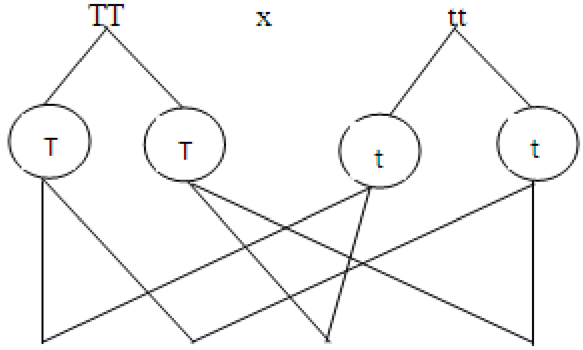
T represent the allele for tallness, t represents the allele for shortness

Parents	:	male	x	female
Phenotypes	:	Tall	x	short
Genotypes	:	TT	x	tt

Meiosis

Gametes

Random fertilization :



F_1 genotypes : Tt Tt Tt Tt

Genotypic ratio : All Tt, Phenotypic ratio : All tall

To obtain F_2 generation, F_1 hybrids were selfed as shown below

Let;

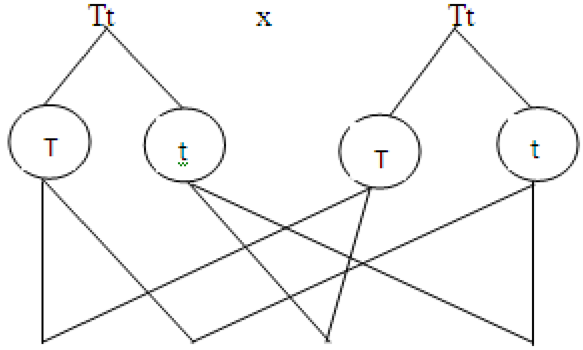
T represent the allele for tallness, t represents the allele for shortness

Parents	:	male	x	female
Phenotypes	:	Tall	x	tall
Genotypes	:	Tt	x	Tt

Meiosis

Gametes

Random fertilization :



F_2 genotypes : TT Tt Tt tt

Genotypic ratios: 1TT : 2Tt : 1tt; Phenotypic ratios: 3tall : 1 Short

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

NB: 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 F_1 hybrids show the dominant trait. In addition, a larger proportion of the F_2 hybrids show the dominant trait while those showing the recessive one are always fewer

WORKED EXAMPLES

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 F_2.
   a. Using suitable genetic symbols, workout the genotypes and phenotypes of the F_2 generation
   b. What are the phenotypic and genotypic ratios of the F_2 generation
   c. Explain how you would determine the genotype of F1 tall pea plants formed
   d. Suppose 700 pea plants where produced in the F_2 generation
      i. How many were tall?
      ii. How many were short?
2. Suppose a man who is a tongue roller marries a woman who is a non-tongue roller and all the children obtained in F_1 are tongue rollers.
   (a) Work out the phenotypic and genotypic ratio as obtained in F_2 generation.
   (b) What is the probability that the 4^{th} born is a non-tongue roller?

Note; for any genetic cross:

- Appropriate letters are 'let' to represent respective alleles involved
- 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

Solutions

(a)

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	

F_1 phenotypes: all tongue rollers

By selfing the F_1 hybrids to obtain F_2

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

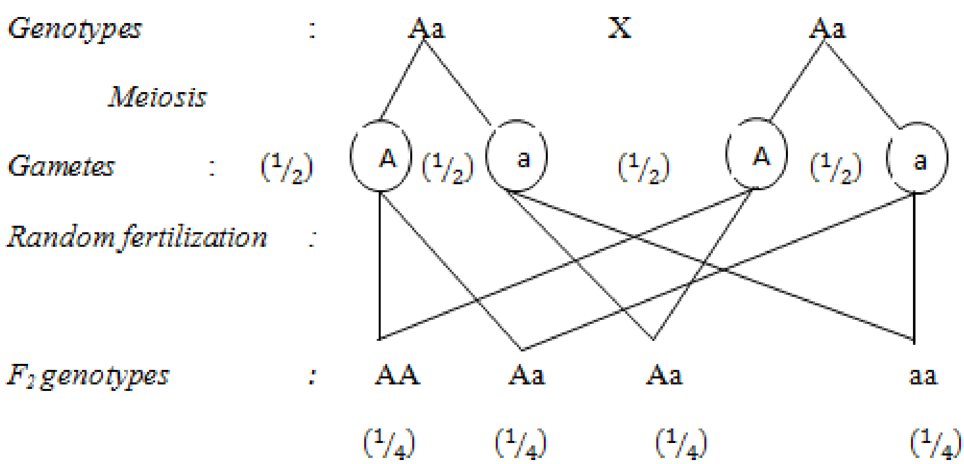
(b) Probability that the 4th born is a non-tongue roller

$= \frac{1}{4} x \frac{1}{4} x \frac{1}{4} x \frac{1}{4} = \frac{1}{256}$

NB:

- The 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,



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

EXAMPLES OF 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 and many more

NB: 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 β-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 tiplet 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 and the disease is known as **sickle-cell anaemia.**

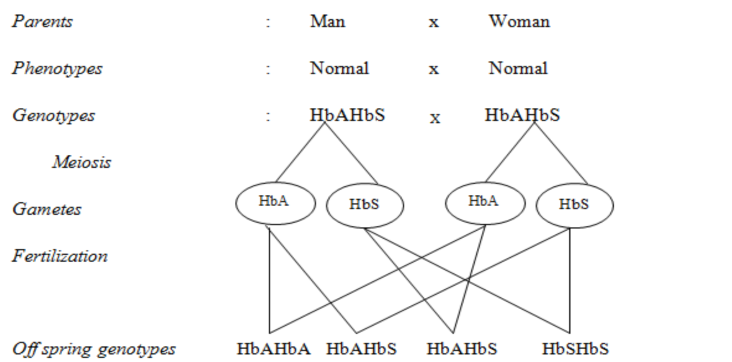
Being a recessive character, for a person to be a sufferer they must possess two copies of the faulty gene (homozygous recessive, i.e. HbSHbS or ss). Heterozygotes (carriers, i.e. HbAHbS or Ss) have one copy of the responsive gene whose effects are masked by the other dominant gene. They don't suffer 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.

Question; if two people suffering from sickle cell trait are married, what is the probability that they will produce an anaemic child?

Solution

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

<u>Complications due to sickle cell anaemia</u>

1. Anaemia this is 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
    - Dilation of the heart which may lead to heart failure
2. 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
    - Liver damage
3. Enlargement of the spleen because the sickle cells collect in the spleen for destruction

The effects above make the homozygous sufferers to often die before reproductive age.

NB: 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

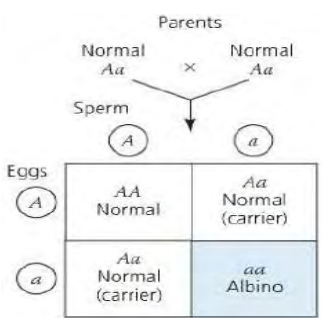
INHERITANCE OF ALBINISM

Albinism is a recessive character which results into failure of formation of body pigments.

Albinos have the following characteristics as a result;

- Light-coloured skin
- White hair
- Pink eyes

SQ; 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

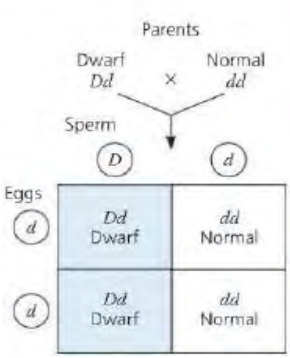
This is a recessive character caused by a mutation resulting into accumulation of abnormally **thick and sticky mucus** that blocks the pancreatic duct, bile duct and air passages.

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. This is known as cystic fibrosis.

In the pancreas, fibrous patches called cysts develop (hence the name) and complications include digestive problems due to poor release of pancreatic enzymes, poor absorption of digestive products, chronic lung diseases, reduced fertility etc.

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 as shown below.



Since this character is dominant (caused by a dominant allele), all people who are not achondroplastic -99.99% of the population-are homozygous for the recessive allele. Like the presence of extra fingers or toes mentioned earlier, achondroplasia is a trait for which the recessive allele is much more prevalent than the corresponding dominant allele.

DIHYBRID INHERITANCE AND MENDEL'S SECOND LAW OF INHERITANCE

Dihybrid inheritance refers to the inheritance of two pairs of contrasting characteristics simultaneously.

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 F_1 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 F_1 plants and obtained an F_2 progeny, this comprised of a variety of phenotypes as summerised in the table 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 F_2 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 F_1 but separated and behaved independently in the F_2.
- Two of the F_2 phenotypes resembled one or the other of the parental phenotypes WHILE two new combinations of phenotypes appeared in the F_2; (Tall/white and Dwarf/red). These are known as recombinants.

- The allelomorphic pairs of characteristics (controlled b 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 characters may combine randomly with either one from another pair"**

Below is a full genetic explanation of the 9:3:3:1 ratio of phenotypes in the F_2generatioon 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	:			
F_1genotypes	:		All TtRr	

Phenotypic ratios : All Tall with red flowers.

By selfing F_1 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

NB: When performing a dihybrid cross;

- 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 withy or y but not T as in the above case
- 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.

