PREFACE

This book has been compiled by ROBERT BANDIKUBI to simplify the biology notes to students preparing for A-level Biology paper 1 and 2 (P530/1/P530/2) examination at Uganda Advanced Certificate of Education and any other pre-university entrance examinations.

This book contains exhaustive theory explanatory notes that simplify students understanding of A level biology concepts.

It also contains well organized A- level biology notes that are in line with the NCDC syllabus, this therefore provides a comprehensive coverage of the A-level syllabus in biology.

This book is expected to improve on their Knowledge, attitude, practices and confidence, hence enabling the students excel in A-level Biology theory (P530/1 and 2) examinations.

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SIMPLIFIED "A"-LEVEL BIOLOGY NOTES

FOR PAPER 1 &2

VOLUME ONE

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TOPIC 1: CELL BIOLOGY

CYTOLOGY is the study of cells by microscopy.
Cell biology is the study of cells as a branch of biology.
The cell is the basic unit of structure and function in living organisms.
This definition comprises the cell theory which proposes that organisms are composed of cells and new cells only come from pre- existing cells.

The cell of a living organism

The cell can be defined as the basic unit of structure and function in a living organism. This generalization is known as the ***cell theory*** and it embraces four ideas;

- The cell is the building block of structures in living cells
- The cell is derived from other cells by cell division
- The cell contains hereditary information that is passed from parent cell to daughter cell
- The cell is the functioning unit of life i.e. the chemical reactions of life takes place within cells

The cell theory states that "***a cell is the fundamental and functional unit of*** life" i.e. the cell is the basic unit of the structure and function in living organisms.

Exceptions (discrepancies) to the cell theory.

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

1. Viruses are obligate intracellular parasites capable of replicating only inside host cells using the machinery of the host. Viruses are therefore considered biotic but not organisms.
2. Coenocytic algae like Vaucheria and many fungi have a body that is a continuous mass of protoplasm with many nuclei but without cell wall separations i.e. are aseptate.
3. Skeletal muscles have very long cells (up to 300 mm long) with hundreds of nuclei i.e. are Syncytia.
4. Giant algae is an organism made of one long cell (up to100 mm long) but with only one nucleus.
5. Unicellular organisms can be considered acellular because they are larger than a typical cell/carry out all functions of life.
6. Some tissues / organs contain large amounts of extracellular material e.g. vitreous humor of eye / mineral deposits in bone / xylem in trees.

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Factors that limit cell size

1) Surface area to volume ratio

Small cells have large surface area: Volume ratio (SA: V ratio) while large cells have a small SA: V ratio.
A large SA: V ratio enables fast rate of diffusion while a small SA: V ratio slows the rate of diffusion
Small cells have low metabolic demands and form low amount of wastes while large cells have higher metabolic demands and form much amount of wastes.
Therefore, the large SA: V ratio in small cells enables adequate supply of oxygen and nutrients and expulsion of wastes e.g. carbon dioxide via the surface of the cell by simple diffusion while the small SA: V ratio in large cells limits diffusion hence the supply of nutrients by simple diffusion is inadequate to meet the metabolic demands of the cell.

Hence:

- In animals, some large sized cells take in substances in bulk by endocytosis and expel bulk substances by exocytosis to supplement on simple diffusion.
- Some animal cells increase their surface area by forming many tiny projections called microvilli.
- Some cells divide when they reach a certain size to maintain suitable Surface Area: Volume ratio.

Note: **Surface Area: Volume ratio** particularly limits the size of bacterial cells, i.e. prokaryotic cells which are incapable of endocytosis and exocytosis.

2. Nucleocytoplasmic ratio

DNA in the nucleus provides instructions for protein synthesis hence controls activities of the whole cell.

Each nucleus can only control a certain volume of cytoplasm.

Specialization forms some long / large cells, therefore to overcome this limitation such cells are modified to become multinucleate / coenocyte e.g. skeletal muscle cells and fungal hyphae.

3. Fragility of cell membrane

As cell size increases, the risk of damage to the cell membrane also increases. This limits the maximum size of cells, especially animal cells. Hence;

- In animals, some large sized cells take in substances in bulk by endocytosis and expel bulk substances by exocytosis to supplement on simple diffusion.
- Some animal cells increase their surface area by forming many tiny projections called microvilli.
- Some cells divide when they reach a certain size to maintain suitable SA: V ratio.

4. Mechanical structures that hold the cell together

Cells with tough cell walls e.g. plant cells are larger than cells with only the fragile cell membrane e.g. animal cells because the tough walls provide support and maintain cell shape.

Cells with complex internal cytoskeleton are larger than cells with little cytoskeleton because the cytoskeleton protects and supports the cell structure and maintains cell shape.

The main functions of the cell include

- **Basic unit of life**. The cell is the smallest part to which an organism can be reduced that still retains the characteristics of life.
- **Protection and support.** Cells produce and secrete various molecules that provide protection and support of the body. For example, bone cells are surrounded by a mineralized material , making bone a hard tissue that protects the brain and other organs and that supports the weight of the body.
- **Movement.** All the movements of the body occur because of molecules located within specific cells such as muscle cells
- **Communication.** Cells produce and receive chemical and electrical signals that allow them to communicate with one another. For example, nerve cells communicate with one another and with muscle cells, causing them to contract
- **Cell metabolism** and energy release. The chemical reactions that occur within cells are referred to collectively as cell metabolism. Energy released during metabolism is used for cell activities, such as the synthesis of new molecules,muscle contraction, and heat production, which helps maintain body temperature.
- **Inheritance.** Each cell contains a copy of the genetic information of the individual. Specialized cells are responsible for transmitting that genetic information to the next generation

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TYPES OF CELLS

There are two fundamentally different types of cell; prokaryotic cells and eukaryotic cells.

In prokaryotes the DNA lies free in the cytoplasm in the nucleoid region with no true nucleus.

In eukaryotes the DNA is found inside the nucleus, a structure enclosed by two membranes forming the nuclear envelop.

ORIGIN OF EUKARYOTIC CELLS

Endosymbiotic Theory.

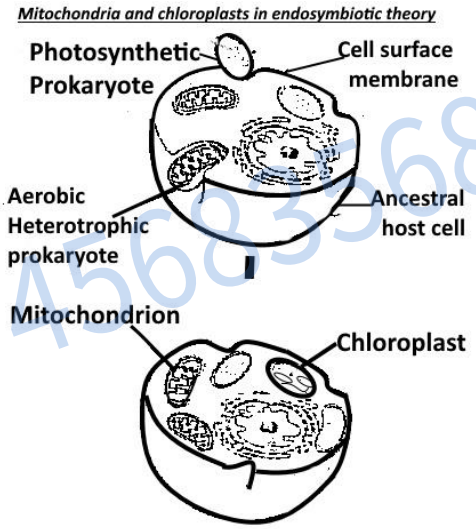
As proposed by **Lynn Margulis (1967),** the endosymbiotic theory suggests that mitochondria and chloroplasts were once separately existing small aerobic bacteria and photosynthetic bacteria respectively.

Larger anaerobic bacteria engulfed the smaller bacteria by the process of endocytosis, but digestion failed.

Initially, the smaller bacteria could have lived inside larger bacteria either as parasites or phagocytic vesicles, after which a mutually benefitting relationship called endosymbiosis resulted, where the larger cell provided protection and shelter while the smaller organisms removed oxygen which was toxic to the anaerobic larger cell.

With time, mitochondria and chloroplasts were modified into organelles suited for respiration and photosynthesis inside the larger eukaryotic cells. Note: Secondary endosymbiosis involves a larger eukaryotic cell engulfing a smaller eukaryotic cell.

DESCRIPTION OF THE ENDO-SYMBIOTIC THEORY OF THE OF A CHLOROPLAST AND MITOCHONDRION



Endo-symbiotic theory suggests that chloroplasts **and** mitochondria evolved from endo-symbiotic bacteria.

Initially a heterotrophic eukaryote may have ingested photosynthetic prokaryote and aerobic prokaryote and instead of being digested became symbiotic inside the heterotroph. This enabled eukaryote to carry out photosynthesis thus providing organic energy source while the eukaryote provides with an inorganic source and shelter.

The prokaryote which could respire aerobically to provide the cell with ATP than would be produced by anaerobic respiration while the eukaryote cell provided glucose and other nutrients.

Eventually these bacteria became permanent inhabitants of eukaryotic cells whereby since they have their own DNA.

They divided inside the host cell every time the host cell it shelf divides.

The photosynthetic bacteria became its chloroplast anaerobic bacteria its mitochondrion.

Cells having both types of bacteria became plant cells and those with only the respiring bacteria became animal cells.

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EVIDENCES FOR THE ENDOSYMBIOTIC THEORY

- Both mitochondria and chloroplast have naked and circular DNA
- Both mitochondria and chloroplast have 70S ribosome
- Both mitochondrial and chloroplast protein synthesis are sensitive to antibiotics for example chloramphenical and streptomycin
- The ability of the mitochondria and chloroplast to divide themselves/self-replication
- Ribosomes of mitochondria and chloroplasts resemble those of bacteria and cyanobacteria, with respect to size and nucleotide sequence
- Mitochondria and chloroplasts reproduce independently of their eukaryotic host cell by a
- Process similar to the binary fission of bacteria.
- The thylakoid membranes of chloroplasts resemble the photosynthetic membranes of cyanobacteria.

There is great similarity between prokaryotic cells and the organelles of eukaryotic cells

Alternatively the organelles could have risen by **invaginations of the plasma membrane** which pitched off to form a separate membrane structure inside the cell

SUBTOPIC 1: CELL STRUCTURE

One of the most important tools for studying cells is the microscope which magnifies objects to larger sizes that can be studied and drawn.

MICROSCOPES

These are instruments that can magnify images a, making it relatively easy to observe the size, shape and motility of cells.

Terms used in microscopy

Resolution is the ability of a microscope to clearly separate two objects that are very close together.

Resolving power is the minimum distance existing between two objects when those objects can still be viewed as separate entities.

The smaller the resolving power of a microscope, the better its resolution.

The resolving power of a microscope depends on the quality and type of lens, wavelength of the light, magnification, and how the specimen was prepared.

Refraction is the bending of light rays as light passes from glass to air.

Contrast is the number of visible shades in the specimen. The highest contrast is two shades i.e. black and white

TYPES OF MICROSCOPES

There are two types of microscopes;

1. Light microscopes

These use visible light for observing objects.

They can magnify images up to x1000.

The resolving power of the best light microscope is **0.2um**, which is sufficient to observe the general morphology of a prokaryotic cell but too low to distinguish a particle the size of most viruses.

These microscopes are very easy to operate, cheap and may use sunlight as a source of light, do not need prior killing of the cell.

Their main disadvantage is that they have low resolving power which hinders formation of images containing much more detail, Have low magnification power of only up to **x1000,** relatively low resolving power and produce coloured images.

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Type of light microscope	Mechanism	Uses/comment
Bright field light microscope	Illuminates the field of view evenly	Most common type
Phase contrast	Amplifies differences in refractive index to create contrast	Makes unstained cells more readily visible
Interference	Two light beams pass through the specimen and then recombine	Cause the specimen to appear as a three-dimensional image
Dark field	Light is directed toward the specimen at an angle	Makes unstained cells more readily visible; organisms standout as bright objects against a dark background.
Fluorescence	Projects ultraviolet light, causing fluorescent molecules in the specimen to emit longer wavelength light	Used to observe cells that have been stained or tagged with a fluorescent dye
Confocal	Mirrors scan a laser beam across successive regions and planes of a specimen. From that data, a computer constructs an image.	Used to construct a three dimensional image of a structure; provides detailed sectional views of intact cells.

Advantages of light microscope

- It is cheap to purchase and operate
- It can be used to examine living specimens.
- It is small and portable which reason it can be used almost everywhere.

Disadvantages of light microscope

- It can magnify an object effectively, only about 1,500 times. In other words a light microscope has a low magnifying power.
- It has a low resolution (resolving power) of 200nm

Magnifying power/ Magnification of a microscope

This is the number of times larger an image is made larger relative to the specimen using a microscope.

Resolving power or resolution of a microscope

Resolving power is the ability of two objects which are close to one another to be seen as separate entities, rather than a single fused image. In other words, resolving power can be interpreted as the degree of detail which can be observed.

2. Electron microscopes

This uses **electromagnetic waves** and **electrons beams** to create the final image instead of light as a source of radiation. It also uses electromagnets, instead of glass lenses used in light microscope as objective and eye pieces. Because it has a shorter wavelength than sunlight, electron microscope has a high resolving power, which enables it to produce images containing so much more detail than those of the compound microscope.

This microscope uses electromagnetic lenses, while the light microscope uses the glass lenses, i.e. objective and eye lenses.

The electron microscope uses a small copper grid to support the specimen, while with the light microscope, the specimen is mounted on the glass slide.

The specimen I the electron microscope is mounted in vacuum, on the copper grid, while in light microscope, it is mounted on the glass slide and on stage irrespective whether, there is air or not.

The images formed with the electron microscope are black and white and those of the light microscope are usually coloured.

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MAIN TYPES OF ELECTRONS MICROSCOPE

1. **transmission Electron Microscope (TEM)**
2. **Scanning Electron microscope (SEM).**

a) SCANNING ELECTRONIC MICROSCOPE

In this type of electron microscope an electron beam is scanned to and from across the specimen and electrons that are reflected the surface collected and used to form a TV- like image on a cathode ray tube.

This involves penetrating or bombarding the solid specimen with a beam of electrons, which causes secondary electrons to be emitted from the surfaces of the specimen, to enable the details of the surface to clearly observe. **SEM** is used to produce three-dimensional image of the surface of specimens. Electrons are reflected from the surface of a specimen stained with heavy metal.

Advantages of SEM

- Great depth of field is achieved, giving a three dimensional effect.
- Surfaces of structures are shown
- Much larger samples can be examined than with TEM.

b) Transmission electron microscope (TEM) is an electron microscope in which the electron beam is transmitted through the specimen before viewing. **TEM** is used to study the details of the internal structure (the ultra-structure) of cells.

The principle is the same as in the light microscope in that of beam of radiation is focused by condenser lenses through the specimen and the image in magnified by further lenses.
Use electron beams in place of visible light to produce the magnified image.
Can clearly magnify images up to x100000.
Rather than using glass lenses, visible light, and the eye to observe the specimen, the electron microscope uses electromagnetic lenses, electrons, and a fluorescent screen to produce a magnified image.
The image can be captured on a photographic film to create an electron photomicrograph.
It has a contrast of only black and white images, which may enhanced artificially with color to add visual clarity to the image.
Have a resolving power of $0.3x10^{-3}$um. Much more detail can be observed due to much higher resolution.
The main drawback is that the lenses and specimen must be in a vacuum because the molecules of air can interfere with the path of electrons, which necessitates use of non-living dehydrated specimens as compared to the light microscope which uses living specimens.
This results in an expensive, bulky unit and requires substantial and complex specimen preparation.

Advantages of TEM

- It has a high magnifying power of over 500,000 times.
- It has a high resolution power ranging between 0.2-0.5nm

Disadvantages of TEM

- It is expensive to purchase and operate.
- The material for examination must be put in a vacuum and therefore dead.
- It is very large (not portable) and therefore must be operated in a special room
- Preparation of specimens is lengthy and requires expertise and complex equipment.
- All images are black and white.
- It is difficult to be sure that the specimen resembles a living cell in all its details because staining and presentation may change or damage its structure.

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Differences between the TEM and Light microscope

TEM	Light microscope
1. Uses electrons as radiation source.	Uses light as radiation source.
2. Has a short wavelength of 0.005nm.	It has a long wavelength of 400-700nm.
3. It has a low maximum resolution power	Has a high max. resolution power
4. Has a high max. useful magnification	Has a low max. useful magnification
5. Uses electromagnetic lenses	Uses glass lenses
6. Used to observe only dead specimen	Used to observe living & dead specimens.
7. Specimen is mounted in a vacuum and is supported by a small copper grid.	Specimen may be mounted in both vacuum and aerated conditions and is supported by a glass slide.
8. Staining of the specimens occurs in with heavy metals.	Staining of specimen occurs with coloured dyes.
9. The image is black and white	The image is usually coloured.
10. Images are three dimensional.	Images are single dimensional.

Type of electron microscope	Mechanism	Uses/ comment
Transmission	Transmits a beam of electrons through the specimen	Elaborate specimen preparation is required
Scanning	A beam of electrons scans back and forth on the surface of the specimen	Used for observing surface details; produces three dimensional effect
Atomic force	A probe moves in response to even the slightest force between it and the sample	Produces a map showing bumps and valleys of the atoms on the surface of the sample.

OTHER TYPES OF MICROSCOPES

1. Phase-contrast microscope

This has an optical system which makes it possible to distinguish between parts of a transparent specimen, which have very slight differences of refractive index.

In this microscope, the phase effects are translated into variations in intensity.

This is achieved by the introduction of a ¼ λ phase plate in the objective lens, used in conjunction with a special condenser and a backstop, which is fitted into the sub stage, so that light passing directly through the specimen is made to interfere with that which is diffracted by it, so converting the phase changes into amplitude changes which are easily seen.

The major advantage of the instrument is that, great contrast between parts of living protoplasm can be seen without the need for staining.

2. Polarizing microscope, as used with transparent objects, incorporates, the polarizer beneath the sub-stage condenser and a similar analyser, in the eye piece system.

Thus the transmitted light is plane polarized before entering the objet, and any effect which the object may have on the plane of polarization can be detected.

3. X-ray microscopes utilizes rays of short wave-length of the order 0.1nm.

An additional advantage is that X-ray photography will reveal internal structure and can be manipulated, so that the living tissue is not killed.

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UNITS USED IN MICROSCOPY

The commonest units used in microscopy include **micrometers (µm)** and nanometers **(nm)** because microscopic images are very minute.

1meter (m) = 1000 mm ($1x10^3$ mm)

1 micrometer **(µm)** = 1/1000 mm (1x $\mathbf{10^{-3}}$ mm)

1 nanometer (**nm)** = 1/1000 µm (1x $\mathbf{10^{-6}}$ mm)

1 mm = 1000 micrometer (µm)

1cm= 10,000 micrometer (µm)

Units of measurement used in cell biology

Unit	In meters	Also
Millimeter (mm)	10^{-3}m	
Micrometer(um)	10^{-6}m	10^{-3}mm
Nanometer (nm)	10^{-9}m	10^{-3}um

Magnification for specimen observed under a microscope and drawn

For example at a given magnification of the microscope say **x40;**

STEPS INVOLVED

(i).Measure diameter of field of view in **mm** using a transparent ruler, then convert into micrometer.

Eg. **2mm**

1mm= 1000 µm

2mm =2x1000 **µm**

Diameter of the flied of view **=2000 micrometers (µm)**

(ii).Mount and observe specimen (e.g. spirogyra filament or epidermis of onion/epidermal cells)

(iii).Observe the cells across the above diameter and count them e.g. **5 cells** counted lengthwise.

(iv).Calculate the actual length of each cell

5 cell are seen in a flied of view of **2000µm**

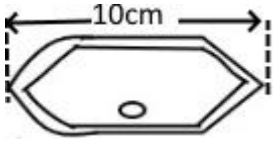
How about **one cell = 2000**

5

Actual size of one cell **is = 400 micrometers** and this is the object size

(v). One clearly observed cell is drawn and its length is measured in **cm** and converted into micrometers.

Eg. Assuming a cell drawn is measuring 10cm



Convert the **10cm** into mm

1cm=10mm

10cm= 10x10 = 100mm

But 1mm=**1000 µm**

1mm= 1000micrometers

100mm= 100x1000

=100,000 µm

Image size of one cell =10cmx10mmx1000um **=100,000 µm**

(vi) Magnification of cell drawn

= **Image size**

Actual Object size

=**100,000**

400

= **X250**

Calculating magnification for a cell from a field of view completely covered by cells;

Calculate the area of the field of view

Count the number of cells in the field of view

Calculate the area of one cell from

=area of field of view ; this is the object size

Number of cells

Draw one cell and calculate its area, this is the image size

RESOLUTION AND MAGNIFICATION

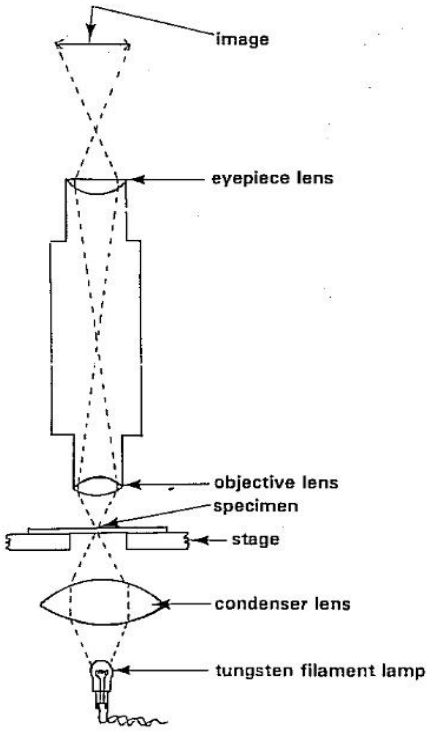
The ability to distinguish between two separate objects close together rather than to see them as a single image is known as the resolution for the resolving power.

The poor resolution of a light microscope could only be overcome by using a form of radiation with a wave length less than of light. This led to electrons have shorter wave length less than that of light. This led to the development of higher magnifying power with much greater resolution whereas the light microscope uses glass lenses to focus the light rays, the electron microscope is focused by powerful electromagnets.

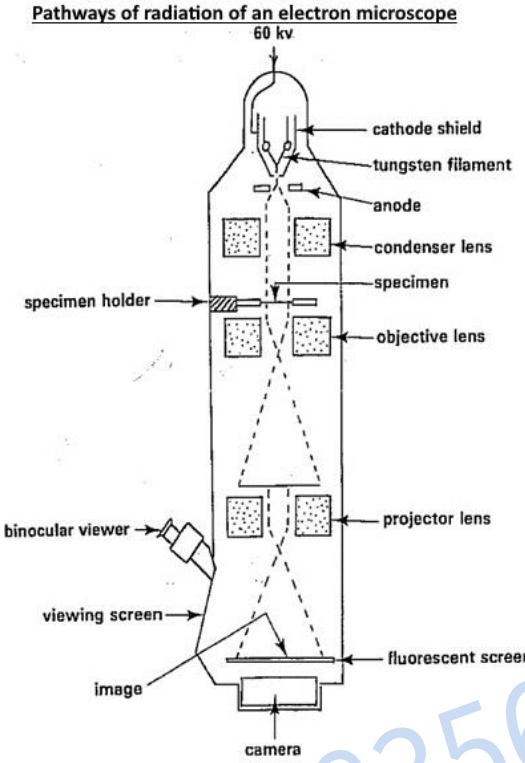
The image produced by the electron microscope cannot be seen by the naked eye. Instead the electron beam is directed onto a screen giving black and white images.

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Pathways of radiation of light microscpe



Pathways of radiation of an electron microscope



Comparison between the light microscope and electron microscope

Transmission electron microscope	Compound light microscope
The source of radiation are electrons	The source of radiation is light
Electrons have a shorter wave lengths of about 0.000nm	Light has a longer wave length of about 400-700nm
The maximum resolutions is greater at about 0.5nm	The maximum resolutions lower at about 200nm
The maximum useful magnification on screen is higher at about x250,000	The magnification is lower at about x1500
Uses powerful electromagnets as lenses	Use glass lenses
The specimen is dead, dehydrated and relatively small or thin	The specimen may be living or non living.
The specimen is supported on a small copper grid in a vacuum	The specimen is supported on a glass slide.
The stains used contain heavy metals to reflect electrons	The stains use are coloured dye
The image is black or white	The image is usually coloured.

A comparison of the relative advantages and disadvantages of the light and electron microscope

Advantages	**Disadvantages**
Cheap to purchase and operate	Expensive to purchase and operate
Small and portable, thus can be used almost anywhere	Very large and fixed and must be operated in special rooms.
Not affected by magnetic fields	Affected by magnetic fields
Preparation of material is relatively quick and simple and requires only a little expertise and simple equipment.	Preparation of material is lengthy and requires considerable expertise and complex equipment

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Material rarely distorted by preparation	Material is usually distorted by the preparation, preparation and staining may change or damage the structure.
The natural colour of the material can be observed	All images are in black and white
The specimen may be living	The specimen must be dead because its viewed in vacuum
The specimen does not deteriorate easily allowing more study time.	The specimen gradually deteriorates in the electron beam and so photomicrographs must be taken when further study is required.

Disadvantages

Light microscope	**Electron microscope**
Has a lower magnification of up to x1500	Has a higher magnification of up to x250,000
Has a restricted depth of field	Enables investigation of a greater depth of field.
Has a lower resolution of about 200m	Has a higher resolution of about 0.5nm

TYPES OF CELLS

Cells can be classified according to whether they have a distinct nucleus or not, or according to the organisms where they are found. The cells which contain a nucleus with a nucleus membrane, are called **eukaryotic cells**, while those cells whose nucleus materials are not enclosed by a nuclear membranes is known as **prokaryotic cells.**

Prokaryotic cells are possessed by the primitive groups of organisms, which include; bacteria and blue-green algae.

Eukaryotic cells are found in most animals and plants. Cells which are classified according to the groups of organisms include plant and animal cells. In sexual organisms are reproductive cells, called gametes and body cells called somatic.

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PROKARYOTIC AND EUKARYOTIC CELLS

Prokaryotes appeared about **3500** million years ago, while in Eukaryotes about **2000 million** years ago. It is believed that eukaryotic cells probably evolved as a result of symbiotic associations of prokaryotes

PROKARYOTIC CELLS

There are two groups of prokaryotic cells; (**pro-before, karyon-nucleus**): the bacteria and the blue-green bacteria.

Prokaryotes are organisms composed of cells that **lack a true nucleus**.

Characteristics of prokaryotic cells

- These are cells that do not have a true nucleus.
- They have no membrane bound organelles.
- An **organelle** can be defined as a membrane-enclosed structure with specialized functions, suspended in the cytosol of eukaryotic cells.
- Their nuclear material lies in a free region known as a nucleoid e.g. in bacteria. They were probably the first organisms on earth
- The cell has no distinct nucleus. The nucleoplasm appears scattered in the cytoplasm or the nuclear materials e.g. DNA.
- The cell lacks a nuclear membrane.
- The hereditary material is a single "naked" DNA molecule without the proteins that are associated with DNA.
- The cell walls of bacteria, when present are constructed from **peptidoglycans,** a polysaccharide-protein molecule.

- Prokaryotic ribosomes are smaller(70s with 50s AND 30s subunits) than those of eukaryotes(80s with 60s and 40s subunits)
- Each cell has got very few cell organelles (cell parts) e.g. they do lack the chloroplasts and mitochondria.
- The cell has a single circular chromosome in the form of a ring, of Deoxyribonucleic Acid (DNA) in the cytoplasm, not contained in a nuclear membrane
- Duplication of the chromosomes occurs but not on the spindle i.e. their cells are capable of multiplication
- They are extremely small, ranging in size between 1-10milimetres in diameter
- Flagella, when present in prokaryotes are not constructed of microtubules

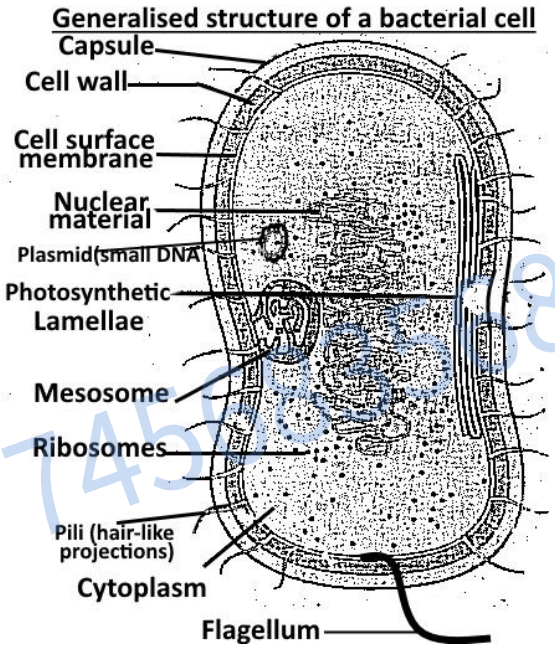
Examples include bacteria and cyanobacteria i.e. first organisms on earth.

THE ROLES OF BACTERIAL CELL COMPONENTS

A. Structures always present

1. Cell wall

The bacterial cell wall is rigid and strengthened by the presence of molecule consisting of parallel polysaccharide chain cross –linked at regular intervals by short amino chains



The cell wall is a physical barrier which;

i. Protects against mechanical damage
ii. Prevents the cell bursting when it takes in water osmosis.
iii. Allows entry of some substances, such as water ion and small molecules.

2. Cell surface membrane

The cell membrane has the same structure and function as in eukaryotic cells.

It also acts as the site of some respiratory enzymes.

Differentially permeable layer which controls entry and exit of chemicals;

3. Ribosomes

Prokaryotic have 70S ribosomes which are slightly small than the 80S eukaryotic ribosomes.

Ribosomes are sites of protein synthesis.

4. Circular DNA

The DNA comprises a single circular molecule possessing the genetic information needed to replicate new cells.

5. Food reserves (glycogen granules and lipid droplets)

Food reserves include stored glycogen and lipid

6. Cytoplasm

Prokaryotic cytoplasm contains few organelles

7. Flagellum

For movement of bacterium because it's rigid, corkscrew shape and rotating base helps the cell spin through fluids. It's a simple structure used for locomotory purposes.

8. Pili (Fimbriae)

The pili are numerous, fine, protein rods projecting from the walls of some bacteria.

- The pili are for attachment to specific cells or surface.
- The F plus is involved in sexual reproduction.

9. Capsule

Capsules are slimy or gummy secretions of some bacteria.

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- In some cases, the capsular secretions unite bacteria into colonies.
- Capsules enable bacteria to stick to surfaces such as rocks and mud.
- Offer additional protection such as from phagocytes.

10. Plasmids

Plasmids are small, self-replicating strands of extra DNA plasmids possess only a few genes and are generally concerned, survival in adverse conditions.

Plasmid genes are known to;

i) Confer resistance to antibiotics
ii) Confer resistance to disinfectors
iii) Cause disease
iv) Are responsible for fermentation of milk to cheese by lactic acid bacteria.
v) Confer the ability to use complex chemicals such as hydrocarbons as food.

11. Mesosomes

Mesosomes are intense inholdings of the cell surface membrane.

- Are sites of respiration.i.e provide large surface area for attachment of respiratory enzymes
- Involved in cell division and DNA replication

12. Photosynthetic membranes /Photosynthetic lamellae

Photosynthetic bacteria possess sac-like, tubular or sheet like inholdings of a cell surface membrane containing photosynthetic pigments like bacteriochlorophyll and enzymes for photosynthesis.

13 Membrane for nitrogen fixation

14. Spores

Some bacteria form end spores (spores produced inside cells).the spores are thick-walled, long lived and extremely resistant particularly to heat, drought and short wave radiations.

ADAPTATIONS OF BACTERIA

- Capsules and slimy layer/gummy secretions make them less susceptible to phagocytosis by white blood cells
- Cell wall rigid due to peptidoglycan/murein for support/ prevent osmotic shocks/ Gram negative bacteria have lipid-rich layer covering murein which confers resistance to antibiotics
- Flagellum long to propel the bacteria along
- Pili/Fimbriae for cell to surface attachment providing support/cell to cell attachment forming colonies
- Sex pilus sexual reproduction/conjugation
- Mesosomes in folding of the plasma membrane, housing enzymes for respiration/aid in the formation of the new cross wall/facilitates the separation of the two daughter molecules of DNA
- Photosynthetic sacs tubular/sheet-like containing photosynthetic pigments for photosynthesis
- Circular DNA containing genes which control the activities of the cell
- 70s Ribosomes; sites for protein synthesis
- Production of large quantities of spores which results into rapid multiplications
- Endospores thick walled extremely resistant to harsh condition
- Plasmid extra- chromosomal DNA which confers ability to antibiotics resistance/ use of hydrocarbons/sexual reproduction/ conjugation;
- Small in size decreases nutrient requirements/increasing surface area for diffusion of nutrients into the cell

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EUKARYOTIC CELLS (true cells ("eu"-true, "karyo"- nucleus))

These are cells whose nuclear material is enclosed by the nuclear membrane. These cells have several organelles more than the prokaryotic cells.

An organelle is a minute structure within a plant or animal cell that has a particular function, e.g. mitochondria, chloroplasts, nucleus etc. The organelles of the eukaryotic cells include; the nucleus, mitochondria, centriole, endoplasmic reticulum, etc

THE STRUCTURE OF EUKARYOTE CELLS

There are two main types of **eukaryotic** cells; the **plant cell and the animal cell**.

These are cells with a true nucleus. Their nuclear materials are found inside the nucleus surrounded by two membranes. They probably evolved about 1000 million years ago, 2 million years after the prokaryotes.

- The cell has a nucleus separated from the cytoplasm by its nuclear membrane
- The nucleus contains chromosomes in which DNA occurs
- The cytoplasm is compartmentalized by membranes into regions called organelles e.g. endoplasmic reticulum, mitochondria and chloroplast.
- The cells are 10-100µm in diameter
- The cell wall, when present, usually includes cellulose or chitin.

A COMPARISON OF PROKARYOTES AND EUKARYOTES

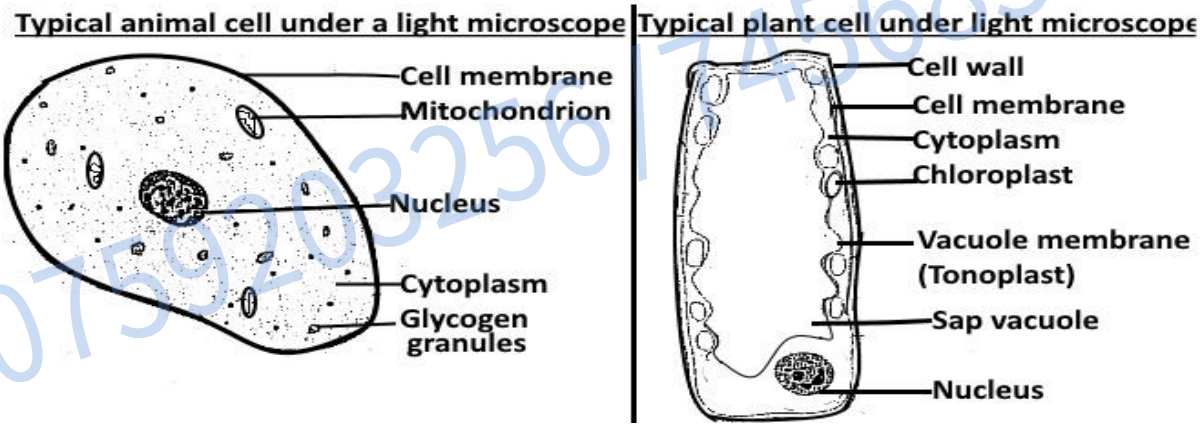
Prokaryotes	**Eukaryotes**
The prokaryotes include bacteria and blue green bacteria	The eukaryote include protoctists, fungi and animals.
Prokaryotic cells are smaller cells with a average diameter 0.5 – 10um	Eukaryotic cells are bigger with average diameter of 10-100um
Prokaryotes are mainly unicellular	Eukaryotes are mainly multicellular except protoctists which mainly unicellular.
Prokaryotes evolved 3.5 thousand million years ago	Eukaryotes evolved from prokaryotes 1.2 thousand million years ago.
Prokaryotic cells divide mostly by binary fission with no spindle formation	Eukaryotic cells divide by either mitosis, meiosis, or both with formation of a spindle
The DNA is circular and lies free in the cytoplasm hence lack a true nucleus	The DNA is linear and is contained in a true nucleus.
The DNA is naked (not associated with proteins or RNA to form chromosomes	The DNA is associated with proteins and RNA to form chromosomes
Possess smaller 70S ribosome's	Possess larger 80S ribosomes
Possess no endoplasmic reticulum hence possess 3 ribosome's	Ribosomes may be attached to endoplasmic reticulum forming rough endoplasmic reticulum (RER)
Possess few organelles	Possess many organelles
Internal membranes are scarce	Possess numerous organelles bound by single membranes such as Golgi apparatus lysosomes, vacuoles, micro bodies ER.
Possess no double membrane organelles	Possess double membrane organelles such as nuclei mitochondria chloroplasts

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Possess rigid cells walls containing polysaccharides with amino acids and strengthen with murein	Green plants and fungi possess rigid cell walls containing only polysaccharides and strengthened with cells lose in plant cell walls and chitin in fungal cell walls. Animal cells lack cell walls.
Flagella (if present) a simple lack microtubules and are extracellular (not enclosed by the cell surface membrane	Flagella (not present) are complex have microtubules with a '9+2' internal fibre by the cell surface membrane arrangement and are intracellular.
Possess smaller flagella with 20nm diameter	Possess bigger flagella with 200nm diameter
Respiration occurs on mesosomes in bacteria and on cytoplasmic membranes in blue green bacteria	Aerobic respiration occurs in mitochondria
Photosynthetic prokaryotes lack chloroplasts and photosynthesis occurs on unstacked photosynthetic membrane	Photosynthetic eukaryotes possess chloroplasts which contain photosynthetic membrane stack into lamellae or grana.
Some prokaryotes can fix nitrogen	No eukaryotes can carry out nitrogen fixation.

CELLS AS SEEN WITH THE LIGHT MICROSCOPE

A light microscope is the microscope that uses light as a source of radiation.



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Note: **A generalized cell** is a cell which shows all the typical features found in a cell.

Description of the generalized structure of a cell.

A cell is a small unit of living protoplasm, always surrounded by a cell surface membrane and sometimes by a non-living cell wall as in plants and fungi.

The most conspicuous structure in the cell is the nucleus which contains chromatin. Chromatin is the loosely coiled form of chromosomes.

Chromosomes contain genetic material in a form of DNA

The living material between the nucleus and the cell surface membrane called cytoplasm.

Contains organelles (distinct part of cell with particular function)

The c**ytoplasm** contains organelles

An organelles is a distinct part of a cell which has a particular structure and function.

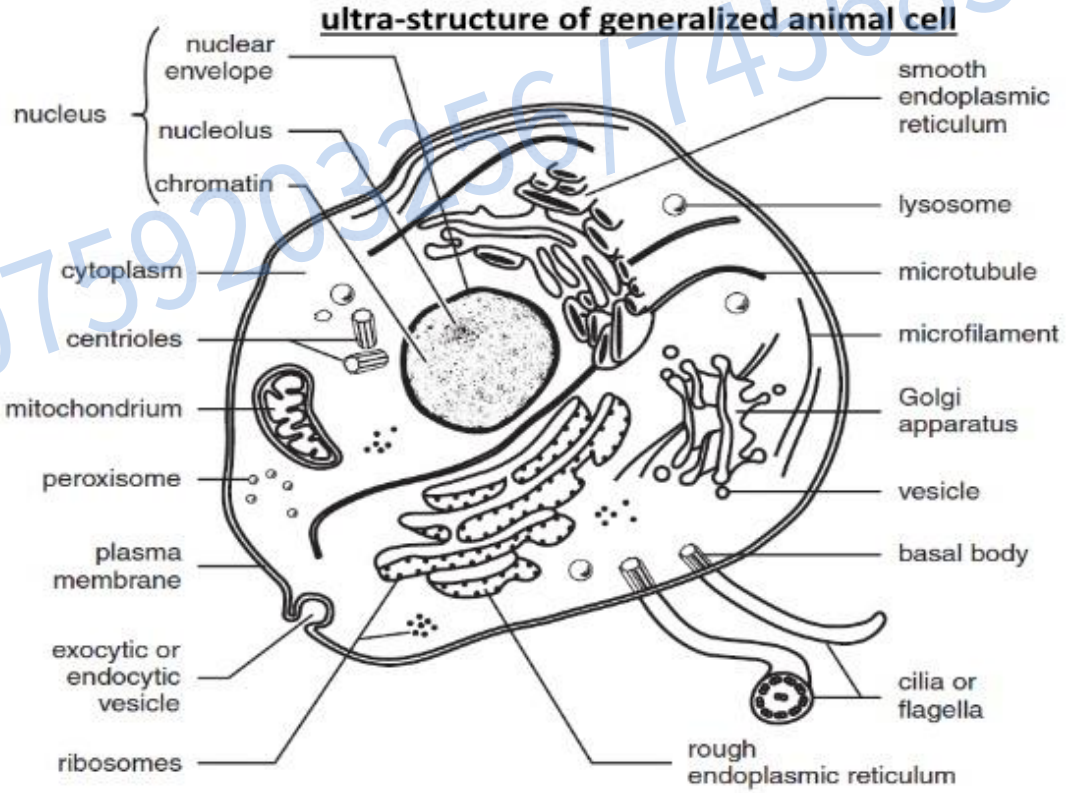
Plant cells are similar to animal cells but have more structures such as;

Cell wall outside the cell surface membrane, chloroplasts in photosynthetic plant cell and a large central vacuole

DIFFERENCES BETWEEN A BACTERIAL CELL AND A HIGHER PLANT CELL.

Bacterial cell	**Higher plant cell**
Has no distinct / true nucleus	Has a distinct/ true nucleus
DNA not incorporated in chromosomes	DNA incorporated in chromosomes
DNA is circular	DNA is linear
No spindle is formed during cell division	A spindle is formed during cell division
Few organelles	many organelles
Lacks organelles surrounded by two membranes envelope	Has organelles surrounded by 2 membranes.
Cell wall made of amino acids and polysaccharides strengthened by murein	Cell wall made of polysaccharides strengthened by cellulose.
Smaller average diameter 0.5 to 10um	Large average diameter 10-100um
No chloroplasts –photosynthesis occurs on unstacked membranes	Has chloroplasts containing membranes stacked into lamellae or grana
Some can fix nitrogen	Non can fix nitrogen
Respiration occurs on mesosomes in bacteria and cytoplasmic membranes in blue green bacteria.	Aerobic respiration occurs in mitochondria, and anaerobic respiration occurs in cytoplasm.
Some have flagella	Non has flagella
Has smaller 70S ribosome's	Has larger 80S ribosomes
Divide by binary fission mostly	Divide by mitosis, meiosis or both.

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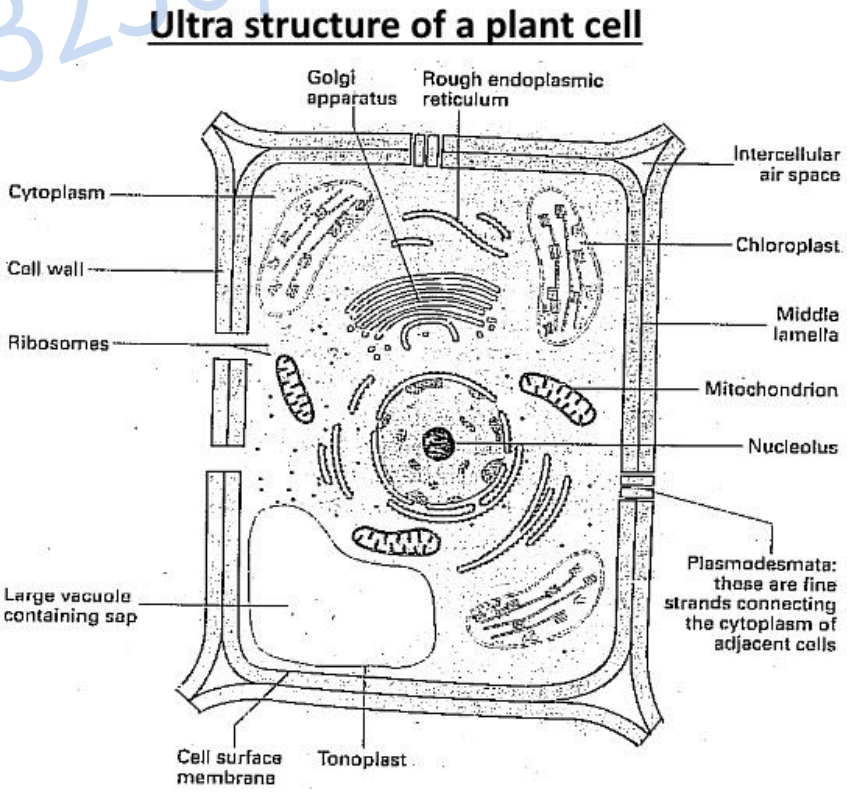


Plant cells	Animals cells
Have a tough, slightly elastic cellulose cell wall outside the cell surface membrane	Have no cell wall only a cell surface membrane surrounds the cell
Have pits and plasmodesmata in the cell wall.	Have no cell wall and thus have no pits and plasmodesmata
Have middle lamellae joining the cell walls of adjacent walls	Middle lamellae are absent; the cells are joined by intercellular cement.
Possess plastics such as chloroplasts	Lack plastids
Mature cells possess a large, single , centriole vacuole filled with cell sap	Possess only small vacuoles scattered throughout the cell.
The cell vacuole is enclosed by tonoplast	Vacuoles lack tonoplast
Have a thin layer of cytoplasm confined at the edge of the cell	Having much cytoplasm spread throughout the cell.
The nucleus is located at the edge of the cell	The nucleus is usually placed centrally in the cell
Higher plant cells lack centrioles	Possess centrioles
Higher plant cells lack cilia and flagella	Often possess cilia and flagella.
Store food as starch grains	Store food as glycogen grains
Only some cells are capable of division	Almost all cells are capable of division
Only some cells are capable of division	Almost all cells are capable of division
Plant cells produce few secretion	Animal cells produce a wide variety of secretions
Have a regular (definite) shape	Have an irregular shape.

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Note: The fine structure of the cell as seen with the electron microscope is known as the ultra-structure.

THE STRUCTURE FOUND IN CELLS



1. THE CYTOPLASM

Cytoplasm together with the **nucleus** form the living part of the cell called the **protoplasm.** The cytoplasm is a jelly-like material, surrounding the nucleus of a cell, which largely consists of an aqueous 'ground substance', called **cytosol (hyaloplasm).**

Cytosol may be a solution or colloidal suspension of many vital cellular chemicals.

A colloidal solution is the false solution which consists of two phases, i.e. the dispersion medium or continuous phase of water, in which the small particles, known as the disperse phase, are permanently suspended.

Sols are non-viscous dispersions of small particles, permanently in a liquid disposed in water.
Gels are viscous colloids in which both dispersed and continuous phase have a 3-dimensional network, throughout the material, so that it forms a jelly-like mass, e.g. gelatin.
In the cytosol some materials which include water, salts, sugars, amino acids, vitamins, dissolved gases, nucleotides, fatty acids etc. are stored. Some large molecules e.g. proteins exist there, in form of a colloidal solution, which could **be a sol** (non-viscous), or **a gel** (viscous). The **sol** always occupy the central region, while the outer regions of the cytoplasm are occupied by the gel e.g. in Amoeba.
Functions

- **Cytosol also** serves as a site where the metabolic processes take place from.
- It also participates in the transportation of materials from one part of the cell to another.
- The cytosol is the soluble part of the cytoplasm, in which a network of fine strands of globular proteins known as microfilaments and **microtubules forming the cytoskeleton** of the cell is suspended.
- The cytoplasm is capable of mass flow in a process known as **cytoplasmic streaming** in sieve tube elements.
  Cytoplasmic streaming which is the active mass movement of the cytoplasm, in a particular direction. It is so common in cells e.g. young sieve tube elements. These include ions such as sodium, phosphates and chlorides, organic molecules such as amino acids ATP, acids nucleotides vitamins **Or** Dissolved gases and storage material such as oil droplets.
- Store of vital materials such as salts/sugars/ions/vitamins
- Ground substance is a site for metabolic pathway e.g. glycolysis/synthesis of fatty acids/nucleotides/amino acids
- Cytosol also contains free ribosomes often in the polysomes form. They contain many different types of proteins and ribosomal RNA or r-RNA.

2. **CELL SURFACE MEMBRANE (PLASMA MEMBRANE)**
Observations from the electron microscope revealed that the plasma membrane is not just a simple membrane but contains micro structures that relate to its functions. The plasma membrane serves as a bounding between the cells and its environment.
This is a **partially or semi-permeable** membrane, forming the outer limit of a cell. The membrane being partially permeable it permits different substances to pass across it at different rates.
The materials which penetrate the membrane, include, water, gases, salts, glucose, amino acids, fatty acids, glycerol, also organic solvents e.g. alcohol, ether, chloroform can penetrate through the membrane.

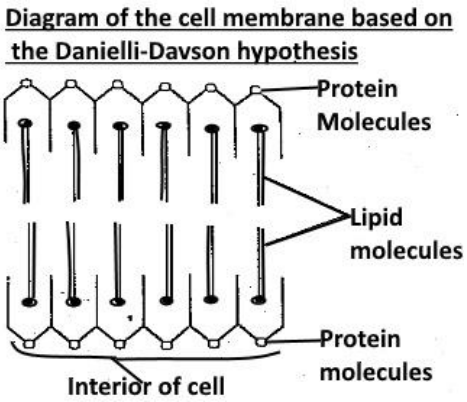
The electron microscope has revealed that the plasma membrane is mainly composed of **proteins and lipids**. The lipids are mainly phospholipids, glycolipids, and sterols. Phospholipids (i.e. a lipid with a phosphate groups) have a polar (water-loving) head and two non-polar (water-hating) tails. Glycolipids are lipids combined with carbohydrate, which also have polar heads and non-polar tails. Steroids are mainly of the cholesterol.
The hydrophobic tails of phospholipids project inwards towards the centre of the membrane, while the hydrophilic heads are located at the periphery.
The **phospholipids** occur in two layers called the **biphospholipid layer** or bimolecular layer of phospholipids. Plasma membranes include the cell surface membrane, nuclear membrane, and tonoplast, membranes of the endoplasmic reticulum, plastids and other organelles.
The mode of arrangement of the plasma membrane components were explained **by two theories** which include;

a) **Protein-phospholipids sandwich – theory (by Davison and Danielle).**
b) **Fluid-mosaic model (by J.J Singer and G.L Nicholson).**

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a) DAVISON AND DANIELLE PROTEIN-PHOSPHOLIPID SAND-WICH THEORY

Davison and Danielle proposed that the cell membrane is composed of protein molecules on either sides of the bimolecular layer of lipids, which occur in form of phospholipids, glycolipids and sterols, rather like bread on either sides of a sandwich. Each lipid is molecule is composed of a hydrophilic head projecting towards the periphery, with two hydrophobic tails, associating with one another, and extending towards the centre of the membrane cytoplasm. In this kind of arrangement, both the lipids and proteins are solids, incapable of movement and serve the role of the structural support of the membrane, as shown by the **diagram.**



THE FLUID MOSAIC MODEL OF THE CELL MEMBRANE.

The model consists of a bimolecular phospholipid layer with inwardly directed hydrophobic (water hating) tails and outwardly directed hydrophilic heads and a variety of proteins with an irregular arrangements (mosaic pattern).

Each phospholipids molecule consists of a polar hydrophilic head containing phosphates and two non-polar hydrophobic hydrocarbon tails from the fatty acids used to make the molecule.

There are three main forms of protein in the membrane dotted about in the cell membrane;

Peripheral or extrinsic proteins occurring on the surface of the phospholipids bi layer.

Integral or intrinsic proteins extending into the phospholipids bi-layer and Trans-membrane proteins extending completely across the membrane.

In addition, the membrane contains glycoproteins, glycolipids and cholesterol.

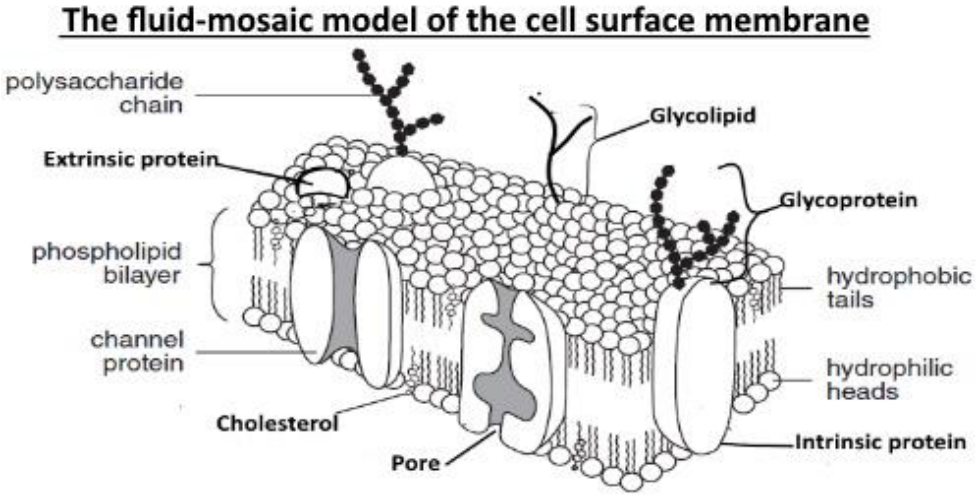
The **glycoproteins** consist of an outward branching carbohydrate portion combined with a globular protein.

The **glycolipids** comprise a branching carbohydrate portion attached to a phospholipids, but the glycolipids are less common than the glycoproteins.

Cholesterol is a steroid and is thus closely related to lipids and slightly polar at one end.

The phospholipids bi layer is capable of much movement and is thus fluid.

And the protein are dotted throughout the fluid phospholipid bi layer in a mosaic arrangement hence the name **fluid mosaic model.**

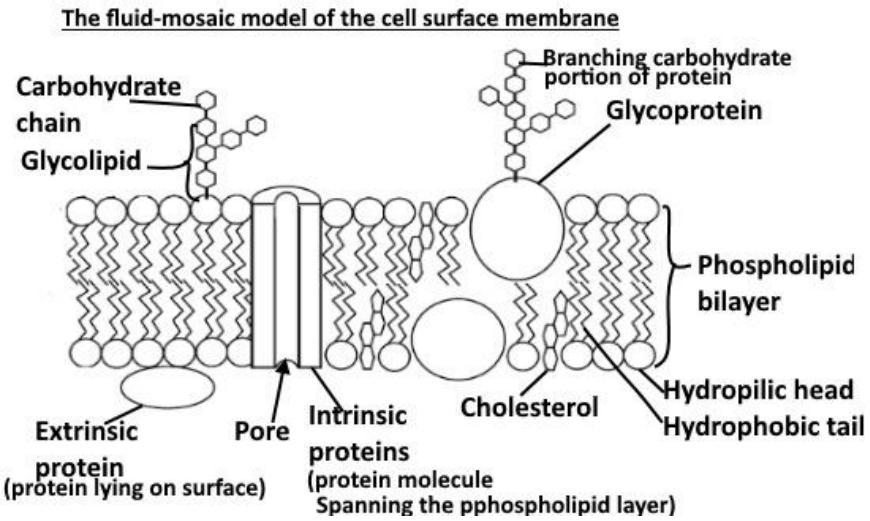


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Summary of *fluid mosaic model the plasma membrane consists of*

A bimolecular *phospholipid heads. This phospholipid layer is capable of much molecular movement, i.e. is fluid in nature.*

A variety of globular *protein molecules with an irregular arrangement within the bimolecular phospholipid layer. Some proteins occur on the surface of the phospholipid layer (peripheral or extrinsic proteins) while others extend into it (integral or intrinsic proteins) and some even extend completely across (transmembrane proteins). Viewed from the surface, the proteins are dotted throughout the phospholipid layer on a mosaic arrangement. Hence the name fluid-mosaic* model.



THE RELATIONSHIP BETWEEN THE STRUCTURE OF THE CELL MEMBRANE AND ITS FUNCTIONS.

The fluid mosaic model of the cell membrane is closely related to its functions in these ways;

(i)The **phospholipid**s are fluid and move about rapidly by diffusion in their own layers. The fluidity of the membrane depends on the relative proportion of the saturated and unsaturated fatty acid tail. Unsaturated tails bend and fit together more loosely therefore the more unsaturated the tails are the more fluid the membrane is. Fluidity ensures that the membrane does not easily break down and if flexible.

(ii)The non- **polar hydrophobic tails** of the phospholipids affect the permeability of the membrane especially to polar molecules such as glucose and amino acids. The membrane thus presents a barrier to the movement of ions and polar molecules which are repelled by the hydrophobic tails of phosphor lipids. This prevents the aqueous content of the cell from escaping.

(iii) Like unsaturated fatty acids cholesterol disturbs the close packing of phospholipids and keeps them more fluid. Actually it makes the membrane less fluid at higher temperature and more fluid at lower ones. This is of great importance to organisms of low temperature when membranes can solidity.

(iv) **Cholesterol** being largely non-polar acts like a plug, reducing further the escape or entry of polar molecules through the membrane.

(v) Since cholesterol disturbs the close packing of the phospholipids allowing greater fluidity it thus increases the flexibility and stability of the membrane without cholesterol membranes break up.

(vi) **Glycolipids** have branching carbohydrate side chains acting as 'antennae' marking specific cell. They act as cell to cell recognition sites e.g. the ABO blood system as a result of the different glycolipids on the cell membrane of red blood cells. This makes specificity of the glycolipid carbohydrate chain also enables them act as receptor sites for chemical signals such as hormones.

(vii) In addition, together with glycoproteins, glycolipids are involved in sticking the correct cells together in tissue during tissue formation.

(viii) **Glycolipids** also help make the membrane more stable.

(ix) Channel proteins and carrier proteins are involved in the selective transport of polar molecules and some across the membrane. This is done through facilitated diffusion and active transport.

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(x) Some **proteins act as enzymes** e.g. the microvilli on the epithelial cell lining some parts of the gut contain digestive enzymes in their cell surface membrane.
(xi) **Proteins have very specific shapes** owing to the specificity of their surface configuration. They therefore act as ideal receptors molecules for chemical signaling between cells. The protein act as recognition sites for the reception of body chemical signals like hormones and neurotransmitters.

(xii) In photosynthesis and respiration membrane proteins take part in the energy transfer systems that exist in the membranes of chloroplasts and mitochondria respectively and there the protein act as energy transducers and electron carriers.
xiii) The various proteins dotted throughout the **phospholipid bilayer provide structural** support for the cell membrane.
(xiv) **Glycoproteins act as antigens**. Since their branching carbohydrate, side chains and act like cell identify marking antennae. The enormous number of possible chain shapes, means that each cell can have its own specific markers. This enables cell to cell recognition allowing cells to behave in an organized way e.g. during development of tissue and organisms in multi cellular bodies.
(xv) The **marking by glycoprotein** also serve as receptors sites for chemical signals such as hormones and neurotransmitters.
(xvi) The cell membrane is only about 7nm wide. This thinness allows faster diffusion and osmosis across the membrane.
Non protein components of the cell surface membrane and their uses include

- The phospholipids affect the fluidity and permeability of the membrane.
- Cholesterol makes the membrane less fluidly at high temperatures, but fluidier at lower temperatures, that is, serves to restrict movement and therefore stabilizes the membrane structure.
- Glycolipids acts as recognition sites, e.g. the human ABO blood system is the result of different glycolipids on the cell membrane of the red blood cells. They also participate in making the membrane more stable. .
- Cholesterol molecules distributed throughout the phospholipid bilayer provide some rigidity to the plasma membranes of animal cells. In plant cells, related substances (Sterols) provide a similar function.

The **glycocalyx is a carbohydrate "coat"** covering the outer face of the plasma membrane. It consists of various oligosaccharides that are attached to membrane phospholipids (**glycolipids**) and proteins (such as the **glycoproteins** of recognition proteins).

Roles of glycocalyx

- The glycocalyx provides markers for cell-cell recognition.
- Functioning as receptor sites for chemical signals such as hormones
- Binding cells together into tissues
- carbohydrates are negatively charged so limit entry and exit of negatively charged substances

Organelles *are bodies within the cytoplasm that serve to physically separate the various metabolic reactions that occur within cells.*

Exercise: a) Describe structure of the cell membrane according to the fluid mosaic model (10 marks)
(b) Explain the role of the plasma membrane in exocytosis and endocytosis (5 marks)
c) Explain role of proteins with in the plasma membrane.

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A summary of the role of proteins with in the plasma membrane

(i) Anchoring cells

Membrane proteins anchor cells to the outside membrane and also to micro filaments within the cell.

(ii) Transport

Membrane proteins form channels that allow selective passage of ions or molecules e.g. carrier proteins during facilitated diffusion. Some carrier proteins pump solutes across membranes by active transport.

(iii)Enzymatic activity

Some membrane proteins are enzymes that catalyze reactions that place within or along the surface of the membrane.

iv) Signal transduction

Receptor proteins bind with signal molecules such as hormones and neurotransmitters, and transmit information into the cell.

(iv)Cell recognition

Proteins act as identification tags for cells

(v)Junctions between cells

Cell adhesion proteins attach membranes of adjacent cells.

(vi)Energy transducers and election carriers

In photosynthesis and respiration, membrane protein take part in energy transfer.

Vii) Structural support

The various proteins dotted throughout the phospholipid bilayer support structural support to the cell membrane.

Adaptations of the cell surface membrane

- Phospholipid molecules give the membrane fluidity
- Arrangement of non-polar hydrophobic tails and polar hydrophilic head of phospholipids affects permeability making the membrane selectively permeable
- Cholesterol disturbs close-packing of phospholipids making membranes less fluid at higher temperatures and more fluid at lower ones.
- Cholesterol is non-polar thus reduces escape or entry of polar molecules through the membrane
- Membrane cholesterol increases flexibility and stability of the membrane prevent membranes breaking up.
- Carbohydrates side chains of glycolipids act as antennae marking specific cells, this enables cell-cell recognition as in the ABO blood system.
- Glycolipids act as receptor sites for decimal signals such as hormones
- Glycolipids and glycoprotein are involved in sticking the correct cells together in tissues
- Channel proteins and carrier proteins transport polar substances across the membrane through facilitated diffusion and active transport
- Some membrane proteins act as enzymes making the membrane metabolically active
- Some membrane proteins act as receptor sites for body chemical signals like hormones and neurotransmitters during coordination
- Some proteins act as energy transducers and electron carriers enabling energy transfer in photosynthesis/chloroplasts and respiration/mitochondria
- Proteins dotted throughout the biphospholipid layer provide structural support to the cell membrane.
- Carbohydrate side chains of glycoproteins act as cell-marking antennae enabling cell-cell recognition during tissue development.

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- Glycoprotein act as antigen recognition sites for recognition of foreign bodies during immune responses
- Glycoproteins act as receptor sites for chemical signals such as hormones and neurotransmitters during nervous and hormonal coordination.
- Cell membrane is very thin (approx. 7 mm) for fast diffusion of materials across

How phospholipid properties maintain cell membrane structure

1. Hydrophilic / hydrophobic layers restrict entry/ exit of substances.
2. Phospholipids are held together by hydrophobic interactions
3. Phospholipid layers are stabilized by interaction of hydrophilic heads and surrounding water
4. Phospholipids with short fatty acids and those with unsaturated fatty acids are more fluid. Fluidity is important in breaking and remaking membranes (e.g. endocytosis / exocytosis)
5. Phospholipids can move about / move laterally (horizontally) / "flip flop" (move transversely) to increase fluidity
6. Phospholipids allow for membrane fluidity/ flexibility. Fluidity/ flexibility enables membranes to be functionally stable

Note: The fluid mosaic model was proposed in the 1970s by S.J Singer and G.L Nicholan as a modification of an earlier proposed model by J.F Danielli and H. Davison of the 1930s called the sandwich model.

A COMPARISON OF THE DANIELLI-DAVISON AND SINGER NICHOLSON (FLUID MOSAIC MODEL) MODELS OF THE CELL MEMBRANE.

A. Similarities

(i) Both comprise a bimolecular layers of phospholipids.
(ii) Both contain protein molecules.
(iii) In both, the phospholipids possess hydrophilic heads and hydrophobic tails.
iv) In both the phospholipids tails extend towards while the heads lie at the periphery.
v) In both, the main structural skeleton of the membrane comprises lipids and proteins.

Differences

Danielli- Davison model (sand witch)	**Singer- Nicholson (fluid mosaic)**
Proteins regularly arranged to form a continuous layer covering both sides of the membrane	Proteins arranged irregularly in a mosaic pattern
Proteins lie on the surface and do not get in the membrane	Some globular proteins lie on the surface, some extend into the lipid layer to varying degrees and others extend throughout both layers
Lipids and proteins are rigid and cannot move	Lipids and proteins capable of much movement like a fluid
Protein molecules are of the same size	Protein molecules are of different sizes
Proteins lack pores	Some proteins have pores
All proteins are for structural support only	Proteins may be structural carries, channels or enzymes

Functions of the unit membrane

1) Surface membrane forms a protective barrier between cell contents and external environments, and determines the shape of the cell.
2) They form membrane organelles e.g. mitochondria, chloroplasts e.t.c.
3) Membranes are selectively permeable and regulate movement of substances in and out the cell
4) Some membrane proteins act as enzymes e.g. ATP synthase

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5) Cell surface receptor proteins are involved in signal-transduction
6) Some membrane proteins act as electron carriers in the electron transport chain
7) Glycoproteins with branching oligosaccharides act as antigens
8) Glycolipids are involved in cell-cell recognition
9) Folding of cell membranes enables the cell to carry out phagocytosis and pinocytosis which enables the cell to obtain nutrients or to engulf and destroy foreign particles.
10) Folding of membranes also increases the surface area for reactions e.g. the epithelium villus of the ileum
11) Cell adhesion proteins join cells together forming tissues which carry out specific functions
12) Cholesterol molecules stabilize the membrane structure and reduce entry or exit of polar molecules through the membrane

Membrane proteins

- **Channel proteins** provide passageways through the membrane for certain hydrophilic (water-soluble) substances such as polar/charged molecules
- **Transport proteins**/PUMPs spend energy (ATP) to transfer materials across the membrane. When energy is used for this purpose, the materials are said to be *actively* transported, and the process is called **active transport**.
- **Recognition proteins** distinguish the identity of neighboring cells. These proteins are **glycoproteins** because they have short polysaccharide chains (oligosaccharides) attached. The oligosaccharide part of the glycoprotein protrudes from the surface of the membrane like an antenna
- **Adhesion proteins** attach cells to neighboring cells/provide anchors for the internal filaments and tubules that give stability to the cell
- **Receptor proteins** provide binding sites for hormones or other trigger molecules. In response to the hormone or trigger molecule, a specific cell response is activated.
- **Electron transfer proteins** are involved in transferring electrons from one molecule to another during chemical reactions
- **Integral proteins** provide the structural integrity of the cell membrane
- Enzymes catalyzing specific chemical reactions in membranes
- **Carrier proteins;** having receptor sites for binding of molecules to be transported eg glucose;

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Roles played by proteins within plasma membranes

- They provide structural support for the membrane. By various forms of molecular interactions, they help to anchor the phospholipid bimolecular layer.
- They assist in active transport of materials across the membrane by acting as channels through which especially hydrophilic materials pass.
- In combination with carbohydrates, as glycoproteins, they act as recognition sites.
- They act as enzymes, catalyzing many membrane-associated reactions.
- They facilitate diffusion by acting as carries and channels.
- They act as energy transducers. For example, proteins of the election transport system in mitochondria.
- They act as election carriers in many redox reactions.

Molecules and ions can pass through the plasma membrane in four ways:

a) **Directly through the phospholipid membrane**. Molecules that are soluble in lipids, such as oxygen, carbon dioxide, and steroids, pass through the plasma membrane readily by dissolving in the lipid bilayer. The phospholipid bilayer acts as a barrier to most substances that are not lipid-soluble; but certain small, nonlipid-soluble molecules, such as water, carbon dioxide, and urea, can diffuse between the phospholipid molecules of the plasma membrane.

b) **Membrane channels**. There are several types of protein channels through the plasma membrane. Each channel type allows only certain molecules to pass through it. The size, shape, and charge of molecules determines whether they can pass through a given channel. For example, sodium ions pass through sodium channels, and potassium and chloride ions pass through potassium and chloride channels, respectively. Rapid movement of water across the cell membrane apparently occurs through membrane channels.

c) **Carrier molecules**. Large polar molecules that are not lipidsoluble, such as glucose and amino acids, cannot pass through the cell membrane in significant amounts unless they are transported by carrier molecules. Substances that are transported across the cell membrane by carrier molecules are said to be transported by carrier-mediated processes. Carrier proteins bind to specific molecules and transport them across the cell membrane. Carrier molecules that transport glucose across the cell membrane do not transport amino acids, and carrier molecules that transport amino acids do not transport glucose.

d) **Vesicles**. Large non lipid-soluble molecules, small pieces of matter, and even whole cells can be transported across the cell membrane in a vesicle, which is a small sac surrounded by a membrane. Because of the fluid nature of membranes, the vesicle and the cell membrane can fuse, allowing the contents of the vesicle to cross the cell membrane

FACTORS AFFECTING FLUIDITY OF THE PLASMA MEMBRANE

- Temperature high temperature increases fluidity low temperature decreases fluidity
- Length of fatty acids fluidity increases with decreasing length long chain decreases
- Fluidity longer chain increases surface area for interactions between adjacent chains increasing vandarwaals forces of attraction
- Unsaturated fatty acids have kinks in the fatty acid tails which prevents close packing hence increasing fluidity saturated fats lack kinks ;close packing decreasing fluidity
- Cholesterol between phospholipids inhibits close packing/ at high temperature decreases fluidity low temperature increases fluidity

HOW CELL MEMBRANE CHOLESTEROL MAINTAINS FLUIDITY

Cholesterol molecules orient themselves in the lipid bilayer in such a way that their hydroxide groups remain close to polar head groups of the phospholipids; their rigid plate-like steroid rings interact with and partly immobilize those regions of hydrocarbon chains that are closet to the polar head groups, leaving chains flexible; cholesterol inhibits phase transition by preventing hydrocarbon chains from coming together and crystallizing.

Cholesterol also tends to decrease the permeability of lipid bilayer to small water-soluble molecules and is thought to enhance both the flexibility and the mechanical stability of bilayer

MEANING OF THE PHRASE —FLUID MOSAIC MODEL

Fluid because molecules within membrane can move around within their own layer

Mosaic because protein molecules are dotted around within the membrane

Model because no one has seen membrane looking as a diagram and hence it's a representation

ROLE OF CELL MEMBRANE IN MOVEMENT OF MATERIALS ACROSS IT

- Selective barrier allowing passage of specific molecules into cells
- Establishment of concentration gradient determining direction of movement of materials/substances
- Carrier/channel proteins for movement of materials into and outside cells
- Receptors for binding of materials which have to be moved inside cells
- Non-polar to allow movement of non- polar materials e.g steroid hormones

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- fluidity/flexibility to allow movement of transport proteins spanning the membrane easily/phagocytosis possible
- Stability to avoid collapse of membrane
- Membranes budded off forming vesicles during endocytosis to move materials inside cells
- Flexible and fluidity to fuse with other membranes to allow transport of materials
- Microvilli increasing surface area for absorption of materials to be transported

EVIDENCES FOR THE FLUID MOSAIC MODEL

- Water soluble molecules enter the cell less readily than compounds that dissolve in lipids plasma membrane has a higher proportion of lipids freeze- etching has shown when a membrane is fractured along its mid line globular proteins occurs. Some occur on, some buried in the lipid bilayer, rather than forming sheets of proteins on the surface
- Some reactions of proteins in the membrane with enzymes and antibodies have shown that some membrane proteins are exposed on the surface, some are exposed on both surfaces and some inaccessible
- Tagging of membrane components with marker substance/fluorescent dye has shown that the molecules of the plasma membrane are on the move membrane is fluid, ever changing
- At outer surface of the cell, antennae like carbohydrate molecule form complex with many membrane proteins and lipids and their presence can be shown by addition of non-self antigen to the cell

DISTRIBUTION AND FUNCTION OF MEMBRANES IN ORGANISMS

Distribution	**Functions**
Plasma membrane	• Partial permeability, allows osmosis, diffusion active transport and limits cell • Transport in and out of cell/Cell to cell • Recognition/Antigen **p**resentation/Hormonal signaling/ • Separating cytoplasm from the rest of the cell
Nuclear membrane	• Limits DNA; • Allows outward diffusion of RNA • Entry of ATP into the nucleoplasm
Mitochondria outer membrane	• allows entry of products of glycolysis
Mitochondria inner membrane	• attachment of respiratory enzymes
Endoplasmic reticulum	• Cellular transport • Attachment of ribosomes
Chloroplast outer	• Allows photosynthetic products out and substrates in
Chloroplast lamellae	• Reservoir of chlorophyll, carotenes et.c
Golgi	• Sorting of E.R, synthesized material • Storage of glycoproteins • Synthesis of polysaccharides e. cellulose in plants
lysosomes	• Limits autolytic enzymes/limits autolysis
tonoplast	• Limits cell sap
Pinocytotic/phagocytic vesicles	• Uptake of materials
Myelin sheath membrane	• Insulation of nerve fibres
Microvilli (e.g. kidney tubule)	• Increases surface area for absorption of materials
Root hairs	• Increases surface area for absorption of materials

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MEMBRANOUS ORGANELLES

The advantages of having **membrane bound organelles in eukaryote cells.**

- Internal membranes protect the genetic material (DNA) from being digested.
- Internal membranes maintain pH and temperature of internal media for reactions to proceed optimally.
- Internal membranes increase the surface area over which chemical reactions occur were the inner membranes normally occur.
- Inner membranes regulate the entry of metabolites into the cell and organelles, thereby controlling the rate of metabolic activity.
- Internal membranes protect organelles from potentially harmful reactions thereby preventing cell damage.

THE NUCLEUS

The nucleus is located in the centre of the animal cell and at the periphery of the plant cells.

The nucleus is usually the largest organelle of the cell. The nucleus is bounded by a double-layered nuclear membrane. Each layer is a unit membrane, the outer one often covered by ribosomes and continuous with the endoplasmic reticulum. Between the two layers is a perinuclear space, about 20nm wide

The nucleus controls the cell's activities because it contains the organism's genetic (hereditary) information in the form of DNA.

STRUCTURE OF THE NUCLEUS

It is the largest organelle

The nucleus is bounded by a double membrane which is perforated,

The nucleus envelope of the outer membrane is continuous with endoplasmic **reticulum (ER)** and is often covered with ribosomes carrying out protein synthesis.

The inner membrane has 3 proteins on its surface which act as for chromosomes during interphase.

The nuclear envelope is perforated by many large **nuclear pores** which allow exchange of substances between the nucleus and the cytoplasm such as messenger RNA (mRNA)

The cytoplasm –like material within the nucleus is called **nucleoplasm**

The nucleolus contains chromatin, composed of many coils of DNA bound to basic proteins called histones.

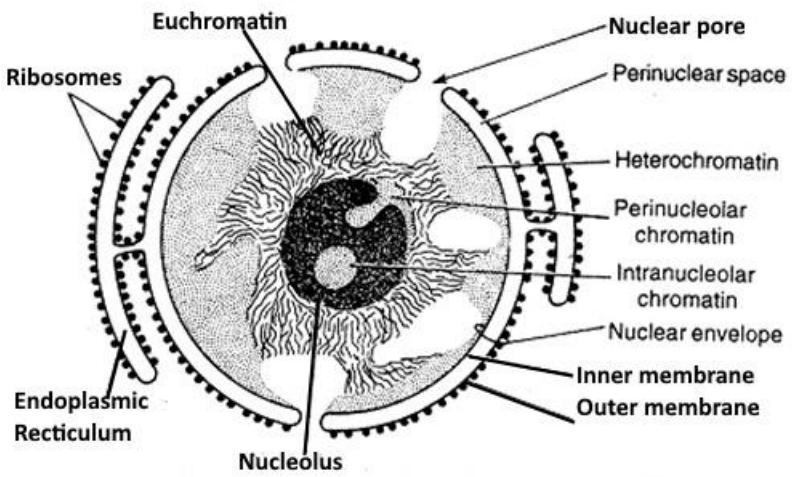
During nuclear division, chromatin condenses into more tightly coiled threads called chromosomes.

The denser more darkly staining areas of chromatin are called Hetero-chromatin. The remaining is called Chromatin.

The nucleus contains one or more small spherical bodies called n**ucleolus**/nucleoli which manufacture ribosomal RNA (rRNA) and assemble ribosomes.

The nuclear pores are plugged with globular proteins

The nucleoplasm also contains lipids, enzymes especially those involved in DNA and RNA synthesis like Na, K, Mg and P



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Functions of the nucleus

- Chromosomes contain DNA, the genetic molecule of inheritance .i.e. Stores DNA, the heredity material
- DNA is organized into genes which control all the activities of a cell
- Nuclear division is the basis of cell replication (cell division) and hence reproduction.
- The nucleolus manufactures RNA and Ribosomes which are the protein factories
- Nuclear DNA carries instructions for the synthesis of proteins i.e. Site for transcription in which messenger RNA are produced for protein synthesis.
- Controls protein synthesis, cell division, growth and differentiation.

Adaptations of the nucleus to its function

- DNA is long to store many genes
- Nuclear membrane has pores for exchange of DNA and RNA between the nucleus and cytoplasm
- Presence of nucleolus that produces ribosomes which are protein factories
- Nuclear envelope that isolates nucleus from interference by processes in cytoplasm
- Nuclear pores are narrow to regulate entry and exit of substances

PLASTIDS

These are organelles found only in cells of higher plants, which develop from small bodies called **proplastids,** located in the meristematic regions. Proplastids can give different types of plastids, which include; **Chromoplasts, Leucoplast and Chloroplasts.**

(i) **Chromoplasts**

These are non-photosynthetic coloured plastids containing mainly red, orange or yellow pigments (carotenoids). They are particularly associated with fruits and flowers, in which their bright colours serve to attract insects, birds and other animals for pollination and seed dispersal.

(ii) Leucoplasts

These are Colourless plastids, which lack pigments. They are mainly modified for food store and are so common in storage organs e.g. amyloplasts store starch, lipidoplasts store lipids and protoplasts store proteins.

(iii) Chloroplasts

Chloroplasts are plastids, biconvex in shape about 2-10um (Average 5um) in diameter, containing chlorophyll and carotenoid pigments for photosynthesis. They are found mainly in mesophyll cells. Each chloroplast is bounded by a double membrane, (chloroplast envelope).

THE FUNCTIONS OF PLASTIDS

Chloroplasts are found mainly in leaves and contain chlorophyll and carotenoids

i) Chlorophyll absorbs light energy for the manufacture of organic food in the process of photosynthesis.

ii) Carotenoids increase the range of light absorption for photosynthesis by absorbing light energy and handing it over to a molecule of chlorophyll in the photo system.

iii) Carotenoids also protect the chlorophyll molecules from damage by oxidation under the influence of high light intensity.

Chromoplasts are found in fruits and flowers and contain, red, orange or yellow pigments (and no green pigments)

iv) C**hromoplasts** provide bright colours to fruits which attract agents of dispersal such as animals and man.

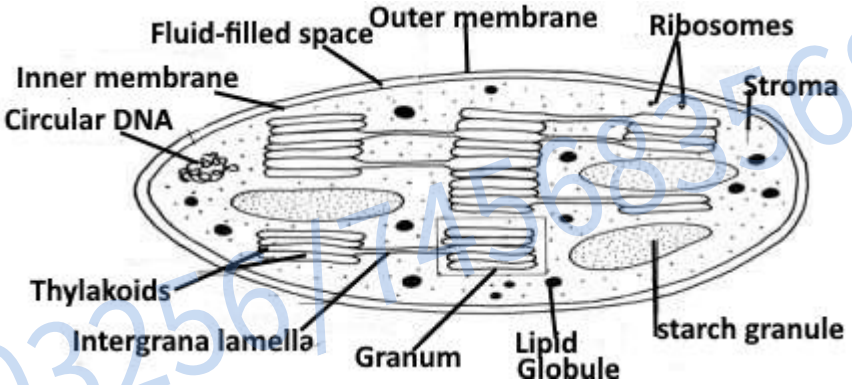
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v) **Chromoplasts** provide brought colours to flowers which attract agents of pollination such as insects, birds and bats.
vi) **Leucoplasts** are used for storage of food in storage organs such as fruits, seeds and young leaves for example leucoplasts called amyloplasts store starch.

THE STRUCTURE OF CHLOROPLAST

Each chloroplast is bounded by **two** membranes forming a chloroplast envelope about 30nm thick.
The **outer membrane** of the chloroplast is smooth, while the inner membrane is folded to give rise to rise to a series of branching layers called lamellae.
The **inner membrane** is highly selective to entry and exit of materials into and out of the chloroplast.
The chloroplast contains chlorophyll and other photosynthetic pigments located on a system of membrane. The membrane system consists of many, closed, flattened, fluid-filled sacs called **thylakoids.**
The thylakoids are stacked at intervals to form **grana** with inter-**grana lamellae** between the grana.
Each granum resembles a pile of coins, while the lamellae are sheet like.
Each chloroplast contains about 60 grana, each consisting of approximately 50 thylakoids but the diameter of granum is about 600nm.

The thylakoids are embedded in a watery, Colourless gelatinous matrix forming a ground substance called the stroma. The stroma contains enzymes, starch granules and other chemicals such as sugars and acids.



THE ADAPTATIONS OF CHLOROPLASTS FOR THEIR FUNCTIONS

- The chloroplasts within the mesophyll cells can move. This positive p**hototaxis** allows chloroplasts to arrange themselves in the best position within the cells for maximum absorption of light.
- The chloroplasts contain chlorophyll and other photosynthetic pigments, enzymes and electron carriers. These molecules form p**hotosystem**s with light harvesting complexes for the conversion of light energy into chemical energy.
- The chloroplasts hold chlorophyll and accessory pigment molecules in a structured way. The photosynthetic pigment enzymes and electron carriers are located on a system of membranes. The system comprises many , closed flattened fluid filled sacs called thylakoids which form stack called grana of intervals, inter connected by lamellae. The arrangement also ensures that the chlorophyll is in close proximity to all other molecules necessarily for its functioning.
- The chloroplast is transparent, allowing maximum absorption of light by the photo synthetic pigment. This occurs since the chloroplasts envelop is thin and the stroma is Colourless.
- The stroma contains enzymes responsible for the reduction of carbon dioxide and other chemical such as organic acids essential in the photosynthetic pathways.
- The chloroplasts envelope consists of two membranes and the inner membrane is folded into a series of lamellae and is highly selective in what it allows in and out of the chloroplast.

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- Chloroplasts of flowering plants have a biconvex shape which increases the surface area for the exposure of the photosynthesis pigments.
- It has a double membrane with an outer membrane (surface) membrane which prevents the photosynthetic reactions from mixing with those in the cell cytoplasm
- The surface membrane is permeable to gases like carbon dioxide which is a raw material for photosynthesis

Functions of the chloroplasts

It is where chemical reactions of photosynthesis take place. It should be noted that the light stage of photosynthesis occurs in the grana, whereby solar energy is used to produce, reduced Nicotinamide Adenine Dinucleotide Phosphate (NADPH) and ATP.

The stroma contains enzymes necessary for the dark reactions of photosynthesis in which NADPH carbon dioxide and ATP are used to synthesize organic compounds e.g. sugars and starch.

Note:

The circular DNA of chloroplasts, facilitate the formation of protein, inside the organelles, hence enabling it to undergo replication.

2. THE MITOCHONDRIA

Mitochondria basically act as sites for certain stages of aerobic respiration in aerobic Eukaryotic cells.

THE STRUCTURE OF A MITOCHONDRION

Mitochondria vary in shape from sausage shape, spiral, cup-shaped, branched and even highly elongated. Their length ranges from 1.5-10um and width 4 from 0.25-1.00um but their diameter does not exceed 1um.

A mitochondrion is bound by a double membrane where the outer is smooth and selectively permeable and the inner membrane is folded in words to form cristae

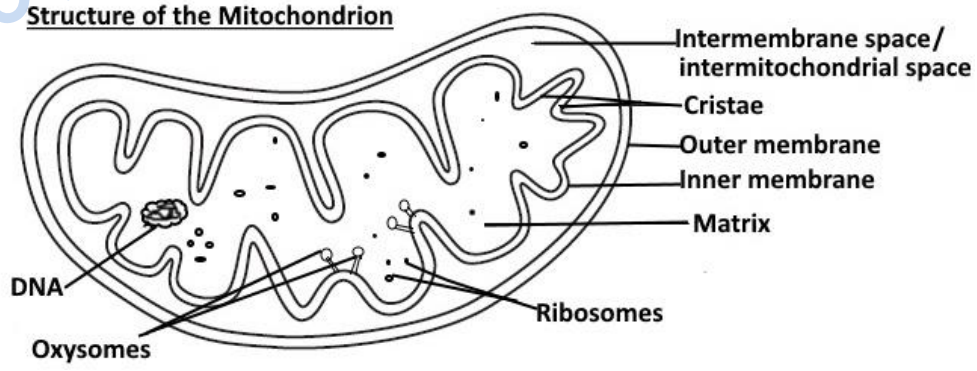
Each cristae has many stalked particles which stick from it into the matrix.

Each stalked particle consists of the head concerned with ATP synthesis the base which consists of respiratory chains and the stalk which joins the head and base.

The outer and inner membrane is separated by the narrow fluid filled space.

Inside the inner membrane is a matrix which consists of numerous chemicals compounds like enzyme circular mitochondrial DNA, ribosomes and RNA

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Functions of mitochondria

(i)Act as sites for the Krebs cycle during aerobic respiration site they contain enzymes for oxidative phosphorylation which brings about the formation of ATP

(ii) Important in formation of yolk during development of the ovum.

(iii)Constituents of the middle of sperm during spermatogenesis and provide energy for the lashing movements of the sperm tails important in surrounding of the sperm up through the uterus and into the oviducts and during fertilization.

(iv)Mitochondria provide energy for the elongation of fatty acids.
(v). they are sites of ATP formation
(v).They are sites of aerobic respiration

Adaptations of the mitochondria to its function (energy production)

1. The double membranes separate the mitochondrion from interference by processes in the cytoplasm
2. small size gives a large surface are to volume ratio for the rapid uptake / release of materials
3. matrix contains enzymes of the Krebs cycle
4. Inner membrane invaginates (in-folds) forms cristae to increase the surface area for electron transport chain (oxidative phosphorylation)
5. inner membrane has cristae with **oxysomes** that contain ATP synthetase (ATPase) and stalked particles that make ATP
6. Narrow inter membrane space (gap between inner and outer membranes) enables pH / H^+ / proton concentration gradient to be rapidly established / steeper chemiosmosis therefore more efficient / chemiosmosis can occur
7. inner membrane contains molecules for electron transport pathway
8. DNA is present to act as genetic material for synthesis of some protein / control of metabolism
9. Presence of many ribosomes for protein synthesis to reduce on importation of some proteins Phosphate used in glycolysis thru protein carriers (not clear

A comparison of mitochondria and chloroplasts

(a) Similarities

- Both contain a small amount of circular DNA
- Both contain 70S ribosomes
- Both are bound by a double membrane
- Both contain internal membrane folded or extended to form structures for increasing the surface area.
- Both are capable of protein synthesis
- Both contain DNA which is not contained in chromosome and not bound by a nucleus.
- Protein synthesis in both inhibited by the anti-biotic chloramphenicol and not cycloheximide.

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Difference between mitochondria and chloroplasts

Mitochondrion	**Chloroplasts**
Shape ranges from sausage shape, spiral, cup shaped, branched and even highly elongated	May be biconvex (disc shaped) spherical or oval
Not pigmented with chlorophyll	Pigmented with chlorophyll
The inner membrane of the envelope is folded to form cristae	The inner membrane of the envelope is not folded
Contain no thylakoid, grana or lamellae	Contain thylakoids, grana or lamellae
The structure for increasing surface area are in folds of the inner membrane	The structure for increasing the surface area are closed flattened fluid filled sacs which may be stacked together.
For aerobic respiration	For photosynthesis

COMPARISON OF STRUCTURE OF NUCLEUS AND MITOCHONDRIA

SIMILARITIES

- Both contain DNA
- Both contain RNA
- Both contain ribosomes
- Both are enclosed by a double membrane
- Both contain enzymes

DIFFERENCES

NUCLEUS	**MITOCHONDRION**
Linear DNA	Circular DNA
DNA contained in chromosomes	DNA not contained in chromosomes
Larger 80S ribosomes	Smaller 70S ribosomes
Membrane has pores	Membrane has no pores
Inner membrane not folded	Inner membrane folded to form cristae
Over-shaped or spherical	Sausage –shaped , spiral or cup-shaped
Outer membrane continuous with endoplasmic reticulum	Outer membrane not continuous with any organelles
Ribosomes may be attached on outer membrane.	Ribosomes not attached on outer membrane.

THE ENDOSYMBIOTIC THEORY FOR THE EVOLUTION OF MITOCHONDRIA AND CHLOROPLAST.

Endosymbiosis is a condition where one organism lives inside the cells of another, as in the mutualistic relationships between the unicellular green algae Chlorella found in the endoderm of the cnidarian hydra.

The endosymbiotic theory suggest that chloroplasts and mitochondria were prokaryotic organisms / bacteria) which invaded eukaryotic organisms during the early stages of evolution of life and entered into symbiotic relationship with eukaryotes.

The process of endosymbiotic evolution of mitochondria and chloroplasts.

Initially a heterotrophic eukaryote may have ingested an autotrophic prokaryote (bacterium) which instead of being digested entered a permanent symbiotic relationship as inhabitants of the eukaryotic cell.

The prokaryotic with could respire aerobically provided the eukaryotic cells inorganic new material with more ATP, while the eukaryote cells provided glucose and shelter. These aerobic prokaryotes become the mitochondria.

The photosynthetic prokaryote provided the eukaryotic cell with an organic food source, while the eukaryotic cell provided inorganic raw materials and shelter. These photosynthetic prokaryotes become the chloroplasts.

Since the mitochondrion and chloroplast have their own DNA and make source of their own proteins which divide inside the host cell every time the host cell itself divides.

However, with time some of their genes moved to the nucleus of the eukaryotic cell and so the task of making the mitochondria and chloroplast proteins is now shared with the nuclear DNA.

This explains why these organelles can no longer live independently.

Therefore these organelles represent an extreme form of obligate endosymbiosis.

Evidence for the endosymbiotic theory for the evolution of mitochondria and chloroplasts.

The following similarities between prokaryote, Mitochondria, and chloroplasts suggest that these organelles were once free living bacteria which invaded an ancestral eukaryotic cell and entered into a successful mutualistic union with it.

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(i) All contain circular DNA which is not contained in chromosomes and not branch by a nucleus.
(ii)All contain small 70S ribosomes.
(iii) All are capable of protein synthesis which can be inhibited by the antibiotic chloramphenicol and not by cydoheximide.
All are very small structures with average diameter of 10um or less.

Differences of prokaryotic chloroplasts and mitochondria from eukaryotes.

Prokaryotes, chloroplasts and mitochondria	**Eukaryotes**
Circular DNA	Linear DNA
DNA not contained in chromosomes and not bound in a nucleus	DNA contained in chromosome and bound in a nucleus
Smaller 70S ribosome's	Larger 80S ribosome's
Protein synthesis inhibited by chloramphenicol and not cycloheximide	Protein synthesis inhibited by cycloheximide not chloramphenicol
Smaller structure of average diameter 10um or less	Larger structure of average diameter 10-100um.

THE ENDOPLASMIC RETICULUM (ER)

The **ER** is an elaborate system of membranes running throughout the cytoplasm of the cell.
It is an extension of the outer nuclear membrane with which it is continuous and forms a cytoplasmic skeleton called cytoskeleton.
The **ER** consists of long flattened sac-like, straight tube, bundles and parallel membrane boundaries called **cisternae.**
Where the membranes are covered with ribosomes they are called **rough endoplasmic reticulum (RER).** The RER is concerned with the synthesis and transport of proteins.
Where the membranes lack ribosomes they are called smooth endoplasmic reticulum (SER). The SER is concerned with the synthesis of lipid.

The functions of the endoplasmic reticulum

(i)The ER provides a large surface area for biochemical reactions.
(ii) The ER provides a pathway for transport of materials thru cell.
(iii)The RER produces proteins such as glycoproteins, and enzymes.
(iv) The SER produces and stores lipids.
(v)The SER produces and stores carbohydrates
(vi) The SER of contains lytic enzymes.

Functions of RER

1. Rough ER is concerned with the transport of proteins which are made by ribosomes on its surface
2. The protein is extensively modified as it passes through the cisternae e.g. converting it into a glycoprotein.
3. Checks the quality of proteins formed, especially correct ordering and structure

Functions of SER

1. Enzymes of SER are important in the synthesis of lipids including oils, phospholipids and steroids e.g. lipids from fatty acids and glycerol in the epithelium of the intestine. Testes and ovaries are rich in SER because they secrete steroid hormones
2. Other enzymes of SER detoxify drugs, alcohol and poisons, especially in the liver
3. SER becomes modified to form the sarcoplasmic reticulum surrounding the muscle myofibrils
4. SER attaches receptors to cell membrane proteins in plant cells
5. Synthesis and repair of membranes by producing cholesterol and phospholipids
6. For metabolism of glycogen in the liver e.g. glucose-6-phosphatase enzyme in SER converts glucose-6-phosphate to glucose.

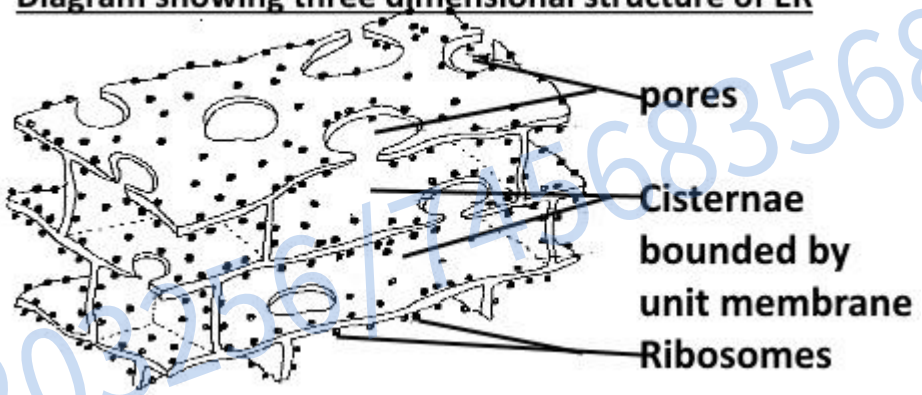
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7. Contains enzymes that detoxicate lipid soluble drugs, alcohol and metabolic wastes from the liver
8. The SER also stores calcium ions

Adaptations of ER to its function

1. The interconnected network provides the cell with skeletal framework.
2. Forming an extensive network increases the surface area for metabolic reactions e.g. protein synthesis at RER.
3. The endoplasmic reticulum membrane compartmentalizes the cytoplasm (isolates lumen from cytosol), which;
    - Enables transporting soluble and well packaged substances to their specific destinations.
    - Prevents interference of different metabolic processes taking place in the cell at the same time.
4. Contains a variety of enzymes for performing diver roles in cell metabolism.
5. The SER is modified into sarcoplasmic reticulum storage and release of calcium ions.
6. The membrane has a variety of proteins that offer unique properties including signal reception.
7. The RER membrane has sites for attachment of many ribosomes for protein synthesis

Diagram showing three dimensional structure of ER



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THE GOLGI APPARATUS/complexes/body (dictyosomes)

The Golgi apparatus discovered by Camilla Golgi in 1898 consists of a stack of flattened membrane bound sacs called **cisternae** together with a system of associated membranous sacs called **Golgi vesicles.**

At one end of Golgi apparatus new cisternae are constantly formed by vacuoles from SER. This "Outer" or forming face is convex.