In summary; the following can be noted from Mendel's hypotheses:

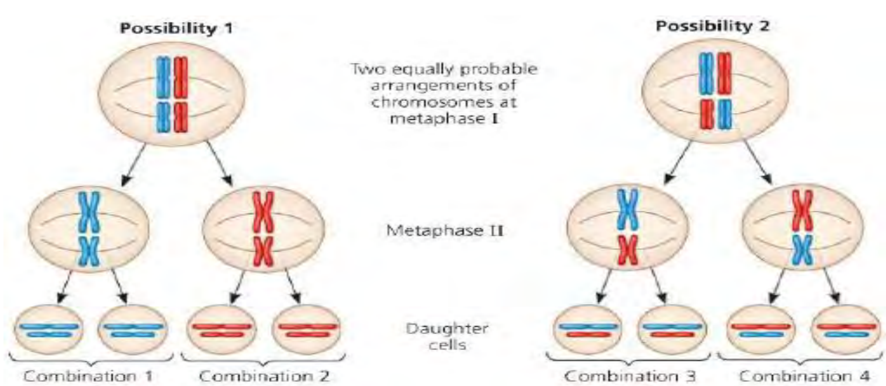
- Each characteristic of an organism is controlled by a pair of alleles.
- During meiosis, each pair of alleles segregate (separates) and each gamete receives one of each pair. This is known as the law of segregation.
- During gamete formation, either one of a pair of alleles can pass into the same gamete 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).

<u>MEIOSIS EXPLAINS:</u>

Mendel's second law can be explained/accounted for on the chromosomal basis by meiosis.

During formation of gametes by meiosis, the distribution of each allele from a single pair is entirely independent of alleles from other pairs. This in turn depends on the random orientation of homologous chromosomes onto the equatorial spindle in metaphase I. Subsequent separation during anaphase I leads to a variety of allele combinations in gametes. In this process; any one of a single pair of alleles can combine randomly with either one form another pair.

Illustrations:



NB: For the haploid number of chromosomes = n, the total number of possible combinations in gametes is given by 2^n

WORKED EXAMPLES:

1. When a pure breeding broad and long winged female fly was crossed with a narrow and vestigial winged male fly all the F_1 offsprings obtained head broad abdomen and long wings.

a) Using suitable genetic symbols work out the phenotypes and genotypes that were obtained in F_2 generation.

b) Suppose 480 flies were obtained in F_2 work out the numbers of the flies for each phenotype class.

c) How many of these flies were recombinants.

Solutions:

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, Long wings	X	Narrow abdomen, vestigial wings
Genotypes	:	BBLL	X	bbll
Meiosis	:			
Gametes	:	all BL		all bl
Random fertilization	:			
F_1 genotypes	:	All BbLl		

Obtaining F_2

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 = $\left(\frac{Ratio}{Total}\right) x480$ Flies

i. Broad abdomen, long winged = $\frac{9}{16}$ X 480 = 270 flies

ii. Broad abdomen, vestigial winged = $\frac{3}{16}$ X 480 = 90 flies

iii. Narrow abdomen, long winged = $\frac{3}{16}$ X 480 = 90 flies

iv. Narrow abdomen, vestigial winged = $\frac{1}{16}$ X 90 flies

(c)Number of recombinants = (90 + 90) flies = 180 flies

SAMPLE QUESTIONS:

1) In guinea pigs, there are two alleles for hair colour and two for hair length. In a breeding experiment, all the F_1phenotypes 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 F_2 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 **(9:7)**

EXCEPTIONS TO MENDEL'S LAWS

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, 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: 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. 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

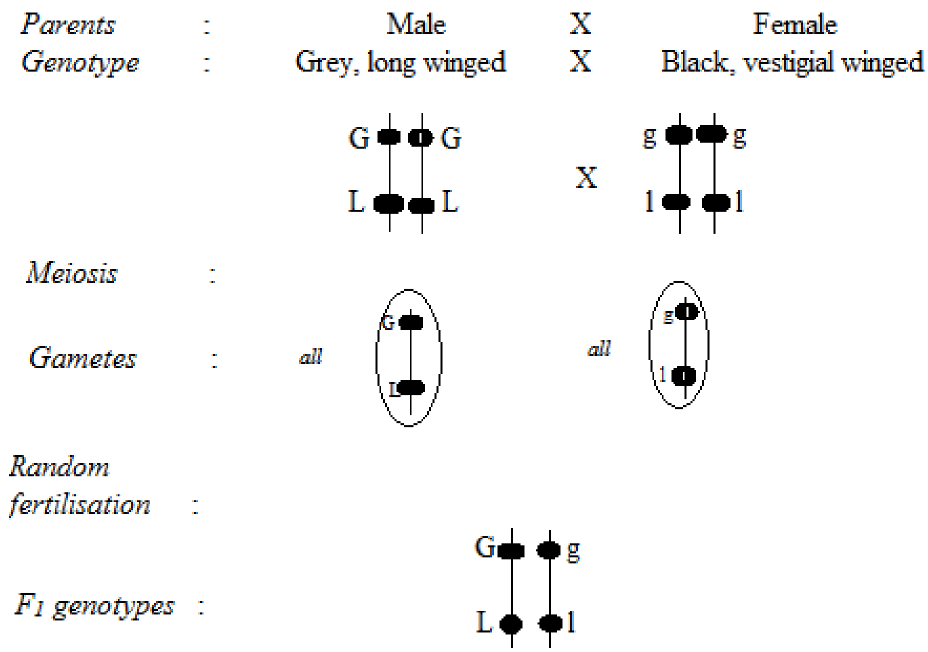
Such genes form a linkage group and pass into the same gamete during meiosis and are therefore inherited together. As a result, these genes do not show independent assortment (applies to genes on non-homologous chromosomes) and fail to produce the 9:3:3:1 ratio.

Linked characteristics (traits) are characters controlled by genes found on the same chromosomes and therefore inherited together

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.

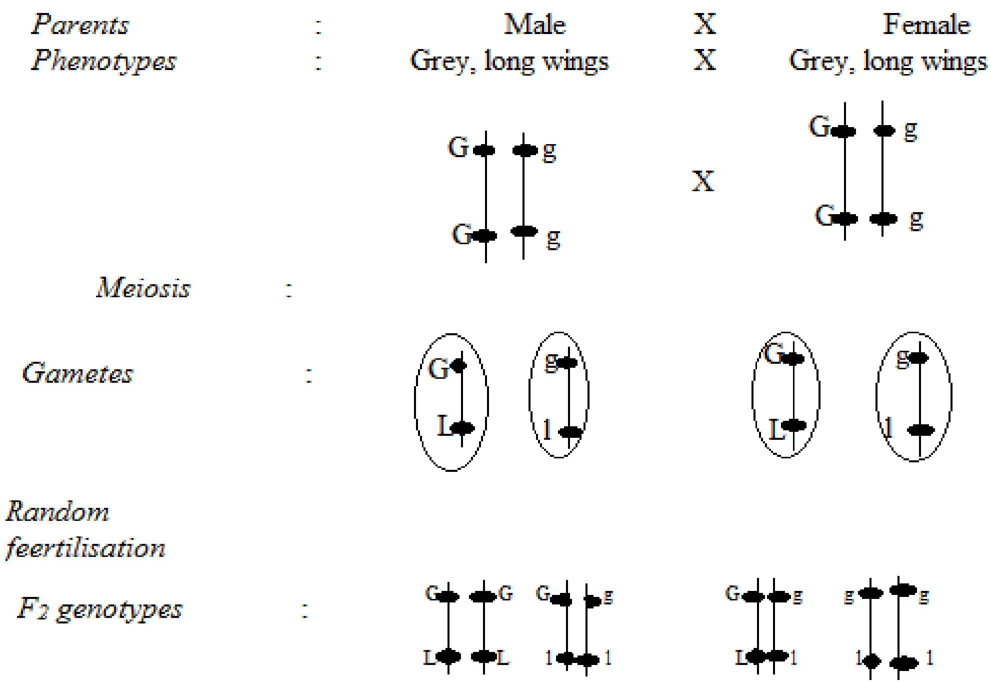
Let: G represent allele for grey body, g for black body

L represent allele for long wings, l for vestigial wings



F_1 phenotypes: all grey with long wings

Obtaining F_2 generation:



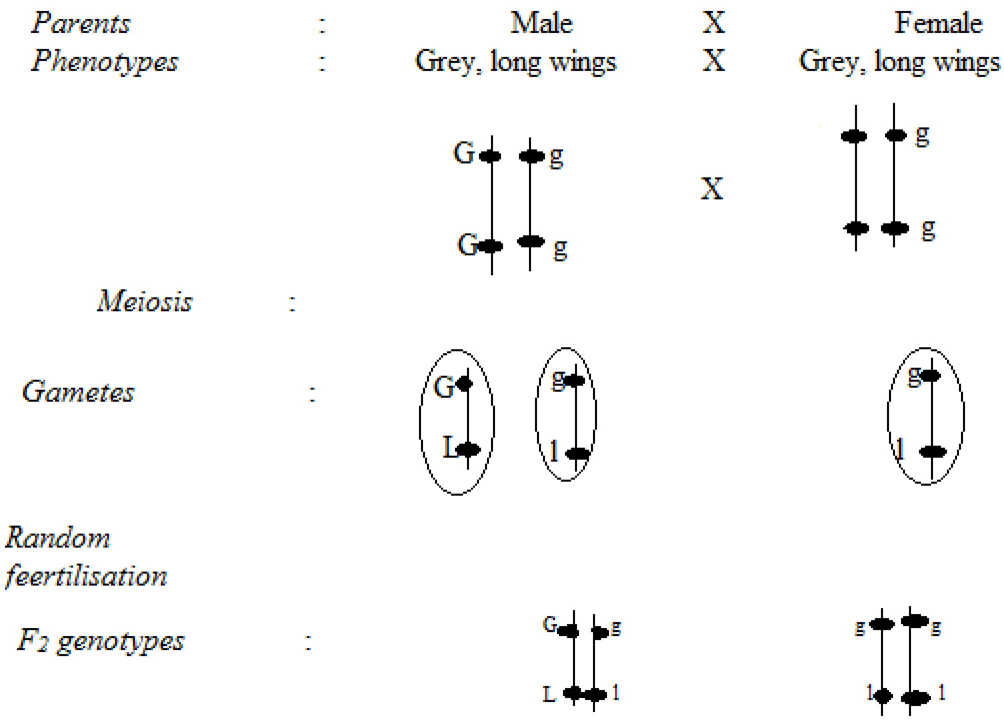
Phenotypic ratio is 3 grey long winged: 1 black vestigial winged.

Surprisingly, 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.

Definition: 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.

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 below**.



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 summerised below.

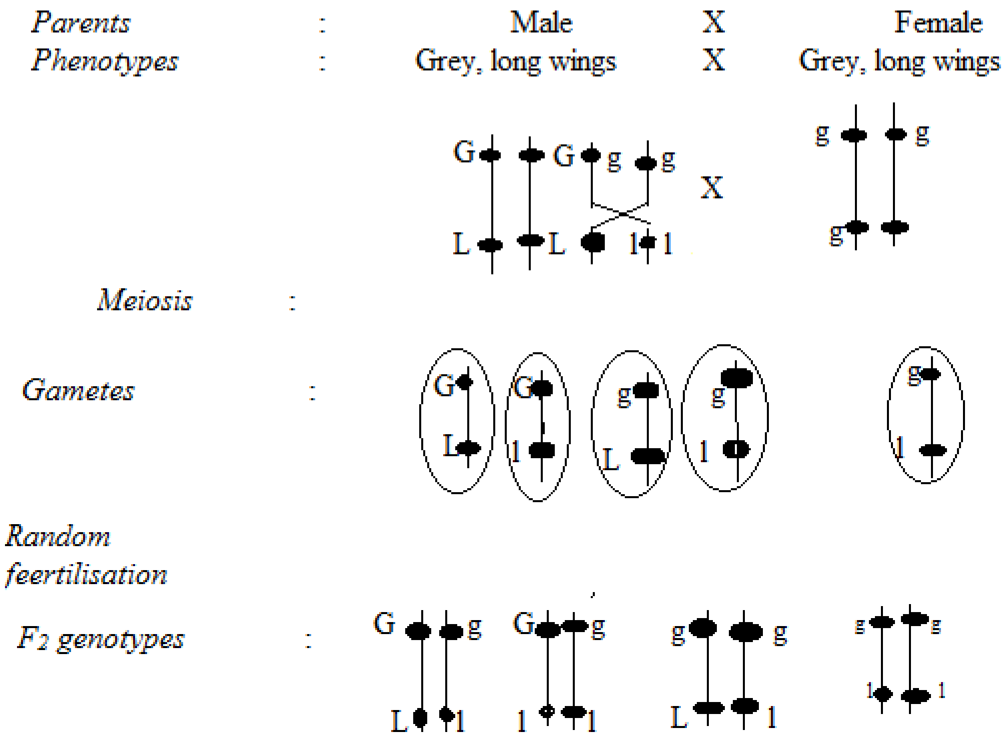
41.5% grey, long winged

41.5% black, vestigial winged

8.5% grey, vestigial winged

8.5% black, long winged

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.



Sample question:

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. **(Normal)**

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 ration of recombinants to the total number of offsprings.

$$CoV = \frac{Number\ of\ recombinants}{Total\ number\ of\ offsprings} x100$$

Example

In a test cross carried out on a grey long winged drosophila, the following results were obtained

Phenotype	**Number of offsprings**
Grey, long winged	965
Black, vestigial winged	944
Black, long winged	206
Grey, vestigial winged	185

Solution:

$$CoV = \frac{Number\ of\ recombinants}{Total\ number\ of\ offsprings} x100$$

$$CoV = \frac{206 + 185}{(965 + 944) + (206 + 185)} x100$$

= 17%

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**.

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.

Answer. Draw the chromosome map for these genes

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.

Example

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 f_1 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

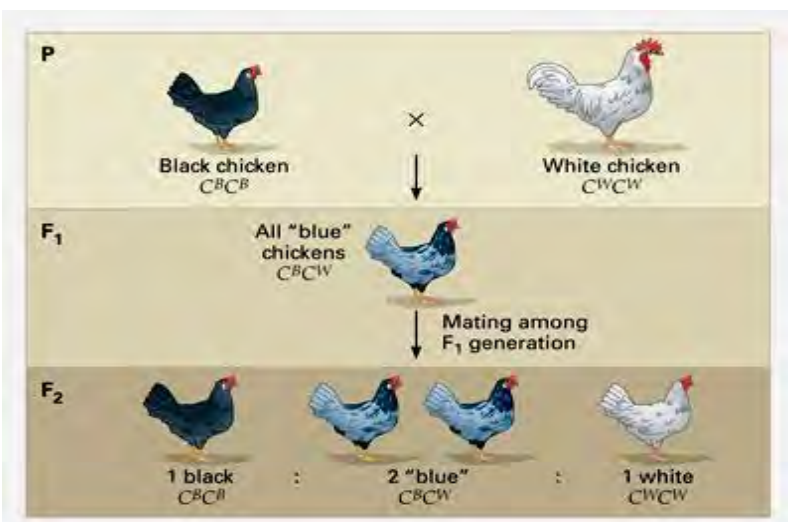
In the conventional Mendelian inheritance, each trait is controlled by a pair of alleles located at the same locus of homologous chromosomes, one dominant and the other recessive. In such cases, offsprings always resemble **one or the other of the parents** and phenotypes of the heterozygote and the 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.

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

Other examples of incomplete dominance include:

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.

During the inheritance of fur/coat colour in short-horned cattle, when red and white cattle are mated, the F_1 hybrid has white fur thickly interspersed with red fur. This phenotype is referred to as roan

Let;

R represent allele for red fur, W represents allele for white fur

Parents	:	Bull	X	Cow
Phenotypes	:	Red fur	X	White fur
Genotypes	:	RR	X	WW
Meiosis	:			
Gametes	:	All R		All W
Random fertilization	:			
F_1 genotypes	:	All RW		

Other examples of codominance include ABO blood groups and 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.

Blood group	Possible genotypes
A	Ao, AA
B	Bo, BB
AB	AB
O	Oo

Sample question: 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.

Solution

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

Example:

Work out the possible blood groups of the offsprings produced if a man of blood group A marries a woman of blood group AB

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 cause 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^- woman.

ASSIGNMENT

1. Suppose a man having blood group A marries a woman who is heterozygous for blood group B what are the possible genotype and phenotypes.
2. A boy has blood group A and his sister has blood group B. what are the possible phenotypes and genotypes of their parents.
3. If a father has blood group A and the mother blood group AB what are the possible genotypes and phenotypes of the offspring.

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 environment

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 (4) 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 summerised 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

Starting with pure breeding parents, the following are the expected results for F_1 and F_2 generations.

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

Obtaining F_2

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

Sample question

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. The gene for coloured fur is hypostatic to the gene responsible for colour of fur (hypostatic).

This interaction produces three possible phenotypes as summerised below.

Phenotype	Possible genotypes
Grey (agouti)	AAGG, AAGg, AaGG, AaGg
Black	AAgg, Aagg
Albino (white)	aaGG, aaGg, aagg

Examples

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_1 genotypes	:		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

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.

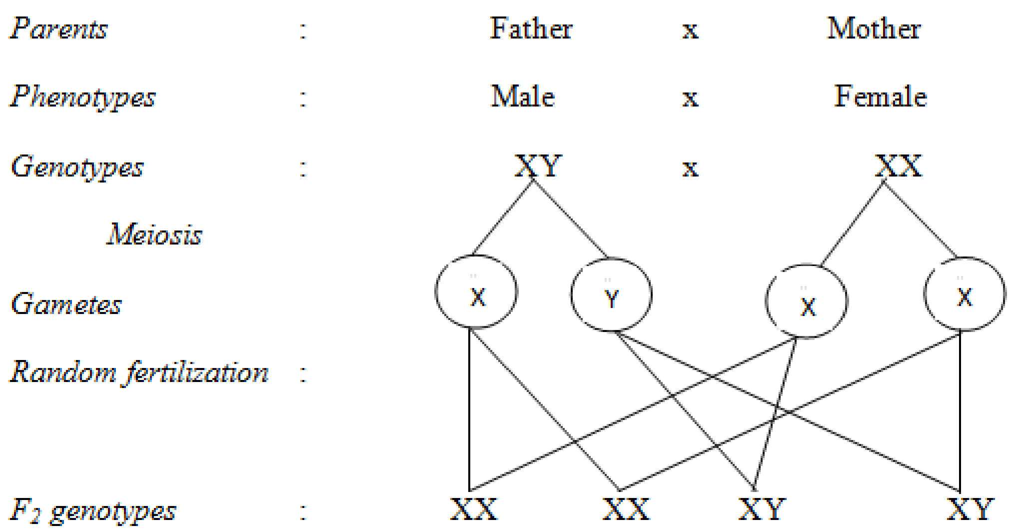
In man, there are 23 pairs of chromosomes; of these only one pair carries genes for sex determination. These are called sex chromosomes (heterosomes) designated X and Y, and the other 22 pairs are called autosomes. A genotype XX is described as homogametic and is female while XY is described as heterogametic 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.