At the other end the cisternae break up into vesicles again. This "inner" or maturing face is concave

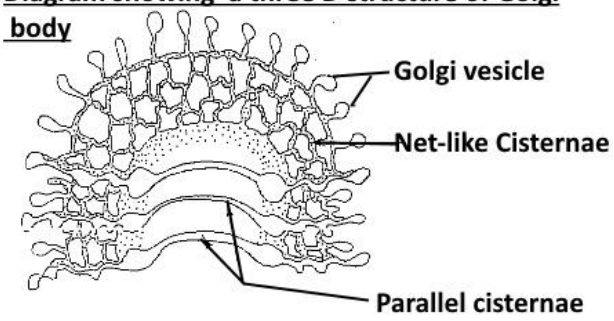
Mode of action of the Golgi

i. Proteins made at RER have, as part of their amino acid sequence, a signal that directs them where to go:
ii. Proteins arriving at cis-Golgi but having RER retention signal (were wrongly sent), are repackaged into vesicles then returned to RER.
iii. Soluble or properly folded macromolecules (proteins, lipids and polysaccharides) from RER enter cis-Golgi network via transport vesicles
iv. Within cis-cisternae, macromolecules are partly modified i.e. carbohydrates are added to proteins (glycosylation), phosphate is added to protein (phosphorylation) etc.
v. After partial modification, coated vesicles bud (pinch) off the swollen ends of cis-cisternae and fuse with ends of medial cisternae.

From trans-cisternae, the transformed macromolecules exit the Golgi and are sorted into different transport vesicles destined for lysosomes, plasma membrane or storage vesicles for secretion.

Within medial-cisternae, different enzymes further transform macromolecules differently, depending on their structures and destination i.e. some are modified for secretion, others for the membrane, and some for lysosomes.

Diagram showing a three D structure of Golgi body



After further modification within the medial-cisternae, coated vesicles bud (pinch) off the swollen ends of the medial-cisternae and fuse with the ends of trans-cisternae for further transformation

a) Vesicles containing hydrolase enzymes fuse with membranes of growing lysosomes so that the contents of both structures fuse.
b) Vesicles containing hormones e.g. insulin remain until when signaled by the cell, the vesicles then fuse with plasma membrane to release (secrete) the hormone outside the cell by exocytosis.
c) Vesicles containing membrane proteins fuse with the cell membrane and some of the modified proteins become part of the cell membrane e.g. protein receptors.

THE FUNCTIONS OF THE GOLGI APPARATUS

- The function of the Golgi apparatus is to transport and chemically modify the materials contained within it.
- Golgi apparatus forms lysosomes containing hydrolytic enzymes
- Golgi body is involved in the formation of peroxisomes
- Golgi apparatus in the leaf glands of some insectivorous plants e.g. sundews secrete a sticky slime and enzymes which trap and digest insects
- The membranes of the vesicles from the Golgi apparatus for the first layer of the new cell wall that develops between the two daughter cells as they divide.
- Golgi is sometimes involved in the secretion of carbohydrates e.g. polysaccharides are attached to a protein to form proteoglycans present in the extracellular matrix of the animal cell
- To form carbohydrates.
- Transport of lipid molecules around the cell.
- Secretory vesicles produced by Golgi contain a variety of important substances e.g
- Neurotransmitters, hormones, Mucin, zymogen e.g. pepsinogen, etc.
- Fusion of Golgi vesicles with cell membrane maintains the membrane which is used to form phagocytic vacuoles and Pinocytic vesicles
- They form lysosomes if or when they contain digestive enzymes

Adaptations of the Golgi

- Cisternae are enclosed by permeable membranes, which isolate the inside cavity from cytosol for efficient functioning.
- Tubular structure enables transportation of soluble protein and lipids from the endoplasmic reticulum for modification.
- Variety of enzyme systems for modifying proteins by adding carbohydrates and phosphate by the process of glycosylation and phosphorylation respectively.
- Many cisternae increase the surface area for modifying synthesised macromolecules.
- There are many compartments at the cis, located at the beginning of the Golgi apparatus to facilitate passage of proteins through the Golgi apparatus

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LYSOSOMES

Lysosomes "Lysis" –splitting; soma-body" are spherical bodies surrounded by a single membrane that contain digestive enzymes such as proteases, nucleases and lipases. Enzymes contained in lysosomes are synthesized on RER and transported to the Golgi apparatus. Golgi vesicles containing the lysozymes bud off to form the lysosomes.

These are tiny membrane bound organelles that **contain hydrolytic enzymes**. Lysosomes occur only in animal cells and there are primary and secondary lysosomes. The primary lysosomes are tiny vesicles from the Golgi body while the larger secondary lysosomes are formed when the primary lysosomes fuse with small vacuoles of the animal cells.

They are usually absent in plants except insectivorous plants e.g. *Nepenthes, Dionaea.*

Lysosomal enzymes work best in the acidic environment found in lysosomes. If a lysosome breaks open or leaks its contents, the released enzymes are not very active because the cytosol has a neutral pH. However, excessive leakage from a large number of lysosomes can destroy a cell by *auto digestion.*

Particles taken in by cells or made in the cell are digested on the lysosome. Lysosomes contain enzymes e.g. lipase which hydrolyses lipids to fatty acids and glycerol, carbohydrases which hydrolyze carbohydrates to simple sugars, peptidases which hydrolyze peptides to amino acids, RNA-ase, DNA-ase, and others.

Types of Lysosomes

Lysosomes are of two types:

1. Primary lysosome, which is pinched off from Golgi apparatus. It is inactive in spite of having hydrolytic enzymes

2. Secondary lysosome, which is the active lysosome. It is formed by the fusion of a primary lysosome with phagosome or endosome.

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FUNCTIONS OF LYSOSOMES

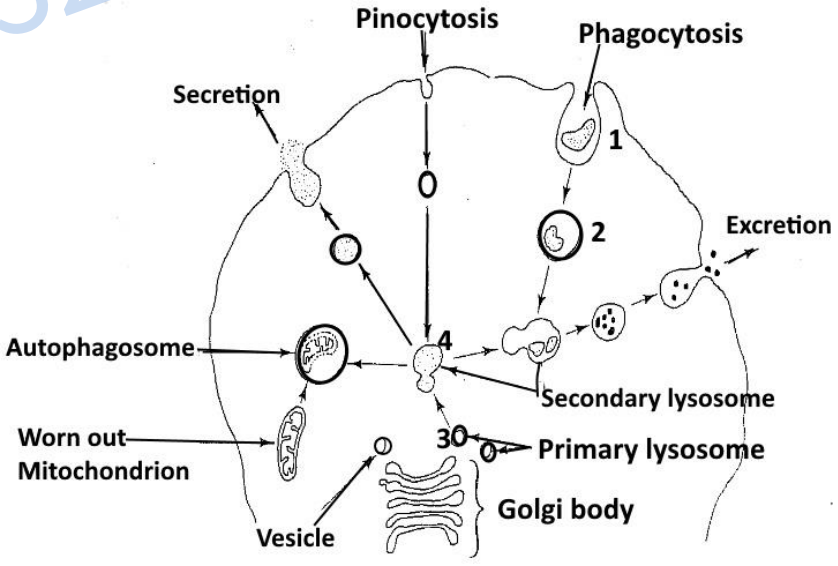
Digestion of material taken in by endocytosis

Lysosomes fuse with vesicles or vacuoles formed by endocytosis releasing their enzymes into the vacuole reside and digesting the material inside.

The material may be food in the case of protozoans, bacteria and other harmful material in the case of white blood cells (phagocytes).

After digestion, the useless debris is released from the cell by exocytosis.

Summary of the functions of Lysosomes



Autophagy/ Degradation of worn-out organelles

Autophagy is the process by which unwanted structures within the cell such as worn out organelles are engulfed and digested within lysosomes. The rough endoplasmic reticulum wraps itself around the worn-out organelles like mitochondria and forms the vacuoles called autophagosomes. One primary lysosome fuses with one autophagosome to form the secondary lysosome. The enzymes in the secondary lysosome are activated. Now, these enzymes digest the contents of autophagosome.

Removal of excess secretory products in the cells

Lysosomes in the cells of the secretory glands remove the excess secretory products by degrading the secretory granules.

Exocytosis

Lysosomes sometimes release their enzymes outside the cell by exocytosis.

This occurs during the replacement of cartilage by bone during ossification, the remodeling of bone, the re-absorption of the tadpole tail during metamorphosis and the acrosome reaction during fertilization

N.B The acrosome is a special lysosome.

AUTOLYSIS

Autolysis is the self- digestion of a cell by releasing the contents of lysosome within the cell. Autolysis may occur following the death of a cell after delivery, the uterus returns to its normal size by autolysis in an exercised muscle cells as they deteriorate or even as a result of lysosomal diseases.

On the sperm head is an organelle called acrosome which is actually a lysosome, it contains enzymes that enable the sperm to penetrate the ova.

Secretory function – secretory lysosomes having secretory function called secretory lysosomes are found in some of the cells, particularly in the cells of immune system. The conventional lysosomes are modified into secretory Lysosomes by combining with secretory granules (which contain the particular secretory product of the cell

Examples of secretory lysosomes:

i. Lysosomes in the cytotoxic T lymphocytes and natural killer (NK) cells secrete perforin and **granzymes,** which destroy both viral-infected cells and tumor cells. Perforin is a pore-forming protein that initiates cell death. Granzymes belong to the family of serine proteases (enzymes that dislodge the peptide bonds of the proteins) and cause the cell death by apoptosis

ii. Secretory lysosomes of melanocytes secrete melanin

iii. Secretory lysosomes of mast cells secrete serotonin, which is a vasoconstrictor substance and inflammatory mediator.

Role in fertilization; Acrosome in spermatozoa releases enzymes which digest the limiting membrane of the ovum to enable sperm entry and start fertilization. The lysosome in cytoplasm of Ova enables digestion of stored food

Role in development; Tadpole metamorphosis (regression of tail) and regression of Wolffian ducts involve shedding of tissues with removal of whole cells and extracellular material by lysosome enzymes during bone development, osteoclasts release lysosomal enzymes that remodel bones.

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PEROXISOMES (MICROBODIES)

Microbodies are small spherical membrane bound bodies containing metabolically important enzymes such as catalase (the enzymes which catalyse the breakdown of hydrogen peroxide).

Functions of peroxisomes

• Peroxisomes contain enzymes peroxidases and catalase which are concerned with the metabolism of peroxide. Thus, the peroxisomes are involved in the detoxification of peroxide.

• Peroxisomes are also capable of carrying out β-oxidation of fatty acid.

Glyoxysomes contain enzymes that degrade lipids into sugars during seed germination.

VACUOLES

A vacuole is a fluid filled sac bounded by a single membrane.

Animal cells contain small vacuoles such as autophagic vacuoles, phagocytic vacuoles, food vacuoles, contractile vacuoles.

Mature plant cells have a large central cell vacuole surrounded by a membrane called the tonoplast. The fluid contained in the plant cell vacuole is known as cell sap a concentrated solution of mineral salts, sugar, organic acids, gases, pigments, wastes and excretory products of metabolism.

THE FUNCTIONS OF VACUOLES

i) Serves as a temporary store for food substances (sugars and amino acids), pigments and organic wastes (tannins).

ii) The plant cell vacuole sometimes contain pigments in solution e.g. **anthocyanins** which are responsible for determining the colour of flowers petals buds and leaves or fruits to attract pollinating insects birds and animals 4 dispersal.

iii) Plant cell vacuoles act as temporary stores for organic wastes such as tanning. These wastes accumulate in the vacuoles of leaf cells and removed when the leaves fall.

iv) Plants vacuoles sometimes contain hydrolytic enzymes in thus perform functions similar to those of lysosomes such a autolysis.

(v)When water enters the concentrated Cell sap by osmosis through the partially permeable tonoplast, pressure build up within the cell and the cytoplasm is pushed against the cell wall. This osmotic intake of water is important in cell expansion during cell growth, the buildup of turgor pressure to support herbaceous parts of woody plants and influencing the normal water relations of plants.

(vi)The accumulated waste products and secondary product of plants metabolism in the vacuole may serve certain secondary purposes such as defense. Alkaloids and tannins may offer protection from consumption by herbivores. Latex (a milky liquid) of the rubber trees contain the chemicals needed for the synthesis of rubber. The latex of the opium poppy contains alkaloid such as morphine from which herolin is made.

(vii). Food vacuoles formed by endocytosis enable bulk intake of large food particles

(viii).Contractile vacuoles in unicellular organisms e.g. amoeba and paramecium, regulate water content in the cell.

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Non-membranous structures

RIBOSOMES

Ribosomes are small cytoplasmic granules that act as sites of protein synthesis.

Each ribosome consists of two sub units one large and one small sub unit.

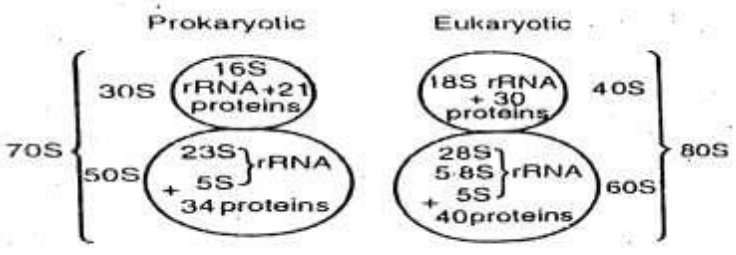
Prokaryotes possess 70S ribosomes which are slightly smaller than the 80S ribosomes found in eukaryotes. Ribosomes comprise nearly equal amounts of ribosomal RNA (RNA) and protein.

Ribosomes may occur in groups called polysomes (poly ribosomes and may be associated with the ER forming RER or occur freely within the cytoplasm.

STRUCTURE OF RIBOSOMES

Oblate spheroid structures (hydrated/porous); two subunits; one larger subunit is larger and
Has dome shape-like shape; while other is smaller with cap-like shape 70S consists of 50S and
30S subunits and 80S consist of 60S and 40S subunits;

Ribosomes are also found inside mitochondria and chloroplasts of the eukaryotic cells. These ribosomes resemble those of prokaryotes, showing an evolutionary relationship of the two organelles within eukaryotic cells. Ribosomes are either free or found stack on endoplasmic reticulum to form the rough endoplasmic reticulum. Free ribosomes located in the cytoplasm are the sites of synthesis of proteins retained within the cells whereas ribosomes stack on endoplasmic reticulum produce proteins that are secreted outside the cell. During protein synthesis, ribosomes move along the mRNA, like beads, on a string. The resulting chains of ribosomes are called polysomes or polyribosome.



Functions: sites for protein synthesis

STORAGE GRANULES

Storage grains or granules act as limited stores of food energy within cells or organelles. These store food in an insoluble form as in starch grains; glycogen, granules, oil droplets and fat granules.

MICROTUBULES AND MICRO FILAMENTS

Networks of fibrous protein structures occur in eukaryotic cells forming the cytoskeleton. The cytoskeleton consist of three types of fibre microtubules, micro filaments and intermediate filaments. These fibres are together concerned with movement, ability of cells to maintain their shapes, endocytosis, exocytosis and various other activities.

Microtubules are slender, unbranched, hollow tubes of about 24nm diameter.

They are made of two similar proteins alpha-tubulin and beta-tubulin.

Micro filaments are very thin strands about 6nm in diameter. They are made of the protein actin and myosin.

THE FUNCTIONS OF MICROTUBULES.

i. By forming a network of fibres spreading the matrix of living eukaryotic cells, microtubules provide an internal skeleton called **Cytoskeleton:**

Cytoskeleton, for

- Supporting framework for organelles and hence maintain their shape.
- Anchoring the plasma membrane and certain cell junctions.
- Providing a suitable surface for chemical reactions to take place.

The microtubules, together with the microfilaments and intermediate filaments, provide an internal skeleton for cells forming a cytoskeleton. The cytoskeleton determine and maintains cell shape.

ii) Intracellular transport microtubules are involved in the movement of other cell organelles (such as Golgi vesicles) and other materials within the cell by providing movement routes.

iii) They provide a **framework along** which the cellulose cell wall of a plant is laid down.

iv) Within the **spindle fibres during** cell division and within the centrioles from which the spindles are formed, microtubules aid in drawing chromosomes or chromatids to the opposite poles.

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Functions of microfilaments

- Component of cytoskeleton; give support and maintain cell shape
- Actin and myosin filaments are needed for muscle contraction
- Constriction of filaments causes cleavage and furrow formation in cytokinesis of animal cells
- They play a role in cellular movements e.g. cytoplasmic streaming, cell motility, involved in phagocytosis and pinocytosis.

15) Centrioles and nuclear inclusions

Centrioles are small hollow cylinder about 0.5 um in diameter which occur in pairs in animals cells.

Each centriole contains nine triplets of microtubules.

At nuclear division the centrioles migrate to opposite poles of the cell where they synthesize microtubules of the spindle called spindle fibres. These control the separation of chromatids or chromosomes.

Functions

a. Centrioles act as organizers of spindle fibres and are involved in the separation of chromosomes or chromatids during cell division
b. In some cells, centrioles divide to produce basal bodies from which flagella and cilia develop.

FLAGELLA, CILIA AND BASAL BODIES

These are organelles that project from the surface of cells but are connected to a basal body just below the membrane.

Flagella occur singly or in small numbers, whereas cilia occur in large numbers on larger cells, and are typically shorter than flagella.

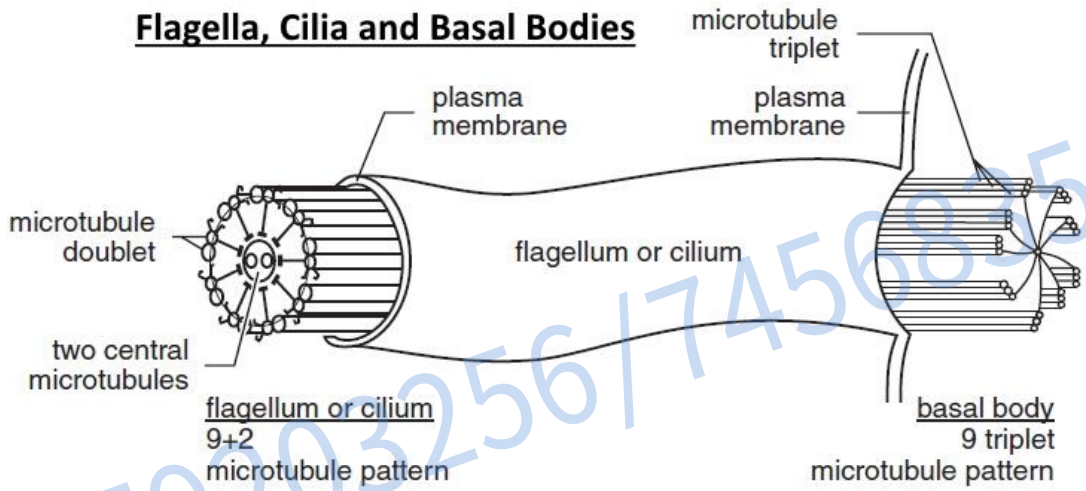
Flagella and cilia are enclosed by a plasma membrane. Internally, they consist of microtubules arranged in an outer ring of nine pairs surrounding two central pairs ('9 + 2' arrangement).

Flagella and cilia move by means of sliding movements of one member of a microtubule pair relative to the other.

Cilia and flagella have identical structures but cilia are shorter and more numerous.

Cilia and flagella contain characteristics (9+2) arrangement of microtubules.

Cilia and flagella are cellular out growths and can beat either in one direction (cilia) or like a wave (flagella). They function to move either an entire organisms or cell to more fluids over the surface of cells.



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STRUCTURE OF CILIUM

Microtubules a pair of central singlets surrounded by nine peripheral doublets/ring of nine paired ones with arm-like process 9+2 array/pattern surrounded by cell surface membrane each peripheral filaments consists of an A and B microtubule A microtubule has protein dynein/ATpase central filaments connected to microtubule A by radial spokes

Compare cilia and flagella

Similarities

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

Differences between Cilia Flagella

Cilia	**Flagella**
• More Numerous	Fewer/less in number
• May occur throughout the surface of the cell	Occur at one end of the cell
• Shorter processes	Longer processes
• Beat in coordinated rhythm	Beat independently
• Sweeping/pendular motion	Undulatory motion
• other functions such as feeding/circulation/sensory	Locomotory functions only

FUNCTIONS OF CILIA AND FLAGELLA

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

MICROVILLI

The microvilli are tiny finger like extensions of the cell surface membrane of certain animals' cells, such as these of the intestinal epithelium

Microvilli are massed together forming a brush border at the edge of cells bearing them.

Each microvillus contains bundles of actin and myosin filaments, allowing the microvilli to contract.

Microvilli provide a large surface area for absorption and digestion.

THE CELLULOSE PLANT CELL WALL

The plant cell wall consists of regularly or irregularly arranged cellulose micro fibrils embedded in an amorphous matrix of polysaccharides, such as pectin.

The wall laid down during plant cell division is the primary wall, which may later be thickened to form the secondary wall.

The polysaccharide matrix consists of pectin and hemicelluloses. The middle lamellae that holds neighboring cell walls together is composed of sticky gel-like pectates of magnesium and calcium.

In some cells such as xylem vessel elements and sclerenchyma, extensive lignification occurs whereby the complex polymer lignin is deposited in all the cellulose layers. Lignin cements and anchors cellulose fibres together.

It acts as a very hard and rigid matrix, giving the cell wall extra tensile and compressional strength which prevents buckling. Lignin also protects cell from chemical and physical damage.

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DESCRIPTION OF THE CELL WALL STRUCTURE

The cell wall is made up of primary cell wall, middle lamellae, secondary cell wall and tertiary cell wall; primary cell wall consists of cellulose microfibrils running through matrix of polysaccharide; pectates and hemicellulose deposited on either sides of the middle lamellae microfibrils run in all directions portion of the endoplasmic reticulum is trapped across the middle lamellae and forms the plasmodesma outermost layer comparatively thin elastic delicate and permeable; simple and smooth secondary cell wall formed by further deposition of cellulose on the inside of the primary cell wall microfibrils tightly packed thicker impermeable; found below primary cell wall cellulose cell walls oriented in the direction of the cell elongation; impregnated with cutin/suberin.

Tertiary cell wall found below secondary cell wall thicker than secondary and primary found in tracheids and gymnosperms impregnated with XYLAN.

CHEMICAL CHANGES THAT OCCUR DURING CELL WALL GROWTH

- **Lignification** deposition of lignin on cell wall
- **cutinization** conversion of cellulose into cutin in the cell wall
- **suberisation** deposition of suberin on the cork cell walls
- **Mineralization** deposition of mineral substances such as silica, calcium carbonate and calcium oxalate
- **mucilaginous** changes cellulose cell wall is converted into mucilage; Eg bacteria

FUNCTIONS OF THE CELL WALL

- Mechanical strength and skeletal support provided for individual cells and for the plant as a whole; due to extensive lignification;
- Cell walls resistant to expansion and allow development of turgidity as a result of osmotic influx of water molecules;
- Orientation of the cellulose microfibrils limits cell growth and shape;
- System of interconnected cellulose cell walls/apoplast; functions as a major pathway of transport of water and dissolved salts; plasmodesmata in cell walls for symplast pathway;
- Develop coating of waxy cutin/cuticle; epidermal cells reducing water loss and risk of infections; cork cells are impregnated by suberin to prevent desiccation;
- Walls of the xylem vessels/tracheids and sieve tubes are adapted for long distance transport of materials through cells;
- Cell walls of endodermal cells are impregnated by suberin forming barrier to water movement;
- Some Cell walls modified for as food reserves; as in storage of hemicellulose in seeds;
- The cell walls of transfer cells develop an increased surface area and the consequent increase in surface area of the cell surface membrane increases the efficiency of transfer by active transport

RELATIONSHIP BETWEEN STRUCTURE AND FUNCTION OF CELL WALL.

i) Provide mechanical strength and skeletal support to the cell and the plant as a whole.
The strength may be increased by extensive lignification as in trees and shrubs.

ii) Cell walls are rigid and quite resistant to expansion. And therefore as water enters the cell by osmosis, the cell walls resist expansion and an internal turgor pressure is built up which provides turgidity for the plant. This provides support in herbaceous plants and herbaceous structures such as leaves.

iii) The rigid cell also prevents the cell from bursting when exposed to a dilute solution and takes in water by osmosis.

iv) The orientation of cellulose micro fibrils limits and helps to central cell growth and shape because the cells ability to stretch is determined by their arrangement.

v) The system of interconnected cell walls called the apoplast is a major pathway of movement for water and dissolved mineral salts. The cell walls possess minute pores through which structures called plasmodesmata can pass forming living connections between cells and allowing all protoplasts to be linked a stem called symplast.

vi) The presence of cutin, suberin and lignin in the matrix of some cell walls makes the cell less permeable to substances and cutin in the leaf epidermis (forming the waxy cuticle) reduces water loss and infection.

vii) The cell walls of xylem vessels and sieve tubes are adopted for long distance translocation of materials.

viii) Some cell walls of transfer cells develop an increased surface area. The consequent increase in surface area of the cell surface membrane. Increase the efficiency of transfer by active transport.

ADAPTATION OF THE CELL WALL TO ITS FUNCTION

a) The cell wall has cellulose polymers associate through very many H-bonds whose cumulative bonding energy provides high tensile strength of the cell wall for providing support and preventing rupturing
b) The cell wall has relatively thick multiple wall layers provide mechanical support
c) The cell wall has secondary walls which may be cutinized / suberinised for preventing water loss

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d) The variety of functional proteins like oxidative enzymes (peroxidases), hydrolytic enzymes (pectinases, cellulases) enable performing several functions like protection against pathogens, cell expansion, cell wall maturation
e) The cell wall has extremely rigid secondary walls that provide compression strength
f) Deposition of cellulose fibrils in alternating layers enables some degree of flexibility
g) The cell wall is semi-permeable in nature to allows exchange of water, dissolved salts and small protein molecules

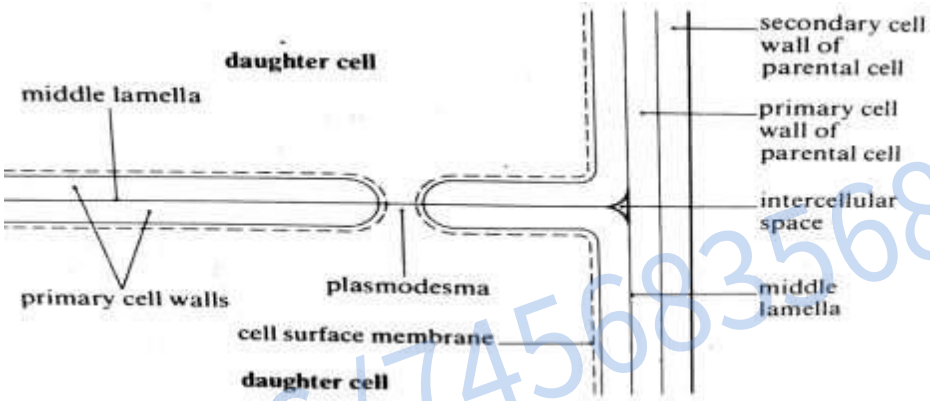
PLASMODESMATA

The plasmodesmata is a fine cytoplasmic thread linking the cytoplasm of two neighboring cells through a fine pore in the cell walls.

The plamodesmata enable a continuous system of cytoplasm (the symplast) to be formed between neighboring cells for transport of structures between cells.

The cell wall is differentiated into three layers

- Primary cell wall
- Secondary cell wall
- Tertiary cell wall



COMPARISONS

Primary cell wall	Secondary cell wall	Tertiary cell wall
Outermost layer of cell wall	Found below primary cell wall	Found below secondary cell wall
Comparatively thin and elastic, delicate and permeable	Comparatively thick, and impermeable	Thicker than secondary
Found in meristemic, young and paranchymatous cells	Found in mature and permanent cells	Found in tracheids and mature gymnosperms
Made up of cellulose	Cellulose, pectin, lignin, and other substances	Made up of Xylan
Simple and smooth	Simple	Forms fingerlike process by evagination of the cell wall

Advantages of having membrane bound organelles

1. Potentially harmful reactions (enzymes) can be isolated inside an organelle so that they do not harm the rest of the cell
2. The rate of any metabolic reactions inside an organelle can be controlled by regulating the rate at which the membrane allows the first reaction to occur or to enter
3. The containment of enzymes for a particular metabolic pathway within the organelle means that the products of the reaction will always be in close proximity to the next enzymes within the sequence. This increases the rate of metabolic reactions
4. Many metabolic processes which involve enzymes occur in the membrane.

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Question

ii. What are the advantages of the multicellular state over the unicellular membrane.

iii. How have organisms over the challenges of being multicellular

Advantages of multicellular state over unicellular state

- Being multicellular allows increase in size. In the unicellular state size is limited by the need to maintain a large surface area to volume ratio and the fact that one nucleus can only exert control over a limited volume of cytoplasm.
- Multicellularity allows cell speciation leading to development of tissues organs and organ systems with different parts of the body performing different functions. The division of labour promotes greater efficiency enabling exploitation of various habitants and niches the cell of unicellular organism needs to remain capable of various life activities and is thus unable to separate.
- Multicellular organisms comprise numerous cells making the total surface area available for exchange of materials many tissues greater than the area of the external body surface. Unicellular organisms rely on small body size to maintain efficient exchange by diffusion over a large surface area to volume ratio.
- Multicellular organisms comprise body cells making the volume.
- Multicellular organisms comprise body cells bathed in a tissue fluid where composition can be regulated by homeostasis, improving overall cell efficiency unicellular organism cannot exert control over the external surrounding of the cell loading to inefficiency.
- Developed of specialized internal organ for material exchange and excretion allows the body surface of a unicellular to be made impermeable and water proof, reducing water loss and adapting multicellular organisms to a full terrestrial life. Even in desert conditions.
- Unicellular organisms carry out material exchange and excretion over the entire body surface which must therefore remain moist and permeable. This leaves the organisms' prone dehydration and desiccation is dry condition improving limitations on terrestrial life.
- Specialized structures of multicellular organisms such skeleton and xylem and maintain body shape and position by offering support and mechanical strength unicellular organisms are largely unable to maintain body shape and position.
- Increase body size in multicellular organisms reduces area to volume ratio therefore reducing the rate of heat loss to surroundings.
- Unicellular organisms have a large surface area to volume ratio with high rates of heat loss to surroundings.
- Specialization allows development of muscle skeletons and protective and offensive structures that allow multicellular organisms to take large, prey and also immediate or run away from potential predators. Unicellular organisms can only feed on small prey and are vulnerable to being preyed upon.

How organisms overcome the challenges of being multicellular.

Challenges	**Solution**
Need for greater support	-Development of specialized materials tissues and organs of support such as chitins, lignin cellulose , none cartilage colevelligua , xylem, sclerenchyma
Greater food requirements	-Becoming heteroautophic and mostly holozoic but some are parasitic well developed digestive system with a specialized alimentary canal. -Varied food sources and feeding habits in comparting carnivores, herbivores and omnivores modes of life.

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Greater food requirements	-Filling parts of the body with dead tissues such as xylem which do not require nutrients. -Development of a hollow centre to vacuole food requirement. -An efficient nucleus of locomotion to enable organisms search for food. -Development of muscle and skeletal systems to provide support for their structures. -To enable taking of large prey and carcasses -Autotrophism in plants.
Surface area to volume ratio	-Development of hollow centre to the surface area to volume ratio such as spongecoel and coleleuteous. -Flattening the body to increase surface area to volume ratio -Development of specialized internal as external surfaces of exchange area such as gills, alveoli, ileum, blood capillaries. -Development of thin flattened structures such as leaves, root hairs.
Increased metabolic wastes	-Development of a transport system which transports waste -Development of excretory organs and systems to expel metabolic wastes from the body. -Development of nervous and endocrine systems to control the process of excretion. -Ability to release various waste products of metabolism in plants. -Autotropism in higher plants ensures that organic compounds are produced on demand with little weak substances. -Storage of metabolic wastes in dead permanent plant tissues such as back. -Ability to detoxify toxic wastes such as ammonia to urea and uric acid.
Movement	Berom sessile in plants -Slow waving animals have reduced to water. -Development of locomotory structures such as liquids, fins, wings, legs, flippers. -Development of established and muscle systems to provide a propulsive force during locomotion --Development of numerous systems and sense organs to coordinate and facilitate locomotion. -A bilateral symmetry gives a compact elongated streamlined from which offer least resistance to movement. -Bilateral symmetry also confers anterior, posterior, dorsal, ventral right and left aspect to the animals body for further speciation. -Sessile and slow movement form exhibit radial symmetry so as to encounter environmental challenges from all directions.
Complex development of multicellular animal from unicellular zygote	Along gestation period to provide ample time for complex processes. A period of embryonic …often followed by a larva phase and metamorphosis before adult form is achieved

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	Evolution of oviparity Nursing of young ones and parental care.
Transport between body surface and outer	Development of blood and lymph vascular systems in animals. Development of respiratory pigments for transport of respiratory gases. -Development of tracheal system -Development of xylem and phloem in plants.
Need to coordinate functioning as one living unit	Development of a central nervous system to coordinate all body activities. Development of peripheral nervous system to relay information found from central nervous system. Development of endocrine system to facilitate nervous system during coordination and homeostatic. -Cephalization Involving formation a definite head region where the major sense organs and nerve centres are situated at the anterior end of the body as so suitably placed to the first structures to encounter any environmental changes ahead.
Increased risk of predation in case of prey.	

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SUB-TOPIC 4: CELL DIVISION AND CHROMOSOME CONCEPT

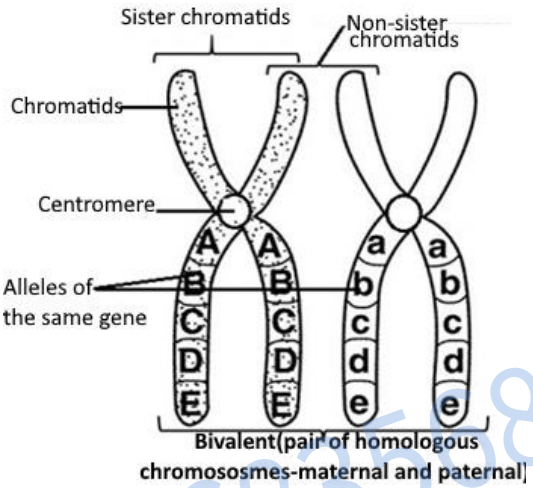
Cell division is a process by which a cell divides to give rise to daughter cells.
Cells undergo a series of changes in their life time during which they produce new daughter cells. Indeed, every cell is formed from an already existing cell by cell division i.e. where a cell exists, there must have been a pre-existing cells.

The continuity of life is based on the reproduction of cells or cell division. When a unicellular organism such as amoeba divides and forms two offspring amoeba cells, the division of one cell reproduces an entire organism.
There are two forms of cell division namely

1. **Mitosis**
2. **Meiosis.**

Mitosis promotes the multiplication of cells to bring about growth whereas **meiosis** promotes the multiplication of the species by promoting gamete formation in sexual reproduction.
Cell division occurs due to the presence of **chromosomes** in the nucleus of the cell.
Each chromatid contains many bead like structures made of DNA called **genes** which determine the characteristics of organisms. Chromosomes occur in pairs within the nucleus of the cell and the chromosome number varies from species to species e.g. in human beings there are 23 pairs of chromosomes in the nuclear cell i.e. 46 chromosomes. Therefore human beings are described as diploid organisms because they have diploid cells.
IMPORTANT TERMS USED
Chromosome; this is a thread-like structure in the nucleus that carries the genes of an organism.
Chromosomes are thread-like structures in the nucleus of the cell made of DNA molecules and histone protein.

Homologous chromosomes refer to structurally similar chromosomes one obtained from the mother and another from the father during fertilization which exists in the nucleus of a somatic cell of an organism. Pairs of chromosomes are a result of one set coming from the female parent gamete (ovum) and the other from the male parent gamete (the sperm)
A chromosome is composed of DNA and **Histone protein.**
In a non-dividing cell, individual chromosomes are not distinct/visible but the chromosomal material can be seen if stained and this material is called chromatin
At the onset of cell division, each chromosome becomes visible and it is seen to consist of two threads called chromatids formed at the centromere.



Structure of a chromosome

Chromosomes vary in shape and size both within and between species. Each species has a characteristic number of chromosomes

e.g.

In humans	**46**
Fruit fly (Drosophila melanogaster)	**8**
Zea mays	**20**
Cows	**60**
Sheep	**56**

Chromosomes occur in pairs and since the two members (or chromosomes) are similar in structure (appearance), they are said to be homologous.

Advantages of possessing two sets of chromosomes

- Genetic variation is increased since each individual will have a mixture of characteristics from both parents.
- If a gene on one chromosome is faulty, the one on the second chromosome may provide a normal

Chromatid; this is one half of a chromosome. Structurally a chromosome contains a pair of elongated structures called **chromatids** which are joined together by the structure in the middle of the chromosomes called **centromere**.
Sister chromatids; these are chromatids of the same chromosome.
Sister chromatids are pairs of chromatids located on the same chromosome while non-sister chromatids are pairs of chromatids located on different chromosomes.
Homologous chromatids; these are chromatids of different chromosomes in a bivalent.

Bivalent; this is a pair of homologous chromosomes.
Centromere; this is a structure of chromatid attachment and separation on a chromosome.
Chiasmata; this is a crossing over point between two homologous chromatids.
Haploid; this is where a cell has half the number of chromosomes compared to the parent cell.
Haploid (n); describes a cell or nucleus or organism having one set of chromosomes.
A **haploid** cell is one having only one set of chromosomes in the nucleus.
Before replication, each single chromosome contains at least one long linear DNA molecule that carries many genes which control the characteristics of an organism. The associated **histone protein** molecules maintain the structure of the chromosome and control the activity of genes.
Diploid (2n); is a condition where a cell or nucleus or organism has two sets of chromosomes.

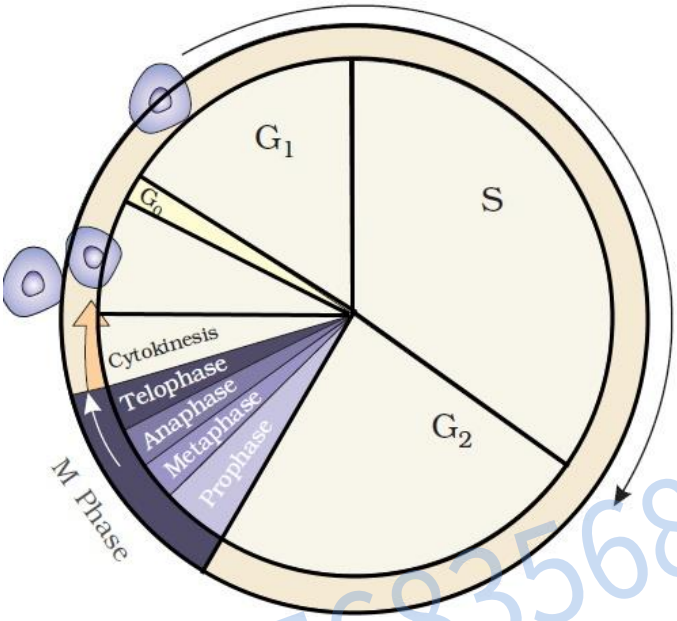
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A diploid cell (2n) is the one in which there 2 sets of chromosomes of which one set is inherited from the mother and another set from the father. This implies that human beings have a chromosome number of 46 in their somatic cells or body cells and 23 chromosomes in their gamete cells.
Replication; this is where a structure produces an exact copy of itself.
Polyploidy; is an organism or cell having three or more sets of chromosomes in its cells.

THE CELL CYCLE

This is the sequence of events which occurs between one cell division and the next. **It can also be defined** as the life of the cell from the time it is first formed from a dividing parent cell until its own division into two or four cells.

A dividing cell duplicates its DNA and allocates the two copies of DNA to opposite ends of the cell and then splits into daughter cells, thereby making the daughter cells identical



The **above cell cycle** shows that the life cycle of the cell mainly involves **interphase** i.e. a period in which the cell prepares for the next cell division which is followed by nuclear division during mitosis and finally cytokinesis during telophase of mitosis. Mitosis therefore involves both nuclear division and cytokinesis which alternates with a much longer stage called interphase.
The cell cycle is divided into three main phases

1. **Interphase**
2. **M phase(mitosis phase)**
3. **Cell division (cytokinesis)**

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1. INTERPHASE
This is the longest stage of mitosis and it's also referred to as the resting stage of the parent cell, is the time during which the cell is preparing for division by undergoing both **cell growth and DNA replication** in an orderly manner. It lasts more than **95%** of the duration of cell cycle.
During interphase, the cell grows, carries out its functions and replicates its DNA. After the DNA is replicated, new proteins becomes attached to it.
This is a period of synthesis and growth and it is divided into three phases
a) G_1 (gap 1 or 1ST growth phase)
This is the first growth phase and comes after cytokinesis. it takes about **8 hours to** complete.

- The cell grows rapidly to mature size.
- Synthesis of RNA and ribosomes
- Cell metabolic rate increases and production of biochemicals
- Synthesis and replication of cell organelles occurs.
- Synthesis of proteins occurs and other materials that will be used for DNA synthesis

b) S phase (synthesis phase). It lasts about 6 hours to complete.

- Replication DNA and chromosome occurs
- Duplication of histone proteins occurs/histone proteins are synthesized.

At the beginning of the **S stage,** each chromosome is composed of one DNA double helix. Following DNA replication, each chromosome is composed of two identical DNA double helix molecules. Each double helix forms a chromatid.

c) G_2 phase (gap 2 or second Growth phase). It lasts about 4 hours for this stage to be completed.

- Completion of DNA replication to the onset of mitosis.
- Cell synthesizes proteins that will assist cell division. E.g. the cell makes the proteins that form microtubules.
- Synthesis and replication of cell organelles like mitochondria, chloroplasts, E.R occurs
- Mitotic spindle begins to form. Microtubules are used during the mitotic stage to form the mitotic spindle.
- Energy stores are increased prior to cell division, either mitosis or meiosis, the mother cell undergoes a preparation stage known as **interphase.**

Note:

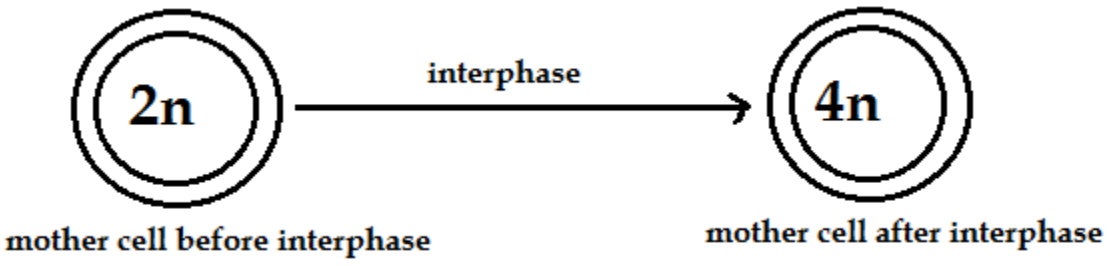
G_0 phase (quiescent stage): Most non-dividing cells e.g. brain cells go into this phase

G_0 phase is a period in the cell cycle where cells do not divide further and exist in a quiescent state. it occurs in response **to a lack of growth factors or nutrients.** Cells in this stage remain metabiologically active but no longer proliferate. It's a very common phase for most mammalian cells

During interphase the chromosomes are usually seen as tiny coiled threads known as **chromatids** and are therefore described as invisible chromosomes because details of the chromosome structure cannot be see. During interphase the cell undergoes a period of intense chemical activity.

During inter phase four important changes take place in the cells.

- There is duplication of DNA and chromosomes so as to double their amounts i.e. there is replication of DNA and chromosomes.
- There is synthesis of a lot of ATP so that there is sufficient energy for the next cell division.
- There is replication of cell organelles like mitochondria, endoplasmic reticulum, and Golgi body etc.
- There is synthesis of histone proteins, RNA and other types of proteins occurs
- The chromosomes are seen as tiny thread like structures that are highly coiled and therefore described as invisible (as their details cannot be clearly seen)
- In addition replication of the centrioles occurs in animal cells.
- The nucleus becomes enlarged and thin



2. M-phase

Nuclear division take place during **mitosis** and the chromatids containing replicated DNA are separated from each other and redistributed as chromosomes in the nuclei of the two new daughter cells

Nuclear division. This is where the contents of the nucleus divide and is distributed in the daughter cells.

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Mitosis: is the process of nuclear division which involves four stages; **Prophase, metaphase, anaphase and telophase.** It lasts about 1 hour.

3. Cell division (cytokinesis)

It is s process of division of the cytoplasm (cytokinesis) to form two daughter cells. **Or** this is where the cytoplasm content divides and is distributed in the daughter cells. The cell membrane constricts to surround the formed cells each containing a nucleus. This results into formation of daughter cells. The length of the cycle depends on the type of cell and external factors but takes between 8 and 24 hours.

TYPES OF CELL DIVISION

1. **Mitosis**
2. **Meiosis**

MITOSIS

This is a type of cell division in which the parent cell divides to give rise to two identical daughter cells having exactly the same number of chromosomes as the parent cell. This implies that mitosis maintains the chromosome number. Mitosis occurs in somatic cells and also can occur in haploid, diploid and polyploidy cells.

STAGES OF MITOSIS

The stages of mitosis include the following;

1. Prophase
2. Metaphase
3. Anaphase
4. Telophase

1. PROPHASE

This is the longest stage of cell division. It is sub-divided into two sub stages, early prophase and late prophase.

During early prophase the following changes occur in the cell;

- Chromatin threads coil and condense (thicken/fatten) & shorten and become visible as single threads with bead like structures in the middle known as centromere.
- Each chromosome is seen to consist of a pair of chromatids lying parallel to each other and associated at the centromere. Each chromatid has the same cell genetic composition as the other.
- Centrioles migrate to the opposite poles in case of animal cells.
- The centrioles begin to synthesis spindle fibres that grow towards the nuclear membrane.
- Establishment of the poles and migration of the centrioles to opposite poles of the cell.

In case of animal cells

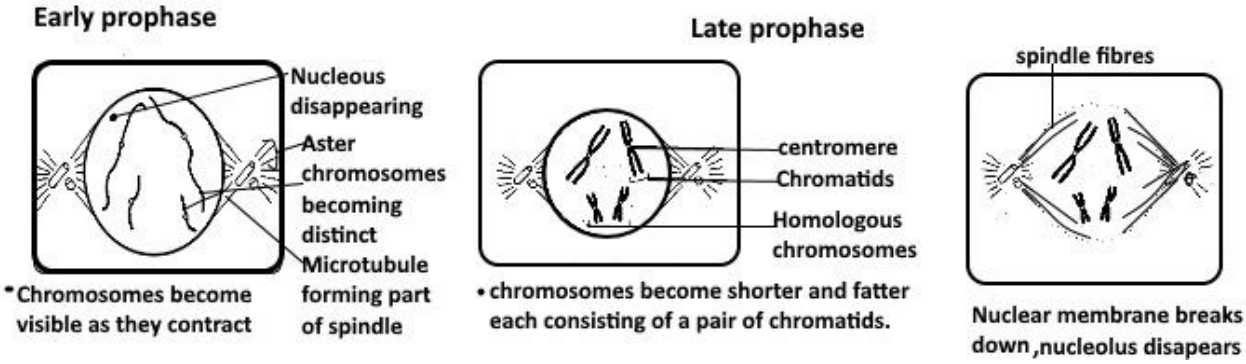
- The centrioles begin to synthesis spindle fibers that grow towards the nuclear membrane.
- The nucleus starts shrinking.
- Spindle fibres begin to form

By the late phase the following changes will have taken place in the cell;

- Further condensation of chromosomes takes place and each chromosome is seen to consist of a pair of chromatids joined at the centromere i.e.
- **The chromosomes** further contract and become more clearly visible.

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- The spindle fiber development is completed and these meet at the centre of the cell a point known as the equator of the spindle.
- The nucleolus completely disappears.
- The nuclear membrane completely breaks down.
- Each chromosome divides up longitudinally into two sister chromatids held together at the centromere.



Note:

- An **aster** refers to a radial array of short microtubules that extend from a centromere to the cell surface.
- Spindle fibres originate from Golgi apparatus in plant cell
- A centrosome is non-membranous region at the pole of the cell containing centrioles which organizes the microtubules of the cell

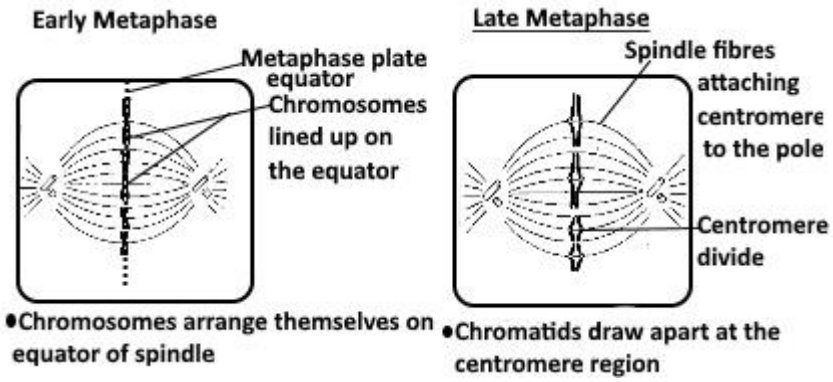
2. METAPHASE

This is the second stage of mitosis also having early metaphase and late metaphase.

During this stage the chromosomes line **up at the equator of** the spindle independently attached by their centromere to the spindle fibers i.e. homologous chromosomes do not associate together.

- Chromosomes move to the central plane of the cell and arrange themselves at the spindle equator, independently attached to the spindle fibres by their centromeres.
- Homologous chromosomes do not associate and so each attaches itself at its own spindle fibre.
- The spindle fibres (microtubules) start contracting and draw individual chromatids slightly apart, orienting them towards opposite poles.

At late metaphase the sister chromatids slightly repel each other at the centromere due the contraction of the spindle fibres which also occurs slightly, thereby orienting the chromatids towards opposite poles.

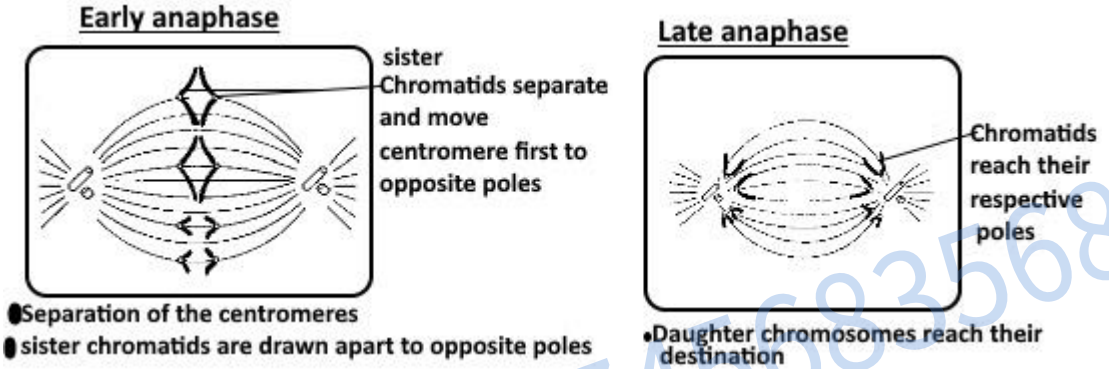


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3. ANAPHASE

This is the third and shortest stage of mitosis. It is divided into early anaphase and late anaphase. During early anaphase, the centromere split and the spindle fibers contract and start pulling the daughter centromeres formed together with the sister chromatids attached to opposite poles of the cell, the fibres continue coiling thereby becoming shorter and this process uses a lot of energy in form of ATP.

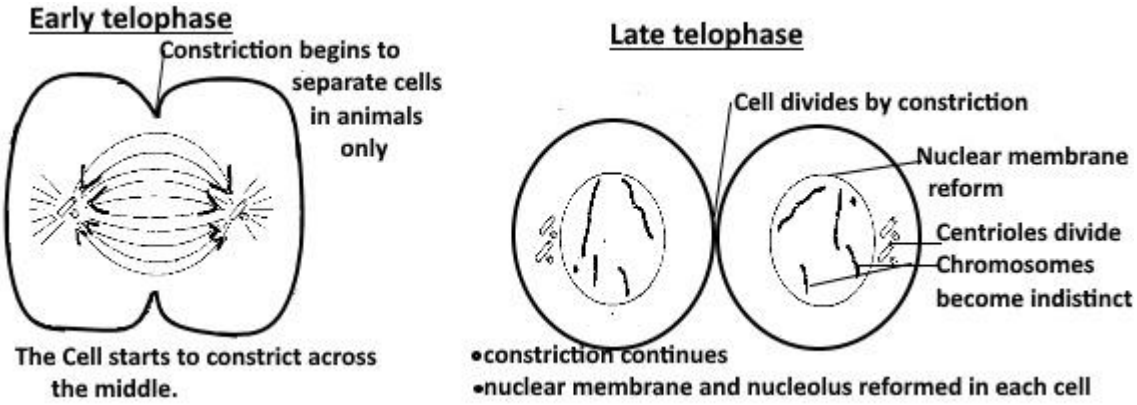
- The centromeres are split into two and chromatids are separated.
- The spindle fibres continue to contract and shorten and pull chromatids towards the opposite poles using energy from hydrolysis of ATP.
- This stage ends when the daughter chromosomes have reached the opposite poles.
- By late anaphase the chromatids will have reached the poles of the cell.



4. TELOPHASE

This is the last stage of mitosis and it involves the following changes;

- The chromatids at the pole uncoil and lengthen to form chromatin and become invisible again i.e. the chromatids become chromosomes which uncoil and gain their thread like nature
- The nucleolus and nuclear membrane reappears.
- The spindle fibers breakdown
- A nuclear membrane reforms around the chromosomes at each pole.
- The cell constricts in the middle which separates the mother cell into two daughter cells each having the same number of chromosomes as the mother cell.



In animals, this involves the constriction of the cell membrane to form a cleavage furrow which cuts across the equator dividing the cell into two.

Separation of the mother cell into two daughter cells including the division of the cytoplasm is described **as cytokinesis.**

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Cytokinesis in animal cells is brought about by the alignment of the micro filament in the middle of the cell. When the microfilament contract, a furrow is formed from either side of the cell and when these furrows become big enough, the mother cell divides into two daughter cells.

Cytokinesis in plant cells

Mitosis in plant cells is similar to that in animal cells except that,

- Plants do not have centrioles and their spindle fibers are produced by the Golgi body
- Cytokinesis in plants does not involve formation of furrows but instead a primary cell wall develops in the middle of the mother cell to separate it into two daughter cells.

In plants, a cell plate develops in the middle of the cell. Where by membrane-enclosed vesicles derived from the Golgi apparatus migrate to the centre of the cell and fuse to form a cell plate.

Eventually, the growing cell plate fuses with the existing plasma membrane, its deposited with callose and cellulose to form a cell wall, producing two daughter cells, each with its own plasma membrane.

The development of the primary cell wall begins with small vesicles that line up across the mother cell and eventually fuse together to form a cell plate which later becomes the primary cell wall

During telophase in plant cells, the vesicles derived from the Golgi apparatus move along microtubules to the middle of the cell where they fuse together to produce a cell plate. The cell wall materials carried in the vesicles collect in the cell plate as it grows. The cell plate then enlarges due to these materials until its surrounding membrane fuses with the plasma membrane along the perimeter of the cell. Two daughter cells result each with its own cell membrane and a new cell wall arising from the contents of the cell plate separates the two daughter cells. This is illustrated in the diagrams below;

In plants, mitosis occurs in.

- ❖ Meristematic (growing) tissues at the tips of the roots and shoots
- ❖ Cambium tissues.
- ❖ Buds

In animals, mitosis occurs in.

- ❖ The somatic cells e.g. bone cells, Malpighian layer of the epidermis of the skin

Differences between mitosis in plant and animal cells

Plant cell	Animal cell
Higher plants lack centrioles and do not form asters during mitosis	They have centrioles and so form asters during mitosis
Cytokinesis involves formation of a cell plate across the equator from the centre outwards	Cytokinesis involves constriction of the cell forming a cleavage furrow from outside to the inside, along the equator
Only meristematic cells undergo mitosis (shoot and root apex)	Most animal cells are capable of mitosis apart from gametes.

Similarities

- In both, chromatids move to opposite poles
- In both cytokinesis occurs
- In both the process uses energy from A.T.P

Separation of the mother cell into two daughter cells including the division of the cytoplasm is described as cytokinesis.

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Cytokinesis in animal cells is brought about by the alignment of the micro filament in the middle of the cell. When the microfilament contract, a furrow is formed from either side of the cell and when these furrows become big enough, the mother cell divides into two daughter cells.

Importance of mitosis

a. It maintains the chromosome number of the daughter cells similar to that to the parent cell i.e. it creates genetic stability. The chromosomes in the daughter cell carry the same genetic information in their genes similar to that of the parental chromosomes from where they were formed by replication. The daughter cells are therefore genetically identical to the parent cell and no variation in genetic information can be introduced in mitosis. This result in genetic stability within populations derived from cells made by mitosis.

b. It promotes growth and repair of the body as it increases the number of cells within an organism to cause growth. In addition cells are constantly dying and being replaced by mitosis to form new cells.

c. It is a basis for asexual reproduction.

d. It promotes formation of gametes in organisms that reproduce by parthenogenesis (in animals) e.g. male bees called drones, aphids i.e. the development of an organism from unfertilized eggs e.g. bees, aphids and parthenocarpy in plants e.g. pineapples.

e. Mitosis enables regeneration to occur. During regeneration, some animals are able to regenerate (re-develop) whole parts of their bodies such as legs in crustacean and arms in starfish.

Summary on the Significance of mitosis

- Mitosis ensures genetic stability of cells obtained from the parent cell by maintaining a diploid number of chromosomes.
- It promotes growth in multi cell organisms
- It is important for repairing and replacement of cells and tissues
- It is important for a sexual reproduction to take place
- It is used for regeneration of parts of the body in some animals.

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MEIOSIS (reduction division)

This is the process where by four daughter cells are formed, each with half the number of chromosomes as the parent cell. **Or** This is the form of cell division in which the diploid mother cell undergoes two successive nuclear divisions to form four haploid daughter cells which are genetically different from each other and also have half the number of chromosomes of the mother cell.

In other words, meiosis is the process of formation of 4 haploid daughter cells from a parent cell. Meiosis however is divided into the first stage i.e. Meiosis I/first meiotic division and the second stage i.e. Meiosis II/second meiotic division.

Interphase

This is the first stage of meiosis I. The features of this stage are the same as those of Interphase of mitosis and these include:

- ❖ Replication of DNA and cell organelles.
- ❖ Formation of energy in form ATP.
- ❖ Chromosomes are in long, thin, coiled form called **chromatins**

Meiosis occurs in gonads (gamete producing cells called germ cells) such as ovaries in females and testes in males where the diploid germ cells produce gametes which are haploid. Therefore meiosis occurs during gametogenesis in animals and also during spore formation in plants as well as formation of gametes in flowers (pollen grains and the ovules).
A gamete is sexually reproducing cell which cannot develop further unless it fuses with another gamete cell.

Importance of meiosis

- It leads to the production haploid gametes in sexual reproduction.
- it ensures a constant no of chromosomes in the offspring as the diploid condition is restored when haploid gametes fuse.
- When gametes with haploid number of chromosomes fuse together at fertilization to form the zygote, the diploid number is restored in the offspring form.
- it promotes genetic variety via crossing over at the chiasmata during prophase I and also via independent assortment and segregation of homologous chromosomes during metaphase (I).

It brings about genetic variation among organisms which is a raw material for evolution of new species.

- It is a basic for sexual reproduction since it leads into gamete formation.

STAGES OF MEIOSIS

Meiosis is sub divided into two phases i.e. meiosis I (first meiotic division) and meiosis II (second meiotic division), each of which is subdivided into four stages namely: prophase, metaphase, anaphase and telophase.

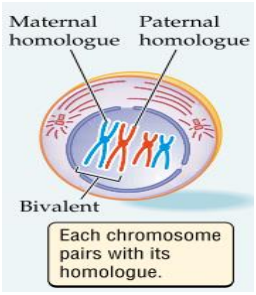
Meiosis I

After Interphase, the cell goes through

- ❖ Prophase I
- ❖ Metaphase I
- ❖ Anaphase I
- ❖ Telophase I

Prophase I

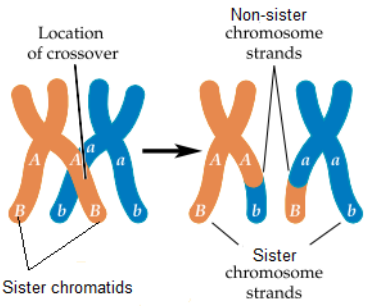
- During this stage the chromatins, thicken, shorten, and become visible **chromosomes.**
- The homologous chromosomes move close together to form a pair called **bivalen**t of which one pair comes from the male parent and the other pair from the female parent.
- The process by which the homologous chromosomes come together in prophase I of meiosis to form a pair of bivalent is known as **synapsis**.i.e.the process of formation of the bivalent
- Afterwards, the homologous chromosomes slightly separate and remain in contact at a position called **chiasma** (plural **chiasmata).**



Portions of non-sister chromatids of both chromosomes break at the chiasmata and become exchanged, a process known as **crossing over.**

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Diagram showing crossing over



Crossing over is the exchange of genetic material between two non-sister chromatids of homologous chromosomes. Crossing over enhances gene mixing and hence leads to genetic variation (differences).

During this stage the non-sister chromatids of the homologous chromosomes overlap and join together at a points known as chiasmata. At the chiasmata the non-sister chromatids break as the homologous chromosomes continue repelling each other and then the broken segments portions which contain genes are exchanged between the non-sisters chromatids to form new chromosomes.

This process by which the non-sister chromatids break and exchange their genetic material is known as **crossing over**. This is the basis for genetic variation among the gametes and among the offsprings that are formed later. During crossing over, the genes from one chromosome are exchanged with the genes from the other chromosome in a pair, leading to a new combination of genes in the resulting chromatids.

Note:

- Crossing over occurs by chance in the chromosomes
- The chromosomes formed by the exchange of genetic material during crossing over are called recombinant chromosomes and the gametes which contain such chromosomes are called **combinant chromosomes**.

Chromosomes which do not undergo crossing over are known as parental chromosomes

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Early prophase I

- they contract/thicken and shorten become visible
- **The Centrioles** migrate towards opposite poles and start manufacturing spindle fibres.
- nucleolus shrinks

Mid prophase I

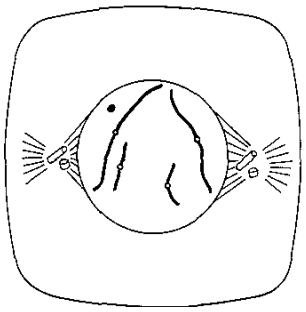
- Homologous chromosomes come together forming a bivalent
- nucleolus disappear

Late prophase I

- Eac h chromosome divides up longitudinally into two sister chromatids held together at the centromere
- The nucleolus shrinks and disappears.
- Crossing over takes place at the chiasmata
- Nuclear membrane breaks down

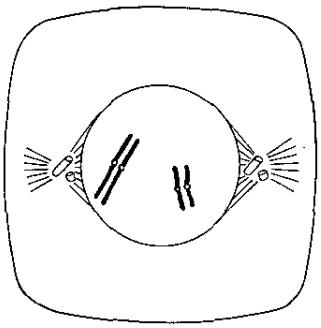
B Early prophase I

Chromosomes contract, becoming more clearly visible. Nucleolus shrinks.



C Mid prophase I

Homologous chromosomes come together (synapsis) forming a bivalent.



Prophase I

This is the longest part of meiosis 1 and it is subdivided into five sub stages namely;

a. Leptotene

b. Zygotene

c. Pachytene

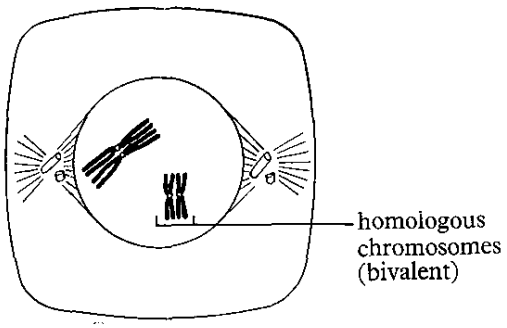
d. Diplotene

e. Diakinese

a. Leptotene

D Late prophase I

Each chromosome seen to consist of a pair of chromatids.



This is the first step of prophase I and it involves the following changes

- Establishment of the poles of the cell
- The centrioles migrate to opposite poles of the cell
- The centrioles begin to synthesize spindle fibres
- The chromosome begin to condense and are seen as single threads with beadlike structures in the middle called centromeres i.e The nucleolus and the nuclear membrane begin to break down and eventually they disappear completely

b. Zygotene

In this stage, **f**urther condensation of the chromosomes occurs and each chromosome is seen to consist of a pair of sister chromatids joined at the centromere. The homologous chromosomes move close to each other, one from the male parent and the other pair from the female parent.

The process by which the homologous chromosomes come together in prophase I of meiosis to form a pair of bivalent is known as **synapsis**.

The homologous chromosomes move close together to form a pair called **bivalen**t of which one pair comes from the male parent and the other pair from the female parent.

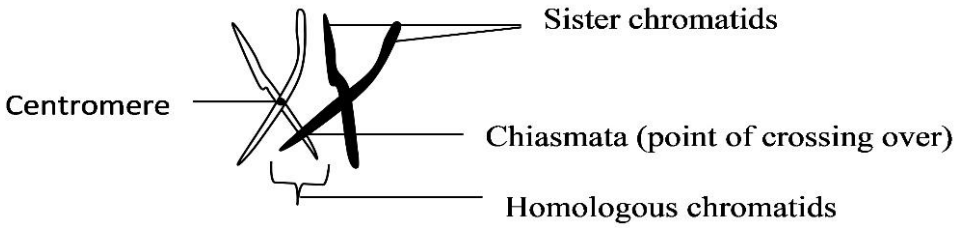
c. Pachytene

At this sub stage the homologous chromosomes repel each other and are partially separate but remain joined together at a point called **chiasma**.

In this stage the non-sister chromatids of the homologous chromosomes overlap and join together at a points known as chiasmata. At the chiasmata the non-sister chromatids break as the homologous chromosomes continue repelling each other and then the broken segments portions which contain genes are exchanged between the non-sisters chromatids to form new chromosomes.

This process by which the non-sister chromatids break and exchange their genetic material is known as **crossing over**. This is the basis for genetic variation among the gametes and among the offsprings that are formed later. During crossing over, the genes from one chromosome are exchanged with the genes from the other chromosome in a pair, leading to a new combination of genes in the resulting chromatids.

Diagram to illustrate crossing over



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Note:

- Crossing over occurs by chance in the chromosomes
- The chromosomes formed by the exchange of genetic material during crossing over are called **recombinant chromosomes** and the gametes which contain such chromosomes are called **combinant chromosomes**.
- Chromosomes which do not undergo crossing over are known as parental chromosomes

d. Diplotene

In this stage, the chromatids of homologous chromosomes continue to repel each other and this makes bivalents to assume particular shapes depending upon the number of chiasmata.

e. Diakinesis (Terminalisation)

During diakinesis continued repulsion of homologous chromosomes occurs between the homologous chromosomes that are still fixed by chiasmata, this pushes the chiasmata towards the ends of the chromatids a process known as **terminalisation**.

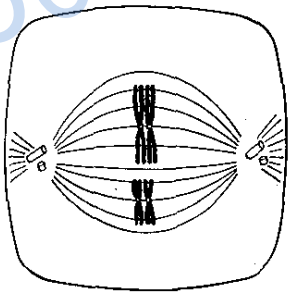
However the chiasmata remains holding the non-sister chromatids towards the end of the chromatids. After terminalisation, the chromosomes completely separate and this marks the end of prophase I.

2. **Metaphase I**

During this stage, the homologous chromosomes live up together at the equator of the spindle inform of bivalents. The chromosomes occupy one spindle fibre at the equator of the spindle and so the chromosomes are said to have associated.

- The nuclear membrane continues to shrink and eventually disappears.
- The spindle fibres become fully formed.
- Homologous chromosomes assemble on the spindles fibers, while in association.
- Homologous chromosomes slightly separate from each other, and project themselves towards the opposite poles.

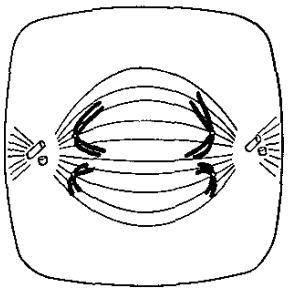
E Metaphase I
Chromosomes arrange themselves on equator of spindle



During this stage chromosomes are distributed randomly at the equator of the cell and **segregate (separate) independently** which leads to the mixing of genes in the daughter cells formed at the end of meiosis. This results into genetic variation.

3. **Anaphase I**

F Anaphase I
Homologous chromosomes part company and migrate to opposite poles of the cell.



The spindle fibers undergo spiral coiling thereby pulling the homologous chromosomes on them to opposite poles due to contraction of the proteins that make up these fibres. The homologous chromosomes part company and move towards the pole of the cell. By late anaphase1, the chromosomes will have reached the poles.

4. **Telophase I**

This stage occurs when homologous chromosomes arrive at the poles. The following events take place;

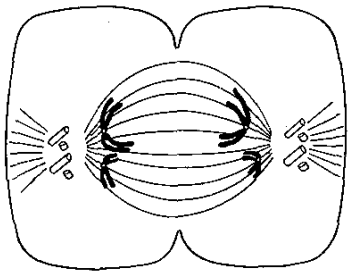
- The mother cell constricts to divide into two daughter cells.
- Homologous chromosomes regain their thread-like nature at the poles and become invisible again

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- The nucleolus and the nuclear membrane reappear so as to enclose the chromosome.
- The spindle fibers breakdown and cytokinesis then occurs as in mitosis.

This halves the diploid chromosome number into the haploid number into the two daughter cells. The chromosomes arrange themselves across the middle of the two daughter cells and each daughter cell undergoes a second meiotic division to form two more daughter cells.

G Telophase I
The chromosomes have reached their destination and the cell constricts across the middle as in mitosis.



The mother cell constricts to divide into two daughter cells.

This halves the diploid chromosome number into the haploid number into the two daughter cells. The chromosomes arrange themselves across the middle of the two daughter cells and each daughter cell undergoes a second meiotic division to form two more daughter cells.

Late telophase I

Each formed daughter cell undergoes the second meiotic division leading to formation of 4 daughter cells each with half the number of chromosomes of the parent cell.

MEIOSIS II

After meiosis II, each of the daughter cells formed enters a short interphase period. During this period, the cells synthesize more ATP and replication of cell organelles such centrioles occur. **However**, during this interphase period replication of DNA chromosomes does not occur. Meiosis II is also sub divided into four stages namely; prophase II, metaphase II, anaphase II, and telophase II.

The events which occur during meiosis II are similar to those of mitosis as summarized in the diagrams below;

As shown in the diagrams above, the two haploid daughter cells formed in meiosis I immediately undergoes metaphase II in most cases, prophase II is very rare BUT when it occurs the following events occur;

- The centrioles move to opposite poles
- The nucleolus and nuclear membrane break down
- New spindle fibres are formed in each of the two daughter cells of meiosis I

a. Metaphase II

The chromosomes line up individually on the equator of the spindle as in meiosis.

b. Anaphase II

The centromeres split and chromatids of the two chromosomes in each cell separate and move to opposite poles due to spiral coiling of spindle fibers.

c. Telophase II

Each cell divides by constricting across in the middle. The chromatids unwind and become indistinct so as to become chromosomes. Four new cells form each half the number of chromosomes compared to the original parent cell. The genetic composition of a chromosome is altered by the crossing over of prophase I and events of metaphase I.

As in mitosis the spindle fibers disappear and the nucleus, nucleolus as well as the nuclear membrane reform such that the cells enter interphase.

Meiosis brings about genetic variation in the following ways

a. By crossing over between homologous chromosomes during the pachytene stage of prophase I which separates linked genes on the chromosomes and rearranges these genes which were originally

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located on the same chromosome. This leads to a variety of new gene recombinations on the chromosome in the daughter cells which leads to genetic variation.

b. During metaphase I, homologous chromosomes are distributed randomly at the equator of the cell and aggregate independently leading to the mixing of genes in the daughter cells formed.

c. It results into the formation of haploid cells (gametes) which when fused randomly at fertilization results into offsprings with different genetic constitution due to the recombination of the parental genes.

COMPARISON BETWEEN MITOSIS AND MEIOSIS

SIMILARITIES

- Both involve four stages of cell division namely; prophase, metaphase, anaphase and telophase.
- Both require the interphase period before they occur.
- Both are energy consuming processes i.e. they require ATP.
- Both can lead to the formation of gametes.
- Both involve condensation of the chromosome
- Both involve nuclear division and cytokinesis.

DIFFERENCES

MITOSIS	MEIOSIS
• It results into formation of two daughter cells	It results into formation of four daughter cells
• Daughter cells which identical to the mother cell	Daughter cells are different to the mother cell
• It occurs in somatic cells during growth and developing and in asexual reproduction	It occurs during the formation of gametes in germ cells
• No crossing over occurs	Crossing over occurs.
• It occur in haploid, diploid and polyploidy cells	It occurs in diploid cells only
• Prophase is sub divided into early and late stages	Prophase I is sub divided into five stages namely; leptotene, zygotene, pachytene, diplotene and diakinesis.
• Chiasmata are not formed	Chiasmata are formed
• Homologous chromosomes do not associate	Homologous chromosomes associate
• There is no formation of bivalents	Bivalents are formed in prophase I.
• It involves only one nuclear division	It involves two successful nuclear divisions
• It maintains the chromosomes number between the daughter cell and mother cell.	It halves the chromosome number of the mother cell within the daughter cells formed.
• It takes a shorter time	It takes a longer time
• Chromosomes form a single raw at the equator of the spindle during metaphase I	Chromosomes form a double raw at the equator of the spindle during metaphase I
• Chromatids move to the opposite poles.	Chromosomes move to the opposite poles during meiosis I

Cell cycle is the sequence of events which occur between one cell division and the next

Changes that occur in the nucleus during meiosis

During interphase, the cell is non dividing condition and its DNA and some cell organelles undergo replication. There is also synthesis of ATP molecules.

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Early prophase I

- Chromosomes contract or condense becoming shorter, thick and clearly visible.
- Homologous, chromosomes come together thereby forming bivalents.
- Spindles begin to form from the centrioles at opposite poles
- Chiasmata formation and closing over may occur

In late prophase, each chromosomes is seen to consist of two chromatids
Nucleolus breaks down and disappears.
The nuclear envelope also breaks down

During metaphase I

- chromosomes arrange themselves on the equator of the spindle fibres by their centromeres
- Homologous chromosomes or bivalents behave as a unit.
- Homologous chromosomes undergo independent or random assortment and segregation.

During anaphase I

- Spindle fibres contract pulling homologous chromosomes apart towards opposite poles.

During telophase I

- The chromosomes reach their destination or the opposite poles.
- The nuclear envelope may form around each group of chromosomes
- Cytokinesis take places and the cells may enter interphase (ii) without replication of DNA.

During prophase II

The centrioles have already replicated and they move to opposite poles at right angles to the plane of, previous division and therefore the spindle fibres are formed at right angles to the spindle axis of the first division.

Metaphase II

Chromosomes arrange themselves at the equator of the spindle fibres without association and their centromere split up enabling the sister chromatids to project towards opposite poles.

Anaphase II

Sister chromatids are pulled to opposite poles

Telophase II

The chromatids reach the opposite poles and uncoil and regain their thread like form.

- Nucleolus and nuclear membranes are reformed
- Spindle fibres disappear
- Each cell constricts in the middle and eventually divides into two daughter cells.

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Differences between prophase I of meiosis and prophase of mitosis

prophase I of meiosis	prophase of mitosis
• There is synapsis	There is no synapsis
• There is chiasmata formation	There is no chiasmata formation
• There is crossing over	There is no crossing over
• There is mixing of genetic material between homologous chromosomes	There is no gene mixing

How meiosis result into variation and evolution

During crossing over at the chiasmata there is mixing up of genetic material which can result into different genetic combination in the gamete hence genetic variation.
Due to genetic variation the well adapted organism tends to have a survival and reproductive advantage over the poorly adapted due to selection pressure of nature.
This enhances transmission of the adapted characteristic to offsprings of the subsequent generation which can undergo adaptive radiation and evolution of new species.

Significance of meiosis

- Because meiosis occurs in reproductive cells, it(meiosis) is important for gamete formation
- Meiosis, by leading to formation of haploid gametes helps in formation of diploid organisms via fertilization in every generation
- During crossing over, there is gene mixing which can lead to **genetic variation**
- Genetic variation among organisms due to crossing over can lead to **evolution**
- By forming gametes, meiosis serves as a basis for sexual reproduction

Where does meiosis occur?

❖ In animals, Meiosis occurs in testes and ovaries

❖ In plants, Meiosis occurs in ovary and anther heads

Differences between meiosis and mitosis

MEIOSIS	**MITOSIS**
Occurs in gamete producing cells	occurs in somatic cells
Mainly for gamete formation	Mainly for growth.
Four daughter cells are formed from the parent cell	Two daughter cells are formed from the parent cell
Each daughter cell has haploid (half) number of chromosomes	Each daughter cell has diploid (double) number of chromosomes.
Occurs in two phases i.e. meiosis I and meiosis II	Occurs in one phase only.
There are bivalents formed	No bivalents formed.
Synapsis occurs	Synapsis does not occur
Chiasmata are formed	No chiasmata are formed.
There is crossing over	No crossing over occurs.
Homologous chromosomes assemble on the spindle with association.	Homologous chromosomes assemble on the fibres without association.
Leads to genetic variation.	No genetic variation occurs
Homologous chromosomes migrate to opposite poles during Anaphase I	Sister chromatids migrate towards opposite poles
Leads to evolution	Does not lead to evolution.
Serves as a basis for sexual reproduction.	Serves as a basis for asexual reproduction
Takes a long period of time.	Take a short period of time.

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Similarities between meiosis and mitosis.

1. They all involve Interphase, Prophase, Metaphase, Anaphase and Telophase.
2. There is disappearance of the nucleus and nuclear membrane in both
3. They both involve use of energy
4. All involve formation of daughter cells from parent cells
5. They all involve division of the cell i.e. Karyokinesis and cytokinesis.
6. They involve formation of spindle fibres.
7. They all involve assembling of homologous chromosomes on the spindle fibres.

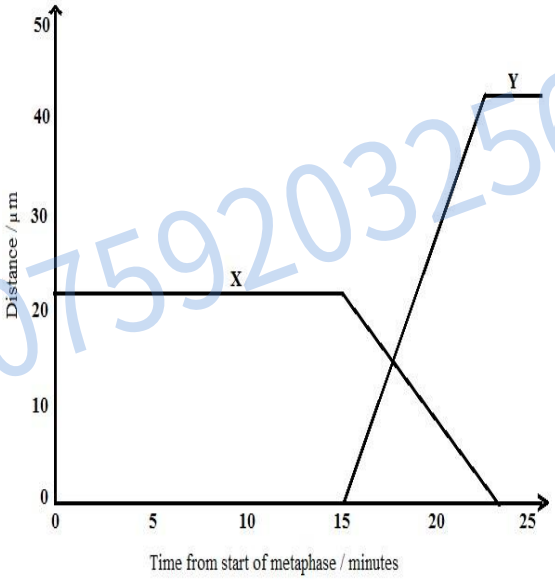
How Meiosis brings about genetic variation.

a. By **crossing over** between homologous chromosomes during. This leads to a variety of new gene recombination on the chromosome in the daughter cells which leads to genetic variation.

b. **During metaphase I,** homologous chromosomes are distributed randomly at the spindle equator of the cell and are moved independently leading to the mixing of genes in the daughter cells formed.

c. It results into the formation of haploid cells (gametes) which when fused randomly at fertilization results into offspring with different genetic constitution due to the recombination of the parental genes.

1. The graph below shows how the position of centromeres change during mitosis. Line X is the distance between the centromeres and the ends of the spindle. Line Y is the distance between the centromeres of pairs of chromatids. Measurements started at the beginning of metaphase. (Adopted from Advanced Molecular sciences By Mike Bailey and Keith Hirst, 2nd edition)



(a) How long was;

(i) Metaphase?

15 minutes;

(ii) Anaphase?

8 minutes;

(b) What was the distance between the poles of the spindle in this cell?

44µm;

(c) Explain the trend in distance represented by i) curve **X**

From <u>0 to about 15 minutes</u> the distance between centromeres of chromatids and poles of the cell remains constant; and relatively long; because the cell is in metaphase stage chromosomes are at metaphase plate (half-way between the poles); with sister chromatids still held at centromeres;

From about <u>15 minutes to about 23 minutes</u> the distance between centromeres of chromatids and poles of the cell decreases rapidly; to 0 µm; because after splitting during anaphase stage; sister chromatids are pulled rapidly towards poles by microtubules (spindle) ; and eventually arrive at the poles during telophase stage;

(i) curve **Y**

<u>15 minutes to about 23 minutes</u> the distance between the centromeres of pairs of chromatids increases rapidly; because during <u>anaphase</u>; the chromatids are pulled apart by spindles;

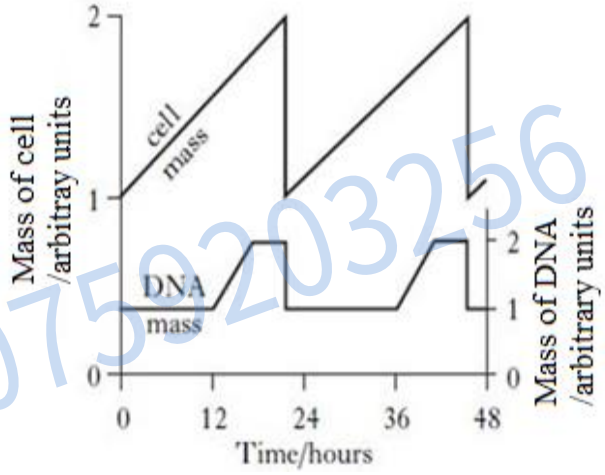
<u>From about 23 minutes to 25 minutes the</u> distance between the centromeres of pairs of chromatids remains constant; because during <u>telophase</u>; the centromeres remain the same distance away from each other at the poles;

(d) Explain the variation in the maximum distance achieved in X and Y

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	The maximum distance for **Y** (between centromeres of sister chromatids) is almost (**twice); longer** than for **X** (distance between centromeres of chromatids and poles) **;** During metaphase, chromosomes are at metaphase plate which is equidistant from either pole of the cell therefore maximum for X is shorter**;** Maximum for Y is longer since spindles pull chromatids to the extremes of the cell (poles) which are very distant apart**;**

2. The figure below shows changes in the quantities of nuclear DNA and cell mass during repeated cell cycle. (Adapted from BIOLOGY IN CONTEXT For Cambridge International A Level By Glen and Susan Toole)



(a) For one cell cycle only, describe the:

(i) Mass of DNA with time

One cell cycle lasts from 0 hour to about 23 hours**;**

From 0 hour to 12 hours**;** DNA mass remains constant**;** From 12 hours to about 18 hours**;** DNA mass increases**;**

From about 18 hours to about 23 hours**;** the DNA mass remains constant**;**

During the 23 hour**;** the mass of DNA decreases**;**

(ii) Mass of the cell with time

(c) For one cell cycle only, explain the trend in the:

(i) Mass of DNA with time

From <u>0 hour to 12 hours,</u> the DNA mass remains constant**;** This the first growth (**G_1**) phase**;** cell contents <u>replicate</u> except DNA**;**

From <u>12 hours to about 18 hours</u> the mass of DNA increases rapidly**;** This is the synthesis (**S**) phase**;** DNA <u>replicates</u> to double original mass**;**

<u>From 18 hours to about 23 hours</u> the mass of DNA remains constant**;** This is the second growth (**G_2**) phase**;** and mitosis**;** no DNA synthesis**;**

<u>During the 23 hour</u> the mass of DNA decreases very rapidly**;** This is because cytokinesis occurs**;** halving the DNA mass in each new cell to the original mass**;**

(ii) Mass of the cell with time

From 0 to about 23 hours the cell mass increases rapidly**;** this marks the period of interphase**;** and mitosis**;** during which organelles like mitochondria, cytoskeletal elements, endoplasmic reticula, ribosomes, Golgi apparatus, centriole, e.t.c. <u>replicate</u> and increase in number**;** and the cell grows (***G1 phase***)**;** DNA replicates**;** and the chromosome content doubles**;** histones and other nuclear proteins

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From 0 to about 23 hours; the cell mass increases; to a peak; During the 23 hour; the mass of the cell decreases; (b) For once cell cycle only, compare the mass of the cell and the mass of DNA, with time. (04 marks)	are synthesised (***S phase***) ; Synthesis of additional proteins that support cell metabolism occurs (***G2 phase***); During the 23 hour, the mass of the cell decreases very rapidly; cytokinesis divides the parent cell into equal sized daughter cells;

SUBTOPIC 2: DIVERSITY OF SPECIALIZED CELLS AND TISSUES

HISTOLOGY

This is the study of tissues.

A tissue is defined as a group of physically similar and linked cells, together with the associated intercellular substances, that is specialized for one or more functions.

Different tissues are often grouped together into a larger and distinct functional unit, called **an organ.**

Characteristics of tissues

- Cells of a tissue are physically linked
- The cells of a tissue may be interspaced with intercellular substances.
- Cells of a tissue share similar origin in the embryo
- A tissue may comprise one or more types of cells
- A tissue is specialized to perform a particular function(s)

A collection of tissues together as a functional unit is called **an organ** such heart, stomach, ileum.

A collection of organs and associated tissues working together as functional unit is called an **organ system, fo**r example the digestive system (duodenum, ileum, colon, and so on…), vascular system (heart, blood vessels, and so on…)

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PLANT TISSUES

Plant tissues vary depending on the age of the plant and the cell types that make up the tissue.

Depending on age, plant tissues can be divided into two;

a) **Temporary tissues/Meristematic tissues: T**hese include apical meristems, lateral meristems and intercalary meristems. They exist at the time of germination and they are replaced by other tissues in woody plants only. They also exist at the growing points of the shoot and root.

b) **Permanent tissues:** These replace the temporary tissues in all non-herbaceous plants.

Which are divided into two major groups;

i) Ground tissues, which include; **Parenchyma** tissues, **Collenchym**a tissue, **Sclerenchyma** tissue

ii) Vascular tissues, they include; Xylem and Phloem

Plant tissues may be made up of one cell type or many cell types and can be divided into two groups;

a) Simple plant tissues consisting of one type of cell. These are parenchyma, collenchyma, and sclerenchyma.

b) **Complex plant tissues** consisting of more than one type of cell. These are photosynthetic tissue and vascular tissues (xylem and phloem).

Therefor Plant tissues include;

1. **Meristematic tissues**
2. **Parenchyma tissues**
3. **Epidermal tissue**
4. **Photosynthetic tissue**
5. **Mechanical tissue**
6. **Vascular tissue**

MERISTEMATIC TISSUES

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

The **structure of Meristematic tissue**

- Meristematic cells are relatively small and cuboidal in shape.
- Cells have a thin cellulose cell wall.
- Meristematic cells have dense cytoplasmic contents
- Cells have few small vacuoles
- They also possess undifferentiated plastids called **proplastids**
- Meristematic cells are packed tightly together with no obvious air spaces between them.

A **Meristem** is a group of cells which retain the ability to divide by mitosis producing daughter cells, which grow to form the rest of the plant body.

The most important meristems are those occurring at the tip of the **shoot** and the **root,** called apical meristems

TYPES OF MERISTEMS

- **Apical meristems:** Meristems which divide by mitosis, continuously, and give rise to cells, which differentiate into the different tissues of the root and stem, resulting into their **primary growth**.
- **Lateral meristems (cambium):** Meristems which divide mitotically and result into secondary growth in dicotyledonous plants i.e. increase in girth of a dicotyledonous stem.
- **Intercalary meristems:** These meristems occur at the nodes of the plants

DISTRIBUTION, ROLE AND FUNCTION OF DIFFERENT TYPES OF MERISTEMATIC CELLS

Type of Meristem	**Distribution**	**Role and function**
Apical meristems	Found at root tip, shoot apex, and axillary buds	Divide continuously by mitosis, leading to primary growth of the plant body Differentiate into primary tissues to cause increase in length of shoot or root
Lateral meristem (cambium)	Laterally located in older parts of the plant, parallel with the long axis of organs for example cork cambium (phellogen) vascular cambium	Responsible for secondary growth of the roots and shoots Vascular cambium gives rise to secondary vascular tissue including secondary phloem and secondary xylem (wood) Cork cambium/phellogen gives rise to periderm, which replaces the epidermis and includes cork Secondary growth causes increase in the width/girth of roots and shoots Allows growth in length, in the regions other than the root and shoot tips
Intercolumn meristems /intercalary meristem	Located between regions of permanent tissues; for example at **nodes** of monocotyledonous plants, such as leaf bases of grasses such as base of the **internodes** and leaf sheaths of grasses	Causes increase in length of the plant body Differentiate in to primary tissues causing primary growth. Allows growth in length in regions other than tips. Causes increase in length of the internodes. Ensures continued growth where tips are damaged, for example through eating by herbivores, slashing of lawn grasses, or wave action in kelps. Removes necessity of branching from the main axis.

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B) Parenchyma

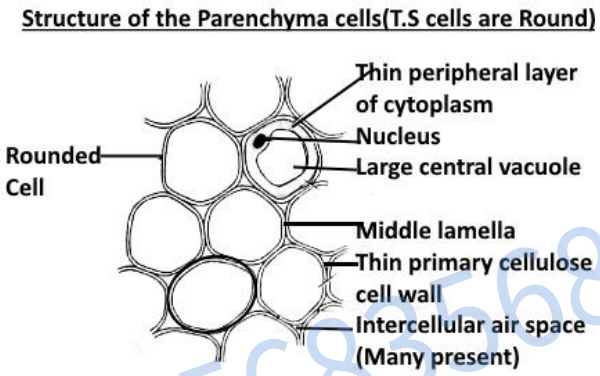
This is a plant tissue consisting of roughly spherical and relatively undifferentiated cells, frequently with air spaces between them.

Distribution of parenchyma

- They form packing tissues between more specialized tissues e.g cortex, pith and medullary rays.
- Found in the periphery of stems, roots and leaves.
- Parenchyma cells also found among the xylem vessels and phloem cells.

The structure of parenchyma tissue

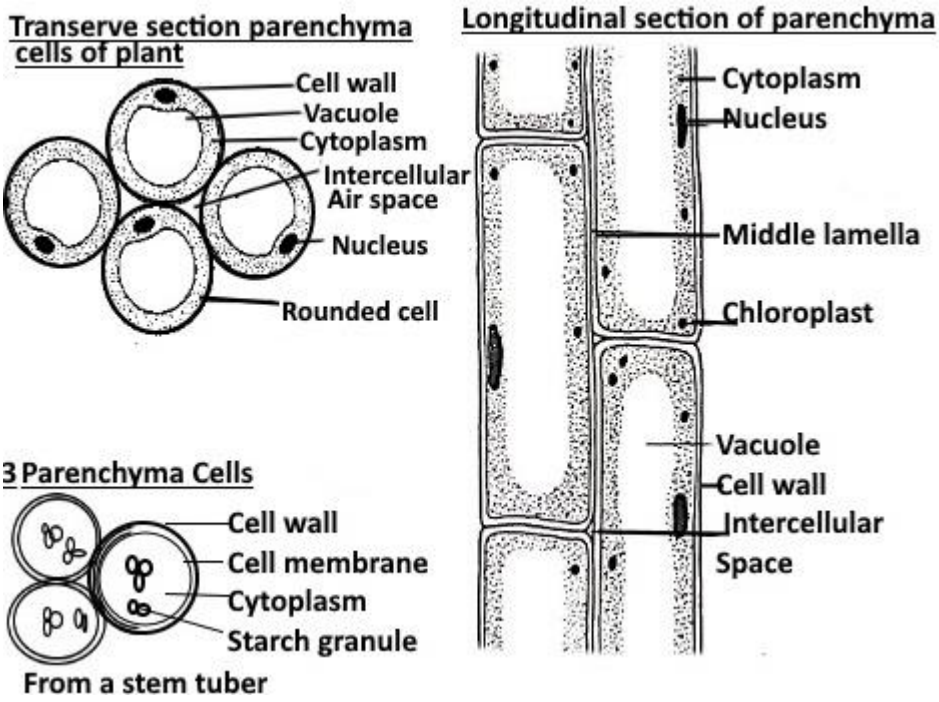
- Comprises of living cells which are relatively undifferentiated
- The cells are either roughly spherical or elongated
- Cells have thin cell walls containing cellulose, hemicellulose and pectin.
- The thin walls are permeable to water and permit the passage of solutes.
- Cells have many intercellular air spaces between them
- The cells have large central vacuoles with a nucleus and thin peripheral cytoplasm/thin layer of cytoplasm pushed to the membrane.



Functions of parenchyma

- They fill spaces between other tissues and hence acting as packing tissues between more specialized tissue of the plant as in the cortex
- Parenchyma cells are metabolically active as it is composed of living cells, for example, some parenchyma are photosynthetic due to presence of chloroplasts.
- Some parenchyma cells, like mesophyll cells, contain chloroplasts and carry out photosynthesis
- Some have intercellular air spaces between them to allow gaseous exchange
- Storage of food in storage organs such as stem tubers and roots due to possession of starch granules and large food vacuoles
- Transport of materials e.g. water through cell walls by apoplast pathway
- Turgid parenchyma cells and tightly packed, provide support to herbaceous plants and non-woody parts of the woody plants.
- The parenchyma cells in flowers and pericarps contain chromoplasts to attract pollinating agents and dispersal agents of seeds and fruits.

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Adaptations of parenchyma tissue for its function

- Has unspecialized tissue to perform a variety of functions.
- Have many intercellular spaces to allow diffusion of gases during gaseous exchange.
- Have isodiametric, roughly spherical or elongated cells to serve as packing material between specialized cells.
- Have thin cellulose cell walls to permit, passage of materials.
- Have transparent cell walls to allow entry of sun light for photosynthesis.
- Have permeable walls to allow osmotic entry of water which causes turgidity to provide support
- Have large cell walls with large vacuoles to provide space for storage of materials.
- Cells have chloroplasts to allow photosynthesis.
- Cells have leucoplasts such as amyloplasts to store food such as starch.
- Cells contain large quantities of sap to provide support by turgidity
- Cell walls contain cellulose, pectins, and hemicelluloses for support
- Cells are closely packaged to provide support when they become fully turgid because of osmotic uptake of water.

Modified parenchyma tissue

Modified parenchyma tissue include; epidermis, mesophyll, endodermis, pericycle, companion cells and transfer cells.

i) Epidermis/epidermal cells

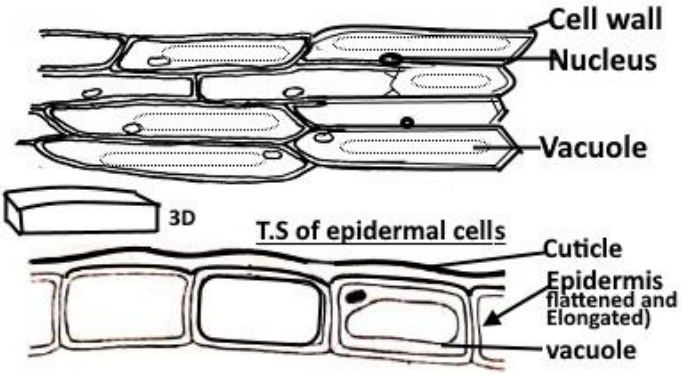
This is the outermost layer of one cells thick, covering the whole of the primary plant body.
The epidermal cells secrete waxy substance called **cutin** which forms a layer of **waxy cuticle** on the outer surface of the epidermis.