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. In some animals like birds (including poultry), moths and butter flies; the sex genotypes are reversed. The homogametic genotypes (XX) are male while the heterogametic genotype (XY) is female.

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 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.

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 un fertilized eggs and are haploid, without feathers.

Example:



Genotypic ratios: 1XX: 1XY

Phenotypic ratios: 1female: 1male

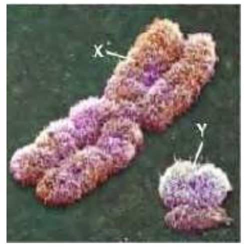
This shows that there is a 50% chance of any child being a male or female

Environmental determination of sex

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 warm sand develop into females while those laid in cool sand develop into females.

SEX CHROMOSOMES

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.

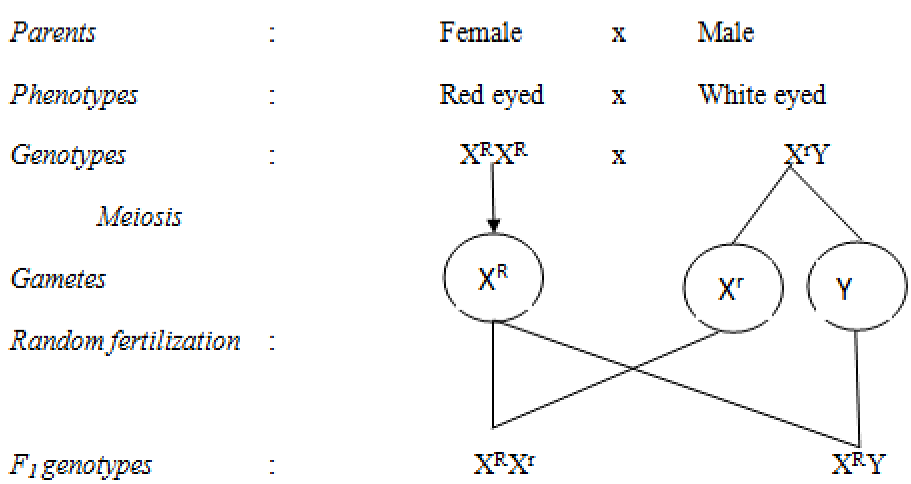
Note: The Y chromosomes don't carry genes, sex linked genes are specifically carried on the X sex chromosomes but not on the Y chromosome.

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.

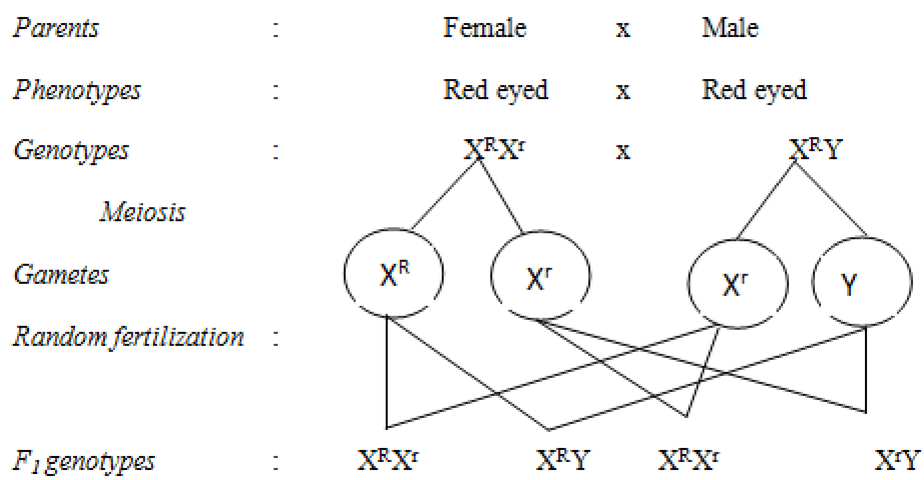
In conclusion, all the F_1 were red eyed; implying that this allele is dominant over that for white. Since in the F_2 all the white eyed were males, this indicates that the gene for eye colour is located on the X chromosome and there is no corresponding locus on the Y chromosome; otherwise some females would also be white eyed

Let;

R *represent the allele for red eyes, r represents the allele for white eyes*



Obtaining F_2 generation;



Phenotypic ratios: 3 red eyed: 1 white eyed

Note that all the white eyed are males yet some red eyed are males

Sample question:

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.

Examples of sex linked characters in man include the following

- Haemophilia
- Colour blindness
- Pre-mature balding
- Eye colour in drosophila

Most of these characters are caused by recessive alleles and in a genetic cross, these must be represented as superscripts on the x sex chromosome.

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.

Example: When a carrier woman is married to a normal man

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

It can be noted that there is a 50% chance of a daughter being a carrier and a 50% chance of a son being haemophiliac. 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. Girls can inherit from both parents.

Today, people with hemophilia are treated as needed with intravenous injections of the missing protein.

COLOUR BLINDNESS

It is a recessive sex linked character that leads to inability of the individual to distinguish between colours.

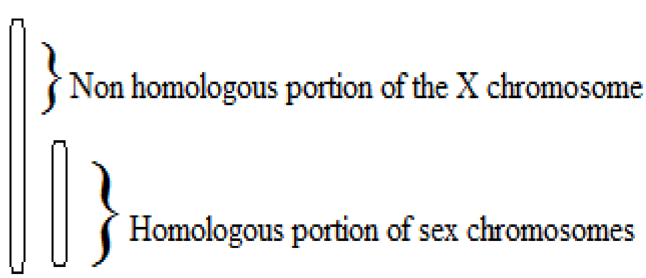
It is caused by a recessive allele, carried on the X chromosome and inherited in the same way as haemophilia. Colour vision is due to presence in the retina of red, blue and green cones needed for seeing the respective colours. The recessive alleles result into absence of some of these cones which renders inability to identify such colours from other related colours. This is called colour blindness; the commonest being red-green colour blindness where individuals lack red and green cones in their eyes.

Example

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

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.

NB: Sex linked characters have been found to occur more commonly in males as compared to females in the human population. 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

Se 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.

Examples include;

Facial hair, deep voice, baldness etc in males

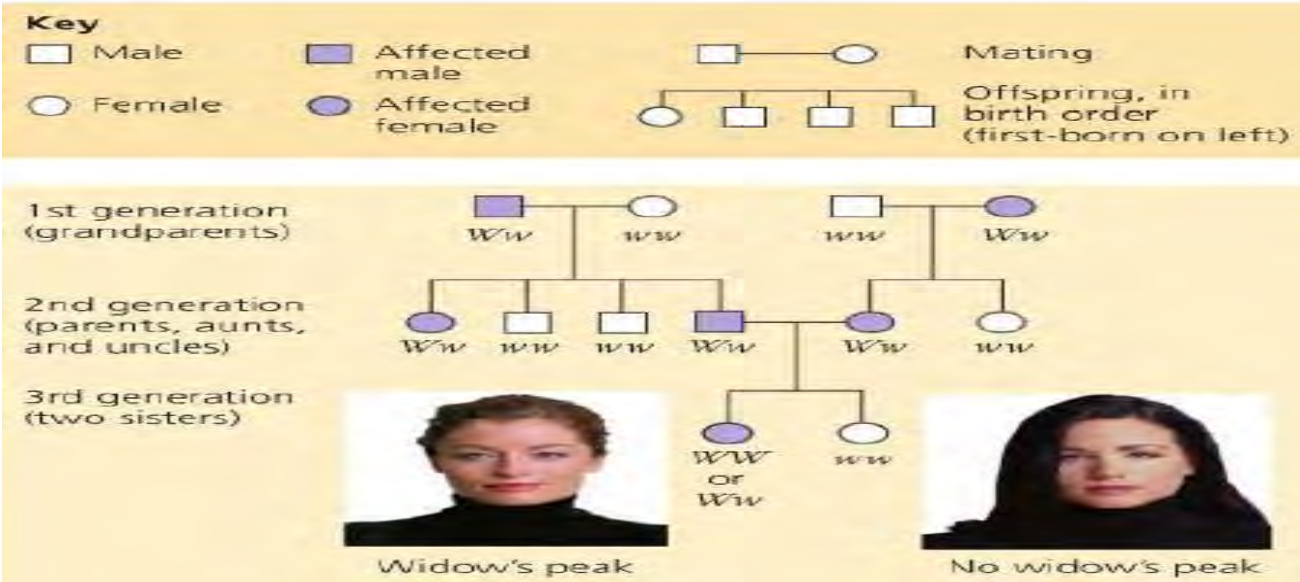
Breasts, lactation, widening of hip bones, high pitched sound etc

PEDIGREE ANALYSIS

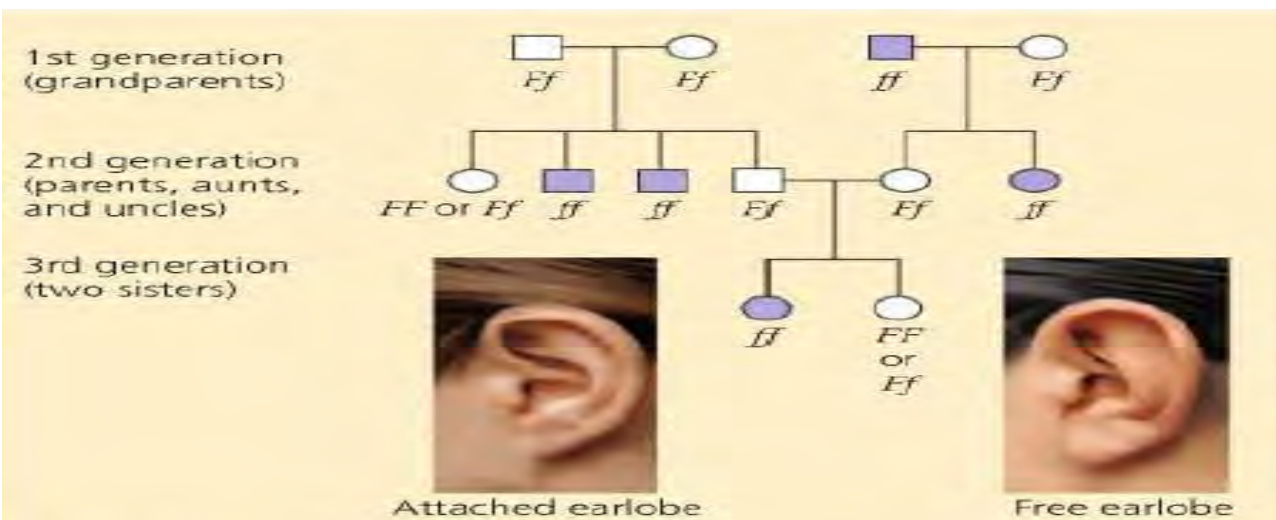
Whereas peas are convenient subjects for genetic research, humans are not. The human generation span is about 20 years, and human parents produce relatively few offspring compared to peas and most other species. Even more important, no one would consider it ethical to ask pairs of humans to breed so that the phenotypes of their offspring could be analyzed! In spite of these constraints, the study of human genetics continues to advance, spurred on by the desire to understand our own inheritance. New techniques in molecular biology have led to many breakthrough discoveries, as we will see in Chapter 20, but basic Mendelism endures as the foundation of human genetics .Unable to manipulate the mating patterns of people, geneticists must analyze the results of matings 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. Figure 14.1Sa 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* matings. 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).* Figure 14.1Sb 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.

An important application of a pedigree is to help us calculate the probability that a child will have a particular genotype and phenotype. Suppose that the couple represented in the second generation of Figure 14.15 decides to have one more child. What is the probability that the child will have a widow's peak? This is equivalent to a Mendelian F] 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). 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 . 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).* 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).

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.

QUESTIONS

I. Beth and Tom each have a sibling with cystic fibrosis, but neither Beth nor Tom nor 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 Tom is a carrier but Beth is not?

2. Joan was born with six toes on each foot, a dominant trait called polydactyly. 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.

3. What would you suspect if Peter was born with polydactyly, but neither of his biological parents had extra digits?

1. Incomplete dominance and *epistasis* are both terms that define genetic relationships. What is the most basic distinction between these terms?

2. If a man with type AB blood marries a woman with type 0 blood, what blood types would you expect in their children?

3. 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?

1. 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?

3. 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.

HISTOLOGY (TISSUE ORGANISATION)

A tissue is a group of cells linked together to perform a particular function. These are two main types of tissues i.e. plant and animal tissues.

ANIMAL TISSUES

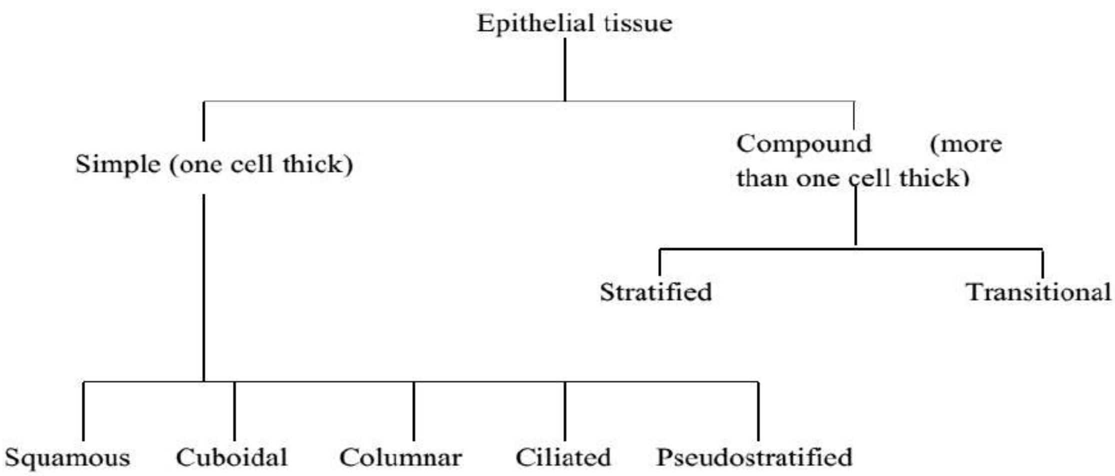
There are 4 major groups of animal tissues i.e.

i) Epithelial tissue
ii) Connective tissue
iii) Muscular tissue
iv) Nervous tissue

EPITHELIAL TISSUES

They are comprised of a single or several shifts of cells held together by intercellular substances. The bottom layer of cells is attached to a basement membrane made up of collagen fibres.
Epithelial cover inner and outer surfaces where they always have a protective function.
The cells may be linked by keratin to resist abrasion and divide rapidly to replace cells that are worn out.
When diffusion is to take place across a surface, the epithelial layer has to be thin. Many epithelial are specialized for absorption e.g. intestines and for secretion e.g. salivary gland.

Summary of animal epithelial tissues



SIMPLE EPITHELIAL TISSUE

1. Squamous epithelial (pavement epithelial):

Cells form a single layer attached to a basement membrane. In surface view, the cell outlines are irregular and closely packed. The cells are thin, shallow and flattened.
Adjacent cells may be joined by strands of cytoplasm. Such epithelia form structures and surfaces over which diffusion can occur hence are important in the alveoli of the lungs, Bowman's capsule and in capillary walls. Their smooth surface provides a friction free lining for blood vessels.

2. Cuboidal/cubical epithelial

Such epithelium has a secretory function in glands like thyroid, sweat and salivary glands. It also has a non-secretory function e.g. the lining of the kidney collecting tubules, proximal and distal convoluted tubules, pancreatic ducts, etc.

Its cells are cuboidal and form a single layer attached to a basement membrane.

Longitudinal section of cuboidal epithelial

3. Columnar epithelium

These are tall and narrow cells with a nucleus near their base. Their surface area is increased by micro villi at the free end. Such cells are mostly found in areas that have an absorptive role.

Secretory goblet cells are found within the columnar cells. This tissue is found lining the digestive system where secretion of mucus and absorption of food takes place. It is also found lining the kidney ducts and the thyroid glands.

Longitudinal section

4. Ciliated epithelium

It comprises of columnar cells with cilia at their free edges. They have many mucus secreting goblet cells present. The combination of mucus and cilia allows substances to move through ducts e.g. in the oviduct, trachea, spinal cord, bronchus and bronchioles where it moves materials from one location to another.

Longitudinal section

5. Pseudostratified epithelium

The nuclei of this type of epithelium appear to be at several different levels because not all the cells reach the free surface. Nevertheless, the epithelium is still one layer or one cell thick with each cell attached to a basement membrane. It is found lining the urinary tract and respiratory passages e.g. bronchi.

COMPOUND EPITHELIAL

1. Stratified epithelium

It is made of many layers of cells and therefore thicker than the simple epithelium and forms a germinating layer and they undergo cell division. As new cells form, older ones are pushed near to the surface changing shape and flattening to form squamous. The squamous may remain un keratinized as in the oesophagus or may be heavily thickened with keratin (cornified) e.g. the skin where there is a dead layer of cells like those found lining inside the mouth and vagina. Therefore they are for protection from abrasion to areas exposed to wear and tear.

2. Transitional epithelium

It is found in structures which must stretch e.g. the urinary bladder and parts of the kidney. It comprises of 3 or 4 layers of cells which may be flattened towards the surface which are not shed like those of the stratified epithelium. Transitional epithelium lacks a basement membrane.

The functions of transitional epithelium include:

- By changing the shape, the transitional epithelium allows the expansion of the organ.
- It prevents the loss of water from blood to urine.
- Due to its thickness, it prevents the urine from escaping into the surrounding tissue.

GLANDS - GLANDULAR EPITHELIUM

1. Based on the kind of secretion and the duct present, glands are of two types;

i) Exocrine glands: these pour their secretions through the ducts to their respective sites of action e.g. salivary, tear intestinal and gastric glands. Their secretions are called enzymes.

ii) Endocrine glands: these do not possess ducts and pour their secretions directly into the blood stream. Their secretions are known as hormones.

2. Based on number of cells, the glands are of 2 types;

i) Unicellular: an individual epithelial cell is modified into a glandular cell as in goblet cells.

ii) Multicellular: number of glandular cells aggregate to form a multicellular gland. Multicellular glands can further be divided into simple or compound glands e.g. sweat glands.

3. **Based on the shape and complexity, the exocrine glands are of 2 main types**; simple and compound glands which may further be modified.

i) **Simple glands:** these have a single unbranched duct. The secretory part could be in the form of (called tubular) or sacs (alveolar). These could be coiled or uncoiled, branched or unbranched. Various forms of simple glands are given below;

Simple tubular e.g. crypts of Lieburkuhn in intestine	Simple coiled e.g. sweat glands	Simple branched tubular e.g. gastric glands and Brunner's glands of intestine.	Simple alveolar e.g. mucous secreting glands in frog skin.	Simple branched alveolar gland; number of sacs opening in same duct e.g. sebaceous glands.

ii) **Compound glands**: these have number of ducts forming a branching pattern.

Compound tubular glands e.g. salivary glands.	Compound alveolar e.g. mammary glands, pancreatic glands.	Compound tubular alveolar e.g. parts of salivary and mammary glands.