The structure of epidermis

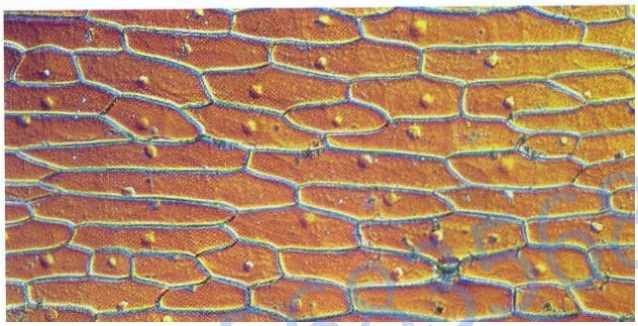
- Comprises of a layer of living, elongated and flattened cells.
- Lack intercellular air spaces

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- The cell wall comprises of cellulose, pectins and hemicelluloses and a covering of waterproof layer of **cutin**
- Cells are irregular in shape without intercellular spaces.
- The outer cellulose cell wall may be coated with a thick layer of cuticle.
- The cells have no chloroplasts with exception to guard cells.
- They may bear unicellular or multicellular hair.



Onion epidermal cells as seen under a light microscope



The distribution of the epidermis

- The epidermis occurs as a single layer of cells covering the entire plant body.
- Located in young stems and leaves forming plant outer surface.
- Located in leaves as in guard cells and as piliferous layer in roots.

Functions of epidermis

- The basic function of epidermis is to **protect** the plant body from desiccation and infection.
  The epidermal cells secrete a waxy substance which forms a layer called **cuticle,** which covers the epidermal cells and protect them from injury, infection and reduces water loss, from the plant.
- Some epidermal cells are modified to form guard cells, occur in pairs which control the opening and closure of the stomata allowing gaseous exchange and transpiration.
- Some epidermal cells tend to grow some **hair- like extensions,** either unicellular or multi-cellular, to serve various functions**, which include;**

1. Behind the root tip, there are unicellular root hairs for increasing the surface areas for water, and mineral salt absorption.
2. Some epidermal hairs of mainly the leaves and even stems, reduce water loss from the plant tissues, by trapping a film of moist still air near the plant, as well as reflecting sun's radiation.
3. Some plants e.g. the climbing plants, their epidermis has hooked hairs, to enable them be attached and supported on to another plant or any support.
4. Some epidermal hairs serve as barriers around the nectarines of flowers, preventing access to crawling insects and helping to promote cross-pollination by larger flying insects.
5. Some epidermal cells may be **glandular** and having hairs which can be used in carnivorous plants to trap and kill insects, by secreting a sticky substance, either for protection or may contain enzymes for digestion and subsequent absorption of food.
6. Some epidermal glandular hairs give off scent needed to attract pollinators.

Adaptations of epidermis to perform its functions

- Being transparent, the epidermis allows passage of light to the mesophyll cells for photosynthesis.
- Tightly packed cells to reduce water loss and to offer protection
- Transparent cells for easy penetrating of sun light for photosynthesis
- The epidermis is thick and tough to protect the inner tissues from mechanical damage.
- The epidermis secretes a waxy cuticle to reduce water loss and prevent pathogen entry.

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- Some epidermal cells are modified into guard cells which control the opening and closing of stomata pores to allow gaseous exchange.
- In roots, the epidermal cells grow unicellular, hair-like extensions, called root hairs which increase surface area for absorption of water and mineral salts.
- In climbing plants, the epidermal cells develop hooked hairs to prevent the stems slipping from their support as in goose grass (***Galium aparine***).
- The epidermal hairs of leaves and stems (pubescence) reduce water loss from the plant tissue, as well as by reflecting the suns radiation.
- Some epidermal hairs are short and stiff to offer mechanical and discourage herbivores for example the stinging nettle (***Urtica dioica***).
- The epidermis may develop hairs which form a barrier around the nectarines of flowers preventing access to crawling insects and help to promote cross pollination by large flying insects.
- Some epidermal cells are glandular and may secrete a sticky substance that traps and kills insects, either for protection or its secretions contain enzymes, for digestion and subsequent of food nutrients as in insectivorous plants.
- Some epithelial cells develop glandular hairs which produce scent needed to attract agents of pollination and as in the Lavender (***Lavendula***)

Note: During secondary growth the epidermis may be ruptured and replaced by a cork layer.

ii) Mesophyll/photosynthetic tissue (chlorenchyma)

Mesophyll is packing tissue located between the upper and lower epidermal layer of leaves, consisting of parenchyma modified for photosynthesis. Photosynthetic parenchyma cells are sometimes called **chlorenchyma.**

The cytoplasm of mesophyll cells contains chloroplasts which contain chlorophyll for absorption of sunlight energy, needed during the light stage of photosynthesis.

There are two types of mesophyll cells

1. Palisade mesophyll cells

Located below the upper epidermis layer.

Structure

- Cells are elongated and column-shaped.
- Contain a large number of chloroplasts. Most photosynthesizing cells
- Cells are tightly packed together with very few and narrow air spaces, which allows circulation of air

Function

It contains many chloroplasts for maximum sun light absorption for the leaf to carry out photosynthesis**.**

Adaptations

- Contain many chloroplasts for maximum light absorption for photosynthesis
- Cylindrical shape for lose packing
- One single layer for sun light to penetrate for photosynthesis

b. Spongy mesophyll cells

Located in the lower layer called the spongy mesophyll.

- Cells are spherical and irregularly shaped
- Have fewer chloroplasts than palisade cells to carry out photosynthesis.
- They are loosely packed with many intercellular air spaces between the cells.

Adaptations

- Cells are spherical in shape for loose packing
- Have large air spaces for circulation of air for gaseous exchange
- Have chloroplasts for trapping sun light for photosynthesis

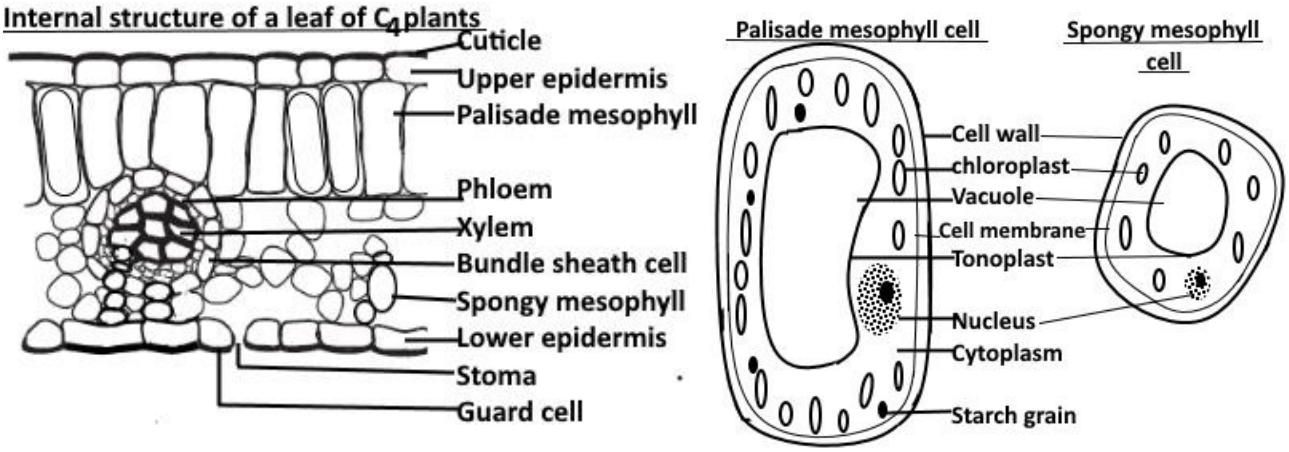
The distribution of mesophyll

Located between the upper and lower epidermis of leaves. I.e. below the palisade mesophyll cells

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Functions of mesophyll

- Contain chloroplast hence carry out **Photosynthesis**
- Intercellular air spaces hence they carry out **Gaseous exchange**
- Contain starch grain hence **store food**(starch)



Adaptations of mesophyll to its functions

- Palisade mesophyll cells with numerous chloroplasts to carry out photosynthesis.
- Palisade mesophyll cells tightly packed together forming continuous layer that absorbs light.
- Chloroplasts within the mesophyll cells can move towards light allowing them to arrange themselves in the best positions to receive light.
- Chlorophyll within chloroplasts is contained within the grana, where it is arranged on the sides of a series of unit membranes allowing chlorophyll to receive maximum light.
- Structural arrangement of chlorophyll on the photosynthetic membrane brings chlorophyll in close proximity to other pigments and substances, such as carotenoids and enzymes necessary for its functioning during light harvesting.
- Spongy mesophyll cells are irregularly shaped, hence fit together loosely leaving large air spaces to allow efficient gaseous via the stomata.
- Mesophyll cells contain numerous amyloplasts for storing starch.

iii) Endodermis

Endodermis is the inner most layer of the cortex, surrounding the vascular tissue of roots and stems.

The structure of the endodermis

- Consists of living elongated and flattened cells.
- The cell wall of endodermal cells comprise cellulose, pectins, hemicelluloses, and in places deposits of suberin.

The distribution of the endodermis

Found in the inner most layer of the cortex, surrounding the vascular tissue of roots and stems.

Functions of endodermis

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

Adaptations of endodermis to its functions

- In roots the endodermis is impregnated with **suberin** to form a distinct **casparian strip** and prevent the movement of water via the apoplast pathway.
- The casparian strip is impermeable to water and prevents water and solutes from flowing through the air spaces of the cell walls of the endodermal cells.

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- This forces water and solutes to pass through the cell surface membrane and into the cytoplasm of endodermal cells.
- This allows endodermal cells to control and regulate the movement of solutes through the xylem.
- Active pump of salts by endodermal cells into the xylem enables rapid movement of water by osmosis into the xylem, leading to a buildup of root pressure.
- Control of movement of water and solutes by endodermal cells acts as a protective measure, against the entry of pathogens and toxic substances into the xylem.
- In dicot stems, endodermal cells contain amyloplasts for storing starch grains forming a starch sheath.
- Sedimentation of starch grains inside endodermal cells in response to gravity enables plant geotropic response.

An illustration of endodermis//Bs 448

Iv) Pericycle

The pericycle is a layer of modified parenchyma, one to several cells thick, located in roots between the central vascular tissue and the endodermis.

The structure of the pericycle

Consists of one to several layers of living, roughly spherical and elongated cells.

Cells of the pericycle have cell walls composed of cellulose, pectins and hemicelluloses.

The distribution of the pericycle

Located in roots between the central vascular tissue and the endodermis.

Functions of the pericycle

- Produces lateral roots.

Contributes to secondary growth.

Modifications of the pericycle to perform its functions

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

v) **Companion cells**

Companion cells are specialized parenchyma cells found adjacent to sieve tubes

The distribution of companion cells

Adjacent to sieve tubes of the phloem

The structure of companion cells

- Have a prominent nucleus, dense cytoplasm with numerous small vacuoles, plastids and the usual cell organelles.
- Are metabolically very active, with numerous mitochondria and ribosome.
- Each companion cell is connected to a sieve element by plasmodesmata.

Functions of companion cells

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

Modifications of the companion cells for their function

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

vi) **Transfer cells**

Transfer cells are a modified form of parenchyma companion cell found next to the sieve tube.

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The structure of transfer cells

- Transfer cell have numerous internal projections of the cell wall formed by extra thickening of the cell wall.
- Posses numerous mitochondria in the dense cytoplasm.

Functions of transfer cells

- Active uptake of salts from neighboring cells

Distribution of transfer cells

Found adjacent to sieve tubes of phloem

Modifications of transfer cells to their function

- Numerous internal projections of the cell wall, increase the surface area of the cell surface membrane, lining the cell wall, and bring into closer association with the cytoplasm.
- Numerous mitochondria in the cytoplasm provide energy for active transport of organic solutes such as sugars from neighboring cells.

iii) Collenchyma

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

The structure of collenchyma

- Consists of living cells.
- Cell walls consist of cellulose, pectins and hemicelluloses.
- Cells are closely packed with thick cell walls.
- Cells are elongated and polygonal with tapering ends.
- Extra deposition of cellulose at the corners of the cells causing uneven thickening of cell walls.
- Cells elongated, parallel to the longitudinal axis, of the organ in which they are found.

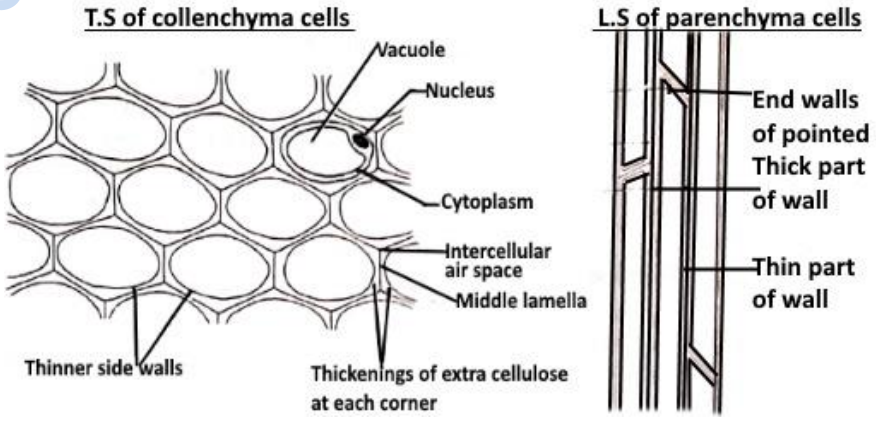
Distribution of collenchyma

Outer region of the cortex, as at angles of stem midribs of leaves.
Collenchyma is the first strengthening tissue to develop in a primary plant body.
Important in young plants, herbaceous plants, and in organs such as leaves, and flowers where secondary growth does not occur.

Functions of collenchyma

- Collenchyma is a mechanical strengthening tissue.
- Provides support for those organs where it's found

An illustration of the structure of collenchyma cells



Adaptation of collenchyma to its function

- Deposition of extra cellulose at the corner of cells leads to development of unevenly thickened cell walls to provide mechanical support.
- Cells are polygonal, closely packed and elongated parallel to the longitudinal axis of the organ where they are found to provide support and mechanical strength.

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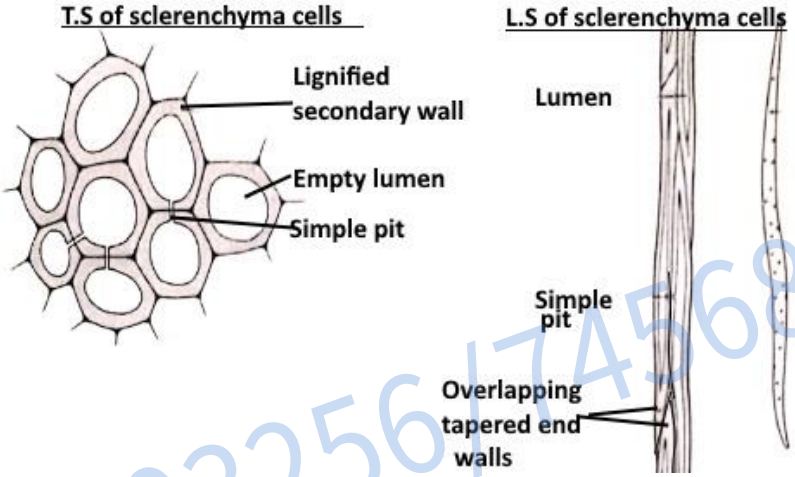
- Cells are living and can grow and stretch, thus provide mechanical strength without imposing limitations on the growth of other cells around it, allowing continued growth in young stems and leaves.
- Located towards the peripheral of the organ just below the epidermis in the outer regions of the cortex to increase its support value in stems and petiole.

iv) Sclerenchyma

Sclerenchyma is mechanical tissue which provides support and mechanical strength of the plant.
The distribution of sclerenchyma is related to the stresses to which different organs are subjected.

The structure of sclerenchyma

- Mature cells are dead.
- Mature cells contain no cytoplasm.
- The primary cell wall is heavily thickened with deposits of lignin.
- Its thick cell walls contain simple pits, areas where lignin is not deposited on primary wall due to presence of group of plasmodesmata.



There are **two types** of sclerenchyma cells.

1. **Fibres** and
2. **sclereids** (stone cells)

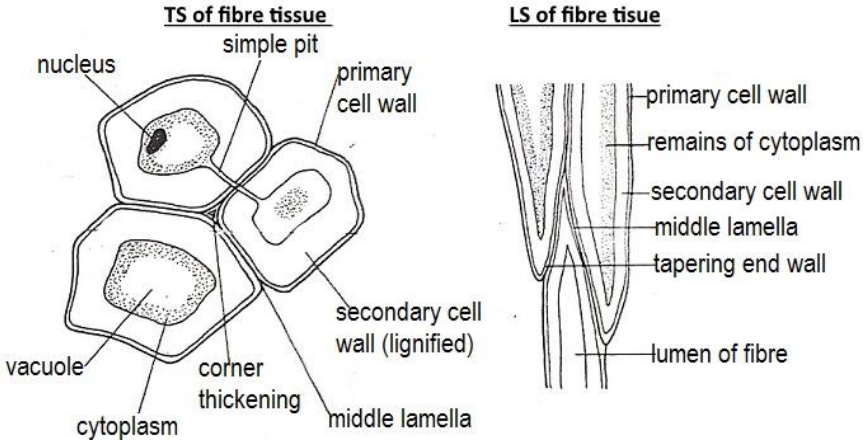
a) Fibres

Structure of fibres

- Dead cells with no cytoplasm.
- Thick cell walls composed of lignin, cellulose, pectins and hemicelluloses.
- Cells are elongated and hallow with narrow lumens
- Cells are polygonal in shape with tapering interlocking ends.
- The cell walls of these cells have some parts without lignin forming pits. This allows movement of materials from one cell to another.

Location:

They are located in the xylem, phloem and pericycle.
They are also found in the outer region of the cortex and the epidermis of especially fibrous plants.



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Adaptations of sclerenchyma fibres to its functions

- Cells have highly lignified thick walls to provide enough resistance to forces of the environment.
- Cells are dead and therefore take no extra metabolic demand on the plant.
- Fibres are elongated and arranged in sheets/strands to increase strength.
- Fibres are interlocked to enhance their combined strength.

b) Sclereids (stone cells)

Structure of sclereids

- Dead cells with no cytoplasm.
- Thick cell walls composed of lignin, cellulose, pectins and hemicelluloses.
- Cells have rough spherical or irregular shape.
- They have a narrow lumen and simple branched pits.

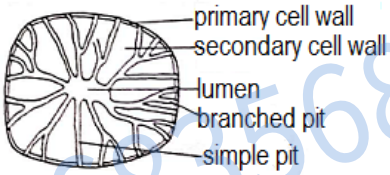
Distribution of sclerenchyma

Distribution of fibre cells

Outer regions of the cortex, pericycle of stems, xylem and phloem of stems, phloem of stems, leaves and roots.

Distribution of sclereids (stone cells)

Located in the cortex, pith, phloem, shells and stones of fruits, seed coats.



Sclereid tissue

Functions:

- Provide support, firmness and hardness where they occur.
- Responsible for grittiness when the fruit is eaten.

Differences between fibres and sclereids

Fibres	Sclereids
✦ Cells are elongated and polygonal.	Cells are broad/isodiametric (roughly spherical).
✦ The pits are narrow and unbranched.	The pits are deep and branched.
✦ Have tapering interlocking ends.	Have blunt broad ends.

Functions of sclerenchyma

- Fibres are for support, while sclereids are for support or mechanical protection.
- Hallow structures permit easy flow of materials.
- Narrow lumens facilitate capillarity in the fibres of the phloem.

Adaptations of sclerenchyma to its function

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

V) VASCULAR TISSUE

Vascular tissue consists of **xylem and phloem** which are specialized for the internal transport of substances in the plant.

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i) Xylem tissue

Xylem is vascular tissue with two main functions;

- The conduction of water and mineral salts from the roots to the leaves.
- Providing mechanical support to the plant.

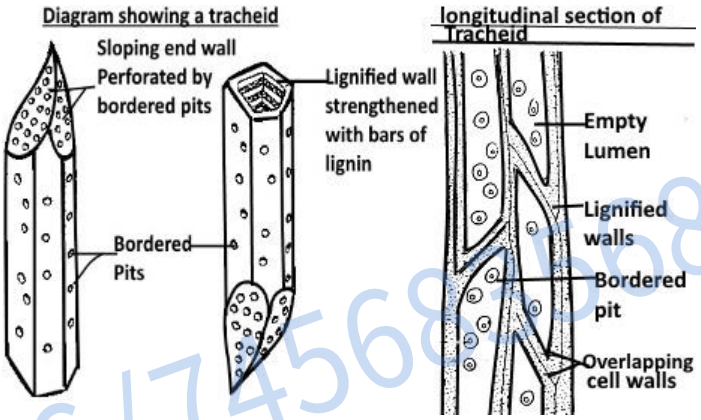
The structure of xylem

Xylem consists of **four types** of cells;

- **Tracheids**
- **Vessel elements,**
- **Parenchyma and**
- **Fibres**.

A) TRACHEIDS

Tracheids are single **elongated** cells with **thick cell** walls; extensively **lignified** by heavy deposits of lignin.



- Have **tapering** end walls that **overlap** with adjacent tracheids.
- They consist of dead cells which are tubular with no cytoplasm; create space for conduction of water and empty lumens when mature.
- End walls of tracheids are **perforated by bordered pits**. Water tends to flow from one tracheid to another, via pits.
- Tracheids are typically five or six-sided in cross-section and are not open their ends, but their end walls are perforated by pits.
- The cell walls also contain lignin, cellulose, hemicellulose and pectin.

Location and distribution: predominant in lower vascular plants of ferns and coniferophytes.

Functions:

- Provide mechanical support.
- Form primitive water conducting tissues of gymnosperms and ferns.

Adaptations of tracheids to their function

- They have tapering end walls that overlap with adjacent tracheids, which enables them to offer mechanical strength and support to the plant.
- They are dead with empty lumens when nature, which enables them to transport water without any obstructions or barrier.
- Have bordered pits through which water and mineral salts pass from one tracheid to another.

b) Xylem Vessels

Vessels are very long tubular structures formed by fusion of several elongated cylindrical end to end in a row.

Each cell of a xylem vessel is called a **vessel element** placed end to end**.** Vessel elements are shorter and wider than tracheids.

A vessel is formed when neighboring vessel elements of a given row fuse as a result of their end walls breaking down.

The cell walls are impregnated with lignin for support with bordered pits.

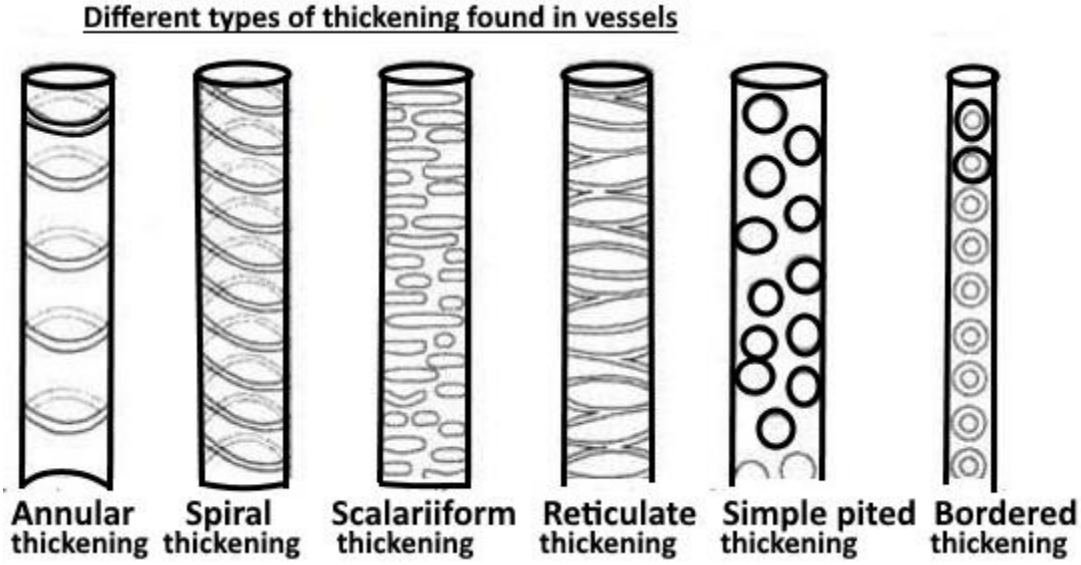
The end wall may have a single opening called a simple perforation plate or many openings called **multiple perforation plate.**

The thickenings on the vessels could be **annular, spiral, scalariform, reticulate or pitted forms.**

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Thickening/lignification gives the vessels additional strength and prevents the walls from curving in.

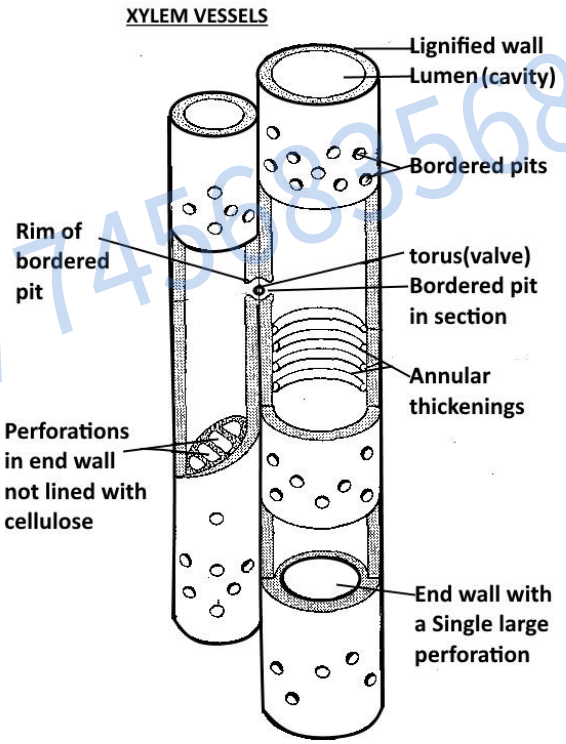
Different types of thickening found in vessels



A xylem vessel is formed from a chain of elongated cylindrical cells formed end-to-end. The horizontal end-walls break down partially or completely during the course of development to allow open communication between cells.

During development of the xylem tissue, the cellulose side walls of this tissue become impregnated or coated with lignin, a very hard layer which makes them impermeable to water, solutes and gases hence leading to the death of the protoplasm of the tissue. This leads to the formation of a hollow tube called xylem vessel hence more water can flow through the hollow continuous tube with less friction.

The lignified walls are perforated by numerous pits which allow horizontal movement of the lumen of water in and out of the lumen of vessels. Most pits are bordered by a lignified rim. In conifers, the bordered pits contain a valve-like plug called torus which controls the passage of water through the pits.



Lignification of the side walls (replacing cellulose with lignin) gives the xylem vessel extra mechanical strength, which prevents its walls from curving in or collapsing during the passage of water under a high tension. This lignification of the side walls occurs in four different patterns which include, annular lignification, simple spiral lignification, multi spiral lignification and reticular lignification

Protoxylem and metaxylem

Protoxylems are the first formed primary xylem vessels, found in the expanding region of roots and shoots, just behind the apical meristem in the shoot and root, before the shoot or root has completed the elongation process.

Mature protoxylem vessels can be stretched, as surrounding cells elongated, because lignifications is not over the entire cellulose wall, but only in **rings or in spirals.** There is incomplete lignification in the walls of protoxylem vessels. Lignin is deposited in rings to form **annular vessels** in spirals to form spiral

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vessels. These annular and spiral vessels can be stretched to provide support for vessels during elongated and growth of the young stems and roots.
Protoxylem soon die and generally get crushed and stretched to the point of collapsing as growth continues around.
They are eventually replaced by metaxylem
As growth proceeds, new vessels are formed with more extensive lignification, these are called **metaxylem.** Metaxylem have bigger lumen and are able to transport more water and mineral ions to the older plant. The presence of pits in the metaxylem vessels allow lateral movement of water and mineral ions to the surrounding living cells (from one tracheid to another). Secondary xylem is formed from the activity of the vascular cambium of dicotyledonous plants during secondary growth.
Although the vessels and tracheids of the xylem tissues are meant for transportation of mineral salts from roots to leaves. They also provide mechanical strength and greatly offer support to the plant.

Functions of xylem vessels

- They conduct water and dissolved mineral salts in angiosperms.
- They provide mechanical strength and support to the plant due to their being lignified.

Differences between the xylem and the tracheids.

Differences	
Xylem vessels	**Tracheids**
• Cylindrical shape	Are 5 to 6 sided in cross section
• Have open ends at their sides	Perforated end walls
• Have non tapering (pointed) ends	Have tapering ends
• Offers less resistance towards water passage	Offer more resistance towards water passage
• It is formed by fusion of several cells with dissolution of end walls.	Single elongated cells
• They have a wider lumen.	They have a narrow lumen.
• End walls may have one or several openings/perforations.	End walls are not perforated and water moves through bordered pits on the walls

c) Xylem parenchyma

- Xylem parenchyma occurs in both secondary and primary xylem but it is more extensive in secondary xylem.
- Two systems of parenchyma exist in secondary xylem, derives from Meristematic cells called **ray initials** and fuse to form parenchyma.
- Ray parenchyma forms radial sheets of tissue called **medullary rays**
- Fusiform initials normally give rise to xylem vessels or phloem sieve tubes and companion cells, but occasionally, they give rise to parenchyma cells.
- Fusiform parenchyma cells form vertical rows of parenchyma in the secondary xylem.

The secondary xylem parenchyma gives rise to medullary rays which are important for;

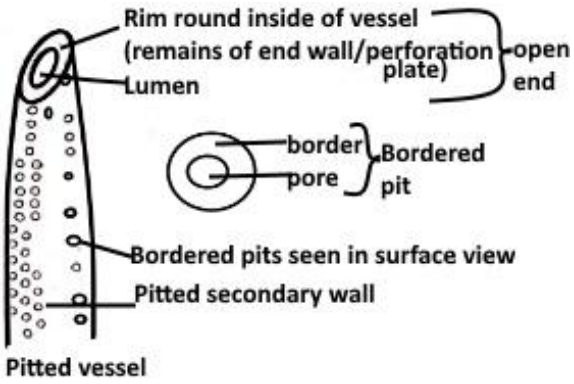
- Food storage
- Deposition of tannins, crystal etc.
- Radial transport of food and water.
- Gaseous exchange through the intercellular spaces.

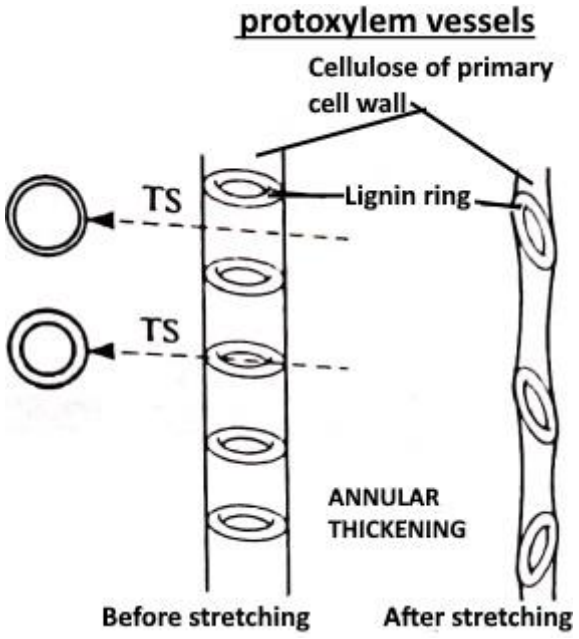
d) Xylem fibres

- Xylem fibres are shorter and narrower than tracheids, and have much thicker walls.
- Xylem fibres have pits similar to those in tracheids.

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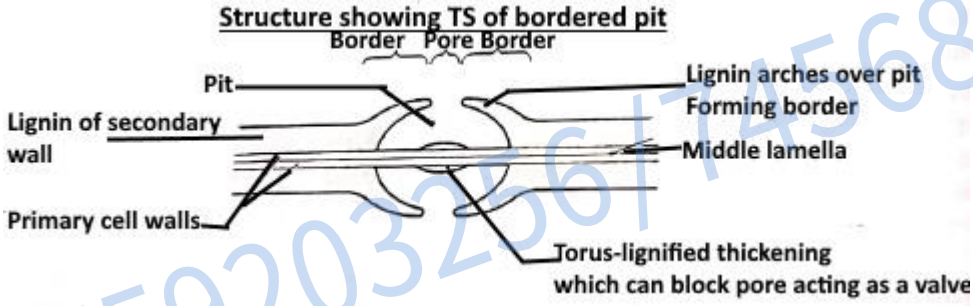
- They closely resemble sclerenchyma fibres, and have overlapping end walls.
- Fibres do not conduct water; have much thicker walls and narrower lumens than the xylem vessels; hence provide additional mechanical strength to the xylem





Note: scalariform thickening is similar to reticular but with fewer interconnections between the bars of thickening. It usually grades into reticulate thickening by progressive lignifications.

The transverse section showing structures of bordered pits



The distribution of the xylem: Located in the vascular system of the plant over the whole plant body in roots, stems, leaves and flowers.

Function of the xylem

- Tracheids and vessels conduct water and mineral salts.
- Provides mechanical support to the plant.

Xylem parenchyma has functions which include;

- Food storage
- Deposition of tannins, crystals and so on
- Radial transport of food and water
- Gaseous exchange through the intercellular spaces

Adaptation of xylem to its function

- Xylem vessels and tracheids consist of long cylindrical cells joined end to end, hence are continuous with each other ensuring continuous flow of water in a continuous unbroken column.
- End walls of xylem vessels are completely broken down to form continuous tubes that allow uninterrupted flow of water.
- Tracheids have tapering, elongated, sloping end walls that overlap with adjacent tracheids, perforated with large cellulose-lined bordered pits, that allow water to pass from one cell to another

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- During development, the protoplasmic contents of vessels and tracheids die leaving empty hallow lumens, permitting uninterrupted flow of water without obstruction by living content.
- Side walls of the vessels and tracheids are perforated with numerous pits permitting lateral /sideways flow of water and salts in and out of the lumen where necessary.
- Cell walls of tracheids and vessels are impregnated with lignin.
  Lignification of walls confer rigidity preventing walls collapsing under large tension forces set up by the transpiration pull.
  Impregnation of cellulose walls with lignin increases adhesion of water molecules to walls, thereby facilitating the rise of water by capillarity.
- Narrowness of lumens of vessels and tracheids increases the rise of water by capillarity.
- Extreme narrowness of lumens of tracheids and vessels offers them a high tensile strength preventing xylem from collapsing during transport of water through them.
- Xylem fibres have extremely thick walls which are heavily lignified and narrow lumens, to provide additional mechanical strength and support to the xylem.
- Vessel, tracheids and fibres are dead at maturity, and thus provide mechanical strength and support to the plant.
- Xylem parenchyma maintains a living link through wood between the pith and the cortex; allowing food storage, deposition of tannins and crystals thus preventing herbivore by making the plant poisonous; radial transport of food and water and gaseous exchange through the intercellular spaces.

Adaptations of the xylem tissue for water transport

- Xylem vessels have a narrow lumen which enables the upward movement of water from roots to leaves due to the high capillarity
- Xylem vessels and tracheids have lignified cell walls which enable upward movement of water through them at a high tension as lignin prevents curving in of the walls due its tensile strength and it makes the xylem water proof.
- Xylem vessels and tracheids lack living protoplasmic contents which enable them to remain hollow so that they allow water to move through with minimum resistance.
- Xylem vessels and tracheids have partially or completely broken down to allow open communication of one cell to another such that there's free passage of water through them.
- Xylem vessels and tracheids side walls are perforated by lateral pits to allow horizontal movement of water in and out of the xylem tubes.
- In some plants like conifers, the bordered pits of the tracheids have a plug-like torus which controls the lateral passage of water through the pits
- In the protoxylem, annular and spiral thickenings allow the stretching of the walls and further elongation of the stem is possible

Note: In the metaxylem, scalariform, reticulate and pitted thickenings provide additional mechanical strength to older stems. Metaxylem vessels have bigger lumens than protoxylem to transport more water.

ii) PHLOEM

This is a tissue that conducts food materials in vascular plants from regions where they are manufactured (notably the leaves) to regions where they are needed e.g. growing and storage regions.

Phloem is vascular tissue modified for translocation of organic salts and solutes.
Translocation of organic food molecules from the leaves where they are manufactured takes place through sieve tubes of the phloem. The sieve tubes are long tubes formed from the fusion of end to end sieve tube elements, where end walls break down to a greater or lesser extent to allow the passage of materials.

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The structure of the phloem

Phloem is composed of tubes with living cells and have no mechanical function

The phloem tissue consists of five types of cells; **sieve tube elements**, **companion cells**, **parenchyma cells, fibres** and **sclereids Sieve tubes and companion cells**

The sieve tubes are long tubes formed from the fusion of end to end sieve tube elements, where end walls break down to a greater or lesser extent to allow the passage of materials.

Rows of sieve elements develop from procambium strands of the apical meristems where primary phloem develops, together with primary xylem in vascular bundles.

Protophloem and metaphloem

The first formed primary phloem, produced in the zone of elongation of the growing regions of root and stem, are known as **protophloem**

Protophloem becomes stretched and eventually collapses becoming non-functional, as the tissue around it grows and elongates.

These cells are replaced by yet another group of phloem cells, which mature after elongation has stopped and these are called **metaphloem.**

The walls of the sieve tube elements are made up of cellulose and pectic acids, like in the parenchyma cells, but their nuclei degenerate and are lost as they mature.

Although have no nuclei, the sieve elements remain living, but relying on the metabolically active companion cells, adjacent to them.

In between the sieve tube elements, are sieve plates, which are formed from the adjoining end walls of the elements, and these plates have pores within them.

Sieve tube elements

Sieve tube elements have walls made of cellulose and pectins, but their nuclei degenerate and are lost as they mature.

The cytoplasm is confined to a thin layer around the peripheral of the cell.

Sieve elements are living but metabolically on adjacent companion cells.

In between sieve tube elements are sieve plates, formed from the two adjoining end walls of neighboring sieve elements. The side walls of the sieve tube elements are impregnated or coated with a lot of cellulose and pectic acid.

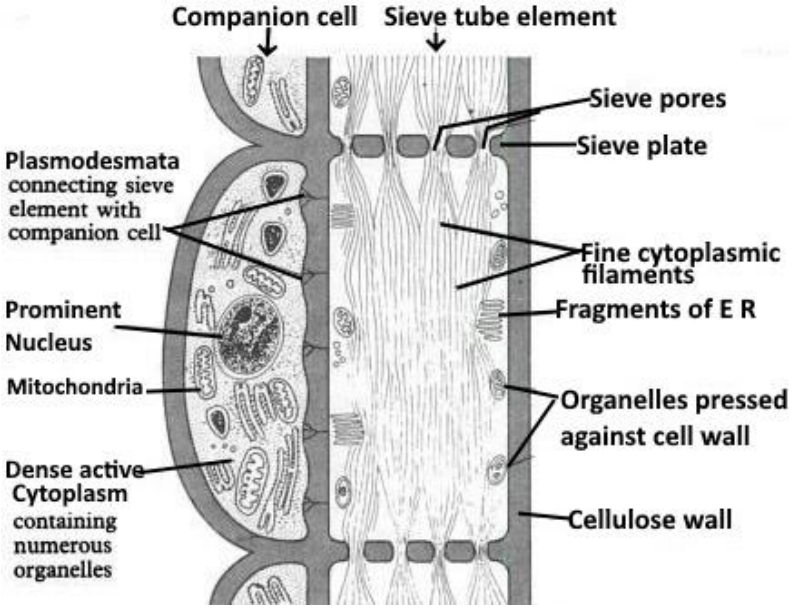
Sieve plates are perforated by sieve pores formed by enlargement of plasmodesmata.

Sieve plates mark successive sieve elements. Sieve tube elements get coated with cellulose, and form a **sieve plate** that is perforated by **sieve pores**. Through the sieve pores are **cytoplasmic filaments** or trans-cellular strands which run across and are continuous with all the sieve tube elements in the tissue. The cytoplasm of these trans-cellular strands is structurally very simple without organelles because all the organelles degenerate during its development

Secondary phloem develops from vascular cambium and is crossed by bands of lignified fibres and medullary rays of parenchyma.

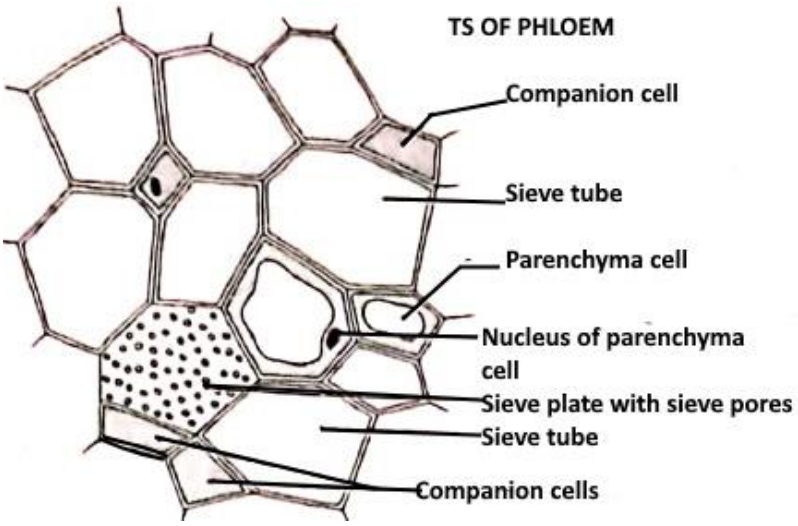
Companion cells

Alongside each sieve tube element is one or more companion cells made of thin cellulose walls, enclosing a protoplast with a dense cytoplasm. The companion cells are the metabolically active cells



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of this tissue with a prominent nucleus, numerous mitochondria, ribosomes, plastids, and small vacuoles, extensive endoplasmic reticulum and many other organelles. Therefore most important processes which involve active metabolism are conducted within the companion cells and all the required materials for these processes and all the required materials for these processes are passed via plasmodesmata from the companion cells or to the sieve tube elements and vice versa. The sieve tube elements are therefore living cells.



Phloem parenchyma, fibre and sclereids

- Phloem parenchyma and fibres are found in dicotyledonous plants, but not in monocotyledonous plants.
- Phloem parenchyma is composed of elongated cells.
- In secondary phloem, parenchyma occurs in medullary rays and vertical strands.
- Phloem fibres are exactly similar to sclerenchyma, and commonly found in secondary phloem in dicots than in primary phloem.
- Sclereids occur mostly in older phloem.

The distribution of phloem

Located in the in the vascular system of a plant, **in leaves, roots, stems and flowers.**

Adaptations of the phloem for its function

- ✦ Sieve tube elements are joined end to end; their walls are perforated with sieve pores in sieve plates, allowing passage of materials unimpeded from one cell to another.
- ✦ Sieve elements lack nuclei, and possess a thin cytoplasm pushed to the sides of the cell, creating room for passage of organic materials in solution with minimal obstruction.
- ✦ Plasmodesmata connect sieve elements to companion cells which are metabolically active, allowing communication and exchange of materials between sieve elements and companion cells.
- ✦ Sieve elements contain fine cytoplasmic filaments, continuous with similar filaments in other sieve elements via sieve pores in the sieve plate; which consist of a contractile phloem protein capable of streaming and sliding organic materials from one sieve element to another by wave-like movements of the filaments.
- ✦ Companion cells contain dense cytoplasm with numerous mitochondria, a large nucleus, plastids, small vacuoles and extensive endoplasmic reticulum; making them metabolically active to meet the metabolic needs of sieve elements.
- ✦ Companion cells possess numerous mitochondria to provide energy in form of ATP for the active transport of materials.
- ✦ Modified parenchyma companion cells called transfer cells found next to sieve tubes bear numerous internal projections increasing the surface area of the cell membrane, and

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- ✦ Numerous mitochondria in transfer cells provide energy for active uptake of solutes from neighboring cells during loading of sieve tubes.
- ✦ Phloem consists of living cells allowing live active transport of materials, since the mechanism of loading sieve tubes and transport of solutes requires energy.
- ✦ Sclereids are lignified to provide support to the vascular tissue of the phloem.

An explanation of the distribution of mechanical tissues of plants

- Collenchyma is distributed in young herbaceous plants and organs without secondary growth in order to supplement the support provided by turgid parenchyma.
- Collenchyma is distributed in stems and petioles at the periphery just below the epidermis in the outer region of the cortex, to increase its value as supportive tissue.
- Sclerenchyma is distributed according to the degree of stress in the organs and strengthened by its arrangement into strands or sheets of tissue scattered over the organ giving combined strength and firmness.
- Xylem is centrally distributed in roots to withstand strains as aerial part of the plant bend and lean over.
- Xylem is peripheral in a ring in dicotyledonous stems and scattered in monocotyledonous stems such that separate rods run through the structure to provide more support.
- Secondary xylem is added by secondary growth to support the large structure of trees and shrubs as they undergo secondary growth and increase in girth.

Similarities

- Both are concerned with transport of materials with in plants
- Both are composed of elongated cells, joined end to end
- Both are composed of elongated/cylindrical cells
- Both have perforated cells.
- Both are surrounded by parenchyma cells.

Differences

Xylem vessel	**Phloem**
Is open ended/has no cross walls	Has cross walls/perforated to form sieve plates
Cells have pits on their walls	Cells have no pits
Composed of lignified cells	Composed of unlignified cells
Cells are not associated with companion cells	Cells are associated with companion cells
Cells have no protoplasm,i.e are empty	Cells contain strands of cytoplasm and few organelles
For transport of water and mineral salts	For transport of manufactured food/solutes
Movement of materials does not require energy/passive	Movement of materials requires energy/is active
Transportation of materials is from roots to leaves	Transportation of materials can be in either direction/or both
Has dead cells.	Has living cells

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ANIMAL HISTOLOGY

Animals are multicellular and they need to have a combination of the individual cells so as to form tissues. This enables the animal to function properly. Animals have a small surface area to volume ratio as compared to unicellular organisms. Therefore, simple processes of diffusion, osmotic uptake of molecules, phagocytosis e.t.c. are not adequate in their function and therefore, there's need for the cells to combine together to form tissues and even in the complex animals, tissues form organs so as to carry out the various functions over a surface with a small surface area to volume ratio.

Animal tissues are divided into six groups;

1. **Epithelial tissue**
2. **Connective tissue which includes fibrous tissue, adipose tissue, and blood.**
3. **Skeletal tissue which include bone and muscles,**
4. **Reproductive tissue**
5. **Muscular tissue**
6. **Nerve tissue.**

(A) Epithelial tissue [Epithelium)

An epithelial tissue is a group of cells arranged in single or multi-layered sheets which covers the internal and external surface of the body of an organism.

Epithelial tissues consists of a single multi-layered sheets of closely packed cells specialized to perform the covering or the lining of all internal and external body surfaces of organisms.

Epithelial tissue that lines the inner surface of the body cavity and lumen is called the **endothelium** as in the inside of the heart, mouth lining, trachea, tubules, oviducts, blood vessels and lymph vessels.

Epithelial cells are attached to the underlying tissue by a basement membrane, made of a network of white wavy, non-elastic collage fibres.

Characteristics of epithelial tissue

1. The adjacent cells are joined by intracellular cement

Epithelial tissue consists of tightly packed cells that are firmly attached to each other with little intercellular material between them.

Epithelial cells are held together by small amounts of cementing substance containing a carbohydrate derivative called **hyaluronic acid. T**he junctions maybe, anchoring junctions or gap.

2. They are attached to the basement membrane which is produced by the cells themselves

The bottom of epithelial cells rests on a basement membrane composed of a network of collagenous fibers. The portion of epithelial cells attached to the basement membrane is called the basal surface, the opposite side facing the external environment or the lumen of a body cavity is called the apical surface/ free surface.

The basement membrane provides structural support to the epithelium binds the epithelium to neighboring structures and serves as scaffolding upon which new cells attach themselves during healing of injured epithelial cells.

3. Epithelial tissues lack blood vessels hence the tissue lacks vasculature. However, nerve endings (innervated), may occur in the epithelium.

4. Supported by connective tissue

Epithelial tissue receives oxygen and nutrition by diffusion from the underlying connective tissue through the basement membrane.

As the epithelial cells are not supplied with blood vessels, they rely on diffusion of nutrients and oxygen, from lymph vessels, which run through nearby intercellular spaces.

5. Epithelial cells have a high regeneration capacity, due to rapid cell division to resist wearing away/abrasions. This gives epithelial tissue quick recovery after any injury or abrasions.

6. Germ cell origin

Epithelial cells are derived from all the three primary layers; ectoderm, mesoderm, endoderm.

Epithelial cells of the skin, oral cavity, cornea, and lens have ectodermal origin.

Epithelial lining of blood of blood vessels, pleural and peripheral cavities have mesodermal origin.

Epithelial lining of the respiratory system and digestive tracts have endodermal origin.

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Functions of epithelial tissue

1. **Protection**

Epithelial tissue basically protects the underlying tissues from injuries by chemicals, pressure, abrasion and infection.

Adaptation of epithelial tissue for protection

- Columnar epithelium lining of the stomach is interspersed with goblet cells which secrete mucus. The mucus protects the stomach lining from acidic contents of the stomach and from digestion by enzymes.
- Mucus also lubricates the passage of food thereby protecting the lining from abrasion.
- The shorter cells of the pseudo stratified (false layer) epithelium lining the trachea and bronchi secrete mucus which trap the bacteria and dust particles in inhaled air, and the cilia on the longer cells beat expelling them outer ward direction.
- Keratinized squamous stratified epithelium on external skin surfaces lining the buccal cavity and the vagina is highly resistant to mechanical damage due to cornification (addition of keratin)protecting the underlying tissue from abrasion.
- The layers of non-keratinized stratified squamous epithelium lining the pharynx and oesophagus are thick, protects the under lying tissue from mechanical damage by the food that mechanical damage by the food that is swallowed.
- The many layers of the cells of the stratified cuboidal epithelium lining the salivary, pancreatic sweat ducts; protects them against mechanical and chemical stress.
- The layer of columnar cells of the stratified columnar epithelium lining the ducts of the mammary glands; protects them from mechanical and chemical injury.

2. Secretion

A number of epithelial cells are modified to produce secretions such as mucus, hormones etc.

Adaptation of epithelium for secretion

- Cuboidal epithelium lining the salivary glands and thyroid gland secrete saliva and thyroxine respectively.
- Columnar epithelium lining the stomach is interspersed with goblet cells which secrete mucus.
- The stratified columnar epithelium lining the ducts of the mammary glands, secrete fluid

3. Excretion

The epithelial cells of the kidney tubules and sweat glands remove excessive and toxic metabolic wastes the body thus helping the body in excretion.

Adaptation of epithelium for excretion

- Cuboidal epithelium lining the proximal and distal convoluted tubule and collecting ducts of the kidney are selectively permeable to molecules and ions to facilitate excretion.
- Ciliated cuboidal epithelia lining parts of the nephron have cilia which beat to facilitate the flow of glomerular filtrate.

4. Absorption

Cuboidal and columnar epithelia are modified for absorption of materials.

Adaptation of epithelia to absorption

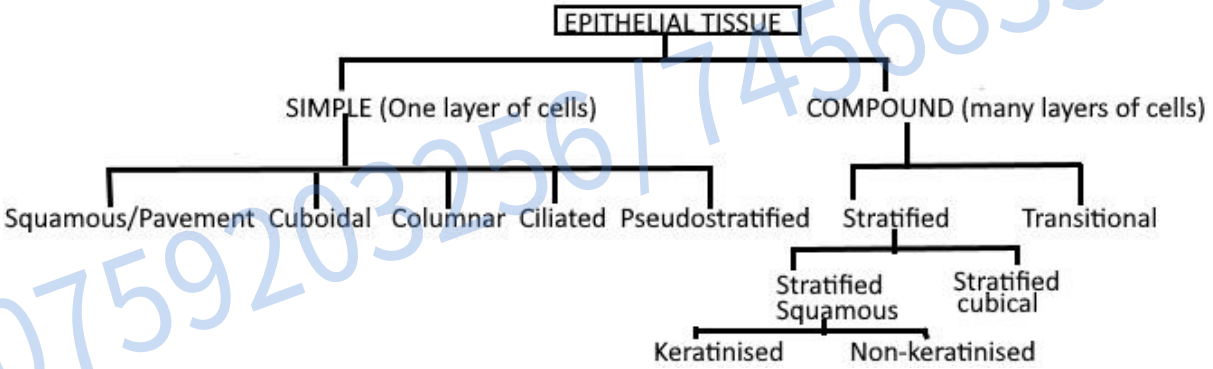
- Squamous epithelium lines the renal corpuscles of the kidney, the alveoli of the lungs and the blood capillary walls where its extreme thinness permits rapid diffusion of materials through it.
- Cuboidal epithelial cells lining the proximal convoluted tubules possess extensive microvillus forming a brush border which increases surface area for selective reabsorption of molecules and ions.
- Columnar epithelial cells lining the small intestines, possess a brush-border of microvillus which increases surface area for absorption of nutrients.

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5. Exchange of materials and gases.
Squamous epithelium is extremely thin and flattened promoting exchange of materials and gases by diffusion, such as the alveoli of the lungs.
6. Sensory: Reception of stimuli for sensory purpose, as in skin and eye retina
Epithelia bearing sensory cells and nerve endings are specialized to receive stimuli, as in the skin, retina of the eye and tongue.
7. Movement of materials: for example ciliated columnar/pseudo stratified epithelium.
Epithelia may be modified to aid movement of materials
Adaptations of epithelia to move materials

- Ciliated columnar epithelium lining the inside of the oviduct, spinal canal and the respiratory passages bear numerous cilia at their free surface.
- These are associated with mucus-secreting goblet cells producing fluids in which the cilia beat, rhythmically setting up currents which move materials from one location to another.
- Pseudostratified epithelium lining the trachea and primary bronchi posse's longer ciliated cells and shorter mucus secreting cells without cilia.
- The mucus traps bacteria, dust and other small particles preventing it from reaching the lungs
- The cilia wafts mucus up to the throat for swallowing
- Squamous epithelia lining hallow structure e.g. the heart chambers, blood vessels are flat and smooth, allowing friction-free passage of fluids through them.

THE CLASSIFICATION OF EPITHELIAL TISSUE
Epithelial tissues are classified according to the number of cell layers, and the shape of the individual cells.



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SIMPLE EPITHELIUM
It is the tissue composed of a single layer of cells, covering the surface of the animal, and the organs, cavities and tubes within it.

Characteristics of simple epithelial tissue

- Consist of a single layer of cells
- All the cells rest on the basement membrane
- Cuboidal and columnar epithelial may have cilia, and often have goblet cells which produce mucus
- Cuboidal and columnar epithelia may possess microvillus forming a brush border
- The free surface / apical of some epithelial cells may have stereo cilia.
- Mostly effective for secretion and absorption; but not effective for protection; as simple epithelium is extremely thin.
- Simple epithelia may be squamous, cuboidal, columnar, ciliated, or pseudo stratified.

Location
1. Simple epithelium is found in places where the protective covering needs to be readily permeable to molecules for example in the lining of the capillaries, alveoli, Bowman's capsule.

It also provides a smooth lining to structures such as all blood vessels and chambers of the heart where it allows passage of fluids such as blood.

2. **Cilia are** hair-like, thin and motile protoplasmic extensions that move to and fro

Cilia have a basal granule in the cytoplasm, and are associated with the flow of materials in a particular direction, as in the respiratory tract and oviduct

3. **Sterocilia** are elongated, non-motile, protoplasmic extensions; broad at the base tapering to the top.

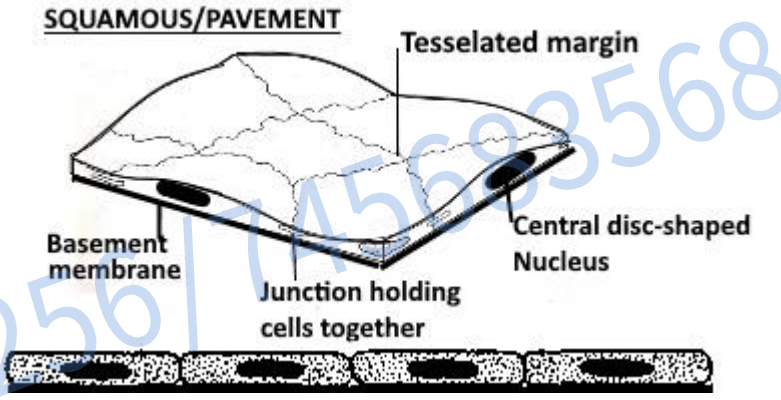
Sterocilia do not have base granules and associated with the flow of sperms in the epididymis and vasa deferentia.

4. **Microvilli** are thin short, closely packed, invaginations of the plasma membrane giving a brush-border appearance. Microvillus increases the surface area for absorption in the nephron and small intestines.

a. Simple squamous epithelium

Structure

- Cells are very thin and flattened.
- Cells contain little cytoplasm which encloses a disc-shaped nucleus.
- Special junctions bind neighboring cells firmly together
- Edges of the cells are irregular (tessellated
- The nucleus is centrally placed
- The cells are flat in nature and fixed on a basement membrane.
- It consists of delicate cells usually less than 20mm thick
- They have little intercellular substance (matrix) in which the cells are embedded



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Distribution: It is found in places where the protective covering needs to be readily permeable to molecules in solution e.g.

- Lining of blood vessels
- Lining of alveoli of the lungs
- Lining of lymphatic vessels
- Renal capsules of the kidney
- The lining of Blood capillary walls

Functions

- Diffusion of materials.

In the Bowman's capsule and glomerulus, the tissue is permeable to fluids and there's quick diffusion of the fluids

- Exchange of gases
- Provides smooth linings to blood vessels and the chambers of the heart, where it allows efficient passage of fluids e.g. blood, without friction.

Adaptations

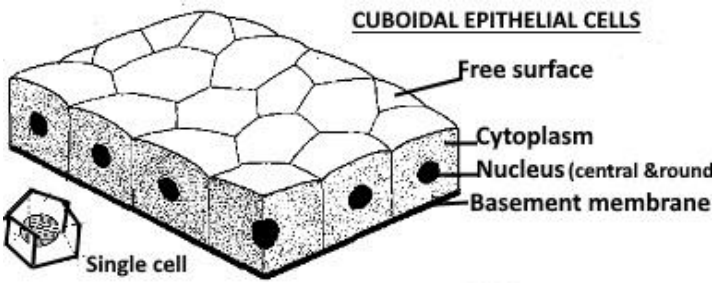
- Thin and flattened cells to reduce the distances across which materials diffuse
- Provides a smooth lining to allow, relatively friction free passage of fluids and materials through the hallow structures.

b) Simple cuboidal epithelium

Structure

- Cells are Cuboid in shaped
- Cells possess a spherical centrally positioned nucleus.
- Cells appear pentagonal or hexagonal in the surface view.
- Some cells may have microvilli in the surface to increase surface area

Note; it's the least specialized of all the epithelial tissues. They are non-secretory in the proximal &distal convoluted tubules, salivary and pancreatic ducts.



Distribution

Lining the salivary ducts, pancreatic ducts, convoluted tubules and collecting ducts of the kidneys.
Lining the salivary glands, sweat glands and thyroid glands.

Function

- **Protection**
- **Excretion of** waste products in the human kidney i.e. lining the Loop of Henle and collecting duct
- **Absorption**
- **Secretion**

Adaptation

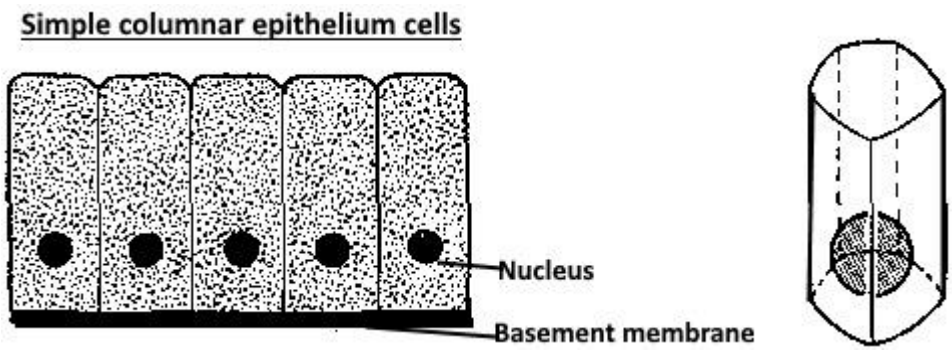
- Possess finger-like projections called microvillus which increase the surface area for absorption such as digested food in the intestines
- Possess mucus-secretory cells; mucus protects the gastric walls from Hydrochloric acid and digestive enzymes.
- Mucus from goblet cells also lubricates the passage of food in the intestines.

Simple columnar epithelium

This consists of cells elongated at right angles to the basement membrane, where the cells appear to be tall and column – like when viewed in section.

Structure

- Tall, column-like narrow cells
- Cells bear numerous cilia at their free ends
- The nuclei of the cells are at the base of the cells
- The cells may at times have the mucus secreting cells (goblet cells) interspersed among them and the tissue is known as glandular columnar epithelium.
  The goblet cells produce mucus for the reducing friction and for protection against digestive enzymes



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Distribution: Columnar epithelium is found lining areas where secretory and absorptive activities take place from. E.g.

- Lining the intestine e.g. lines the stomach, gastric glands
- Lining of the many Kidney ducts
- Lining of the thyroid gland and gall bladder

Functions

- **Protection:** Columnar epithelium lines the stomach, where mucus secreted by goblet cells protects the stomach lining from acidic contents and enzyme actions.
  It also lines the intestines, where mucus again protects it from self-digestion and also lubricates food passage.
  It is also found lining the kidney ducts, thyroid gland and gall bladder, for protection.
- **Absorption**: Columnar epithelium lines the small intestine, where digested food material is absorbed into the blood stream.
- **Secretion:** Goblet cells which secrete mucus

Adaptation

- Possess many Golgi bodies which perform functions of secretion of hormones and enzymes.
- Some possess microvillus which increase surface area of the cells which are in contact with the fluids for example for reabsorption of materials from renal fluids in the kidney tubules.

Simple ciliated columnar epithelium

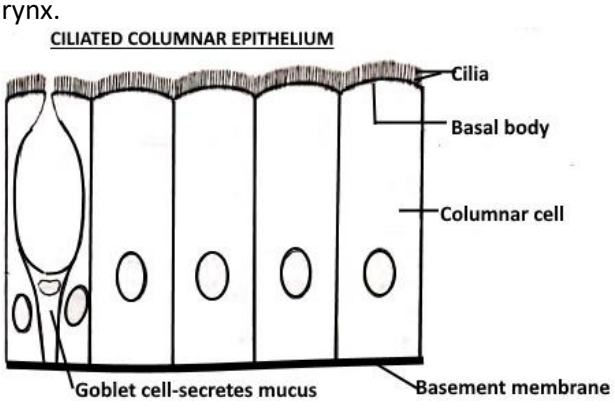
This is usually composed of columnar cells in shape, having numerous cilia, at their free surface ends. These cilia are capable of beating rapidly and rhythmically.

Structure

- Cells bear numerous cilia at their free ends
- They have many mucus secreting goblet cells in between the cells. The mucus-secreting goblet cells, produce fluids in which the cilia set up currents.

Distribution

- Lining cavities in charge of movement or those of in charge of tiny particles.
- In the respiratory tract (trachea) where dust particles and bacteria are trapped by mucus preventing it from reaching the respiratory surface and then waft mucus up to the throat for swallowing or moved by cilia into the pharynx.
- In the oviduct where they transport the ova
- In the brain cavities/ventricles of brains and the spinal canal where they keep the fluids in motion



Functions

- Mucus protects lining and lubricates the passage of materials.
- Cilia sets up currents for movement of materials in a particular direction
- In certain animals like flatworms, cilia lining the underside of the body is important in Locomotion.

Adaptations

- Cells are tightly packed together with little intercellular substance between them to offer protection from injury and infection.
- Possess many Golgi bodies which perform functions of secretion of hormones and enzymes.
- Some posse's microvillus which increase surface area for example for reabsorption of materials from renal fluids in the kidney tubules.

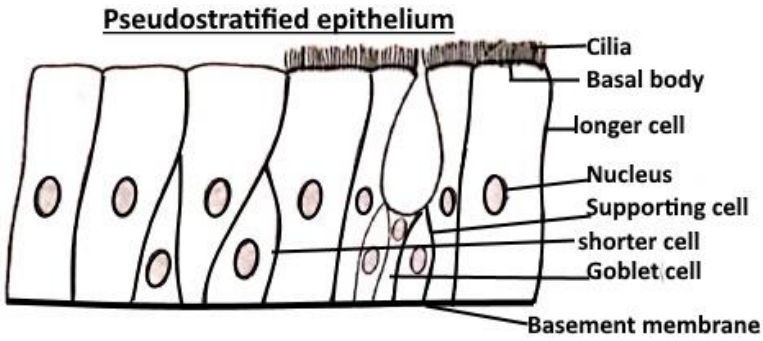
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Pseudostratified epithelia

This is a single layered and one cell thickened epithelium with each cell attaching to the basement membrane. But when viewed in section, the nuclei of this type of epithelium appear to be at several different levels, because not all the cells do reach the free surface.

Structure

- One layer of columnar cells that appear to be in layers
- All cells rest on a basement membrane
- Its cells don't reach the free surface uniformly. i.e. Not all cells reach the free surface
- The cells are of unequal size
- Longer cells have cilia
- Shorter cells lack cilia and secrete mucus.



- The nuclei of the epithelium appear at different levels. i.e. Nuclei located at different levels

Distribution:

This epithelium is found lining the urinary tract, the trachea, (as pseudostratified columnar)

- Lining of respiratory passages e.g. lining in the cavities of nasal passages
- Olfactory mucosa

Functions

- Mucus traps bacteria and dust particles preventing them from reaching the lungs
- Cilia waft mucus up to the throat for swallowing

Adaptations

- Long cells posses' cilia which waft mucus with its trapped with its bacteria and other dust particles up to the throat for swallowing.
- The short cells produce mucus which traps bacteria and dust particles in inhaled air.

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COMPOUND EPITHELIUM

This is more than one cell thick

Characteristics of compound epithelium

- Consists of many layers of cells
- Only the lower layer of cells rests on the basement membrane.
- Mostly used for protection and secretion.

Compound epithelia may be; **stratified or transitional.**

1. Stratified epithelium

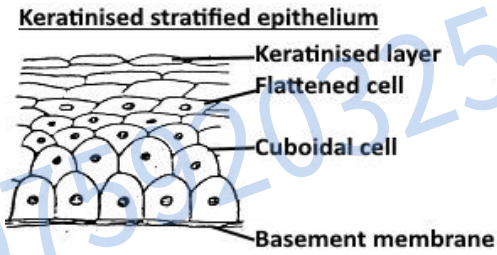
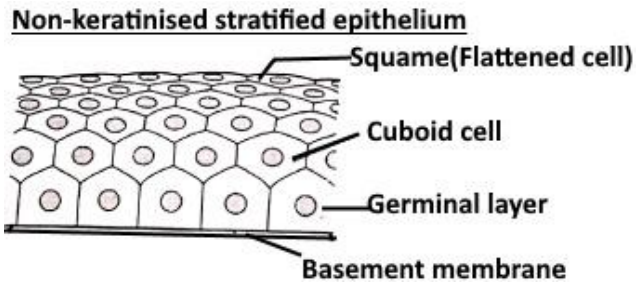
This is composed of a number of layers of cells, and therefore much thicker than the simple epithelia, and forms a relatively tough and impervious barrier.

Characteristics of stratified epithelium

- Much thicker than simple epithelium, and has many layers of cells.
- Only the lower most layers of cells rests on the basement membrane.
- The basement membrane is germinal and gives off more cells by mitotic divisions.
- The first cells to be formed are cuboidal; and as they are pushed outwards they become flattened, cuboidal or columnar.
- Being multilayered; stratified epithelium, mostly play a protective function.
- Stratified epithelium maybe squamous, cuboidal or columnar.

The multi-layered nature of the stratified epithelium is due to the fact that, the germinal layer of cells at its base, maintain the capacity to divide repeatedly and mitotically along a plane, parallel to the basement membrane.
After being formed, the first-formed daughter cells appear **cuboidal in shape**, but as they are pushed outwards the free surface of the epithelium, they **become flattened** and become known as **squames**.
The squames may eventually flake off, to be replaced by new ones from beneath, as with the cornified epidermal cells of the skin. These cells become **keratinized** and become dead and horny cells, which eventually flake away, to protect the body against abrasion.
Such cornified stratified epithelial cells can be found lining the buccal cavity, vagina etc.
Some squames may remain uncornified, as in the oesophagus, where the epithelium protects the underlying tissues against mechanical damage, by friction with food, as it moves through it.
Stratified epithelium can be named according to the shape of cells which makes it up e.g. stratified **squamous lining the oesophagus,** stratified cuboidal in the sweat ducts, stratified columnar in the mammary gland ducts, stratified transitional in the bladder**.**

A summary of the characteristics of the types of stratified epithelium

Structure	**Distribution**	**Function**
1.Stratified squamous epithelium Upper layers of flattened cells called **squames**	Areas / ducts that are delicate or large flow of fluids	Protection and secretion
2.**Keratinized squamous stratified epithelium** Conified by heavy deposits of keratin in the upper layer to form a dead horny layer The dead horny layer eventually flakes away 	External skin surface Lining of the buccal cavity and vagina	Impervious of water Protects against abrasion Resistant to mechanical damage
3.**Non-keratinized squamous** stratified epithelium Layer of living squamous cells formed by lower cuboidal cells. 	Lining of the pharynx and oesophagus Lining of the large salivary and pancreatic ducts Lining the ducts of mammary glands	Protects the underlying tissue from mechanical damage friction as food is swallowed Protection against mechanical and chemical damage Protection and secretion

Distribution:

- Areas or ducts that are delicate or have large flow of fluids.
- External skin surface, lining of buccal cavity and vagina.
- Lining of pharynx and oesophagus.

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Function:

- Protection from abrasion to areas exposed to wear and tear.
- Protection of the tissue from mechanical damage by the food that is swallowed.
- Protection of the underlying tissue from mechanical damage.

Adaptations of stratified epithelium

- It is composed of several layers of cells which are tough impervious and some cells keratinized/cornified for protection against mechanical abrasions.
- Cells of germinal layer divide repeatedly by mitosis to replace the cells that are breaking off wearing off at the surface.
- Some cells can change their shape when subjected to tension to allow stretching where they are located e.g. in urinary bladder.

2. Transitional epithelium

This is a modified type of stratified epithelium.

Characteristics of transitional epithelium

- Consists of 3 to4 layers of cells which are all of similar size and shape.
- The cells at the free surface are more flattened.
- The cells are living, large and stretch to change the thickness of the tissue.
- The surface cells do not slough off, and all cells are able to modify their shape when placed under different conditions.

Location

Transitional epithelium is located where structures are subjected to considerable stretching stress; such as in the urinary bladder, ureter, and the pelvic region of kidney.

Adaptations of transitional epithelium for its functions

- By changing shape the transitional epithelium allow expansion of the organ, such as the urinary bladder; this increases in the volume of the organ.
- Transitional epithelium is composed of many layers of cells making it impermeable to water from blood to urine.
- Due to its thickness it prevents urine escaping into the surrounding tissue

Glandular epithelium

Amongst the epithelial cells there may be individual glandular cells, such as goblet cells or a collection of glandular cells, which form a multicellular gland.

An epithelium with many goblet cells is called a **mucous membrane**.

Glands are secretory in function. They produce secretions such as sweat by the sweat glands, sebum by the sebaceous glands, tears by the tear glands e.t.c

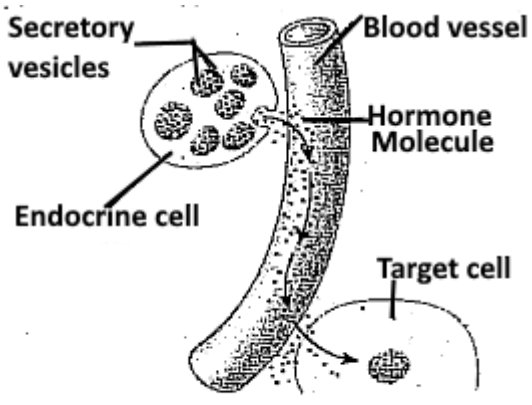
Glands have cuboidal or columnar epithelium called glandular epithelium.

NOTE; the pancreas and the stomach are both exocrine and endocrine.

The classification of glands

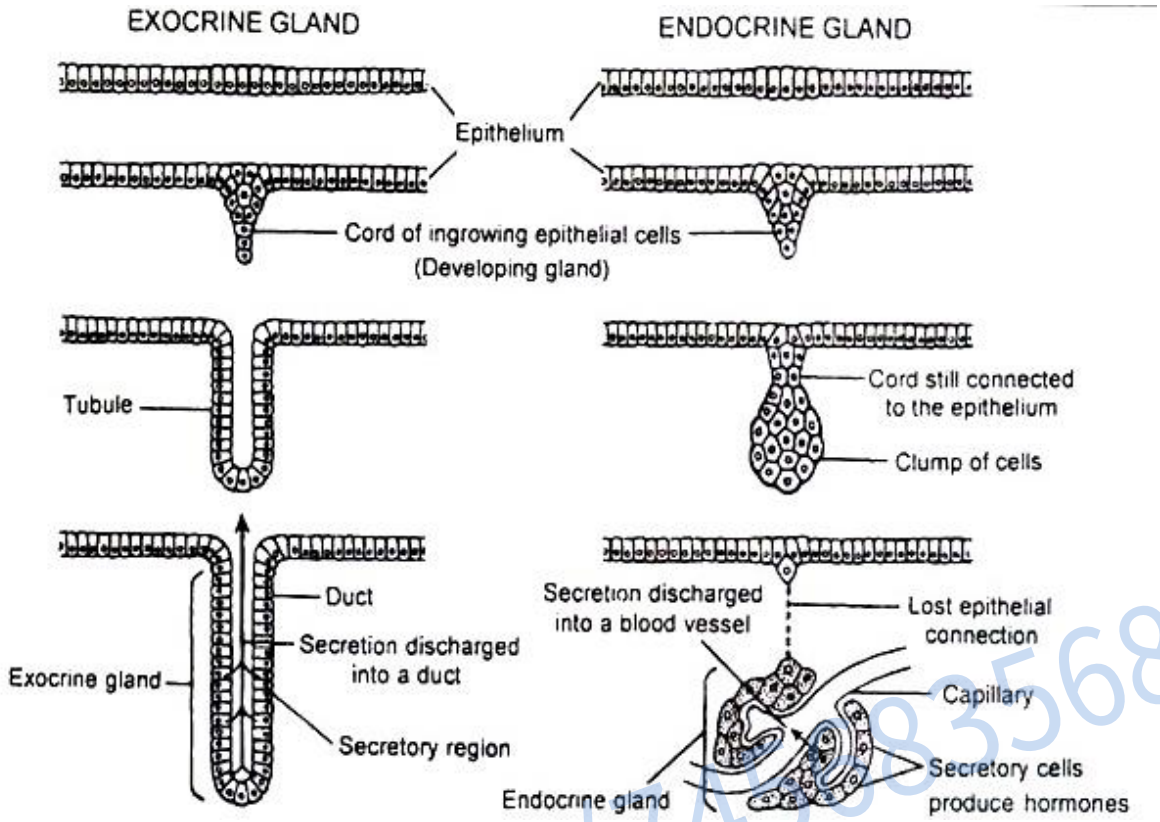
1. Based on the kind of secretion and duct present, there are two types of glands; that is exocrine and endocrine glands.

i) Exocrine glands: These discharge/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** (ductless gland): **Have** no duct in the gland and pour their secretions directly into the blood stream. Their secretions are known as **hormones.**



A hormone from endocrine cell is secreted into the blood to target cell

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Differences

Exocrine glands	Endocrine glands
• Possess ducts • Secretions are mostly enzymes • Secretions pass through ducts to their site of action • Examples are; salivary, tear (lachrymal) and intestinal glands	• Lack ducts/ ductless gland • Secretions are hormones • Secretions reach sites of action through the blood stream. • Examples; pituitary, thyroid, parathyroid, and adrenal gland

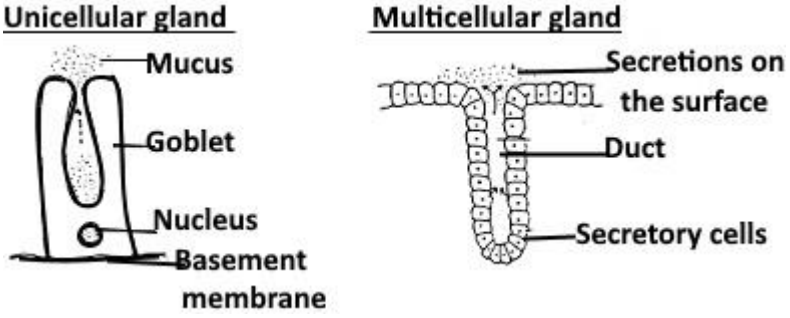
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2. Based on number of cells; there are two types of glands:

I) Unicellular: an individual epithelial cell is modified into a glandular cell for example the mucus producing goblet cells. Cuboidal epithelium interspersed with large numbers of goblet cells, constitutes mucus epithelium.

ii) Multicellular glands

A number of glandular cells aggregate to form a multicellular gland. Multicellular gland maybe simple or compound glands. E.g. sweat glands



3. Based on the shape and complexity, the exocrine glands are of two types; simple and compound.

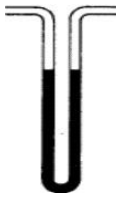
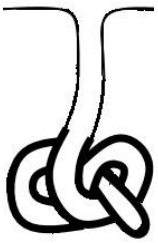
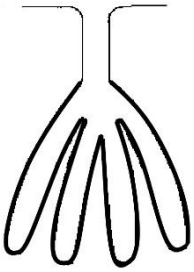
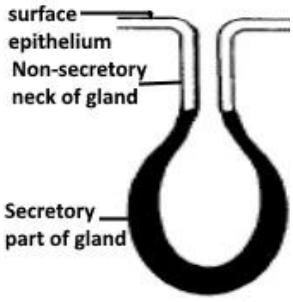
i) Simple gland

Simple gland have a single unbranched duct

The secretory part could be in form of a tube called a **tubule** or sacs called alveolar (saccular)

The tubes or sacs maybe coiled or uncoiled, branched or unbranched

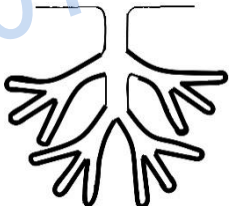
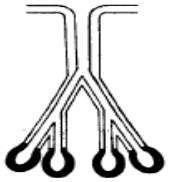
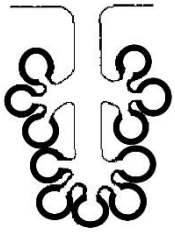
FORMS OF THE SIMPLE EXOCRINE GLAND

Simple tubular gland	**Simple coiled gland**	**Simple branched tubule gland**	**Simple alveolar/ saccular**	**Simple branched alveolar/saccular**
Gland is elongated and tube like  **Examples** The Crypts of **Lieberkühn in** the wall of the mammalian small intestine	The secretory tubule of the gland is coiled.  Sweat glands in mammalian skin	Tubules are branched but the ducts is single  Brunner's gland in the wall of the ileum, gastric glands in the wall of the stomach	The secretory region is sac-like or flask-shaped  Mucus glands in the skin of frogs and often amphibians	Comprises of a number of secretory ducts opening on the same duct  Sebaceous /oil glands in the mammalian skin.

2. Compound glands

- Compound ducts have a number of ducts forming a branching pattern
- The secretory part could be in form of tubes, called **tubules** or sacs called alveoli or both.

Forms of compound exocrine glands

Compound tubular glands	**Compound alveoli glands**	**Compound tubular alveoli glands**
Secretory part is tubular  Examples; salivary gland	Secretory part is alveolar  Examples; mammary gland and pancreatic gland	Secretory part comprises both tubules and alveoli  Examples; parts of salivary and mammary glands.

4. Based on the mode of secretion, the exocrine gland are of three types

a) Merocrine gland

Secretions released within the cells, are discharged on its cell surface without losing any of its cytoplasm; the cell therefore remains intact.

These glands release their secretions via the cell membranes at the free surface of the cell

Examples; goblet cells, pancreatic glands, sweat glands

b) **Apocrine glands**

Secretions are stored in the apical part of the cell, which bursts open to release its contents

The cell loses the part of the cytoplasm while releasing its secretion.

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Some glandular epithelia shed their secretion by the top part of the cell, loaded with secretion, breaking away from the rest of the cell e.g. in mammary glands. Such glands are called **apocrine glands.**

c) Holocrine glands:

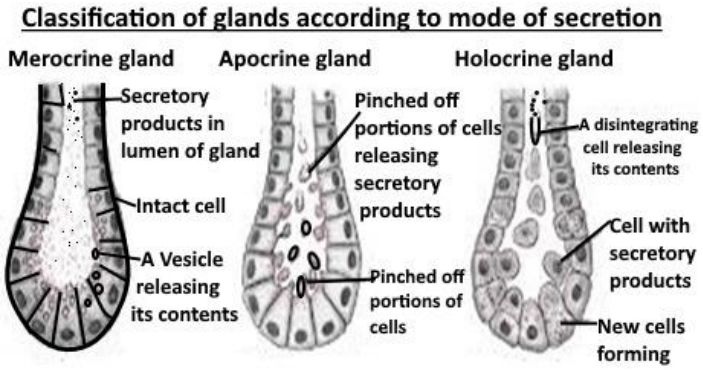
The entire secretory cell disintegrates and shed the secretion from the epithelia.

The entire cell breaks down to release its secretions which extrude from the epithelial surface.

Example; sebaceous glands of the mammalian skin

Note

Some glands, like mammary glands, have cells, secretory in more than one way; they secrete lipids like apocrine glands and protein like merocrine glands



5. Based on the nature of secretion, glands are of three types

a) Mucus glands

Secrete a viscous, mucus fluid

Cells are called mucus cells or **mucocytes**

Example; goblet cells found in the intestines

b) Serous gland: if the secretion produced is clear/watery and contains enzymes, the gland is called a **serocyte**. Examples; sweat glands

c) Mixed glands: If both secretions are produced from within the same glands, then it is called a mixed gland. Have both serocytes and mucocytes

Secrete both serocous and mucous secretions

Examples; gastric and pancreatic glands

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CONNECTIVE TISSUE

These are tissues which bind other tissues together e.g. in the muscles. They include the adipose (fat) tissue, collagen tissue, and skeletal tissue which is composed of bones and cartilage. They bind or support other tissues of the body.

Main characteristics of connective tissue

- They possess a considerable number of fibres in the intercellular substances
- They have a large amount of intercellular substances
- They are all developed from the mesoderm

The structure of connective tissue

Connective tissue is a composite tissue and has three basic components.

i. Cells

- Cells are the living components of connective tissue.
- The cells are widely spaced from each other with large intercellular spaces.
- The cells are of various types.
- The cells are of mesodermal origin.

Ii) Fibres

- Connective tissue contains several types of fibre scattered between cells.
- The fibres are the non-living products of the cells.
- Fibres form the extracellular material.

Note; blood lacks fibres.

Iii) **Matrix**

- The matrix forms the basic ground tissue in which the cells and the fibres are suspended.
- The matrix is non-living.
- The matrix maybe amorphous, transparent, fluid or semi-fluid in nature.
- The matrix contains various inorganic and organic substances; the most important being hydrochloric acid.
- The kind of matrix varies in different tissues

The distribution of connective tissue

- Present in-between different tissues.
- Present in-between different organs.
- Present in and around body organs.
- Skeletal tissue occurs as bone and cartilage.
- Fluid connective tissue occurs thought the body.

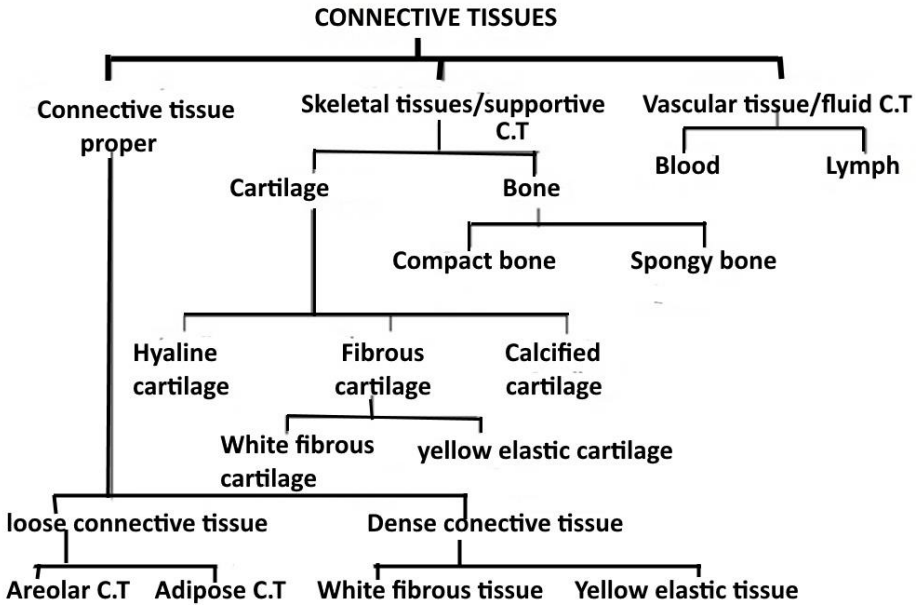
The functions of connective tissue

- It binds the various tissues together, like the skin and underlying structures with muscles and muscles with bones.
- Its packing tissue forming sheath like bags and around the body organs.
- Areolar tissue protects the body the body against wounds and infections.
- Adipose tissue stores fat, and insulates the body against heat loss.
- Connective tissue is the major supportive tissue of the body, composed of bones and cartilage which provide the body with a supportive frame work.
- Haemopoietic tissue for production of blood.
- Lymphatic tissue builds body immunity by producing antibodies.
- Connective tissue separates the body organs, so that they do not interfere with each other's activities.
- Protects blood vessels and organs where they enter or live organs.

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THE TYPES OF CONNECTIVE TISSUE

Connective tissue is classified into various types depending on the kind of matrix present.



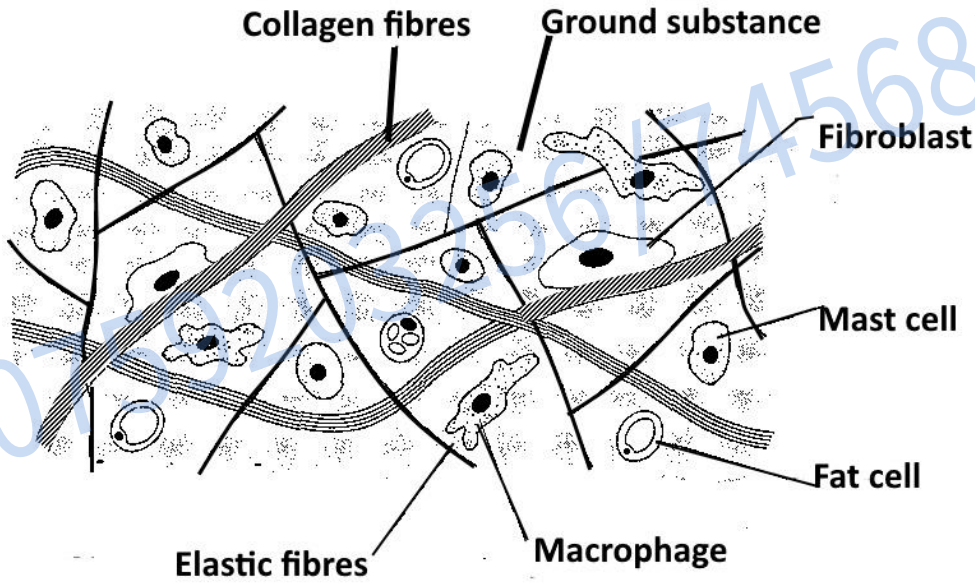
LOOSE CONNECTIVE TISSUES

1. AREOLAR TISSUE: This is a loose type of the connective tissue, whose cells are widely separated, in the matrix and have loosely and randomly woven fibres. The matrix is a transparent semi-fluid which consists of gelatinous glycoproteins containing many types of cells and protein fibres.

The structure of areolar tissue

- Loose connective tissue with widely separated cells.
- Has a different type of fixed and wandering cell.
- Has loosely and randomly woven fibres.
- Consists of a gelatinous glycoprotein matrix or ground substance containing four main types of cells and two types of protein fibre.
- The four main types of cells include; fibroblasts, mast cells, fat cells, and macrophages.
- The ground substance contains a mixture of glycoprotein, mucin hyaluronic acid and chondroitin sulphate
- Within the ground substance are **two types of protein fibres,** the **Collagen fibres** which are white fibres, unbranched, flexible, very strong, and non-stretchable, exist in bundles and run parallel to each other.
- The **elastic fibres** are yellow fibres, which are branched, flexible and elastic.

Diagram of AREOLAR tissue as it appears in microscopic section



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1.Fibroblasts

Description

- Spindle shaped cells.
- Long Flattened cells.
- Long protoplasmic processes.
- Oval nucleus.
- Large and long cells



Functions/adaptations

- Long flat which produce collagen fibres and elastic fibres.
- Can migrate to wounded tissue and secrete more fibres to effectively seal the injury.

2. Macrophages (histocytes)

- Large, amoeboid, polymorphic cells.
- Phagocytic.
- Kidney-shaped nucleus.



Functions/adaptations

- Defend body against infection/diseases by engulfing the microbes and any foreign particles and destroy them.
- Engulf bacteria and other foreign particles.
- Ingest a variety of foreign particles and damaged cell tissue.

3.Mast cells



- Small, oval-shaped cells.
- Granular cytoplasm.
- Found close to blood vessels.

Function

- Secretes the matrix and anticoagulant such as **heparin and histamine**
- Heparin is an anti-coagulant which neutralizes the action of thrombin, preventing the conversion of prothrombin to thrombin. Hence preventing blood clotting.

Heparin is a blood anti-coagulant, but blood clotting remains normal during anaphylactic shock.

- Mast cells secretes histamine which causes:

i. Vasodilatation and increased permeability of small blood vessels which results in such symptoms as localized swelling, itching, sneezing, and runny eyes and nose.
ii. Contraction of smooth muscle and stimulates gastric secretion.
iii. Inflammation and is released from injured tissue.

Mast cells secrete histamine, which is a substance that is released during allergic reactions.
Allergy is a condition in which the body produces an abnormal immune response to certain antigens, called a**llergens**, which include dust, pollen, certain foods, drugs or fur.

4. Fat cells

- Contain large lipid granules filling the bulk of the cell.
- Cytoplasm and organelles confined to the margins.

Function: fat Cells are responsible for storage and metabolism of fats

Plasma cells

- Small, round, or irregular cells.
- Produced by mitotic division of migratory lymphocytes.

Function/adaptation

Produce antibodies which defend the body against infection and disease**. I.e.** they are important components in the body's immune system

Chromatophores cells

- Found in skin and eyes.
- Highly branched cells.
- Densely packed with melanin granules which gives the skin its characteristic colour and in the retina of the eye they prevent back reflection of light.

Function: Produce organ colorations.

Mesenchyme cells

- Undifferentiated cells in the tissue

Function: Act as undefferianted cell reserves which can be stimulated to differentiate into any of the above cells when need arises

Collagen fibres and elastic fibres.

i. Collagen/ white fibres

- Long, waxy, unbranched fibres run parallel to each and
- Arranged in bundles.
- Form a loose network.
- Flexible, but inelastic as they contain the protein collagen.

Function/adaptation

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Provide strength and toughness to the areolar tissue since they are Very strong, flexible, and inelastic (do not stretch).

ii. Elastic/yellow fibres.

- Long, straight and branched fibres.
- Arranged singly to form a fine network criss-crossing the matrix.
- Flexible and elastic as they contain the protein elastin.

Function/adaptation

Network of flexible and elastic (stretchable) fibres; strengthen the tissue, and give tensile strength and resistance.

The parts of areolar tissue and their functions

Part and structure	Function and adaptations
Reticulate fibres Very fine, short, thread-like fibres. Generally located around blood vessels and nerves. Quite rigid and composed of immature collagen fibres. Found covering muscle fibres.	Strong and inelastic; thus offer tensile strength.
Ground matrix Mixture of glycoprotein, mucin, hyaluronic acid and chondroitin sulphate.	Suspends and embeds various fibres and cells.

Distribution of areolar tissue

- Found beneath the skin connecting to the structures below.
- Found all over the body, supporting and connecting tissues together.
- Binds sheets of epithelium to form mesenteries.
- Ensheathes blood vessels and nerves where they enter or leave organs.

Functions of areolar tissue

- Binds tissues and organs together.
- Serves as packing tissue filling spaces between adjacent tissues.
- Support various tissues.
- Provides tissues with resist strain and displacement.
- Provides protection against wounding and bacterial infection of the body.

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Allergy

Allergy is a condition in which the body produces abnormal immune response to certain antigens called allergens, which include dust, pollen, drugs, fur, and certain foods.

An allergen is an antigen that causes an allergic body response.

The process of allergic reaction

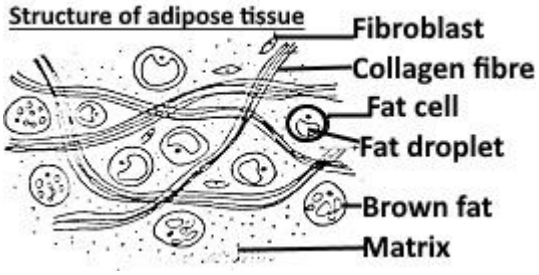
- Allergic reactions occur as a result of an overreaction of the immune system to contact with antigens called allergens.
- In a person with an allergy, contact with allergens cause the production of large amounts of a kind of antibody called
- These antibodies stimulate mast cells, found in all tissues close to the walls of blood vessels, to release excessive amounts of inflammatory substances, such as histamine and cytokines.
- These chemicals cause an acute inflammatory reaction in which, the blood vessels dilate, which lead to reddening and swelling of the skin and exudation of fluids in the tissue; smooth muscle in airways contracts, rashes appear on the skin, tissues swells as fluid accumulates in them.
- In some cases it may lead to bronchial spasms and asthma, or cramps in intestinal muscles.

However the allergic reaction does not occur on the first contact with the allergic but only on subsequent contacts when the person is said to have become sensitive.

2. ADIPOSE TISSUE (fatty tissue)

Adipose tissue is a modified form of areolar tissue that contains a large number of fat cells called adipocytes.

The structure of adipose tissue



- Consists of a glycoprotein matrix containing a large number of fat cells called **adipocytes** arranged in lobules
- The matric also contains a densely packed collagen fibres.
- An adipocyte is a large spherical, almost entirely filled with central fat.
- Each fat cell is filled mainly with a central fat droplet, which pushes the cytoplasm and the nucleus and organelles to the sides of the cell.
- Adipocytes are of two types; white adipose tissue contains a **large central fat droplet**; and a brown adipocyte contains a number of **small fat droplets i.e.** do not form big globules. The nucleus of the brown remains centrally placed.

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.

- Bubble-like matrix of large adipocytes that contain a fat when mature.
- Rich vascularization
- Nucleus is pushed to periphery
- It is distributed throughout the body particularly subcutaneous deposits in areas like breasts, thighs, hips, and abdomen and in the deep layers of the skin.

Functions

- Largest stores of energy; adipocytes can also synthesize fatty acids from glucose
- Thermal insulation since they are poor heat conductors
- Cushions and maintains organ placement, absorbs shock
- Adipocytes release **leprin**, satiety factor that regulates appetite

ii) Brown/yellow adipose tissue:

- Brown adipocytes are smaller than white adipocytes
- Has central nuclei
- Has numerous fat droplets in adipocytes hence multilocular

Commonly in young mammals and some hibernating mammals.

Function

- It is important in temperature regulation. I.e. promote heat production
- Brown adipose can increase as part of cold adaptation.