4. **Based on the mode of secretions, the exocrine glands are of 3 types;**
   i) **Merocrine glands**: the secretions produced within the cell are discharged on its cell surface without losing any of its cytoplasm. E.g. goblet cells, pancreatic glands and sweat glands.
   ii) **Apocrine glands**: in these glands, the cell loses a part of its cytoplasm while releasing its secretions. The secretions are stored in the apical part of the cell which bursts open to release the contents e.g. mammary glands.
   iii) **Holocrine glands:** the entire cell breaks down in order to release its secretions which extrude from the epithelial surface e.g. sebaceous glands.
5. **Based on the form of secretion, glands are of 3 types.**
   i) Mucous glands: secretion is in form of viscous mucous fluid. They are called mucocytes.
   ii) Serous glands: secretion is clear, watery fluid containing enzymes. They are called serocytes.
   iii) Mixed glands: secret both.

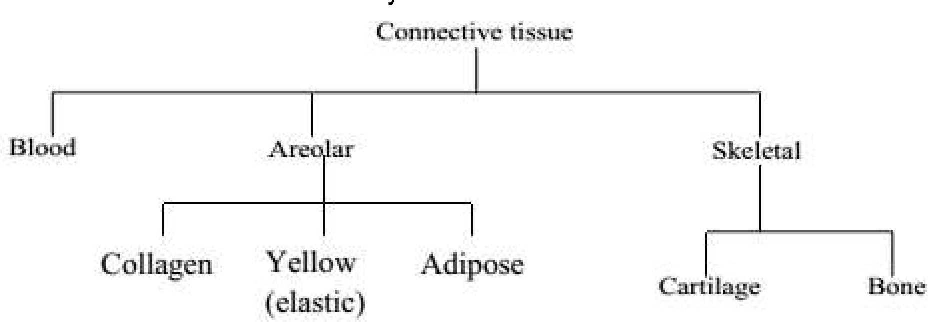
Functions of epithelial tissues

The epithelial tissues serve the following functions; protection, secretion, absorption, exchange of materials/gases and sensory.

CONNECTIVE TISSUE

It is composed of a variety of cells embedded in a large amount of intercellular substance called matrix. Connective tissues develop in the embryonic mesoderm. It provides the main supporting tissues in form of blood. Other connective tissues insulate the body e.g. adipose tissue.

Summary of the connective tissue



1. AREOLAR TISSUE

This is one type of connective tissue found all over the body i.e. beneath the skin connecting organs together and filling spaces between adjacent tissues.

Areolar tissue consists of a glycoprotein matrix containing four types of cells and two types of protein fibres. The areolar cells include:

i) **Fibroblasts:** These are long flat cells which synthesize collagen and elastic fibres.
ii) **Mast cells:** These are amoeboid in shape or oval shaped and contain granular cytoplasm. They secret fats filled cells and an anticoagulant or ground matrix or substance and macrophages.
iii) **Fat cells:** These are fats storing cells which accumulate fats in the body structures to form the adipose tissue.
iv) **Macrophage or histocytes:** These are amoeboid cells which are large which ingest a number of foreign particles hence are important in defense against foreign bodies. The fibres present in areolar tissue give it its strength and toughness.

There are two types of fibres in areolar tissue:

a) The unbranched collagen fibres/white fibres: these appear parallel to each other and are arranged in bundles. They are mainly found in tendons.
b) Branched elastic fibres/the yellow fibres: these form a dense network of fibres. They cross the matrix. The structures are stretchable and are found in ligaments.

Transverse section of areolar

FA page 36 fig.3.5

Three other types of connective tissues are derived from areolar tissue and only differ from each other in the structures present in the matrix. These include;

a) Collagen tissue/white fibrous tissue:

This consists of glycoprotein matrix containing densely packed collagen fibres. Collagen tissue has fibres which are inelastic and have a high tensile strength. They are found in the tendons where they attach muscles to bones. They are found in the Dura matter of the brain and also in the cornea of the eye.

b) Elastic tissue/yellow fibrous tissue:

This consists of a glycoprotein matrix containing only elastic fibres. It is strong and elastic. Such tissue is found in ligaments where it binds bones to other bones. It is also found around the walls of arteries and it is also found as a component of the lungs and associated air passages as well as in the great cords of the neck.

c) Adipose tissue (fatty tissue):

This contains closely packed fat filled cells known as adipocytes. Its functions are storage of fats and it is a site for energy production. The fats are deposited in a number of parts of the body e.g. the dermis of the skin where it insulates the body against heat loss. There are two types of adipose tissue;

i) White adipose tissue:

The white adipose tissue is called so because the cells appear white due to accumulation of fats. It is distributed throughout the body particularly the deep layers of the skin.

ii) Brown/yellow adipose tissue:

This is commonly in young mammals and some hibernating mammals. It is important in temperature regulation. It is supplied within blood capillaries and appears red. It differs from the white because of;

- ✓ It's coloured and has limited location in the body e.g. it is found around the neck.
- ✓ The fats in brown remain as small droplets i.e. do not form big globules.
- ✓ The nucleus of the brown remains centrally placed.

2. BLOOD TISSUE

In blood, the matrix is the watery plasma which carries a variety of different cells. The cells present include:

i) Erythrocytes (RBC):

These are biconcave in structure. They lack nucleus and are formed in red bone marrow.

Their main function is transport of oxygen within the body. They contain red pigment haemoglobin which combines with oxygen to form oxy-haemoglobin; the form in which oxygen is transported in the body.

ii) Leucocytes (WBC):

- ✓ They are larger and nucleated.
- ✓ Most of them are made in the bone marrow while others are made in the lymph nodes and in the thymus gland.
- ✓ Their main role is defense of the body.

There are two types of white blood cells, i.e.

a) **Granulocytes:**
They have granular cytoplasm with a lobbed nucleus.
They engulf bacteria by phagocytosis.

b) **Agranulocytes:**
They have a non-granular cytoplasm with a compact nucleus.
Most of them also ingest bacteria. They are produced from the lymph nodes and thymus glands and are known as lymphocytes. Their function is the produce anti bodies.

iii) Platelets (Thrombocytes)

These are tiny cell fragments important in blood clotting.

Formation of blood cells

The process of formation of erythrocytes is known as haemoporesis and the tissue which forms then is known as haemopoetic tissue.
In the fetus, erythrocytes are formed in the liver and spleen. In an infant all bones contain haemopoetic tissue. In adults, erythrocytes are formed in the bone marrow of the bones of the pelvis, sternum, vertebrae, clavicle, scapula and skull. During the process of formation of cells, the bone marrow undergoes two major changes;

i) The amount of haemoglobin increases in the cytoplasm.
ii) There is progressive loss of nuclear material and reduction in the size of the cell. A mature erythrocyte does not contain the nucleus and almost the entire cell is filled with haemoglobin.

The erythrocytes are nucleated at infant/fetal stage.
Iron and proteins form the basic raw material for haemoglobin synthesis.
Vitamin B_{12} and folic acid stimulate the maturation of erythrocytes.
WBC like lymphocytes are formed in the thymus gland and lymph nodes whereas the other types of WBC are formed in long bones e.g. the limb bones which have white bone marrow.

Questions:

1) ***Outline the differences between RBC and WBC.***
2) ***Outline the adaptations of WBC and RBC to their functions.***

3. SKELETAL TISSUE

This is made up of cartilage and bone.

CARTILAGE

The matrix of cartilage is made up of chondrin and chondrocytes which are embedded in it. It has fibres composed of collagen. The structure of cartilage is hard but flexible and found at the ends of bones, respiratory passages e.g. trachea and parts of the ear. It comprises the skeleton of cartilaginous fish e.g. sharks. Cartilage can contain a large number of collagen fibre s making it stronger and less flexible; such types of cartilage make up the intervertebral discs.

Types of cartilage

1. Hyaline cartilage

The simplest form of cartilage is known as hyaline cartilage which consists of only chondrin matrix and chondroblasts which secret it. It is glassy in appearance and has very few fibres. This type of cartilage forms the basis of growth and development in embryos. It also makes or forms parts of the respiratory tracts like the trachea, parts of the ribs and ends of bones and the nose.

Hyaline cartilage is bounded by fibrous layer known as perichondrium in which there are blood vessels. It reduces friction in areas where it is found.

Transverse section through the hyaline cartilage

2. Fibrous/tensile cartilage

This has got many fibres not as flexible and elastic as those of hyaline. It is adapted to resist compression due to presence of large bundles of collagen fibres. Its functions are to allow flexibility and reduce friction. It is also found in vertebral discs and around the pubic symphisis. It also provides a cushioning effect around areas it occurs.

3. Elastic cartilage

This has many yellow fibres. It is more flexible and elastic than all the other types of cartilage. It is found in the epiglottis, respiratory tract, the nose and the pinna of the ear supporting the Eustachian tube and the external auditory parts.

THE BONE TISSUE

The ostein matrix of bone is made up of collagen together with inorganic substances e.g. calcium, magnesium and phosphorus. Such components are arranged in concentric circles called lamellae which surround the Haversian canal containing an artery, lymph vessels and nerve fibres.

Structure of a bone:

Each bone is enclosed in a layer of white fibrous connective tissue called the **Periosteum**. It is through the Periosteum, the blood vessels and nerves pierce in. in a bone, the matrix is arranged in concentric circles called **lamellae.** In between the lamellae are present, number of living bone cells called **osteoblasts** or **osteocytes**, in the fluid-filled cavities called **lacunae**. Osteoblasts are active bone cells while osteocytes are inactive osteoblasts. Each lacuna has fine cytoplasmic extensions called **canaliculi** which pass through lamellae and make connections with other lacunae.