Distribution of adipose tissue

- Found beneath the skin in the dermis region.
- Found in mesenteries.
- Found around the kidneys, heart and eyeballs and act as energy reservoirs and shock absorbers.

Functions of adipose tissue

- It serves as an energy store and metabolic water.
- It absorbs shock organs like the heart, kidney etc.
- It insulates the body against heat loss.

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Adaptations of adipose tissue to its functions

- As it synthesizes, store and metabolizes fats; it is a considerable reserve of energy and metabolic water.
- As it contains large deposits of fat; it acts as a shock absorber around kidneys, the heart and eyeballs, to prevent mechanical shock since fat is a poor conductor of heat ; adipose tissue forms an insulating layer, protecting the body against heat loss.
- Since lipids are less dense than water, large adipose tissue deposits in the blubber of aquatic organisms aid buoyancy and floatation.

DENSE CONNECTIVE TISSUE

Dense connective tissue has more fibres embedded in the matrix than the cells, which makes it more compact than loose areolar tissue.

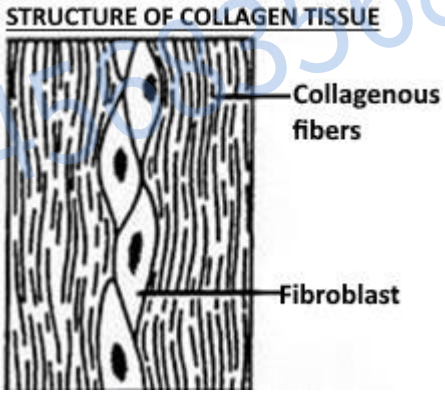
The fibres maybe regularly or irregularly arranged.

There are two types of dense/compact fibrous connective tissue; white fibrous tissue (collagen tissue) and yellow elastic tissue.

3. Collagen tissue or White fibrous tissue

The structure of white fibrous/collagen tissue

- Tough, strong, shiny and flexible
- Consists of a glycoprotein matrix, containing densely-packed highly organized bundles of collagen fibres running parallel to each other.
- Rows of fibroblasts are interspersed among the collagen fibres and alongside the bundles.
- Fibroblasts produce collagen fibres.
- Each collagen bundle is bound to the other by areolar tissue.



The distribution of white fibrous tissue

They are located in areas with great tension such tendons; some ligaments, the sclera and cornea of the eye, the kidney capsule, the perichondrium of cartilage, the periosteum of bones.

Adaptation of white fibrous tissue to its functions

- Composed of numerous, highly organized bundles of collagen fibres densely packed together, and running parallel to each other; making the tissue strong, tough, flexible, yet inextensible with highly tensile strength.
- The collagen fibres are precisely arranged to run parallel to the lines of stress encountered during the functioning of the body structures containing collagen; in order to provide adequate protection against mechanical stress and tension.
- Each strand of collagen possess three chains of tropocollagen plaited together like a rope; making the tissue extremely strong and tough.

4. Elastic tissue or Yellow elastic tissue

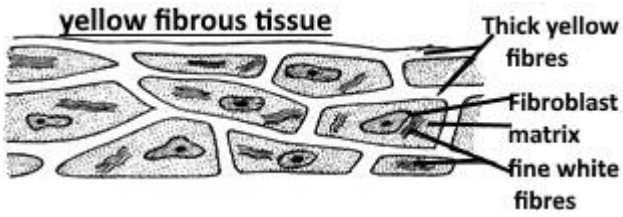
The structure of yellow elastic tissue

- Elastic, flexible and strong fibrous tissue
- Consists of a glycoprotein matrix having irregularly arranged, branched/a loose network of yellow elastic fibres.
- The tissue has randomly scattered fibroblasts, throughout the matrix and some fine collagen fibres.

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Location

Combining strength with elasticity, the tissue is **found in ligaments** which bind bones together, the walls of arteries, lungs and the air passages.



a) **Ligaments**

The structure of a ligament

- Loose network of irregularly arranged elastic fibres.
- Some collagen fibre present.
- Fibroblasts scattered in between the yellow elastic fibres and white collagen fibres.

Functional distribution ligaments

Ligaments connect bones to bones at the joints and hold them together.

Adaptation of ligaments to their function

- Predominant yellow elastic fibres give elasticity.
- Collagen fibres give strength.

Comparison of tendon and ligaments

Similarities

- Both contain a ground matrix of glycoprotein.
- Both contain collagen fibres.
- Both contain fibroblasts.

Differences between tendons and ligaments

Tendons	Ligaments
• Predominantly composed of collagen fibres. • Fibres regularly arranged in parallel bundles. • Dense network of fibres. • Fibroblasts arranged in neat rows alongside fibres. • Join skeletal muscle to bones. • Inextensible/inelastic	• Predominantly composed of yellow elastic fibres. • Fibres irregularly arranged. • Loose network of fibres. • Fibroblasts scattered all over. • Joins bone to bone at a joint. • Extensible/elastic

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SUPPORTIVE CONNECTIVE TISSUE

SKELETAL TISSUES

These are also types of connective tissues, generally responsible for supporting the body and providing it with a rigid framework.

There are **two types of skeletal tissues**, which include;

5. Cartilage

Cartilage is a tough, hard, but flexible connective tissue consisting of cells **called chondroblasts** and chondrocytes suspended in a matrix called **chondrin.** Chondrin is secreted by the chondroblasts.

General function

Cartilage is tough, hard and flexible to resist strain and absorb mechanical shock.

The structure of cartilage

- It consists of a firm **translucent matrix** of muco-polysaccharide called **chondrin.** The matrix is secreted by cells called **chondroblasts** which are distributed in the matrix in groups of single pairs or fours.
- The surface of cartilage is covered by a dense layer of fibrous connective tissue and cells called the **perichondrium.**

- Next to the perichondrium is a layer of chondroblasts.
- Chondroblasts divide repeatedly into small groups of cells, which gradually get separated from one another; as each secretes a resilient matrix of **chondrin**.
- The matrix possess many fine fibrils mostly made up of collagen.
- The chondroblasts eventually become enclosed in spaces called **lacuna** and become chondrocytes.
- Each lacuna contains two or four chondrocytes.
- Each chondrocytes is a large, angular cartilage cell with a distinct nucleus.
- There are no processes that extend from the lacunae into the matrix.
- The matrix lacks blood vessels; and exchange of materials between the chondrocytes and matrix is by diffusion only. The matrix may be impregnated with collagen as in the vertebral disc and elastic fibres as in the ear and the nose

HOW CARTILAGE GROWS

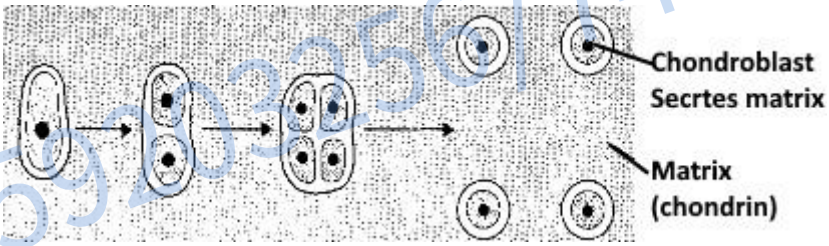
Cartilage is hard but flexible tissue consisting of a group of cells, known as **chondroblasts,** suspended in an organic matrix known as **chondrin**. Chondrin is secreted by the chondroblasts.

These chondroblasts divide repeatedly into small groups of cells, which gradually get separated from one another, as each secrets the matrix material. Chondroblasts eventually get enclosed in spaces called **lacunae** and become **chondrocytes.**

Each chondroblast secretes some matrix and then divides first into 2 and then into 4. As the daughter cells secrete matrix, they get pushed apart, and end up trapped in small spaces **(lacunae)** within the matrix they have secreted.

New chondroblasts develop from fibroblasts recruited from the perichondrium at the surface.

Chondroblasts continuously divide into small group of cells each of which secretes a resilient matrix of chondroitin sulphate.



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NOTE

Cartilage grows by a combination of **appositional** growth (additional of new cells and matrix onto the outside of the growing structure) and **interstitial expansion** (cell division and secretion of new matrix within an established structure).

Interstitial growth - Chondroblasts within the existing cartilage divide and form small groups of cells, which produce matrix to become separated from each other by a thin partition of matrix. Interstitial growth occurs mainly in immature cartilage.

Appositional growth - Mesenchymal cells surrounding the cartilage in the deep part of the perichondrium differentiate into chondroblasts. Appositional growth also occurs even in mature cartilage.

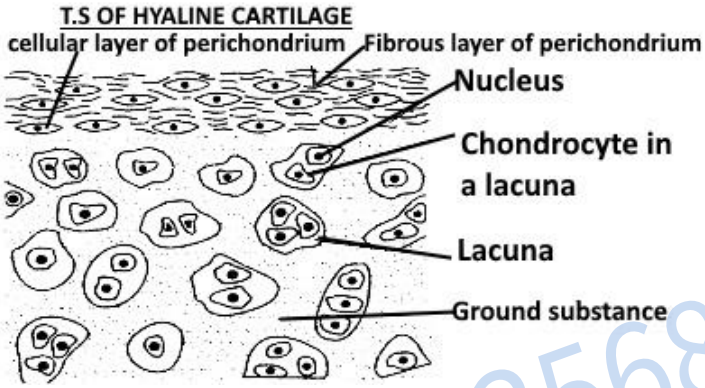
Depending on the nature of the matrix, there are three types of cartilage**; hyaline cartilage, yellow/elastic and white fibrous cartilage/fibro-cartilage.**

HYALINE CARTILAGE

It's the most common type of cartilage, its matrix is translucent and contains very fine collagenous fibres.

Structure

- It's a solid flexible connective tissue composed of a translucent mucopolysaccharide matrix (chondrin) in which are distributed cartilage cells (chondroblasts) and many intercellular substances like fibres.
- Chondrin lacks direct blood supply except in the Perichondrium; a tough fibrous membrane surrounding cartilage.
- Peripheral chondrocytes are flattened in shape; internal chondrocytes are angular in shape.
- Each chondroblast lies in a small chamber called lacuna surrounding by a capsule.
- Each lacuna may enclose one, two, four or eight chondroblast.
- In some cases chondroblasts occur in cell nests i.e. a pair or 2 pairs of cells encased by one capsule.



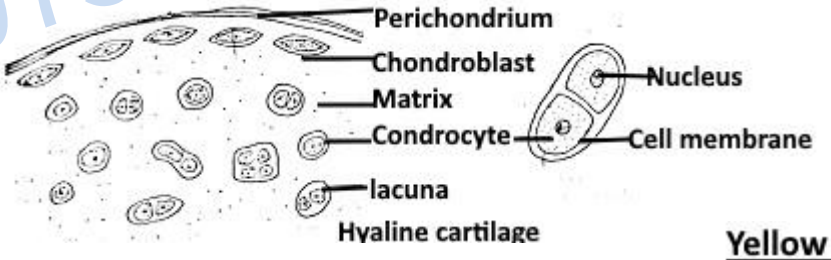
Distribution

- The elastic, compressible tissue located at the end of bones.
- In the nose and air passages of the respiratory system.
- In the larynx, ends of long bones, ribs, trachea rings, foetal skeleton
- It's the only skeletal material of cartilaginous fish/chondrichthyes/elasmobranches.
- Forms the embryonic skeleton in the bony vertebrates.

Adaptations

- Has a tough fibrous sheath called the perichondrium surrounds the cartilage, protecting the inner tissue from mechanical damage, infection, and abrasion where bones articulate at the joints.
- It's slightly elastic and compressible, but tough hence it can absorb considerable mechanical shock without breaking for instance, the cartilage joining ribs to the sternum allows limited flexing of ribs during breathing.

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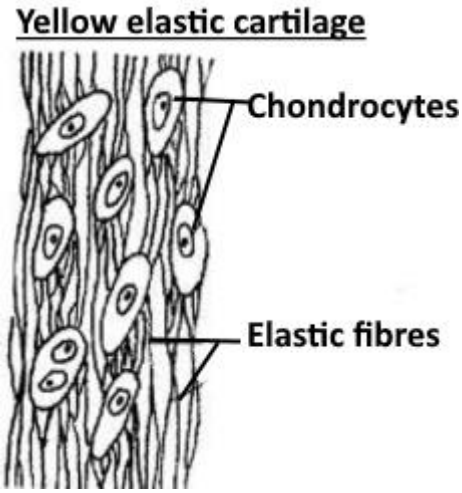
ELASTIC CARTILAGE

Structure

The matrix is semi-opaque and contains a network of yellow elastic fibres

It's more flexible than hyaline cartilage because the matrix contains many elastic fibres in addition to collagen fibres.

Elastic cartilage comprises a matrix of chondroitin sulphate, with a network of yellow elastic fibres, making it highly elastic and flexible, but strong.



Function
It provides mechanical support, and permits tissue to quickly recover its shape after distortion, such as in the pinna of the ear, the epiglottis and pharynx.
Adaptations
Highly elastic and flexible; and permits tissue to quickly recover its shape after distortion.
Distribution
Located in the external ear/pinna, Eustachian tube, and epiglottis.
Forms cartilages of the pharynx.

WHITE FIBROUS CARTILAGE
Structure
- Contains dense collagenous fibres embedded in matrix, it absorbs shock and reduces friction between joints and can withstand tension and pressure.
- White fibrous cartilage comprises a matrix of chondroitin sulphate, providing great tensile strength, with a small degree of flexibility as it resists stretching
- The matrix contains a large number of bundles of densely packed white collagen fibres.

Adaptations
- Provides great tensile strength and a small degree of flexibility.
- Acts as a shock absorber by providing a cushioning effect, such as in the intervertebral discs of the vertebral column of the upright bipedal vertebrate.

Distribution
Occurs as discs between adjacent vertebrates, called intercalated discs.
Found in the region between two pubic bones of the pelvis, called the symphysis pubis.
Found in the ligamentous capsules of joints.
In the **pubic symphysis** between the two bones of the pelvis, the cushioning effect of white **fibrous cartilage** consisting of many white collagen fibres, gives considerable strength with a degree of flexibility; which allows flexibility at parturition without complete breakage.

THE MAIN FUNCTIONS OF CARTILAGE TISSUE
Reducing friction at the joints; supporting tracheal and bronchial tubes; acting as shock absorbers between vertebrae; maintaining the shape and flexibility of ear and nose.

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BONE
Bone is a rigid, tough, hard calcified connective tissue, made up of cells embedded in a firm matrix.
Bone provides support, protection and metabolites.
- About 30% of the matrix is composed of organic substances consisting mainly of collagen fibres; while 70% is inorganic bone salts.
- The main component of the bone is calcium phosphate called **hydroxyapatite,** $Ca_{10}(PO_4)6(OH)_2$; but some sodium, magnesium, potassium, chloride, fluoride, hydrogen carbonate, and citrate ions are also present in variable amounts.
- The matrix contains protein
- In the matrix, there is a large number of small cavities called **lacunae** which contain the bone cells called, **osteoblasts**, which secrete the inorganic components of bone.
- When osteoblasts are no longer active in matrix secretion, they reduce the number of their cell organelles, and become inactive **osteocytes**, which perform other cellular activities such as respiration and exchange of materials with the blood.
- In the matrix there are small canals called **canaliculi** that contain cytoplasm, and connect the lacunae to each other; blood vessels passing through the canaliculi provide means by which osteoblasts exchange materials.

- Bone collagen fibres are bound together by a protein called **osteonectin**, and eventually impregnated with apatite crystals, which provides the bone with strength and resistance against compressional and tensional forces, imposed on them.
- Bone is surrounded by an outer membrane called the **periosteum**; which contains connective tissue, blood capillaries, nerves, and a number of types of cell; including **osteoclasts.**
  The periosteum plays an important role in bone repair and growth.

The structure of bone

- It's a rigid, tough, connective tissue composed mainly of calcified substance.
- Each bone is enclosed in a layer of tough white fibrous connective tissue called the **periosteum.**
- Blood vessels and nerves pierce the bone through the periosteum.
- In a bone, the matrix is arranged in concentric circles called lamellae.
- In between the lamellae is a number of living bone cells called **osteoblasts** or osteocytes in the fluid-filled cavities called **lacunae.**
- Osteoblasts are active bone cells that secrete the inorganic matrix components; which osteocytes are inactive osteoblasts.
- Each lacuna has fine cytoplasmic extensions called **canaliculi** which pass through lamellae and make connections with other lacunae.

Several tissue types make up bone; including the mineralized bone tissue that gives it rigidity and brittleness, collagen fibres that provide slight elasticity, marrow, endosteum, periosteum, nerves, blood vessels and cartilage.
All bones consist of living and dead cells embedded in the mineralized organic matrix called osteon that makes up the bone tissue.

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TYPES OF BONES
There are 3 types of bones, which include;

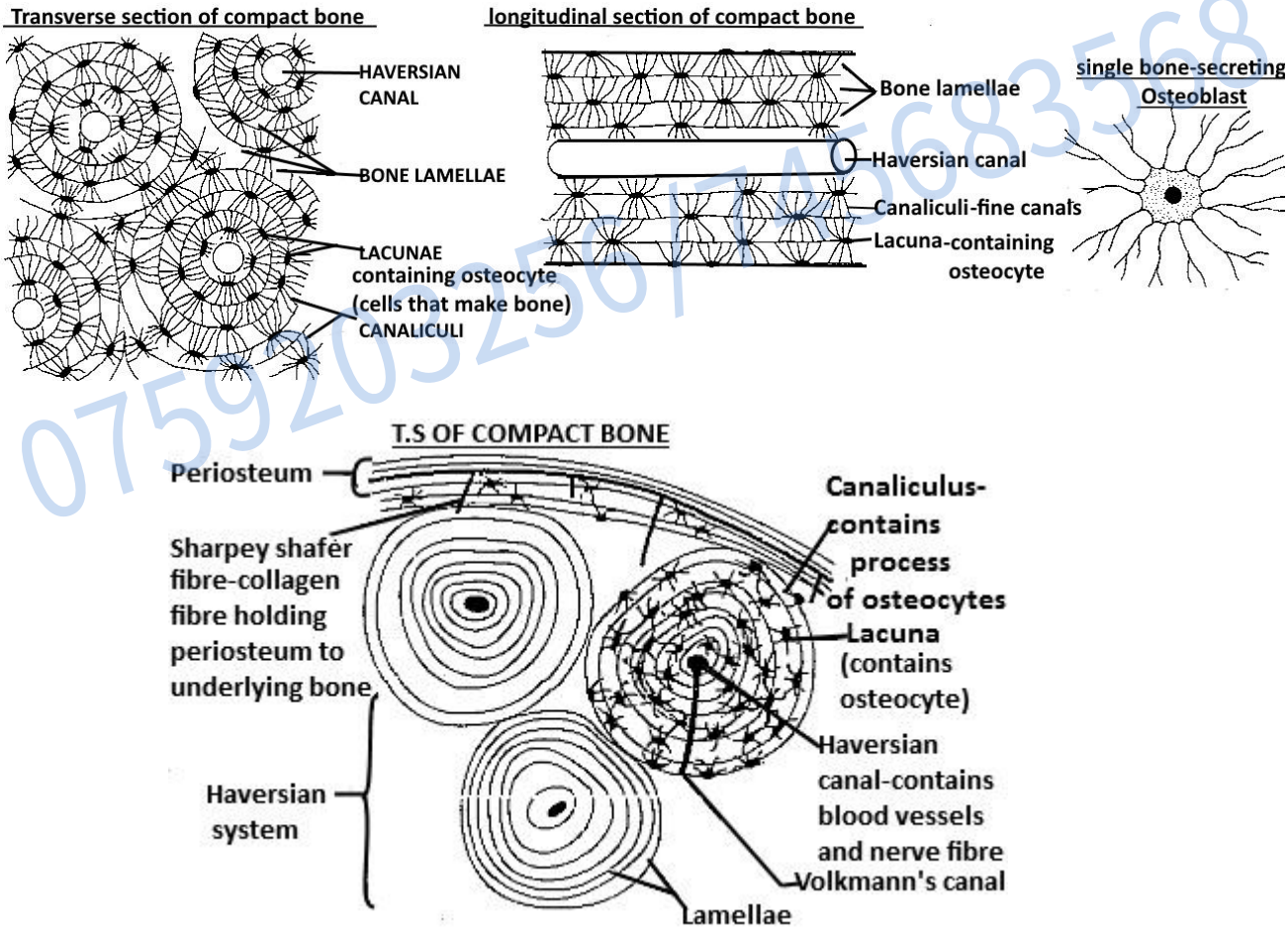
a. **Compact or dense or harvesian bone**
b. **Spongy or trabecular bone**
c. **Membrane or dermal bone**

COMPACT/ DENSE BONE
This consists of numerous cylinders of concentric rings of bony lamellae, whereby each lamella is a surrounding a central hole called **harversian canal.**
Compact bone consists of osteoblasts and osteocytes in a solid, hard, rigid, organic matrix with deposits of calcium salts, plus collagen fibres.

The structure of compact bone
A compact bone consists of numerous cylinders, each surrounding a central Haversian canal.
One such cylinder plus its canal is called a Haversian system or osteon.
The structure of the Haversian canal system (osteon)

- Each Haversian canal system consists of a Haversian canal in the center through which an artery, a vein, a lymph vessel and a nerve fibre pass through.
- The matrix is arranged in concentric layers called lamellae.
- In between the lamellae are numerous fluid-filled spaces called **lacunae,** containing living bone cells called **osteoblasts** when active or osteocytes when inactive.
- Radiating from each lacuna are many fine channels called **canaliculi** containing cytoplasm, which may link up with the central Haversian canal, with other lacunae, or pass from one lamella to another, forming a network of cytoplasmic extensions.

- The bone lamellae and osteoblasts or osteocytes in the lacunae are also arranged concentrically around the Haversian canal.
- The Haversian canal, along with the lamellae, lacunae and canaliculi form the Haversian canal system or osteon.
- The canals of Volkmann connect various Haversian canal systems together.
- Haversian canals are present transversally as well as longitudinally.
- Transversal Haversian canals communicate with the bone marrow cavity in the center of the whole bone, and also interconnected with the Centre of the whole bone, and also interconnect with longitudinal Haversian canals.
- Longitudinal Haversian canals contain larger blood vessels, and are not enclosed by concentric lamellae.
- In the center of a compact bone lies a bone marrow cavity, lined by endosteum.
- The matrix of a compact bone is composed of collagen, manufactured by osteoblasts, and hydroxyapatite together with quantities of magnesium, sodium, carbonates and nitrates.
- Covering the bone is a layer of dense connective tissue called the **periosteum**.
- Bundles of collagen fibres called **sharpey-shafer** fibres from the periosteum Peirce the bone.
- The inner region of the periosteum has blood vessels, and forms a layer which contains cells that can develop into **osteoblasts**.



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Description of External bone structure

A tough, fibrous, vascularized connective tissue called **periosteum** encloses a compact outer layer. Most bones have a **shaft** called **diaphysis,** which is usually hollow, slightly narrow and contains bone marrow which produces most of the various kinds of blood cells.

At the end bones are usually expanded to form the **epiphyses**. Each epiphysis is covered by articular cartilage. These are sites for attachment of tendons and articulation with other bones,

Bone is covered by a layer of tough fibrous membrane called the **periosteum**.

Distribution of compact bone

- Used in growth of long bones of limbs (limb bones).
- Forms the long shaft of the bone between the two swollen ends.

Spongy (trabecular) bone

This is formed from the embryonic cartilage and it is formation is called **endochondral ossification.**

It's composed of a thin meshwork of interconnecting bony struts called **trabeculae.** These trabeculae are oriented in directions, in which they are stressed or exposed to tensional and compressional forces, in order to enable it resist and withstand them, with minimum bone weight.

The matrix of spongy bone consists of less inorganic material than compact bone, which means that the spongy bone is less compact and hard than compact bone.

The inorganic material is primarily composed of collagen fibres.

The spaces between the trabeculae are filled with soft marrow tissue, appearing either red or yellow coloured.

If the marrow is red, as at the epiphyses of long bones such as femur, the cells are predominantly **red blood cells.**

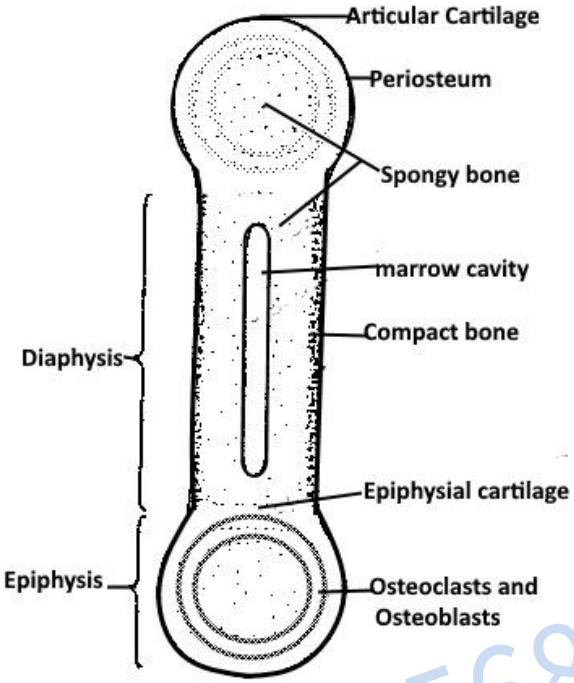
If the marrow is yellow as in the **diaphysis** of long bones, the cells are primarily fat cells.

The matrix of a spongy bone is secreted by **osteoblasts**, which become inactive, after serving that role and change into **Osteocytes.**

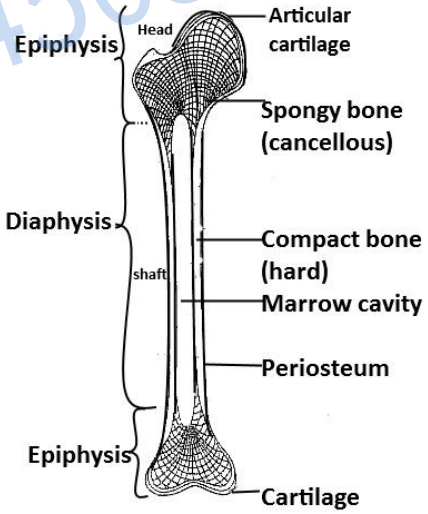
On the surface and inside the periosteum, are **osteoclasts**, which can resorb the calcified bone matrix, for further development and restructuring of the bone, during growth, development and repair.

The trabeculae are oriented in the direction in which the bone is stressed.

Diagram of the main parts of a BONE



Vertical section through femur



Distribution of spongy bone

- Occurs in the embryo, growing organisms, and **epiphysis** of long bones

MEMBRANE (DERMAL) BONE

- Dermal bone is not formed from the embryonic cartilage, but originates directly by **intramembranous ossification** in the dermis of the skin.
- In the dermis of the skin, aggregates of osteoblasts from rows of cells which manufacture bone trabeculae.
- As such, flat bony plates are produced very close to the skin surface.
- The bony plates go on increasing in size, as more bone is deposited on their inner and outer surfaces.
- Eventually the bony plates may sink further into the body to become part of the skeleton.

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Distribution of dermal bone

- Membrane bone forms components of the skull, jaw bones and pectoral girdle.

Differences between spongy bone and compact bone

Spongy bone	Compact bone
Consists of small pieces of bone.	Matrix is hard, solid and dense without any spaces
Forms the expanded ends (epiphyses) of long bones.	Forms the shaft (diaphysis) of long bones.
Filled with a soft tissue called Red marrow produces red blood cells and white blood cells.	Filled with Yellow marrow which stores fat cells.
Lacks Haversian canal system	Have a number of Haversian canal systems.

Similarities between bone and cartilage

- Both bone and cartilage consist of living cells and extracellular matrix
- Cells reside in lacunae in both.
- Both are capable of growth.
- Both have collagen fibres

Differences between cartilage and bone

Cartilage	Bone
Comparably soft, elastic and flexible.	Quite tough, rigid and inelastic.
The matrix contains the protein chondrin.	The matrix contains the protein casein.
Have spherical cells.	Have stellate cells.
The matrix does not contain deposits of calcium salts.	The matrix and the bone cells contain deposits of carbonates and phosphates.
The matrix is not arranged in concentric circles.	The matrix is arranged in concentric circles called lamellae.
Each lacuna has one to eight cartilage cells.	Each lacuna has only one bone cell.
The lacunae do not have any canaliculi and so cartilage cells are not interconnected.	Lacunae have canaliculi and so the bone cells are interconnected.
Lacks Haversian canal system.	A long bone has a number of Haversian canal systems.
Matrix is chondrin	Matrix is ostein
Surrounded by perichondrium	Surrounded by periosteum.
The matrix lacks blood vessels.	The matrix has a network of blood vessels.
Cells occur either singly, or in a group of two or four.	Cells arranged singly in a regular pattern.
Composed of a solid, elastic matrix.	Composed of a hard rigid matrix.
Cartilage cells are chondroblasts and chondrocytes.	Bone cells are osteoblasts, osteocytes and osteoblasts.

Differences between a dried bone and Decalafied bone

Dried bone	Decalafied bone
Bone that has been dried by subjecting it to a high temperature	Bone that has been treated with dilute hydrochloric acid.
Doesn't have the bone marrow.	Has the bone marrow.
Lacunae are present.	Lacunae are absent.
Contains mineral matter.	Contains only the organic matter, with no mineral matter.
Lacks the structure of a bone, and is in powdered form.	Has the structure of a typical bone

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MAIN FUNCTIONS OF BONES

A. Mechanical

- They protect internal organs, e.g. the skull protects the brain, the rib cage protects the heart and lungs
- They provide a frame work to keep the body supported.
- Bones, skeletal muscles, tendons, ligaments and joints function together to generate and transfer forces to cause movement.
- Bones in the ear (ossicles) transmit vibrations that result in hearing.

B. Synthetic

- Bone marrow, located within the medullary cavity of long bones and interstices of cancellous bone, produces blood cells in a process called haematopoiesis.

C. Metabolic

- Bones act as reserves of minerals important for the body, most notably calcium and phosphorus.
- Mineralized bone matrix stores important growth factors such as insulin-like growth factors, transforming growth factor, etc.
- The yellow bone marrow acts as a storage reserve of fatty acids.
- Bone buffers the blood against excessive pH changes by absorbing or releasing alkaline salts.
- Bone tissues can also store heavy metals and other foreign elements, removing them from the blood and reducing their effects on other tissues. These can later be gradually released for excretion
- Bone controls phosphate metabolism by releasing fibroblast growth factor – 23, which acts on kidneys to reduce phosphate reabsorption. Bone cells also release a hormone called osteocalcin, which contributes to the regulation of blood glucose and fat deposition. Osteocalcin increases both the insulin secretion and sensitivity, in addition to boosting the number of insulin-producing cells and reducing stores of fat

Adaptation of bone to its functions

- A tough fibrous layer of dense connective tissue called the Periosteum provides a tough and hard covering that surrounds the bone and protects the inner cells.
- Bundles of collagen fibres called sharpey-shafer from the Periosteum penetrate the bone; giving more mechanical strength; providing an intimate connection between the underlying bone and the Periosteum; and acting as a firm base for insertion of tendons, which contribute to movement and location.
- Osteoblasts are arranged in concentric rings, round a series of Haversian canals in compact bone; thus lay down the matrix in a similar rigid and dense regular pattern, to provide uniform mechanical strength.
- Bone lamellae contain numerous lacunae containing living bone cells called osteoblasts, which secrete the matrix of the bone.
- Mature less active osteoblasts called Osteocytes can be reactivated quickly regaining the structure of active osteoblasts, and depositing bone matrix when structural changes in bone are required.
- Bone cells are embedded in a firm, calcified bone matrix, which is rendered hard by deposition of calcium salts and other inorganic ions.
- Bone matrix comprises collagen, hydroxyapatite together with other mineral ions; the combination of organic and inorganic materials produces a structure of great mechanical strength, which is harder than cartilage but not brittle.
- The matrix and lamellae are laid in a series of cylindrical layers, situated to the forces acting upon the bone, and the load that has to be carried.
- Bone cells called osteoclasts responsible for bone resorption, enable reconstruction and remodeling of bone, during endochondral ossification and repair of damaged and fractured bones.

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- An artery, a vein, and a lymph vessel pass through a Haversian canal of compact bone; allowing the passage of nutrients, respiratory gases and metabolic wastes towards and away from the bone cells.
- Each lacuna has fine cytoplasmic extensions called canaliculi which pass through lamellae and make connections with other lacunae and with the central Haversian canal; allowing communication between the lacunae in different lamellae, and with the central Haversian canal.
- Presence of nerve fibres in the Haversian canal allows coordination of bone resorption and reconstruction, enabling each bone to adapt its structure to meet any change in mechanical requirement of animal during its development.
- Bone releases calcium and phosphate into the blood stream, as required by the body, under control of the hormone parathormone and calcitonin.
- Spongy bone has spaces between the trabeculae, reducing the weight of the bone allowing less restricted movement and locomotion.
- The trabeculae of spongy bone are oriented in the direction in which the bone is stressed, enabling the bone to withstand tension and compression forces effectively, whilst at the same time keeping the weight of the bone to a minimum.
- Bone marrow produces red blood cells, white blood cells and platelets.

THE DEVELOPMENT OF BONE [OSSIFICATION]

Ossification is the process of formation and development of bone.

Bone originates in two ways; intramembranous ossification and endochondral ossification.

Intramembranous ossification: The formation of bone from embryonic connective tissue

The process by which connective tissue other than cartilage is converted to bone e.g. in the skull, mandible, maxilla, and clavicles

- The thin bony plates of the skull and parts of some other bones are formed directly by cluster of ossification which appears inside fibrous membranes.
- The strands of bone formed by different clusters are called trabeculae, and become linked to form a loose network described as spongy bone.
- Thus spongy bone is formed by intramembranous ossification.
- As development continues, remodeling of skull plates converts some of the spongy bone to compact bone and allows the plates to reach their adult shape and size.

Endochondral ossification: The process of bone formation from embryonic cartilage. E.g. the formation of long bones and most other bones in the body.

- The skeleton of a vertebral embryo consists mainly of hyaline cartilage
- Each cartilage element is surrounded by a connective tissue jacket; the perichondrium is the same shape as the bone that replaces it. Thus the cartilage acts as a model for bone formation.

ENDOCHONDRAL OSSIFICATION

Endochondral ossification involves the following stages:

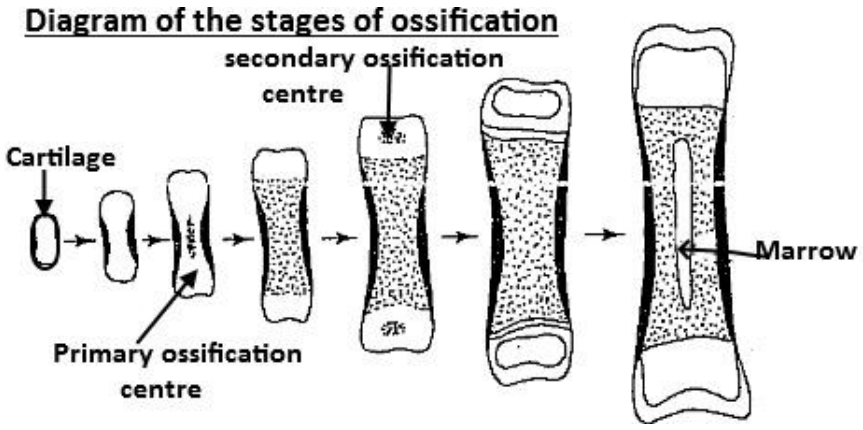
●Development and growth of the cartilage model i.e. cartilage templates (structures shaped like future bones) form.

●**Primary ossification Centre** develops at the diaphysis i.e. the cartilage cells, at the point where ossification is starting enlarge and arrange themselves in rows. Chondroblasts secrete more matrix in which they get imbedded, so that they become further separated from each other. Calcification of the matrix separates the cells from each completely by calcified substance which encloses the chondroblasts in cavities thus limiting their nutrition and causing death. The spaces left by dead cells are invaded by blood vessels and osteoclasts which erode the matrix leaving spaces which eventually fuse to form the medullary (marrow) cavity.

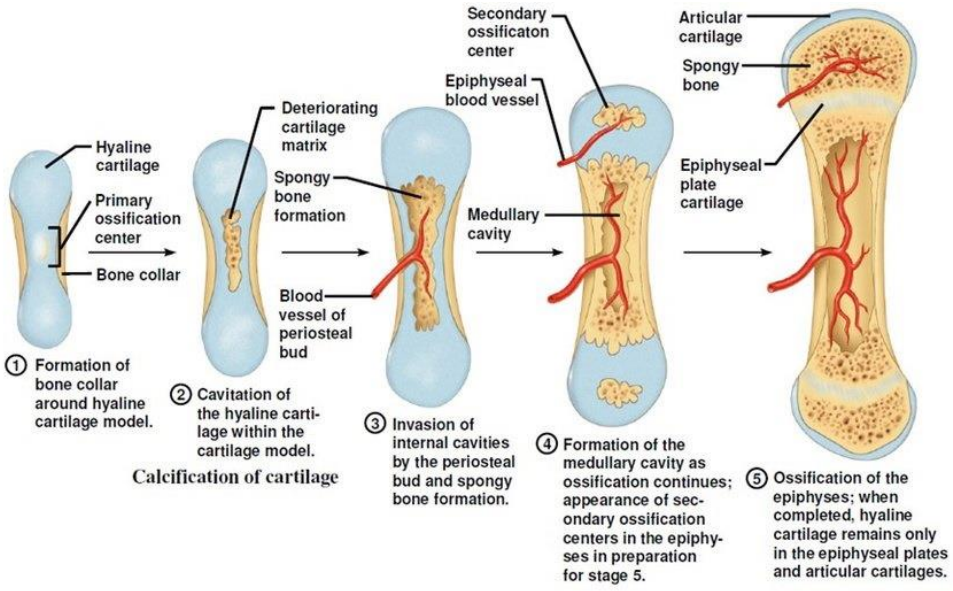
Blood vessels penetrate the perichondrium to stimulate some of its cells to become Osteoblasts which produce a collar of compact bone in the shaft region.

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●Development of the **secondary ossification centres** in the epiphyses in a manner similar to the development of primary ossification Centre.
●Articular cartilage forms, and epiphyseal discs with actively dividing cells remain in the epiphyses, until the bone attains the desired length and then the discs disappear.



NB: In long bones the epiphyseal plate / discs (a plate of cartilage) remains through adolescence at the junction between epiphysis and diaphysis), which is a site of bone elongation.
Ossification of bones (such as the long bones of the arms and legs) begins when blood vessels penetrate the perichondrium of the cartilage mid-way along the shaft (or diaphysis) of the cartilage model. Vascularization of stimulates some of the cells of the cartilage perichondrium to become osteoblasts, which produce a collar of compact bone in the shaft region. The jacket of connective tissue covering the developing bone is now called the Periosteum.
A **primary ossification Centre** appears inside the shaft, and is progressively invaded by a proliferating number of blood vessels and osteoblasts. The matrix of the cartilage tends to become calcified by deposition of calcium and phosphate, but is eroded by the osteoclasts, leaving spaces, leaving spaces which eventually fuse to form the marrow cavity.
Osteoclasts are large multinucleated bone cells, similar to macrophages, which continually erode the bone matrix. Like other macrophages. Osteoclasts develop from monocytes. Working in small groups, osteoclasts tunnel through bone, leaving cavities which are invaded by blood capillaries and new bone-forming osteoblasts. Within the tunnel, osteoblasts lay down a new bone matrix in concentric rings, forming an arrangement called a Haversian canal system.



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BONE REMODELING

Adult human bones experience continual remodeling i.e. there is reabsorption followed by replacement of bone with little change in shape. **Osteoclasts** (mature bone breakdown cells) degrade worn-out cells and deposit calcium in the blood, followed by the disappearance of Osteoclasts and the destruction they would have caused is repaired by Osteoblasts (immature bone forming cells). As the Osteoblasts absorb calcium from blood to form new born, some of them get caught in the matrix they secrete and are converted to Osteocytes (mature bone cells)

The purpose of bone remodeling is to regulate calcium ion levels in blood, repair micro-damaged bones (from everyday stress) but also to shape and sculpture the skeleton during growth.

Cartilage continues to grow at either end producing an increase in length. Most of cartilage is later replaced by spongy bone.

In mammals, secondary ossification centers develop in the swollen ends (or epiphyses) of the cartilage models of long bones. The epiphyses ossify more or completely, except for a thin layer of cartilage, called an epiphyses plate, separating each epiphysis from the main shaft and a thin surface layer of articular cartilage. This arrangement gives the bone, strong rounded ends but permits continued increase in length.

Increase in diameter of the bone shaft is achieved by continual remodeling and deposition of new bone by the osteoblasts of the Periosteum.

As maturity approaches, the thickness of the epiphyseal plates is reduced and finally, the epiphyses and the bone shaft fuse completely leaving a faint epiphyseal line.

Ossification of all bones in human skeleton is normally completely by age 25.

OSTEOPOROSIS

Bone disorder during which bone mineral density is reduced, bone micro architecture is disrupted, and the amount and variety of non-collagenous proteins in bone is altered due to bone synthesis exceeded by bone absorption.

Osteoporosis is increased by advancing age; high alcohol consumption; decreased oestrogen levels in women; smoking; low calcium, protein and fluoride intake; reduced physical exercise.

Dentine (ivory)

- Dentine has the same composition as bone; however it contains a higher inorganic component making it harder than bone.
- Dentine contains no lacunae and has an arrangement of osteoblasts different from that of bone.
- In dentine osteoblasts is confined to the inner odontoprocess which contain microtubules and frequently blood vessels and nerve endings sensitive to touch and low temperatures.
- Collagens fibres manufactured and laid down at apices of the odontoblastic process ultimately become calcified by impregnation with apatite crystals to form new dentine.

Distribution of dentine

- Located between the enamel and pulp cavity in teeth, above and below gun level.

Functions of dentine

- Dentine forms the bulk of teeth

Haemopoietic tissue

Functions of haemopoitic tissue

Forms red blood cells and white blood cells.

Distribution of haemopoitic tissue

Located in the red bone marrow and lymphoid tissue of adult mammals.

The structure of haemopoitic tissue

- Haemopoitic tissue consists of free cells enmeshed in a stroma of loose sclera protein fibres called reticular connective tissue.
- Bone marrow (myeloid tissue) produces red blood cells and granulocytes.
- Lymphoid tissue produces lymphocytes and monocytes.

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Bone marrow (myeloid tissue)

- The stroma of the myeloid tissue consists of very loose reticular connective tissue, permeated by wide intercellular spaces.
- Traversed by numerous, thin-walled wide blood sinuses, through which mature blood cells escape into the blood stream.
- Lining the sinuses are Phagocytic cells which form part of the body's reticulo-endothelial system.

Functions of bone marrow

Blood cells are derived from primitive (undefferianted) cells called;

(i) Hemocytoblasts which differentiate into erythroblasts, the precursors of erythrocytes.
(ii) Myelocytes are the precursors of granulocytes.
(iii) Lymphoblast's the precursor of lymphocytes.
(iv) Monoblasts, the precursor of monocytes.
(v) Megakaryocytic cells which produce platelets.

Lymphoid tissue

There are three types of lymphoid tissue;

- Loose lymphoid tissue where the stroma of reticular connective tissue predominates over the free cells.
- Dense lymphoid tissue where there are more free cells embedded in stroma.
- Nodular lymphoid tissue which possess dense aggregates of free cells.

- The free cells are composed primarily of lymphocytes of various sizes and functions.
- Also present are plasma cells derived from lymphocytes of various sizes and functions.
- Also present are plasma cells derived from lymphocytes and occasionally monocytes and eosinophils are present.

MUSCLE TISSUE

Muscle tissue derived from the embryonic mesoderm and consists of highly specialized contractile cells or fibres, held together by connective tissue.

There are three types of muscle in the body, classified by the method of innervations; voluntary muscle, involuntary muscle, and cardiac muscle.

The basic structure of muscular tissue

- All muscles are made up of elongated and thin cells called **muscle fibres.**
- Muscle fibres contain specialized cytoplasm called **sarcoplasm** that contains a network of membranes called sarcoplasmic reticulum.
- Muscle fibres may be bound by a cell membrane called **sarcolemma**.
- Each muscle may contain numerous **thin myofibrils.**

Voluntary/ striated/ striped muscle

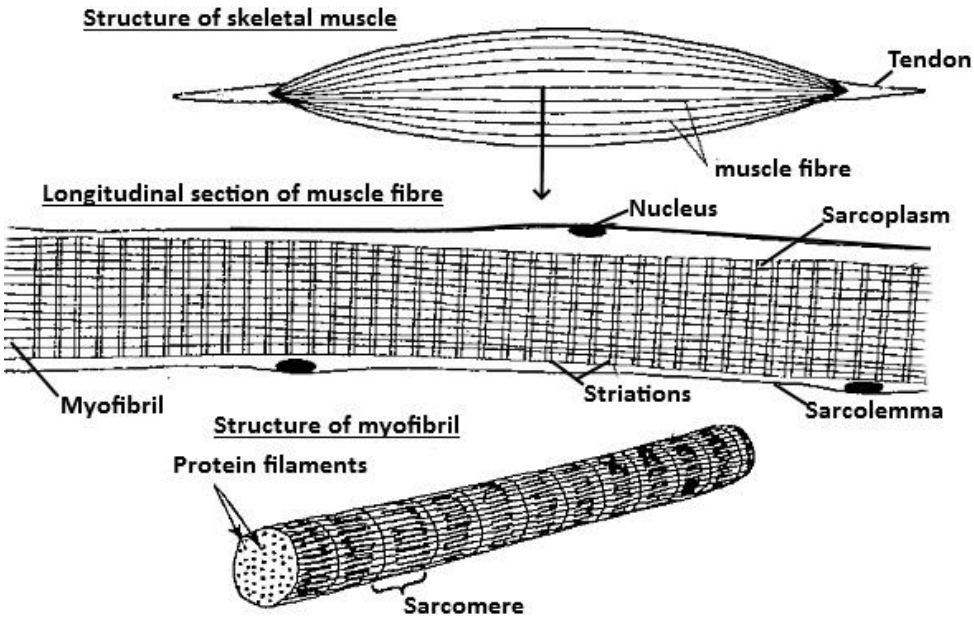
Distribution of skeletal muscle

- Found attached to the skeleton in the head, trunk and limbs hence the name (skeletal muscle)

The structure of skeletal muscle

- Skeletal muscle possesses distinct cross-striations in the form of **light bands** and **dark bands** and **A bands** respectively (hence striated /striped muscle).
- **I** means isotropic, as it allows light to pass through and so appear lighter.
- A means Anisotropic, as it does not allow light to pass through and so appears darker.
- A muscle is composed of a number of cells called **muscle fibres.**
- Each muscle fibre consists of numerous thin myofibrils.

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The structure of skeletal muscle fibre

- A skeletal muscle fibre is elongated, unbranched and cylindrical in shape.
- A number of muscle fibres are arranged parallel to each other and are bound together by vascular connective tissue.
- Skeletal muscle fibres are multinucleated.
- The nuclei are present near the periphery just beneath the bound membrane (**sarcolemma).**
- Light and dark bands are visible due to cross striations present in myofibril.
- Myofibrils are arranged along the long axis of the fibre.

The structure of a myofibril

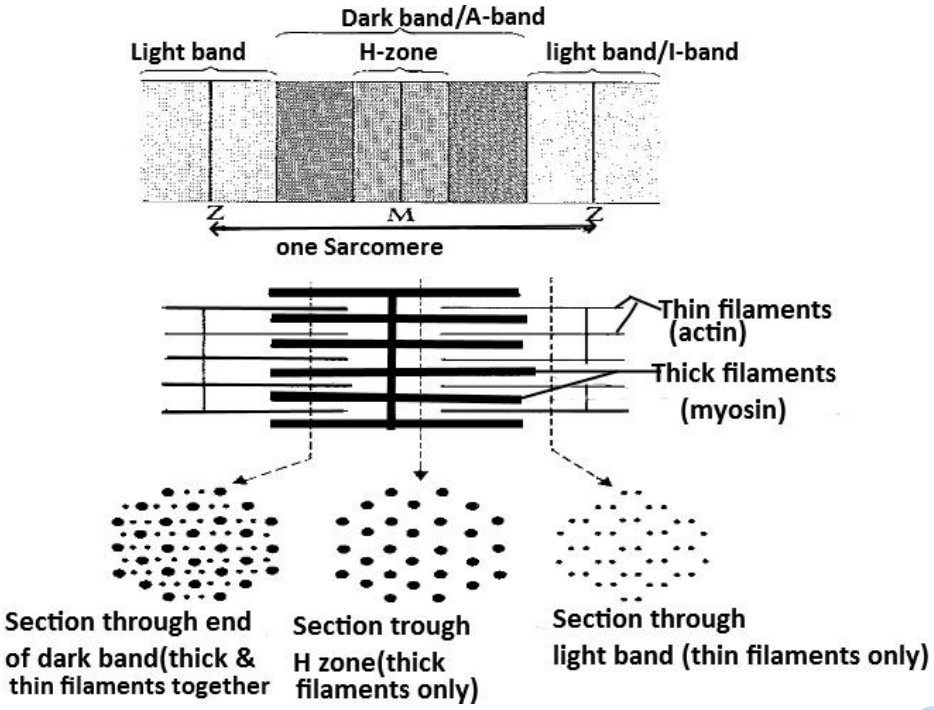
- The myofibrils are divided into compartments called **Sarcomeres** by internal membranous partitions called **Z-lines**
- Each skeletal myofibril shows alternate **(I-bands**) light in appearance and dark (**A-bands**).
- **I-bands** are regions where only thin filaments of the protein actin are found inside the sarcomeres.
- Between the I-bands and in the middle of each sarcomere are the **A-bands** which are dark in appearance and contain the thick filaments of the protein myosin
- In the middle of each **A-band** is a lighter **H-zone/ band** where there are thick filaments only.
- The area between **the Z-line** is called the sarcomere.
- The sarcomere is the basic structure and functional unit of the muscle capable of contraction.
- A myofibril and therefore a muscle fibre, is made up of thousands of sarcomeres.
- The **I and A** bands are due to the specific arrangement of two proteins; Actin and myosin present in form of filaments.

The structure of sarcomere

- Various parts of sarcomere have a specific arrangement of **actins and myosin** filaments.
- Actin forms thin filaments while myosin forms thick filaments.
- The I-band has only the Actin filaments.
- The A-band has both thin Actin and thick myosin filaments.
- The H-zone has only thick myosin filaments.
- The Z-line is a membrane to which the Actin filaments are attached on both sides.

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The fine structure of skeletal muscle



Innervations and activity of skeletal muscle

- Innervated by the voluntary nervous system, that is the peripheral and central nervous system. (Hence voluntary muscle).
- Thus, striated muscle is voluntary in function and so works under one's own will.
- Brings about movement of organs and locomotion of the whole body.
- Also brings about the ability of the body part to resist external forces, enabling support of the body and maintenance of body position and posture.
- Responsible for voluntary body movements.
- Contraction of skeletal muscle attached to the bone allows movement of the body and hence locomotion.
- Under goes powerful and rapid contraction, with short refractory (rest) period; and so gets easily fatigued.
- Require large amounts of energy in form ATP and so are heavily supplied with numerous blood capillaries, and also have numerous elongated oval mitochondria and numerous glycogen granules.

Differences between Actin and myosin filaments

Actin filaments	Myosin filaments
▪ Made up of a thin and lighter protein called Actin. ▪ Found in both I and A bands. ▪ Cross bridges are absent.	▪ Made up of a thick and heavier protein called myosin. ▪ Found in A-bands only. ▪ Cross bridges are present.

Adaptations of voluntary muscle tissue for its function

- Consists of elongated cells called muscle fibres, allowing considerable contractile length.
- Numerous muscle fibres are arranged to each other giving maximum combined contractile effect.
- The ends of the muscle fibre are tapered and interwoven with each other; to provide adequate mechanical strength during contraction.
- Has a large number of mitochondria to provide a large amount of energy in form of ATP, rapidly for rapid contraction.

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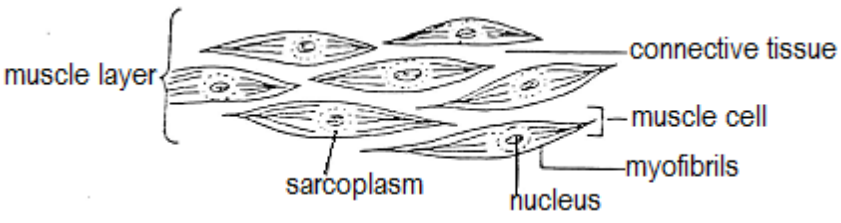
- Comprises thin Actin filaments and thick myosin filaments fitted into each other; to allow sliding over each other during muscle contraction.
- Has a rich supply of blood capillaries to rapidly provide oxygen and nutrients for metabolism, and to rapidly get rid of metabolic wastes.
- Contains respiratory pigment myoglobin, to store oxygen; and release it for respiration when blood oxygen levels are low.
- Has a specialized region called motor end-plate, where the axon of the motor neuron divides and forms fine nonmyelinated branches ending in synaptic knobs running in shallow troughs on the sarcolemma (cell surface membrane) of the muscle fibre allowing nervous stimulation and control of muscle.
- The sarcolemma folds inwards and forms a system of tubes called the T-system (transverse tubes) which run through the sarcoplasm to the Z-lines; allowing a nerve impulse arriving along a motor neuron at the neuromuscular junction at the surface of a muscle fibre to be propagated as a wave of depolarization (action potential) through the T-system causing release of calcium ions by the sarcoplasmic reticulum to activate the process of muscle contraction.
- The specialized endoplasmic reticulum of the muscle fibre called the sarcoplasmic reticulum forms the vesicles (swollen areas) at the Z-line of the sacomeres contain calcium ions used to activate the process of muscle contraction.
- Ability to generate ATP using phosphocreatine during anaerobic conditions for a constant supply of ATP in the muscle.
- Ability to respire anaerobically for continued muscle contraction in anaerobic conditions.

10) Unstriated/ unstrapped/ involuntary/ smooth muscle

- Each muscle fibre is spindle shaped tapering at both ends and uinucleated (containing one nucleus).
- The nucleus is single, elongated in shape, centrally placed and surrounded by little sarcoplasm.
- The muscle fibre lacks a sarcolemma.
- Each muscle fibre contains numerous inconspicuous, fine contractile myofibrils arranged longitudinally.
- The Actin and myosin filaments are distributed; hence there are no striations or light and dark bands.
- Smooth muscle fibres are shorter than striated muscle fibres.
- Has prominent mitochondrion but less numerous in striated muscles.
- Has individual tubule of the smooth endoplasmic reticulum and glycogen granules.
- Has sarcoplasmic reticulum but less extensive than in striated muscle.
- Rings of smooth muscle fibres are called sphincter muscles for example; pyloric, cardiac and anal sphincters.

Innervations and activity of smooth muscle

- Smooth muscle is involuntary in action; so cannot be moved by one's own will.
- Innervated by two sets of nerves from the autonomic nervous system (parasympathetic and sympathetic nerves).
- Smooth muscle fibres undergo prolonged and slow, sustained rhythmical contractions and relaxations as in peristalsis; hence fatigue slowly.
- Functionally smooth muscles are of two types; single-unit muscles and multiunit muscles.



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Adaptations of Striated (skeletal) muscular tissue

Structure	Function
Elongated fibres	Allow considerable contraction.
Parallel fibres	Give maximum contractile effect
Fibre ends tapered and interwoven	Provide strength
Large number of mitochondria	Provide large amount of ATP
Actin and myosin arrangement in sarcomere	Allows contraction by filament sliding over each other
Rich supply of blood vessels	Provide adequate supply of oxygen and glucose.
Myoglobin present	To store oxygen for release when blood oxygen levels are low.
Motor end plates	Allow muscle stimulation
Fibres arranged in motor units	To allow variable degrees of contraction.

Differences between single-unit muscles and multiunit muscles

Single-unit smooth muscle	Multiunit smooth muscle
▪ Muscles fibres closely joined together. ▪ All fibres, contract together as a single unit, automatically and rhythmically. ▪ Present in the walls of hallow visceral organs as in the stomach, intestine, urinary bladder.	▪ Muscle fibres are not closely joined together. ▪ Individual fibres contract as separate units more or less as independent muscle. ▪ Present on hair roots and walls of large blood vessels.

Note; humans learn to control many smooth muscle for example humans control the movement of the anal sphincter muscle.

Functions of involuntary muscle

- The pyloric sphincter controls passage of food from the stomach to the duodenum.
- The anal sphincter controls the elimination of faeces from the body.
- Small sphincter muscle surround some blood vessels; enabling control of distribution of blood and regulation of blood pressure.
- Control movement of materials with the body visceral organs.

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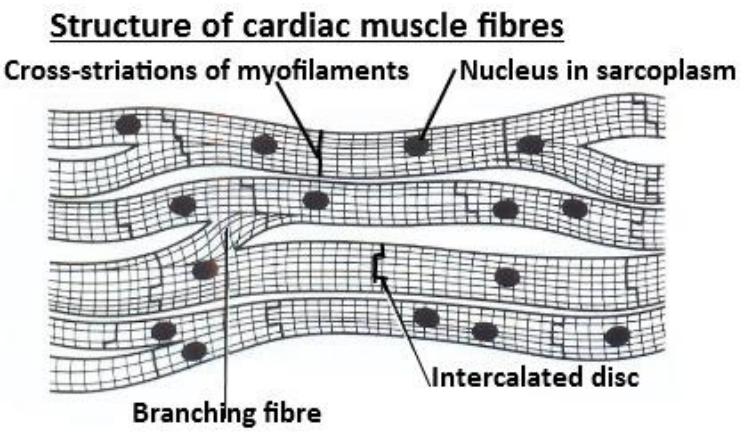
CARDIAC MUSCLE

Distribution of cardiac muscle

- Found only in the heart.

The structure of cardiac muscle

- A cardiac muscle consists of a network of interconnected cells called **cardiac muscle fibres.**
- Each cardiac muscle fibre is short, cylindrical and branched.
- Each muscle fibre possess one numerous large mitochondria, abundant cytoplasm, glycogen granules, well developed T-system and poorly developed endoplasmic reticulum consisting of a network of tubules.



- Cardiac muscle fibres are terminally branched and connected to each other by special interdigitating processes (**zigzag junctions**) called **intercalated discs.**
- Actin and myosin filaments are regularly arranged to give faint but regular cross striations.
- Muscle fibres branch and cross connect with each other to form a complex net-like arrangement.

Innervations and functions of cardiac muscle

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

Adaption of cardiac muscle to their function

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

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A comparison of voluntary, involuntary and cardiac muscle; similarities and differences

Features	Striated muscle	Smooth muscle	Cardiac muscle
Names	Striated, striped, smooth, voluntary, striated muscle	Unstriated, unstrapped, smooth, voluntary, non-striated muscle	Heart muscle, cardiac muscle
specialization	Mostly highly specialized	Least specialized	More specialized than involuntary
shape	Elongated, cylindrical and unbranched muscle fibres	Spindle shaped muscle fibres with tapered ends	Elongated, cylindrical and branched muscle fibres
Arrangement	Arranged in bundles	Arranged in bundles, sheets or rings	Interconnected forming a network
sarcolemma	present	absent	present

Nucleus	Multinucleated, myofibrils with peripherally located nucleus	Uinucleated, myofibrils with centrally located elongated nucleus	One or two nuclei in between intercalated discs.
Cytoplasmic contents	-Numerous mitochondria in rows at the periphery and between fibres -prominent smooth endoplasmic reticulum forming network of tubules -T-system well developed -glycogen granules and some lipid droplets	Prominent, but less mitochondria Individual tubules of SER Glycogen granules present	Numerous large mitochondria Poorly developed SER consisting of network of tubules T-system well developed Glycogen granules present
Feature	**Striated muscle**	**Smooth muscle**	**Cardiac muscle**
Blood supply	Rich blood supply	Poor blood supply	Rich blood supply
Striations or bands	Striations of light and dark bands	No striations or bands	Faint, regular striations present
Intercalated discs	Absent	Absent	Present
Myofilaments /myofibrils	Very conspicuous	Inconspicuous	Conspicuous
innervations	Under control of voluntary nervous system	Under control of autonomous nervous system	Myogenic; but rate of contraction can be influenced by autonomous nervous system
Contractions	Powerful, rapid contraction with short refractory (rest) period	Shows sustained slow and rhythmic contractions and relaxation; with long rest period, peristalsis	Continuous, rapid, rhythmical, contraction and relaxation; with long refractory period; hence contraction not sustained
Fatigue	Fatigues quickly and easily	Does not fatigue easily	Does not fatigue
location	Attached to the skeleton in the head, trunk and limbs	In walls of intestinal, genital, urinary and respiratory tracts in walls of blood vessels	Only in the walls of the heart
Energy	Large amount of energy at once	Much energy needed but constant supply required	Needs a constant and good energy supply
Mode of working	voluntary	involuntary	involuntary

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NERVOUS TISSUE

Nervous tissue contains densely packed nerve cells called neurones, which are specialized for conduction of nerve impulses.

Among other cells present are receptor cells and Schwann cells.

Nervous tissue is frequently enclosed by connective tissue which contains blood vessels.

Neurones have two basic functional properties; excitability and conductivity.

Neurones

- Neurones are the basic functional units of the nervous system.

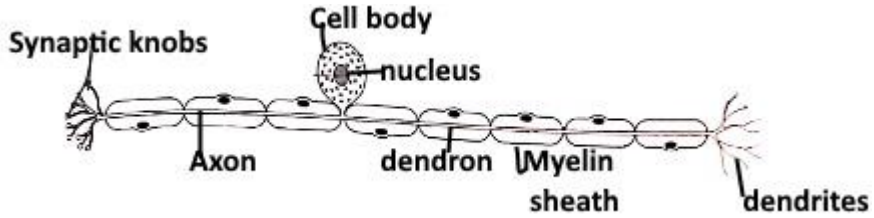
Functions of neurones

- Neurones transmit electrical impulses thus providing a means of communication between receptors (the cells or organs which receive stimuli) and effectors (the organ or tissue which respond to stimuli such as muscle and glands.

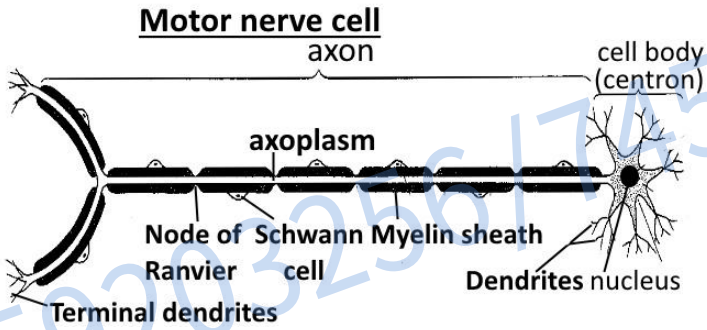
Types of neurones

(i) Sensory neurones conduct towards the central nervous system (brain and spinal cord).
(ii) Motor neurones conduct impulses away from the central nervous system.
(iii) Interneuron frequently connect sensory neurones with motor neurones.

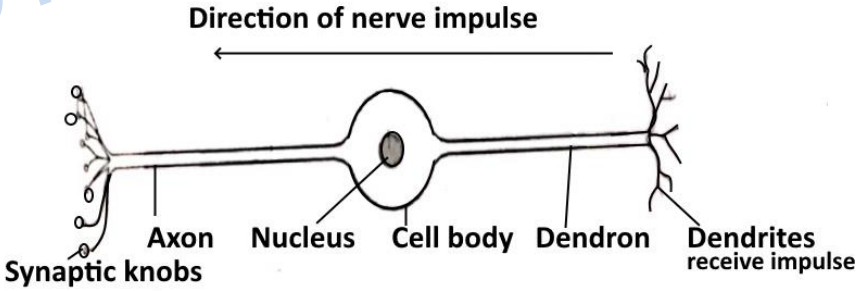
The structure of different types of neurons **a) Sensory/ afferent neuron**



b) Motor/efferent / effector neurones



c) Interneuron/ intermediate /associated /relay neuron

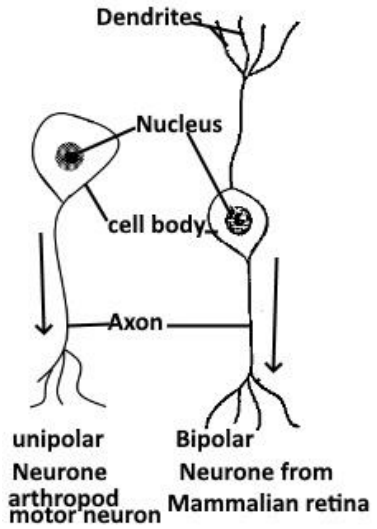


THE STRUCTURE OF A NEURON

- Each neuron possess a cell body (**soma or perikaryon**)and cytoplasmic extension (nerve fibres)
- Each cell body contains a nucleus and abundant granular cytoplasm.
- The cytoplasm also contains prominent conical, angular or rhomboidal granules called Nissl's granules which are groups of ribosome and rough endoplasmic reticulum rich in RNA and associated with protein synthesis.
- From the cell body, extends out two types of cytoplasmic extensions; Dendron and axons.

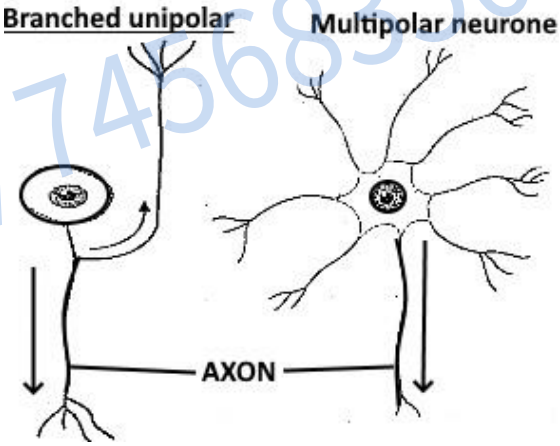
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- Depending upon the number and arrangement of these processes the neurones are said to be unipolar, pseudo unipolar and polar multipolar.



1. A **unipolar neuron** such as the arthropod motor neuron
2. A pseudo unipolar neuron
3. A bipolar neuron such as from mammalian retina
4. A multipolar neuron such as the mallian spinal cord

- **A unipolar neuron** is one which the axon is the only large branch from the cell body.
- A **bipolar neuron** is one with axon and Dendron.
- A **multipolar neuron** has one axon and several Dendron.
- Nerve fibres which conduct impulses away from the cell body are called dendrons.
- Dendrons are small, relatively wide, and break up into fine terminal branches called dendrite.
- Nerve fibres which conduct impulses away from the cell body are called axons.
- Axons are thinner than dendrites and maybe several meters long.
- The end of an axon breaks up into fine branches with swollen endings called synaptic knobs.
- Synaptic knobs are neurosecretory and release neurotransmitters.
- Axons communicate with other neurons via gaps called synapses.
- Each axon is filled with cytoplasm called axoplasm that is continuous with the cytoplasm of the cell body.
- The axoplasm contains numerous mitochondria, RER, neurofibrils, but lucks Nissl's granules, Golgi apparatus and a nucleus.
- The axon is covered by a membrane called the axolemma.



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Differences between the dendrons and axon

Dendron	Axon
• Small, numerous, branched. • Have fine terminal branches. • Conduct nerve impulses towards the cell body. • Have Nissl's granules and Golgi apparatus	• Long, generally unbranched. • Have terminal end branches with swollen ends (synaptic knobs) • Conduct nerve impulses away from the cell body. • Do not have Nissl's granules and Golgi apparatus.

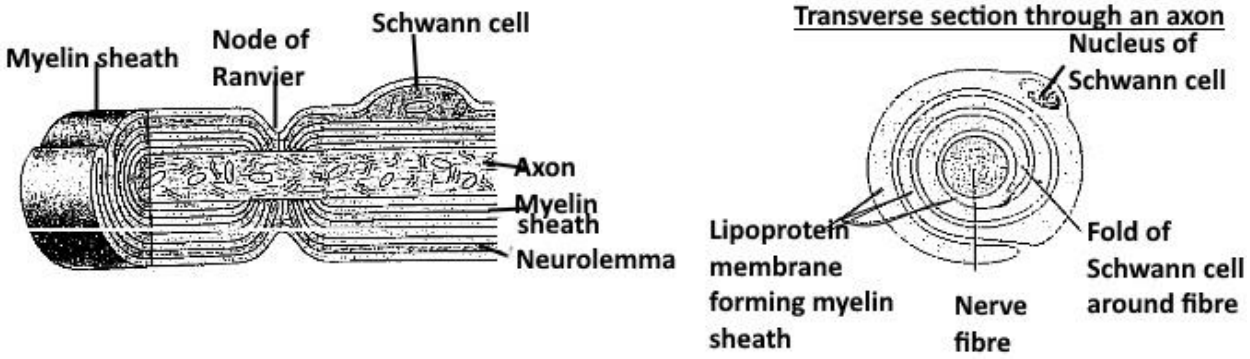
Types of nerve fibres

There are two types of nerve fibres; myelinated and non-myelinated nerve fibres.

a) Myelinated/medullated nerve fibres

- Myelinated nerve fibres completely surrounded and insulated by a fatty myelin sheath formed by another type of cell called a Schwann cell.
- The cytoplasm remains in a region called **neurilemma**
- The myelin sheath is interrupted at regular intervals by constrictions called nodes of Ranvier.

- The nodes occur between the Schwann cells and one Schwann cell nucleus is visible in the sheath between each successive pair of nodes.
- The cell surface membrane of the Schwann cell becomes extended and wraps itself like a rod of carpets round the nerve fibre. This extension forms the myelin sheath, which is mainly lipid and lacks the protein normally found in membranes.
- A node of Ranvier the axon is surrounded by the axolemma and neurilemma only.



b) Non-myelinated/ non-medullated nerve fibre

Non-myelinated nerve fibres are those without a myelin sheath.

These lack nodes of Ranvier and are only surrounded by Schwann cells which do not form a myelin sheath.

Differences between myelinated and non-myelinated nerve fibre

Myelinated nerve fibres	Non-myelinated nerve fibres
• Nerve fibres have myelin sheath surrounding axon. • Have nodes of Ranvier at regular intervals. • Nerve fibres are thicker. • Nerve impulses travel at a much faster speed. • Present in cranial and spinal nerves, in the central nervous system.	• No myelin sheath surrounding axon • Nodes of Ranvier absent • Nerve fibres are thinner. • Nerve impulses travel at much slower speeds. • Present in autonomous or autonomic nervous system.

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NERVES

Nerves consist of bundles of nerve fibres in a connective tissue sheath called **the epineurium**.

Each nerve fibre is surrounded by a sheath of connective tissue called the **endoneurium**.

A number of nerve fibres are bound together in smaller bundles by a connective tissue called the **perinerium.**

Adaptations of neurons to their functions

- The cell body contains prominent nucleus and most of the nerve cell's other organelles and thus controls the metabolic functioning of the cell.
- A group of ribosome and rough endoplasm called Nissl's granules produce proteins required for transmission of a nerve impulse.
- The cytoplasm of the cell body, dendrons and axon contain numerous mitochondria to produce large amounts of energy in form of ATP for active processes involved in impulse transmission such as the sodium-potassium pump.
- Schwann cells of myelinated axons form a fatty myelin sheath with high electrical resistance and acts as an electrical insulator, insulating the axon of the neuron and leading to increased speed of impulse transmission, through salutatory (jumping) conduction.
- The myelin sheath of myelinated axons is interrupted at regular intervals by breaks called Nodes of Ranvier, where the resistance to current flow between the axoplasm and the fluid outside the cell is lower and at this points local circuits are setup and current flows across the

axon membrane to generate the nerve impulse, leads to increased speed of impulse transmissions.

- Nerve fibres contain neurofibrils for transportation of materials from the cell body to the nerve fibres and from the nerve fibres to the cell body.
- Dendrites make synaptic connections with the neighboring excitatory cells and tissues allowing transmission of nerve impulses from cell to cell.
- Giant axons typical of annelid, arthropod and mollusks, have a large diameter of approximately one millimeter which decreases the resistance of axoplasm to ionic exchange and increase the length of axon membrane influenced by local circuits, lengthening the distance between adjacent depolarization, leading to increased velocity of impulse transmission.
- Neurones are long cells whose length depends on their precise role in the nervous system, for example, motor neurones supplying the muscles in the Curaffe's leg are several meters long allowing conduction of impulses to and from all parts of the body.
- Special gaps between the nerve cells, allow nerve impulses to be transmitted from one neuron to another, either by chemical or electrical transmission.
- Size and shape of neurones varies widely to meet the nervous needs of the body, from unipolar, pseudo unipolar, bipolar to multipolar; depending on the extent of the nervous links required.

1) Sometimes, the axon divides into branches called collaterals so that impulses from one neurone can reach several different destination increasing dexterity and complexity of nervous condition of the body.
2) Integration of synaptic input received by dendrites is focused on a specialized region of the cell body called the axon Willock, until a threshold level is reached and the axon Hillock fines a nerve impulse into the axon.

TYPES OF NERVES

Nerves are classified according to the direction in which they convey nerve impulses into;

1. **Sensory/afferent nerves** convey impulses to CNS for example, the optic, auditory and olfactory nerves.
2. **Motor/efferent nerves** conduct impulses away from the central nervous system, for example; oculomotor, pathetic, abducens.
3. **Mixed nerves** convey impulses in both directions, that is to and away from the CNS for example all the spinal nerves, trigeminal, facial, vagus, gloss pharyngeal.

Neuroglia cells

In the CNS connective tissue is almost absent, and the majority of the interneuron space is filled by special non-nervous cells called Neuroglia cells (Glial cells)

Functions of Neuroglia cells

1) Bind the nervous tissue together by functioning as packing cells filling the spaces in-between.
2) Function as packing cells providing mechanical and metabolic support to the delicate network of neurones carrying the nerve impulses.
3) Involved in the memory process by storing information, in form of an RNA code.
4) Provides nourishment to the cytoplasmic extensions (nerve fibres) of the neurones.
5) Satellite Neuroglia called Schwann cells synthesize the myelin sheath of myelinated nerve fibres.
6) Ependymal cells line the brain cavities and spinal canal, and form an epithelial layer in the choroid plexus these serve to connect the cavities with the underlying tissues.
7) Microglia is divided into categories; astrocytes and oligodendrocytes.
8) Protoplasmic astrocytes are located in the grey matter. These possess numerous branches, short thick processes radiating from the cell body; which contain an ovoid nucleus and much glycogen.

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9) Fibrous astrocytes are located in the white matter. These possess fewer branches, long processes radiating from the cell body, which contain an ovoid nucleus and much glycogen.
10) The branches of astrocytes but upon the walls of the blood vessels; and the astrocytes convey nutrients from the blood stream into the neurone.
11) Both types of astrocytes are interconnected forming an extensive three dimensional network in which neurones are embedded; and also divide frequently to form scar tissue if the central nervous system is injured.
12) Oligodendrocytes are located in the grey and white matter. These are smaller than astrocytes and possess a spherical single nucleus; and fewer, finer branches radiate from the cell body which contains cytoplasm rich in ribosome.
Note; Schwann cells are specialized oligodendrocytes

1. Microglias are located in the grey and white matter but are more numerous in the grey matter.
2. Microglia posses' thick processes arising from the end of a small elongated cell body which contain lysosomes and a well-developed Golgi apparatus. All branches possess further lateral branches.
3. When the brain is damaged microglia are stimulated to become Phagocytic and more round in amoeboid fashion to combat invasion of foreign particles.
4. Microglia is capable of dividing and regenerating and thus repairs the injured tissues.

Note; due to their ability to divide, microglia is the major sources of brain tumors.

Differences between neurons and neurologlia

Neurones	**Neuroglia**
1. Conduct nerve impulses from one part of the body to another. 2. Incapable of division. 3. Specialized to carry information only to and from the CNS 4. Much less in number	1. Do not conduct nerve impulses; but bind nerve tissues together. 2. Capable of division and regeneration. 3. Specialized forms can perform nutritive, Phagocytic and regeneration function. 4. Ten times more numerous than neurons.

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Multiple sclerosis

Multiple sclerosis is a major neurological disease that resists in the gradual deterioration (demyelinated) of the myelin sheath around the neurones of the brain and spinal cord in demyelinated regions hardened scars or plaques called scleroses replace the sheath.

Effects of multiple sclerosis

The scleroses interfere with transmission of nerve impulses, slowing them down and causing a gradual loss of motor activity.

Symptoms of multiple sclerosis (Ms)

- Loss of coordination
- Blurred vision
- Body weakness

Cause of Ms

- Proteins within the myelin sheath are attached by enzymes from the body's immune system.

Occurrence of multiple sclerosis

- More common in temperate regions than in tropical regions.
- Affects more men than women.
- May progress unrelentingly or have intermittent periods of relapse and remission.

Treatment of multiple sclerosis

- No cure of multiple sclerosis.
- Symptoms relieved by therapy
- Rate of relapse reduced by steroids and other drugs

Roles played by dead cells in multicellular organisms

i) **Support and protection:**

Nails, horns, hooves, down feathers and dead skin cells in animals.

Sclerenchyma has thick walls for mechanical support.

Heart wood gives a strong internal support.

ii) Protection from loss of fluids and invasion of harmful microbes in:

The outer layer of skin in animals.

The cork and bark of the tree.

iii) Create channels for conducting without leakage. Xylem vessels have dead walls which help conduct water and minerals to great heights without leakage.

iv) Development of other organs:

During metamorphosis many tissues and organs like gills and tail in tadpole stage die and help it to become a frog.

During maturation of xylem in cells of flowering plants, the cross walls dissolve giving rise to long columns to help in the conduction of water and minerals.

TOPIC 2: CHEMICALS OF LIFE

These are compounds needed in living organisms to maintain life. They are substances that control body processes and ensure that metabolic processes take place efficiently. They constitute the cell protoplasm and life cannot exist without them, hence they are called **Chemicals of life**.

i) The study of these chemicals and the reactions they undergo in the body is called **biochemistry.**

ii) The study of the structure and behaviour of individual molecule in living things is called **molecular biology**

Chemical compounds in the body are generally divided into two groups

i) Organic compounds, which are compounds of carbon

ii) Inorganic compounds, which are not complexes of carbon but derivative ions

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TYPES OF CHEMICALS OF LIFE

1. **Organic chemicals of life: which** are all derived from carbon.
2. **Inorganic chemicals of life:** Don't contain carbon. i.e. They are not complexes of carbon.

All inorganic and organic chemicals of life must be supplied in appropriate quantities in the diet except nucleic acids and a few vitamins. Therefore there is need for a balanced diet to keep the cells alive.

Organic chemicals of life	Inorganic chemicals of life
▪ Carbohydrates	▪ Water
▪ Proteins	▪ Acids
▪ Vitamins	▪ Bases
▪ Nucleic acids (DNA and RNA),	▪ Mineral salts
▪ Lipids	
▪ Waxes and steroids	

The chemicals of life are taken in the bodies of living organisms in form of **nutrients**.

Some nutrients are needed in bulk while others are needed in relatively small amounts.

1. macro-nutrients nutrients: Needed in relatively large amounts

- Carbohydrates
- Proteins
- Lipids
- Water

2. micro-nutrients: Needed in relatively smaller amounts

- Vitamins
- Nucleic acids
- Mineral salts.

INORGANIC CHEMICALS OF LIFE

WATER

Water is formed when two hydrogen atoms combine with an oxygen atom by sharing electrons. The result is a stable molecule, which is relatively unreactive. The shape of the water molecule is triangular rather than linear and the angle between the nuclei of the atoms is approximately 105^0. Overall the molecule is electrically neutral, but in both of the oxygen-hydrogen bonds, the oxygen draws electrons away from the hydrogen nucleus.

Thus there is a net negative charge on the oxygen atom and a net positive charge on the hydrogen atom. A molecule that carries an equal distribution of electrical charge is called a **polar molecule**.

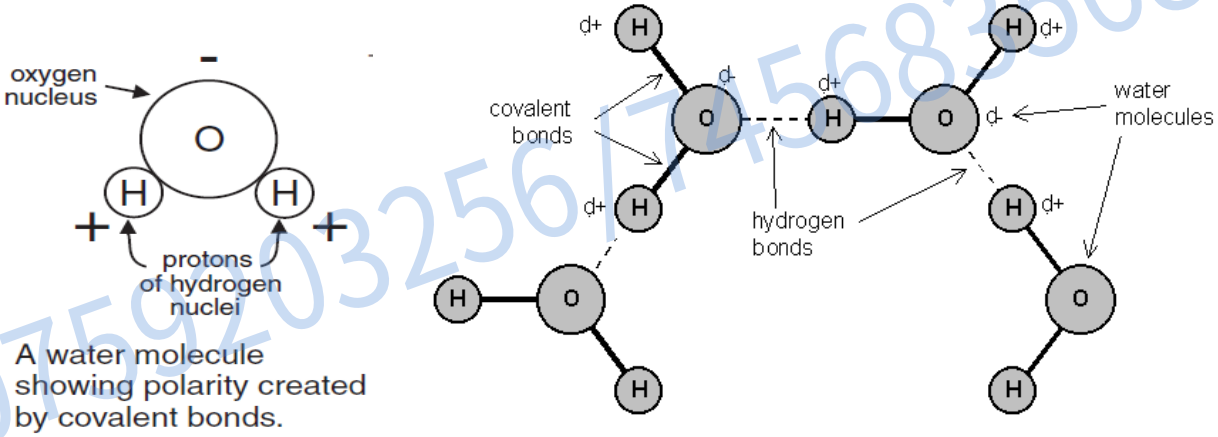
Because of this charge separation, water has an overall neutral molecule. Water molecules form relatively weak bonds called **hydrogen bonds** with other water molecules. Water molecules therefore have electrostatic attractions for each other.

Hydrogen bonds are also formed with any charged particles that dissolve in water, and charged surfaces in contact with water. Hydrogen bonds account for the unique properties of water.

Water forms 75% of most of the cells and it is unique in the way that it has a range of important properties from the way in which the oxygen and hydrogen atoms are linked in the water.

Water has both chemical and physical properties that are rather unusual and these are due to:

i) **Small size,**
ii) **Its Hydrogen bonds between the molecules**
iii) **Polarity**



A water molecule showing polarity created by covalent bonds.

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Polarity is uneven charge distribution within the molecule.

Because of its size, and polarity, water is cohesive, adhesive and denser as a liquid than when it is a solid and absorbs large amounts of heat

Hydrogen bonds are constantly formed, broken and reformed in water although individually weak their collective effect is responsible for the unusual properties of water

PROPERTIES OF WATER AND THEIR BIOLOGICAL IMPORTANCE

1. It is a universal solvent for polar substances (charged or ionisable substances) e.g. salt**.** This implies that water can dissolve a variety of solutes as it is polar and most solutes are polar.

This property enables water to carry out the following **functions;**

- Medium for chemical reactions in living organisms since these reactions occur in solution.
- It is a lubricant e.g. in the joints where it forms the synovial fluid which enables protection against damages.
- It acts as a transport medium as blood, lymph, in the expiratory system as well as in the alimentary canal where it transports materials from one point to another.

- It is an important constituent of the excretory waste products, by which toxic materials are removed from the body.
- It is the largest constituent of the protozoan protoplasm of all cells where it contributes up to 60%.
- Non-polar substances such as lipids are immiscible in water and serve to separate aqueous solutions into compartments.

2. It has a high heat capacity

Specific heat capacity. Specific heat capacity is the amount of heat required to raise the temperature of a kilogram of water by 1°C. Water has a specific heat capacity of 4.2 J g^{-1} °C^{-1}

The high heat capacity of water means that the large increase in heat energy around water results into a relatively small rise in the temperature of water because much of the energy supplied to water is used in breaking the hydrogen bonds which restricts the movement of molecules.

The temperature changes within water are therefore minimized as a result of its high heat capacity,

Biological importance

- It enables life processes such as temperature regulation and gaseous exchange to occur in organisms.
- Such a suitable temperature enables body enzymes to function well without denaturation and/or inactivation.
- It provides a constant internal and external environment for many cells and organisms/provides thermally stable environment for cells and aquatic organisms

3. It has a high heat of vaporization.

A relatively large amount of energy is needed to vapourise water due to the hydrogen bonds within water and as a result water has a high boiling point. This implies that a lot of heat must be supplied to the water in its liquid state to turn it into the vapour.

Importance

- Evaporative cooling with minimal water loss through sweating, transpiration in plants, so as to reduce body temperature.
- It is an important heat sink where large bodies of water are responsible for modifying climate by absorbing heat from the sun.

4. High latent heat of fusion/fission:

Latent heat of fusion is the measure of the heat required to change a solid to liquid state at constant temperature. In this case ice with its high heat of fusion requires a large amount of heat to melt down. On the other hand water requires to lose a relatively high amount of heat to freeze.

Importance

- Contents of the cells and their environment, organisms, and water bodies do not easily freeze.
- It provides a sustainable habitat for aquatic organisms since the habitat does not easily get frozen in cold weather.
- It maintains an effective transport medium of materials in the body since it maintains its liquid form even in the cold weather.

5. Water has a high surface tension and cohesion.

Cohesion is the force of attraction between molecules of the same kind. This implies that on the surface of water, strong forces of attraction (cohesion) hold the surface molecules, together.

At the surface of the liquid a force called surface tension exists between the molecules due to the cohesive forces between the molecules. **Surface tension** is the force that causes the surface of a liquid to contract so that it occupies the least possible area. Cohesion is a force whereby individual molecules of a substance stick together. Water molecules "stick together" due to their hydrogen bonds, so water

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has high cohesion. This explains why long columns of water can be sucked up tall trees by transpiration without breaking. **Adhesion.** Water is adhesive to any substance with which it can form hydrogen bonds. That is why substances containing polar molecules get "wet" when they are immersed in water, while those that are composed of nonpolar molecules (such as oils) do not.

Importance

- Surface tension enables small organisms to settle on water or skate over the water surface.
- The high cohesion of water molecules enables the movement of water through the xylem to the leaves.
- It enables the water to participate in the absorption of mineral salts from the soil.
- The strong cohesion force of attraction in the water molecular maintains the Transpiration steam as unbroken water column and aid water movements in plants

6. Water has a Low viscosity

This is a measure of how resistant a liquid is to flowing. The lower the viscosity the easier the liquid flows. Water has a viscosity that is lower than that of ethanol. Water can flow freely through narrow vessels. Watery solutions can act as a lubricant

Biological functions

- Water flows freely through narrow vessels, and solutions serve as lubricants. i.e. Important in the transport system of living organisms e.g. in blood as it flows through vessels.
- Water enables dispersal of seeds and fruits such as coconut as well as dispersal of the gametes and larval forms of aquatic organism.
- It breaks the testa of seeds to allow embryo growth during germination.
- The significance of this property is that water can easily be pumped and moved in the small tubes of the body.
- Water also forms a medium within which swimming by aquatic organisms is made easy because of the relatively low viscosity of water.

NB: If too much water is lost from the body, then the viscosity of blood increases, flow slows and transport is less efficient.

Plants rely on the flow of water in the Xylem and Phloem vessels to transport substances around their bodies.

7. Water is Colourless, and transparent

Pure Water is transparent and this is important for aquatic organisms because it allows light to penetrate to some depth in clear water bodies. This enables growth of green plants and hence other organisms which depend on the plants.

Importance

- Water allows sufficient amounts of light to pass though for the photosynthesis of aquatic plants and other photosynthetic organism.
- The transparency increases visibility for organisms in large volumes of water penetrated by light, allows vision by aquatic animals to find prey, mates and escape predators.

8. Density of water:

Anomalous expansion of water i.e. density of water decreases below 4°C evenly forming ice at around 0°C. The ice floats on water leaving the relatively warm water below. This favors survival of aquatic organisms especially those living in temperate regions during winter.

The rising up of cold water over the warmer water also circulates nutrients in large water bodies, resulting into nutrient recycling and colonization of the water body to a greater depth.

9. Incompressibility

Water is incompressible. This is the basis of the hydro skeleton that some organisms depend on for both support and locomotion.

Biological importance

- It forms the hydro-static skeleton of animals such as earthworms.

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- It provides support to the non woody plants e.g. herbaceous plants by maintaining turgidity of the cells.
- Support to organs, and organisms

10. Density and freezing properties

The density of water decreases below **4°C** and ice therefore floats on water. Water below 4 ^{O}C tends to rise which maintains the circulation in large water bodies.

Importance

- It makes water an important factor in the cycling of nutrients needed by living things.
- It allows Survival of aquatic organisms(both plants and animals)in freezing conditions

11. Water is highly reactive /acts as a reagent

Water is an essential metabolite i.e. it participates in the chemical reactions of metabolism.

Importance

- Essential metabolite in metabolism e.g. most bio-chemical reactions taking place such as photosynthesis, respiration, and digestion water is raw material.
- Water is a medium in which most bio-chemical reactions take place.

12. High tensile strength

Water can be lifted by forces applied at the top as seen in movement of water to the xylem of tall trees due to strong cohesive forces between water and the walls of the conducting vessels.

13. Water is denser than air

- Water supports organisms as large as whales. It also supports and disperses reproductive structures such as larvae and large fruits e.g. coconuts.
- Supports large organisms, and disperses reproductive structures
- Water is a pre-requisite for fertilization, where fertilization involves mobile gametes e.g. external fertilization in lower plants, fish, amphibians, and internal fertilisation in higher vertebrates and plants.

14. Water has a neutral PH

This makes it a good medium of chemical reactions in the body since most of them take place in neutral PH.

Water itself is partially ionized $H_2O_{(l)} \longrightarrow H^+_{(aq)} + OH^-_{(aq)}$ so it is a source of protons (H^+ ions), and indeed many biochemical reactions are sensitive to pH (-log [H^+]). Pure water cannot buffer changes in H^+ concentration, so it is not a buffer and can easily be any pH, but the cytoplasm and tissue fluids of living organisms are usually well buffered at about neutral pH (pH 7-8).

15. Water repels non–polar molecules

Hydrophobic interactions determine nature of cell membrane, and three-dimensional structure of protein and nucleic acids.

BIOLOGICAL IMPORTANCE OF WATER TO ALL ORGAANISMS

METABOLIC ROLE OF WATER

i. Hydrolysis

Water hydrolyses many substances like proteins to amino acids, fats to fatty acids and glycerol, starch to maltose,

ii. Medium for chemical reactions

All biochemical reactions take place in aqueous medium provided by water.

iii. Diffusion and Osmosis

It is essential for the diffusion of materials across surfaces such as the lungs or the alimentary canal e.g. diffusion of food materials into the blood stream since such surfaces are moist to facilitate diffusion and the moisture is provided by water.

iv. Photosynthetic substrate

Water is a raw material for photosynthesis

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WATER AS A SOLVENT

It dissolves other substances and is therefore used in the following ways;

i. Transport

Blood plasma, tissue fluid and lymph are all made up of water and dissolve a number of substances which can then be easily transported.

ii. Removal of wastes

Metabolic wastes like ammonia, urea, excess salts require water to be removed from the body in solution form.

iii. Secretions

They are transported from their place of secretion in solution form (aqueous form) e.g. most digestive juices have enzymes in solution, tears mainly consist of water, snake venoms have toxins in suspension composed of water.

WATER AS A LUBRICANT

Water' properties especially its viscosity make it a useful lubricant. Lubricating fluids that have a component of water include;

- **Mucus** which externally facilitates movement in organisms like the snail and earthworm or internally in the walls of the gut and vagina
- **Synovial fluid** which lubricates movements in the joints of vertebrates.
- **Pleural fluid** which lubricates movements of the lungs during breathing
- **Pericardial fluid** which lubricates movements of the heart
- **Perivisceral fluid** which lubricates movements of internal organs like peristaltic movement of the alimentary canal

SUPPORTING ROLE OF WATER

With its large cohesive forces, water molecules lie close together due to the hydrogen bonds between them and therefore not easily compressed, making it a useful means of supporting organisms.

i. Hydrostatic skeleton

Animals like earthworms are supported by the pressure of the aqueous medium within them.

ii. Turgor pressure

Herbaceous plants and herbaceous parts of woody plants are supported by osmotic influx of water into their cells.

iii. Humours of the eye

Aqueous and vitreous humors give the shape of the eye and they are mainly made up of water.

iv. Amniotic fluid

It supports and protects the mammalian foetus during development and is mainly made up of water.

v. Erection of the penis

The pressure of blood which is mainly made up of water makes the penis erect for copulation to take place.

vi. Habitat

Water supports organisms that live in it. Very large organisms like whales return to water as their sizes make movement on land very difficult.

Other functions of water

- Medium of dispersal i.e. seed dispersal, gametes and larvae stages of some aquatic organisms
- Seed germination
- Osmoregulation
- Migration of aquatic organisms
- Fertilization, by transporting gametes
- Hearing and balance. The watery endolymph and perilymph in the mammalian ear plays a significant role in hearing and balancing.

How electronegativity affects the interactions between water molecules

Electronegativity is the attraction of an atom for the electrons of a covalent bond.

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Since oxygen is more electronegative than hydrogen, the oxygen atom in the water molecule pulls the bonding electrons towards itself, resulting in a partial negative charge on the oxygen atom and partial positive charges on the hydrogen atoms.
Oppositely charged ends of water molecules are attracted to each other by weak electrostatic forces of attraction, forming hydrogen bonds.

ACIDS AND BASES

Acids

A compound which when dissolved in water ionizes to produce hydrogen ions as the only positive charged ions e.g. hydrochloric acid, nitric acid, Sulphuric acids e.t.c.
Note: The strength of the acid is determined by the extent to which it dissociates .e.g. HCl is considered to be a strong acid because it completely dissociates in solution to give hydrogen ions. Whereas ethanoic acid is a weak acid because it partially dissociates in solution

The acidity of the solution is expressed as its negative log concentration of H^+ in moles/litre. A pH of 7 represents neutrality while a pH below 7 represents acidity while that above 7 represents alkalinity or basis.

FUNCTIONS OF ACIDS

- They provide a suitable pH for the proper functioning of enzymes e.g. pepsin
- Acids like hydrochloric acids activate organic substances like pepsinogen
- Acids kill bacteria, which may be ingested together with food

BASE

A base is a compound, which can react with acids to produce a salt and water only. Some bases are alkalis.
An alkali on the other hand is a substance which when dissolved in a solvent produces hydroxyl ions as the only charged ions. This implies that alkalis are bases but not all bases are alkaline.
Strong alkali completely ionize e.g.

$$NaOH(aq) \longrightarrow Na^{+}_{(aq)} + OH-$$

Weak alkali don't ionize completely e.g. ammonium hydroxide

FUNCTIONS OF BASES

- Provide an optimum pH range for enzyme activity e.g.in the duodenum
- They are buffers in the body

A buffer solution is any substance which resists change in the pH when small amounts of acids or bases are added. Consider the reactions below;
$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$
$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$
From the above equations, it is clear that $NaHCO_3$ removes ions from aqueous solutions thereby lowering the aqueous solutions acidity in so doing it is working as buffer.
However, although sodium hydrogen carbonate works as a buffer on its own, in most cases two or more compounds interact to form a buffer solution or system.
In case of increased acidity, the $NaHCO_3$ combines with free hydrogen ions as shown above if alkalinity is increased, it reacts with free hydroxyl ions to form carbonate ions and water.

$$HCO^-_{3(aq)} + OH^-{}_{(aq)} \longrightarrow CO^{2-}_{3(aq)} + H_2O_{(l)}$$

In the human body, bi-carbonate ions play a minor role as buffers. A more important role is by the appropriate salts e.g. K_3PO_4 Na_3PO_4 etc.
These combine with hydrogen ions to form $H_2PO_4^-$ Di-hydrogen phosphate.

$$H^+{}_{(aq)} + HPO^{2-}_{2(aq)} \longrightarrow H_2PO^-_{4(aq)}$$

Certain organic compounds like proteins and haemoglobin can also accept H^+ and are therefore important as buffer.
Since they occur in higher ions, than the phosphate salts they are even more important than the acids and the bases.

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The biological importance of these buffers is that cells and tissues can only function properly at a narrow range of pH, which is usually around neutrality.
Acids and bases also provide rightful pH ranges for certain chemical reactions to effectively proceed in the body basicity.
NB: A number of acids are found in the body and these include

- Nucleic acid
- amino acids
- Succinic acid
- lactic acid
- HCl
- Uric acid

MINERAL SALTS
A salt is a compound which is formed when the hydrogen ions in an acid are either partially or fully replaced by a metal ions or NH_4^+eg.

HCL	**NaCl, KCl, NH_4Cl**
H_2CO_3	**Na_2CO_3, $NaHCO_3$**
CH_3COOH	**CH_3COONa**

In the body, some of the most common salts are found in H_2O as salts. The salts are therefore ionic compounds and since they decomposed by electricity, their free ions are able to cost electric currents and they therefore referred to as electric.
The mineral ions in the body can be grouped as major or minor ions depending of their need in the body.
Major/ macro ions are needed fairly in large amounts than minor ions.
Functions of mineral salts (General functions of mineral)

1. They form body tissues such as bones and teeth, etc. Comprise calcium ions, phosphate ions etc. They also form connective tissue and other structures a body.
2. They form body pigments e.g. Haemoglobin contains Iron, cytochromes contain copper and chlorophyll contains magnesium.
3. They are metabolic activators. Certain ions activate enzymes e.g. magnesium activates enzymes that are involved in phosphorylation of glucose.
4. They are constituents of enzymes e.g. nitrogen in proteins.
5. Constituents of various chemicals e.g. ATP contains phosphorous while thyroxin contains iodine.
6. Components of nuclei acids / DNA and RNA.i.e.Sulphur and Nitrogen form proteins, nucleic acids
7. Involved in transfer of energy in ATP
8. Important in muscle and nuclear activity.
9. Needed for proper heart functioning
10. Important for amino acid formation and muscle growth.
11. Important for wound healing
12. Maintenance of water balance. Mineral salts and other solutes determine the osmotic pressure of cells and body fluid. The osmotic pressure must not be allowed to fluctuate beyond narrow limits since much of the physiology is directed to preventing this.
13. Essential for clothing of blood
14. Formation of hydrochloric acid in stomach

Macronutrients

ELEMENT& sources	***FUNCTIONS***	***DEFFICIECY***
Nitrogen Lean meat, fish, milk	Nitrogen is a component of amino acids, proteins. Vitamins, co-enzymes, nucleotides and chlorophyll, Hormones like auxin in plants and insulin in animals.	Strong Chlorosis (yellowing of leaves) old leaves and stunted growth.
Phosphorous	Component of nucleotides ATP and some proteins used in phosphorylation on the	Deficiency of phosphates in plants lead to stunted growth especially

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Dairy products, meats and greens	sugars in respiration. A major constituent of bone and teeth, components of cell membranes in form of phospholipids. They work as buffers mainly in the salt form. nucleotide synthesis, acid-base balance	of roots and the formation of dull, dark green leaves. In animal's deficiency can result in a form of bone malformation called rickets. Loss of minerals/ca^{2+} from bones
Sulphur Proteins from many sources	Sulphur is a component of some proteins and certain co-enzymes e.g. acetyl co-enzyme A.	Forms important bridge between the polypeptide chains of some proteins giving them their tertiary structure. Deficiency in plants causes chlorosis.
Potassium Meats, dairy products, grains, many fruits and vegetables,	Maintain the electrical and anion/cation balance across all membranes. Assists active transport of certain materials across the cell membrane. Necessary for protein synthesis and perspiration. A constituent of sap vacuoles in plants also helps to maintains turgidity.	Potassium plays role in the transmission of nerve impulses, paralysis, Muscular weakness, nausea , heart failure Yellow and brown leaf margins; premature death;
Calcium Dairy products, dark green vegetables and legumes	In plants calcium is a major compound of the middle lamella of cell wall and therefore necessary for their proper development, It also aids the translocation of carbohydrates and amino acids. **In animals it's** the main constituent of bones, teeth formation and shells. **Needed** for blood clotting and contraction of muscles.	In animals, its deficiency may cause muscular cramp also common that deficiency is rare.
Chloride Cl$^-$ Table salt	It is important for regulation of osmotic pressure. Chloride helps to maintain water balance and pH balance They activate salivary amylase. it is needed for the formation of HCl in gastric juice. Assists in the transport of CO_2 by blood(chloride shift) Assist in active transport.	In animals, deficiency may cause muscle cramps, reduced appetite Its wide spread in soils makes deficiency in plants practically unknown.
Magnesium ion Mg^{2+} Whole grains, green leafy vegetables	A constituent of chlorophyll an activator for some enzymes e.g. ATP one component of bones and teeth Co-factor, ATP synthesis	Deficiency in plants leads to chlorosis Nervous system disturbance
Micro nutrients		
Iron Fe^{2+} or Fe^{3+} Meats, eggs, legumes, whole grains, green leafy vegetables	A constituent of electron carriers e.g. cytochromes needed in respiration and photosynthesis. A constituent of certain enzymes e.g. dehydrogenase, decarboxylase and Catalase required in breakdown of hydrogen peroxide.	Deficiency in plants leads to strong chlorosis of young leaves and In animals Iron-deficiency causes anaemia, weakness, impaired immunity

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	Forms part of haem group in respiratory pigments such as haemoglobin haemoerythrin, myoglobin chlorocuoron	
manganese Mn^{2+} Nuts, grains, vegetables, fruits, tea	Activators of certain enzyme. E.g. phosphates. Enzyme cofactor A growth factor in bone development.	Deficiency in plants produces Leaf flaking. i.e. Leaves with grey spots and in animals, bone deformation/ Abnormal bone and cartilage.
Copper Cu^{2+} Seafood, nuts, legumes, organ meats	A constituent of electron carried e.g. cytochromes needed in respiration and photosynthesis. A constituent of certain enzymes e.g. dehydrogenase, decarboxylase peroxide and Catalase required in the synthesis of chlorophyll. Forms part of haem group. Enzyme cofactor in iron metabolism, melanin synthesis,	Anemia, cardiovascular abnormalities Die back of shots
Iodine I^- Seafood, dairy products, iodized salt	A constituent of the hormone thyroxin, which controls metabolism in animals.	Iodine is needed by higher plants. Deficiency in humans causes tension in children as **goitre** in adults, in some vertebrates it is for metamorphosis.
Cobalt Co^{2+} Meats and dairy products	Constituent for vitamin **B_{12}** which is important in the synthesis of RNA, and red blood cell.	Deficiency causes **perinea** anaemia
Zinc Zn^{2+} Meats, seafood, grains	Development of phosphate gland. An activator of certain enzyme, carbonic anhydrase required in plants for leaf formation the synthesis of iodole acetic acid (auxin) and anaerobic respiration (alcoholic fermentation)	Carbonic vital in the formation of CO_2 in vertebrates. Growth failure, skin abnormalities, reproductive failure, impaired immunity. Deficiency in plants produces malformed leaves e.g in cocoa.
Boron B	Required for the uptake of ca^{2+} by roots. Aids the germination of pollen grains and meiotic cell division in meristem Nitrogen fixation.	Boron isn't required in animals. Deficiency in plants causes --------- and young shoots growth may cause diseases such as cork of apples of beet and cells.
Molybdenum $MO^{4+}MO^{5+}$ Legumes, grains, some vegetables	Required by plants for reduction of nitrates to nitrites in the formation of anino acids. Enzyme cofactor; Essential for nitrogen fixation by prokaryotes uric acid formation. Strengthening of teeth	Deficiecny production in plants yield. **Not vital in most animals.** Disorder in excretion of nitrogen containing compounds
Selenium Seafood, meats, whole grains	Enzyme cofactor; antioxidant functioning in close association with vitamin E	Muscle pain, possibly heart muscle deterioration
Chromium Brewer's yeast, liver, seafood, meats, some vegetables	Involved in glucose and energy metabolism	Impaired glucose metabolism

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ORGANIC COMPOUNDS AS CHEMICALS OF LIFE

These are the chemicals of life which always contain **carbon**, hydrogen and oxygen as the major elements. The proteins and nucleic acids in addition to these elements also contain nitrogen.

Importance

- They are the structural components of the bodies of organisms.
- They are regulators of chemical processes occurring in organisms.

1. Carbohydrates

These are organic compounds made up of carbon, hydrogen and oxygen, in which the ratio of hydrogen to oxygen is 2:1 as in water. They have a general formula of $\mathbf{C_x (H_2O)_y}$ where **x and y** are variables. The ratio of carbon atoms to hydrogen to oxygen **is 1:2:1.**

Carbohydrates are mainly concerned with the storage and liberation of energy. A few carbohydrates such as cellulose form important structures of organisms e.g. the plant cell walls.

There are **3 main** classes of carbohydrates i.e.

1. **Monosaccharide (single sugar)**
2. **Disaccharides (double sugars)**
3. **Polysaccharides(Many sugars or complex sugars)**

Chemically carbohydrates have the following properties;

i. They are either aldehydes or ketones.
ii. They contain hydroxyl groups.

MONOSACCHARIDES

They are single sugar units with the general formular of $(CH_2O)n$ where n = number of carbon atoms and has a value between 3 and 9. They may contain either an aldehyde group or a ketone within their molecule. If they contain an aldehyde **group (-CHO)** they are called aldoses or aldo-sugars. If they contain a ketone group in their molecules, they are called ketoses or keto-sugars.

- They are sweet.
- They are readily soluble in water.
- Their names end with a suffix -ose.
- They are very small molecules.
- They are crystalline.

Monosaccharides have ringed structure and they exhibit isomerism. Isomers are compounds with the same molecular formulas but different structure formulae. For example, the formula $C_6H_{12}O_6$ can be used for glucose, fructose and galactose.

Monosaccharides can link together to form larger molecules i.e. they form building units used to form complex sugars. Some monosaccharides act as a source of energy when oxidized in respiration e.g. **glucose.**

NATURALLY OCCURRING MONOSACCHARIDES

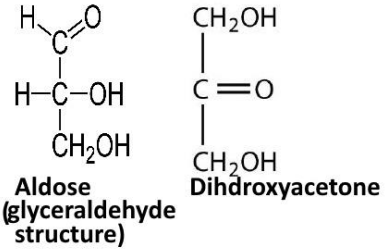
No. of Carbon atoms in the molecule	Molecular formula	Name of the monosaccharide
3	$C_3H_6O_3$	Triose sugar
4	$C_4H_8O_4$	Tetrose sugar
5	$C_5H_{10}O_5$	Pentose sugar
6	$C_6H_{12}O_6$	Hexose sugar
7	$C_7H_{14}O_7$	Heptose sugar

However, the pentoses and Hexoses are most commonly found in special form of bacteria.

Trioses	Pentoses	Hexoses
glyceraldehyde Dihydroxyacetone	Ribose, Arabinose ribulose	Mannose, galactose, glucose, fructose

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Monosaccharide can also be grouped basing on their reducing groups e.g
Ketoses (Ketones) e.g. dihydroxyacetone
Aldose (aldehyde) e.g. glyceraldehyde
Ketone (Ketones) and Aldoses

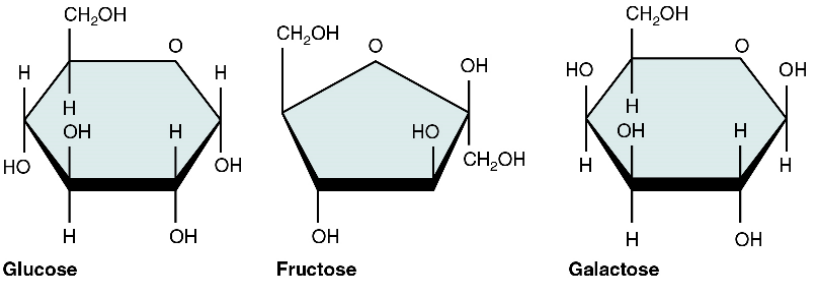


NB: The carbon atom with a double bond in Aldehydes is at the end of the chain while in Ketones it is on the second carbon or on the carbon next to last (middle).

Both Aldoses and Ketones are reducing sugars together with a few disaccharides like maltose, lactose that have the capacity to reduce the copper II in copper II Sulphate to insoluble copper (I) oxide.

Ring structures of monosaccharide start

Most pentose and Hexose sugars can exist in rings in addition to their basic straight chain.

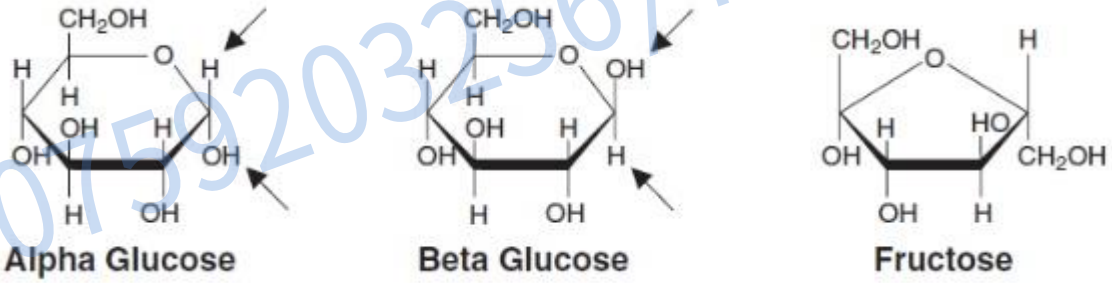


(a) Hexoses

There are 2 alternate ring forms i.e. α **and** β **the** carbon atom (i) is got from the right hand side connected to carbon atom **5** to give a 6 numbered structure. The structure of α and β differ only in position hydrogen and hydroxyl groups attached to the first atom.

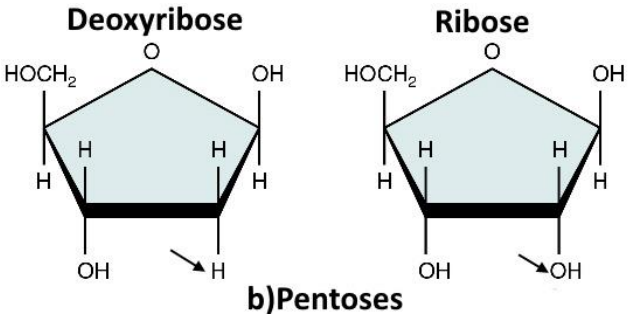
In α, the OH is below the ring while in β above.

ILLUSTRATION OF α **AND** β **GLUCOSE RINGS.**



Existence of α **and** β **r**ings gives a greater chemical verity and helps in building up the complex carbohydrate atom on the 4th carbon atom to give a 5 member ring called fructose ring. In the Hexoses, it is a 6-member ring called pyranose. Consider the ribose ring above.

D-glucose (dextrose or blood sugar) is found in fruits, vegetables, and honey. It is a building block of the disaccharides like sucrose, lactose, and maltose, and polysaccharides such as amylose, cellulose, and glycogen.



Galactose is found in **milk and milk** products. In a condition called galactosemia, an enzyme needed to convert galactose to glucose is missing. The accumulation of galactose in the blood and tissues can lead to **cataracts**, mental retardation, and cirrhosis (a chronic liver disease marked by degeneration of cells, inflammation, and thickening of tissue) The treatment for galactosemia is the removal of all galactose-containing foods, mainly milk and milk products, from the diet.

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Fructose (fruit sugar), is the sweetest of the carbohydrates, twice as sweet as sucrose (table sugar).

Monosaccharides	**Sweetness relative to sucrose**
Galactose	**30**
Glucose	**75**
Fructose	**175**

IMPORTANCE OF MONOSACCHARIDES

Trioses $C_3H_{10}O_5$ e.g. glyceraldehydes, dihydroxyacetone are intermediates in respiration, **photosynthesis** and other branches of carbohydrate metabolism

Pentoses $C_5H_{10}O_5$ e.g. ribose, ribulose deoxyribose

- Synthesis of nucleic acid; Ribose is a constituent of RNA, deoxyribose of DNA.
- Synthesis of some co-enzymes e.g. ribose is used in the synthesis NADP and NAD, FAD.
- Synthesis of ATP, ADP AMP also requires ribose
- Ribulose bisphosphate is the CO_2 acceptor and is made from a 5C sugar ribulose

Hexoses e.g. glucose, fructose, galactose

Source of energy when oxidized in respiration; glucose is the most common monosaccharide

- Synthesis of disaccharides; two monosaccharide can link together to form a disaccharide.
- Synthesis of polysaccharides (pentosanes); glucose is particularly important in this role

Chemical test for monosaccharides

Most of the monosaccharides are the reducing sugars because they reduce **Cu^{2+}** in Benedict's solution to **Cu^{+} ions** giving an orange precipitate of copper (1) **oxide (Cu_2O) when boiled.** They have an aldehyde group or a free ketone group. Ketoses first isomerise to aldoses before they can act as reducing sugars. Those colours: green, yellow, orange and brown, depends on the concentration of the sugar. Both tests involve the use of an alkaline solution of **$CUSO_4$** blue in colour reduced to insoluble **Cu_2O** (copper (i) oxide

$$\underset{\text{blue soln}}{Cu^{2+}_{(aq)}} + e^- \rightarrow \underset{\text{orange/brown ppt}}{Cu^{+}}$$

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Main functions of carbohydrates

- They are a primary source of energy being oxidized in the body to release energy
- They are structural 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 recognition units on the surface of body cells i.e. they are component structures of the surface cell membranes recognized by antibodies.

DISACCHARIDES ($C_{12}H_{22}O_{11}$)

A disaccharide is a sugar formed as a result of the combination of two monosaccharides sugars by condensation reaction. Because of this reason they are also known as **double sugars.**

General formula **$C_{12}H_{22}O_{11}$ and** not **$C_{12}H_{24}O_{12}$ as** expected because these formations involve the loss of one water molecule as shown in the equation below;

$$C_6H_{12}O_6 + C_6H_{12}O_6 \rightleftharpoons C_{12}H_{22}O_{11} + H_2O$$

The bond formed between the two molecules is called a glycosidic bond and is normally found between carbon atoms 1 and 4. Disaccharides include maltose, from α glucose + α glucose.

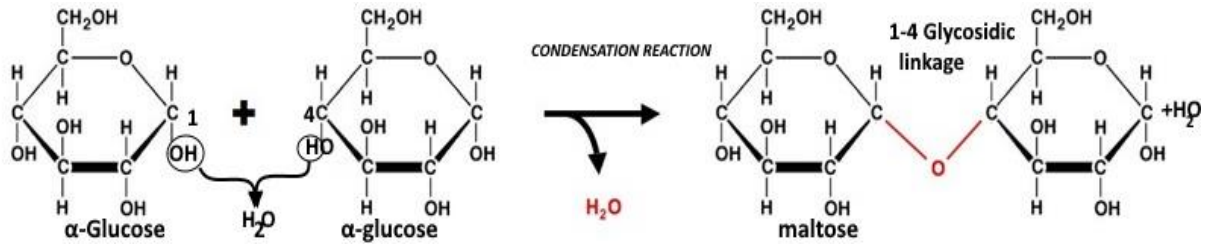
Characteristics

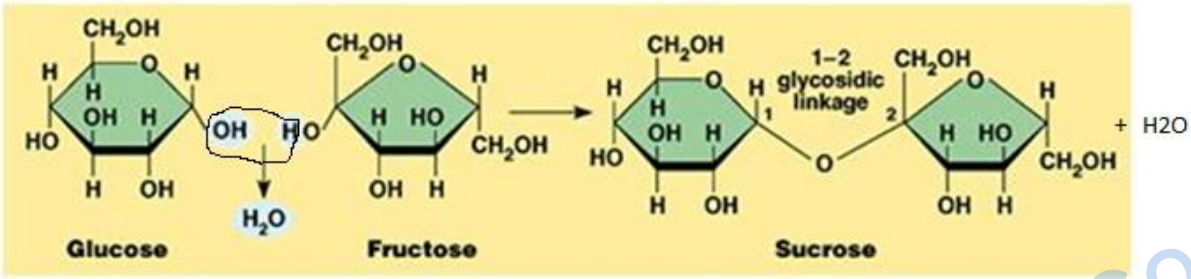
- They are small molecules with a low molecular mass
- They are readily soluble in water
- Have a sweet taste
- They exist in crystalline form

- They are made by combining two monosaccharides in a condensation reaction

The equation for disaccharide formation (maltose) is below.

FORMATION OF DISACCHARIDES





The two monosaccharide units in a disaccharide are held together by a covalent bond known as a **glycosidic bond** through the loss of small molecules usually water.

A **condensation** reaction between the hydroxyl groups at **carbon 1** of one monosaccharides and **carbon 4** of the other results in a bond called **1-4 glycosidic bond**. If the reaction is between the hydroxyl groups at **carbon 1** and **carbon 6**, **1-6 glycosidic bond**.

The addition of water, under suitable conditions, is necessary if the disaccharide is to be split into its constituent monosaccharides. This is called **hydrolysis** i.e. breakdown by water.

Most disaccharides are reducing sugars however there are some few which are non-reducing sugars e.g. sucrose because they lack the reducing group in these molecules.

Examples of Disaccharides

The most common disaccharides are:

Maltose: which is formed by a combination of two glucose molecules

Lactose: formed from glucose and galactose

Sucrose: formed from glucose and fructose

The main natural sources of these disaccharides are:

Maltose:

Action of amylases on starch during digestion in animals

Germinating seeds

Lactose:

Found in milk, hence called the milk sugar

Sucrose:

Translocated in large amounts through the phloem of plants tissues e.g. sugar cane, bee

Note. Monosaccharide monomers may also combine other types of molecules to form conjugated molecules. Chains of monosaccharide units can combine with lipids to form glycolipids, or with proteins to form glycoproteins. These molecules are important in the cell membrane.

CHEMICAL TEST FOR DISACCHARIDES

Maltose and Lactose are reducing sugars and have the same chemical test as monosaccharides.

Sucrose is non-reducing and so it must be first hydrolysed to its constituent reducing sugars, to give a positive test in Benedict's or Fehling's solution.

A solution with a non-reducing sugar is hydrolysed by boiling it with a dilute acid for about 2 minutes followed by a base to neutralize the acid. After hydrolysis, the Benedict's test is carried.

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FUNCTIONS OF DISSACCHARIDES

- They are food reserves in organisms and when they are hydrolysed to monosaccharide and used in cell metabolism.
- Storage materials in some plants like sugar canes.
- They are energy reserves.
- They are the main forms of transport of organic substances in the phloem. Sucrose is particularly important as the main form of transport of organic solutes in the phloem. This is because sucrose is soluble but metabolically inert hence does not cause an osmotic pressure in plant cells. Glucose is not transported because it's soluble and metabolically active hence causing an osmotic potential in plant cells which can affect the movement of water in plant cells.
- Lactose, also called milk sugar, is the nutritional source of energy for infants during nursing. Lactose makes milk taste sweet and is an ingredient in many processed foods that contain dairy such as breads, cookies, cakes, doughnuts, breakfast bars and ice cream.

NB: Starch is hydrolysed in plants to maltose so as; -

i. To be transported easily because it's soluble in water.
ii. Maltose is less reactive hence won't be used.

POLYSACCHARIDES ($C_6H_{10}O_5$) n (not sugars)

These are formed when many monosaccharide units combine as a result of condensation of to form chains. The chains in polysaccharides may be of;

- Variable length although usually very long.
- Branched or unbranched.
- Folded in which case they are suitable for storage e.g. starch
- Straight or coiled: in which case they are ideal for making meshes and for construction e.g. in cellulose used in building cell wall.

They are complex carbohydrate with a large number of molecules consisting of chains of monosaccharide units. They are normally used for food storage because; -

i. They can be easily hydrolysed to sugars when required for production.
ii. They fold into compact shapes which cannot diffuse out of the cells.
iii. They exert no osmotic or chemical influence on the cell.
iv. They have large sizes that make them insoluble in water.
v. They are non diffusible i.e. they don't leave sites of storage
vi. Making structures compact e.g. cellulose.

The monosaccharide polymer may be branched, unbranched or coiled. In cells they exist as granules or grains.Most polysaccharides are formed from the hexose sugars and have a general formula: $\left(C_6H_{10}O_5\right)_n$ where **n** is greater than **40.**

COMMON TYPES OF POLYSACCHARISES

1. Starch

It is a main food storage form of plants and it is a polymer of α glucose it exists as grains in the cells. It is mainly found in seeds, leaves and tubers.

Starch is made up of two major components namely amylose (20 to 30% of starch) and amylopectin (79% of starch) together with other substances 1% such as phosphates.

Starch is made up of **many alpha glucose molecules** which is found in most parts of the plant. Starch is made from excess glucose produced during photosynthesis and it is the reserve food in plants.

The polymer is a straight chain joined by 1,4 glycosidic bonds and the branches involve 1, 6 glycosidic bonds. It has a straight chain component called amylose and a branched chain component called amylopectin.

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The main difference between the two is that amylose has a straight chain structure (unbranched) made up of between 200 – 1000 glucose residues linked by only α 1,4 glycosidic bonds whereas amylopectin is branched forming 1,6 glycosidic bonds. The molecule takes the form of a helix. Because of its tightly packed structure (it takes up less space than amylopectin), amylose is more resistant to digestion than other starch molecules.

Amylopectin is soluble and contains from 2000 to 200,000 α-glucose units per molecule.

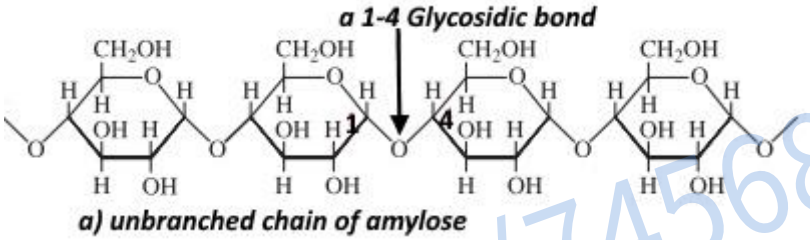
These components are coiled to form a helix. In this helix, the ˉOH group points into the interior and they are not free to take part in its bonding. For this reason, there are no cross linkages in starch. It is therefore not strong enough to form structured polysaccharides like cellulose.

Starch is a storage polysaccharide of plants and is normally stored in form of large molecules called starch granules because it can't diffuse out of cells and has little or no osmotic effects.

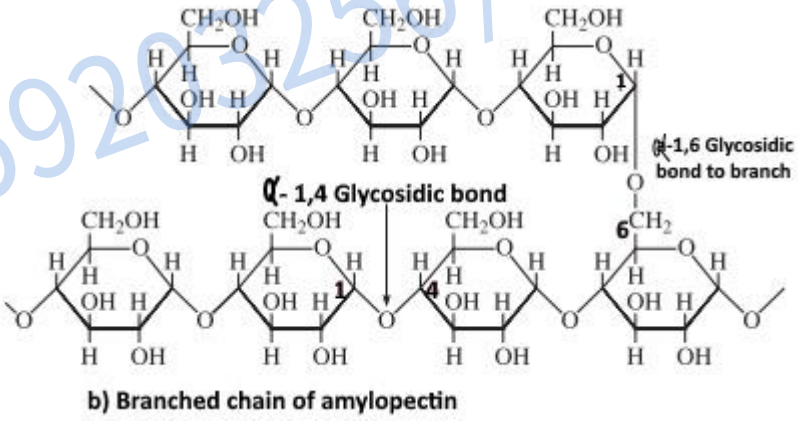
N.B

Amylopectin is a soluble molecule that can be quickly degraded as it has many end points onto which enzymes can attach. In contrast, amylose contains a straight chain. This causes amylose to be hydrolyzed more slowly, but have higher density and to be insoluble.

STRUCTURE OF AMYLOSE

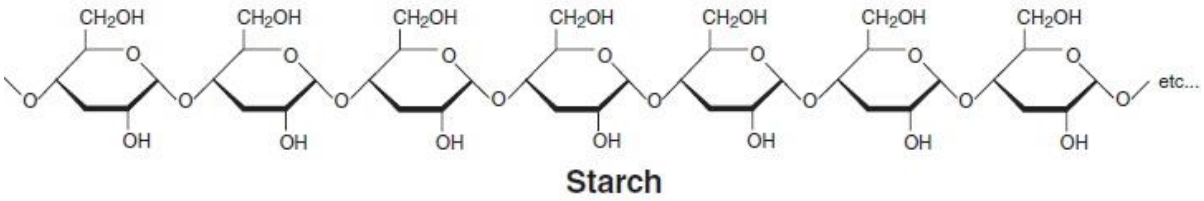


STRUCTURE OF AMYLOPECTIN



Structure of starch

Starch is made up of amylose with straight chains of many glucose molecules joined by **1,4** glycosidic bonds coiled helically into a compact shape; and amylopectin with many branches of **1,6** glycosidic bonds to form a compact shape;



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Differences between amylose and amylopectin

Amylose	Amylopectin
Stains blue with iodine	Stains red-purple with iodine
Has an RMM, maximum 50,000	Has a high RMM up to 500000
Has between 200 to 3,000 glucose units	Has between 2,000 to 200,000 glucose units
Has unbranched helical chain	Has branched chain between glucose unit 24 and 30
Has 1,4 but lacks 1,6 glycosidic bonds	Has both 1,4 and 1,6 glycosidic bonds
Has 20 to 30% composition in starch molecule	Has 70 to 80% composition in starch molecule

GLYCOGEN (ALSO FOUND IN FUNGI)

This is the major polysaccharide storage material in animals and fungi. It is stored mainly in the liver and muscles this is mainly because it provides energy more readily than fat within the active tissues of the muscles and the liver

It is the animal equivalent of starch, being a storage polysaccharide made fro**m α-glucose.**

It is a storage polysaccharide mostly found in animal cells and fungi. Its being highly branched compared to amylopectin, it can be broken down to glucose very quickly by enzyme glycogen phosphorylase to release energy. It is mostly stored in the liver and muscles that provides a useful energy reserve. It has a molecular structure similar to that of amylopectin.

Glycogen is more soluble in water than starch and in the cytoplasm it exists as tiny granules.

Features of glycogen

- Polymer of **alpha glucose** monomers.
- It is more soluble in water than starch
- It has highly branched chains
- It has Alpha /α – 1, 4 glycosidic and 1, 6 glycosidic bonds.
- Hydroxyl groups project inwards
- It's a major energy storage molecule in animals, **no** structural role
- glycogen can be used during anaerobic respiration to provide energy in the muscles e.g. during heavy and physical exercise

CELLULOSE

This is a polysaccharide made of many beta glucose molecules that form long unbranched parallel chains. It is mainly found in plants because it is the main structure material in plant cell walls and in cotton it makes up to 90%, although it is found in some invertebrates and ancestral fungi.

STRUCTURE

It has many chains running parallel to each other and have cross linkages between them.

Cellulose consists of long straight chains of glucose molecules; with many of OH groups projecting outwards on both sides of the chain to alternate position which enable cellulose to form cross linkages giving cellulose its considerable stability which makes it a valuable structural material for support; therefore the free -OH groups are in exposed positions for hydrogen bonding with neighbouring -OH groups of other chains which results in the formation of bundles of cross linked parallel chains.

Features of cellulose

- Polymer of ß-glucose mononers
- Consists of straight chained molecules, with cross-linkages due to hydrogen bonds
- Forms cross bridges between chains
- Monomers rotate alternately at 1800 to each other
- It contains ß-1,4 glycosidic bonds linkages
- forms micro fibrils
- Hydroxyl groups project outwards
- performs structural role not for storage
- It is found in cell walls in plants where it has strengthening role
- . It is hardly/Difficult digested by organisms i.e. only a few bacteria and protozoans can digest it.

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- It is very stable due to possession of many cross linkages.

SHAPE OF THE CELLULOSE MOLECULE

Chains of β-glucose associate in groups of 60 - 70 to form micro fibrils. The chains in microfibrils are held together by lignin, which is composed of amino acids and sugars. Microfibrils associate in groups to form macro fibrils.

The microfibril and the macro fibrils are held together by hemicellulose that gives them great tensile strength.

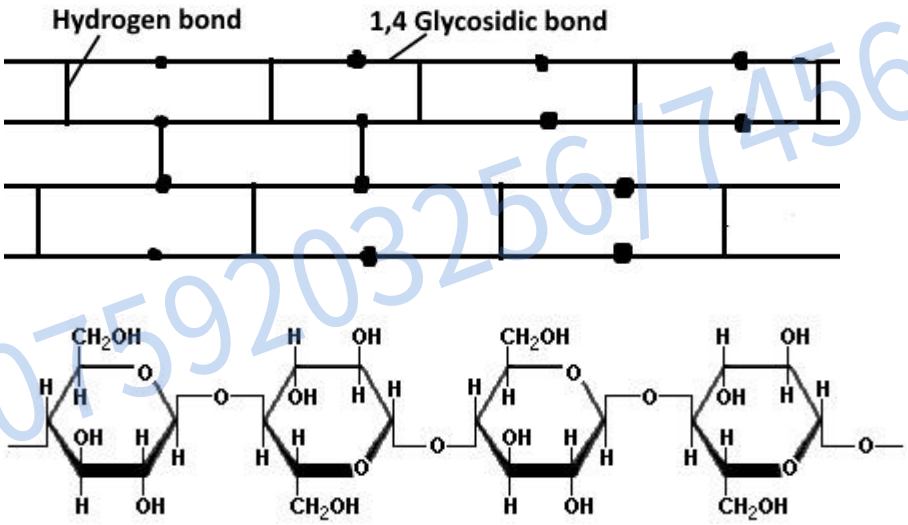
It consists of straight chains of molecules which project both sides of the chain at alternative positions i.e. alternating heads up and tails down.

The plant cell wall is permeable to water because the matrix has minute water channels through which diffusion occurs. Salts, sugars, and other polar molar molecules can easily disuse through these minute channels. Cellulose is hydrophilic and this makes the cell walls always saturated with water.

The structural properties of cellulose combine the strength of glycosidic bonds and hydrogen bonds to make cellulose such a strong polysaccharide suitable for conferring strength with the cell walls of plants. Further strength is usually provided by the combination of cellulose with Calcium pectates especially in the middle lamella.

The pectates are formed from pectins which are a group of polysaccharides made up of galactose found in the cell walls.

Structure of cellulose showing Hydrogen bonds and cross- linkages.



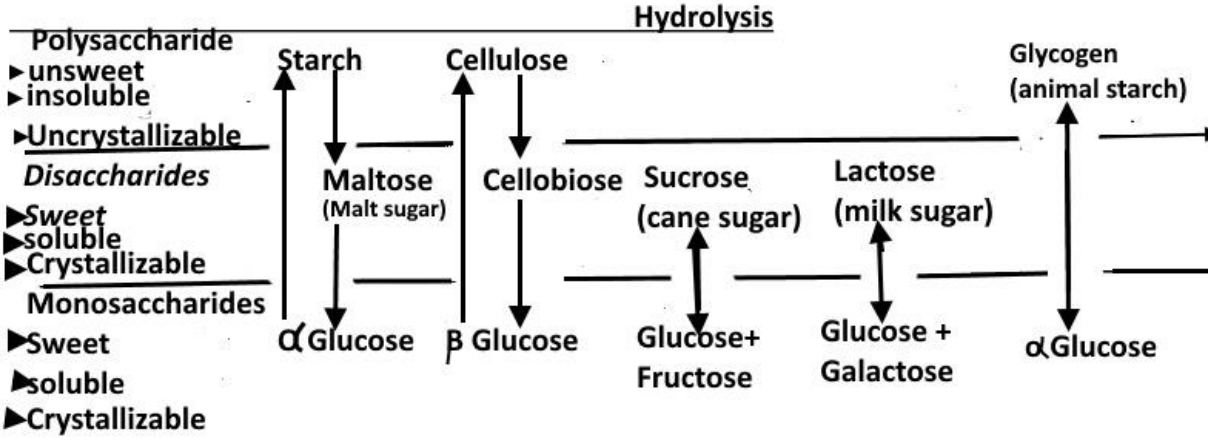
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NB: Lignin is a polymer of amino acids and various sugars and is deposited in spaces between cellulose making cellulose rigid and fairly waterproof. This makes the protoplasm of such lignified and the whole process is referred to as lignification.

USES OF CELLULOSE

- It is commercially used in textiles in the manufacture of paper, plastics, tyre cords, cellophane, and in making packaging materials.
- Its chains are linked by hydrogen bonds to make cellulose microfibrils which are very strong and rigid and therefore give strength to plant cells and young plants.
- It is a constituent of cotton.
- It is food for some bacteria, protozoon.
- Celluloids are used in photographic films and cellulose derivatives.

Chart showing how one carbohydrate can be converted into another by condensation or Hydrolysis



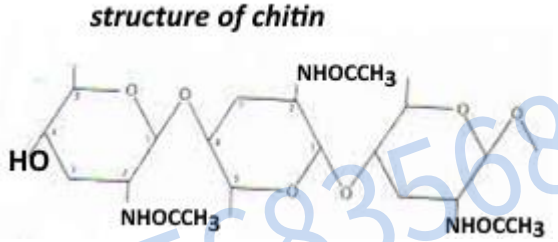
COMPOUNDS CLOSELY RELATED TO POLYSACCHARIDES

CHITIN (β-Glucose monomers with amino acids group attached)

The chemical structure and nature of chitin is like that of cellulose but the OH group is replaced by aminoacyl group ($NHOCCH_3$). Carbon 2

Like cellulose, it has a structural function and it is the major component of the exo-skeleton of insects and crustaceans. It is also found in fungal cell walls.

structure of chitin



INULIN (α-fructose)

Is an unbranched chain of fructose with 1-2 glycosidic bonds found as a storage carbohydrate in some plants. This is a major storage form of carbohydrates in plants like Dahlia (Jerusalem artichoke). It is a polymer of fructose molecules. It comprises **1,2 glycosidic** bonds and has unbranched chain of fructose molecules.

PECTIN (galactose and galactonic acid residues)

This is a major component of the middle lamella of plants cell and its major role is to provide strength in structures where it is found

HEMICELLULOSE (Pentose Sugar and Sugar Acids)

This material binds microfibrils in chitin forming microfibrils. Its major role is to provide strength

MUCO POLYSACCHARIDE

These are formed from amino sugars e.g. glucose amine. An amino sugar is a sugar containing nitrogen. This material is a lubricant. It is found in connective tissues of vertebrates and it comprises monomers of sugar, which are condensed with amino acids.

Examples of mucopolysaccharides include the following;

I. **Hyaluronic acid:** this forms part of the vertebrate connective tissues. It is therefore found in cartilage, bones, vitreous humor of the eye and in the synovial fluid. Hyaluronic acid is also found in anti-coagulant called **heparin.**

Ii.Other **mucopolysaccharides** are mainly found in the cell walls of prokaryotes such as bacteria.

LIGNIN

Chemically, it resembles mucopolysaccharides. It is a polymer formed from sugars and amino acids. It is rigid involving chain molecules which are condensed and it binds cellulose chains to form microfibrils.

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- Lignin impregnates the cell walls of water transporting tubes (xylem) to forma an impermeable lining, a process called lignification.
- It also prevents rot, infections and decay.

NUCLEOTIDES. A nucleotide is where pentose sugars join with organic bases. Nucleotides are the basic building blocks of nucleic acids such as DNA on which heredity depends and RNA on which protein synthesis depends. Other nucleotides are mainly used in respiration and these include Adenosine Tri Phosphate (ATP), Nicotinamide Adenine Dinucleotide (NAD), and Flavine Adenine Dinucleotide (FAD).
Carbohydrates have a variety of structural features which account for the wide variety of polysaccharide formed and these include:

- Both pentoses and hexoses can be used to make polysaccharides though normally one type of monosaccharides is used in each polysaccharide type like hemicellulose, nucleic acid sugars may be aldoses and ketoses.
- Capacity to form 1, 4 and 1, 6 glycosidic bonds are common between sugar units e.g in cellulose. This accounts for the case of branching and hence formation of different types of polysaccharides.
- Capacity to form chains of various length and branching
- Existence of alpha and Beta forms of monosaccharide account for the variation of polysaccharides e.g. starch, alpha glucose monosaccharide while cellulose made of beta glucose units.
- Sugars may be Ketoses or aldoses, these increase the polysaccharide variation like inulin is made of Ketose monosaccharide units while starch and glycogen are made of aldose monosaccharide units.
- The high chemical reactivity of sugar and OH groups and their variation in exposure increases polysaccharide variability.

CHEMICAL TESTS FOR POLYSACCHARIDES

Starch

The iodine test is the standard test for starch. Addition of **Iodine solution** to a starch containing substance results to a **blue-black** colour and absence of starch is manifested by the colour of the mixture turning to **yellow**/pale brown solution

Cellulose

The chemical test for cellulose is using the **Schultz solution** which when added to a cellulose containing substance turns violet in colour. An alternative test would be conc. Sulphuric acid and Iodine and if the substance contains cellulose, a bright blue colour is observed.

Glycogen

It turns violet with Iodine solution.

A suspension of **Amylopectin** in water also gives **a violet/purple colour** with Iodine solution

DIFFERENCES BETWEEN CELLULOSE AND GLYCOGEN

CELLULOSE	**GLYCOGEN**
Polymer of beta glucose	Polymer of alpha glucose
Monomers rotate alternately at 180^0 to each other	No rotation of adjacent monomers
Straight chains, with cross-linking due to hydrogen bonds	Branched chains
ß-1,4 linkages	∝-1,4 and 1,6 linkages
forms micro fibrils	Does not form micro fibrils
hydroxyl groups project outwards	Hydroxyl groups project inwards
performs structural role not for storage	Performs storage role, no structural role
found in plants	Found in animals & fungi
few organisms can digest cellulose/ Difficult to digest	Many organisms can digest cellulose/easily digested

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DIFFERENCES BETWEEN CELLULOSE AND STARCH

Cellulose	Starch
• Consists of **β** glucose mononers	Consists of **α** glucose monomers
• Consists of straight chained molecules	Consists of coiled helical molecules
• Forms cross bridges between chains	No cross bridges between chains

How carbon is uniquely suited to its role as the main element in living organisms.

- Great strength of the carbon-to-carbon bond ensures that carbon-based molecules are very stable.
- Great strength of the carbon-to-hydrogen bond ensures that the hydrocarbon skeleton, typical of carbon-based organic molecules is very stable.
- Ability of carbon to form repetitive bonds with itself/catenation leads to; enormously varying lengths of chains, enormously varying extent of branching, enormously varying length of branches, enormously varying forms of ringed compounds, ensuring that carbon-based molecules can form a variety of shapes.
- Great stability of the +4 oxidation state of carbon owing to its very small atomic size, ensures high stability of carbon-based molecules formed in the +4 oxidation state.
- Ability of carbon to form multiple bonds with itself and other elements, leads to a wide variety of carbon-based molecules.
- Ability of carbon to form stable covalent bonds with other elements, ensures that carbon-based molecules contain a variety of elements

LIPIDS

Lipids are natural fats and oils made up of carbon, hydrogen and oxygen but the ratio of hydrogen to oxygen in not 2:1 as in carbohydrates instead the hydrogen atoms are far more than the oxygen atoms. They are larger groups of organic compounds like carbohydrates.

Lipids include natural fats which are solid at room temperature and oils (liquid at room temperature). They are insoluble in water but soluble in organic solvents. The solubility is from the fact that they have a low oxygen content. I.e. the number of polar OH groups are few. It is those that normally confer solubility in water to the carbohydrates.

They are made up of glycerol molecule onto which 3 fatty acid molecules are combined in a condensation reaction. The combination forms a triglyceride (lipid molecule) as well as 3 water molecules

CHARACTERISTICS OF LIPIDS.

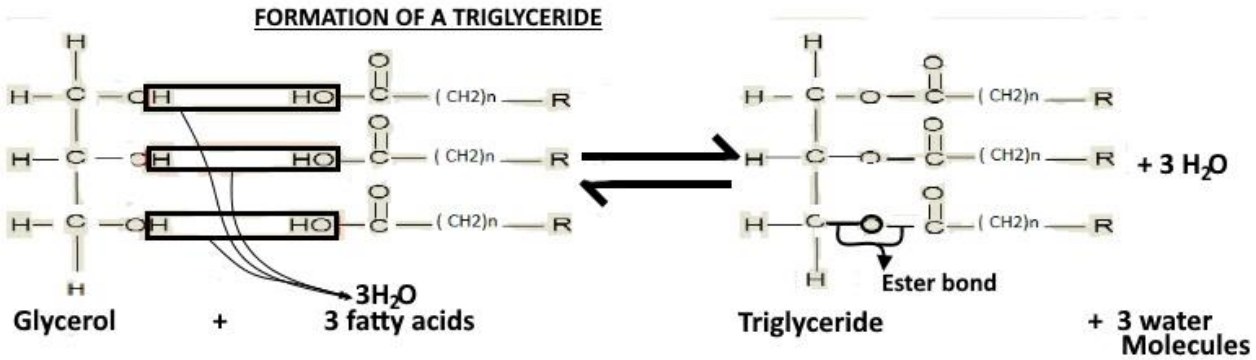
1. They are made up of carbon, hydrogen and oxygen. They are composed of 3 fatty acids and glycerol (3 -CH_3 groups). The general formula of glycerol is $C_3H_8O_3$. The fatty acids contain the carboxylic acid carboxyl group (-COOH) and a hydrocarbon group.
2. They have a high proportion of hydrocarbon groups in their molecules.
3. They are insoluble in H_2O but soluble in organic solvents e.g. benzene and chloroform, alcohol. This is because lipids have a low O_2 and the numbers of polar hydroxyl groups are few and this decreases their solubility in H_2O.
4. They are either solids (fats) or liquids (oils) at room temperature.
5. The higher the proportion of unsaturated fatty acids, the lower will be their melting points.
6. They are non-polar and this makes them effective storage materials. They are less dense than H_2O and this helps the aquatic organism to float on H_2O.
7. They have a functional group -COOH composed of fatty acids glycerol.

FORMATION OF LIPIDS

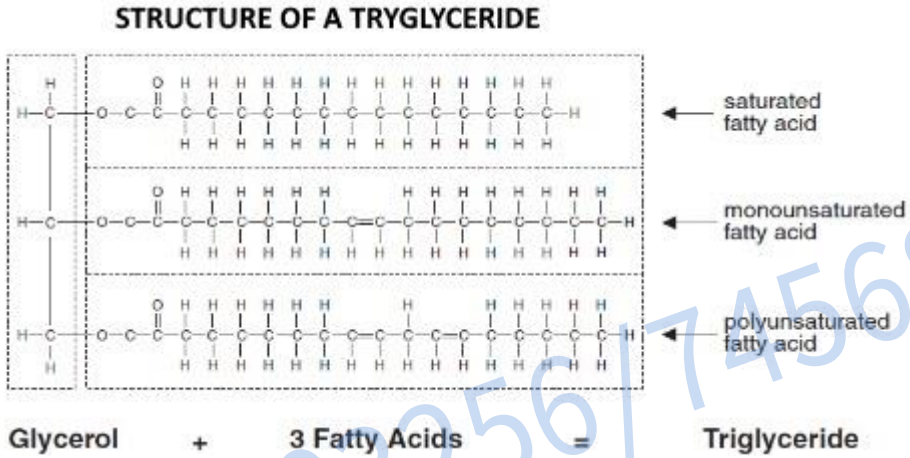
In the formation of lipids, 3 fatty acids and one glycerol molecule combine to form a triglyceride accompanied by removal of three H_2O molecules and formation of 3 ester bonds.i.e. **a condensation reaction occurs.** During this reaction, the hydroxyl group **(OH)** of glycerol reacts with a carboxyl group **(-COOH)** of the fatty acids to form water and **triglyceride joined** by ester bonds.

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The fat or oil formed depends on the fatty acid involved i.e. they could be saturated or unsaturated as shown below.



Triglycerides include fats, oils, and waxes.



Description of the structure of triglycerides

- Triglycerides are Composed of Carbon, Hydrogen and Oxygen.
- Have relatively more Carbon and Hydrogen with less Oxygen atoms
- Composed of three fatty acids attached to a glycerol/$C_3H_8O_3$ molecule.
- Fatty acids are hydrocarbons (chains of covalently bonded carbons and hydrogens) with a carboxyl group (–COOH) at one end of the chain.
- Triglyceride is joined by ester bonds as shown in the diagram above/ C-**O**-C=O
- Three fatty acids / hydrocarbon chains linked to each glycerol
- 12-20 carbon atoms per hydrocarbon tail
- Saturated if all the **C-C** bonds are single and unsaturated if one or more double bonds
- Whole molecule is nonpolar / hydrophobic

Fatty acids vary in structure by the number of carbons and by the placement of single and double covalent bonds between the carbons, as follows:

A saturated fatty acid has a single covalent bond between each pair of carbon atoms, and each carbon has two hydrogens bonded to it (three hydrogens bonded to the last carbon). You can remember this by thinking that each carbon is "saturated" with hydrogen.

A monounsaturated fatty acid has one double covalent bond and each of the two carbons in this bond has only one hydrogen atom bonded to it.

A polyunsaturated fatty acid is like a monounsaturated fatty acid except that there are two or more double covalent bonds.

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Lipids are better storage compounds than carbohydrate because;

- More energy is produced when they are oxidized i.e. they have a high calorific value.
- Relatively more stable than carbohydrates.
- Compact hence taking little space
- Insoluble in water and so do not dissolve away
- They are light (have low density) which minimizes weight especially of aquatic animals. This contributes to buoyancy of aquatic organisms like whales and seals.

FATTY ACIDS

All occurring fatty acids can be saturated or unsaturated

Unsaturated fatty acids are ones where the hydrocarbon part contains one or more double bonds like in linoleic acid and oleic acid. The saturated don't contain double bonds. The saturated fatty acids have a high boiling or melting points compared to the unsaturated of the same molecular mass.

Fatty acids have a general formula of $\mathbf{C_nH_2nO_2}$. Their structural formula can be summarized as below $\mathbf{R(CH_2)nCOOH}$. Where n is any even number between 4 and 24. R can be CH_3CH_2, $CH_3CH_2CH_2$ e.t.c.

Fatty acids can be classified as **unsaturated** if they contain one or more **double bonds** e.g. oleic acid. Fatty acids lacking double bonds are said to be **saturated** e.g. Stearic acid.

Unsaturated fatty acids melt at a much lower temperature than saturated fatty acids. Consequently, **saturated** fatty acids are normally found in fats while unsaturated fatty acids are commonly found in oils. Lipids vary due to the presence of many fatty acids. Fats differ from oils in two fundamental ways;

i. Fats are made from saturated fatty acids while oils are made from unsaturated fatty acids.
ii. Fatty acids in oils are smaller than those in fats.

Fatty acids	***Formula***	***Saturation***	***Sources***
Linolenic acid	$C_{17}H_{31}COOH$	Unsaturated	Vegetable oil
Linoleic acid	$C_{17}H_{31}COOH$	Unsaturated	Sunflower oil
Oleic acid	$C_{17}H_{33}COOH$	Unsaturated	Olive oil
Palmitic acid	$C_{15}H_{31}COOH$	Saturated	Palm oils
Stearic acid	$C_{17}H_{35}COOH$	Saturated	Adipose fats
Arachidonic acid	$C_{19}H_{31}COOH$	Unsaturated	Meat, eggs, fish
Lauric acid	$C_{11}H_{23}COOH$	Saturated	Coconut oil

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LIPIDS AND THE DIET

There are two groups of fatty acids;

a) Essential fatty acids

They cannot be synthesized in the body. Therefore, they have to be obtained from the diet. Their deficiency results into retarded growth, reproductive deficiency and kidney failure. These are **alpha-linolenic acid** (an omega-3 fatty acid) and **linoleic acid** (an omega-6 fatty acid).

b) Non-essential fatty acids

The body synthesizes some fatty acids and they are synthesized from compounds of protein and carbohydrate metabolism.

N.B

- Carboxylic acids have two ends; the alpha end (-COOH) and the Omega end (CH_3) and so Omega -3 fatty acids have a double bond on carbon number 3 and omega 6 have the double bond on carbon number 6.
- Gram per gram, fat stores more energy than glycogen. The C - H bonds of fatty acids make them a richer source of chemical energy than glycogen, because glycogen has many C - OH bonds. i.e. glycogen has more Oxygen molecules than fat. Therefore, nearly all animals use fat in preference to glycogen for long-term energy storage.

FUNCTIONS/ IMPORTANCES OF LIPIDS.

Physiological functions

i) They are energy sources and stores and so they yield a lot of energy when oxidized. i.e. they have a high calorific value than carbohydrates of similar molecular mass. i.e. 1g of lipids yields 38kJ (9k) calories 1g of carbohydrates yields 17kJ (4 kCal.)

ii) They provide a lot of metabolic water to desert animals when oxidized e.g. in camels where they are heavily deposited in the hump and also developing birds and reptiles while enclosed in their shells.

Structural functions

Lipids form very important structures in organisms, the structures include;

- They form the phospholipid layer of the cell membrane by combining with phosphorous to form the phospholipids
- They form the subcutaneous fat layer beneath the dermis of the skin
- They form a component of the waxy cuticle of plants and arthropods hence water proofing the organisms and thus reducing/prevent excessive water loss since they are insoluble in water
- They form the adipose tissue usually around the delicate organs such as the heart
- They form suberin in plant cell walls especially in endoderm cells
- Formation of bee wax for constructing and repairing honey combs
- Lipids are insulators since they are poor conductors of heat. In animals, they are found below the skin. They are mostly found in animals living in cold climates and aquatic mammals with very thick subcutaneous fat (also called blubber in seals and whales)
- They are constituents of the plasma membrane when they combine with phosphoric acids to form phospholipids.
- They form a component of the waxy cuticle of plants and arthropods hence water proofing the organisms and thus reducing/prevent excessive water loss since they are insoluble in water

Storage of materials

Lipids are good storage compounds in the body e.g. **they store a lot of water and fat soluble vitamins e.g. A, D, E and K.** Lipids are good storage compounds because of the following reasons;

- They are insoluble in water and therefore cannot dissolve away and cannot affect the osmotic potential of the cells
- They are much lighter than carbohydrates so as to keep the weight to the minimum
- They have a high calorific value i.e. they have a high energy content
- They are compact and therefore they take up very little space in the cells
- Lipids are poor conductors of heat in the body

Protection

- Fats are used as packing material around delicate organs of the body such as kidneys, heart, lungs and intestines so as to protect them from physical damage by acting as shock absorbers.

Other functions

- Lipids speed up impulse transmission along nerves using the myelin sheath
- Lipids are useful source of metabolic water for desert animals when broken down in respiration
- Plant scents are fatty acids or their derivatives and so aid in the attraction of pollinators
- Buoyancy function in that they help the aquatic organism to float and the oils on bird feathers help the aquatic varieties to float.
- Formation of plant scents for attracting insects for pollination
- Lipids insulate the body against heat loss as they are poor conductors of heat. This explains why the major fat deposits of the body are found under the skin as subcutaneous fat layer, and around vital organs such as the heart, kidneys, lungs, intestines e.t.c. whose temperatures

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should not vary much. Aquatic mammals, e.g. whales, seals and manatees, have an extremely thick subcutaneous fat, called blubber, which forms an effective insulator.

SUITABILLITY OF LIPIDS OVER GLYCOGEN

- Lipids yield more metabolic water on oxidation important for survival of desert animals
- Fat insulates the body against heat loss whereas glycogen does not.
- Fats stored around delicate organs protect them from mechanical/physical damage.
- Fats stored fat-soluble vitamins A, D, E and K
- Fats are more compact than glycogen and so occupy less space
- Lipids are lighter than glycogen hence contribute less weight to organism and structures
- Lipids are store and yield more energy than glycogen
- Lipids are less dense than water and so aid buoyancy of aquatic animals

LIPID DERIVATIVES

WAXES:

These are similar to lipids in composition except that the fatty acids are linked to long chained alcohols instead of glycerol. These are made of ester bonds by linking one fatty acid+ a long chain of alcohol. Waxes are used as water proof material by plants and animals. They are also used as additional protective layers on the surface or epidermis of some plant organs like leaves.

They make exoskeletons of arthropods and bee wax is a constituent of the honeycomb of bees.

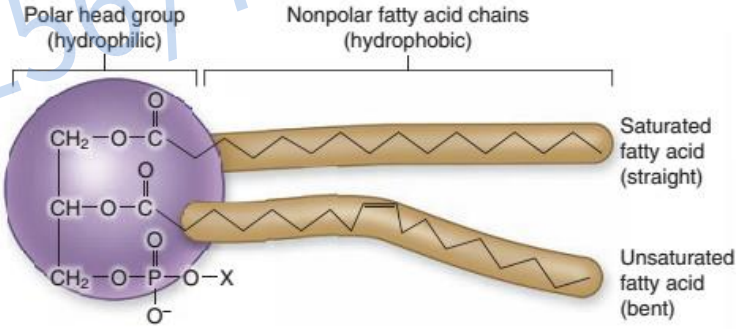
PHOSPHOLIPIDS (LIPIDS WITH PHOSPHATE).

A phospholipid differs from having a phosphate group (PO¬43-) group attached to one of the hydroxyl groups of glycerol such that they have two fatty acids linked to glycerol by condensation reaction instead of three fatty acids.

They are components of the cell membrane. They are made up of two molecules of fatty acids linked to a molecule of glycerol as in fats. But the third position is occupied by a phosphate group.

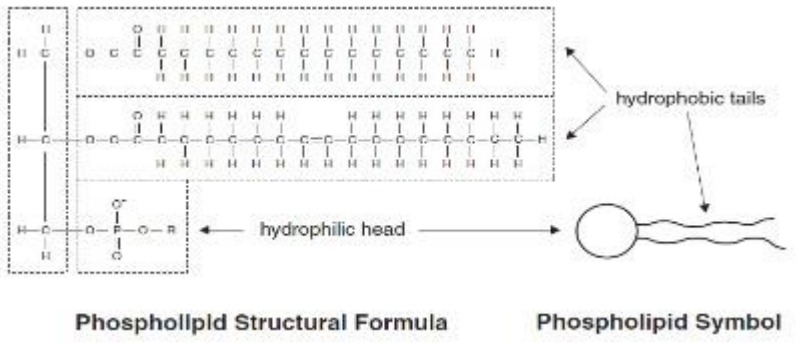
The molecules consist of a phosphate head and two hydrocarbon tails (fatty acids).

The polar ends of the molecule being **soluble enter the water** while the insoluble hydrocarbon chain project out wards at right angles to the surface. This property of the phospholipids is important in determining the structure and functions of the cell membrane.



PHOSPHOLIPID MOLECULE

The **phosphate group** is electrically charged (PO_4^{3-}) and therefore polar and so unlike fatty acids dissolve in water. Phospholipids are therefore able to dissolve in both water and organic substances i.e. phospholipids are both hydrophilic and hydrophobic.



Phospholipid Structural Formula Phospholipid Symbol

This property of phospholipids is important in determining the structure and functioning of the cell membrane. In water, phospholipid molecules collect together in a single layer (monolayer) with the hydrophilic head poking into the water. In cells, both the intracellular environment and immediate external environment are watery. This causes phospholipids to form a double layer, with the

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hydrophobic tails pointing inwards, away from the watery environment. The phospholipids bilayer gives cell membranes their fluid properties and allows lipid soluble substances to pass easily

GLYCOLIPIDS

They are lipids with a carbohydrate attached by a glycosidic bond. Their role is to serve as markers for cellular recognition. The carbohydrates are found on the outer surface of all eukaryotic cell membranes

LIPOPROTEINS

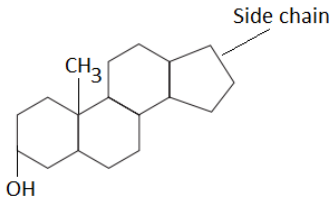
This forms part of the cell membranes and it is the chemical form in which lipids are transported.

STEROIDS

These are lipids whose molecules contain 4 rings of carbon and hydrogen atoms. Steroids are therefore bigger than the common lipids and they are saturated hydro carbons.

Three of the rings are six numbered and one of them is five numbered. All together there are 17 carbon atoms, six of which are shared between the rings and they are saturated hydrocarbons. They cannot be hydrolysed. Some are formed by the **smooth ER** of cell membranes

The structure of cholesterol



EXAMPLES OF STEROIDS	***FUNCTION***
Cholesterol	It's a major component of cell membrane and it's a raw material for many other steroids but it is absent in plants
Bile acids (e.g. glycolic acid)	They form bile salts, which emulsify fats during digestion.
Adrenal corticosteroids	These are hormones produced in the cortex region of the adrenal gland, important in coordination, especially in stress responses.
Sex hormones like Oestrogen and progesterone in females and testosterone in males	They are reproductive hormones in females which regulate the menstrual cycle and control pregnancy. In males Testosterone controls sexual behaviour and spermatogenesis.
Calciferol (Vitamin D)	It promotes calcium and phosphate absorption and metabolism
Ecydsone.	It's a hormone responsible for ecdysis (moulting in insects / shedding off of the exoskeleton) to allow growth.

TEST FOR LIPIDS

1. Ethanol test. (Emulsion test)

To 1cm^3 of food substance add 5 drops of ethanol then add 3 drops of distilled water and shake.

Observation

Presence of lipids is shown when the colourless solution turns to a creamy milky emulsion.

Absence of lipids is when the Colourless solution remains clear or when no emulsion appears.

2. Sudan (III) Reagent

To 1cm^3 of the lipid in the test tube is added 3 drops of Sudan (III) reagent and shake the mixture. Leave to mixture to stand for 2 minutes. The oil layer which settles at the top is red in colour and water beneath remains this indicates presence of lipids.

3. Translucent paper mark test.

If a drop of a liquid is smeared on a piece of paper and later the spot dried. A translucent mark will remain on the paper suggesting that lipids were present in the smeared drop.

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PROTEINS

Proteins are complex organic compounds with a large molecular mass made of carbon, oxygen, hydrogen, nitrogen and in some cases sulphur. They are not truly soluble in water, but form colloidal suspensions. Proteins are rarely stored by organisms except in eggs or seeds where they are used for formation of new tissues. Proteins are made up of small units called **amino acids.**

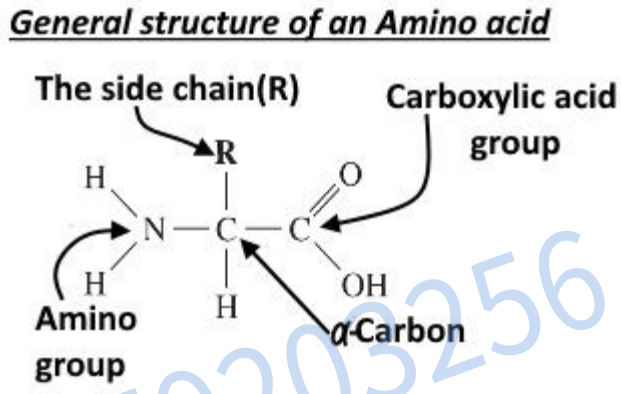
The variety of proteins is unlimited because the sequence of amino acids in each protein molecule which is genetically determined by DNA within cells during protein synthesis.

Proteins are the most abundant molecules to be found in the cells and comprise over 50% of their total dry weight. They are therefore an essential component of the diet of animals and may be converted to both fats and carbohydrates by the cells.

The structural diversity of proteins enables them provide a range of structural and metabolic activities within the organisms. The number of amino acid sub-units may range between several thousands to millions e.g. β- lactoglonin found in milk has a molecular formula of $C_{1642}H_{2652}O_{492}N_{420}S_{18}$

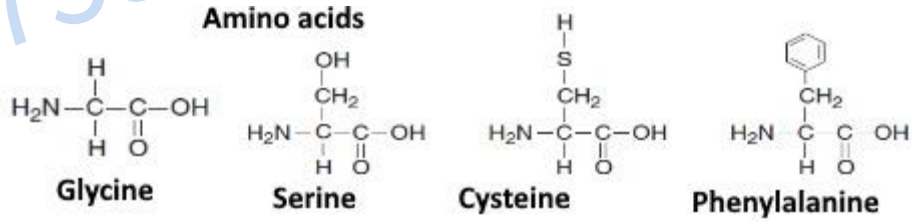
AMINO ACIDS

There are 20 common naturally occurring amino acids whose different combinations result in a great variety of the proteins since each amino acid has its own set of properties. The general formula of amino acids is $RCHNH_2COOH$ whose structure is shown below



The structure shows that amino acids are composed of four different parts namely;

i) A hydrocarbon group (-CHn)
ii) A carboxyl group (-COOH)
ii) An amino group (NH_2)
v) An R group. It is in this R group of the amino acid that lies the difference in the amino acid e.g. in amino acids, glycerine which is the simplest amino acid, R is a hydrogen atom (H) while In alanine, the R –group is CH_3 and when R is substituted with **C_3H_7**, the amino acid formed is Valine.



Amino acids are soluble in water but insoluble in organic solvents. **At neutral pH** (found in most living organisms), the groups are ionized as shown above, so there's a positive charge at one end of the molecule and a negative charge at the other end. The overall net charge on the molecule is therefore zero.

Majority of amino acids possess one acidic or carboxylic group and one basic or amino group and hence they are termed as **neutral amino acids.**

PROPERTIES OF AMINO ACIDS

They are colourless crystalline solids

- They are generally soluble in water but insoluble in organic solvents
- They are amphoteric in nature i.e. possess both basic and acidic groups.

They can donate a proton like acids and also accept protons like bases.

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The amphoteric nature is used biologically in pH buffering in body solutions. They do this by accepting protons as pH decreases and donating protons as PH increases, so that the pH is kept optimum or near neutral.

AMINO ACIDS AS BUFFERS

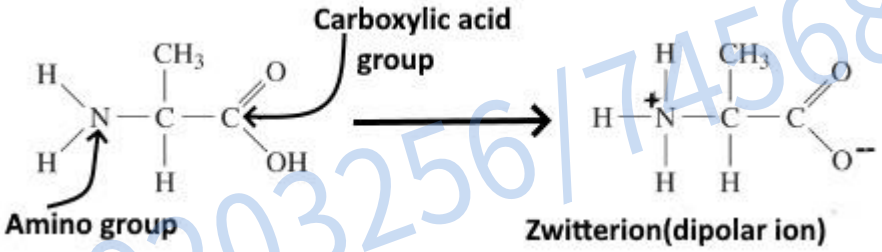
A buffer solution is a solution which absorbs hydrogen ions when their concentration is high and releases them when their concentration is low, thus maintains the pH/ hydrogen ion concentration constant when small amounts of acid or alkali are added. **I.e.** ***it's a solution which is able to resist changes in the pH of the solution.***

Amino acids therefore can donate hydrogen ions as the pH increases so as to lower the pH and also accept hydrogen ions from the solution as the pH decreases so as to raise the pH. Amino acids therefore play an important role as buffer in the tissue fluid and in the cytoplasm of most cells thereby maintaining the pH within the narrow limits needed for normal metabolism and efficient enzyme functioning. This is because changes in pH denature enzyme which can be fatal to the living organism**.**

Amino acids are amphoteric because they have both basic and acidic properties. The acidic property is derived from the carboxyl group (-COOH) which donates a proton (H^+) so that the molecule becomes negatively charged

The basic property is derived from the amino group (-NH_2) which can take up a proton so that the molecule becomes positively charged therefore the amino acid carries a (+) amino group and a (-) carboxyl group which qualifies it to be a dipolar substance And because of the above property the ***amino acid buffer solutions.***

In this form, they form Zwitterions.



Biological functions of amino acids

- Amino acids are used to build up proteins/monomers for protein synthesis, which have functional roles such as enzymes and hormones, and structure roles such as keratin and collagen.
- The amino acid act as buffers, by taking up hydrogen ions in acidic solution; and losing hydrogen ions in alkaline solutions hence resisting changes in pH in the body fluids.
- Amino acids act as intermediate pathways in metabolic pathways, e.g. citric acid pathways; release energy in times of starvation; i.e. used as substrates in cell respiration to provide energy in cases of starvation.
- They are also used to synthesize neurotransmitters. For example, tyrosine is used to synthesize adrenaline and norepinephrine.
- Amino acids are regulators of gene expression. They do so by modulating the translation of mRNA

CLASSIFICATION OF AMINO ACIDS

The 20 common Amino acids are classified as **essential** or **non-essential.**

Essential amino acids: These are the amino acids which cannot be synthesized by the body or their rates of synthesis are not sufficient to meet the body needs. and therefore must be obtained from the diet.

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Essential amino acids include:

1. **Lysine**
2. **Histidine**
3. **Isoleucine**
4. **Methionine**
5. **Tryptophan**
6. **Arginine**
7. **Thiamine**
8. **Leucine**
9. **Valine**
10. **Phenylalanine**

NB: Histidine and Arginine are only essential in children.

Foods containing all the essential amino acids are known as **first class proteins** and they include all animal proteins and some few plant proteins e.g. soya beans. Foods lacking one or more amino acids are **second class proteins**.

NON-ESSENTIAL AMINO ACIDS

These are amino acids which the body can synthesise in such sufficient quantities for them not to be required in the diet. The absence of one or more of these amino acids results in retarded growth and particular symptoms,

The process of synthesis of amino acids involve a process called **Transamination** which is carried out by **transaminase enzymes.**

The raw materials for the process are the essential amino acids provided in the diet and carbohydrate derivatives (keto- acids) like the intermediate compounds of carbohydrate metabolism e.g. Pyruvic acid which is obtained from the breakdown of sugar during respiration.

Non-essential amino acids include:

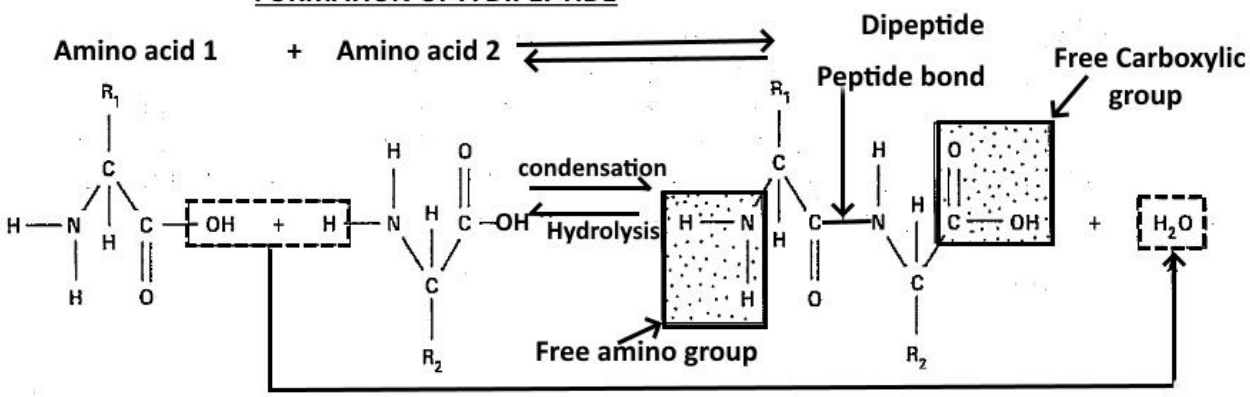
1. **Glycine (R is -H)**
2. **Alanine (R is $-CH_3$)**
3. **Aspartic acid (R is $-CH_2COOH$)**
4. **Asparagine**
5. **Proline.**
6. **Glutamic acid**
7. **Cysteine(R is $-CH_2-S-H$)**
8. **Serine**
9. **Tyrosine**
10. **Glutamine.**

FORMATION OF A POLYPEPTIDE

- Initially **two amino acids** combine in a **condensation** reaction to form a dipeptide linked by **peptide bonds** with the loss of a water molecule. A reaction occurs between the amino group of one and the carboxylic group of another.
- The dipeptide formed possesses a free carboxyl group at one end and a free amino group that attract further amino acid molecules to a dipeptide, thereby building up a chain of amino acids residues.
- Later several dipeptides combine in several condensation reactions to form a long chain called **polypeptide** which consist of up to 500 amino acids or more.
- The individual amino acids within the polypeptide chin are linked by peptide bonds to form a protein.

These polypeptides made are then folded and twisted in an appropriate way as directed by a particular gene (DNA) which also determines the sequence of amino acids in the chain. This is illustrated on the right

FORMATION OF A DIPEPTIDE



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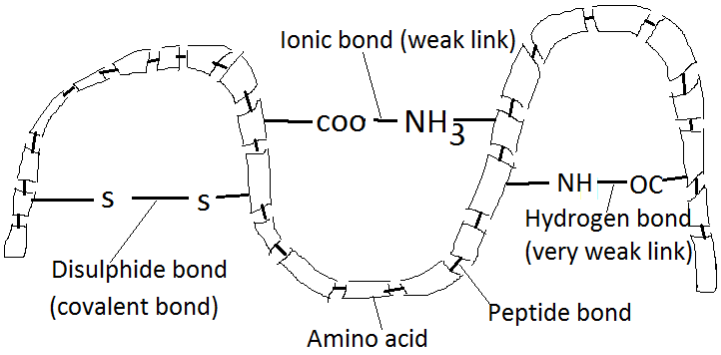
A protein may consist of several polypeptide chains which may be straight, folded, branched or cross linked at intervals.

Apart from the peptide bonds, amino acids are able to form a variety of other chemical bonds with other reactive groups and this is what leads to further elaboration in the polypeptide chain to form a protein.

LINKAGES IN POLYPEPTIDES

1. Disulphide bonds.
2. Ionic bonds.
3. Hydrogen bonds.
4. Hydrophobic bonds

Illustration



1. IONIC BOND

At a suitable pH an interaction may occur between ionised amino groups and a carboxyl and this results into the formation of an ionic bond between the two amino acids. This bond can be easily broken in an aqueous medium by changing the pH of the medium.

Ionic bonds give a polypeptide molecule its particular shape and they are relatively weaker than covalent bonds.

2. Disulphide bonds

This bond arises between sulphur containing groups of any two oxidised cysteine molecules of amino acids.

Some amino acids have a **Sulphur group** on the **R-Group**. When 2 molecules with a Sulphur group are lined up alongside each other, the **S-H** groups are oxidized to form a disulphide bond e.g. in when cysteine amino acids come together.

- Disulphide bonds may be formed between different parts of the same chain (hence folding the chain into a particular structure) or different chains of amino acids.
- The disulphide bonds make the molecule fold into a particular shape such that these molecules are strong and not easily broken.
- They are strong and not easily broken.

3. HYDROGEN BOND

This occurs between certain hydrogen atoms and certain oxygen atoms that contain ion pairs of electrons.

When hydrogen is part of the **P-H** / **N-H** groups taking part in a reaction, it becomes slightly positive charged and is therefore attracted to the negatively charged neighbouring oxygen atom.

- The hydrogen bond is very weak but plays a role in maintaining the shape and stability of the polypeptide molecule

4. HYDROPHOBIC INTERACTION

Within a polypeptide chain, hydrophobic interactions or bonds can be registered. They arise in situations where the R-groups are non-polar and therefore hydrophobic. The polypeptide chain will tend to fold so that the maximum number of hydrophobic groups come into close contact and exclude water. This is how many globular proteins fold up. The hydrophobic groups tend to point inwards towards the centre while the hydrophilic groups face outwards in the aqueous environment making protein soluble. They are also weak bonds.

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CLASSIFICATION OF PROTEINS

Proteins can be classified according to **structure, composition and function**.

a) Proteins can be grouped according to **their functions.** Some major categories follow:

1. **Structural proteins** such as keratin in the hair and horns of animals, collagen in connective tissues, and silk in spider webs.
2. **Storage proteins** such as casein in milk, ovalbumin in egg whites, and zein in corn seeds.
3. **Transport proteins** such as those in the membranes of cells that transport materials into and out of cells and as oxygen-carrying haemoglobin in red blood cells.
4. **Defensive proteins** such as the antibodies that provide protection against foreign substances that enter the bodies of animals.
5. **Enzymes** that regulate the rate of chemical reactions.

b) According to **structure proteins** are classified into the following

The proteins are also classified as **primary** structure proteins, **secondary, tertiary and quaternary** structure proteins.

PRIMARY STRUCTURE

This refers to the sequence of amino acids found in the polypeptide chains of the proteins

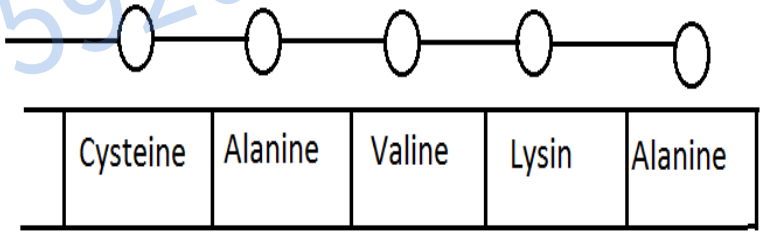
This structure shows the number and sequence of amino acids in the protein molecule, held **together by peptide bonds** in a polypeptide chain.

One major importance of the primary structure of the protein in relation to function is found in **enzymes, in which the structural configuration of the active site of the enzymes determines** whether a particular substrate will fit in the active site of that enzyme.

The primary structure is clearly shown by insulin hormone

The primary structure is specific for each protein and is determined by the DNA of the cell from which it is made. **E.g.** the primary structure of Myoglobin is composed of a single polypeptide chain of 153 amino acids, the haemoglobin molecule is made up of **four** polypeptide chains: **two** alpha chains of **141** amino acid residues each and **two** beta chains of **146** amino acid residues each.

The alpha and beta chains have different sequences of amino acids, but fold up to form similar three-dimensional structures



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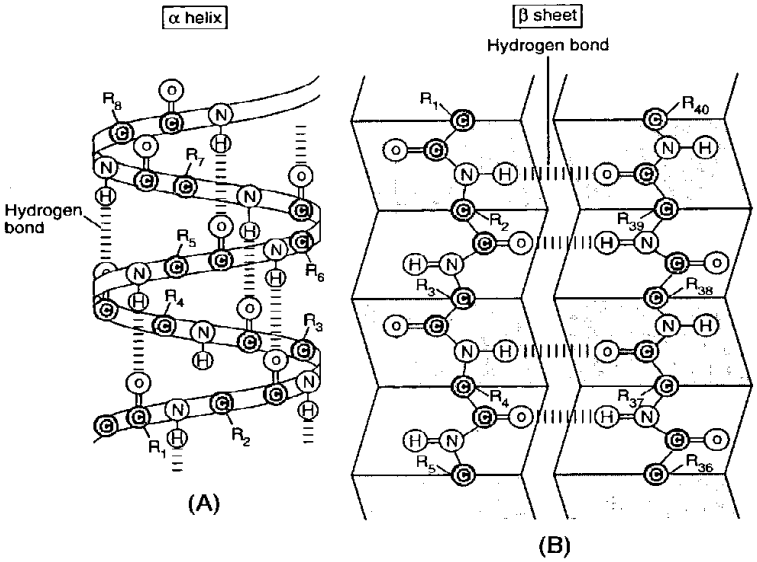
SECONDARY STRUCTURE

This refers to the coiling or folding up of the polypeptide chain of a protein into a helix structure, maintained by Hydrogen bonds formed between adjacent CO- and -NH groups (NH------OC) along the chain. This is because after their formation, the chain of amino acids in the polypeptide folds spontaneously to make complex configurations categorised into **alpha-helices** or **beta-pleated** sheets held together by hydrogen bonds.

Structure of alpha helix

The **hydrogen bonds stabilise the helix by joining together** the amino group of one turn and a carboxyl group of another turn. Therefore, the importance of the secondary structure is that it maintains a particular shape of a protein keeping it stable by twisting it.

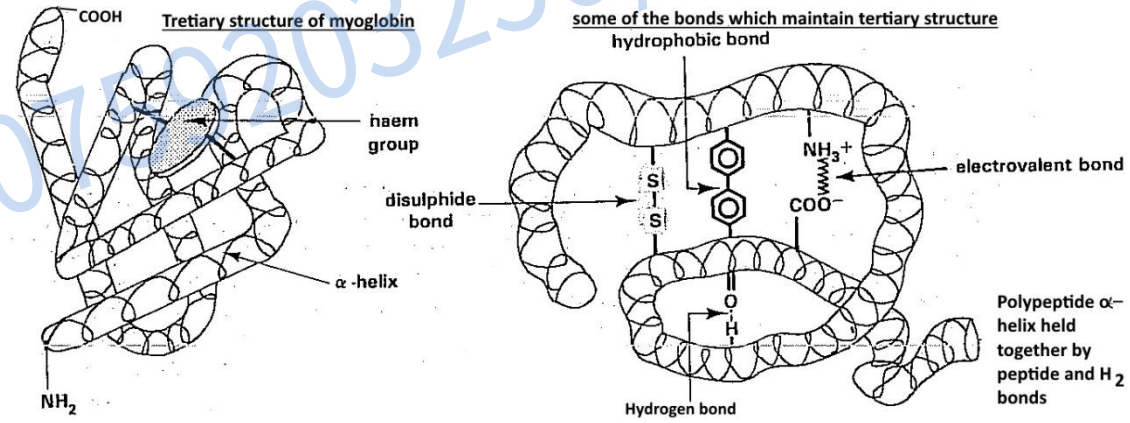
- This secondary structure is of greater **importance in the biological function** of proteins particularly enzymes and antibodies whose efficiency depends on maintaining a particular shape.
- It is also important in the formation of fibrous proteins which are insoluble in water and are resistant to changes in temperature and pH.
- The secondary structure of a protein is of particular importance in the formation of structural proteins such as keratin, silk and collagen. Keratin is a fibrous protein found in the hair, nails, horns, feathers and wool. Collagen is also a fibrous protein found in mammalian connective tissue such as bones, cartilage, tendons and the skin. Both keratin and collagen contain a secondary structure in the form of an alpha –helix.



TERTIARY STRUCTURE

This is a structure resulting from other uniform coiling and folding of the polypeptide helix in to a very compact structure.

It is due to the bending and twisting of the polypeptide helix (secondary structural helix). This results in the formation of cross linkages which are maintained by the interaction of 3 types of bonds i.e. **ionic, disulphide and hydrogen bonds.** Common example include myoglobin. All these contribute to the maintenance of the tertiary structure.



It is the structure which explains the complex molecular shape of some proteins especially **globular proteins, especially enzymes, myoglobin and insulin**. This structure contains many cross linkages formed by many bonds within the polypeptide chains which make the proteins strong molecules.

These are soluble in water because they consist of polar groups and amino acids which congregate outside and interact with water. There hydrophobic chains contain non polar amino acids and are usually pushed inwards into the centre of the molecules

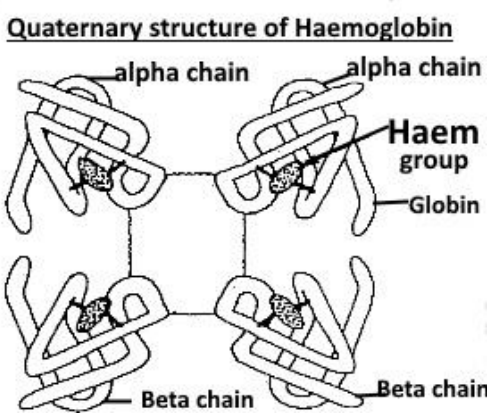
QUARTENARY STRUCTURE

This is the structure which arises from the combination of a number of different polypeptide chains and associated non protein groups into a large protein molecule. Such a structure is shown by **haemoglobin**

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This is formed when two or more polypeptide chains are clumped together. The separate chains are held together by **hydrophobic, ionic and hydrogen bonds.**
They also consist of non-protein structures called the **prosthetic group** other examples include; mucin, casein, cytochromes

Structurally haemoglobin consists of 2 α-polypeptide chains and 2 β-polypeptide chains arranged around a complex ion containing prosthetic groups called **haem** groups. Such polypeptide chains are normally fitted together in such a way that they form larger and more complex protein structure.
The 4 polypeptide chains in heamoglobin are called **globin.** Each chain in haemoglobin carries a haem group to which one molecule of oxygen bonds.



SUMMARY

Structural level	characteristics
Primary	Sequence of amino acids in the protein molecule, held by **peptide bonds** in a polypeptide chain.
Secondary	The coiled α helix or folding up of the polypeptide chain of a protein into a helix structure, maintained by **Hydrogen bonding** between peptide bonds along the chain. The hydrogen bonds stabilise the helix by joining together the amino group of one turn and a carboxyl group of another turn.
Tertiary	Proteins with uniform coiling and folding of the polypeptide helix into a very compact structure. Three-dimensional shape stabilized by interactions **between R groups** of amino acids Cross linkages are maintained by the interaction of ▪ ionic between R groups of amino acids, ▪ hydrogen bonds between R groups of amino acids and ▪ disulphide when the sulphur atom in the amino acid cysteine ▪ bonds to the sulphur atom in another cysteine
Quaternary	Protein that is assembled from **two or more separate peptide chains** to form a biologically active protein. E.g. globular protein haemoglobin, consists of **four** peptide chains that are held together by hydrogen bonding, interactions among R groups, and disulphide bonds.

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TYPES OF PROTEINS
Proteins are classified into three main groups on the basis of their **tertiary structure**
I.e. globular proteins, fibrous proteins, and conjugated proteins.

1. GLOBULAR PROTEINS
They have irregular sequences of amino acids in their polypeptide chains. All enzymes are globular proteins.
Properties
- Relatively soluble in water
- Their polypeptide chains are tightly folded to form spherical shapes or helixes
- They do not form true solutions but exist as colloidal suspensions.
- They are compact and are far less stable and have metabolic roles within organisms.

Occurrence

They are found in the blood plasma where they work as buffers e.g. Haemoglobin and Myoglobin.

They are also found in cells where they are important in maintaining the composition of the protoplasm.

They are found in the plasma membrane as structural constituents but also as carrier proteins and passage proteins. Examples; Enzymes, some hormones (like insulin and glucagon, adrenal corticotropic hormone), globulin of blood, haemoglobin, myoglobin, antibodies and immunoglobulins.

Function

- Regulation through enzymes, hormones, antibodies, haemoglobin.
- They are also structural components of cell membranes.

FIBROUS PROTEINS

These have a primary structure of regular repetitive sequences. They form long chains which may run parallel to one another, being linked by cross bridged..

Properties

- They are insoluble in water
- They have large parallel polypeptide chains or cross linked at many points due to hydrogen bonds and other bonds to form fibres or tissues and because of the cross linkages between the parallel chains, fibrous proteins are physically tough.
- They are very stable molecules and have structural roles with organisms e.g. collagen.
- The main structure is the secondary one.

Occurrence;

They are found in structures like hair, hooves, horns, nails, connective tissue and muscles.

Examples;

Keratin (hair), collagen (connective), elastin (connective), Myosin and actin (muscles)

INTERMEDIATE PROTEINS

They are fibrous but soluble proteins e.g. Fibrinogen which can form insoluble fibrin during blood clotting.

CLASSIFICATION OF PROTEINS ACCORDING TO COMPOSITION

i) CONJUGATED PROTEINS.

These are proteins comprising of a globular protein and a non-protein part referred to as the **prosthetic group**. If the prosthetic group in a protein is **organic** in nature then such a group is called a **co-enzyme**. If the prosthetic group is **inorganic** in nature then such a group is called a **co-factor.** E.g. the prosthetic group in haemoglobin is the Haem group.

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Conjugated protein	Prosthetic group	Location/function
1. **Glycoproteins**	carbohydrate	Plasma membrane, mucin in saliva
2. **Lipoproteins**	lipid	Cell membrane, the form in which lipids are transported in the body
3. **Phosphoproteins**	phosphate	Casein of milk, vitelline of egg, plasma membrane.
4. **Nucleoproteins**	Nucleic acid	Component of ribosomes and chromosomes
5. **Chromoproteins**	Haem pigment	Haemoglobin, cytochromes
6. **Flavoproteins**	FAD	Electron transport system
7. **Metal proteins**	Metal ion	Nitrate reductase

(ii) **SIMPLE PROTEINS**

These don't have any non-protein e.g. albumin in eggs, globulins in blood, fibrinogen, keratin, collagen, etc.

Comparison of globular proteins and fibrous proteins	
Fibrous proteins	**Globular proteins**
▪ Repetitive regular sequence of amino acids	Irregular amino acid sequence
▪ Actual sequence may vary slightly between two examples of the same protein	Sequence highly specific and never varies between two examples of the same protein

▪ Polypeptide chains form long parallel strands	Polypeptide chains fold into a spherical shape
▪ Not easily denatured by high temperature	Easily denatured by high temperature
▪ Length of chain may vary between two examples of the same protein	Length always identical in two examples of the same protein
▪ Stable structure	Relative unstable
▪ Insoluble in water	Soluble in water
▪ Support and structural functions	Metabolic functions
▪ Consists of log fibrous molecules	Consist of compact and spherical molecules
▪ Secondary protein	Tertiary protein
e.g. collagen and keratin	e.g. enzymes, hormones and haemoglobin

CHARACTERISTICS OF PROTEINS

1. They are colloidal in nature

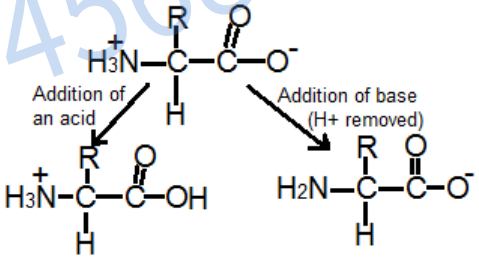
In solution, proteins form colloids since they have large sizes, they do not go into true solutions but form colloidal suspensions. A colloidal is a particle which remains suspended in solution rather than dissolving, settling down or floating. I.e. too small to settle out under gravity but also too large to dissolve.

The importance of colloids being dispersed in solution is that it gives them a large surface area which makes them very reactive. This is important in enzymes.

2. They have amphoteric propertiesi.e. They are basic and acidic nature because they have both basic and acidic groups. The amphoteric nature of amino acids is useful biologically as it means that they serve as buffers in solution resisting changes in PH.

The buffer action depends on concentration of hydrogen ions.

When an acid is i.e. more hydrogen ions(H+), the hydrogen ions(H+) are **accepted by the amino acids** making them positively charged hence reducing the H+ concentration of the solution. When a **base is added,** or a decrease in H+ concentration of the solution, the amino acid releases H+ to the solution.



3. They are made of large molecules

4. They show specificity e.g. in enzymes which are specific in nature

On hydrolysis, they yield a mixture of amino acids.

5. They are insoluble in organic solvents.

CLASSIFICATION OF PROTEINS ACCORDING TO FUNCTIONS

Enzymes:

These are biological catalysts which control chemical reactions in organisms e.g. amylase

Structural proteins

These form part of the body of organisms e.g. collagen which makes up tendons and ligaments. Keratin is a major component of hair and nails

Signal proteins

These carry messages around the body e.g. insulin hormone and glucagon involved in controlling glucose levels in blood

Contractile proteins

These are involved in movement after contraction e.g. actin and myosin which are proteins that aid muscle contraction

Storage proteins

These keep materials e.g. albumen in the egg which nourishes the chick while it is still inside the egg.

Defensive proteins

E.g. antibodies, thrombin, fibrinogen which are important for fighting infections.

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Transport proteins e.g. haemoglobin which carries oxygen around the body

FUNCTIONS OF PROTEINS

Vital activity	Protein function	Function
Nutrition	Digestive enzymes, e.g. ▪ trypsin ▪ Amylase ▪ Lipase	Catalyses the hydrolysis of protein to polypeptides Catalyses the hydrolysis of starch maltose Catalyses the hydrolysis of fats to fatty acids and glycerol
	Fibrous proteins in grana lamellae	Help to arrange chlorophyll molecules in a position to receive maximum amount of light for photosynthesis
	Mucin	**(1)** Assists trapping of food in filter feeders. **(2)** Prevents autolysis. **(3)** Lubricates guts wall.
	Casein	Storage protein in milk
	Ovalbumin	Storage protein in egg white
Respiration and transport	Haemoglobin/ haemoerythin/ haemocyanin/ chlorocruorin	Transport of oxygen
	Myoglobin	Stores oxygen in muscle
	Prothrombin/fibrinogen	Required for the clotting of blood
	Mucin	Keeps respiratory surface moist
	Antibodies	Essential to the defence of the body, e.g. against bacterial invasion
Growth	Hormones, e.g. thyroxine	Controls growth and development
Excretion	Enzymes, e.g. urease, arginase.	Catalyses reactions in the ornithine cycle thus useful in protein breakdown and urea formation
Support and movement	Actin/myosin	Needed for muscle contraction
	Ossein	Structural support in bones
	Collagen	Gives strength with flexibility in tendons and cartilage
	Elastin	Gives strength and elasticity in ligaments
	Keratin	Tough for protection, e.g. in scales, claws, nails, hooves, skin.
	Sclerotin	Provides strength in insects exoskeleton
	Lipoproteins	Structural components of all cell membranes
Sensitivity and coordination	Hormones, e.g. insulin/glucagon, adrenocorticotrophic hormone, vasopressin	Controls blood sugar level Controls the activity of the adrenal cortex Controls blood pressure
	Rhodopsin/opsin	Visual pigments in the retina, sensitive to light
	Phytochromes	Plant pigments important in control of flowering, germination, e.t.c.
Reproduction	Hormones e.g. prolactin	Induces milk production in mammals
	Chromatin	Gives structural support in chromosomes
	Gluten	Storage protein in seeds, nourishes the embryo
	Keratin	Forms horny and antlers which may be used for sexual display

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Other functions

- They form structures in the body e.g. the plasma membrane, hair, skin, horns.
- They regulate the internal environment of living things as hormones e.g. Insulin and glucagon and as buffers e.g. haemoglobin.
- They regulate and catalyse the rate of metabolism as enzymes.
- They are involved in the transportation of respiratory gases e.g. Haemoglobin and Myoglobin.
- They are important in the body movements like muscle contraction, Actin and Myosin.
- They defend the body against diseases in form of antibodies and Immunoglobulins.
- In extreme cases of starvation, they can be hydrolysed to release energy for other metabolic processes.

PROTEIN DENATURATION AND RENATURATION

Protein denaturation is the loss of its 3-dimensional structure which makes it unable to carry out its normal Biological functions. The three-dimensional structure of a protein is, in part at least, due to fairly weak ionic and hydrogen bonds.

A protein is said to be denatured when its 3-dimensional structures is lost. This is due to the breaking of the weak hydrogen and ionic bonds that support it.

Renaturation

This is the reconstruction of a protein that has been denatured to a small extent such that its molecules regain the original 3 dimensional configuration and function by providing them with the ideal conditions of mainly the pH, and temperature. If the degree of denaturation is great, renaturation cannot take place even if the ideal conditions are provided.

AGENTS THAT CAUSE DENATURING OF PROTEINS.

Factor	Explanation	Example
High temperature or radiations	Increases kinetic energy which makes atoms of the proteins to vibrate rapidly, thus breaking hydrogen and ionic bonds resulting into coagulation	Coagulation of albumen (boiling eggs makes the white more fibrous and hence insoluble)
Acid	Addition H^+ in acid which combine with COO-groups on amino acids and form COOH. Ionic bonds are broken.	The souring of milk by acid e.g. lactobacillus bacterium produces lactic acid.
Strong acids, bases, salts and high salt concentration	Breakdown bonds disrupt ionic bonds hence coagulation of proteins. Peptide bonds can also break if the protein is mixed with a reagent for long.	
Heavy metals	The ions of heavy metals such as Hg and silver are highly electropositive. They combine with COO-groups and disrupt ionic bonds. Similarly, highly electronegative ions e.g. cyanide (CN^-) combine with amino groups and disrupt ionic bonds.	Many enzymes are inhibited, denatured in presence of certain ions e.g. cytochrome oxidase (respiratory enzymes) is inhibited by cyanide (CN^-)
Organic solvents and detergents	These disrupt hydrophobic bonds and form bonds with hydrophobic groups which eventually disrupt the Hydrogen bonding	Alcohol denatures certain bacteria proteins. This is what makes it useful for sterilization
Mechanical force	Physical movement may break hydrogen bonds.	Stretching the hair breaks the H_2 bonds in the Keratin helix. The helix is extended and hair stretches. If released, the hair returns to the normal length. If however wetted and dried under tension, it keeps its new length.