Structure of a compact bone:

A compact bone has number of Haversian canal system arranged concentrically. The haversian canals are present transversally as well as longitudinally. They form an interconnected network communicating with the bone marrow as well. In the centre of a compact bone is present a bone marrow cavity lined by Endosteum.

Transverse section of compact bone

Diagram in FA page 38 fig. 3.7 A

Longitudinal section through a bone

Ossification (development of bone from cartilage)

This is the process by which cartilage change to bone. It is also referred to as 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 let 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 let 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 let down a matrix in layers.
- ✓ Osteoblasts are then enclosed in lacunae interconnected by canaliculi.

Differences between bone and cartilage

Bones	Cartilage
Matrix is ostein	Matrix is chondrin.
Matrix is firm, inelastic and rigid.	Matrix is firm, elastic and flexible.
Surrounded by periosteum.	Surrounded by perichondria.
Blood vessels and nerves present.	Blood vessels and nerves absent.
Have osteoblasts that form the osteocytes.	Has chondroblasts that form the chondrocytes.
Osteoblasts form the ostein matrix.	Chondrocytes form the chondrin matrix.
Have inorganic materials like Ca and P ions.	Lacks the inorganic molecules.
Marrow cavity is present in long bones.	Marrow cavities absent.
Have concentric circles of lamellae with lacunae and canalicunae.	Lacks the lamellae, lacunae and canalicunae.
Osteoblasts are star shaped.	Chondroblasts are spherical.

Relatively metabolically active.	Not metabolically active.
Osteoblasts are arranged in concentric circles.	Chondroblasts are scattered randomly in the matrix.
Can manufacture blood cells from the bone marrow.	Cannot manufacture blood cells.
Matrix has haversian canals.	Matrix has no canals.
Has a secretory function.	No secretory function.

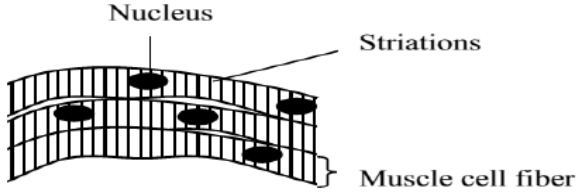
MUSCULAR TISSUE

There are 3 main types of muscular tissue all made up of cells and fibres which are capable of contraction. They are derived from the mesoderm of the embryo. They include:

1) Voluntary (skeletal/striated/stripped) muscles.
2) Involuntary (smooth/unstriated/unstripped) muscles.
3) Cardiac muscles.

Voluntary muscles

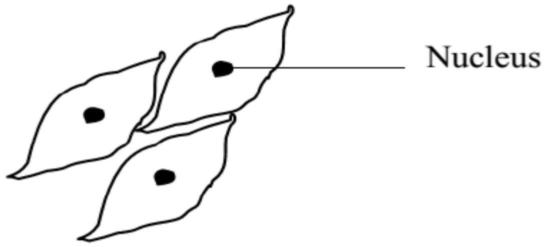
- ✓ It consists of numerous multi-nucleate cylindrical muscle fibres.
- ✓ The muscle fibres have alternate light and dark band or striations due to the banding pattern and arrangement of thin filaments called myosin filaments.
- ✓ The muscle fibres do not extend the whole length of the muscle but consists of functional units called ***sarcomeres.***
- ✓ Each multi-nucleate muscle fibre is contained in a plasma membrane called the ***sarcolemma*** surrounding cytoplasm called ***sarcoplasm.***
- ✓ The sarcoplasm contains thousands of myofibrils with characteristic striations, numerous mitochondria and smooth endoplasmic reticulum.
- ✓ Groups of fibres are bound by a thin film of connective tissue and the whole muscle is bound by a sheath of connective tissue.
- ✓ Blood vessels run longitudinally besides the fibres with many capillary connections.
- ✓ Every muscle cell is served by a motor nerve ending in a motor end plate.
- ✓ Its contractions are quick, powerful and voluntary with a short refractory period.
- ✓ They are attached to the skeleton.



Involuntary muscles

- ✓ It consists of densely packed and elongated fibres running parallel to each other and bound by connective tissue.
- ✓ Each muscle fibre is a single cell containing one nucleus.
- ✓ There are numerous fine contractile fibrils.
- ✓ The fibrils are made up of thin actin filaments and thick myosin filaments.
- ✓ There are no cross striations in the muscle fibres.
- ✓ Each muscle fibre is served by its own nerve cell.
- ✓ These muscles contract rhythmically and do not fatigue easily.
- ✓ Their actin is controlled by the autonomic nervous system.
- ✓ They are found in the alimentary canal, walls of blood vessels and tubes of urino-genital system.

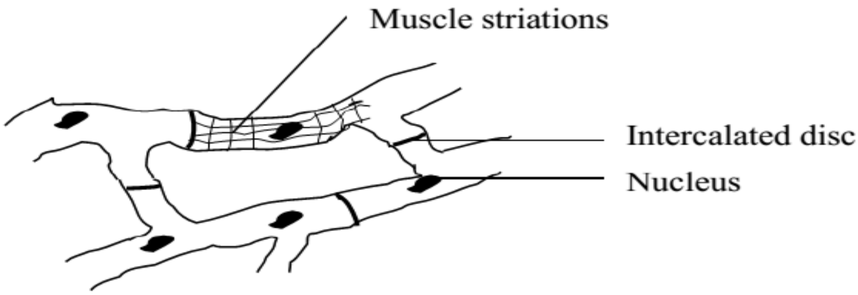
Longitudinal section of the involuntary muscle from the alimentary canal



Cardiac muscle

- ✓ It is a specialized muscle found inside a cell.
- ✓ It is capable of rhythmic contraction over a long period of time.
- ✓ Cardiac muscle is myogenic and its contraction is stimulated from within the heart itself.
- ✓ Each muscle cell has one or two nuclei.
- ✓ Their cells have a network arrangement which allows waves of contraction to spread rapidly over the heart.

Transverse section through the cardiac muscle



Nervous Tissue

It is derived from the embryonic ectoderm. It is comprised of closely parked nerve cells called neurons with little intercellular space. Neurons are bound together by connective tissue. *(To be covered under coordination)*

Diagrams in BS page 193

PLANT TISSUES

They may be simple or compound.

SIMPLE PLANT TISSUES

These consist of one type of cell in one layer. They are grouped according to the degree of thickening present in the cell wall. They are mainly of three types i.e. parenchyma, collenchyma and sclerenchyma.

Parenchyma tissue

- ✓ Its cells are usually spherical though sometimes distorted by pressure from adjacent cells.
- ✓ Parenchyma tissue stores food but when tightly parked and turgid, it provides support in herbaceous plants.
- ✓ Some are photosynthetic (parenchyma cells) are known as chlorenchyma.
- ✓ The epidermis is a specialized parenchyma capable of forming a waxy cuticle of cutin that prevents desiccation.
- ✓ Parenchyma also forms guard cells within the lower epidermis.
- ✓ In roots, cellular hairs near root tips are also made up of parenchyma tissue that assist in water uptake.

Transverse section of parenchyma tissue

Collenchyma tissue

- ✓ It is made up of cell walls which have additional cellulose deposited in the corners to provide additional strength.
- ✓ They are elongated and important in growing since they can stretch.
- ✓ They are found just under the epidermis of the cell.

Transverse section of a collenchyma tissue

Sclerenchyma tissues

- ✓ Mature sclerenchyma cells are dead and therefore not capable of growth. They develop fully when growth of the surrounding tissues is complete.
- ✓ Sclerenchyma cells are strengthened by lignin together with cellulose which is deposited to the primary cell wall where the cell contents are lost after wards.
- ✓ In some places lignin is not deposited due to plasmodesmata. Such regions are called pits.
- ✓ Some sclerenchyma cells are spherical and known as sclerids which are found in small groups of seeds and fruits, cortex, pith and phloem. Their function is to toughen these structures.
- ✓ Elongated sclerenchyma cells called fibres provide the main supporting tissue of mature stems by forming a cylinder below the epidermis. They are also found in xylem and phloem.

Transverse section of sclerenchyma tissue

Structure:

- ✓ It consists of fibres which are elongated cells and sclerids (torn cells) which are roughly spherical.
- ✓ Primary cellulose cell wall is thickened with deposits of lignin.
- ✓ Mature cells have an empty lumen hence are dead cells.
- ✓ Simple pits appear in the walls as they thicken and they interconnect adjacent cells.
- ✓ A secondary cell wall is built up in the layers.