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CHEMICAL REACTIONS IN CELLS

ENZYMES

An enzyme is an organic catalyst protein in nature which speeds up the rate of metabolic reactions in an organism without itself undergoing a permanent change.

Without enzymes the chemical reactions that occur in living organisms would proceed so slowly, if at all, to cope up with the rates required for maintenance in life. Also increasing the rate of a body reaction would be by increasing the temperature of the body. This would denature proteins, disrupt membranes and be very expensive in terms of energy expenditure. Enzymes therefore enable metabolic reactions to proceed rapidly and at low temperatures.

Enzyme reactions may be described as either **catabolic,** if they are involved in the breakdown of compounds or **anabolic**, if they are involved in the synthesis of compounds. The total of all catabolic and anabolic reactions in a living cell or organism is what is called **metabolism** of the cell or organism.

CHARACTERISTICS OF ENZYMES

- **They catalyse reactions very fast.** The speed of action of an enzyme is called turn over number. The turn over number is the number of substrate molecules that an enzyme converts into products in one minute. E.g. catalase has a turn over number of 600,000per second.
- **Enzymes are not destroyed** or used up by the reactions they catalyse and they can be used over and over again.
- **The reaction catalysed is reversible.** An enzyme can work in either direction i.e. enzymes can catalyse reversible reactions.
- **Enzymes are denatured by excessive** heat (very high temperature). This is so because they are protein in nature.
  NOTE: Organisms living in temperatures exceeding 450c have heat resistant enzymes or have a way of regulating the body temperatures e.g. enzymes living in hot springs (hot spring bacteria)
- **Enzymes are sensitive to PH.** Every enzyme has an optimum PH in which it functions most efficiently. Intracellular enzymes function best at around neutral PH while digestive enzymes prefer alkaline or acidic PH depending on its location in the gut in the gut.
- **Enzymes are specific in the reactions** they catalyse more than the inorganic catalysts. A given enzyme catalyses one reaction or one type of reactions. Most intracellular enzymes work on one substrate. However, digestive enzymes may work on more related substrates e.g. catalase only splits hydrogen peroxide while pepsin works on a wide range of protein molecules.
- All are globular proteins
- They are very efficient i.e. a very small amount of catalysts bring about the change of large amount of substrates .
- Enzymes lower the activation energy of the reactions they catalyze
- They posses active sites where the reactions take place. These sites have specific shape

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MOMENCLATURE OF ENZYMES

Normally an enzyme is named by attaching the suffix “ase” to the name of the substrate on which it acts for example

i. Proteins to protease.
ii. Lipids to lipase
iii. Maltose to maltase
iv. Sucrose to sucrase.

CLASSIFICATION OF ENZYMES

Enzymes group	***Type of reaction (Role)***	***Enzyme example***
Oxireductases	They catalyse biological oxidation and reduction reaction.	Dehydrogenase, oxidase
Transferases	Transfer of a chemical group from one substance to another.	Transaminases Phosphorylases

Hydrolases	Catalyse reactions involving addition of water (hydrolysis) and loss of water molecules (condensation)	Proteases, Lipases
Lyases	These catalyse breakdown of chemical bonds without addition of water or a new group to the free bonds	Decarboxylase Carboxylase
isomerases	These catalyse the rearrangement of groups within a molecule.	Isomerases Phosphoglumutase
Ligases	Formation of bonds between two molecules using energy derived from the breakdown of ATP	Phosphokinases.

ENZYME STRUCTURE

Structurally an enzyme is a complex three dimensional **globular protein** some of which have other associated molecules.

Even though the enzyme molecule is normally larger than the substrate molecule it acts upon, only a small part of the enzyme molecule actually comes into contact with the substrate. This region of the enzyme molecule which comes into contact with the substrate is called the **active site.**

Only a few of the amino acids of the enzyme molecule actually make up the specific sequence of amino acids that make up the active site. The rest of the amino acids in the enzyme molecule are used to maintain the globular structure of the enzymes.

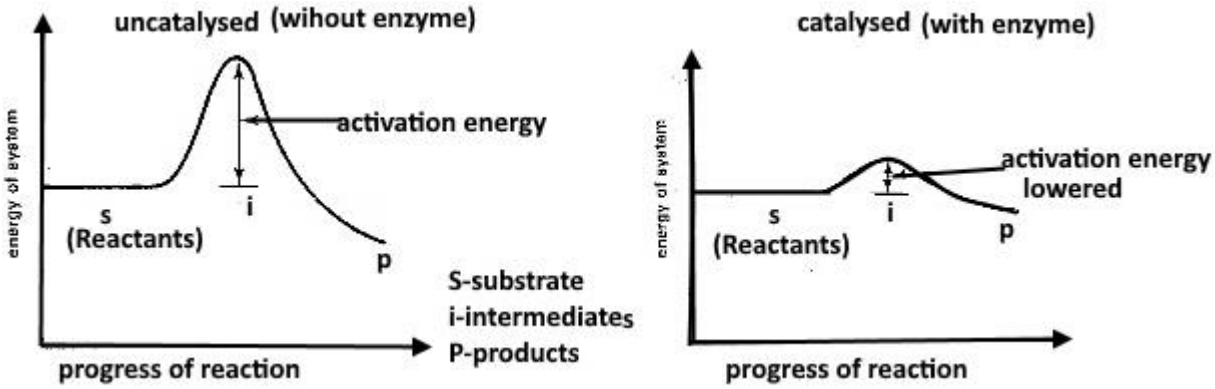
The specific sequence of amino acids in the active site gives the active site of a **specific configuration.** It is the active site configuration which controls enzyme functioning and properties. It is at the active site that bonding of substrates occurs.

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ENZYME AND ACTIVATION ENERGY

Enzymes generally catalyse reactions by lowering the **activation energy**. Enzymes therefore make it easier for a reaction to take place than it would without them. The energy required for a chemical reaction to proceed is called **activation energy**

Before a reaction can take place, it must overcome an energy barrier by exceeding its activation energy. As heat is often the source of activation energy, enzymes often dispense with the need for this heat and so allow reaction to take place at lower temperatures. Many reactions which would not ordinarily occur at the temperature of an organism do so readily in the presence of enzymes



MECHANISM OF ENZYME ACTION

Enzymes generally work by lowering the activation energy needed to initiate the reaction. They make it easy for a reaction to take place than it would without them. They lower the activation energy through a number of mechanisms described below.

LOCK AND KEY HYPOTHESIS

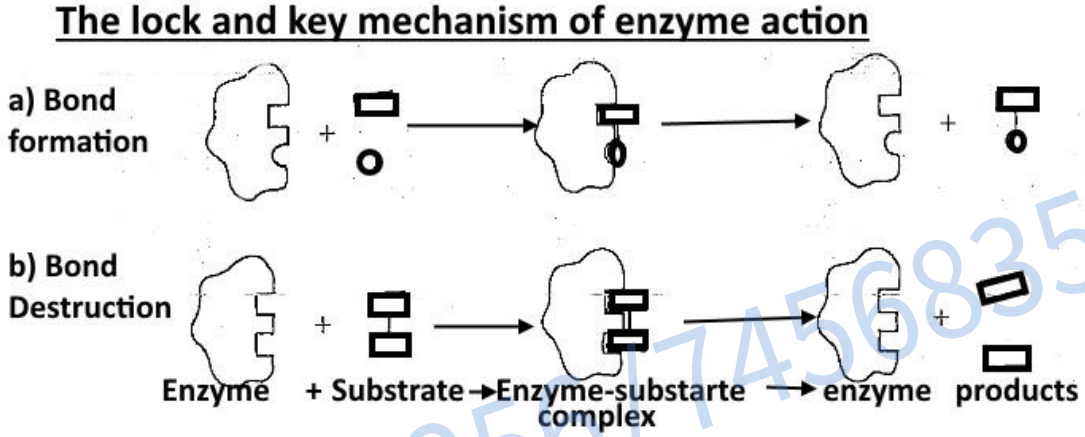
According to this hypothesis, enzymes have **active sites into** which specific substrate molecules fit exactly. The substrate molecule is the key whose shape is complementary to that of the enzyme active site

The enzyme is the lock where the substrate fits therefore both the enzyme and the substrate have the complementary structures.

The substrate molecules combine with an enzyme molecule to form a compound called **enzyme substrate complex**

When the substrate binds with the enzyme molecule, the substrate molecules become slightly distorted putting a strain on the bonds of the substrate molecules which results into breaking of these bonds and re-joining them using less energy.

The enzyme-substrate molecule forms an enzyme-end product complex which splits into the enzyme and the end products. The enzyme remains unchanged while the products are released from the active sites since they have a different shape from the substrate.



SUMMARY OF THE LOCK-AND-KEY HYPOTHESIS

The enzyme has a particular shape into which the substrate(s) fit exactly, like a lock and key. The substrate(s) is like a key whose shape is complementary to the enzyme or lock.

*The site where the substrate(s) bind in the enzyme is called the **active site,** and the shape of the active site is specific and complementary to that of the substrate(s).*

Hydrogen and ionic bonds hold the substrate in the active site to form an enzyme-substrate complex.

After formation of the enzyme-substrate complex, the enzyme changes the substrate either by splitting it apart or linking pieces together.

Once formed the products no longer fit into the active site, and escape into the surrounding medium, leaving the active site free to bind further substrate molecules.

However the lock-and-key hypothesis is not a totally satisfactory explanation of enzyme action, as it supposes that enzyme action depends on the quite unlikely event of randomly moving substrate molecules entering the active site in the right orientation.

The lock and key hypothesis is **important in that it explains the various properties of enzymes** in the following ways;

1. It explains the specificity of enzymes because it shows that only substrates with complementary shapes to the active sites can actually fit into the active sites to form products.
2. It explains how enzymes can be used over and over again. In other words, it shows that once the active site is set free at the end of the reaction, another substrate can combine with it to form an enzyme substrate complex.
3. It explains why to some extent the rate, of an enzyme controlled reaction is limited by increasing the substrate concentration. This is so because the reaction is inhibited when all the active sites of an enzyme have been bonded to.

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4. It explains why and **how enzymes can be inhibited this** is because inhibitors having a similar shape to that of the active site of the enzyme may occupy the active site before the substrate and prevent the substrate from occupying the active site hence inhibiting the reaction.
5. It further explains **how heating lowers the rate of a controlled** reaction. This is because heating denatures the enzyme their by changing its shape which prevents the substrate from fitting into the active site.
6. Also changes in PH break the bonds which maintain the three dimensional shape of the enzyme and as a result change the active site configuration. This makes the substrate fail to fit through the active site.
7. It explains why enzymes are protein in nature because the structure of proteins is based on a sequence of amino acids in their primary structures which sequence also exists in the active sites of enzymes thereby determining the properties of enzymes.
8. It explains how enzymes reduce the activation energy of a chemical reaction by showing that when a substrate binds to the enzyme, substrate molecule becomes slightly distorted which strains the bonds in it and as a result less energy is needed to break the bond.

INDUCED FIT HYPOTHESIS

This alternative hypothesis is proposed in line with more recent evidence that the lock and key are not actually static but are able to change their shapes during combination so that the two fit each other properly .In the presence of the substrate, the active site of an enzyme may change in order to suit the shape of the substrate.

The enzyme initially has a binding configuration which attracts the substrate on binding to the enzyme, the substrate disturbs the shape of the enzyme and causes it to assume a new configuration that is catalytically active and affect the shape of the enzyme, thus lowering its activation energy.

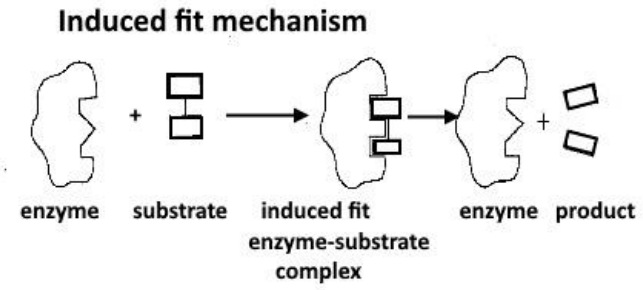
It is this new configuration which allows the substrate to suit properly in the active site and this enables the formation of an enzyme substrate complex in which the substrate molecules become slightly distorted. This strains the bonds in a substrate and as a result less energy is needed to break these bonds to form an enzyme product complex.

Summary of induced fit hypothesis

This is a modification of the lock-and-key hypothesis, which states that the active site is able to change its shape to enfold a substrate molecule.

The amino acids which make up the active site are moulded into a precise most effective catalytic shape after binding with the substrate.

The shape of the enzyme is distorted by the substrate, just as the shape of a glove is affected by the hand wearing it.



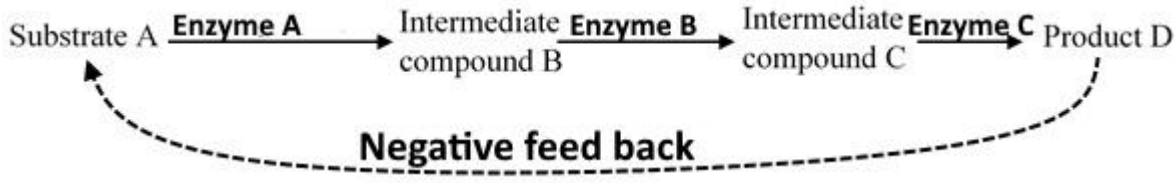
The distorted enzyme molecule in turn distorts the substrate molecule, straining or twisting the bonds, making the substrate less stable, reducing its potential energy, and lowering the activation energy of the reaction.

The reaction occurs and the formed products can no longer bind to the active site, and so move away. The flexible enzyme returns to its original shape, ready to bind the next substrate molecule.

THE CONTROL OF METABOLIC PATHWAYS

Commonly a number of enzymes are used in sequence to convert one substance into one or several products via a series of intermediate compounds. The chain of reactions involved in converting the substrates to their products through a series of intermediate compounds i.e. known as the **metabolic pathway**.

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Many such pathways can proceed simultaneously in a single cell. The reactions proceed in an integrated and controlled way and this can be attributed to the specific nature of enzymes.
A single enzyme will catalyse only a single reaction, therefore enzymes serve to control the chemical reactions that occur within the cells and ensure that these reactions proceed at an efficient rate. The cells also make use of the properties of enzymes to exercise control over metabolic pathways as illustrated in the example above. The high concentration of the end product of the pathway may inhibit the enzyme at the start of the pathway **this is called end product inhibition.**

In the example illustrated above, **end product B** acts as an inhibitor to **enzyme A.** If the level of **product D falls**, this inhibition is greatly reduced and so more of substrate **A** is converted to B, more of B is converted **to C,** and finally more **of C** is converted **to D.** If the level of end **product D** rises above normal, inhibition of **enzyme A** increases greatly and so the level **of D** is reduced. This is because **substrate A** will no longer be converted to intermediate **compound B.** In this way homeostatic **control of D** is achieved. The mechanism is termed as **negative feedback** because the information from the end of the pathway which is feedback to the start of the pathway has a negative effect i.e. a high concentration of **product D** reduces its own production rate.

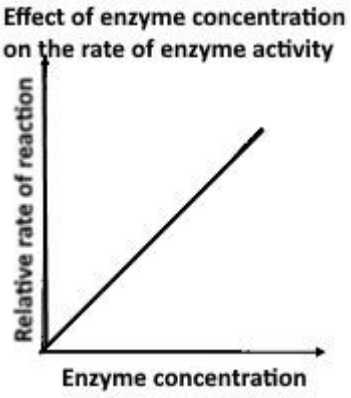
Control of the metabolic pathways has the following advantages;

- It allows energy to be derived in usable form from many small catabolic reactions than it would be in a single large reaction.
- It allows substrates to be partially broken down so as to provide raw materials for other reactions in the cell. Some of the intermediate compounds formed in the pathway have increased functions to perform within the cell.
- It allows the synthesis of complex organic compounds from simple raw materials using the genetic conditions prevailing in the cells which would not be synthesized in one step pathway.
- It increases the ability of the cell to control the products made in anabolic pathways when the reactions in them proceed in small steps.

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FACTORS WHICH AFFECT ENYME ACTIVITY /REACTION

1. **ENZYME CONCETRATION**



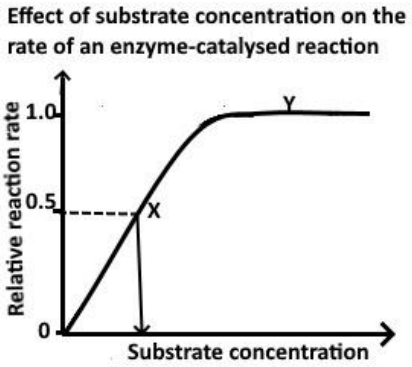
Provided that the substrate concentration is maintained at a high level and other conditions such as pH and temperature are maintained constant, the rate of a reaction increases with increase in enzyme concentration until when the rate remains constant. This is because the number of active sites increases which leads to increase in number of substrate molecules that fit into and occupy the active sites hence increase in the rate of product formation. Usually the enzyme concentration is much lower than the substrate concentration. Therefore as the enzyme concentration increases, the rate of substrate is either being exhausted in the reaction or greatly reduced thereby limiting the reaction

SUBSTRATE CONCENTRATION

The rate of enzyme controlled reaction increases with increase in the substrate concentration for a given quantity of an enzyme until such a concentration when all the active sites of an enzyme are saturated. At such concentration the rate of reaction becomes constant or levels. After leveling of the

rate of the enzyme-controlled reaction, the rate can only be increased by increasing enzyme concentration which would provide new active sites for the substrate.

The increase in substrate concentration increases the interaction between the enzyme molecules and the substrate molecules which increases the rate of collision between the enzyme and the substrate so as to form the products.



Point X: The rate of reaction increases with enzyme concentration because there are many free active sites into which more substrates fit increasing the rate of enzyme-substrate complex formation hence more products

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

TEMPERATURE

An increase in temperature affects the rate of enzyme controlled reaction in two ways

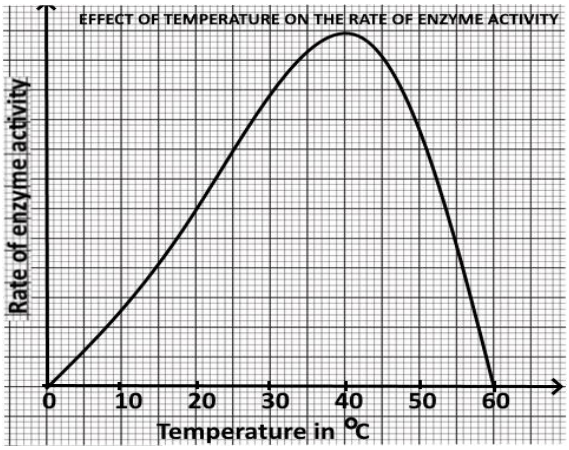
a) As the temperature increases, the kinetic energy of the substrate and enzymes increases and so they move faster. The faster these molecules move, the more often they collide with one another and the greater the rate of reaction. The temp that promotes maximum activity is known as optimum temperature.

b) Secondly as temperature increases more atoms which make up the enzyme molecules vibrate. These vibrations break the hydrogen bonds and other forces which hold the molecules in there precise shape hence changing enzyme active sites. The three dimensional shape of the enzyme molecules is therefore changed by these vibrations as the bonds, hydrogen bonds and hydrophobic interactions, which were holding it get broken to such an extent that the active site no longer allows the substrate to fit. Under these conditions the enzyme is said to be denatured by the increasing temperature and therefore loses its catalytic properties. Therefore increasing the temperature beyond the optimum temperature rapidly denatures enzymes and very low temperatures inactivate enzymes. At the optimum temperature enzymes attain there maximum activity thereby providing the maximum rate of the reaction. Inactivated enzymes are not denatured and therefore they can regain their catalytic properties when higher temperatures are provided.

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At 0^0C:

At 0^0C the rate of reaction is **0.0** arbitrary units, because there is no enzyme activity, as enzymes are **inactivated,** by freezing temperatures



From 10^0C to 30^0C:

At the low temperature of 10^0C the rate of reaction is low, because enzymes are nearly inactivated/low activation, by near-freezing temperatures below the optimum temperature.

Increase in temperature from 10^0C to 30^0C causes rapid increase in the rate of reaction, due to rapid increase in activity of enzymes, caused by rapid increase in kinetic energy of enzyme and substrate molecules, causing rapid increase in the number of molecular collisions between the enzyme and substrate molecules, causing rapid increase in the rate of formation of enzyme-substrate complexes, and thus rapid increase in catalysis.

From 30^0C to 40^0C:

As temperature increases from **30^0C to 40^0C** the rate of reaction increases rapidly, because high increase in temperature, causes rapid increase in activity of enzymes, caused by rapid increase in

kinetic energy of enzyme and substrate molecules, causing rapid increase in the number of molecular collisions between the enzyme and substrate molecules, causing rapid increase in the rate of formation of enzyme-substrate complexes, and thus rapid increase in rate of catalysis.

At 40^0C the rate of reaction attains a peak, because **40^0C** is the optimum temperature for enzyme activity.

From 45^0C to 55^0C:

As temperature increases from **45^0C to 55^0C the** rate of reaction decreases rapidly, as enzymes are rapidly denatured, due to heating beyond the optimum temperature, because the increased energy beyond optimum temperature causes the hydrogen and ionic bonds that maintain the enzymes' shape to break, altering the shape of the enzymes' active sites, so the substrates can no longer fit into the enzymes active sites, preventing formation of enzyme-substrate complexes, and enzyme activity is lost.

At 60^0C:

The rate of reaction is 0.0 arbitrary units, because there is no enzyme activity, as all enzymes are completely denatured, by excessive heating far beyond the optimum temperature.

As temperature is increased molecules have increased active energy, and reactions between them go faster. In chemical reactions, **for every 10^0C** rise in temperature the rate of the reaction approximately **doubles**. We can speak of the temperature **coefficient (Q_{10})** of a chemical reaction.

$$Q_{10} = \frac{\text{Rate of reaction at } (X+10^0C)}{\text{Rate of reaction at } X\ ^oC}$$

=2 (for most chemical reactions)

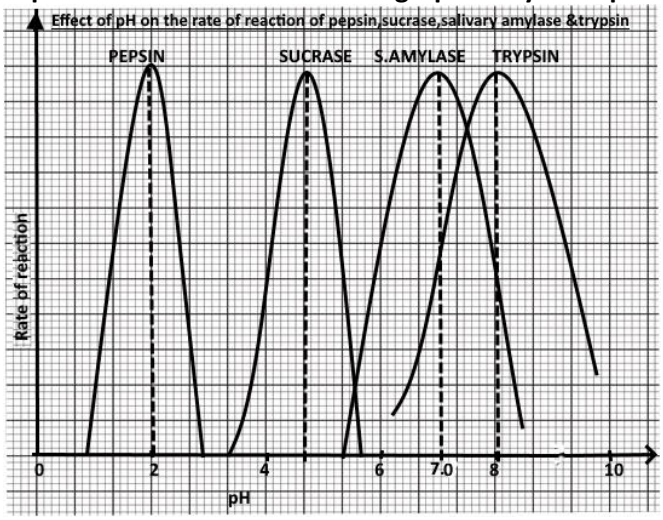
Note. The optimum temperature for an enzyme varies considerably. Many arctic and alpine plants have enzymes which function at a temperature 10^0C, whereas those in algae inhabiting some hot springs continue to function at temperatures around 80^0C. For many enzymes, the optimum temperature lies around 40^0C and denaturation occurs at about 60^0C.

PH

PH is the measure of the hydrogen ion concentration. Under conditions of constant temperature most enzymes are effective and efficient in only a narrow pH range. The optimum pH is that at which the rate of enzyme activity is greatest/ maximum rate of reaction can occur. As pH decreases, acidity and concentration of H^+ ions increases .This increases the positive charge in the medium.

Deviations from the optimum pH can cause bonds to be broken especially **hydrogen bonds and ionic bonds** which maintains the specific shape of the enzyme including its active site, so that the enzyme **becomes denatured.** The substrate no longer fits readily into the active site to form an enzyme-substrate complex, so the enzyme becomes less effective.

Explanation of the behaviour of graph away from pH 8 for trypsin.



At pH 8 the rate of reaction attains a peak, because pH 8 is the optimum pH for the enzyme's activity.

When the pH is changed below or above the optimum pH 8, the rate of enzyme activity decreases rapidly, due to rapid enzyme denaturation, because the hydrogen and ionic bonds which give enzymes their molecular shape are rapidly broken, rapidly altering the shape of the enzymes' active sites, so the substrates can no longer fit into the enzymes active sites, preventing formation of enzyme-substrate complexes, and enzyme activity is rapidly lost.

NB:

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Enzymes work best on specific pH ranges however most of them work best in neutral pH values. Consider the enzymes below and their corresponding pH values.

Enzyme	Optimum pH
1. Pepsin	1.6-2.0
2. Sucrase	4.5
3. Enterokinase	5.5
4. Salivary amylase	6.8-7.0
5. Catalase	7.0-7.6
6. Pancreatic lipase	9.0
7. Trypsin	7.8-8.7

ENZYME INHIBITORS

Inhibitors slow down or stop the rate of enzyme-catalysed reactions. There are two types of inhibition namely;

I. Competitive inhibition.

II.Non- competitive inhibition.

COMPETITIVE INBIBITORS

This is where inhibitors are structurally similar to the substrate molecules and as a result compete with the substrate for the active site on the enzyme molecules. The degree of inhibition depends on the relative concentration of a substrate and inhibitor. This inhibition is therefore always reversible i.e. the inhibition effect can be removed by increasing the concentration of the substrate.

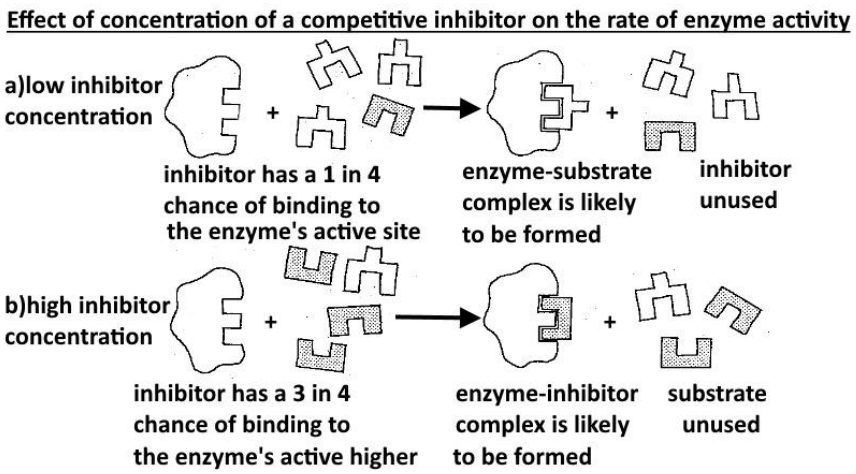
This inhibition occurs when the inhibitor is of a higher concentration than the substrate. This inhibition is therefore temporary and therefore does not cause permanent change to the enzyme

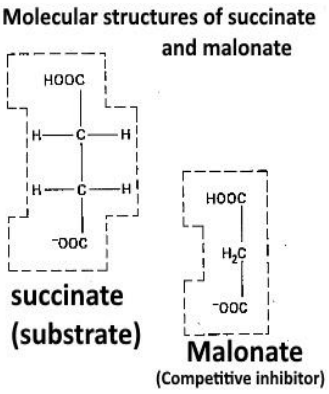
When both the substrate and inhibitor molecules are present, they compete for the active site of the enzyme thereby slowing down the rate of reaction.

For this reason, the degree of inhibition depends on the relative concentration of both the substrate and the inhibitor and if the concentration of the substrate is high there is no much problems and this offers a means of reducing the inhibitors.

If the concentration of the inhibitors is high, the reaction is slowed down, competitive inhibitors is not permanent and can be reversed.

An example is in the oxidation of succinic acid. The enzyme catalyzing this reaction is succinic dehydrogenase. However**, malonic acid** has a molecular configuration similar to that of succinic acid if it's added to the system; the rate of reaction is reduced. This is because malonic acid is so similar to succinic acid that it fits in the active site of the enzyme. Thereby competing with the normal substrate for the active site. When it is attached by the enzyme, it prevents the normal substrate from doing so. This is known as competitive inhibition.





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NON –COMPETITIVE INBIBITORS

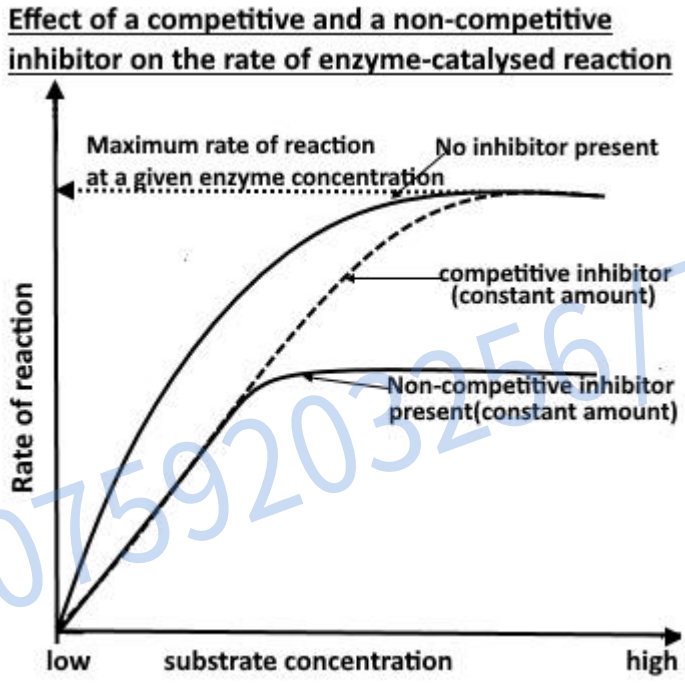
This is the type of inhibition in which inhibitor molecules attach themselves to a site other than the active site *of the enzyme,* called an **allosteric site,** altering the shape of the active site, preventing formation of enzyme-substrate complexes, so, do not compete with the substrate molecule for the active site.

Increase in the concentration of the substrate molecules does not affect the effect of the inhibitor molecules on the rate of reaction, and so the rate of reaction remains at a constant lower rate

The degree of inhibition depends on the concentration of the inhibitor alone and cannot be varied by changing the amount of the substrate. This inhibition may be reversible to some extent or irreversible in most cases it is irreversible, this is because it depends mainly on the concentration of the inhibitor alone because the substrate does not compete with the inhibitor. In this inhibition the enzyme active site is changed in such a way that it can no longer accommodate the substrate.

Examples of non-competitive inhibitors. **Cyanide**, arsenic neuro gases, and heavy metals like Zinc, mercury and silver, etc.

Non-competitive inhibitors can be divided into major categories i.e. non-competitive reversible inhibitor.



Competitive inhibitor molecules, with similar shape to the substrate molecules, and so fit into the active sites of the enzymes, preventing the substrate molecules forming enzyme-substrate complexes, by occupying the active sites of the enzymes.

Increase in the concentration of the **substrate molecules increases** the chances of the substrate molecules to bind with the active sites of the enzymes, reducing competition for the enzymes active sites by the molecules of competitive inhibitor, thereby increasing the rate of reaction.

*As the substrate molecules outcompete the inhibitor molecules, thus the rate of reaction is equal to that in absence of the inhibitor***.**

Non-competitive inhibitor molecules, which bind to a site other than the active site of the enzyme, called an allosteric site, altering the shape of the active site, preventing formation of enzyme-substrate complexes, so, *inhibitor does not compete with the substrate molecule for the active site.*

Increase in the concentration of the substrate molecules will not overcome inhibition and so the rate of reaction remains at a constant lower rate.

NON-COMPETITIVE REVERSIBLE INBIBITION

This type of inhibitor has no structural similarity to the substrate and combines with an enzyme at a point other than the active site. *Reversible inhibitors bind to an enzyme* ***with weak bonds*** *such as hydrogen bonds which are easily broken.* ***Reversible inhibitors*** *affect the enzyme only so long as they are attached to it. As soon as they are detached, the enzyme can function normally again.*

It does not affect the ability of the substrate to bind to the enzyme but it makes it impossible for catalysis to take place. The rate of reaction decreases with increasing inhibitor concentration and when the inhibitor saturation is reached, the rate of reaction will be almost nil.

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NON-COMPETITIVE IRREVERSIBLE INBIBITION

This is where once the inhibitor molecule has combined with the enzyme it leaves it permanently damaged and unable to carry out its catalytic function. They cannot be detached even if the enzyme were to break onto fragments. ***Irreversible inhibitors*** *attach to an enzyme with* ***strong covalent bonds which are difficult to break*** *without damaging the enzyme. Consequently the effect of an irreversible inhibitor is permanent.*

Example of inhibitors include **potassium cyanide** which attaches its self to the copper prosthetic groups of an enzyme called cytochrome oxidase thereby inhibiting respiration hence causing death. Others include heavy metal ions such as **mercury ions Hg, Pb and Ag** which cause disulphide bonds in proteins to break whereby denaturing all the proteins. Disulphide bonds maintain the shape of the enzyme molecule and once broken the structure of the enzyme molecules becomes irreversibly altered with a permanent loss of its catalytic property

Importance of enzyme inhibitors

- They provide important information about the shapes and properties of the active site of an enzyme.
- They can be used to block particular reactions thereby enabling bio-chemists to re-construct metabolic pathways
- They can be used in medicine and agriculture e.g. as drugs and pesticides respectively.
- Enzyme inhibition is also used to control the metabolic pathways by regulating the stages in them. E.g. end product inhibition and allosteric inhibition.
- Inhibition controls enzyme activity
- Balances stimulation of a process in organisms e.g. in muscle contraction, the impulse will be accompanied by one to prevent muscle contraction of its antagonistic one
- Regulates metabolism; e.g. in allosteric enzymes where enzymes exist in different shapes
- Helps in drug action in humans e.g. antibiotics and sulphonamides are competitive inhibitors
- Applied in respiratory poisons e.g. cyanides
- Works by inactivating the enzyme cytochrome oxidase during respiration

ALLOSTERIC ENZYMES

Allosteric enzymes are the ones which can change the shape of the active site due to the presence of a non-competitive inhibitor at a second site where the inhibitor binds known as allosteric sites.

An allosteric effect is the one where a chemical reaction involving one region of a protein molecule changes the shape and property of the second region of the protein molecule known as an active site.

One of the commonest ways of regulating metabolic pathways in the body cells is by means of allosteric enzymes .These are enzymes which are designed to change shape they are regulated by enzymes which act as non competitive inhibitors . These compounds bind to the enzyme at specific sites well away from the active site. They modify the enzyme activity by causing a reversible change in the structure of the enzymes active site.

The word allosteric means different shapes and its characteristics of such enzymes that exist in 2 forms i.e. and active form and an inactive form.

The inactive form of an enzyme is shaped in such a way that the substrate will not bind into the active site. For the enzyme to work it must be transformed into the active form and this means/involves changing its shape to that the substrate will fit into the active site.

NB:

Allosteric enzymes can be inhibited by certain molecules which combine with another part of the enzyme other than the active sites such inhibits prevents the enzyme form changing into the active form.

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ENZYME CO-FACTORS.

These are non protein substances required by enzymes for their efficient activity. Co-factors may vary from simple inorganic ions to complex organic molecules and may either remain unchanged at the end of the reaction or be regenerated by a later process

There are three types of co-factors

1. **Prosthetic group.**
2. **Co-enzymes**
3. **Activators.**

1. PROSTHETIC GROUP

This is a non-protein organic or inorganic substance which is essential for the efficient functioning of some enzymes and it bound to the enzyme.

The non-protein groups can permanently attached on to the enzyme. They function by transferring atoms from the active site of enzymes to other sites e.g. FAD (Flavine Adenine dinucleotide) this contains riboflavin(vitamin B_2) the function of which is to accept hydrogen .FAD is concerned with cell oxidation pathways and is part of the respiratory chain in respiration .

2. ACTIVATORS (INORGANIC IONS)

These are inorganic substances, usually metal ions e.g. zn^{2+},Cu^{2+},Mg^{2+} Cl^- etc., which are necessary for the functioning of certain enzymes.

These inorganic chemicals can mould the enzyme or substrate into a shape that an enzyme-substrate complex can be formed easily thereby increasing the chances of a chemical reaction e.g. the activity of **salivary amylase** is increased by the presence of **chloride ions.**

The enzyme **thrombokinas**e which converts prothrombin protein in blood plasma to thrombin during clotting is activated by **calcium ions (Ca^{2+}).**

3. CO-ENZYMES

These are non-protein organic substances which are essential for the efficient functioning of some enzymes but are not themselves bound to the enzyme during the reaction

All co-enzymes are derived from vitamins e.g. NAD is derived from nicotinic acid, a member of vitamin B complex, NADP, acetyl co-enzyme A.

NAD acts as a co enzyme to dehydrogenase by acting as a hydrogen acceptor. It can exist in both reduced and oxidized form

Control of enzyme activities

- Secretion in inactive form like pepsinogen which is only activated at the site of action
- Precursor activation where accumulation of a potential substrate causes particular reaction pathways to be opened up
- Enzymes are contained in membranes like lysosome being released only when there is work to be done
- Dynamic regulation like negative feedback where the end-products inhibit the initial reactions
- Through genetic control where the information stored in the nucleus is used to determine which enzymes are synthesised which in turn determines the limits of cell metabolism

INDUSTRIAL APPLICATIONS OF ENZYMES

- They are used in making biological detergents which are usually made using proteases produced in an extra-cellular form from bacteria
- They are used in baking industry in which fungal α-amylase enzymes which catalyses the breakdown of starch in the flour to be used.
- They are used in making baby foods which contain trypsin used to pre-digest the baby foods.
- They are used in the brewing industry which uses enzymes produced from cereals during beer production to produce simple sugars from starch which is used by the yeasts during fermentation to enhance alcohol production.

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- They are used in the dairy industry where an enzyme rennin derived from the stomach of young ruminant animals is used to manufacture cheese. In addition lactose breaks down lactose glucose and galactose.
- The rubber industry uses catalase enzyme to generate oxygen from peroxides so as to convert latex to form rubber.
- They are used in the paper industry which uses amylase to degrade starch to a lower viscosity product needed for sizing and coating paper.
- They are used in the photographic industry which uses protease to dissolve gelatin away from the scrop films thereby allowing the recovery of the silver present.

NUCLEIC ACIDS

These are nitrogen containing organic acids important for making the genetic material and proteins of all organisms.

Nucleic acids are made of short chains called **nucleotides**. Nucleic acids include

1. Deoxyribose Nucleic Acid (DNA) and

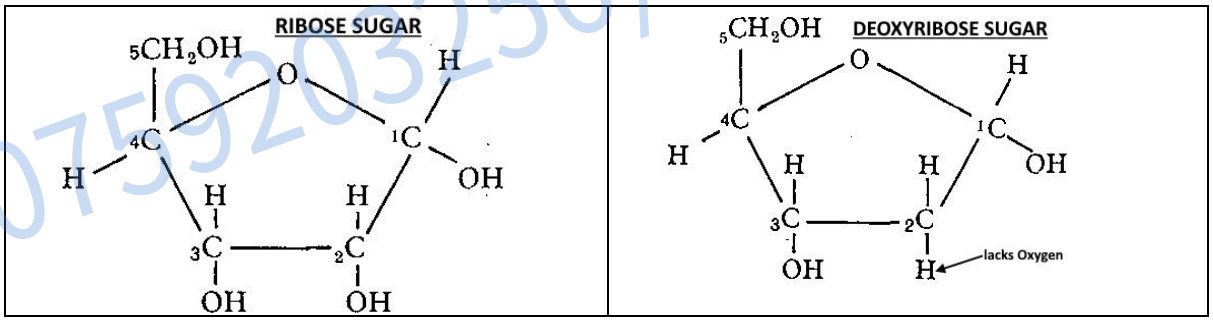
2. Ribonucleic acid (RNA).

THE STRUCTURE OF NUCLEOTIDES

A nucleotide is made up of 3 components namely, **pentose sugar,** a **nitrogenous** base and a **phosphate** derived from phosphoric acid i.e. all nucleotides contain phosphoric acid.

PENTOSE SUGAR

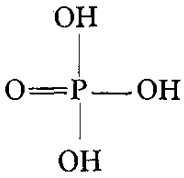
The pentose sugars in nucleic acids are **of 2 types** namely; **ribose sugar in** RNA and **deoxyribose** sugar in DNA. The only difference between these two sugars is that deoxyribose lacks an oxygen atom on the hydroxyl side group at position **two** is replaced by a hydrogen atom in the ring; hence the name deoxyribose; has one less oxygen atom than ribose.



PHOSPHORIC ACID

The second constituent of a nucleotide is phosphoric acid (H_3PO_4)

This acid gives the acidic character to nucleic acids and its structure is shown below;

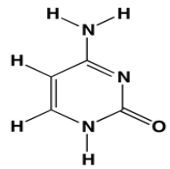
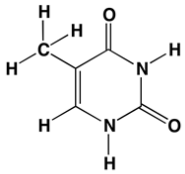
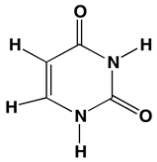


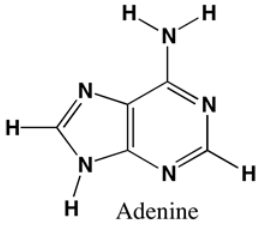
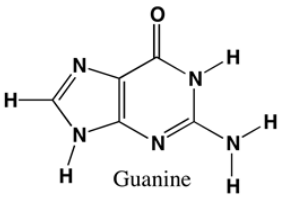
NITROGENOUS BASES

Each nucleic acid contains **four different** bases of which two are derived from **purines** and another two are derived from **pyrimidines.** The nitrogen in the rings gives the molecules their basic structure. **Purines** have two rings in their structure comprising of hexose sugar (6 carbon sugar) a pentose ring (6 carbon ring) while the **pyrimidines** have a single hexose ring in their structure i.e. purines are larger than pyrimidines.

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<table>
<tr><td rowspan="2">Pyrimidines

(Single ringed organic bases)</td><td>Cytosine (C)
 
Cytosine</td><td>Thymine (T)
 
Thymine</td><td>Uracil (U)
 
Uracil</td></tr>
<tr><td colspan="3">DNA contains C and T while RNA contains C and U</td></tr>
<tr><td rowspan="2">Purines

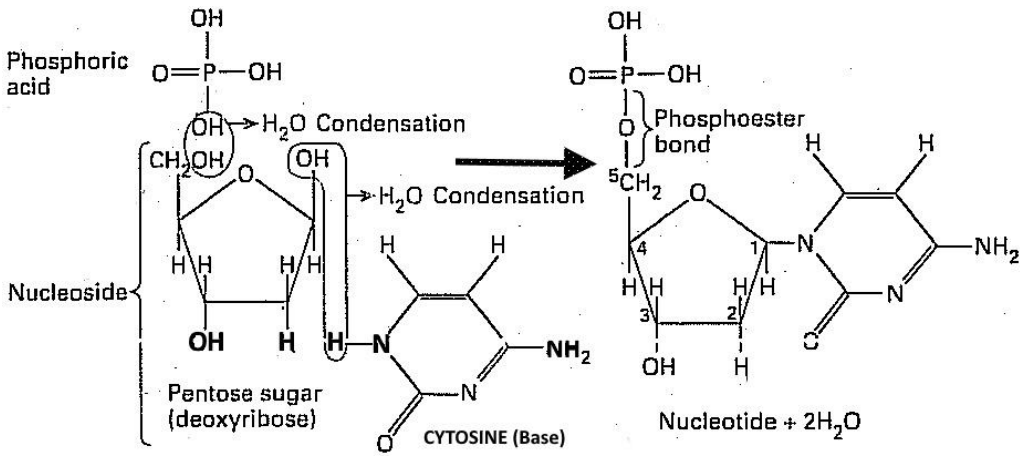
(Double ringed organic bases)</td><td colspan="2">Adenine (A)
 
Adenine</td><td>Guanine (G)
 
Guanine</td></tr>
<tr><td colspan="3">The purines A and G are found in both DNA and RNA</td></tr>
</table>

These determine the particular character of a nucleotide **cytosine and guanine** in DNA and uracil instead of thymine RNA. These bases are commonly represented by their **initial letters A, G, C, T and U.** On each base, there is a hydrogen projection which is very important in the building up of nucleotides.

STRUCTURE OF NUCLEOTIDE MOLECULE

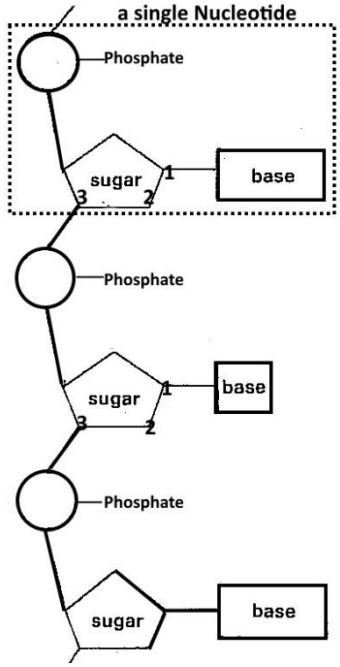
The **three components of nucleotides** are combined together by two condensation reactions to give a nucleotide

- Each nucleotide consists of **deoxyribose sugar** and **organic nitrogen**-containing base (of which there are four different types) and **phosphoric acid**
- The **sugar** and the **organic base** join together and attach on position/**carbon 1** by a **condensation reaction** to form a **nucleoside**. (a condensation reaction results in the removal of a water molecule)
- The second condensation reaction joins the **nucleoside with phosphoric acid** to form the **nucleotide**. This bond forms between carbon 5 of the sugar and the phosphate, and is called a **phosphoester bond. I.e.** Nucleotide forms when a nucleoside (pentose sugar + organic base) joins a phosphate by loss of second water molecule.



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Two nucleotides can join together by a condensation reactions between the phosphate group pf one nucleotide and the hydroxyl group on carbon 3 of the sugar of the other nucleotides to form a **di-nucleotide**. The bonds linking the nucleotides together are strong covalent phosphodiester bonds. Continued condensation reactions lead to formation of a **polynucleotide** chain. The chain has a sugar-phosphate backbone with the organic base projecting outwards.**as shown below;**



The **main function** of nucleotides is the formation of **nucleic acids,** RNA and DNA which play vital roles in protein synthesis and heredity. In addition, nucleotides form part of other metabolically important molecules; such molecules include Adenosine Tri Phosphate **(ATP**), Nicotinamide Adenine Dinucleotide **(NAD),** Flavine Adenine Dinucleotide **(FAD),** Nicotinamide Adenine Dinucleotide Phosphate (**NADP**) and **co-enzyme A.**

RNA (ribonucleic acid)

RNA is a single stranded polymer of nucleotides where the pentose sugar is always **ribose** and the organic bases are **adenine, cytosine,** guanine and **thyamine.** It is mainly found in the cytoplasm

There are many types of RNA found in cells, 3 of which are involved in protein synthesis. These include the following;

a) Ribosomal RNA (rRNA) (80%)
b) Transfer RNA (tRNA) (15%)
c) Messenger RNA (mRNA) (3-5%)

RIBOSOMAL RNA (rRNA)

This is a large complex molecule made up of both double and single helices.

Although it is manufactured by the DNA of the nucleus it is mainly ***found in cytoplasm*** where it makes up more than half of the mass of the ribosomes. It comprises of more than a half of the mass of the total RNA of the cell and its sequence is similar in all organisms.

Manufactured in **nucleolus**.

Function: rRNA is a site of protein synthesis in cells.

Ribosomes are the site of protein synthesis, at the ribosomes the mRNA code is translated into a sequence of amino acids in a growing polypeptide chain. This is possible because ribosomes are often found in clusters linked together by strands of mRNA. This cluster of ribosomes is known as *poly-ribosome* or ***polysome*** and this enables several molecules of the same polypeptide chain to be produced simultaneously.

TRANSFER RNA (tRNA)

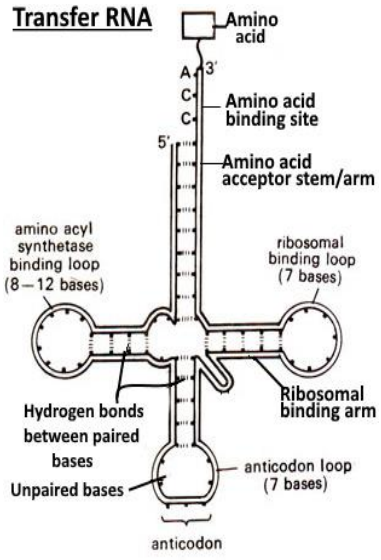
This is a small molecule with about **80 nucleotides** made up of a single strand. It comprises of 10 to 15% of the total RNA within the cell and all types of tRNA are fundamentally similar.

It forms a clover leaf shape with one end of a chain ending in a **cytosine-cytosine-adenine**(**C-C-A**) base sequence. It is at this base sequence that an amino acid attaches itself.

There are at least **20 types of tRNA** each one carrying a different amino acid.

At an intermediate point along the tRNA point is an important sequence of 3 bases called ***anticodon***. These bases line up alongside the appropriate **codon** on the mRNA during protein synthesis.

This implies that each amino acid has its own tRNA molecule which transfers it from the cytoplasm to the ribosome to join the



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polypeptide chain being made. Consequently tRNA acts as an intermediate molecule between the **codon of mRNA** and the amino acid sequence of the polypeptide chain on the ribosomes.

A codon is sequence of three organic bases which together form a unit of genetic code in a DNA or RNA molecule to specify an amino acid that joins a polypeptide

Adaptations of tRNA:

- Active sites (anticodon and amino acid binding site) are maximally separated to avoid interference
- Small size for mobility readily

MESSENGER RNA (mRNA)

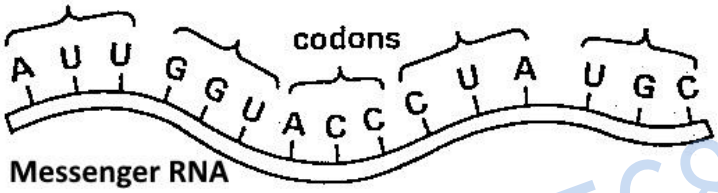
This is also a single stranded molecule containing triplets of bases known as **codons.**

It is formed from a single strand of DNA during protein synthesis by a process **known as *transcription.*** During transcription, the DNA genetic information for protein synthesis is copied from the DNA strand to form codons of mRNA. Thereafter, mRNA attaches itself on a group of many ribosomes thereby forming a structure called polysome which is the site of protein synthesis.

Function: mRNA carries coded information from DNA to ribosomes in the cytoplasm

Manufactured in the nucleus

Average size of eukaryotic mRNAs is 1500 to 2000 nucleotides



DEOXYRIBONUCLEIC ACID (DNA)

This is a double stranded molecule containing repeated combination of many nucleotides which is transmitted from generation to generation in organisms. It's mainly found in the nucleus and comprises of deoxyribose as the 5 carbon sugar of its nucleotides. Individual bases guanine pair with cytosine and adenine with thymine are joined by hydrogen bonds.

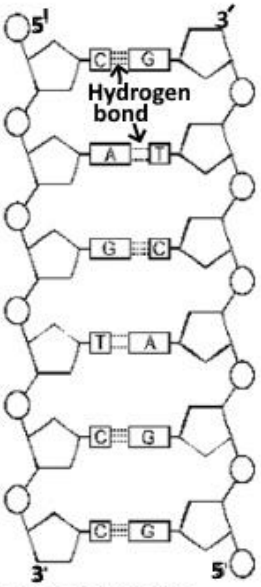
STRUCTURE OF DNA

According to **Watson and Click**, DNA consists of two strands each made up of very many nucleotides that repetitively combine to form very long polynucleotides. Each polynucleotide chain/strand forms a right handed helical spiral and consequently the two chains coil around each other to form a double helix.

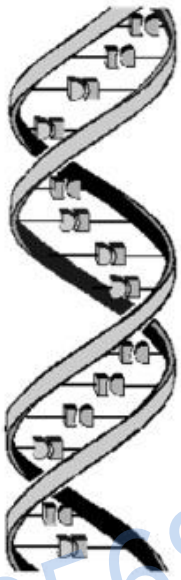
- The DNA molecule consists of two strands of polynucleotide chains.
- Each polynucleotide chain is a long unbranched polymer of DNA nucleotides.
- Each DNA nucleotide consists of the pentose sugar deoxyribose, phosphoric acid and a nitrogen-containing organic base.
- The organic bases present in DNA are either purines; guanine and adenine or pyrimidines; cytosine and thymine.
- Purines have a double ring structure, pyrimidines have a single ring structure.
- The amount of guanine is equal to that of cytosine and the amount of adenine is equal to that of thymine.
- The sugar and organic base join together by a condensation reaction to form a nucleoside.
- Another condensation reaction joins the nucleoside with phosphoric acid to form a nucleotide.
- The phosphoester bond forms between carbon 5 of the sugar and the phosphate.
- Each nucleotide forms a strong, covalent phosphodiester bond by a condensation reaction between the phosphate group of the nucleotide and the hydroxyl group on carbon 3 of the sugar of another nucleotide.
- The polynucleotide chain has a sugar –phosphate backbone with the organic bases projecting outwards.
- Each polynucleotide chain has two distinct ends a **3'** end with carbon **3** of the deoxyribose closes to the end and a **5'** end with the carbon 5 of the deoxyribose closest to the end.

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- The 2 polynucleotide chains are held together by hydrogen bonds between pairs of bases in the two chains.
- According to the complementary base –pairing rule, adenine pairs with thymine forming two hydrogen bonds, guanine pairs with cytosine, forming three hydrogen bonds.
- Hydrogen bonds are formed between the atoms of a base in one formed between the hydrogen atoms of a base in one chain and the oxygen and nitrogen atoms of a base in the other chain.
- The two polynucleotide chains are ant parallel, running in opposite directions where one chain runs from the 3 to the 5' end while the other runs from the 5' to the 3'end.
- The **polynucleotide chains** are twisted around each other to form a double helix, where one complete turn of the helix has ten base pairs.



DNA showing the complementary base pairing between anti-parallel strands


DNA showing the double Helix

Genetic significance of DNA

- It can bring about big variation especially in meiosis.
- It ensures consistency of species i.e. during DNA replication, more DNA is found which will divide into two to maintain the original DNA on the parents.
- It is another way in which all necessary hereditary material is passed onto the new offspring.

Suitability of DNA

The DNA polynucleotide chain to form the genetic triplet code which determines the characteristics of organism.

The nitrogen bases of nucleotides are paired according to the complementary base pairing rule, enabling formation of a complementary DNA copy during DNA replication, and a complementary MRNA copy during transcription. Guanine pairs with cytosine, and adenine pairs with thymine (or uracil of RNA)

DNA has negative charge distributed along its length and positively charged (basic) protein molecules called histones are thus able to bond with it allowing tight-packing of DNA in to nucleosomes, solenoids, chromatic fibres and chromatin enabling organization of hereditary information into chromosomes carried in the nucleus of the cell.

Roles of the three chemical groupings within the nucleotide monomers in the function of the DNA molecule.

- The **Deoxyribose sugar** and the **Phosphate groups** make up the structural framework/backbone which support the Organic bases that project sideways
- The organic bases carry genetic information, because the sequence of bases along the Deoxyribose-Phosphate framework controls which proteins a cell makes, and so determines the nature of each cell

Relationship between the Watson–Crick DNA structure and its function

The Watson –Crick structure of DNA is related to its function of **carrying hereditary information** in the following ways:

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- The DNA polynucleotide comprises numerous nucleotides joined together by **strong covalent sugar-phosphate/phosphodiester bonds**, forming a metabolically stable polymer, ensuring that information is transferred from one generation to the next **without alteration**.
- The two sugar-phosphate backbones are **antiparallel,** which enables **purine and pyrimidine** nitrogen bases to project towards each other for complimentary pairing.
- DNA comprises two strands of **very long polynucleotides chains**, whose extreme length allows DNA to carry a **large amount of information**.
- The double helix structure of DNA consists of two polynucleotide chains joined by pairs of bases held together by **weak hydrogen bonds,** which can be broken down to **unwind and unzip** the structure, to enable DNA replication, and transcription.
- The four nitrogen bases of DNA nucleotides are arranged in **variable sequence** along the DNA polynucleotide chain, to form the **genetic triplet code**, which determines the characteristics of organisms.
- The nitrogen bases of nucleotides are paired according to the **complementary base-pairing rule**, enabling formation of a complementary DNA copy during **DNA replication**, and a complementary mRNA copy during **transcription**.
- Guanine pairs with cytosine and adenine pairs with thymine (or uracil of RNA).
- DNA has **negative charges** distributed along its length, thus **positively charged** (basic) protein molecules called **histones** are able to bond with it, allowing tight packing of DNA into nucleosomes, solenoids, chromatin fibres and chromatin, enabling organization of hereditary information into **compact structures**, called chromosomes, carried in the nucleus of the cell.
- The two sugar-phosphate backbones form a double helix with the nitrogen bases and hydrogen bonds inside, to protect the nitrogen bases and hydrogen bonds.
- Double helical structure enhances compactness to fit in the nucleus.
- Double stranded for replication to occur rapidly and semi-conservatively, as each strand functions as a template.
- The numerous hydrogen bonds increase stability of the DNA molecule.

Differences between DNA and RNA

DNA	**RNA**
Double polynucleotide chain	Single polynucleotide chain
Larger molecule / larger molecular mass	Smaller molecule / smaller molecular mass
Double helix	Single or double helix
Pentose sugar is deoxyribose	Pentose sugar is ribose
Organic bases present are adenine, guanine, cytosine and thymine	Organic bases present adenine, guanine, cytosine and uracil
Ratio of Adenine and Thymine to Cytosine and Guanine is one	Ratio of Adenine and Uracil to Cytosine and Guanine varies
Found almost entirely in the nucleus	Manufactured in the nucleus but found throughout the cell
Chemically very stable	Chemically less stable
Only one basic form	Three basic forms : mRNA, tRNA and rRNA
Amount is constant for all cells of a species	Amount varies from cell to cell.

Similarities Both:

- **Are polymers of nucleotides**
- **Carry genetic information**
- **Have same purine bases adenine and guanine plus pyrimidine bases cytosine**
- **Originate from the nucleus**
- **Occur in the cytoplasm**

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THE ROLE OF DNA IN PROTEIN SYTHESIS

Deoxyribose nucleic acid (DNA) controls the process of formation of messenger Ribose nucleic acid (mRNA) called transcription, and mRNA carries the coded information to the sites of formation of polypeptide in process called translation.

During transcription a specific region of the DNA molecule called the cistron unwinds under catalysis of the enzyme DNA helicase, by influencing breathing of the hydrogen bonds between complementary base pairs causing the DNA helix to unwind and unzip, exposing the nucleotide bases along the strands of DNA molecule.

Only one strand of the DNA molecule acts as a template, and complementary free RNA nucleotides are attracted to the exposed DNA nucleotide bases, according to the base paring rule , where guanine pairs with cytosine, and adenine pairs with thymine(or uracil on RNA), and hydrogen bonding occurs between the complementary base pairs.

The enzyme RNA polymerase catalyses formation of the mRNA molecule by influencing linkage of the RNA nucleotides together to form the mRNA molecule.

DNA re-forms behind the mRNA molecule.

Only about 12 base pairs of the DNA molecule unzip and unwind at any one time.

The length of the DNA cistron determines the length of mRNA/the number of mRNA codons which determines the number of amino acids to be used in assembling a specific polypeptide and thus determines the length of the polypeptide chain for which the DNA codes.

During translation a specific sequence of amino acids is linked together in accordance with the codons on mRNA, and this sequence is determined by the DNA triplet code system and thus determines the type of polypeptide formed.

During translation a group of ribosomes attach to mRNA to form a polysome.

According to the base paring rule a complementary anticodon of a tRNA- amino acid complex, formed during amino acid activation under catalysis of the enzyme aminoacyl- tRNA synthetase, is attracted to the first codon is usually AUG which codes for the first amino acid methionine, and acts as a start signal for formation of a polypeptide. The second codon attracts its complementary anticodon, and the ribosome acts as a framework to hold the mRNA the tRNA-amino acid complexes, and the associated enzymes controlling the process until the two adjacent amino acids are linked together by a peptide bond to form a dipeptide.

Once linked, the ribosome moves one codon along the mRNA molecule to hold the next codon-anticodon complex together, until the third amino acid is linked to the dipeptide.

The tRNA molecule which was previously attached to the polypeptide chain now leaves the ribosome and passes back to the cytoplasm to be reconverted in to a new tRNA-amino acid complex/aminoacyl-tRNA molecule.

This sequence of the ribosome reading and translating the mRNA code continues until it comes to a terminating/nonsense codon, such as UAA, UAG and UGA signalling stop is reached and the polypeptide chain formed is terminated.

The polypeptide chain formed leaves the ribosome with its primary structure having been determined by the DNA and translation is complete.

Other ribosomes may follow immediately behind the first ribosome, along the mRNA molecule, such that many identical polypeptide chains are formed at the same time.

Thus the nonsense codons of mRNA formed during transcription of DNA terminate the formation of a polypeptide thereby determining the length of polypeptide chain.

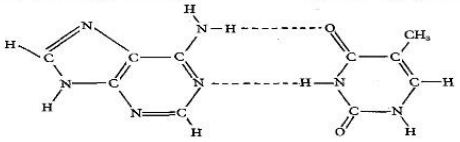
NOTE: The width between the two strands is constant and equal to the width of the base pair i.e. the width is equal to the purine plus the pyrimidine. Two purines would be too large and two pyrimidines would be too small to span the gap between the two chains of DNA. Therefore, adenine must combine with thymine while guanine must combine with cytosine.

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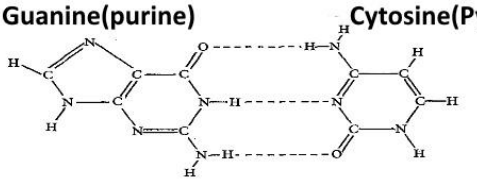
The sequence of bases in one chain of DNA determines that in the other and consequently the two DNA chains are said to be complementary. Each of the polynucleotide chains in DNA is extremely long and may contain many million nucleotide units.

The amount of guanine is equal to the amount of cytosine in DNA and similarly, the amount of adenine is equal to that of thymine e.g. if a DNA molecule contains 40% of its bases as adenine and thymine, how many bases will be guanine in a DNA molecule?

Adenine(purine) **Thymine(pyrimidine)**



Guanine(purine) **Cytosine(Pyrimidine)**



A and T=40%
G and C=100-40 = 60%
Since the amount of C = the amount of G.
Then the number of guanine bases=60/2=30%

DNA REPLICATION

DNA replication is the formation of daughter DNA molecules from the parent DNA molecule within the nucleus of the cell.

This enables the transmission of the same genetic information from cell to cell and generation to generation. Replication is controlled by an **enzyme DNA polymerase** which links the DNA nucleotides to form long strands of DNA and **helicase enzyme** which causes the unwinding (opening up) of the DNA double strands

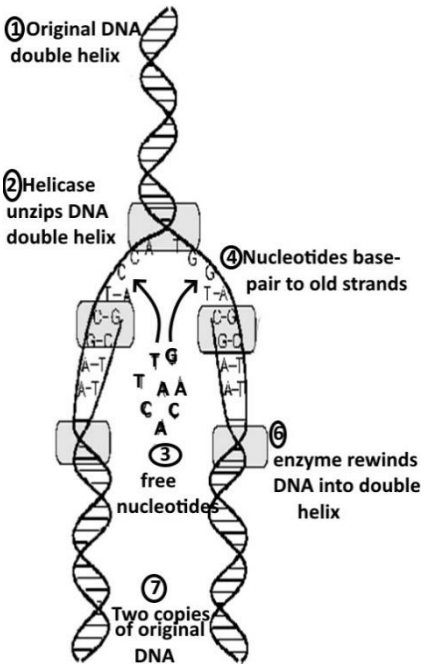
The parent DNA molecule unwinds and unzips, due to breakdown of the weak hydrogen bonds under catalysis of **DNA helicase enzyme** and using energy form hydrolysis of ATP to ADP.

Once separated, the DNA strands are kept apart by DNA binding proteins.

Free nucleotides are attracted to their complementary base-pairing rule where adenine pairs with thymine and guanine pairs with cytosine forming hydrogen bonds.

The **enzyme DNA polymerase** catalyses the polymerization of nucleotides to form a polynucleotide chain in the 5' to 3' direction because **DNA polymerase** moves in the same direction as **DNA helicase** allowing continuous replication of one strand.

Because DNA polymerase has to move away from DNA helicase in the 5' to 3' direction small gaps are left in the other strand because DNA polymerase cannot join the 3' end of one newly synthesized piece of DNA to the 5' end of the next, the gaps in the short portions of the other DNA strand are closed under catalysis of **DNA ligase enzyme** in a process called **discontinuous replication.**



The action of DNA ligase brings about three types of replication as it tries to complete the work of DNA replication. **These types are**

1. **Conservative**
2. **Semi-conservative**
3. **Dispersive replication**

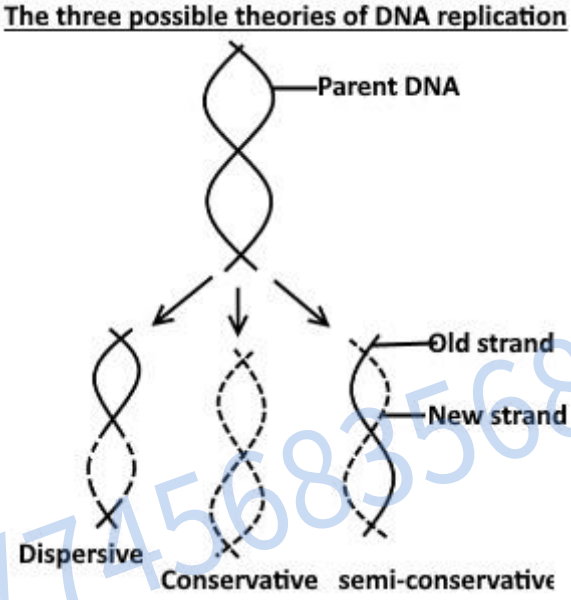
In semi-conservative replication, the parent DNA molecule unwinds and unzips, due to breakdown of the weak hydrogen bonds under catalysis of DNA helicase enzyme and using energy form hydrolysis of ATP to ADP.

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Once separated, the DNA strands are kept apart by DNA binding proteins.
Free nucleotides are attracted to their complementary base-pairing rule where adenine pairs with thymine and guanine pairs with cytosine forming hydrogen bonds.
The enzyme DNA polymerase catalyses the polymerization of nucleotides to form a polynucleotide chain in the 5' to 3' direction because DNA polymerase moves in the same direction as DNA helicase allowing continuous replication of one strand. The new DNA molecule is composed of one old strand and one new strand.

Evidence for the semi-conservative nature of DNA replication

Meselsohn and Stahl grew many generations of ***Escherichia coli*** in cultures containing **^{15}N/heavy** nitrogen to ensure that their DNA **contained ^{15}N.**
They were then transferred to a culture medium containing only **^{14}N/light nitrogen.**
The next two generations of ***Escherichia coli*** each had their DNA separated by centrifugation and the presence of light and heavy nitrogen in the DNA was detected by its absorption of ultraviolet light.
The results showed the first generation of bacteria to have DNA containing equal proportions of ^{14}N **and ^{15}N.**
In the second generation half the bacteria had DNA containing all **^{14}N,** the remainder having DNA with equal portions of ^{14}N and ^{15}N.



In **conservative replication** the DNA strand unzips using helicase enzyme and forms two new DNA strands which zip together to become a DNA double helix made of new strands only. The old strands also zip together again after replication so that they form another new DNA molecule made of old strands only.
In **dispersive replication**, two new strands are formed each containing alternating old and new bases of nucleotides;

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PROTEIN SYNTHESIS

This is the process by which the coded information is transferred from the chromosomes in the nucleus to the ribosomes in the cytoplasm to make the proteins.

The only molecules capable of being synthesised directly from the hereditary material of the cell are the proteins. The instructions for the manufacture of these proteins are located in DNA which is located in the nucleus but the actual synthesis occurs in the cytoplasm and involves ribosomes.
There are four stages of proteins formation

1. Amino acid synthesis.
2. Transcription (formation of MRNA from the unpaired DNA)
3. Activation of Amino acids.
4. Translation (formation of a polypeptide chain)

AMINO ACID SYNTHESIS

In plants, amino acids formation occurs in the mitochondria and chloroplasts in a series of stages which include:
Absorption of nitrates from the soil.
Reduction of nitrates to amino groups (NO_3 to - NH_2)
Combination of the amino group with a carbohydrate skeleton
Transfer of the amino group from one carbohydrate skeleton to another (transamination). The 20 different kinds of amino acids are formed this way.

Animals obtain their amino acids from their diet although some have the ability to synthesise their own non-essential amino acids.

TRANSCRIPTION

Transcription is the process by which a single stranded complementary mRNA copy is made of the base sequence of a specific region / cistron of the DNA molecule which codes for a polypeptide. **Or** ***This is a process by with the base sequence of DNA strand section representing a gene is converted into a complementary base sequence of mRNA.***

It is the method by which the information in a section of the DNA is copied into a smaller mRNA molecule.

The mRNA is got from a short region or section of DNA molecule and this region is called **a cistron**.

The **histone coat** protecting the DNA double helix is stripped away, exposing the polynucleotide sequence of the DNA molecule.

The DNA double helix unwinds by breakage of the relatively weak hydrogen bonds thereby exposing the single strands of DNA. This is under the influence of an enzyme called **DNA helicase.**

Only one of these strands can be selected as a template for the formation of complementary single strand of mRNA. Each base on this strand attracts its complementary RNA nucleotide according to the rules of base pairing however in RNA, Uracil replaces Thymine and so, Cytosine (C) pairs with Guanine and Adenine pairs with Uracil. RNA polymerase enzyme moves along the DNA cistron adding complementary RNA nucleotides at a time to the unwound portion of DNA by condensation (dehydration reaction)

The nucleotides are activated by energy derived from hydrolysis of ATP. At the end of transcription when several molecules of RNA have been made, **RNA polymerase** recognises the stop codon and becomes detached from the gene region.

ACTIVATION OF AMINO ACIDS

This is a process by which amino acids combine with tRNA using energy form hydrolysis of ATP. This is catalysed by **aminoacyl tRNA synthetase** enzyme.

Each type of tRNA binds with a specific amino acid which means there are at least 20 types of tRNA molecules. Each type differs among other things in the composition of a triplet of bases called **anti codon.**

All transfer RNA have in common a free end which terminates in the triplet **CCA**, where individual amino acids get attached.

TRANSLATION

This is the process by which the triplet base (codon) sequences on mRNA are converted into a sequence of amino acids in a polypeptide.

This occurs on the ribosomes in the cytoplasm. Each ribosome is composed of a small and a large subunit. mRNA forms a reversible attachment to the surface of the small sub unit in the presence of Magnesium ions.

Having become attached to the ribosome, two messenger RNA codons are exposed to the larger sub unit of the ribosome. The first codon attracts the first tRNA molecule, having a complementary anticodon and which is carrying the first amino acid of the polypeptide being synthesised. The second codon then attracts a tRNA amino acid complex having a complementary anticodon (i.e. in the cytoplasm, the tRNA molecules which bear a triplet of bases each correspond to a particular amino acid).

Once a new amino acid has been added to the growing polypeptide chain, the ribosome moves along the mRNA to enclose other codons.

The tRNA molecule that was previously first attached to the polypeptide chain now leaves the ribosome and passes back to the cytoplasm to be reconverted into a new aminoacyl transfer RNA complex. This sequence of the ribosome reading and translating the mRNA codons continues until it comes to a codon signalling stop.

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The terminating codons are UAG, UGA and UAA. At this point, the polypeptide chain now with its primary structure, determined by the DNA, leaves the ribosome and translation is complete.
The polypeptide so formed must be assembled into proteins either by folding, spirals to give a secondary structure and tertiary structure. It can combine with other polypeptides to give a quaternary structure.

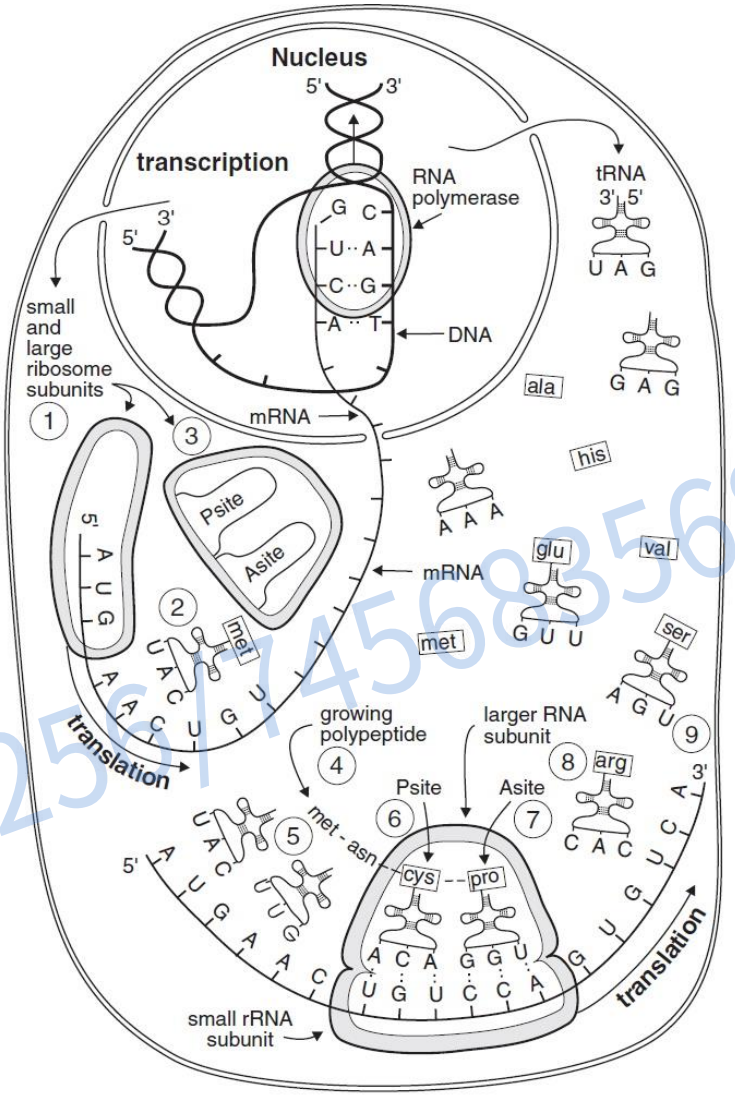
N.B

Several ribosomes may become attached to a molecule of mRNA like beads on a string and the whole structure is called a polysome

The advantage of such a complex is that it allows several identical polypeptides to be synthesised simultaneously. Peptide bonds form between adjacent amino acids and the polypeptide chain grows longer by addition of an amino acid at a time. The ribosome is a framework which holds the mRNA and the **aminoacyl transfer RNA** complex together until a peptide bond forms between adjacent amino acids.

The main steps involved in **translation** may be summarized as

1**) Binding of mRNA to ribosome,**
2) Amino acid activation and attachment to tRNA,
3) Polypeptide chain initiation,
4) Chain elongation,
5) Chain termination,
6) Fate of mRNA



The following is the evidence to show that DNA is a genetic material

- The chromosomes which play a role in cell division are made of DNA and histone proteins only. This implies that when a cell divides DNA is carried to the daughter cells formed.
- DNA is constant in amount in all cells within the species except in gametes where it is a half.
- It undergoes mutations which are inherited and without which it remains very stable so that the code instructions it contains remains unchanged from generation to generation.
- DNA controls the activities of a cell by directing the synthesis of proteins. This is shown by the various transduction experiments in which the Bacteriophage (virus that attacks bacteria) transfers DNA to a bacterium called Escherichia coli (E. Coli). The virus DNA instructs E. coli to make many new bacteriophage viruses.

NOTE: The function of the ribosome in protein synthesis is to hold in position the mRNA, t RNA-amino acid complex and the asserted enzymes controlling the process until a peptide bond forms between adjacent amino acids.

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Similarities between DNA replication and transcription

Both:

- Involve unwinding the helix
- Involve separating the two strands
- Involve breaking hydrogen bonds between bases
- involve complementary base pairing
- Involve C pairing with G
- Work in a 5` to 3` direction
- Involve linking/ polymerization of nucleotides
- dna or rna polymerase require a start signal

Differences between DNA replication and transcription

DNA replication	Transcription
Involves DNA nucleotides, where the pentose sugar is deoxyribose, and the base adenine pairs with thymine	Involves RNA nucleotides where the pentose sugar is ribose, and the base adenine pairs with uracil
Both strands are copied	Only one strand copied not both
Ligase enzyme / no Okazaki fragments are involved	No ligase enzyme / no Okazaki fragments
Has multiple starting points	Has only one starting point
Replication gives two DNA molecules	Transcription gives mRNA

Compare DNA transcription with translation

Both: **(1)** Occur in 5' to 3' direction **(2)** Require ATP

Differences

(i) DNA is transcribed while mRNA is translated

(ii) Transcription produces mRNA while translation produces polypeptides/ protein

(iii) RNA polymerase for transcription while ribosomes for translation/ ribosomes in translation only

(iv) Transcription occurs in the nucleus (of eukaryotes) while translation occurs in the cytoplasm/ at ER

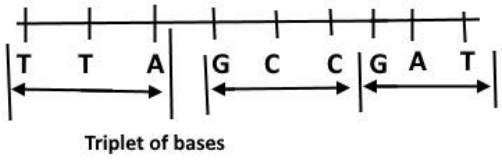
(v) tRNA is needed for translation but not transcription

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THE GENETIC CODE

The genetic code is the sequence of bases in DNA which codes for the sequence of amino acids in protein molecules. DNA provides the code (Genetic message) for the formation of proteins in an organism which may in turn determine the characteristics of that organism.

Every species possesses different DNA and therefore produces different enzymes. The DNA of the different species therefore differs not in the chemicals which it comprises but in the sequence of base pairs along its length. This sequence of triplet base pairs in DNA and mRNA is the code that determines which proteins are manufactured.



Triplet of bases

A code is comprised of three organic bases and are usually known as a triplet code e.g. ACC, CAC, CAA. This means that three bases code for one amino acid.

This triplet code is also called **a degenerate code** since there is more than one triplet for most amino acids i.e. it is a degenerate code because a given amino acid may be coded for by more than one code

The genetic code also leads to the formation of 3 codons namely, **UAA, UAG and UGA** which are called **nonsense codons.** These nonsense codons stop the process of protein synthesis by not coding for a specific amino acid at all.

The genetic code is also described a**s universal** because the same triplets of bases code for the same amino acid in all organisms. In other words all codons are precisely the same for all organisms.
In addition, the genetic code is non-over lapping e.g. each triplet of bases is read separately
UACACCAUGGGC is read as UAC-ACC-AUG-GGC.
NOTE

- Four letters in MRNA can form 64 different codons.
- The order of the triplet codons on the messenger RNA codes dictates the order in which amino acids will be put together to form a protein.
- Each MRNA triplet codon always codes with the same amino acid. This is why DNA determines the make up of structural proteins, enzymes and hormones. Therefore, it controls the whole organism

CHARACTERISTICS FOR GENETIC CODE

- It is universal.
- It is triplet.
- It is non overlapping
- It is degenerative.
- It is punctuated

DETERMINING THE FIXING OF ONE AMINO ACID IN A POLYPEPTIDE
There are 20 amino acids which regularly occur in proteins and each of these must have its own code of bases on DNA i.e. the base pairs arrange themselves in form of triplets. This code is triplet because with only four different bases (A, G, C and T) present in the DNA, if each of them was coded for one amino acid, only four different amino acids could be coded for during protein synthesis which would be insufficient for protein formation. Using a pair of bases to specify an amino acid that should be picked by tRNA during protein synthesis gives 16 different codes that are possible for this picking. Therefore, a triplet code of bases has to be used to specify one amino acid that can be picked by tRNA during protein synthesis as this will produce 64 possible codes more than enough to specify the requirement of the 20 amino acids.

JACOB MONOD HYPOTHESIS
On any given DNA molecule are structural genes determining the amino acids sequence of the protein. They bring about synthesis on an enzyme. There is also the operator gene located close to the structural gene and causes it to promote the synthesis of enzymes. A regulator gene is situated further along the DNA chain or strand. This gene causes the synthesis of a repressor gene which inhibits the operator gene thereby preventing the structural gene from bringing about the synthesis of the enzymes. When the enzyme require, the repressor substance is inhibited, the operator gene becomes functional. The structural gene is activated and the enzyme is produced.
OTHER IMPORTANT BIOLGICAL MOLECULES CONTAINING NUCLEOTIDES

Molecule	Abbreve	Function
Deoxyribonucleic acid	DNA	Protein synthesis function to form MRNA contains the genetic information of cells.
Ribonucleic acid	RNA	Coenzymes important in making energy available to cells.
Adenosine monophosphate	AMP	For metabolic activities.
Flavine adenine dinucleotide	FAD	Electron (hydrogen) carrier important in respiration in transferring hydrogen atoms from Krebs cycle along the respiration.
CO-enzyme A		Coenzyme important in respiration in combining with pyruvate to from acetyl co enzyme A and transferring the acetyl group into the Krebs cycle.

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Nicotinamide adenine dinucleotide phosphate.	NADP	Electron (hydrogen) carrier important in respiration in combining with pyruvate to from acetyl coenzyme A and transferring the acetyl group into the Krebs cycle.
Nicotinamide adenine dinucleotide phosphate	NADP	Electron (hydrogen) carrier important in photosynthesis for accepting electrons from the chlorophyll molecule and making them available for photolysis of water.

REASONS FOR BELIEVING THAT THE HEREDITARY MATERIAL IS IN DNA

VIRAL REPRODUCTION

It gives evidence that DNA exerts potential influence over the biochemical processes taking place in cells. During their reproduction the virus injects its DNA into the host cell which DNA replicates rapidly and controls the complete formation of more viruses thus shows that viral DNA contains all the necessary instructions for directing the synthesis

BACTERIAL TRANSDUCTIONS

Transduction is the transfer of genetic material from one bacteria to another through the agency of a bacteriophage.

When a virus reproduces inside a bacterial cell, some process of bacterial DNA may get enclosed in the new viruses and when these viruses infect other bacteria and initial bacterial DNA is donated to the new host. This DNA becomes incorporated into the host chromosomes conferring new characteristics to the new host. This clearly shows that DNA is carrying the genetic materials.

PROTEIN SYNTHESIS

From these studies, DNA affects the development of an organism by controlling the synthesis of specific enzymes hormones. Scientists believe further that a gene is specifically required to synthesise on protein or part of it or an enzyme.

CYTOPLASMIC INHERITANCE

Organelles like the mitochondria and the chloroplasts are among those that have their DNA and it is observed that they can exhibit self replication.

CANCER

Cancers may be a result of certain cells harbouring genetic material which is possibly derived from viruses. These segments of DNA are found to exist in all cancer cells are referred to as meogen and it those stands which determine cancer development and if they are extracted and introduced into other cells it transforms the cells into cancer cells.

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TOPIC 3: CELL PHYSIOLOGY

SUB-TOPIC 1: MOVEMENT IN AND OUT OF CELLS

There are various organelles and structures with in a cell which require a variety of substances in order to carry out their functions. 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:

1. **Simple diffusion**
2. **Facilitated diffusion**
3. **Osmosis**
4. **Active transport**
5. **Endocytosis**
6. **Phagocytosis**
7. **Pinocytosis**
8. **Receptor mediated endocytosis**
9. **Exocytosis**

The transport of substances is important to;
Supply cells with oxygen for respiration and raw materials for anabolism (synthesis of biological molecules)
Regulate the pH and solute concentration for maintaining a stable internal environment for enzymes to function optimally
Excrete toxic waste substances
Secrete useful substances for cell activities
The transport of substances across the cell membrane takes place by two major fundamental processes i.e. diffusion and active transport

DIFFUSION

This is the net random movement of molecules or ions from a region where they are comparatively high concentration to a region where they are at lower concentration. ***Or is the net movement of molecules or ions from a region of their high concentration to a region of their lower concentration.***
Diffusion of molecules or ions takes place due to their random movement from a region where they are more concentrated to a region of their low concentration using their free kinetic energy until an **equilibrium** is reached where by these ions and molecules are uniformly distributed and the free **energy gradient becomes zero.** Molecules and ions of different substances tend to diffuse at different rates due to various factors which are explained below. Diffusion occurs in living and non-living systems wherever there is a concentration gradient.
Adaptation for diffusion: to maximize the rate of diffusion

- **Maintaining a steep concentration gradient**
- **Having a high surface area to volume ratio**
- **Being thin, minimizing the distance over which the diffusion takes place.**

FACTORS AFFECTING THE RATE OF DIFFUSION

a) Concentration gradient.
This refers to the difference in concentration of molecules or ions of a substance between two regions of that same substance. The greater the concentration difference the higher the rate of diffusion and vice- versa. As molecules or ions of a substance tend to move from a high concentration to a region of low, the concentration gradient goes on decreasing until it becomes to zero.
While at zero there is net movement of molecules or ions from one region to another hence the process of diffusion ceases because of that equilibrium.

b) The surface area which diffusion occurs
The **large surface area over** which the molecules are exposed, the faster the rate of diffusion and vice – versa. Diffusion surfaces are modified in different ways e.g. by flattening , folding , branching in order to provide a larger surface area over which diffusion of molecules or ions takes place at a high rate e.g. highly folded alveoli of the lungs a flattened body of tape worm etc.

c) 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 shorter the distance between two regions of diffusion molecules or ions the higher the rate of diffusion and the greater the distance the lower the rate of diffusion. the rate of diffusion is inversely proportional to the square root of the distance moved by the diffusing molecules or ions .In case of membrane or wall across which diffusion takes place , the thinner the wall or the membrane the higher the rate of diffusion and vice – versa.
The rate of diffusion in a given **direction across the exchange surface:**

- Is directly proportional to the area of the surface
- Is directly proportional to the concentration gradient
- Is inversely proportional to the distance(the length of the diffusion pathway)

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The above **3 factors** are summarized in **Fick's law** which states that the rate at which molecules cross cell membranes by diffusion is proportional to;

Rate of diffusion is proportional to; $\frac{\text{Surface area x Difference in concentration}}{\text{Thickness of membrane/ Length of diffusion path}}$

Increasing the factors on the top line of the equation will make diffusion faster, while increasing that on the bottom will slow it down.

Flick's law applies to situations where there is **no barrier** to the movement of substances.

d) TEMPERATURE

When the temperature of the medium is increased, it causes an increased rate of diffusion because the particles acquire increased kinetic energy which increases speed of random movement of molecules 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.

e) Size and nature of diffusing molecules

The small sized molecules or ions of a substance move randomly faster than the large sized molecules or ions. Also water soluble ions i.e. glucose, amino acids etc. diffuse at a lower rate than the fat soluble molecules.

f) Permeability

The higher the permeability of the cell or membrane towards the diffusing ions or molecules, the higher the rate of diffusion and the vice – versa. The more porous a surface is, the greater the number of particles that diffuse through it hence the greater the rate of diffusion.

h)The density of diffusing

The higher the density the lower the rate of diffusion because the medium being dense offers maximum resistance towards fast movement of the diffusing molecules or ions.

i) The size of the organism.

The smaller the organism, the higher the rate of diffusion and vice –versa, some organisms have a large surface area to volume rate than the large organisms which favours diffusion of molecules or ions at a high rate across their body surfaces.

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SIMPLE AND FACILITATED DIFFUSION

Simple diffusion is the movement of molecules or ions across a cell membrane, down a concentration gradient without being aided by any carriers e.g. O_2 and CO_2.

Facilitated diffusion is the random movement of molecules or ions down a concentration gradient, across cell membrane by the process which involves a specific protein carrier or channel located within the membrane but **doesn't** require expenditure of energy in form of ATP by the cell. **OR**

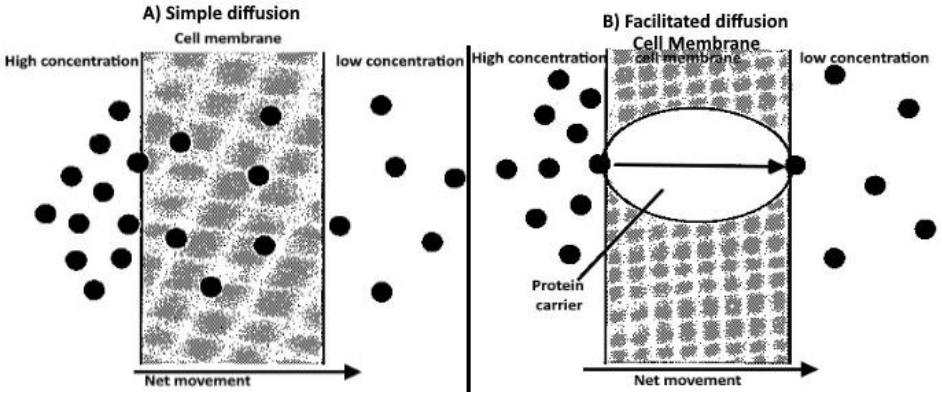
Facilitated diffusion refers to the transport of molecules and ions across a membrane by specific transport proteins, carrier and channel proteins, found within the membrane in the direction of lower concentration down a concentration gradient. Facilitated diffusion is a faster form of movement than 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

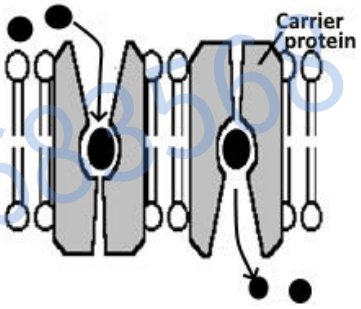
The molecule combines with a carrier molecule on one side of the cell membrane, moves through the membrane and releases the molecule on the other side of the membrane without using energy e.g. glucose moves the protein carrier of the cell membrane.

A diagram showing Simple diffusion AND Facilitated diffusion



Facilitated diffusion by carrier proteins

Carrier protein undergo rapid changes in shape and they exist in two forms, known as the **ping and pong state,** the binding sites of the carrier protein faces outwards in one state and into the cell in the other state.



The higher the concentration of the solute molecules or in the greater it chance of binding.

The carrier protein binds the molecules or at the binding site and then change shape as a result of this binding in such a ways that the molecules are released on the other side of the membrane.

The binding state is called the ping state and the releasing state pong state.

Facilitated diffusion does not involve the use of energy, and so material i.e moved along the concentration gradient.

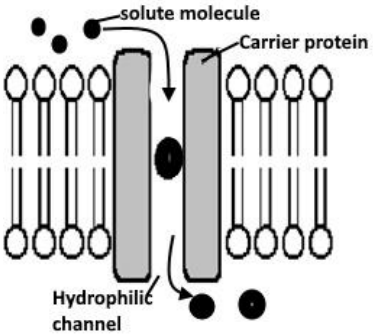
Some small hydrophobic organic molecules e.g. amino acids and glucose pass through the cell membrane by facilitated diffusion using carrier proteins. These proteins are specific for one molecule, so substances can only cross a membrane if it contains the appropriate proteins.

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 alters 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 membrane, down its concentration gradient

Facilitated diffusion by protein channels:

Channel proteins and carrier protein contain water filled hydrophilic channels or pores whose shape is specific for the passage of a particular ion or molecule. Alternatively several proteins may combine to form a channel between them.



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.

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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 down its water potential gradient.

Why facilitated diffusion occurs

- when molecules are large; e.g. amino acids
- when molecules are polar; e.g. amino acids
- when particles are charged; e.g. ions

Why the cell membrane is able to carry out facilitated diffusion.

- cell membrane have special protein molecules which are large and traverse the lipid bilayer these proteins are of two types
- channels proteins have fixed shape but with hydrophilic pores and for selective transport of ions
- carrier proteins rapidly change shape to bind specifically to the molecules they assist to carry over

Comparison between simple diffusion and facilitated diffusion

Similarities

Both move molecules from a region of high concentration to a region of low concentration through a partially permeable membrane

Simple Diffusion	Facilitated diffusion
• The rate of diffusion depends on the concentration gradient • Diffusion can occur in either direction • Similar molecules diffuse at the same rate • does not require special transport proteins	• The rate of diffusion does not depend on the concentration gradient • Diffusion occurs in only one direction • Specific molecules diffuse faster than others • Requires special transport proteins

Significance of diffusion

- 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.
- Absorption of certain digested food materials e.g. glucose in the ileum.
- A means of exchange of materials between blood in capillaries and the tissues
- 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 neuron to another i.e. diffusion facilitates synaptic transmission
- It ensures excretion of waste products e.g. ammonia in fresh water fishes
- It's the main means of transportation of materials within the cell's cytoplasm e.g. in unicellular organisms
- 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 occurs 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

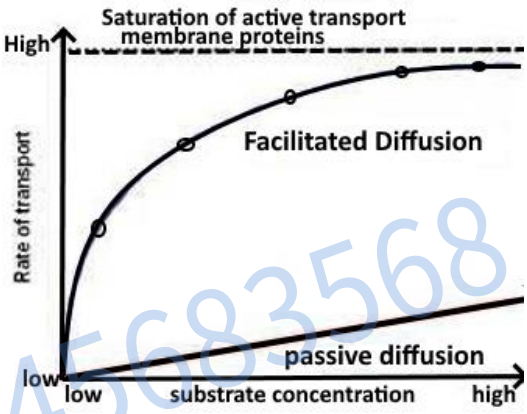
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5. In lungs there are numerous alveoli and in the ileum inholdings known as villi and microvilli which is coupled with a very long ileum also increases the surface area along which particles move into cells hence increase the rate of diffusion.
6. 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

Explanation why Respiratory poison does not affect facilitated diffusion

No effect/ facilitated uptake of glucose continues, because facilitated diffusion does not require energy/ passive process; does not require enzymes and uptake continues whenever concentration gradient exists.

Explanation on the effect of increasing extracellular concentration of glucose on the uptake of glucose when the diffusion is facilitated



Initially, an increase in extracellular glucose concentration caused rapid increase in glucose uptake. This is because more glucose molecules were coming into contact with the carrier channel protein, hence increasing the rate of binding and transportation across the plasma membrane.

The rate of glucose uptake the increased gradually with further increase in extracellular glucose concentration because the rate of binding and transportation of glucose molecules is slow and so became the limiting factor

Thereafter, the rate of glucose uptake remained constant because the carrier/ channel protein become saturated with glucose molecules. At this point, the rate of binding and transportation of glucose remain nearly the same however much the glucose concentration is increased in the extracellular environment.

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1. **ACTIVE TRANSPORT**

This is the movement of ions molecules of a substance a cross a membrane against a concentration gradient using energy. **Or** 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.

Energy is supplied in the form of ATP, and the major ions involved; Sodium ions, Potassium ions and chloride ions.

Active transport is achieved by carrier proteins whose change of shape is provided by ATP from respiration.

Molecules or ions tend to move from where molecules are of low concentration to where they are high concentration through a membrane and because of this that is why they need energy.

Movement of ions or molecules against a concentration gradient across a membrane is usually unidirectional in a way that ions or molecules move to one direction instead of either direction or all directions as it is with diffusion.

Active transport is mostly common to most fresh water organisms where their body fluids are said to be hypertonic to that of the surrounding water such organisms obtain solute material by active transport some marine organisms also whose body fluids is hypertonic to sea water take place in solutes by active transport e.g. the sea weed of marine environment take in iodine by active transport due to use of energy , takes place in living tissues which can respire and affected by the following factors;

- **Concentration of oxygen which determine the amount of energy formed per unit time/** lack of oxygen
- **Temperature**
- **Concentration of food material**
- **Metabolic poisons/**respiratory poisons (inhibitors) e.g. cyanide

Active transport is mainly common in epithelial cells meant for secretions and absorption e.g. the use of the kidney tubules, the gut, and the glands. It is also common in muscles, nerves the brain etc.
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.