COMPOUND PLANT TISSUES

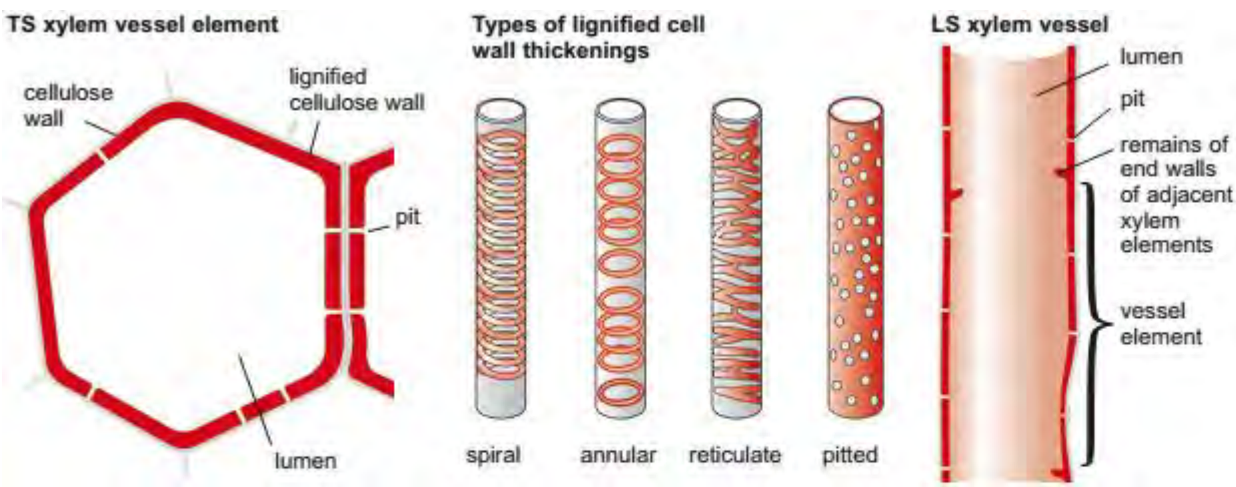
These are made up of different cells arranged in more than one layer. They include xylem and phloem tissues.

XYLEM TISSUE

- ✓ It consists of parenchyma cells and fibres together with two specialized cells known as vessels and tracheids which are both dead.
- ✓ Vessels and tracheids serve the role of support, water and mineral salt transport.
- ✓ The type of vessel found depends on the degree and nature of the cell wall thickened.

- ✓ In proto-xylem, lignin is deposited in rings or spirals such that the cell can still expand.
- ✓ A vessel is formed from a chain of elongated cylindrical cells placed end to end.
- ✓ In the course of development, the horizontal end walls breakdown so that the cells are in linkage with each other.
- ✓ At the same time, the cellulose side walls become impregnated with lignin which makes them impermeable to water and salts.
- ✓ At impregnation, the protoplasmic contents die leaving a hollow tube known as a vessel.
- ✓ The xylem's lignified walls are perforated with pits where lignin fails to be deposited. These pits allow passage of water in and out of the vessel cavity.
- ✓ In some cases, pits are covered by a lignified layer forming a torus kind of plug which controls passage of water.
- ✓ Thickening/lignification gives the vessels additional strength and prevents the walls from curving in.

There are 3 main types of thickening lignification, i.e. annular, spiral and reticulate thickening.

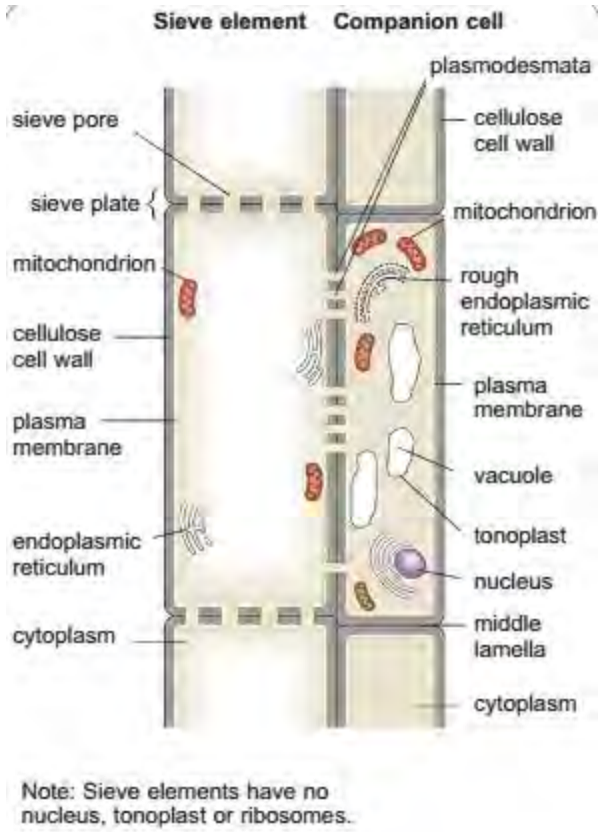


PHLOEM TISSUE

- ✓ Comprises of parenchyma, sclerids and fibres with specialized cells for translocation known as sieve tube elements and companion cells.
- ✓ Long sieve tubes are formed by fusion of the sieve tube elements and the partial breakdown of the cross walls between them to form sieve plates and sieve pores.
- ✓ Their cell walls are thickened with cellulose and pectin together with lignin.
- ✓ Phloem cells lack nuclei and the cytoplasm is confined in a companion cell with a nucleus.
- ✓ Sieve elements and companion cells are connected to each other by plasmodesmata. Each sieve element forms a cell whose nucleus disintegrates during development. Its end walls known as the sieve plates are perforated by numerous pores (sieve pores) which allow the passage of materials from one sieve element to the next.
- ✓ The inside of the sieve elements contains fine cytoplasmic filaments, mitochondria, plastids and or any other organelles that may persist adjacent to the cell wall.
- ✓ Close to the sieve elements are companion cells which possess a nucleus, endoplasmic reticulum, ribosomes and mitochondria. They are metabolically active and all energy needed for translocation in the sieve elements is derived from here.

Structure of the phloem tissue

(Diagram in FA page 193)



LEVELS OF ORGANISATION IN ORGANISMS

Animals are more complex in tissue organization than plants on the fact that they lack the ability to perform chemical processes of photosynthesis.

Organ and organ systems

Organs are structurally distinct parts of the body made up of several types of tissues performing a particular function e.g. the kidney contains blood, smooth muscles, connective tissues and several types of epithelial tissues all combined to carryout excretion. Several organs which perform a specific function form an organ system, for example, the digestive system is made up of the gut and various accessory glands like pancreas and the liver. Sometimes an organ belongs to more than one system like the pancreas is found in the digestive system playing an important role in digestion and also in the endocrine system.
Animals have elaborate organs and organ systems as compared to plants; however the plants have the leaves as organs for photosynthesis and flowers as reproductive organs.
Other organs include the bulbs and corms which are storage or vegetative organs.

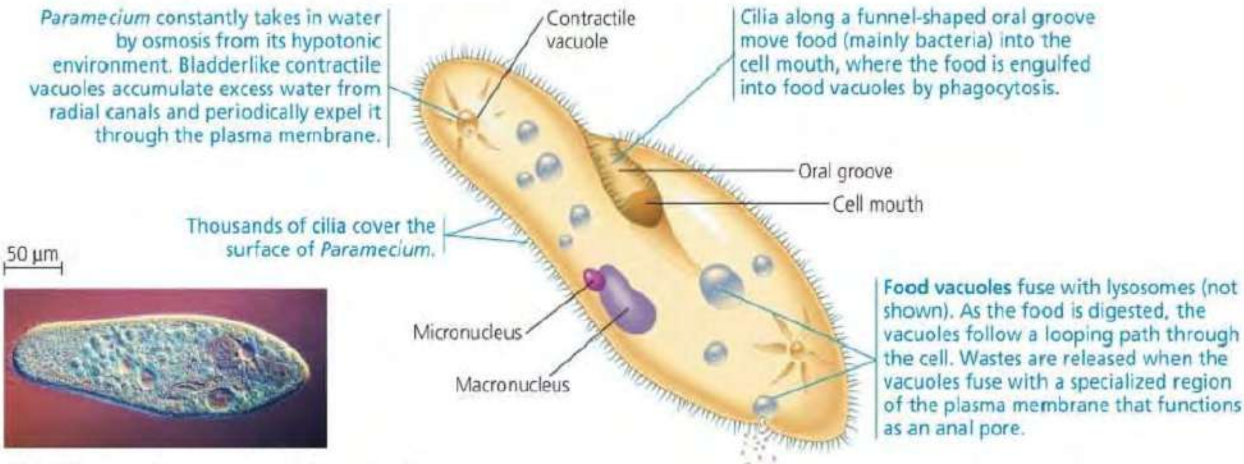
Multicellular and unicellular organization

In unicellular organisms, the single cell has to carry within it self all functions that in a multicellular organism are performed by differentiated tissues and organs. Organelles in unicellular organisms e.g. paramecium take over the functions carried out by organs in multicellular organisms.

Diagram of paramecium (unicellular)

(Check FA page 43)

▼ **Figure 28.11 Structure and function in the ciliate *Paramecium caudatum*.**



(a) Feeding, waste removal, and water balance.

Cilia are responsible for movement and sweeping food into the oval vestibule and food vacuoles formed at the base of the cytopharynx.
Digestion occurs in the cytoplasm and un digestible remains are expelled through the cytoproct.
The contractile vacuole carries out osmoregulation while the trichocysts contain needle-shaped threads that are for defense.
Therefore, the organization of the body of paramecium tends to be as efficient as the organ level of multicellular organization.
Functioning of multicellular organisms needs to be coordinated therefore some animals must have more than one cell but when this occurs independently it is referred to as a colony of single cells e.g. in sponges.
Hydra represents a group of primitive multicellular organisms. It has a few types of cells which engulf food and carries out movements and the stinging cell (nematoblast) for defense and killing their prey. These cells are connected by nerve cells and therefore coordinating its activities.

Diagram of tissue of hydra (multicellular)

(Diagram in FA page 44)

Hydra has a tissue level of organization. Multicellular organization increases the size of the organism and allows specialization where different functions are carried out by different cells which permit greater efficiency and organisms become less environmental dependent. However, the cells lose their ability to exist on their own so they become increasingly dependent on one another's activities and as the number of cells increase, difficulties of acquiring oxygen and food materials by the individual cells also increase.

***

"Every adversity, every failure and every heart-ache carries with it the seed of an equivalent or a greater benefit" Napoleon hill.