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.
During the process, the carrier adheres on to the surface of the molecules to be transported and move along with it across the membrane using energy obtained from hydrolysis of ATP using ATPase enzyme.
The molecules or ions are selected by the carriers and absorbed at different rates and directions e.g. sodium potassium pump of the plasma membrane of most cells, uses energy to pump sodium from the inside of the cell to the outside via the membrane faster than the rate at which it (the pump) pumps potassium from the outside or exterior into the cytoplasm.

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 functioning of antiport carriers
Antiport carriers transport two substances in opposite directions across a cell membrane, for example the sodium-potassium pump in the cell membrane of the nerve cell
The sodium-potassium pump is a carrier protein which spans the cell membrane from one side to the other. It accepts sodium ions and ATP on the inside, while it accepts potassium ions on the outside. The transfer of sodium and potassium ions across the membrane is caused by changes in the shape of the carrier protein induced by attachment of sodium ions and ATP on the inside and potassium ions on the outside facilitated by energy from hydrolysis of ATP to ADP. For every 2 potassium ions taken into the cell, 3 sodium ions are removed. This builds up a potential difference across the membrane with the inside of the cell being negative with respect to the outside. This tends to restrict entry of negatively–charged ions/anions, while attracting positively–charged ions/cations into the cell.

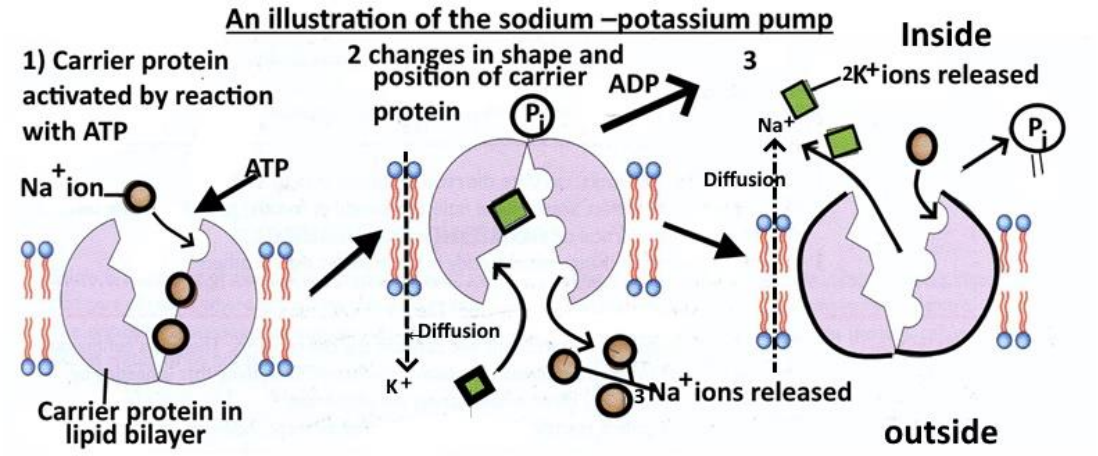
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Direct active transport (e.g. Na^+- K^+ pump)

ATP is hydrolyzed and the binding of the phosphate group to the protein pump changes the protein shape.

Functioning of the sodium potassium pump
A good example of active transport is the sodium –potassium pump who actively removes sodium ions from cells while actively accumulating potassium ions into them from their surroundings.
The sodium –potassium pump as an example of active transport.
The sodium potassium pump is a carrier protein which spans the cell membrane from one side to the other.
It accepts sodium and ATP on the inside; while it accepts potassium on the outside.
The transfer of sodium and potassium across the membrane is brought about by changes in the shape of the carrier protein facilitated by energy by energy from ATP.
For every two potassium ions taken into the cell, 3 sodium ions are removed.
This leads to a buildup of potential difference across the cell membrane, with the inside of the cell being negative with respect to the outside.

This tends to restrict the entry of rely charged ions (anions) such as chloride ions (Cl-), while positive charged ions (cations) tend to be attracted into the cell.
Therefore the direction in which ions cross membrane is determined by both the concentration of the ions and the nature of the changes on the ion.
As sodium ions accumulate on the outside they diffuse back into the cell very slowly, while the potassium ions accumulated on the inside slowly diffuse outside.



Importance of the sodium potassium pump

- It's essential in controlling the osmotic balance of animal's cells in a process called osmoregulation.
  If the pump is inhibited the cell swells and bursts because a buildup of sodium ions results in excess water entering the cell as by osmosis.
  Note: This explains why bacteria, fungi, and plants which have cell walls do not need the sodium – potassium pump.
- It is important in maintain electrical activity in nerve and muscle cells.
- The pump is important in driving the active transport of some other substances such as sugars and amino acids.
- The pump is responsible for providing the high concentration of potassium needed inside cells for protein synthesis glycolysis, photosynthesis and other vital process.

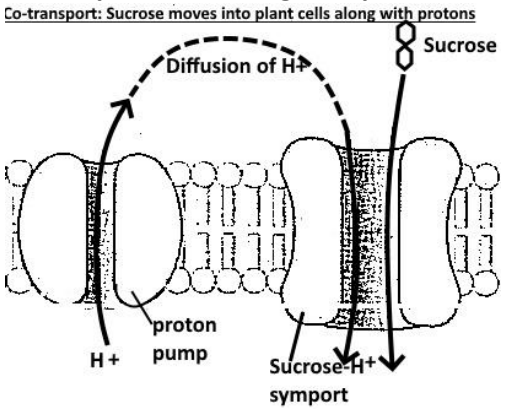
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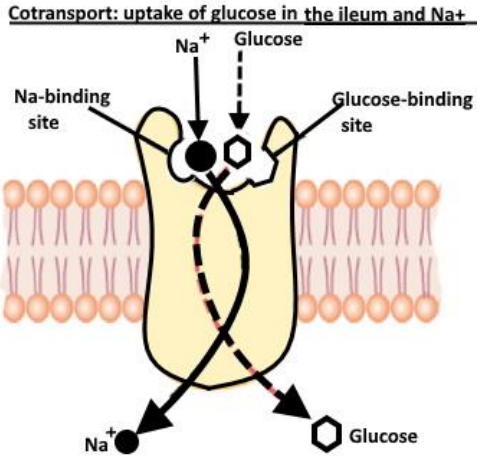
Indirect active transport mechanism (secondary active transport)

Cotransport: is a form of active transport in which the pumping of one substance indirectly drives the transport of one or more other substances against a concentration gradient.
Example
1. Absorption of glucose in small intestines; there is 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.
2. Reabsorption of glucose in kidney tubules. In the membrane is a carrier protein which requires both glucose and Na+ ions to operate.
3. absorption of glucose and amino acids into cells lining the digestive tract requires Na+ pump / amino acid cotransport carrier protein.

4. In plant cells which store sucrose, an ATP-driven proton pump actively transports hydrogen ions/protons out of the cell. This creates a concentration gradient down which the protons can diffuse. Diffusion of protons into the cell via symport carriers enables sucrose to be carried into the cell at the same time. i.e. **Sucrose moves into plant cells along with protons. The protons travel down a concentration gradient.**





The factors affecting active transport

1. Temperature

Increase in temperature increases the rate of transport of substances by active transport, as long as the increase is 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.

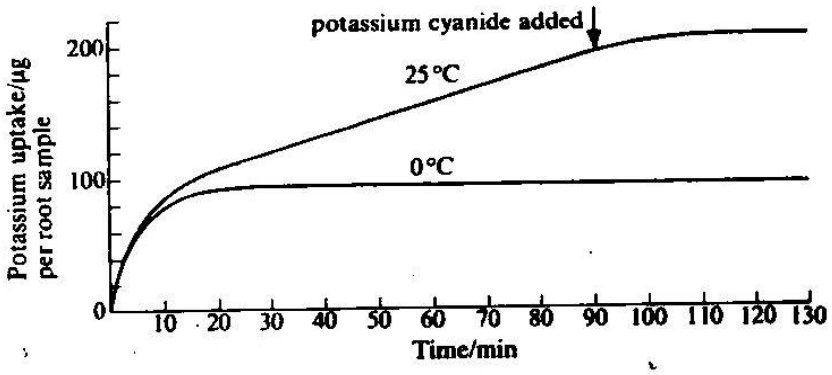
At very low temperatures, below the optimum, the respiratory enzymes together with the carrier proteins are inactive and this reduces the rate of active transport.

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Explanation of the trend of uptake of potassium ions at 0^0C.

From 0 minutes to 7.5 minutes the uptake of potassium ions increases rapidly, because the concentration difference of potassium ions between the root hairs and aerated solution is high, causing rapid diffusion of potassium ions from the aerated solution into the root hairs

From 7.5 minutes to 20 minutes the uptake of potassium ions increases gradually, because the concentration difference of potassium ions between the root hairs and aerated solution decreases, causing gradual diffusion of potassium ions from the aerated solution into the root hairs



From 20 minutes to 130 minutes the uptake of potassium ions remains constant, because there is no concentration difference of potassium ions between the root hairs and aerated solution, stopping diffusion of potassium ions from the aerated solution into the root hairs

Explanation in the difference of potassium ions uptake at the two temperatures.

From 7.5 minutes to 129 minutes the uptake of potassium ions at 0^0C is lower than the uptake of potassium ions at 25^0C, because uptake of potassium ions at 0^0C occurs passively by diffusion, which is a slower process,

depending on the presence of a favourable concentration gradient, while uptake of potassium ions at 25^0C occurs actively by active transport, which is a faster process, depending on consumption of much Adenosine triphosphate produced by much aerobic respiration using the much oxygen available in the aerated solution.

2. Inhibitors e.g. metabolic poisons, 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. **There for the metabolic poisons inhibit ATP synthesis hence** cutting off the source of energy needed to effect the active transport.

Effect of Potassium cyanide/respiratory inhibitor at each temperature.

At 0^0C addition of potassium cyanide has no effect on uptake of potassium ions, because uptake of potassium ions at 0^0C occurs largely by passive diffusion, which is not affected by the respiratory inhibitor

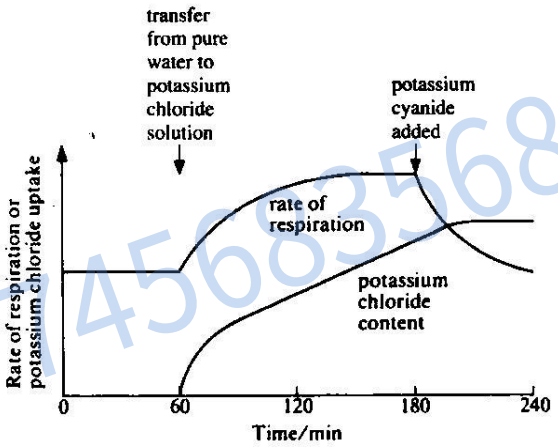
At 25^0C addition of potassium cyanide stops uptake of potassium ions, because uptake of potassium ions at 25^0C occurs largely by active transport, which is inhibited by the respiratory inhibitor, as it stops production of ATP by respiration

Explain the trend in rate of respiration:

a) Before addition of potassium cyanide.

From 0 minutes to 60 minutes the rate of respiration remains constantly low, because of low energy demand by the root cells to run active processes, other than active uptake of potassium ions, at relatively low rate

From 60 minutes to 150 minutes the rate of respiration increases rapidly and then gradually to provide sufficient energy in form of ATP for rapid active uptake of potassium ions from potassium chloride solutions into the root cells due to increase in the concentration of potassium ions in the bathing solution.



From 150 minutes to 180 minutes the rate of respiration remains constant, because due to exhaustion of potassium ions for absorption, there is no energy demand for any more active pumping of potassium ions into the root cells/other factors other than potassium ion become the limiting factor.

After addition of potassium cyanide.

From 180 minutes to 240 minutes the rate of respiration decreases rapidly on addition of potassium cyanide, because potassium cyanide inhibits respiratory enzymes, like cytochrome oxidase, by forming a complex with it, thereby preventing the transfer of hydrogen atoms/electrons for ATP synthesis to oxygen as the last hydrogen acceptor to from water.

3. 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

4. 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

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1. It is a means of absorption of food materials in the mammalian gut
2. It is the means of absorption of mineral salts by plant root hairs and the root epidermal cells of the peliferous layer
3. It facilitates the excretion of waste materials from the cells to the extracellular fluids against a concentration gradient e.g. excretion of urea
4. 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.
5. 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.
6. Active transport is vital in transmission of nerve impulses along nerve cells where it creates a membrane action potential using the potassium-sodium pumps.
7. 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).

Differences between the functioning of carrier proteins in facilitated diffusion and those in active transport

Carrier proteins in Facilitated diffusion	**Carrier proteins in Active transport**
• Do not use ATP	Use energy in the form of ATP
• Carry substances from a region of their higher concentration to a region of their lower concentration/down their concentration gradient	Carry substances usually from a region of their lower concentration to a region of their higher concentration/against their concentration gradient
• Not affected by metabolic rate/respiratory poison/oxygen concentration/respiratory substrate concentration	Affected by metabolic rate/ respiratory poison/oxygen concentration/respiratory substrate concentration
• Carry substances slower	Carry substances faster
• Carry substances in both directions across a membrane	Carry a particular substance in one direction

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CYTOSIS

This is a form of active transport involving inholdings and outfolding of secretions of the cell surface membrane resulting into bulky transport of materials into the cell (endocytosis) or outside the cell (exocytosis. There are two main forms of cytosis.

a. Endocytosis
b. Exocytosis

Endocytosis

This is bulk transport of materials into a 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. Materials are enclosed by a fold of the cell membrane, which then pinches shut to form a closed vesicle.

There are three types of endocytosis;

1. **Phagocytosis**
2. **Pinocytosis**
3. **Receptor mediated endocytosis**

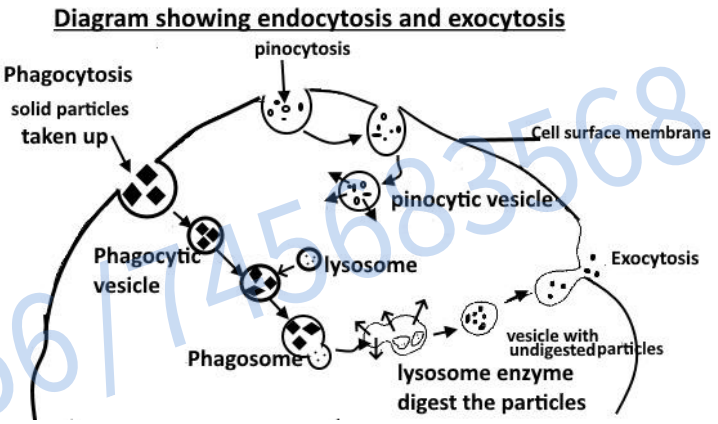
PHAGOCYTOSIS ((phago-feeding: cyto-cell **/cellular eating)**

This is the process by which the cell takes in bulk solid materials. It is also called cellular eating that involves the cell taking in large solid substances.
The cell membrane invaginates to form a cup shaped depression in which the solid materials is contained 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 useful soluble products 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 to the cell surface membrane and fusing with it. Cells specialized for phagocytosis know as phagocytes and are said to be phagocytic as in white blood cells and amoeba.

PINOCYTOSIS

Pinocytosis (**pino-drinking; cyto-cell)** is the process by which the cell takes in bulk liquid material.
Pinocytosis is similar to phagocytosis and the vesicles formed are called pinocytic, ever smaller micro pinocytic vesicles may be formed in which case the process is called **micro pinocytosis.**

Note: Both pinocytosis and phagocytosis are active process by which materials are transported as the cell membranes in bulk. Bulk transport into cells is termed endocytosis, while transport out of cells is called exocytosis.
An illustration of endocytosis and exocytosis.



Significance of phagocytosis

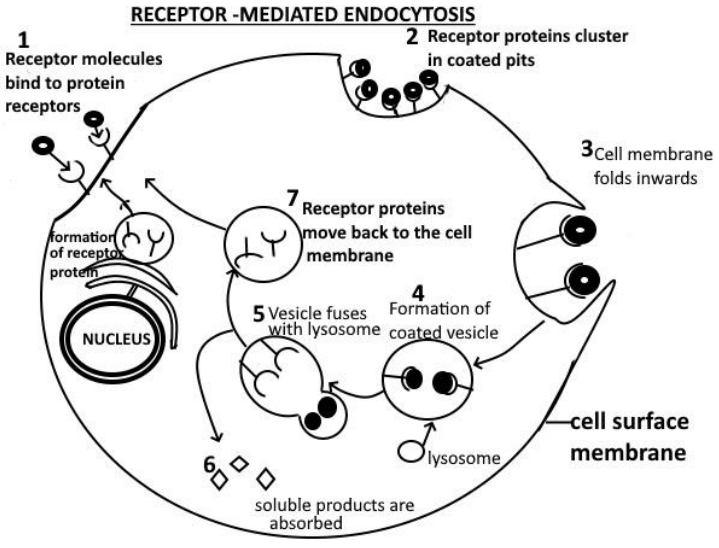
i) White blood cells ingest harmful bacteria by phagocytosis.
ii) Amoeba feed by phagocytosis using pseudopodia.

Significance of pinocytosis

i)Its used by the human egg cell to take up nutrients from the surrounding follicle cells.
ii) In the thyroid, the hormone thyroxine is stored as thyroglobulin in hollow structures called follicles when required thyroglobulin is taken up by pinocytosis. By the follicle cells and then converted to thyroxine for release into the blood.

Receptor mediated endocytosis

Is a specialized type of pinocytosis that enables the cell to acquire bulk quantities of specific substances, even though those substances may not be very concentrated in the extracellular fluid.
Embedded in the cell membrane are proteins with receptor receptors exposed in the extracellular fluid.
The receptor molecules on a cell membrane which binds with specific substance such as



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cholesterol and amino acids from extracellular fluid. The receptor proteins the cluster in the region of the cell membrane known as coated pits.
As the receptor sites are filled with the substance, the cell surface membrane folds inwards forming the coated vesicles containing bound molecules.
The coated vesicle then separates from the cell surface membrane and fuses with lysosomes**.**
After the ingested materials is liberated/released from the vesicle, the emptied receptors are recycled to the cell membrane by the same vesicle.

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.
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.

A summary of exocytosis and endocytosis occur a plasma membrane.
Exocytosis involves the bulk movement of materials out of small vacuoles called vesicles approach the plasma membrane fuse with it and release their bulk solid or liquid content outside the cell.
Endocytosis is the process by which materials are taken into the cell in bulky by phagocytosis or pinocytosis. This is done when the plasma membrane folds to enclose the tiny particles or droplets of fluids and fuse at the point of contact to move materials into the cell.

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IMPORTANCE OF CYTOSIS

- 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
- 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.
- Exocytosis delivers cell wall materials to the outside of the cell from the Golgi apparatus/body through vesicles which contain proteins and certain carbohydrates
- 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.

Comparison of simple diffusion, active transport and facilitated diffusion

Simple diffusion	**Facilitated diffusion**	**Active transport**
Down the concentration gradient from high to low	Down the concentration gradient from high to low	Against a concentration gradient from low to high
No energy expenditure	No energy expenditure	Energy expenditure is in the form of ATP
Carrier protein/ Transporter Not required	Carrier protein/ Transporter required	Carrier protein/ Transporter required

Differences between active transport and diffusion

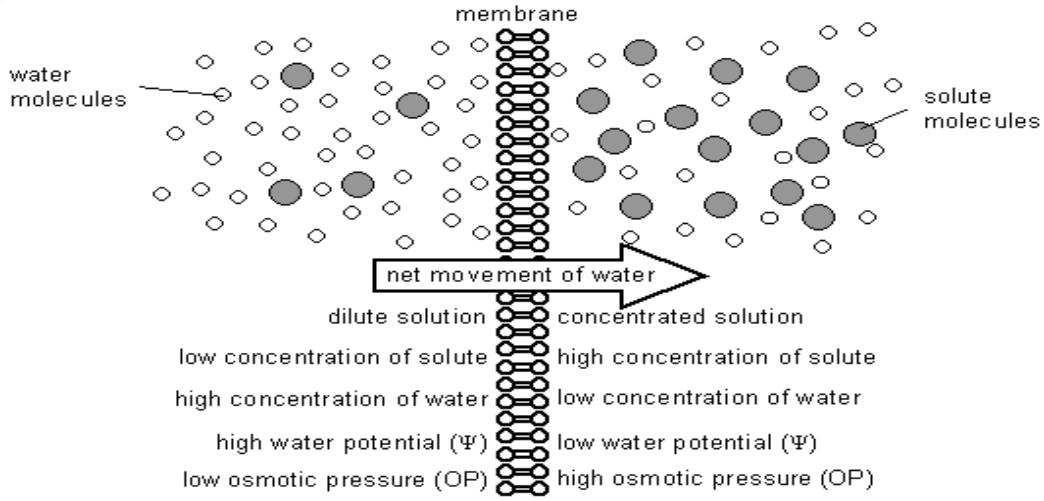
Active transport	Diffusion
• Materials are moved against as well as down their concentration gradient	Materials move only down their concentration gradient
• Energy in the form of ATP is used	Does not require energy
• Takes place in both directions	Takes place in one direction
• It is rapid process	It is a slow process
• Brings about selective uptake of materials	Allows all transmissible molecules to pass through membranes.
• Affected by metabolic rate	Not affected by metabolic rate
• A concentration equilibrium is not attained	A concentration equilibrium may be attained
• Carrier molecules are required	May occur with a without aid of carrier molecules
• Affected by lack of oxygen	Not affected by lack of O_2
• Affected by metabolic poisons	Not affected by metabolic poisons.

OSMOSIS

This 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.

Osmosis is the net movement of water molecules from a region of their high concentration to the region of their low concentration 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

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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 solution, making water**.**
Osmosis can take place when an osmotic gradient or water potential gradient exists between two regions of diffusion solvent concentrations, separated by a partially permeable or semi- permeable membrane.
This can be achieved via.

a) separating a solution with high concentration from that of low concentrating using partially permeable membrane
b) Separating a solution from pure water using a semi or partially permeable membrane.
Free water molecules have kinetic energy and move about at random. The total amount kinetic energy of water molecules on either side of the membrane is called **water potential**. The water potential can be taken to be the measure of tendency is increased by Increase in temperature and pressure but can be decreased by increasing the number of solute molecules.

TERMS USED TO DESCRIBE PLANT WATER RELATIONS

Water potential

This is the net tendency of any system to lose water to its surroundings by osmosis. The water potential is the measure of kinetic energy of water. The symbol for the water potential is **ψ**, the Greek letter psi, and is usually measured in kilopascals (Kpa).

The greater the concentration of water molecules in a system the greater the total kinetic energy of water molecules in that system; the higher is its water potential.

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 (**wp**) of a plant cell ψ_{cell} is the algebraic sum of its wall pressure (pressure potential) ψ_p and its osmotic (solute) potential ψ_s.

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

$$WP = SP + PP$$
$$(\psi = \psi_s + \psi_p)$$

Example if **SP/ψ_s= -1000kpa** and **PP /ψ_p =** +500kpa

Then water potential **(ψ_{cell}) = ψ_s + ψ_p**

= -1000 +500 = -500kPa

If water potential (solution) **= -300kPa**

Then water potential gradient (**ΔWP)**

is given by **Δ ψ =WP/ψ_{cell} - WP ($\psi_{solution}$)**

-500-(-300) = -500+300= -200kPa

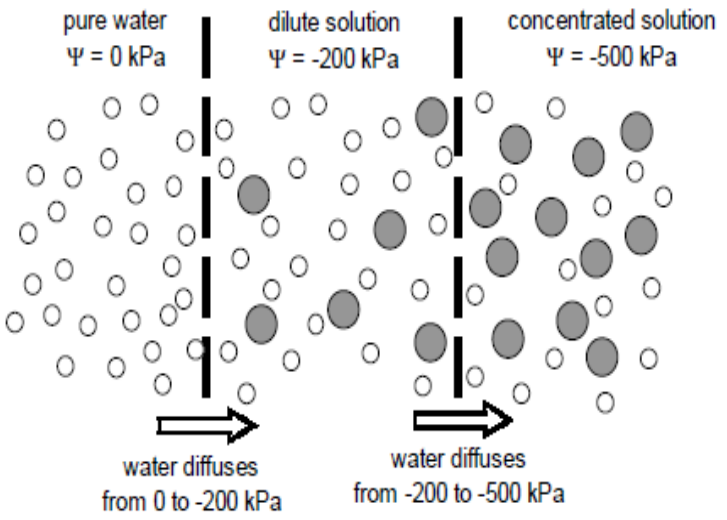
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If water potential gradient is positive; there is a net osmotic withdrawal of water from the cell/exosmosis.
As water is lost the protoplast gradually shrinks and eventually just ceases to press against the cell wall.

Factors affecting the water potential

a) **Amount of solutes**

b) **Addition of solute molecules** to pure water reduces the concentration of water molecules and hence lowers the water potential.



Solute potential (Ψ_s)

The solute potential as a measure of the change in water potential of a system due to the presence of solute molecules**. Or** 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 **zero/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.

Note:

- Solute potential/ ψ_s is also termed **osmotic potential.**
- Solute potential is always negative for solutions
- The more solute molecules present, the lower (**more negative**) is the solute potential.

Pressure potential (Ψ_p)

The pressure potential is the effect of application of a hydrostatic on the pressure on the water potential of a system.

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
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

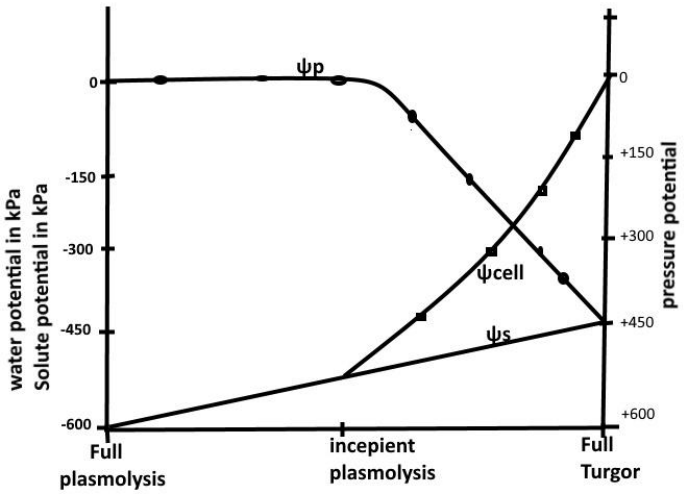
Explain the changes in water potential from full plasmolysis to full turgor

At full plasmolysis the water potential of the cell is low/very negative, due to the low concentration of water molecules in the cell, and because the pressure potential is zero, since the protoplast is completely pulled away from the cell wall, and so the cell wall exerts no pressure against the protoplast.
From full plasmolysis to incipient plasmolysis water enters into the cell by osmosis from the hypotonic solution which has a higher/less negative water potential than the cell contents, increasing gradually the concentration of water molecules in the cell, causing both the water potential and solute potential to increase at the same gradual rate, since the pressure potential is zero, because the protoplast remains pulled away from the cell wall, and so the cell wall exerts no pressure against the protoplast, and **so Ψcell = Ψs.**

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From incipient plasmolysis to full turgor expansion of the protoplast due to further osmotic influx of water pushes the protoplast against the cell wall, and the rigid cell wall pushes back against the protoplast, causing rapid increase in hydrostatic pressure inside the cell, resulting in rapid increase in pressure potential, and since **Ψcell = Ψs + Ψp**, there is a rapid increase in water potential.

At full turgor water potential is **zero** because the pressure potential is equal and opposite to the solute potential and the cell can no longer take in water or expand.



The water potential is a measure of the tendency of a system to lose water / The water potential is a measure of the kinetic energy of water molecules in a system.

The solute potential is a measure of the change in water potential of a system due to the presence of solute molecules.

The pressure potential is the effect of application of a hydrostatic pressure on the water potential of a system.

Explanation why the osmotic potentials of solutions are always negative:

A solution is formed by adding solute molecules to a solvent, such as water.

The osmotic potential is the change in water potential of system due to the presence of solute molecules.

The water potential is a measure of the kinetic energy of water molecules in a system.

By convention the water potential of pure water is zero.

Water molecules are polar/dipolar, and when a solute is added to water, the positive part of the solute/cation gets attracted to the slightly negative part of water/oxygen part, and the negative part of the solute/anion gets attracted to the slightly positive part of water/hydrogen part.

This lowers the mobility of the water molecules, thereby lowering their kinetic energy, and so decreasing the capacity of the system to lose water.

So the effect of addition of molecules to pure water is to lower its water potential from **zero** to a more negative value for a solution. This lowering in water potential which is the **osmotic potential** gives all solutions a **negative osmotic potential.**

Osmotic pressure and cell relationship

Osmotic pressure

The osmotic pressure is the hydrostatic pressure required to prevent the osmotic entry of water into a solution when the solution is separated from pure water by a partially permeable membrane.

Osmotic pressure is the pressure needed to stop osmotic flow to a system. 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 protoctists 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.**

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The more concentrated a solution, the greater is its osmotic pressure.
The osmotic pressure of a solution is equal in magnitude to its solute potential but has a **positive sign**

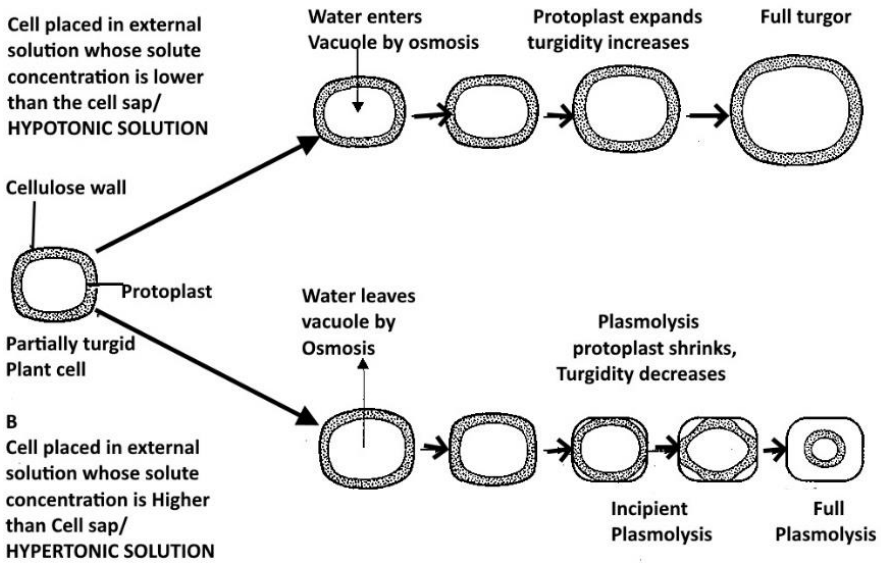
Osmosis and animal cells
If a human red blood cell is placed in an isotonic solution i.e. 0.9% sodium chloride solution, the cell neither shrinks nor swells. If they are placed in a hypertonic solution i.e. 1.2% sodium chloride, it will shrink and appear crinkled and this is called **crenation.**
If 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.

When a red blood cell is put in a hypotonic 'solution, the cell takes up water osmotically and its protoplasm swells up until it bursts a process called **haemolysis.**
When erythrocytes (red blood cells) are put in a **hypertonic solution** the cell osmotically loses water to the solution and shrinks to the extent that all membranes **crinkle** phenomena known as **crenation** or laking.

Osmosis and plant cells
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.

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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**.



This takes into account of three forces which include;

a) **Water potential of the cell sap**
b) **Solute potential**
c) **Pressure potential**

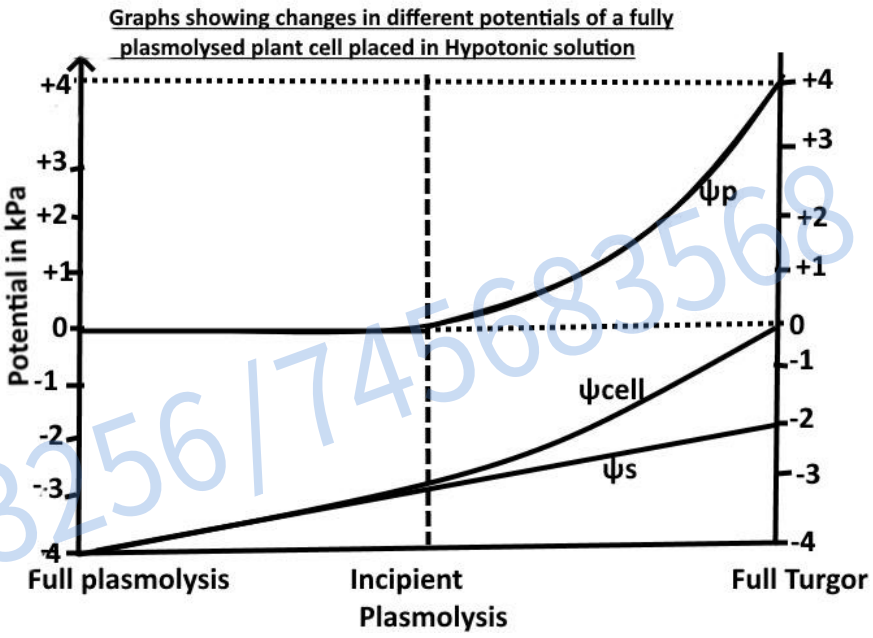
Considering a fully plasmolysed cell which is immersed in pure water, water enters the cell sap osmotically and the protoplasm begins to expand. As the osmotic influx of water continues, the protoplast goes on expanding until it comes into contact with the cell wall.

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 cell sap.

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

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.



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Explanation of changes in potentials:

Change in pressure potential:

At full plasmolysis the pressure potential is **O kPa**, because the protoplast is completely pulled away from the cell wall, and so the cell wall exerts no pressure against the protoplast.

Between full plasmolysis and incipient plasmolysis the pressure potential remains **O kPa**, because the protoplast remains pulled away from the cell wall, and so the cell wall still exerts no pressure against the protoplast.

Between incipient plasmolysis and full turgor the osmotic influx of water causes the volume of the protoplast to increase, so the protoplast exerts pressure against the cell wall, and the rigidity of the cell wall causes a rapid increase in hydrostatic pressure inside the cell, hence a rapid rise in pressure potential.

Solute potential change:

From full plasmolysis to full turgor the osmotic entry of water into the cell gradually reduces the concentration of solute molecules in the cell, causing a gradual increase in its solute potential.

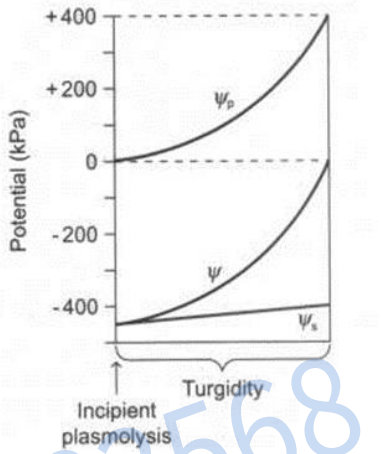
Water potential change:

At full plasmolysis the water potential of the cell is low/very negative, due to the high concentration of solute molecules in the cell, so water enters into the cell by osmosis from the hypotonic solution which has a higher/less negative water potential than the cell contents.

From full plasmolysis to incipient plasmolysis the osmotic entry of water into the cell causes both the water potential and solute potential to increase at the same gradual rate, since the pressure potential is **O KPa,** and so Ψcell = Ψs.

Between incipient plasmolysis and full turgor expansion of the protoplast due to osmotic influx of water pushes the protoplast against the cell wall, and the rigid cell wall pushes back against the protoplast, causing a rapid rise in pressure potential.

Since **Ψcell = Ψs + Ψp,** there is a rapid rise in water potential **to O kPa** at full turgor, when the pressure potential becomes equal and opposite to the solute potential, and the cell can no longer take in water or expand.



In general Ψcell = Ψs (always negative) + Ψp (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.

ROLE OF OSMOSIS IN LIVING ORGANISMS

It is the main form by which root hairs and peliferous layer cells on roots absorb water from the soil

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

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.

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.

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.

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What happens when a turgid cell is put in a hypertonic solution?

When a fully turgid cell is put in a hypertonic solution, it loses water osmotically from its sap vacuole to the hypertonic solution.

As water is lost the protoplast gradually shrinks and eventually just ceases to press against the cell wall this point is called **incipient plasmolysis.**

At this point the pressure potential equals to 0 while the water potential counter balances with the solute potential. As more water is lost, the protoplast shrinks further and reduce more or less spherical mass, completely detaches from the cell and this is called plasmolysis.

Plasmolysis is the loss of water by osmosis from a plant cell to the extent that the protoplast shrinks away from the cell wall.

A turgid cell loses water by osmosis when put in a hypertonic solution which creates a positive water potential gradient as shown below e.g. if water potential of a cell (WP cell) = **- 200 k pa** and that of the solution (**WP** solution) = **- 600 kpa**

The water potential gradient W.P = **- 500 – (-600)= 100kpa**

The positive water potential difference indicates that, the cell wall solution is hypotonic to the external solution and there is not osmotic loss of water from the cell to the hypotonic external solution.

Factors affecting osmosis in physical systems

i)Temperature

Provided pressure is constant, when a partially permeable membrane separates the pure water on two sides the molecules of water will move from a region at a higher temperature to the one at the lower temperature. Increased temperature to the optimum results into increased kinetic energy of the water molecules, hence faster osmosis and vice-versa

ii) Pressure

Provided temperature is constant, when pure water or two sides of a semi permeable membrane is subjected to different pressures and water molecules move from high pressure side to low pressure side.

iii) Solute molecules

Water molecules move from a dilute solution to a concentrated solution through a partially permeable membrane by osmosis.

Kinds of solutions.

There are 3 kinds of solutions on the basis of relative concentration of water and solute molecules with respect to the concentration in the cell;

a) Isotonic : an isotonic solution has the same concentration of water and solute molecules as is inside the cell.

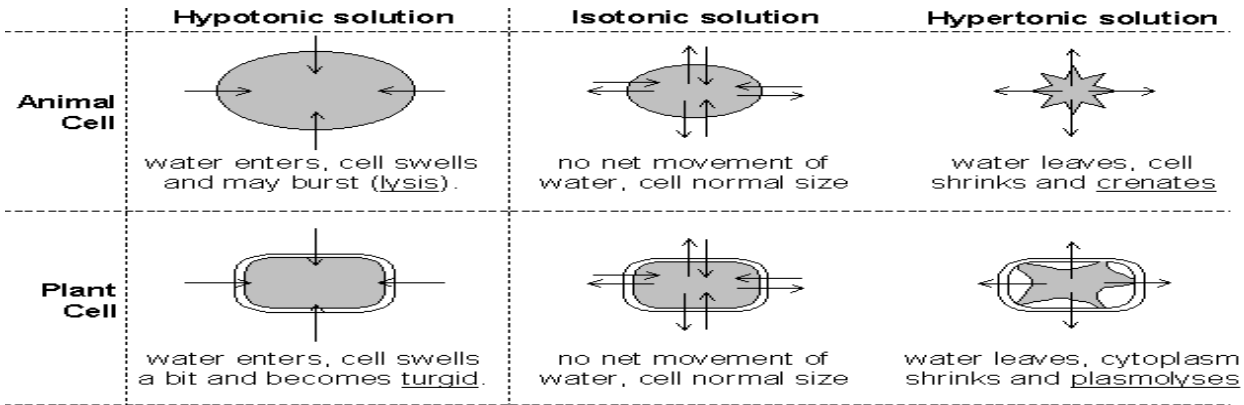
b) **A hypotonic solution** is a solution that has a lower concentration of solute molecules than inside the cell.

c) **A hypertonic solution** is a solution that has a higher concentration of solute molecules than inside the cell.

Dilute solution	Concentrated solution
High concentration of water molecules	Low concentration of water molecules
Low concentration of solute molecules	High concentration of solute molecules higher water potential (less negative)
Higher water potential (less negative)	Lower (more negative) water potential
Higher (less negative)solute potential (osmotic potential)	Lower (more negative) solute potential (osmotic potentials
Slower osmotic pressure	Higher osmotic pressure.

The effect of different kinds of solution on a plant cell

Plant cell in isotonic Solution	Plant cell in hypertonic Solution	Plant cell in hypotonic Solution
Water neither enters nor leaves cell	Water leaves cell	Water enters cell
No change in protoplast	Protoplast shrinks	Protoplast swells
Cell shows incipient plasmolysis	Cell becomes flaccid plasmolysed	Cell becomes turgid
Protoplasts begins to pull away from the cell wall	Protoplast completely pulls away from thee cell wall	Protoplast pushes up against the cell wall.



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Plasmolysis is the shrinking of a plant cell due to loss of water by osmosis when the protoplast pulls away from the cell wall.
Turgidity is the state of a plant cell when the protoplast pulls away from the cell wall due to entry of water by osmosis.
Wilting is the drooping of the shoots and leaves of a plant when the water loss as more than water up take by the roots and the whole cell including the cell wall shrinks.
Water stress; a plant suffers water stress if loses more water by transpiration than it can take up into its roots by absorption.

Effects of water stress in plants.

- Excessive water loss leads to drooping of shoots and leaves a conditions called wilting.
- Stomata rapidly close due to secretion abscisic acid by cells in the wilted leaves.
- Stomatal closure reduces the rate of photosynthesis due to lack of carbon dioxide.
- Reduced photosynthesis causes a reduced growth rate leading to stunting.
- Reduced growth rate causes economic possess in commercial crops through reduction in agricultural yield.
- Excessive water loss can lead to desiccation and drying up of a plant who often leads to death.
- Wilting increases food insecurity due to loss of crops.

Importance of turgidity in plants.

- Turgor pressure maintains the shape and form of the plant.
- Increase in turgidity of parenchyma cells provides mechanical support to non-woody plants and non-woody parts of woody plants. The stems of herbaceous plants and non-woody plants (such as maize, banana and sugarcane) are maintained in an erect position by fully turgid cells tightly packed together to provide support.
- Turgor pressure holds the leaves in flat and horizontal position to receive sun.
- Increase in turgor pressure leads cell enlargement which causes growth of cells and the entire plant. Hence it enhances cell enlargement and stretches the stems leading to increase in growth.
- The opening and opening of stomata is regulated by changes in the turgidity of guard cells. When their turgidity is high, the stomata open, otherwise they close.
- The quick nastic response of some plants such as thigmonastic and sasmonatic collapse of leaves and shoots of mimosa pudica (touch-me-not) are controlled by turgidity.
- Loss of cell turgor in plant leaves that occurs in conditions of water stress closes the stomata and folds up the leaves (wilting). This helps to reduce the effects of water stress on the plant.

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Transpiration is the loss of water in the form of water vapour from the aerial parts of the plant.
Guttation is the exceeding of moisture from the lips of leaves as water droplets in certain plants.
It occurs through specialized cells called **hydathodes** prevent near the vein endings and is common in young grass seedlings and rain forest plants due to in light and high humidity.

Differences between wilting and plasmolysis

Wilting	Plasmolysis
• Occurs due to high temperature	Occurs due to presence of an osmotic gradient
• The entire cell including the cell wall shrinks	Only the protoplast and pulls from the cell wall
• Water loss is serious leading to desiccation which can cause death	Water loss is not a great and serious and can hardly result into death.
• Results drooping of the shoot and leaves of the plant	Does not result into drooping of the shoot and leaves of the plant

Differences between transpiration and guttation

Transpiration	Guttation
• Water is lost in the form of water vapour	Water is lost in form of water droplets
• Occurs through the stomata, cuticle and lenticels	Occurs through special pores called hydathodes
• Occurs during bright lights and high temperatures	Occurs during deem light such as at night and at low temperature.
• Enhanced by low humidity	Enhanced high humidity
• Water lost is pure water and does not contain minerals	Water lost in minerals water it contains sugars, salts and amino acids.
• Increased transpiration leads to wilting	Increased guttation is related to low transpiration and high root pressure and does not cause wilting.

Why red blood cells placed in pure water burst (haemolyse) yet plant cells do not?
Pure water burst haemolyses red blood cells, yet plant cells do not

- Pure water has a higher water potential that the cytoplasm of the red blood cells, so water enters the red blood cells by osmosis through the partially permeable cell membrane.
- The cell protoplast swells and the delicate thin and weak cell surface membrane bursts and the red blood cells are said to be haemolysed.
- When the plant cell takes in water, the protoplast swells and presses against the cell wall.

But the cell wall is tough and rigid so it resists and further expansion of the protoplast as the becomes fully turgid. Thereby stopping further entry of water and preventing bursting

Why all solutions have negative values of water potential and solute potential?

- A solution is formed by addition of solute molecules to solvent such as water.
- The water potential is a tendency of a system to lose water
  Or
- The water potential is the measure of kinetic energy of water molecules in a system.
- Water molecules are polar molecules, actually bipolar

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Differences between osmosis and active transport

osmosis	active transport
Involves movement of solvent molecules such as water across membranes	Involves movement of solute molecules across membranes
Solvent molecules move down their concentration gradient	Solute molecules are moved against as well as down their concentration gradient.
No energy is required	Energy in the form of ATP is required
Can occur in not living tissue	Occurs in living tissues only.
Occurs across a partially permeable membrane	Membrane could be permeable to other solutes and solvents
Not affected by lack of oxygen	Affected by lack of oxygen
A concentration equilibrium may be attained at the end	A concentration equilibrium is not attained
No carrier molecules required	Carrier molecules are used
Not affected by metabolic rate	Affected by metabolic rate.
No affected by metabolic poisons	Affected by metabolic poisons.

Differences between diffusion and osmosis

Diffusion	Osmosis
Involves random and spontaneous movement of solute or gas molecules	Involves passage of solvent molecules
Involves movement of ions or molecules from a region of their concentration to a region of their low concentration	Involves movement of solvent/ water molecules from region of high concentration to their region of low concentration
Occurs where there are no barriers to movement such as through a freely permeable membrane.	Occurs through a partially permeable membrane.

Significance of osmosis

- Facilitates absorption and transportation of water in plants and animals.
- Allows transpiration hence cooling the plant
- Enables movement of minerals salts up a tall plant.
- It participates in the process of excretion and osmoregulation.
- It leads to turgidity in the parenchyma cells of the herbaceous plants which render them strength and support.

TOPIC 4: LEVELS OF ORGANISATION AND DIVERSITY OF LIFE

TAXONOMY (CLASSIFICATION)

Classification:- this is a method of organising and grouping of organisms in various groups known as taxa basing on the degree of resemblance and differences between them. The process by which this is done is known *as identification* and after identification the organism is named by a process known as nomenclature.

Classification is the grouping of things together on the basis of features they have in common Systematic and taxonomy

Systematics is the scientific study of all organisms and the existing relationship among them or scientific study of the diversity of living things

Taxonomy (from Ancient Greek: taxis "arrangement" and Ancient Greek: *nomia* "method") is the science of identifying and naming organisms, and arranging them into groups. The field of taxonomy revolves around the description and use of taxonomic units, known as **taxa** (singular taxon). **Taxonomy** is defined as the science of classification.

During classification, species are the basic units and contain organisms that can interbreed to produce a viable offspring. **It involves grouping** of living organisms based on their similarities and differences. For example, living organisms can be grouped by similar structures present or absent, or places where they live, feeding habits.

WHY SHOULD WE CLASSIFY ORGANISMS?

Organism is a name for any living creature or plant. All things that are alive can be called organisms.

Classification of organisms is important because

1. It enables scientists to identify unknown species and then group them with existing ones.
2 Provides a common reference for those organisms already identified.
3. It is the universal language of communication for scientists
4. Aids communication between scientists and allows information about a particular organism to be found readily.

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Levels of classification there are seven groups of organisms. Organisms are grouped into general groups known as kingdoms. The kingdoms are divided into smaller groups called phyla (singular phylum). The phyla are divided into classes. The classes are further divided into orders. The orders are divided into families and the families are divided into genera (singular genus). Below the genera are the species.

Rank	**Man**	**Cockroach**	**Rat**	**Sweet pea**
Kingdom	animalia	Animalia	Animalia	Plantae
Phylum	Chordata	arthropoda	chordata	Angiospermophyta/spermatophyta
Class	Mammalia	insecta	Mammalia	Angiospermae
Order	primate	dictyoptera	Rodentia	Rosales
Family	hominidae	blattidae	Muridae	Leguminosae
Genus	*homo*	*periplaneta*	*Rattus*	*Lathyrus*
Species	*sapiens*	*Americana* ricana)	*rattus*	*odoratus*

A Genus is made up different species that appear to be closely related e.g a man, monkey and gorilla are of the same genus but they do not inter-breed freely and if by chance mating occurs, the offspring don't mature or, they become sterile.

Species are groups of organisms that inter-breed to give rise to fertile (viable) offspring. E.g, all humans are in the same species. Species are made up of morphologically similar individuals
Or s**pecies** are groups of interbreeding populations which reproductively isolated from other such groups.

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TYPES OF CLASSIFICATION

There are two types of classification ie

1. Artificial classification-classification by differences.

Which is the type of classification that involve arranging organisms in groups according to whether or not possessing a particular characteristic and then subdividing on the basis of presence or absence of anther characteristic. It is based on one or a few easily observable characteristics for simplicity and convenience. **Phenetic 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.

2. Natural classification-classification by similarities, which the type of classification where phenetic and phylogenetic characteristics are used. This type of classification is based on use of morphological, anatomical, biochemical, hybridization and chromosome studies to arrive at tentative conclusions about phylogenetic (evolutionary) relationships between species. Such relationships must be on homologous but not analogous characteristics and evolutionary characteristics. **Phenetic** classification is based on observable, morphological features while **phylogenetic** classification is based on evolutionary changes of the organism.

Homologous characteristics: an organ of one organism is said to be homologous with an organ of anther if both have a fundamental similarity of origin, structure and position which is manifested especially during embryonic development, regardless of their functions in the adult.

Analogous characteristics: an organ of another when both organs have the same function and when they are not homologous.e.g wings of birds and butter flies.

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

The Dichotomous/ identification key : Di- two; chotomous – branches

A **dichotomous key** is a tool that allows a scientist to name and identify organisms in the natural world, such as trees, wildflowers, mammals, reptiles, rocks, and fish. Dichotomous keys always give two choices in each step.

During the construction of the key, external features of the organism are used (parts of the organism). Each of these features is called a characteristic. **BUT** Colour and size are not used as features because they are not permanent.

It is an artificial method of identification because it uses phonetic x-tics but it is however scientifically used in identifying organisms despite of the fact that they are artificial.

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DIVERSITY OF LIVING THINGS

The study of living organisms which have a number of common characteristics .i.e. nutrition, respiration, growth and development, movement, reproduction, irritability and excretion is known as biology. The modern classification has categorised every life form into **FIVE KINGDOMS** basing on the phenetia and phylogenetic x-tics

THE FIVE KINGDOM SYSTEM

In the old classification system, all living things were grouped into two kingdoms; plant kingdom and animal kingdom. However, later discoveries showed that certain organisms could not fit into these two groups.

Initially, fungi were placed within the plant kingdom and yet they did not possess chlorophyll,

Bacteria were placed under both plant and animal kingdoms because they possessed both plant and animal features.

This led to the development of a new system of classification in 1982, known as the five kingdom system, which places fungi and bacteria into separate kingdoms.

1. **Kingdom: Animalia**- Animals. Multicellular eukaryotes, motile organisms. They lack rigid cell walls and feed heterotrophically by ingestion (with exceptions).
2. **Kingdom Plantae - Plants**. Multicellular eukaryotes which feed by photosynthesis. They are producers, sessile organisms. Their cells have walls composed of cellulose. They are autotrophs, and photosynthesize (with exceptions).
3. **Kingdom: Protoctista -** (A group of about 40 phyla of eukaryotic organisms) typically simple, eukaryotic unicellular microorganisms or multicellular microorganisms without specialized tissues.
4. **Kingdom Fungi -** Include yeast and moulds. Multicellular eukaryotes, decomposers. Like plants, they are sessile, but unlike plants they lack chloroplasts and feed heterotrophically by absorption (with exceptions).
5. **Kingdom Monera/prokaryota**- Bacteria, single-celled prokaryotic organisms a few microns in size, with varying morphology. Feed by a variety of different methods

Kingdom	Characteristics	Example of organisms
Monera	▪ They are unicellular and microscopic ▪ Don't have a true nucleus/no nuclear membrane ▪ Most are heterotrophic, some are autotrophic ▪ Cell division mostly by binary fission	Phylum: Bacteria Phylum:Cyanobacteria
Protoctista	▪ Unicellular ▪ Have nuclear membrane and therefore a nucleus	Plasmodium, amoeba, Algae, spirogyra
Fungi	▪ Cell walls made of chitin ▪ Cells have nuclei ▪ Lack chlorophyll ▪ Feed saprophytically or parasitically ▪ Reproduce by means of spores	Mushrooms, yeast, common mould
Plantae	• Multicellular eukaryotes with tissue differentiation • cell walls made of cellulose • Contain chlorophyll • Synthesize food by photosynthesis	Mosses, ferns, pine tree, maize, pyrethrum
Animalia	• Multicellular eukaryotes with tissue differentiation • No cell walls • No chlorophyll • Feed heterotrophically	Hydra, man, earthworm, fish, chicken, spider

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SUBTOPIC 2: VIRUSES (AKARYOTAE)

A virsus consists simply of nucleic acid surrounded by a protein coat and it can only survive and reproduce inside a living cell.

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.

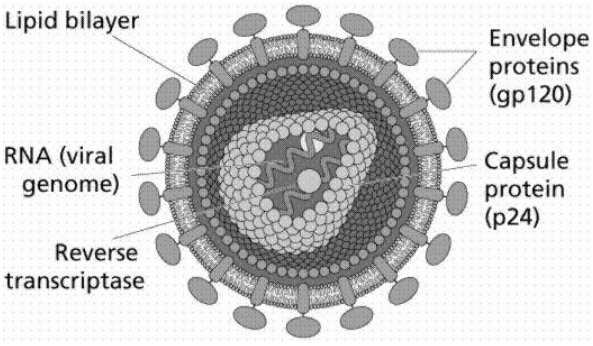
Examples of viral diseases;

In plants

- Cassava mosaic disease
- Tobacco mosaic disease
- Tomato bush stunt disease
- Southern bean mosaic disease

In animals

- Small pox
- The Acquired Immuno Deficiency Syndrome (AIDS)
- Rabies



- Measles
- New castle disease

These are the smallest living organisms ranging from 20 to 300nm.they are ultra-microscopic organism and cannot be seen by a light microscope but only by electron microscope.
Viruses don't fit into any of the above five kingdoms above because they lack cellular organization but have genetic material DNA and RNA and capable of reproducing within the host cells hence they are living.
They are classified into **three groups** depending on their host
Bacteriophage:-these have phagocytic effect on the bacteria cells e.g. E.coli
Plant viruses e.g. cassava mosaic viruses, tobacco mosaic viruses e.t.c
Animal viruses e.g. HIV, influenza polio viruses, rabbies, bird flu, small pox. e.t.c
Viruses are simple non-cellular organisms which are disease causing agents and they reproduce in host cells hence they are considered to be obligate parasites. The infected cells ultimately breaks down and die.

General characteristics of viruses

- They lack a cellular structure i.e. they are a cellular.
- They are microscopic obligate parasites i.e. they can only live parasitically inside other cells.
- They are made up of nucleic acids (either DNA or RNA but not both)
- Their core body is enclosed by a protein coat known as **capsid** which is made up of **capsomere.**
- Their size ranges from 10nm (nanometre)
- They are ubiquitous. (Being present everywhere at once/found in all environments)
- The DNA of the viruses only reproduces in the living host cells and cannot reproduce outside a living cell
- They are highly specific to the host cell they invade. Each virus recognise and infects a particular host
- They cause diseases in plants and animals.
- They depend on host cells for reproduction

Structure of a virus

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

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Viruses are considered as living because

- They are capable of self replication once in the host cell.
- They are able to synthesize nucleic acids in a host cell
- They are able to synthesize proteins within the host cell
- They are able to Mutate and hence evolve
- They are able to transmit characteristics to future generations.

Viruses are considered as non-living because

- They lack a fixed structure
- They lack an enzyme system and incapable of their metabolism
- They lose life when outside the host cell.i.e they form crystals and grains. And gain life when back in the host cell Viral **diseases E.G** Small pox, Corona virus (**covid-19)** ,Influenza , Common cold , Acquired Immune Deficiency Syndrome (AIDS)

Swine fever

SUBTOPIC 3: KINGDOM: MONERA

These are prokaryotic organisms in which the nucleus is not enclosed in a nuclear membrane. They are unicellular and microscopic organisms

General characteristics

- They are unicellular organisms and microscopic with a variety of shapes
- They have a DNA which is distributed in the cytoplasm without a nuclear membrane.
- They lack membrane bound organelles
- They have a cell wall containing a polysaccharides and amino acids, **murein**
- They reproduce asexually by fission or spore formation and sexually by conjugation.
- Majority feed heterotrophically by absorption while a few feed autotrophically by chemosynthesis and photosynthesis which occurs on membranes containing bacteriochlororphyll/no chloroplasts Have the ability to fix nitrogen

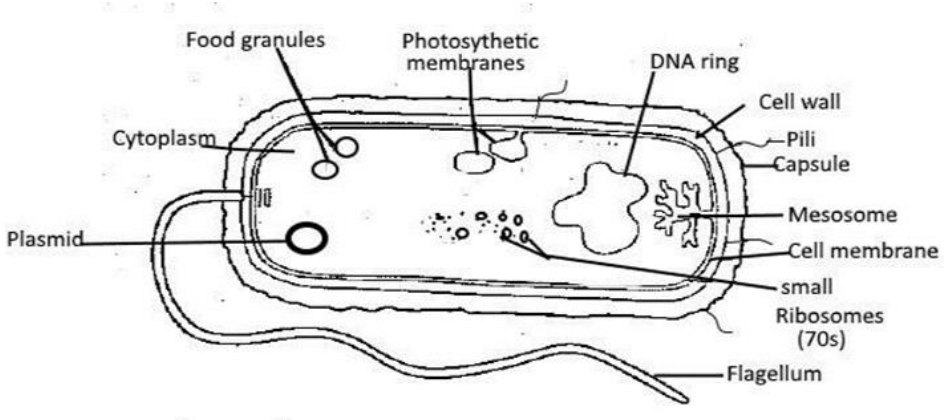
PHYLUM: BACTERIA

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

General Characteristics of Bacteria

- No distinct nucleus
- Lack a membrane bounded nucleus - genetic material lies free in the cytoplasm;
- DNA is naked - not associated with proteins/histones;/DNA not incorporated in chromosomes but comprising of a single circular strand.
- No spindle forms at cell division
- No large cell vacuoles
- Circular DNA – no ends;
- DNA is haploid;
- Complex cell wall made of peptidoglycan (murein);
- If Some have flagella ; lacks 9+2 fibril arrangement for locomotion
- Mesosomes are the sites for respiration – no mitochondria;
- Its cell contains smaller ribosome of 70s
- Have no chloroplasts; Photosynthesis occurs at infoldings of plasma membrane.
- These are mainly unicellular prokaryotic organisms
- Have no nucleus/no nuclear membrane/genetic material is located in the cytoplasm.
- Small sized cells ranging in size from 0.1µ*m*(micrometre) to 20µm
- Its cell contains no double membrane bounded organelles
- Have cell wall impregnated with polysaccharides and amino acids
- Some have the ability to fix nitrogen
- Many of them are saprotrophs, feeding on dead animals and plants and causing decay while others are parasites and cause diseases.
- Cell division is mainly by binary fusion; no spindle fibre formed
- They are found everywhere; in water, soil, air and inside other organisms.

STRUCTURE OF A BACTERIUM



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Function of the different parts of a bacterium cell

Cell Wall	Physical barrier, Protects the cell against mechanical damage and maintains its shape
Capsule	Some bacteria have a slimy layer of **polysaccharides** and polypeptides, allowing them to attach to objects and providing protection.
70s Ribosomes	These are for performing protein synthesis.
Flagellum	Is a projection that propels the bacterium along. A cell may have multiple flagella arranged around it.
Nuclear Material	A folded mass of DNA and RNA, also called **Nuclear zone** .- containing all the genes required to the replicate to new cell
Plasmid	Are additional circles of genetic material/DNA able to replicate independently of the main circular DNA.
Mesosome	An infolding of the membrane that is the site of respiration (like a mitochondrion) - its shape improves surface area.

Viral structure	Bacterial structure
• Are acellular/non-cellular (lack a cellular structure) • Are very tiny (20-300 nanometers in diameter) • May contain DNA or RNA as the genetic material • Genetic material surrounded by a Capsid • Flagella and pili absent • Mesosomes absent • Reverse transcriptase enzyme present • Lacks cell wall and cell membrane	• They have cellular structure • Are relatively larger (0.5-300 micrometers in diameter) • Always contain DNA as the genetic material • Genetic material lacks a Capsid • Flagella and pili may be present • Mesosomes present • Reverse transcriptase enzyme absent • Cell wall and cell membrane present

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REASONS WHY BACTERIA SHOW GREAT DIVERSITY IN THEIR MODE OF LIFE

- **Have varied modes of nutrition** which reduces feeding competition**;**/enables exploiting a variety of habitats**;**
- ***Examples***: some are **heterotrophs (saprophytes, decomposers, parasitic)** others are **autotrophs (photosynthetic, chemosynthetic)**
- **Have complex cell wall** composition of peptidoglycan to exploit a variety of osmotic habitats**;**
- **DNA is haploid;** therefore all alleles are effectively dominant**; recessive mutations** express themselves immediately**;**
- **Asexual reproduction is by binary fission** which is very rapid resulting in many offspring**;;**
- **Ability to fix nitrogen** in some bacteria enables living mutually with legumes e.g. Rhizobium and azotobacter**;**
- **Varied cellular composition** e.g. capsule, flagella, pili etc enable living in **different environments** like soil, dust, water, in and on animals and plants**;**
- **Tolerance to extreme environmental conditions** by some bacteria e.g. hot springs 78^0C freezing ice, under ocean floor at high pressures**;**
- **Very short life cycles** cause rapid multiplication**;**
- **Rapid growth rate** leads to fast attainment of reproductive maturity**;**

- **Very tiny size** enables low food intake**;** /very many occupying little space**;** /fast dispersal**;**
- **Some respire aerobically other anaerobically** therefore habitats with oxygen extremes are occupied**;**
- **Wide variety of species and strains** enables occupying a variety of ecological niches**;**
- **Various resistant stages in life cycle** for surviving harsh environmental conditions**;**
- Reproduction is both sexual and asexual for rapid multiplication;

HOW ARE BACTERIA ECONOMICALLY IMPORTANT?

- They are easily Cultured/grown in laboratories for research purposes;
- Food production e.g Facilitate making of foods like yoghurt, cheese and vinegar;
- Symbiotic relationships with other organisms for example In humans, vitamin K and B complex are produced by the symbiotic bacteria *Escherichia coli* while in herbivores gut cellulase secreting bacteria catalyzes the break down cellulose in grass.
- A source of antibiotics e.g streptomycin
- Manufacturing processes such as tanning leather, retting flax to make linen, soap making and powders
- They cause decomposition of dead organic matter, hence enabling their disposal;
- Breakdown and recycling of plant and animal remains: Take part in nutrient recycling e.g. Rhizobium, Nitrobacter, Nitrosomonas in nitrogen cycle;
- On the other hand, bacteria cause food to get spoilt;
- Pathogenic bacteria are intercellular parasites cause diseases by the toxins they produce.
- Bacteria like *Vibrio cholera* cause the disease cholera which attacks humans;

HOW BACTERIA SURVIVE BAD CONDITIONS

Many bacteria survive bad conditions such as heat, drought or poisons by forming spores. The spores have a thick protective coat around them, they are dormant and they can survive for many years (more than 50 years).

Bacteria reproduce by Binary fission.

a) **Plant-like characteristics of bacteria**

- Some make their own food by the process of chemosynthesis.
- They have a cell wall
- They may store starch granules

b) Animal-like characteristics

- They move by means of flagella
- They may store glycogen
- Some are heterotrophic

Importance of Bacteria in nature or to man

- Bacteria which live in the soil are decomposers of dead organic matter; they add humus to the soil.
- Some bacteria fix atmospheric Nitrogen into the soil, improving on its fertility, e.g Rhizobium which lives in the root nodules of leguminous plants.
- Some bacteria decompose sewage.
- Some bacteria live in the rumen of ruminants and digest food containing cellulose.
- They are used in industries to make yoghurt, cheese, vinegar and butter.
- The majority of bacteria are parasites and cause diseases to other organisms
- They are used to produce enzymes.
- Bacteria like *Thiobacillus* and *Disulphovibrio* produces sulphuric acid which destroys underground metal pipes.

NUTRITIONAL TYPES OF BACTERIA

Bacteria are often classified on the basis of their method of obtaining **energy and carbon source**

a) **Autotrophic bacteria:** build their own organic food by photosynthesis or chemosynthesis

These bacteria manufacture their own organic food from carbon dioxide.

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i) Photoautotrophic (photosynthetic/**light self- feeders**) bacteria use energy of sun light to convert carbon dioxide into carbohydrates.

Photosynthetic bacteria/photoautotrophic bacteria: use the energy of sunlight for manufacture of food. e.g green and purple Sulphur bacteria contain bacteriochlorophyll and photosynthesize using hydrogen sulphide (not water) as a source of hydrogen, Sulphur not oxygen is a by-product.

Examples include; the cyanobacteria (blue-green bacteria), **sulphur bacteria.**

ii) Chemoautotrophic (**Chemosynthetic bacteria /chemical self- feeders):** Do not require sunlight and use simple energy sources such as methane, ammonia or hydrogen sulphide.

They use energy from the oxidation/break down of inorganic materials/compounds and use this energy to synthesize/manufacture their own food. Use carbon dioxide as a raw material for making organic compounds but obtain their energy by oxidizing inorganic chemicals such as ammonia and nitrites. bacteria such as nitrifying bacteria oxidize ammonia to nitrites and release energy in the nitrogen cycle ;Colourless sulphur bacteria oxidize hydrogen sulphide to sulphur and release energy.

Example include. *Nitrifying bacteria/Nitrosomonas/ Nitrobacter sulphur 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.

b) Heterotrophic bacteria: They feed like animals and fungi on already-made organic source of carbon/ food but in different ways.

i) Chemoheterotrophic bacteria *use an organic source of carbon obtain their energy from chemical reactions/oxidation of organic food materials.*

They obtain energy from oxidation/breakdown of living or non-living organic matter and the source of carbon is organic *Examples*

- ***Saprotrophic -Saprotrophs/ decomposers breaking down dead organisms***
- ***Mutualistic bacteria/symbiotic- e.g.***
- ***Parasitic bacteria e.g. infecting other organisms and cause disease.***
- ***Predators eating other microorganisms***

Such as denitrying bacteria that is import in the recycling of nitrogen back to the atmosphere

ii) Mutualistic bacteria /Symbiotic bacteria: live in close associations with other organisms

- *Escherichia. Coli /*Bacteria in the human gut syntheses some of the vitamin **B** complex *and **K** groups*
- Rhizobium-nitrogen-fixer living in the root nodules of leguminous plants as it is provided with a shelter. The rhizobium bacteria fixes nitrogen in air to nitrates in the soil which are absorbed by the p**lants**.

Both organisms benefit and none is harmed.

1. The leguminous plant provides water, shelter, protection and nutrients (organic and inorganic) to the bacteria.
2. The rhizobium bacteria have the ability of fixing nitrogen, in the form of nitrates into the soil from the atmosphere. The nitrates are absorbed and utilized by the leguminous plant.

- Symbiotic bacteria in the rumen and caecum of herbivores secrete cellulase enzyme which digests cellulose.

Parasitic bacteria: lives in or on another organism (host) from which it obtains food and shelter as the host suffers harm from the parasite.

- Some parasites can only survive and grow in living cells and are called **obligate parasites**.
- Others can infect a host bring about death and then live s**apropytically** on the remains.

These are called **facultative parasites** e.g. .***Vibro cholerae*** causes cholera; bacillus causes anthrax.

Bacterial diseases

Plant diseases

Bacteria wilts e.g. wilt of Tobacco caused by pseudomonas bacteria

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Bacteria spot diseases; usually occur on the leaves but fruits and stems may also be affected.

Animal diseases

Anthrax; caused by Bacillus anthrax and occur in herbivorous animals. It affects parts like the intestines. Black leg which infects ruminants.

Saprotrophic -Saprotrophs/ decomposers breaking down dead organisms

Saprotrophs: obtain their food from dead and decaying matter. The saprotroph secretes enzymes onto the organic matter to digest it. The soluble products of digestion are absorbed and assimilated within the body of the saprotroph. Saprotrophs bring about decay and recycling of nutrients

ii) Photoheterotrophic bacteria

These are bacteria that use light energy from the sun to synthesize organic carbon compounds using other organic raw materials for example purple non sulphur bacteria. They cannot use carbon dioxide as their sole source of carbon.

Phylum: cyanobacteria

Cyano-refers to characteristic blue-green appearance of many members of this group, which is caused by the presence of **blue** pigment called **phycocyanin**. They also **contain a red** pigment call **phycoerthrin**

They are responsible for the **blue-green "bloom**" seen on the surface of ponds. They has gas vacuoles which help them float on the water surface

Characteristics of cyanobacteria

- Have ability to carry out photosynthesis
- Have the ability to fix atmospheric nitrogen
- Colonies warm moist soils, marine and fresh water environments
- Reproduce by binary fission and the filamentous ones reproduce by fragmentation

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CLASSIFICATION BY STAINING REACTION

1. **Gram positive bacteria;** they stain purple with a gram stain.

The cell wall lacks an extra outer membrane.

2. **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.

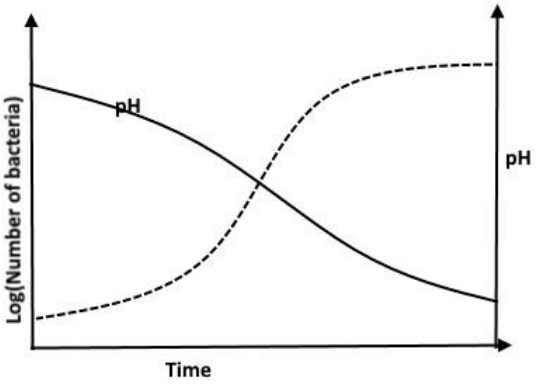
FACTORS WHICH AFFECT BACTERIAL GROWTH

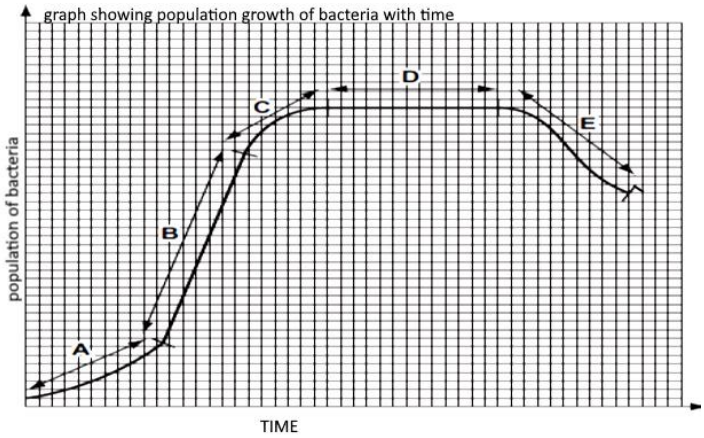
- Nutrient availability
- Oxygen availability
- Temperature
  High temperature speeds up bacterial population growth up to 40^0C after which it declines
  Very low temperatures slow down bacterial growth because the enzymes become inactivated.
- Availability of moisture
- Accumulation of toxic waste 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.

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;

- Stiff competition for decreasing food
- Depletion of oxygen (reduction of oxygen)
- 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.

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SUBTOPIC 4: KINGDOM PROTOCTISTA

Protoctists are eukaryotes and they may be unicellular or multicellular.

CHARACTERISTICS OF PROTOCTISTS

1. **They** often bear cilia and flagella and the flagella has 9+2 arrangement of microtubules.
2. They have various modes of nutrition i.e. autotrophs which are the primary producers in fresh water bodies.e.g unicellular algae and multicellular organisms like spirogyra, brown algae.
3. These organisms are capable of producing their own food in aquatic environments and there for are known as phytoplanktons.
4. They are mainly aquatic unicellular eukaryotic cell organism.
5. They occupy 3 niches of ecosystem i.e producers, consumers and decomposers.

They are divided into two sub-divisions i.**e**

I) PROTOZOAN (ANIMAL-LIKE PROTOCTISTA)
II) ALGAE (PLANT-LIKE PROTOCTISTA)

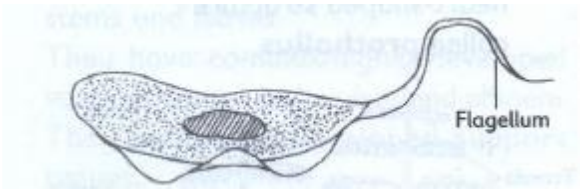
A) PROTOZOA (animal-like): Examples: ***Amoeba, Euglena, Paramecia, Plasmodium, and spirogyra***.

Protozoa has the following characteristics;

i) They are single celled/unicellular heterotrophic organisms.
ii) They contain a single nucleus but sometimes may have many nuclei 3. Most of the members in this phylum are microscopic.
iii) They have membrane-bound organelles
iv) Some member's locomote freely using pseudopodia, cilia, or flagella.
v) It has an eye spot

1 Phylum: Zoomastigina (flagellates) e.g. Examples include Trypanosoma which causes trypanosomiasis (sleeping sickness), trychomonas

- Have one or more flagella(with 9+2 microtubule arrangement) for locomotion
- Unicellular heterotrophic. I.e. feed by parasitism. Hence don't have chlorophyll,
- They may be free-living or parasitic
- They are colourless
- The reproduce both asexually and sexually
- They bear a 9+2 tubule arrangement
- Some are blood parasites that cause African sleeping sickness in man and Nagana in animals



2. Phylum: Rhizopoda (rhizopods) e.g amoeba Class: Sarcodina.

These are animals of phylum Protozoa that move by formation of the false feet, called **Pseudopodia**.
Examples include; ***Amoeba proteus***, which lives in ponds, fresh water and marine water.
Another example is **Entamoeba** which is found as a parasite in the mouth cavity and the intestines of certain mammals. *Entamoeba histolytica* which causes amoebic dysentery

Characteristics of rhizopods

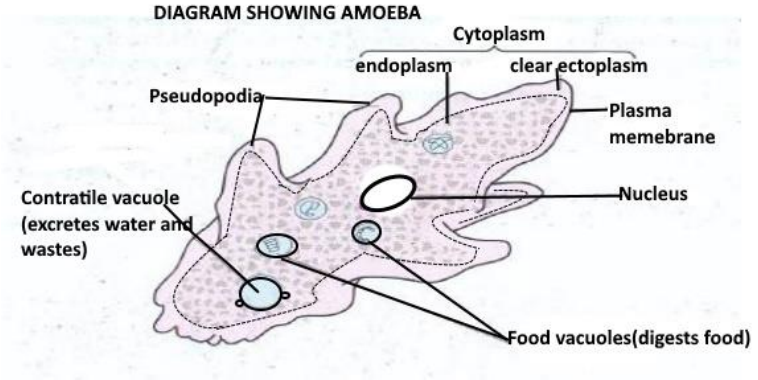
- They are unicellular and bear pseudopodia (false feet) which enables movement and phagocytosis
- They reproduce asexually
- They feed heterotrophically

Characteristics of amoeba

- Has an irregular shape which constantly changes
- Lives in mud at the bottom of the pond
- It has a clear outer layer called the **ectoplasm** and an inner layer called the **ectoplasm**.
- It has a number of food vacuoles.
- It has a contractile vacuole which controls the amount of water present in the organism.
- It moves by forming pseudopodia.

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



Reproduction in amoeba

Amoeba reproduce by binary fission whereby the nucleus becomes long (elongates) and divides into two parts. At the same time, the protoplasm begins to divide into two halves. At the end of the process, two new amoebae are formed, each having the same content as the other and as the mother cell.

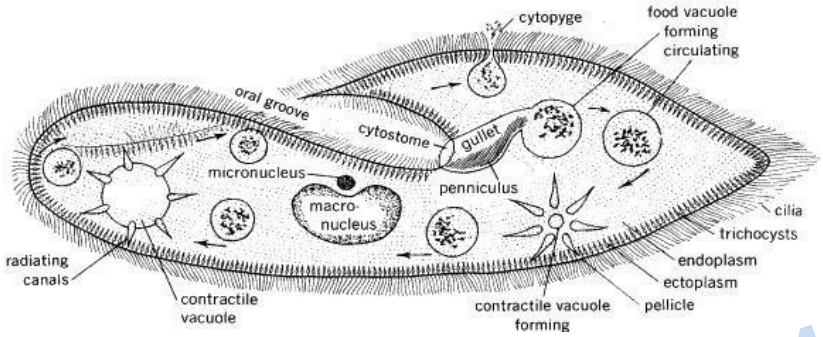
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3: Phylum: Ciliophora (ciliates)

Characteristics

- They feed heterotrophically i.e. They are ciliated heterotrophic protozoans.
- 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 polyploidy i.e. it has more than two sets of chromosomes and the micro nucleus is diploid i.e. it has two sets of chromosomes.
- Have numerous cilia which have the 9+2 microtubule arrangement for locomotion
- The cilia collects food and enable locomotion in water
- They also reproduce asexually by binary fission.
- Ciliates are very numerous in freshwater and marine environments

An example of class Ciliophora includes Paramecium which lives in fresh water and it swims freely.



4. Phylum: APICOMPLEXA (SPOROZOANS)

- These are parasitic protozoan with no locomotory structures.
- They are spore-forming parasites of animals
- They are unicellular and heterotrophic
- They reproduce sexually and asexually
- They have multiple fission stages in their life cycle. They lack locomotory structures
- They are spore producing parasites of animals
- Their lifecycles are complex involving several animal hosts

Examples include; **Plasmodium spp,** a blood parasite that causes malaria in humans and involves adult female anopheline mosquito as the vector and secondary host.

LIFE CYCLE OF PLASMODIUM

An infected anopheles mosquito bites a person, injecting plasmodium sporozoites in its saliva. The sporozoites enter the person's lever cells. After several days, the sporozoites undergo multiple divisions and become merozoites, which use the apical complex to penetrate red blood cells. The red blood cells divide asexually inside the red blood cells. At intervals of 48 or 72 hours (depending on the species), large numbers of merozoites break out of the blood cells, causing periodic chills and fever. Some of the merozoites infect other red blood cells. Some merozoites form gametophytes. Another anopheles mosquito bites the infected person and picks up plasmodium gametophytes along with blood.

Gametes form from the gametophytes; each male gametophyte produces several slender male gametes. Fertilization occurs in the mosquito's digestive tract, and a zygote forms. An oocyst develops from the zygote in the wall of the mosquito's gut. The oocyst releases thousands of sporozoites, which migrate to the mosquito's salivary glands.

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5. Phylum: Oomycota (oomyctes) /fungus like protoctists

- They are fungus like protoctists whose body consists of non-septate hyphae i.e has no cross wall.
- May be parasites or saprobionts
- They resemble fungi in their mode of nutrition i.e have thread-like hyphae which secrete enzymes into the host's tissue which are digested and the soluble nutrients absorbed.
- It has cellulose cell wall yet fungus has chitin. Examples phytophthora infestans

B). ALGAE (plant-like protoctists)

These are photosynthetic eukaryotic organisms ranging from unicellular to simple filamentous forms to huge sea weeds.

- They are used in sewage treatment and as food for animals
- They are the primary producers in water bodies/aquatic
- They are responsible for the production of oxygen in aquatic water bodies used by zooplanktons for aerobic respiration and absorb carbon dioxide.

Spirogyra Is a slender green thread-like organism floating on water. The filaments are not branched and each cell is cylindrical in shape **Kingdom: protoctista:**

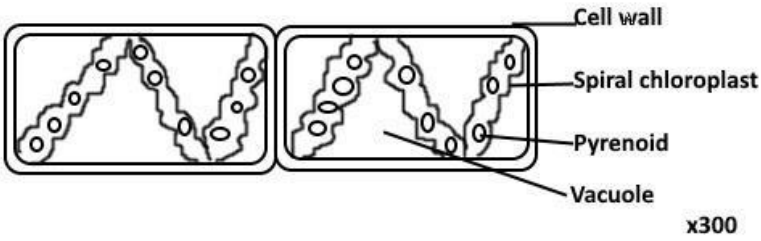
Reasons identical cells and being unicellular
Phylum: **chlorophyta:** filamentous, have chains of identical cells, contain spiral chloroplasts, flat thallus
Class chlorophyceae
Order: zygnematales/conjugales
Genus spirogyra

Structural characteristics of spirogyra

Each filament is a chain of rectangular cells, joined end to end/separated by end walls.i.e

- Its filaments are separate lengthwise.
- It is long, unbranched and filamentous.
- It has long spiral shaped chloroplast.
- It has numerous small circular pyrenoids.
- It has a large vacuole.
- It has thick cell wall.
- It has thin cytoplasm.

Drawing of two cells of spirogyra observed under medium power of a microscope



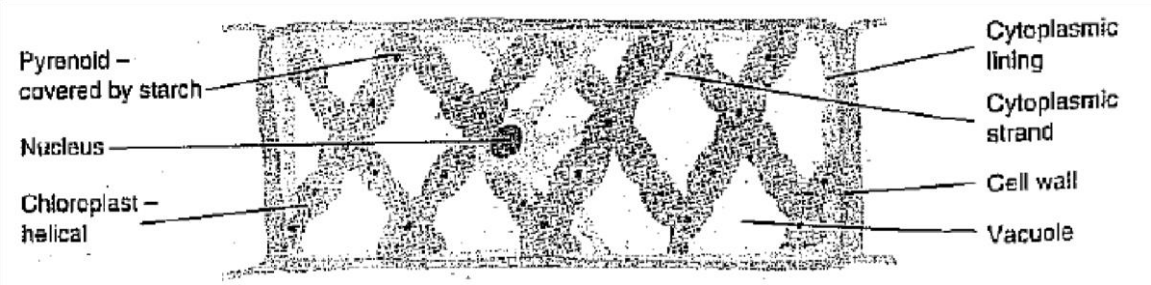
Adaptations of spirogyra to survive in its environment

- It has long filament to increase its surface area for absorbing light and for gaseous exchange.
- The cells are joined end to end to ease fragmentation or sexual reproduction and for flexibility.
- It has long spiral chloroplast to increase surface area trapping sun light for photosynthesis.
- It is a thin filament for easy floating on water.
- It has numerous circular pyrenoids to store much starch(food).
- It has thick cell wall for protection.
- It has an autotrophic nutrition due to possession of green pigment in chloroplast.
- It is smooth, thus its habitat is aquatic to avoid desiccation.

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Economic importance.

- Spirogyra / algae are the primary producers in fresh water ecosystems.
- They release oxygen into the water for use by aquatic organisms. I.e. they create a balance of gases in the aquatic environment by producing Oxygen needed for life and also taking out Carbon dioxide.



Habitat: aquatic. Because its long thin filament slimy for easy floating on water surface.

Nutrition: autotrophic nutrition, due to the green colour/green pigment/chlorophyll that traps sun light for photosynthesis.
They can reproduce sexually by conjugation and asexually by fragmentation. They are covered with a layer of slime which prevents the cells from getting entangled.

Phylum phaeophyta (brown algae)

- They are marine sea weeds brown in colour due to possession of brown pigment known as fucoxanthin.
- Its body is multicellular thallus with very many tissues i.e. its body is not divided into roots, short stem that have no vascular bundles
- They have chlorophyll as the photosynthetic pigment and carotene and xanthophylls.
- They store carbohydrates in form of starch in laminarin and fat in mannitol.
- They have a cell wall containing alginic acid.
- 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 (red algae)

These are red multi-branched filamentous algae whose chloroplast contain chlorophyll a, carotene and xanthophylls masked by a red pigment known as **phycoerthrothrin** that makes the plant to appear red in colour. Phycoerythrin absorbs wave of light of light penetrating deeper in sea water.

Phylum: baciliariophyta (diatoms)

These are multicellular algae whose cell wall consists of cellular impregnated with silica.
The wall is divided into two halves called valves.

Structure of diatoms

Economic importance of algae

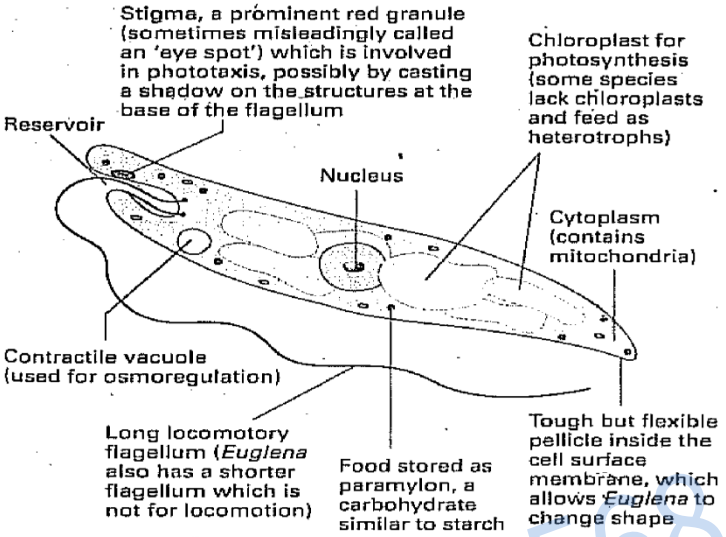
- Green algae provides oxygen for the aerobic organisms which break down sewage
- They are the main primary producers at the base of all the aquatic food chains. i.e. The carry out photosynthesis in oceans which:
  - Provide food for other organisms
  - Release oxygen which is used by aerobic organisms
  - reduce half carbondioxide on the earth which would cause acidity in water
- Used as fertilizers on coastal farms

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- Excessive numbers of algae may develop in water bodies due to pollution/by fertilizer addition causing algal brooms which causes severe water pollution resulting into smell and tastes unpleasant. Algae in some parts of the world is a direct source of food to humans.
- Some of their products are useful in various industrial processes
- Chlorella can be cultivated to provide Single Cell Protein (SCP) for humans and animal consumption

Phylum: Euglenophyta

These are fresh water protozoans that have one or more flagella (flagellum) which is used for movement.



- Some are photosynthetic while others are non-photosynthetic
- They have no cell wall
- Their body is covered by a tough protein layer called pellicle.
- They have one or more long conspicuous flagella for locomotion
- They have chloroplasts containing chlorophyll a and b and carotenoids/carotene, xanthophylls
- They store their carbohydrates as paramylon (similar to starch)

Examples in this class include; **Euglena** (this one contains chlorophyll, its green in colour and its found in fresh water).

Long **Flagellum**(plural: flagella): these are used for locomotion by the organism

Nucleus: controls all cell activities like reproduction by binary fission

Chloroplast: manufactures food for the organism through the process of photosynthesis. **Pellicle**: protects all the internal organelles from mechanical damage

Eye spot: allows in light from one direction

Contractile vacuole: expels excess water from the body of the organism/used for osmoregulation

Characteristics of Euglena

- Plant-like characteristics
- It has chloroplasts
- It has starch granules
- Animal-like characteristics
- It has contarctile vacuole
- It has a flagellum

SUBTOPIC 5: KINGDOM FUNGI

Examples of fungi; mushrooms, toadstools, puffballs, moulds, yeast, penicillium

Characteristics

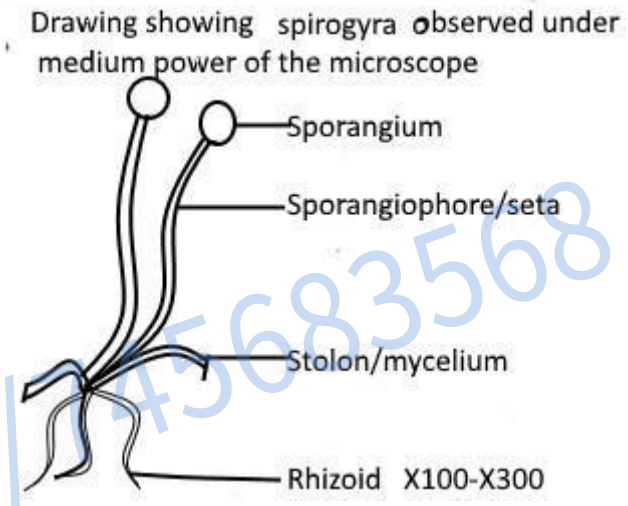
- Normally have hyphae often grouped as mycelium.
- They are decomposers. They feed on dead plant and animal matter. Thereby recycling nutrients.
- Have a rigid cell wall consisting of hemicellulose, chitin liquid and protein rather than cellulose.
- They lack chlorophyll i.e non-pigmented thus feed hetrotrophically (either parasitic or saprophytic.
- They reproduce sexually by fission and asexually by sporulation.
- Body consists of elongated fine filaments which form a network called mycelium.
- They are non-motile
- Some fungi cause diseases

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Characteristics that distinguish fungus 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)
- No vascular tissues commonly associated with most plants

Classification of Rhizopus species
Kingdom: Fungi
Phylum: zygomycota
Class: **zy**gomycetes/phycomycetes
Order: zygomycetales/murales
Genus: rhizopus, mucor.



STRUCTURAL FEATURES OF RHIZOPUS
It consists of a mass on thin branching, threadlike structures known as mycelium, long thin slender stalk called **sporangiophore,** terminating into a black/brown spherical/round head called sporangium/spore case.
Mycelium: It consists of stolon or linking hyphae and rooting hyphae the rhizoids .stolon is long, slender .and thin network of hyphae called **mycelium**. Mycelium has a large surface area for support. **Rhizoids** are numerous, thin and slender .they are**;**

- Thin to easily penetrate the substratum.
- Many numerous to increase surface area for absorbing nutrients.
- To easily absorb nutrients easily by reducing diffusion distance.

Sporangium (spore capsule) It is ball shaped or bulbous or spherical, swollen, and dull coloured or black.
Rhizopus is found in moist places to avoid desiccation. It is smooth, thus it can easily lose water leading to desiccation if exposed to high temperatures.
The nutrition of Rhizopus is heterotrophic due to lack of chlorophyll.

Adaptations of rhizopus to survive in its environment

- It produces numerous spores for easy multiplication of for easy colonization of new areas.
- It has numerous rhizoids to increase surface area for easy absorption of nutrients.
- It has network of hyphae (mycelium) for support.
- It has long sporangiophore so as to raise sporangia above the mycelium for spores to easily be blown by wind for easy dispersal.
- It has thin rhizoids for fast absorption of nutrients and anchorage.
- Has sporangia containing spores that are resistant to adverse conditions and thus resume the lifecycle when conditions become favourable.

Economic importance

- They enhance recycling of nutrients in an ecosystem by decomposing dead organic matter.
- Some species of mucor produce enzymes that ferment sugar and so used in production of alcohol /breweries. Yeast is used in the brewing industry to make alcohol

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- Production of antibiotics, notably from penicilium which kill harmful bacteria and aspergillus.
- Production of other foods.e.g.citric acid for lemonade is produced by the fermentation of glucose by aspergillus species of fungus.
- Yeast is used in bread production. Yeast which respires anaerobically is added to the dough producing CO_2 in it. Upon baking in Oven, the CO_2 expands the bread making it light in texture.
- Many fungus are also harmful to humans by causing
- Decomposition of stored foods and deterioration of natural materials such as leather and wood.
- Some cause diseases to other organisms like man.

Reproduction by rhizopus

Rhizopus reproduces asexually through formation of **haploid spores.** When the spores lands on a suitable medium, it germinates into a vertical hyphae called **sporangiosphore** and horizontal hyphae known as **mycelium**. The sporangiophore develops sporangium which produces many spores. The mature sporangium ruptures to release the spores which under suitable conditions germinate into a fungus "plant". Rhizopus being haploid produces spores by mitosis.

Alternation of generation is the life cycle of plants which consists of two alternating stages of growth/generations between haploid gametophyte which produces gametes by mitosis and a diploid sporophyte which produces spores by meiosis. **Or**

Alternation of generation is defined as the development of a diploid sporophyte generation followed by the development of a haploid gametophyte generation in the life cycle of an organism.

Nutrition: they feed saprophytically.i.e. Secrete various enzymes that digest the dead organic matter externally and absorb the digested food into the mycelium. This type of digestion is referred to as extracellular digestion.

Fungi may be categorized into three groups depending on their mechanism of nutrition.

1. **Saprotrophs**: saprophytes e.g. mucor ,rhizopus, penicilium et.c
2. **parasites**: they may be facultative or obligates e.g coffee rust, ring worms
3. **Mutualistic fungi** e.g. lichens;

- Lichen is a mutualistic association between a fungus and green algae. The fungus forms the outer covering that protects the algae in the interior of the lichen.
- The fungus absorbs food from the algae while the algae obtains protection and mineral salts and water from the fungus.
- The fungus also provides the algae with water and inorganic nutrients and anchorage. In return, the algae photosynthesize and provide the fungus with organic nutrients and oxygen.

CLASSIFICATION OF FUNGI

Kingdom fungi is subdivided into the **following phyla**

Phylum: zygomycota (zygomycetes)

These include mucor,rhizopus .

- They reproduce asexually by means of spores which develop inside the sporangium/spore case/conidia.
- They reproduce sexually by conjugation which gives rise to **zygospore**
- **The hyphae do not have cross walls** in others words they are aseptate/ non-septate/not segmented They have well developed branching mycelia

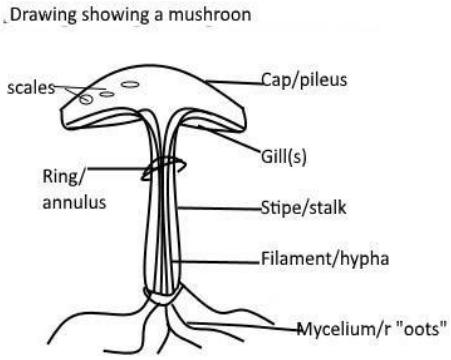
Phylum: Ascomycota (ascomycetes) e.g. **Yeast** belongs to this phylum but differ from others in normally being unicellular and penicilim, mould sordaria

- They reproduce asexually by fission, spores or budding and have no sporangium
- Have septate hyphae which allow streaming of the cytoplasm. The partial divisions are multinucleated.

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- Have Sac-like **ascus** formed during Sexual reproduction by conjugation and fusion of nuclei of two mating types (+ and -) results in the formation of **ascospores** inside the **ascus**
- Penicillium produces penicillin which is an antibiotic, during aerobic respiration.

Phylum Basidiomycota (basidiomycetes) e.g mushrooms, toad stools puffballs and bracket fungi



- They take their name from basidium a structure which bears sexually produced spores
- Have septate hyphae with a cap-shaped tip called **basidium** which has gills or lamellae on their lower surface that produce spores.
- They lack sporangium and conidia but produce spores
- Sexual reproduction by basidiospores outside basidium.

Phylum: denteromycota

Has no sexual reproduction and its classification is uncertain.

Questions

i) Briefly describe the nutritional groups of fungi, giving an example in each case.(10 marks)

ii) Outline the economic importance of fungi (10 marks)

(a) Nutritional groups of fungi include;

Saprotrophic fungi *feed on dead and decaying matter secreting enzymes on to the organic matter and digesting it outside of the organism then absorbing and assimilating the soluble products of digestion, Examples; Penicillium/Mucor/Rhizopus*

Parasitic fungi *live close association with organism of other association with organisms of other species with the fungal parasite benefitting in terms of nourishment and shelter and the host is harmed in some way. Parasitic fungi may be facultative or obligate*

Examples candida/powdery mildews/downy mildews/rusts/smuts.

Mutualistic fungi *live in close association with organisms of other species where both organisms benefit*

Example 1,

Lichen *is a mutualistic association between fungi and green algae or blue-green bacteria/cyanobacteria. The fungus provides absorbs water and mineral salts and conserves water and protection from the environment. While the alga contributes sugars/organic food from photosynthesis, and protects the fungus from high light intensity.*

Some fungi produce pigments *that shield algae from ultraviolet radiation/excess light or toxic substances that discourage algae consumption by grazers*

Example 2

A mycorrhiza *is a mutualistic association between a fungus and roots of plants. The fungus increase the ability of the plant roots to absorb water and mineral salts particularly ammonia, phosphate, potassium and nitrates which pass to the plants and the plant provides carbohydrates and vitamins / organic products of photosynthesis to the fungus.*

There are two types of mycorrhizal relationships namely ***endotrophic and ectotrophic mycorrhizal relationships***

Endotrophic mycorrhizal relationships

Here the fungi forms a loose network of hyphae on the root surface and also penetrates the root cells extensively.

Ectotrophic mycorrhizal relationships

The fungal hyphae only form a loose sheath around the root surface

Significance of the mycorrhiza relationship

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It is the major route of entry of nutrients into the root

(b) -Parasitic fungi cause fungal diseases such as candidiasis/mildews/ smuts/rusts

- Saprotrophic fungi cause food and fruits to go bad through decay causing food loss
- Yeasts produce alcoholic beverages during brewing of beers/wines/ales
- Together with bacteria fungi are used in the manufacture of cheese
- Yeasts make bread rise during baking easing digestion of bread
- Provide man with food such as mushrooms
- Used to produce antibiotics for example streptomycin/penicillin
- Saprotrophic fungi break down dead organic matter thereby facilitating nutrient cycling and increasing soil
- fertility
- Saprotrophic fungi break down sewage to harmless inorganic matter
- Unicellular fungi are used in micro biotechnology for example yeasts produce mycoprotein using single cell protein technology
- Fermentation of glucose by Aspergillus produces citric acid for pemonade

Question

(a) With an example in each case briefly describe the four nutritional categories of bacteria.

b) How does a bacterial cell differ from that of a higher plant

The four nutritional categories of bacteria;

Autotrophic bacteria

Photoautotrophic bacteria *use an inorganic source of carbon/carbon dioxide is source of carbon obtain their energy from light examples blue-green bacteria/Anabaena/Spirulina/Spirogyra/Chlorella (green bacteria, blue-green bacteria, purple sulphur bacterial, purple non-sulphur bacteria.*

Chemoautotrophic bacteria *use an inorganic source of carbon/carbon dioxide is source of carbon obtain their energy from chemical reactions/oxidation of inorganic materials such as ammonia, nitrites examples nitrifying bacteria/Nitrosomonas/ Nitrobacter sulphur bacteria.* ***Heterotrophic***

Photoheterotrophic bacteria *use an organic source of carbon/carbohydrate is source of carbon obtain their energy from light examples purple non-sulphur bacteria*

Chemoheterotrophic bacteria *use an organic source of carbon obtain their energy from chemical reactions/oxidation of organic food materials examples Saprotrophic- Saprotrophs/ decomposers Mutualistic bacteria/ Escherichia, coli, Rhizobium Parasitic bacterial/, (, parasites.*

b) ***Differences between a bacterial cell and a higher plant cell***

Bacterial cell	**Higher plant cell**
Has no distinct / true nucleus.	Has distinct/ true nucleus.
DNA not incorporated; in chromosomes	DNA incorporated in chromosomes
DNA is circular;	DNA is linear
No spindle is formed; during cell division	A Spindle Is Formed during cell division
Few organelles;	Many organelles
Lack of organelles surrounded by two membranes/ envelope;	Has organelles surrounded by two membranes/envelope e.g. mitochondria, chloroplasts
Cell wall made of amino acids & polysaccharides strengthened by murein;	Cell wall made of polysaccharides strengthened by cellulose.
Smaller coverage (diameter 0.5-10mm);	Lager (average diameter 10-100mm)
No chloroplast. Photosynthesis occurs on unstacked membranes;	Has chloroplast containing membrane stacked into lamellae or grana
Some can fix nitrogen;	None can fix nitrogen

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Respiration occurs on mesosomes in bacteria, and cytoplasmic membranes in blue - green bacteria;	Aerobic respiration occurs in mitochondria and anaerobic respiration occurs in cytoplasm
Some have flagella;	None has flagella
Has smaller (705 ribosomes)	Has larger(805 ribosomes)
Divide binary fission mostly	1divde by mitosis, meiosis or both

Nutritional types of bacteria

- ***Symbiotic bacteria;*** *live in the root-nodules of leguminous plants and fix nitrogen in air to nitrates in the soil which are absorbed by the plants*
- ***Symbiotic bacteria*** *in the rumen and caecum of herbivores secrete cellulase enzyme which catalyses the breakdown of cellulose.*
- ***Symbiotic bacteria*** *in the small intestine of humans help to synthesis vitamin B*
- ***Parasitic bacteria*** *cause a number of diseases such as cholera*
- ***Chemo-heterotrophic*** *bacteria such as denitrying bacteria that is import in the recycling of nitrogen back to the atmosphere*
- ***Chemosynthetic bacteria*** *such as nitrifying bacteria are essential links in the nitrogen cycle ;they break down compounds and energy is released and used in the manufacture of food by the bacteria*
- ***Photosynthetic bacteria*** *which are anaerobic and fix solar energy into food in the ecosystem*

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SUBTOPIC 6: KINGDOM: PLANTAE (plants)

Characteristics

- All Plants are multicellular autotrophic eukaryotes with photosynthetic nutrition
- Their cell walls contain cellulose
- They have green plastids called chloroplasts which contains chlorophyll and other pigments except for some parasites that lack chlorophyll
- They reproduce both sexually and asexually
- Have alternating haploid and diploid generations in their life cycle.
- The diploid generation is called **sporophyte** which produces spores in sporangia and the haploid generation is called **gametophyt**e which produces sex cell/gametes

It is made up of the following phyla; 1) **Bryophyta 2) Filicinophyta/pteridophyta; 3) coniferophyta and 4) Angiospermophyta;**

Phylum: Bryophyta (bryophytes)

This is the simplest group of land plants and it includes two classes.

i) Class: **Musci.** This includes mosses

ii) Class: **Hepaticae**This includes Liverworts

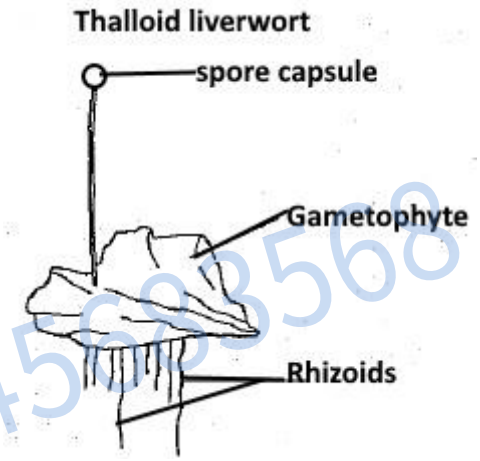
Characteristics of Bryophyta

- They lack true roots, stems or leaves i.e. No true roots but body is anchored by thin filamentous structure called **rhizoids** which are outgrowth from the stem for anchorage, absorption and support.
- They show alternation of generation between gametophyte is the dominant and sporophyte.
- The sporophyte is dependent and attached to the gametophyte i.e. it gains nutrients from the gametophyte.
- Bryophytes are poorly adapted on land and so are mainly confined to damp, shady places.

- The gametophyte is the most dominant generation and is differentiated into simple short stem and leaves but without true vascular tissue (Xylem and phloem)
- They lack vascular tissues
- The plant surface lacks a cuticle and so it has no barrier against loss or entry of water. Water and mineral salts are absorbed by the whole plant surface because the plant surface lacks a cuticle; therefore water uptake occurs by **osmosis**
- The sporophyte (2n) bears sporangium that produces spores by meiosis and the gametophyte bears male organs (**antheridia**) and female organs **(archegonia**) that reproduce sperms/anthrozoids and ova respectively. Examples of bryophytes; Liverworts and Mosses
- Their body is a **thallus** which is differentiated into simple "leaves and stems"
- The gametophyte is anchored by thallus rhizoids which grow from the stem.

Class: Hepaticae .This includes Liverworts

Characteristics of liverworts



- Lack true roots but have unicellular filamentous rhizoids for water absorption; support and anchorage.
- The gametophyte is flattened ribbon or leafy shoot and undifferentiated thallus
- The antheridia and archegonia are born on the thallus/body
- Have colourless translucent seta /stalk
- They show alternation of generation
- They are small green plants found in moist terrestrial/shady places/ habitats.
- Spore capsule splits in four to release spores
- Spores develop directly into photosynthetic gametophyte

Note: the plant body is usually dorsal-ventrally flattened into a horizontally growing, branching and ribbon shaped thallus

Class: Musci

- possession of a large swollen sporangium,
- has numerous thin rhizoids at the base of the stem and
- Has clusters of small spirally arranged leaves.
- The sporangium produces spores for a sexual reproduction, rhizoids are used for anchorage and green small pale leaves are used for photosynthesis.

Kingdom: **Plantae**; Phylum: **Bryophyta;** Class: **Musci** order: **Antherozoidae** Genus: f**unaria**

Structural characteristics

- Have thin numerous multicellular rhizoids
- It has Sessile/unstalked ovate, small sized, net veined, hairy, pale green "leaves" which are spirally arranged on a simple stem.
- Have elongated seta/stalk which attaches the spore capsule at the tip for easy spore dispersal.
- The gametophyte is has spirally arranged leaves with a short stem
- The spore capsule of the sporophyte contains many haploid spores and is covered by **calyptera/operculum**
- Sporophyte is attached to the leafy gametophyte for nutrients/food
- The antheridia (male) and archegonia (female) organs are found on the leaves of several branches of the gametophyte.
- Spores develop into protonema

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.**Adaptations that enables bryophytes to survive in their habitat.**

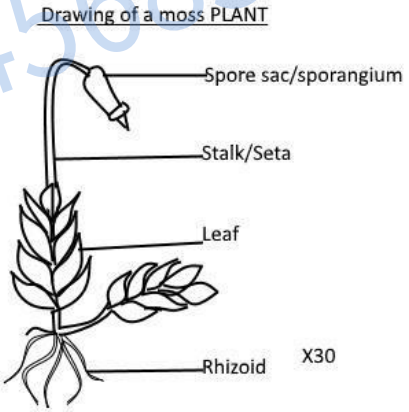
- It has numerous rhizoids for anchorage and absorption of water
- It has a large /swollen spore capsule to produce numerous spores allow quick colonization of sporophyte on the land.
- It has elongated seta/stalk to raise the spore capsule high for easy dispersal of spores.
- Has pale green "leaves" containing chlorophyll for trapping sunlight for photosynthesis.
- Lacks cuticle to enhance water absorption.
- They produce spores which have less food stores which makes them light for easy dispersal there by reducing overcrowding.
- They possess spirally arranged leaves which reduces the rate of transpiration.
- They produce many spores that can withstand unfavourable conditions/they are resistant to adverse environmental conditions so that they can survive and germinate when conditions are favourable.

Qn.Outline the limitations' that moss plants face in surviving on terrestrial habitat

- They have small sessile/unstalked leaves which provides small surface area for trapping sunlight for photosynthesis.
- They possess false roots /rhizoids which are superficial which are incapable of absorbing enough water.
- They have leaves which are pale green and thus have inadequate chlorophyll for photosynthesis
- They have a thallus which provides large surface area for water loss thus liable for desiccation.

Habitat. Moist/Damp shady places e.g. rocky areas and bark of trees.

Moss plant is adapted to surviving in moist areas of land due to possession of swallow rhizoids, very short stalk and small leaves.



Economic importance

- Their decomposition increases soil humus content/fertility.
- They add oxygen to the atmosphere and remove carbon dioxide from it.
- Important in early colonization of bare land, helping to prevent erosion and
- enrich the ground for the growth of larger plants

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Qn.1. Compare moss and liverworts

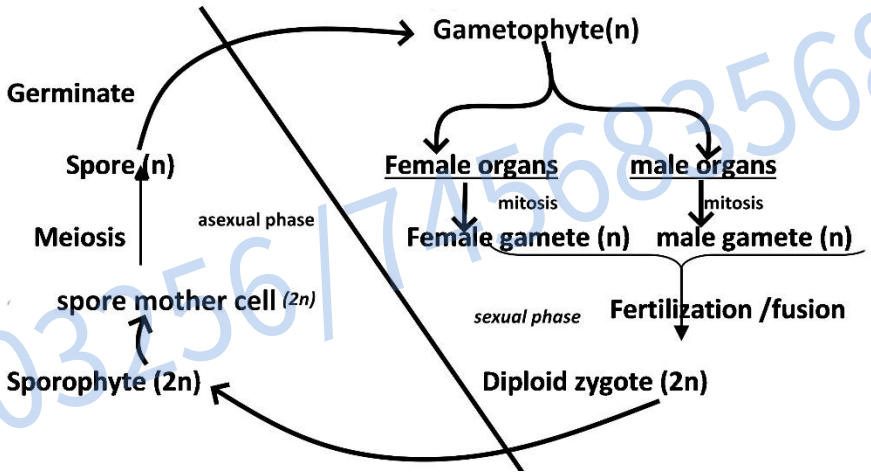
Liverworts	**Moss**
Unicellular rhizoids	*Multicellular rhizoids for ttahment*
Have colourless translucent seta	*Have opaque and green seta /stalk*
Antheridia and archegonia are born on the thallus	*Antheridia and archegonia arefound on the leaves of several branches of the gametophyte*
Gametophyte is flat and normally in form of a thallus	*Gametophyte is leafy in a shoot stem*
Spores develop directly into photosynthetic gametophyte	*Spores develop into protonema*
Spore capsule splits in four to release spores	*Elaborate mechanism for dispersal of spores involving hygroscopic teeth*
Similarities :both bear a spore capsule, seta/stalk; false root/rhizoids	

Qn.2.explain why bryophytes are still considered as primitive

- They still require water/moisture for movement of gametes or fertilization to occur hence are often in damp places.or Depend on water to carry gametes for fertilization to occur.
- They lack xylem for water transport i.e no vascular bundles for transport of materials.
- They lack true roots for water absorption. Or have false roots called rhizoids which don't offer maximum support
- They lack cuticle to minimize water loss thus can easily be desiccated.
- Small in size and are often out competed by larger plants in terms of absorbing enough water and sun light.

Alternation of generations is the life cycle of plants which consists of two alternating stages of growth/generations between haploid gametophyte which produces gametes by mitosis and a diploid sporophyte which produces spores by meiosis. **Or Alternation of generations** is where a haploid; gametophyte generation alternates with a diploid sporophyte generation in the life cycle of a plant. The gametophyte reproduces sexually by means of haploid gametes produced by mitosis and the sporophyte reproduces asexually by means of haploid spores produced by meiosis.

Generalised structural life cycle showing alternation of generation.



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Describe alternation of generations in a moss

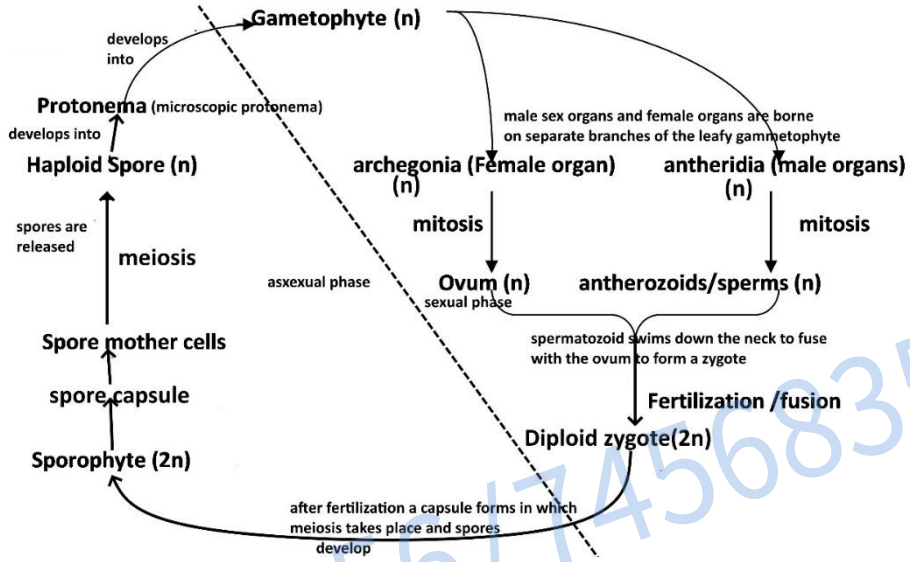
The alternation of generations of a moss/funaria comprises two generations, the dominant haploid gametophyte generation reproducing sexually by means of haploid gametes produced by mitosis alternating with a diploid sporophyte reproducing asexually by means of haploid spores produced by meiosis.

The mature sex organs of the gametophyte produce the gametes by using their gamete mother cells. The gametophyte bears gamete forming structures, male antheridia and female archegonia at the tips of separate branches.

When the moss surface is wet, mature antheridia absorb water and burst, releasing haploid sperms/antherozoids onto the surface. The biflagellate antherozoids swim towards the open necks of archegonia in a film of moisture with the aid of their two flagella and water currents/rain splashes in response to the chemicals /sucrose solutions secreted by the necks of archegonia. The antherozoids swim down the neck of each archegonium towards its base which contains the ovum. At the base of an archegonium the sperm fuses with the haploid ovum form a diploid zygote/oospore in a process of fertilization.

The diploid zygote then develops into a diploid sporophyte/embryo (2n) which remains attached to and dependent on the gametophyte for nutrients/food and water. The sporophyte consists of the seta/stalk that supports the spore capsule/sporangium which produces spores by meiosis. The sporangium/spore capsule of the diploid sporophyte contains spore sacs containing diploid spore mother cells which undergo meiosis to produce numerous haploid spores. Mature thin-walled cells of the annulus swell with water and force the lid/operculum off the capsule/sporangium exposing the inner and outer rings of teeth thereby allowing spores to escape. During damp/moist conditions each spore germinates into a green filamentous **protonema** which produces several buds; each of which latter develops into a haploid leafy gametophyte to repeat the cycle.

Illustration of alternation of generations in a moss



Significance of the gametophyte generation

- Sexual reproduction by random fusion of haploid gametes produced by gametophyte promotes genetic variation.
- Increased genetic variation increases chances of evolution of new species and survival.
- Gametophyte supports and provides food/nutrients to the sporophyte generation increasing chances of species survival and reducing chances of extinction.

PHYLUM: FILICINOPHYTA /Pteridophyta Members include; ***Pteridium and Dryopteris***

Characteristics

- They have clusters of sporangia under side/lower side of the fronds/leaflet/pinnule to form the **sori**
- Have relatively large leaves called fronds. The large surface area of the leaves increases the photosynthetic surface of the plant
- Show alternation of generation in which the sporophyte is the dominant generation
- The sporophyte has true leaves, stems, roots with vascular bundles
- The gametophyte is reduced to a small heart shaped simple prothallus.
- Have well developed vascular bundles and are restricted to damp/moist shady habitats.
- They are non-flowering plants

Examples include; ferns

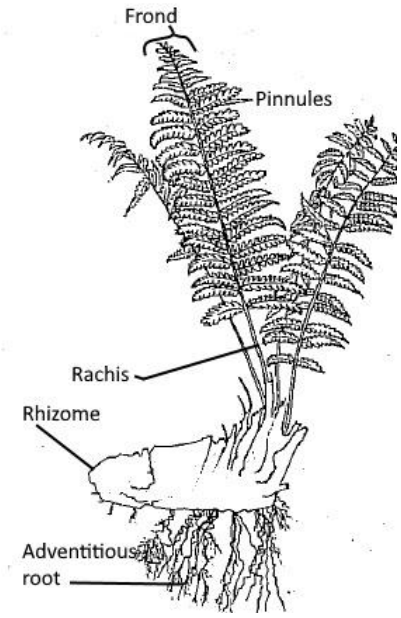
Structure of a Fern

Main rachis, with lateral branches/ pinnae alternately arranged decreasing in length from the base to the tip. Pinnae/leaflets are divided into pinnules with kidney shaped sori. Horizontal stem with many leaves.

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Leaf arrangement: alternate *or opposite to each other*
Each leaf has long stalk, leaflets (pinnae) which further divide into pinnules.

Leaf type:
Compound bi-pinnate. Has sori at underside of fronds/leaves for production
of spores during asexual reproduction .Horizontal, short, rhizome/stem with many hairy, branched roots, has many buds, Fibrous root system with many adventitious roots which are relatively long, hairy, curved Asexual reproduction



***Evidence*:**
Has sori at underside of leaves for forming spores in asexual reproduction

Describe the adaptations of the sorus to function

- Numerous sporangia which accommodate numerous spores for propagation
- Swollen sporangia to accommodate a lot of spores
- Annulus cells which easily break to release the spores.
- Swollen placenta to accommodate a lot of food to nourish the spores/to increase surface in order to accommodate many sporangia

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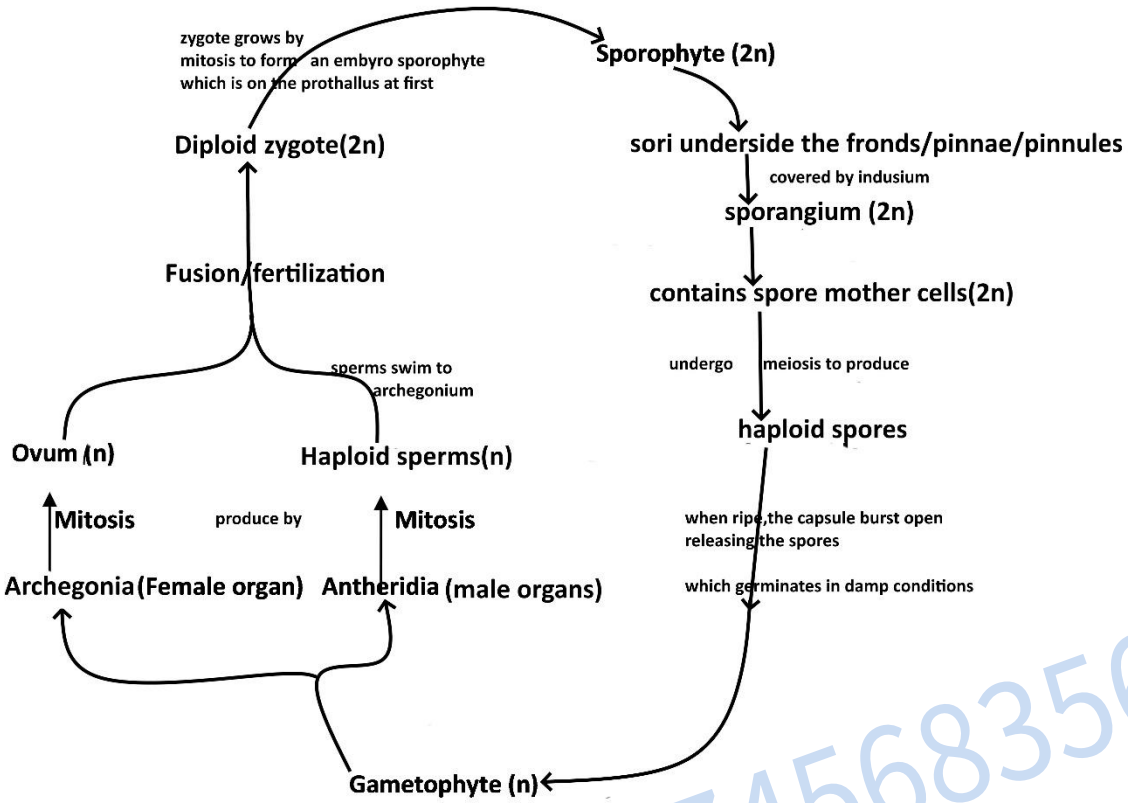
Explain what is meant by alternation of generation?

Is a phenomenon in which two distinct generations; a haploid gametophyte and a diploid sporophyte alternate in the life cycle of the plant. The haploid gametophyte reproduces sexually by haploid gametes produced by mitosis; while a diploid sporophyte reproduces asexually by haploid spores produced by meiosis.

Describe alternation of generations in any named filicinophyte/drypteris.

In the life cycle of the fern there is an asexually reproducing diploid sporophyte and sexually haploid gametophyte alternating with each other. The sporophytes have sporangia which occurs in groups known as **sori** covered by a protective **indusium**. Inside each sporangium there is diploid spore mother cells which divides by meiosis to form numerous haploid spores. When the spores are mature mainly during dry season the indusium shrivels and drops off rendering the exposed sporangium walls also dry out and rupture thereby releasing the spores. The spores germinate to form the haploid gametophyte/prothallus which is thin, heart-shaped plate of photosynthetic cells; fixed in soil by rhizoids. The gametophyte produces haploid antheridia and archegonia by mitosis on its lower surface. Each archegonium produces haploid ovum and each antheridium produces haploid sperm by mitosis. During moist conditions each antheridium releases its sperm which uses a flagellum to swim through a film of water towards the archegonia in order for fertilization to occur leading to formation of a diploid zygote. The zygote germinates into a diploid sporophyte which uses roots to absorb water and nutrients and leaves to manufacture food.

The life cycle of the male FERN, dryopteris



How filicinophytes better adapted to a terrestrial life than bryophytes

- Filicinophytes have rhizomes/horizontal underground stems to survive unfavourable climatic conditions; while bryophytes lack organs of perennation
- Filicinophytes have rhizomes/horizontal underground stems for vegetative propagation; while bryophytes lack organs of vegetative propagation
- Filicinophyte sporophytes have numerous bigger longer true adventitious roots for adequate anchorage in the soil; while bryophytes lack true roots/bryophyte gametophytes are anchored by shorter smaller filamentous rhizoids which provide inadequate anchorage.
- Filicinophyte sporophytes have numerous bigger longer true adventitious roots for absorption and conduction of minerals salts and water; while bryophytes lack true roots/bryophyte gametophytes absorb water and mineral salts throughout their smaller entire epidermis.
- Filicinophytes have more numerous sori thus produce more spores for greater reproductive rate than the less numerous bryophyte spore capsules.
- Filicinophyte fronds have a much larger surface area for light absorption for photosynthesis; while the leaf-like structures of bryophytes have a much less surface area.
- Filicinophyte sporophytes are nutritionally independent; while that of bryophytes depend on the gametophyte plant for nutrients.
- Filicinophyte sporophytes have true vascular tissues for transport of materials; while bryophytes lack vascular tissues
- Filicinophyte sporophytes have true vascular tissue and true stems for support enabling development of a larger complex plant body; while bryophytes lack vascular supporting tissues leading to development of a much smaller primitive plant body.
- Filicinophyte leaves have a cuticle to prevent desiccation; while bryophytes lack a cuticle.

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Question: Compare the sporophyte in bryophytes and pteridophytes

Similarities

- Both have sporangia
- Both have asexual phases
- Both produce haploid spores
- Both have diploid spore mother cells
- Both have mitotically dividing mother cells

Differences

Sporophyte in moss	**Sporophyte in ferns**
• Depends on gametophyte for food and mechanical support	Sporophyte is independent of the gametophyte
• Each sporophyte has one sporangium	Each has many sporangia
• The sporangia are covered by a protective operculum	The sporangia are covered by a protective indusium
• It is non leafy	Its leafy
• It is non photosynthetic	It is photosynthetic
• It is non dominant	Its the dominant generation

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

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Compare the life cycle of a moss and fern

Similarities

- Spores are formed in sporangia
- Spores germinate into gametophyte
- Zygote grows into sporophyte
- Zygote is diploid
- Female gametes are non- motile
- Male gametes are motile/flagellated
- Archegonia retain female gametes
- Spores are produced by meiosis
- Gametes are produced by mitosis
- Medium of fertilization is water

Differences

Life cycle of mosses	**Life cycle of ferns**
Sporophyte is attached to and dependent on the gametophyte	Sporophyte is self supporting plant
Gametophyte is the dominant generation	Sporophyte is the dominant generation
Spores germinate into protenema	Spores germinate into prothallus

Sporophyte has no true roots ,only filamentous; rhizoids	Sporophyte has true roots
Structural di fferences	
Lacks cuticle	Has cuticle
Have small spirally arraged leaflets on the gametophyte	Sporophyte has relatively large leaves
Lacks conductive tissues	Has conductive tissues
Gametophyte is differentiated into simple stems and roots	Gametophyte is just a thallus
Has filamentous unicellular rhizoids	Has true adventitious roots

Ferns are better adapted to terrestrial life than mosses because

- Ferns have rhizomes/horizontal underground stems to survive unfavourable climatic conditions unlike mosses/for reproduction
- Sporophyte generations have true roots for anchorage/transport of absorbed minerals salts and water which are lacking in mosses.
- Sporangium of ferns produce more spores than in moss for greater reproductive rate.
- Have relatively large/broader leaves to present a large surface area for light absorption for photosynthesis.
- Ferns sporophyte generation are nutritionally independent while that of mosses depend on the gametophyte plant for nutrients.
- Ferns have true vascular tissues for transport and translocation of materials
- Ferns have true stems to support the leaves to absorb sunlight for photosynthesis.
- Leaves of ferns have cuticle to prevent desiccation

Disadvantages of ferns over higher plants (why ferns are still primitive

- Growth is only limited to apical meristems i.e no lateral meristems
- The xylem of ferns is dominated by tracheid whereas higher plants are dominated by vessels hence slow transportation of water and dissolved mineral salts.
- The fronds/leaflets serve a dual purpose of photosynthesis and spore bearing organs/sorus.
- The gametophyte though independent and self supportive still depends on water for fertilizatio
- The phloem tubes are not well specialised.

Outline the significance of alternation of generation

- It enables the organisms to colonise more than one habitat with varying environmental conditions
- The gametophyte produce gametes sexually ; thereby leading to variation
- The sporophyte produces spores which can survive in unfavourable conditions
- They produce spores which have less food hence light and can easily be dispersed to longer distances away from the parent thereby reducing overcrowding and risks of disease attack.
- It ensures rapid multiplication of plants since large numbers of spores are produced hence increasing chances of survival.
- Alternation between sporophyte and gametophyte generations ensures that the plant colonises and explores different habitats in the ecosystem.
- Interdependency between gametophyte and sporophyte generation ensures existence of both generations and minimizes chances of extinction of the plant species.

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Importance of alternation of generations:

- Increased dispersal of very light spores enables colonizing of view areas.
- Lager numbers of spores produced ensure rapid multiplication
- Resistant spores ensure survival of unfavorable conditions
- Increased dispersal reduces over crowding
- Increased dispersal reduces intraspecific competition
- Increased dispersal reduces spread of epidemic diseases among species members
- Production of dry, small a light spores encourages increased dispersal by wind.
- Spores germinate only in favourable conditions increasing chances of survival.
- Sexual reproduction by random fusion of haploid gametes promotes genetic variation.
- Production of haploid spores by meiosis encourages variation
- Increased genetic variation increases chances of evolution of new species survival.
- Interdependency between gametophyte and sporophyte minimizes chances of species extinction.

Phylum Spermatophyta

Characteristics

- They show alternation of generations where the sporophyte is the dominant generation and the gametophyte being greatly reduced and short
- Have well developed vascular bundles with well developed xylem; trachieds and phloem for conduction of food
- The body of the seed bearing plants is differentiated into true roots; stems and leaves.
- Seeds are formed after fertilisation and does not require water for fertilisation but facilitated by pollinating agents.
- The plants bear green leaves and therefore photosynthetic
- The sporophyte is differentiated into shoot and root systems
- They produce different spores i.e heterospores e.g. embryo sac and microspores/pollen grains
- They are seed-bearing plants.

They are divided into two subphyla

- Coniferophyta/gymnospermatophyta
- Angiospermophyta

Phylum: coniferophyta/Gymnospermophyta

Characteristics features of conifers

- They have naked seeds (have no fruit wall/not enclosed by ovary wall)
- They have no fruits and no flowers instead they have unisexual cones
- They are Cone-bearing plants: Female cones produce ovules and male cones produce pollen.
- They have true roots, stems and scale-like,
- Have narrow needle-like leaves protected by a thick waxy cuticle to reduce water loss in order to survive water shortage.
- Have simple conductive tissues i.e. xylem dominated by trachieds and phloem tubes and have **no companion cells and no vessels**
- Usually live in mutualistic mycorrhiza association
- Have an alternation of generations
- Conifers reproduce by seeds; gametophyte generation is much reduced and never free living.

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Alternation of generations in coniferophyta

Mature dominant sporophyte generation develops male and female cones with sporophylls i.e. micosporophylls and megasporophylls which produce two different types spores a condition known as **heterospory.**

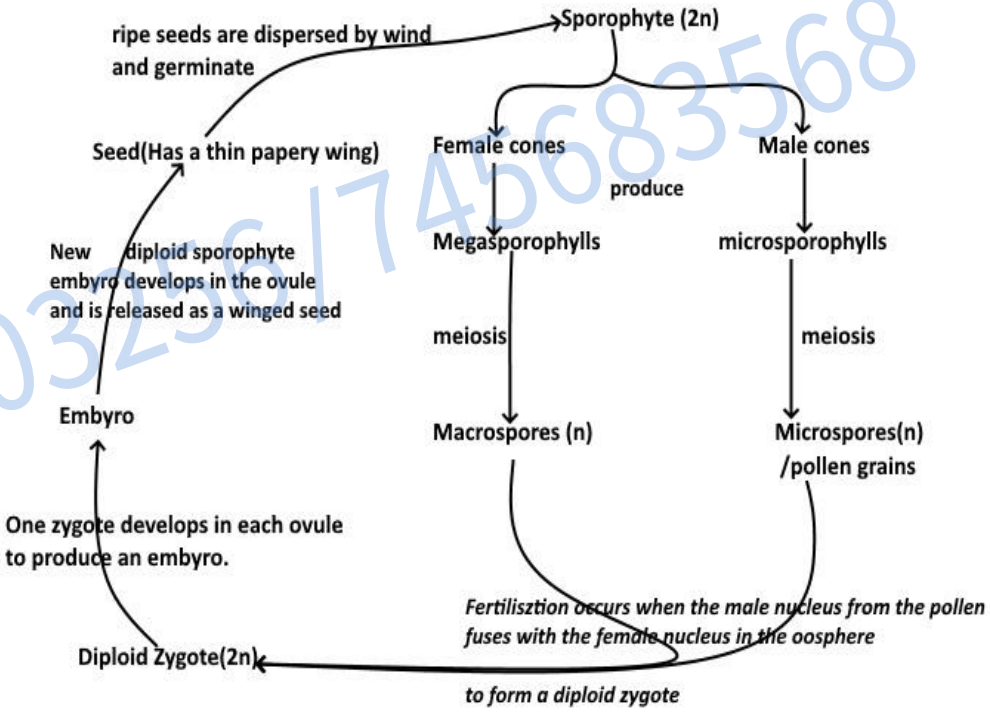
The sporophylls produce the gametes/spores by meiosis. Female cones contain ovules which produce a single diploid megaspore/large spore. Megaspores divide meiotically to form a tiny haploid egg-containing female gametophyte which remains attached to the cone of the parent plant.

Male cones contain microspore mother cells which divide by meiosis to produce four haploid microspores/small spores. The microspores of the male cone with air sac are transferred to the female cones by wind then a pollen tube develops and the haploid microspore divides mitotically to form the male gametophyte male gamete travels down the tube towards the female gametophyte in the ovule.

After fertilization of the egg cell by one male gamete, a new diploid sporophyte embryo develops in the ovule and is released as a winged seed. When the winged seeds land on favourable moist grounds they germinate into the sporophyte plant to repeat the cycle.

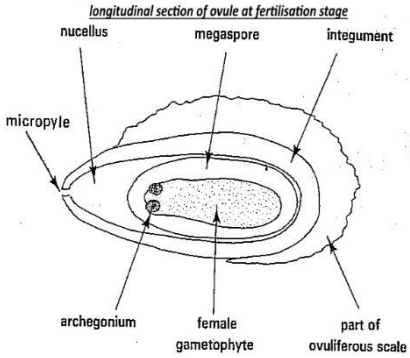
The female cones are normally brown in colour and scaly when mature.

Illustration of Alternation of generations in conifers



Conifers are better adapted to life on land than ferns;

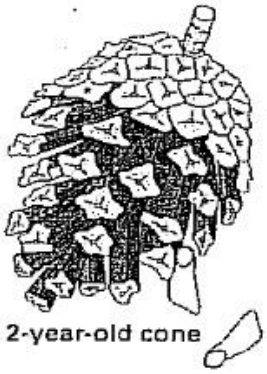
- Do not need water as a medium for fertilization because they produce pollen.
- A pollen tube grows down from the pollen grain to an egg cell and fertilization can take place without the male gamete having to swim through water
- Reproduce using seeds which have more food store Examples: pines, fir, cedar, conifers, cycads
- Their leaves and stem are well adapted to periods of drought compared to the ferns



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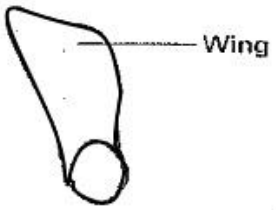
Economic importance

- Hardness of conifers makes them a good source of soft wood for timber
- Pine nuts are used in cooking
- Spruce and firs are used as Christmas trees



Adaptations of conifers

- Their evergreen nature mean that the needles can photosynthesize whenever there is sufficient sunlight
- Pine cones protect the seeds during the harsh winter
- The thin waxy needles reduce water loss
- Coniferous trees have thick bark to protect against the cold
- Thick waxy cuticle that waterproof the leaves
- Have stomata only located on the lower epidermis of their leaves to reduce transpiration
- Have deep roots reaching into fractured bedrock where water can be found to survive droughts
- Have scales on the surface of the seeds to reduce water loss during harsh conditions



A winged seed released from a 2-year-old cone

- Scale-like leaves reduce water loss and don't shed individual leaves but shed short branches bearing one or more years of growth.

PHYLUM: ANGIOSPERMOPHYTA

These are flower bearing plants with the male and female reproductive structures enclosed in a flower.

Characteristic features of angiospermophytes

- They are flower bearing plants that produce spores/microspore/pollen grains and megaspores/macrospores/embryo sac
- Have well developed vascular bundles
- Seeds are enclosed in a fruit formed from and ovary i.e. produce seed enclosed by a seed coat which is dry or fleshy.
- Can also reproduce asexually by vegetative propagation
- They have true roots, stems and leaves

They are divided into **two classes**

Class: Monocotyledoneae

Class: Dicotyledoneae

Class: Monocotyledoneae

Characteristic features of monocotyledonous plant

- Have one cotyledon in the seeds
- Leaves have leaf sheath and parallel veins
- Their stem has no vascular cambium and the vascular bundles are scattered.
- Show no secondary growth/thickening due to lack of vascular cambium
- Have fibrous root system
- The floral parts often occur in multiples of threes
- The perianth is identical i.e. no distinct calyx and corolla.

E.g. palms and grasses; millet; rice; wheat; oats; barley; maize

Class: Dicotyledoneae e.g. beans; ground nuts

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Characteristic features of Dicotyledonous plants

- Have two cotyledons in the Seeds
- Leaves have network veins
- Have tap root system.
- Have vascular bundles arranged in a ring around the cambium in the stem
- Show secondary growth/thickening due to presence of vascular cambium
- Their leaves have a petiole/leaf stalk
- The floral parts usually occur in fours or fives and other multiples Dicotyledonous plants are divided into:

i. Trees e.g. Mango, avocado, cassia ii. Shrubs e.g. hibiscus iii. Herbs; e.g. beans, cow peas

Structural differences between Monocotyledonous and Dicotyledonous plants

MONOCOTYLEDONEAE	DICOTYLEDONEAE
1. Parallel leaf venation	1. Reticulate leaf venation
2. Leaf sheath	2. Solid leaf stalk
3. Narrow and long leaf lamina	3. Broad and short leaf lamina
4. Leaf dorsal and ventral surfaces identical	4. Leaf dorsal and ventral surfaces different
5. Scattered vascular bundles in stem	5. Ring of vascular bundles in stem
6. Stem lacks vascular cambium	6. Stem has vascular cambium
7. Fibrous root system	7. Tap root system
8. More groups of xylem in root	8. Fewer groups of xylem in root
9. Root lacks vascular cambium	9. Root has vascular cambium
10. Embryo has 1 seed leaf/ cotyledon	10. Embryo has 2 seed leaves/ cotyledons
11. Flower parts in 3's	11. Flower parts in 4's and 5's
12. No distinct petals and sepals	12. Distinct petals and sepals

DIFFERENCES BETWEEN ANGIOSPERMOPHYTA AND GYMNOSPERMOPHYTA

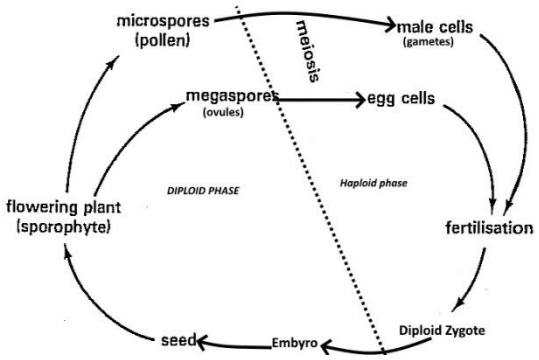
Angiospermophyta	Gymnospermophyta
Ovules protected in an ovary	Ovules unprotected;
Xylem has both vessels and tracheids	Xylem has tracheids ;only
Both non woody and woody	All are woody;
much reduced gametophyte	larger gametophyte;
Ovule protected in ovary	Ovule not protected
Has stigma and style	No stigma and style
No cones	Bears cones
Bears fruits	No fruits
Companion cells present	No companion cells
Has xylem vessels	No xylem vessels

Similarities

- Embryo sac is enclosed in ovule
- Sporophyte generation dominates gametophyte generation
- Male and female spores develop separately
- Fertilized embryo sac develops into seed
- Both produce two types of spores/ Heterosporous;
- Both have tracheids in their xylem;
- Both have sieve tubes in their phloem;
- Both have endosperm in their seeds;
- Both produce pollen grains/ Pollen tube grows
- Both are differentiated into roots, stems and leaves;
- Both have vascular and cork cambium;
- Both produce seeds;

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Alternation of generations in angiospermophytes



Describe the structure and development of an ovule.

Structure of the ovule

- An ovule is spherical/circular/ovoid structure**;**
- Enclosed by outer and inner integuments**;**
- Perforated by the chalaza at the top**;**
- And micropyle at the bottom**;**
- Also has tissue called nucellus**;**
- Composed of an embryo sac**; *whose membrane encloses:***
- One/1 diploid polar nucleus in the centre**;**
- Three/3 antipodal cells at the top/chalaza end/dorsal end**;**
- One/1 haploid egg cell/ovum at the lower/ventral/bottom end**;**
- Two/2 synergids at the lower/ventral/bottom end**;**
- Ovule is attached to ovary wall by short stalk/funicle at the placenta**;**

Development of the ovule

- In flower ovary one nucellus cell grows much larger to become **embryo sac mother cell;**
- Embryo mother cell divides **meiotically** into four haploid cells**;**
- Three cells nearest the micropyle degenerate**;**
- While one cell enlarges to form the **embryo sac;**
- Embryo sac nucleus **mitotically** into two haploid nuclei**;**
- Which migrate to opposite poles of embryo sac**;**
- Each nucleus undergoes **mitosis twice** to form four haploid nuclei at each pole**;**
- One nucleus from each pole migrates to embryo sac centre**;**
- And fuse to form **diploid primary endosperm nucleus/polar nuclei;**
- At the micropyle end one nucleus develops into one **ovum/egg cell;** two nuclei into **synergids;**
- Opposite the micropyle end three nuclei develop into **antipodal cells;**

A great diversity and success of angiospermophyte

- Have well developed conductive tissues for faster transportation of materials
- Have thick waxy cuticle to reduce on the rate of water loss
- Have photosynthetic pigments in their leaves for sun light absorption for photosynthesis
- Have leaves with numerous stomata for easy gaseous exchange
- Have well developed supporting tissues to offer maximum support on land
- Formation of seeds that contain a lot of food nutrient to withstand dry conditions
- Fertilization does not need water because the non-motile gametes are transferred by pollinators to the female organs to enhance fertilisation.
- Have well developed floral structure with attractive colours and nectarines that facilitate pollination.
- Growth of the embryo and germination of the seeds is assured due to presence of large food reserves.
- Have well developed vegetative organs that make them better adapted to new habitat

Adaptations of angiospermophyte to conditions of water stress

A plant is said to suffer from water stress when it loss more water through transpiration than it can take up in its roots. Plants adapted to conditions of water stress include:

- **Xerophytes**-plants adapted to life in dry regions

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- **Mesophyte-**plants adapted to habitats with adequate amount of water supplies and
- **Halophytes**-plants adapted to high saline areas

The adaptations of plants to conditions of water stress include: adaptations to reduce water loss; adaptations to reduce water loss; adaptations to increase water; physiological tolerance of water loss and evasion of extreme dry conditions.

Adaptations to reduce water loss

- Possession of thick waxy cuticle which reduces cuticular transpiration by forming a waxy water proof barrier that prevents water loss as in the prickly pear; cactus opuntia
- The reduction of the of stomata which reduces stomatal transpiration and hence reduces transpiratory water losses as in opuntia
- The stomata of some plants are depressed and sunk down into pits. This lengthens the diffusion path by trapping still, moist air above the stomata, so reducing transpiration as in pine; marram grass
- The opening of stomata at night and close them during day. E.g cactus
- Leaf surface may be covered with a protective layer of numerous fine hairs; to trap a films of air increasing the length of the diffusion path so reducing transpiration e.g *amnophila, ling*
- The leaves may be rolled in cylinders.the curled leaves trap films of moist air within preventing water diffusing out through the stomata which are then confined to inner surface as in amnophila,calluna
- The reduction of leaves into spines/needle-like reducing the surface area over which transpiration occurs.e.g cactus.the spines protect the fleshy photosynthetic stem from grazing.
- The reduction of the surface area to volume ratio of stems, leaves and flowers. This is mainly achieved through adoption of a succulent structure which reduces the surface area over which transpiration occurs as in cactaceae.
- The shedding of leaves during dry season which prevents the possibility of transpiration via leaves as in candle plant, vine cactus.
- Ability to efficiently fix carbon dioxide at night with partial opening of stomata, as in C4-plants such as zea maiz (maize).his allows the plant to keep the stomata closed during much of the day so reducing transpiration.
- Possession of tissues which are tolerant to high temperatures allowing the plant to let its temperature rise to considerably high degrees. This reduces water-loss through

Adaptations of xerophytic angiospermophyte to survive in water shortage

- Have tissues tolerant to dessication
- Survive dry periods as seeds/spores
- Extremely deep root system so that they absorb water from deeper layers
- Some have superficial roots to trap water from large surface
- Some have thick leaves/stems to store water in parenchyma tissues
- Some reduce evaporation by reducing amount of stomata
- Have hairy epidermis to trap still moist air to minimize water loss by evaporation
- Folding of leaves to conceal stomata to reduce evaporation
- Reserving stomatal rythm especially in CAM plant
- Having small leaves/narrow lamina to reduce surface area from which evaporation occurs
- Have sunken stomata to reduce transpiration rate
- Thick waxy cuticle which is impermeable to water
- Shedding of leaves

Challenges or problems faced by plants

- Desiccation/ dry out
- Support in air/ on land
- Obtaining nutrients
- Obtaining gases for respiration

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- Movement of the reproductive gametes
- Environmental variables such as light intensity, temperature, pH e.t.c.

Adaptations of seed bearing plants to life on land

- Leaves possess stomata for gaseous exchange
- Leaves and stems are covered by a waxy cuticle which minimises water loss
- They possess true roots which enable water and dissolved mineral salts to be absorbed
- They undergo secondary growth which enable seed bearing plants to compete effectively for light and other resources
- The fertilized ovule (seed) is retained for some time on the parent plant (sporophyte) from which it obtains protection and food before dispersal.
- Fertilization 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

SUBTOPIC 7: KINGDOM ANIMALIA

Contains multicellular eukaryotic animals with the following characteristics

General characteristics

- Show a great deal of differentiation i.e. division of labour
- Most of them have nervous and endocrine systems for irritability except the sponges
- Have heterotrophic nutrition
- Their cells lack in cell wall
- They mainly reproduce sexually by producing heterogametes that fuse to form a zygote.
- Some animals reproduce asexually i.e. earth worm by fragmentation and hydra by budding.
- Most can move from one place to another i.e. they are motile
- They are multicellular eukaryotes

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They are divided into various p**hyla** i.e.

1. Porifera i.e. sponges
2. Coelenterata (cnidaria) i.e. hydra and sea anemone
3. Platyhelminthes (flat worms)
4. Nematoda (nematode s) i.e round worms.
5. Annelida .i .e. earth worms.
6. Mollusca (snails, slugs, octopus)
7. Echinodermata i. e (star fish)
8. Arthropoda
9. Chordata

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 specialization 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 organized and have structural relationship with each other.

4. Organism

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

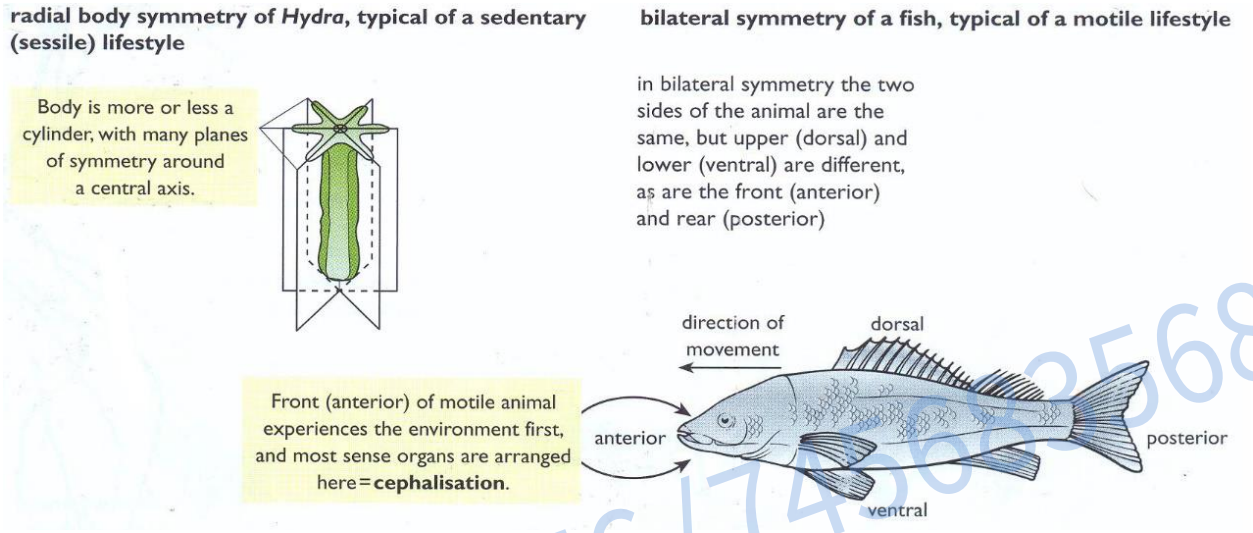
5. Symmetrical body

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

Bilateral symmetrical body: *Meaning that there is only one plane that cuts the body into two equal halves* **OR**
This is the body which can be divided into two identical halves along one plane only.
It's a common symmetry of the body of motile organisms
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.
Diploblastic: Have a body wall compose of just two layers of cells**. I,e**. the outer layer of tissue called the **ectoderm** and the inner layer the **endoderm**
Triploblastic: Have a body wall compose of just three layers of cells. The middle layer called **mesoderm**



LEVELS OF ORGANISATION
Four levels of organisation are recognized;

1. Unicellular level (single cell organisation)

Protoctists 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, and plasmodium e.t.c.

2. Tissue level of organization

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

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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

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PHYLUM: COELENTERATA i.e. jelly fish, hydra and sea anemone

This phylum is sometimes referred to as **PHYLUM CNIDARIA (Cnidarians)**

They are lower animals at tissue level of organization with the following characteristics? Members include Hydra, Obelia, sea anemone, Portuguese man of war and Jelly fish.

Characteristic features of cniderians

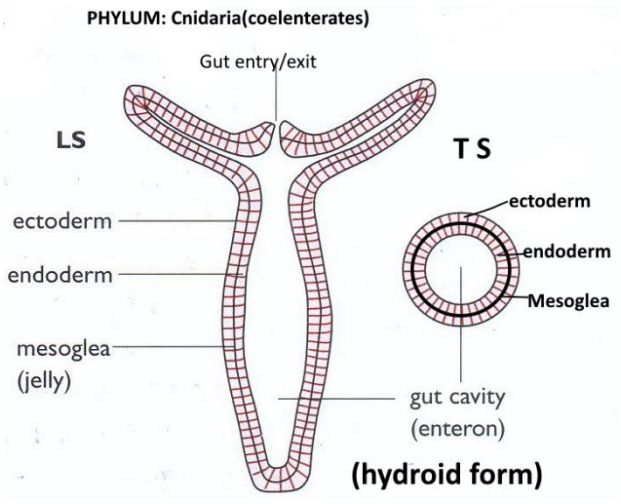
- Have diploblastic body pan. Body wall consists of two cell layers separated by the mesoglea (a Jelly-like non-cellular layer). The mesogloea may contain cells that have migrated from other layers.
- The outer ectoderm and inner endoderm are jelly like with less developed mesoderm called the mesogloea.
- all are aquatic, many marine
- Have a sac-like body cavity, the gut or enteron with a single opening; there is no anus
- 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.
- Ectoderm especially on the tentacles have stinging cells called **nematoblasts/cnidoblast** which inject prey with poison or for protection.
- Have radial symmetry 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 specialized shapes with different functions.

- They exhibit polymorphism i.e. they exist in 2 or more forms i.e. the sessile form which is called the **polyhydroid/hydroid form** and the **floating medusa** form is called the medusoid. The 2 forms alternate in their life cycle i.e. the sessile and medusa.e.g jelly fish

Polymorphism is the situation in which individuals of a species exist in two or more different forms.

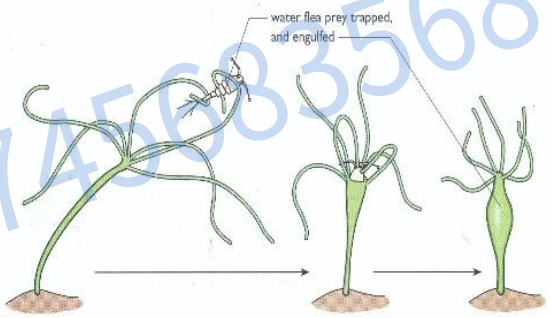
Individuals have specialized shapes with different functions. It's a form of division of labour

Existence of the cell organisms in a number of morphologically distinct forms.



- They have tentacles which bear stinging cells called nematoblasts
- They a simple nervous system.
- They reproduce both asexually through budding and sexually.
- They are heterotrophic animals with intracellular digestion

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. Some coelenterates live in mutualistic relationship with the hermite crab i.e. the sea anemone



The phylum **cnidaria** is divided into 3 classes' i.e.

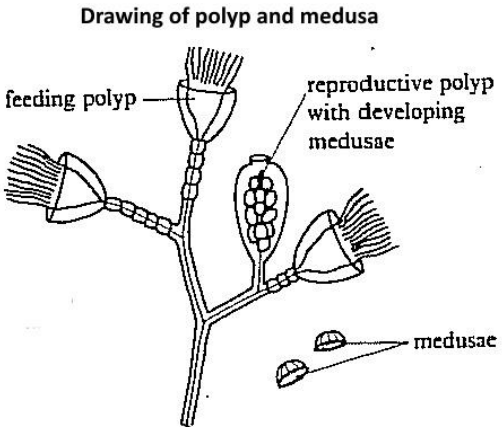
1. **Hydrozoa i.e. hydroids**
2. **Scyphozoa i.e. jelly fish**
3. **Anthozoa i.e. corals and sea anemones**

1. **CLASS: HYDROZOA** include hydroids i.e. hydra-like in appearance (no medusa phase) and obelia.

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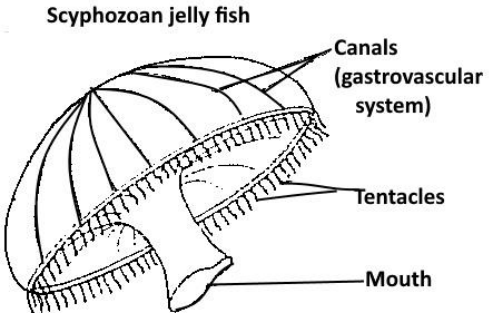
Characteristic features

The polyp/sessile is dominant in the life cycle (the polyp is cylindrical and sessile) . A **sessile organism** is one that remains attached to the surface i.e. rock throughout its life and shows no locomotion or little. The medusa is umbrella shaped and free swimming or floating.



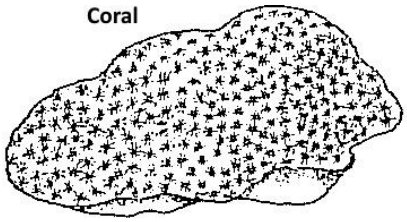
- The medusa is simple.
- The polyps are solitary or colonial.
- They have nematoblasts or stinging cells.
- They have gonads in the ectoderm.

2. CLASS: SCYPHOZOA i.e. Aurelia



- Have mesenteries
- Have no gullet
- The medusa is dominant which is large and high organized
- The polyp is small and sometimes present as a larva stage
- The gonads are endodermic
- They also have nematoblasts.
-

3. CLASS: ANTHOZOA i.e. corals



Characteristics

- have the polyp only which is more complex than those of the hydrozoa
- have no medusa
- Polyps are solitary as anemone or colonial as in corals.
- Have nematoblasts i.e. Actinia (beadlet anemone) and Madreporaria (stony coral)

PHYLUM PLATYHELMINTHES

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

Characteristic features of Platyhelminthes

- 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.
- They are unsegmented body i.e. nematode worms un like annelid worms
- The body is flattened dorso-ventrally to shorten the diffusion distance for effective diffusion.
- They are hermaphrodites, often with elaborate precautions to minimise self fertilisation
- Have flame cells for excretion and osmoregulation
- Possess a mouth but no anus
- Most of them are parasites.

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 include planarians

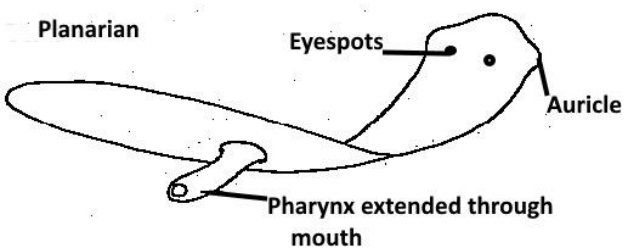
Members in this class include planaria which lives under stones in fresh water streams.

Free-living flatworms usually ciliated on the underside

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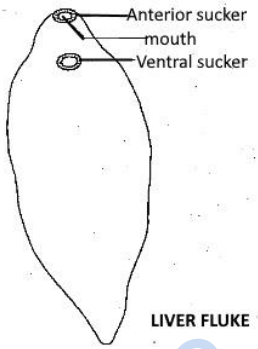
Characteristics

- 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 (liver fluke) and Schistosoma (blood fluke) which causes Schistosomiasis (Bilharzia) in tropical countries.

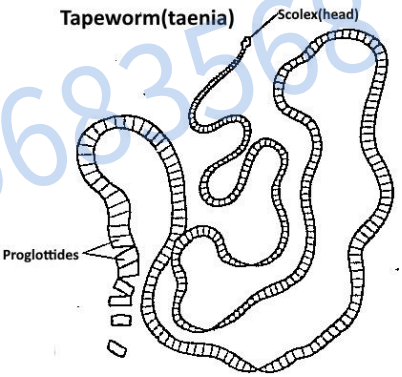


Characteristic features

- 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*



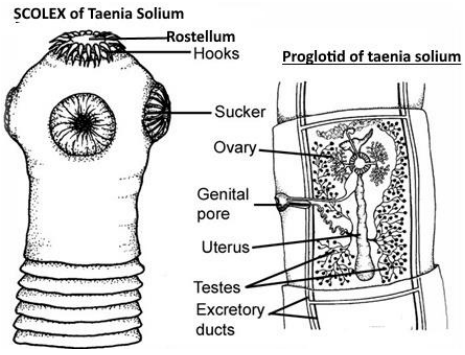
Characteristic features

- 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 proglottides 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, no suckers for attachment to host body

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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.

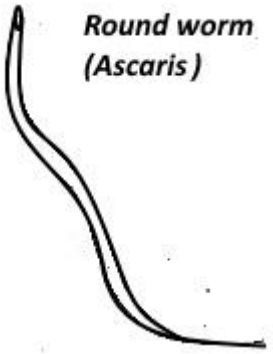


PHYLUM NEMATODA (round worms)

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



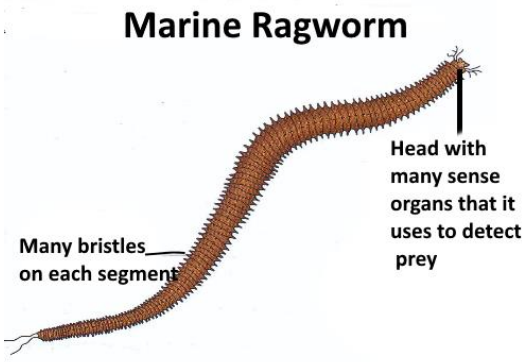
- They are triploblastic
- They have bilateral symmetry
- They have an un-segmented cylindrical body
- Their alimentary canal is straight from the mouth to the anus.
- Their sexes are separate
- Have a narrow body pointed at both ends
- They lack cilia
- Have thick elastic cuticle of protein.
- Some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

PHYLUM ANNELIDA (segmented worms)

General characteristics

- Internally, the segments are separated by septa that divide the coelom into compartments.
- They have no Chitineous cuticle
- Each segment bears bristle-like ***chaetae***
- They exhibit *metameric segmentation* i.e. each segment contains the same pattern of nerves, muscles, blood vessels and excretory organs and are of the same age and size
- They have bilateral symmetry and triploblastic

The main classes of phylum annelida include;



Class Poly chaeta (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*

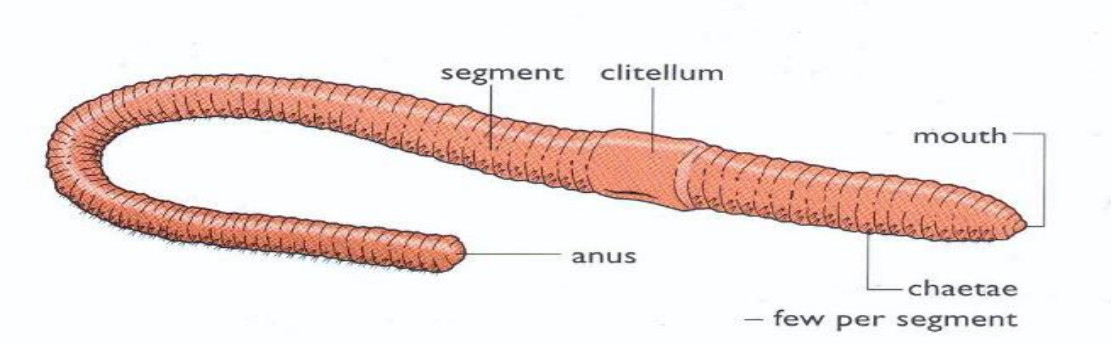
Class Oligochaeta (earthworms)

- They possess relatively few chaetae
- No larval form
- They have a less distinct head
- They lack parapodia/chaetae numerous on lateral extensions on the body.
- They are hermaphrodites
- They live in fresh water or soil

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- *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

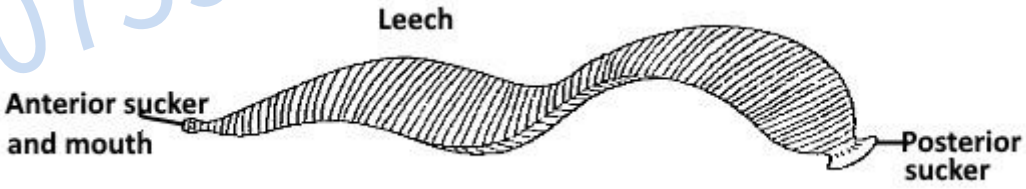
1. They mix soil layers improving soil fertility
2. They burrow tunnels which improves aeration and drainage of the soil
3. They add organic matter to soil by excretion and death
4. Secretions of the gut neutralise acidic soils
5. Dead vegetation is pulled into the soil where decay takes place

Class Hirudinea

Members include Hirudo the medicinal leech

- Free living carnivores
- No chaetae or parapodia
- No distinct head
- No clitellum
- Some leeches are ectoparasites with anterior sucker with sharp teeth for sucking lood and posterior suckers

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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

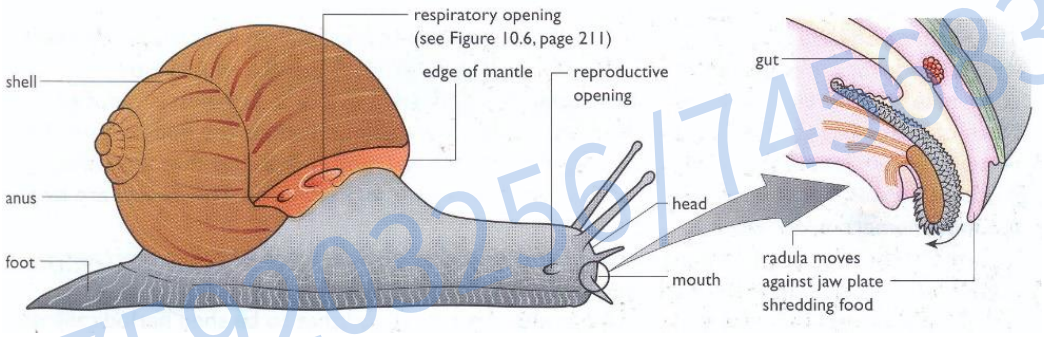
ii. Increased size and complexity requires a more complex coordination system, therefore a more elaborate nervous system

PHYLUM MOLLUSCA

Characteristic features

- These are triploblastic coelomate animals
- They have soft, flexible 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
- Body divided into head foot and hump covered by mantle which secretes the shell
- Have gills or lungs in the mantle cavity for respiration and in some cases,filter-feeding
- Most have a rasping tongue-like radula used for feeding

The classes of phylum **mollusca** include;



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Class Gastropoda

Members include slugs and Helix (the garden snail)

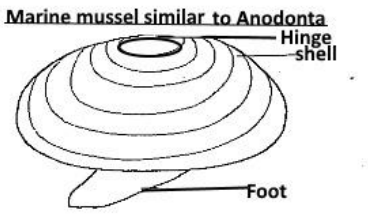
Characteristics

- They have a distinct head with eyes and sense tentacles
- Have large flat foot
- 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 Pelecypoda/lamellibranchiata:

Marine and fresh water molluscs**; Examples** include mussels, oysters and clams.

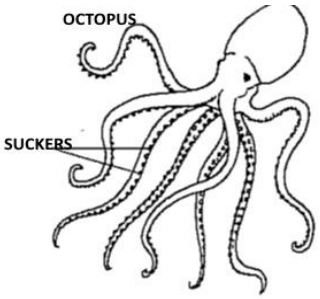
Characteristic features



- Laterally compressed and have No tentacles
- Head and foot generally reduced (foot used for burrowing)
- Have shells divide into two halves (bivalve) that protect the soft parts of the animal
- Have sheet-like gills(hence the name of the group)

- They are filter feeders

Class Cephalopoda

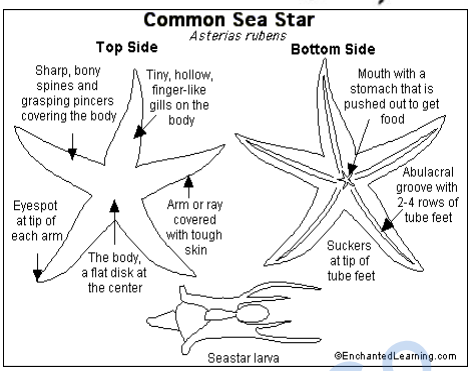


Examples include squids, octopus and cat fish.

- Have foot incorporated into head/posse head-like structure
- Have8/10 sucker-bearing tentacles
- Shell internal and reduced or absent
- Active animals with good sense organs and nerves

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)
- No proper circulatory system
- They are exclusively marine inhabitants
- Skin contains calcareous ossicles and spines(hence name of the phylum)
- 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
- The body is Segmented and is covered by a hard external skeleton made of chitin

Other characteristic features

Open blood circulation with blood in a haemocoel cavity surrounded by all the organs of the body

- 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

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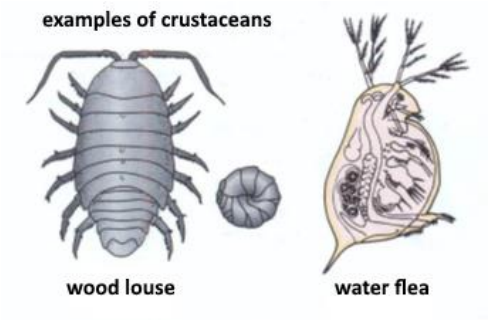
3. During moulting, the body of the arthropod is soft and very vulnerable to attack by predators and pathogens

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.

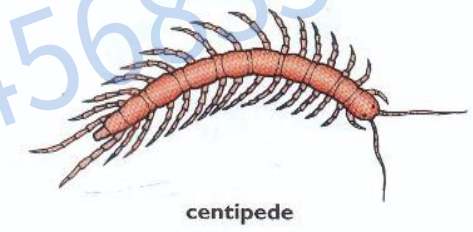


Characteristic features

- Two pairs of antennae e.g woodlouse and water flea
- Dorsal part of the body covered by a shield called the **carapace**
- 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)



- Dorso-ventrally flattened body with numerous leg-bearing joints
- Terrestrial and mainly carnivorous
- Have well-developed head and jaws, 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 long 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 and have a cylindrical body of numerous segments
- Mainly herbivorous
- The head is distinct but all other body segments are similar
- One pair of mouth parts(mandibles)
- One pair of antennae
- Head with simple Eyes or compound, are absent
- Numerous identical legs with two pairs per segment i.e. about **70 pairs** of legs
- They lack a larval form
- Gaseous exchange is by the tracheal system
- No poison claws

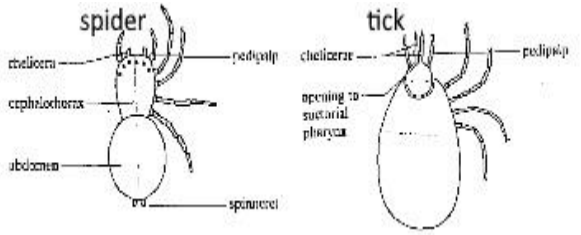
Class Arachnida

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

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Characteristic

- Two major body divisions present i.e. a cephalothorax(head +thorax) and abdomen
- Four pairs of legs attached to the cephalothorax
- Mainly terrestrial and Mainly carnivorous
- No antennae present
- 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
- 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

- One pair of antennae are present on the head and are Mainly terrestrial
- No gills in adults
- They have a pair of compound eyes or simple eyes
- Usually three pairs of mouth parts
- Gaseous exchange occurs by tracheae
- 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

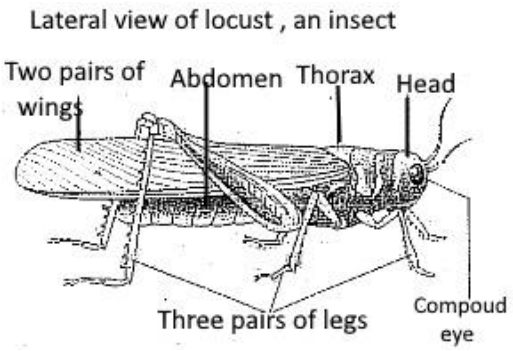
The adult is specialised for dispersal and reproduction

Examples include;

- Pieris (butterfly)
- Apis (honey bee)

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- 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
- Same length of jointed legs e.g 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

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- 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

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PHYLUM: CHORDATA

During their lifetime, all chordates/vertebrate 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. **A tubular, 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. **Gill slits in the throat known as 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. **Closed blood circulatory system** in which blood flows forward ventrally and backwards dorsally
6. **A vertebral column/backbone**
7. **Segmented muscle blocks** (myotomes) which are considered as a secondary adaptation for swimming.

Phylum Chordata is divided into two main groups

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;

i) 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.

ii) 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

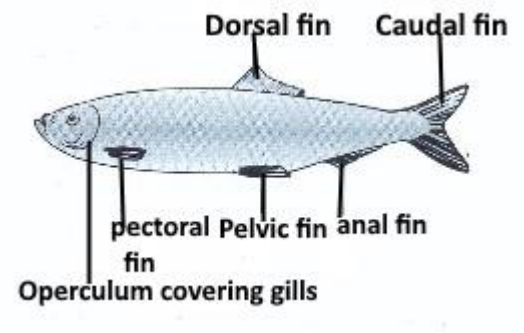
Examples of members of this phylum include dog fish, skates, rays and sharks. Their characteristics include;

- 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

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Class: osteichthyes (the bony fish)

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



- Bony endo skeleton/fish with a skeleton of bone
- Mouth at a terminal position on the head
- The gills (4 pairs) are covered by a body flap, the operculum i.e. Visceral clefts present
- Have homocercal tail fin, fan-like pectoral and pelvic fins
- Fertilisation is external
- The fins are supported by bony rays.
- They are poikilothermic
- The swim bladder is present
- Some are marine while others are fresh water dwellers

Class crossopterygota

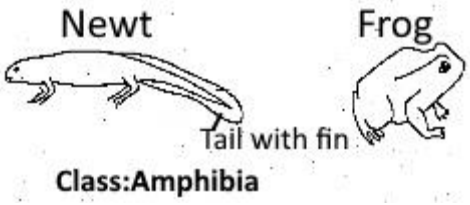
It includes the lung fish.

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

Class Amphibia (The ampibians):

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

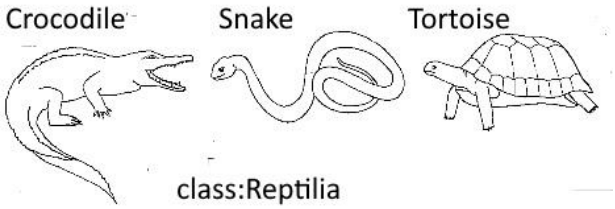
- Have a soft moist skin used as a supplementary gaseous exchange surface
- Partly aquatic and largely terrestrial animals that breed in water
- Have simple sac-like lungs
- They have two pairs of pentadactyl limbs
- Breeding occurs in water i.e. fertilisation is external
- They are poikilothermic
- 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 skin with scales/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)



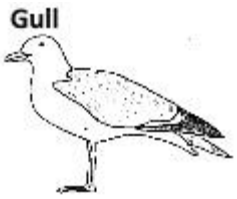
Class: Aves

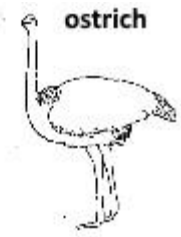
This class includes all birds and their characteristics include;

- The skin bears feathers and skin is covered by scales
- Have a strong, light skeleton, limb bones are hollow

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- Their legs bear scales
- Fore limbs modified into wings
- Toothless jaws covered by horny beak
- Sternum of pectoral girdle expanded foe attachment of muscles
- They exhibit internal fertilisation, eggs are laid with a food store(yolk) and a hard calcareous shell. e.g pigeon
- They lay well developed cleidoic eggs
- They are endothermic, with a high and constant body temperature
- They possess lungs for gaseous exchange





Class:Aves

Class: Mammalia (the mammals)

The characteristics for the members of this class include;

- Having mammary glands
- Have four pentadactyl limbs
- Possession of a pinna (external ear)
- They are endothermic or homeothermic with a relatively high and constant body temperature
- Fertilisation is internal ,the young complete their early development in the uterus
- 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. Subclass: 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

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v. How to reproduce without water

Adaptations of animals to live on land

- 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
- 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.
- 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.
- 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.
- 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 of 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

Advantages of the multicellular state over the unicellular state

- Being multicellular allows increase in size
- In the unicellular state size is limited by the need to maintain a large surface area to volume ratio and the fact that one nucleus can only exert control over a limited volume of cytoplasm.
- Multicellularity allows cell specialization leading to development of tissues organs and organ systems with different parts of the body performing different functions. This division of labour promotes greater efficiency enabling exploitation of various habitats and niches. The cell of a unicellular organism needs to remain capable of various life activities and is thus unable to specialize.
- Multicellular organisms comprise numerous cells making the total surface area available for exchange of materials many times greater than the area of the external body surface.
- Unicellular organisms rely on small body size to maintain efficient exchange by diffusion over a large surface area to volume ratio.
- Multi cellular animals comprise body cells bathed in a tissue fluid whose composition can be regulated by homoeostasis, improving overall cell efficiency. Unicellular organisms cannot exert control over the external surrounding of the cell leading to inefficiency.
- Development of specialized internal organs for materials exchange and excretion allows the body surface of multicellular organisms to be efficient in getting rid of excretory wastes
- Unicellular organisms carry out materials exchange and excretion over the entire body surface which must therefore remain moist and permeable. This leaves the organisms prone to dehydration and desiccation in dry condition imposing limitation on terrestrial life.
- Specialized structures of multicellular organisms such as skeletons and xylem maintain body shape and position by offering support and mechanical strength. Unicellular organisms are largely unable to maintain body shape and position.
- Increased body size in multicellular organisms reduces surface area to volume ratio thereby reducing the rate of heat loss to surroundings. Unicellular organisms have a large surface area to volume ratio with high rates of heat loss to surroundings.

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- Specialization allows development of muscles. Skeletons and protective and offensive structures that allow multicellular organisms to tackle larger prey and also intimidate or run away from potential predators. Unicellular organisms can only feed on small prey and are vulnerable to being preyed upon.

How organisms overcome the challenges of being multicellular

CHALLENGES	SOLUTION
Need for greater support	Development of specialized materials , tissues and organs of support such as chitin, lignin cellulose , bone cartilage , collenchyma , xylem , sclerenchyma Becoming aquatic as denser water provides more support than air.
Greater food requirements	Becoming heterotrophic and mostly holozoic but some parasitic. Well-developed digestive system with a specialized alimentary canal. Varied food sources and feeding habits, incorporating carnivorous, herbivorous and omnivorous modes of life. Development of a hollow center to reduce food requirements. Filling parts of the body with dead tissues, such as xylem which do not require nutrients. An efficient means of locomotion to enable organisms search for food. Development of muscle and skeletal systems to protect and provide support for inner structures.
Surface area to volume ratio	Development of a hollow center to increase surface area to volume ratio such as spongocoel and coelenteron. Flattening the body to increase surface area to volume ratio Development of specialized internal or external surfaces of exchange which increase surface area such as gills, alveoli, ileum, blood capillaries . Development of thin flattened structures such as leaves, root hairs.
Increased metabolic wastes	Development of a transport system which transports waste products to excretory organs Development of excretory organs and systems to expel metabolic wastes from the body. Development of nervous and endocrine systems to control process of excretion. Ability to re-use various waste products of metabolism in plants. Autotrophic in higher plants ensures that organic compounds are produced on demand with little waste substances. Storage of metabolic wastes in dead permanent plant tissues such as … Ability to detoxify toxic wastes such as ammonia to urea and uric acid.
Movement	Become sessile in plants Slow moving animals have returned to water Development of skeletal ……..
Movement	Development of locomoting structures such as limbs, fins, wings, legs, flippers. Development of locomotory systems Aquatic animals have developed bladders and air bladders for buoyancy Development of nervous system and sense organs to coordinate and facilitate locomotion.
Complex development of multicellular animals from unicellular zygote	A large gestation period to provide ample time for complex processes. A period of embryotic development often followed by a larval phase and metamorphosis before adult form is achieved. Development of calcareous –shelled cliodoic eggs Evolution of oviparity , ovoviparity and viviparity Nursing of young ones and parental

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CHALLENGES	SOLUTION
Transport between body surface and center	Development of blood and lymph vascular systems in animals. Development of respiratory pigments for transport of respiratory gases Development of tracheal systems Development of xylem and phloem in plants
Need to coordinate functioning as one living unit	Development of a central nervous system to coordinate all body activities. Development of peripheral nervous system to relay information to and from CNS
Movement	A bilateral symmetry gives a compact elongated streamlines form which offers least resistance to movement. Bilateral symmetry also confers anterior, posterior dorsal, ventral, right and left aspects to the animal's body for further specialization. Sessile and slow moving forms exhibit radial symmetry so as to encounter environmental changes from all directions..
Co-ordination	Cephalisation involving formation of a definite head region where the major sense organs and nerve centers are situated at the anterior and of the body as so suitably placed to be the first structures to encounter any environmental changes ahead.
Increased risk of predation in case of prey and herbivorous in plants	High reproductive rate; mechanical weapons, nutrient exclusion in plants chemical defenses / toxins aposemative colouration, aposematic sound, mullerian and camouflage, unpredictability and disrupture life cycles , show death
Increased need for more prey by predators	Stalking low reproductive rate, weaponing, toxins, hunting parties. Resistance to prey toxins, keen eye sight (Binocular and night vision), naturality keen sense of smell

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TOPIC 5: ECOLOGY

Is the scientific study of the inter- relationships between living organisms and their environment.
The living organisms are flora and fauna.
These interactions determine the distribution and abundance of organisms within a particular environment.
Environment is the immediate surroundings of an organism.

APPROACHES TO ECOLOGY

Two types of ecological studies namely autecology and synecology are commonly carried out.

Autecology is the study of the relationship between a single species and the environment in relation to its environment.

Synecology is the study of the relationship between communities or different populations of organisms in a given environment i.e. the study of the relationship between all plants and animals in a particular area to the environment.

TERMS USED IN ECOLOGY

1. BIOSPHERE/ECOSPHERE.

Organisms live within a relatively narrow sphere (land, water and air) on the earth's surface and this is known as **the biosphere**.
The biosphere therefore is the part of the earth in which life can exist.

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 (hydrosphere).

ii) **Terrestrial regions** covering a few meters deep in the soil (lithosphere) and a few kilometers into the atmosphere (stratosphere).
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.**

2. BIOMES

A biome is a large ecological area on earth's surface with distinctive plant and animal groups which are adapted to that particular environment).
Biomes include;
Tropical rain forests, tundra **regions** (ground is frozen much of the year and vegetation is sparse), **Hot and dry desert regions** (evaporation is high and there is too much heat), **cold deserts** (precipitation coming from colder water sources than 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 live in both intensive hot and drought conditions 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 osmoregulate in highly saline 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 conditions within them.

ii) **Aquatic biome** divided into **surface, intertidal** ,& **benthic zones;** with the organisms in the intertidal zone withstanding 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 heat, while those in subterranean able to survive in low oxygen content.

NB: The zones in a biome are subdivided into **habitats.**

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3. HABITAT

A habitat is a 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 tanks for toads, kitchen for cockroaches, etc

Microhabitat: Small locality within the habitat with particular conditions (microclimate) that support specific organisms e.g. mosses can grow at the upper side of a fallen log

4. SPECIES

A group of organisms showing resemblance among themselves in appearance, behaviour, chemistry and genetic makeup for sexually reproducing organisms, individuals are capable of interbreeding to produce fertile off springs.

5. POPULATION

This is a group of organisms or individuals of the same species which occupy a particular area or habitat at the same point and time e.g. toads in a pond

6. Community

This refers to all populations that occupy a well-defined area at a given time. This implies that all plants, animals and fungi in a particular area form a community therefore a community is a group of plants and animals of different species living together in a certain environment i.e. plant and animal community.

7. Niche /Ecological niche

The role an organism plays in the habitat, and its interactions with other organisms i.e. the sum of all environmental factors that influence the growth, survival and reproduction of a species.

A niche is like the "profession" of an organism.

Describes how an organism meets its need for food and shelter, how it survives, and how it reproduces; therefore reduces intra 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 seen under the soil feeding on decaying organic matter; with centipedes eating small beetles and other organisms; colony of ants working 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 NICHES

1. Fundamental niche

The physical conditions under which a species might live, in the absence of interactions with other species

2. Realized niche

The role an organism plays in the habitat, and its interactions with other organisms in the presence of competition and other constraining factors i.e. is the set of conditions under which an organism exists in nature.

8. Native species

Species that normally survive and shrive in a particular ecosystem

9. Non-native/alien/exotic species

Species that migrate into the ecosystem or are deliberately or accidentally introduced into an ecosystem by humans e.g. crops and game species

10. Indicator species

Species that serve as early warnings of damage to a community or an ecosystem

11. Keystone species

Species that play more important roles than others in maintaining the structure and function of ecosystems of which they are a part i.e. it is a dominant species that dictates community structure by affecting abundances of other species. E.g. elephants uproot and break trees, creating forest openings in the savanna grasslands and woodlands, which promotes growth of grasses for grazers and also accelerates nutrient recycling.

Note: all species play some role in their ecosystems and thus are important, therefore the assertion that some species are more important than others remains controversial

12. Ecosystem

It is natural unit of environment composed of living (biotic) and non-living (abiotic) components whose interactions lead to 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. phytoplankton and zooplanktons.

ii) **Land (terrestrial**) ecosystems include forests, deserts, savanna, etc.

13. Ecotones are boundary zone between two biomes or ecosystem where one merges into the other.

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THE MAJOR COMPONENTS OF AN ECOSYSTEM (structure of the ecosystem)

It consists of:

a) Abiotic / non-living things: these are physical and chemical factors that influence living organisms on land (terrestrial) ecosystems and in water (aquatic).

Examples of abiotic components:

Density independent factors

These are factors affecting the population regardless of the number of individuals within e.g. temperature changes, natural catastrophes like foods, storms, volcanicity, fire, earth quake, drought, etc

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 living 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?

Climatic factors

1. **Temperature**

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 range.

(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 the metabolic rate followed by body temperature fall to the minimum required for maintaining the vital activities of the body) ; allows them to survive extremes of hot temperatures e E.g. African lungfish burrows into mud till the dry season ends, earthworms , garden snails , desert rats, termites also aestivate

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- 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 and metabolic rate fall to the minimum required for maintaining the vital activities of the body) The animals, said to be in 'deep sleep' ably reduce energy needs to survive the winter when food is scarce allowing them survive extreme cold conditions e.g in polar bears.
- Gathering in groups to warm themselves e.g penguins

Rainfall

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 aquatic organisms, for photosynthesis; and aquatic predators to locate their prey
- Important factor in decay and decomposition; therefore increases in recycling of nutrients in an ecosystem.

Humidity;

Amount of water in the atmosphere;

- Affects the rate at which water evaporates from organisms i.e Low humidity results to increasing evaporation while high humidity causes low rate of evaporation; through stomata of leaves in plants.

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 niche 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,

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- 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 light 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 visibility)
- 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 ultra-violet light
- 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

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 slopes
- 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 bacteria, fungi, algae and animals like protozoans, nematodes earthworms, insects, burrowing mammals) and **non-living components (**Particles of various sizes)
- Also present are; mineral salts, water, organic matter, and grasses.

Soil pH

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- Influences physical properties of soil and availability of certain minerals to plants, thus affecting their distribution in soil; 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 matter 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 mineral 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 from aerial parts to help supply the roots.

Biotic content;

- Microorganisms like bacteria and fungi carry out decomposition of dead organic material, therefore recycling nutrients back 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 of 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 microorganisms in the soil that decompose the humus.

***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 physiological adaptations to osmoregulate in the respective salt concentration, **(read adaptations of fresh water fish, marine water fish and migratory fish to their osmoregulatory problems in homeostasis**).
- 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 feeding 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 respectively.
- Metabolic activators; some ions activate enzymes, e.g chloride ions activate salivary amylase, magnesium activate 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

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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 compounds 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 with high protein content grows.
- Destroys pests
- Controls undesirable plant species and weeds

Ecological effects of fire 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. Some trees have heat resistant tissues.

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

These are the components which interact between the different living organisms e.g. competition, predation, symbiosis. Also they are called density dependent factors.
The biotic part includes producers, primary consumers (first level carnivores), tertiary consumers (higher carnivores), decomposers, detritivores, etc

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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 carbon dioxide and water.
- Examples include; large green terrestrial plants e.g trees, shrubs, grass. For aquatic ecosystem, the producers are microscopic 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/obtains 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:

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

Influence of biotic factors on the distribution and abundance of organisms, excluding man.

Predation: A **predator** is an organism that hunts, captures and kills its prey.

Predation affects the distribution and abundance of both the prey and predator, and other organisms influenced by these.

Interaction between prey and predator populations produces characteristic cyclic fluctuations in population sizes, with the populations slightly out of phase, with the prey population leading the predator population

Competition: Organisms compete with each other for food, water, light, shelter, space, minerals, mates and other resources competition within individuals of the same species is **interspecific competition,** and competition between individuals of different species is **interspecific competition.**

The closer the ecological niches of the competing organisms the more fierce the competition.

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When two species occupy the same ecological niche at the same time, interspecific competition leads to extinction of the weaker species, a principle called the **Gaussian/competitive exclusion principle**

Animal pollination: Angiosperms utilize insects, birds and bats to transfer their pollen from one member of the species to another.

This results in a highly complex interdependence in the distribution of the flowing plant and its animal pollinating agent.

Antibiosis: Antibiosis is the production of chemicals by an organism which repel other organisms

Antibiotics may be produced against members of the organism own species, for example, mammals mark their territories with chemicals which deter other members of the species from entering, injured ants produce pheromones when in danger which warm off other members of the species.

Allelopathy: Allelopathy is form of antibiosis where an organism produces poison or growth inhibitors which kill off other organisms usually of their species. For example, the fungus ***Penicillium*** produces the antibiotic penicillin which kills bacteria in their vicinity

Animal dispersal: Many organisms depend on animals to disperse them.

Plants employ a wide variety of animals' species to disperse their seeds, spores, fruits, and various vegetative propagules

The distribution of the organism depends on the distribution of its dispersal agent.

The distribution of organism depends on the distribution of its dispersal agent.

Herbivory: A **herbivore** is an animal which feeds on plant matter.

Herbivory affects the distribution and abundance of both the herbivore and the plant and other organisms influenced by these, such as predators of the herbivore

Mimicry: Organisms seek to resemble other organisms for a variety of reasons.

Mullerian mimicry is the mutual resemblance of several well-protected species such as bees and wasps, thereby reducing the number of individuals killed before a predator learns to avoid a certain **aposematic coloration.**

Batesian mimicry is the resemblance of an unprotected mimic to a well-protected model, such as a harmless fly mimicking a bee, thereby offering the unprotected mimic protection from predators

Animals and plants may also mimic their living background as a means of **camouflage** as in moths and chameleons, either for aggressive or defensive purposes.

In all cases all mimicry, the distribution of the mimic is greatly influenced by that of the model

Parasitism: Parasitism is close association between two living organisms of different species which is beneficial to one (**the parasite)** and harmful to the other (the **host**). The parasite generally obtains food and shelter from the host, as in the case of the human endoparasite, for example ***Plasmodium*** which causes malaria.

The host and parasite populations exhibit cyclic out-of-phase fluctuations, were the host population leads the parasite population

Commensalism: Commensalism is a close association between two living organisms of different species which is beneficial to one (**the commensal**) and does not affect the other (the **host**)

For example the colonial hydrozoan ***Hydractinia*** attaches itself to whelk shells inhabited by hermit crabs. ***Hydractinia*** obtains nourishment from the scraps of food left by the crab after it has eaten and so the crab is totally unaffected by the association.

The distribution of the commensal depends on that of its host, while that of the host is totally unaffected by that of the commensal

Mutualism: Mutualism is a close association between two living organisms of different species which is beneficial to both partners, as in lichens, root nodules of legumes, mycorrhizae

The distribution and abundance of partner in a mutualistic association shows great interdependence, and in some cases one partner cannot survive in the absence of the other.

Overcrowding: Population explosion causes overcrowding which affects the reproductive rate of organisms, even if there is no food shortage.

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Overcrowding causes hormonal changes which causes stressing-induced failure of copulation, stress induced abortions, increased infertility, failure of gonad development, increased infant cannibalism, decreased parental care, early abandoning of the nest by the young, increased aggressive behavior, and increased population dispersion.

Territorial behavior: Organisms acquire, demarcate and defend particular areas with useful resources and conducive conditions. A territory is held and defended by organism or group of organisms against organisms of the same or other species.

The distribution of the territory owners is confined within the territory, and these ward off other organisms of the same or other species which they perceive as enemies such as competitors and predators.

Resource partitioning: With time, species can reduce interspecific competition for a particular resource through specialization over time by evolution.

The more specialized an organism becomes for a particular niche, the less direct competition it faces.

This specialization by different species to make use of different resources is called **resource partitioning** which may be **spatial**(in space) or **temporal** (in time).

Resource partitioning occurs in several forms; behavioral and **morphological** specialization for different foods, as in Darwin's finches, **vertical spatial** separation of feeding habitats as in cape barnacles, **horizontal spatial** separation as occupation of different micro habitats; temporal resource partitioning as in diurnality and nocturnality.

Spatial resource partitioning makes species distribution nearly mutually exclusive.

Saprotrophism: Saprobiontism involves the consumption of complex organic food the bodies of dead or decaying organisms.

Many fungi and bacteria are saprotrophic. Saprotrophs secrete enzymes onto the dead organic matter where it is digested externally and absorb and assimilate the soluble end products.

Saprotrophs create space by removing the remains of dead organisms, decompose dead organic matter, facilitate nutrient cycling and increase soil fertility there by availing more nutrients to plants.

Biotic background: The distribution of organisms whose shape and coloration is such that they are camouflaged when viewed against a particular background is related to the general texture, coloration and pattern of their biotic environment. Insects, amphibians, reptiles, birds, mammals and even plants exhibit various forms of protective offensive camouflage.

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FUNCTIONING OF THE ECOSYSTEM

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 energy 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 to 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; much 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).

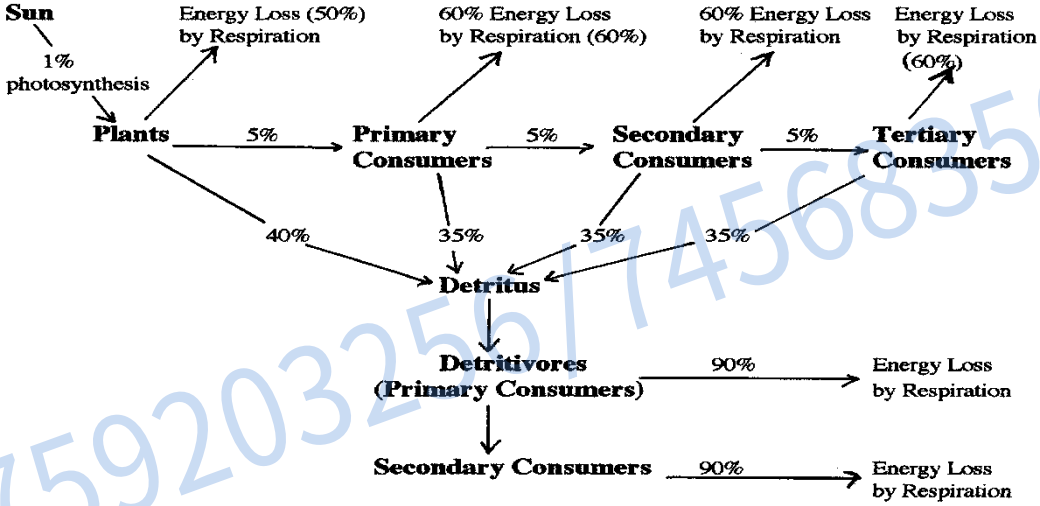
AN OUTLINE OF THE PROCESS OF ENERGY FLOW THROUGH THE ECOSYSTEM

- The primary source of energy is the sun. Of the energy received by the earth, less than 0.1% is fixed by green plants as chemical energy in biomass in organic substances during photosynthesis (Gross

Primary Production); the rest is reflected by the atmosphere, heats the earth's surface or causes evaporation of water.

- Part of gross primary production is used by green plants for aerobic respiration while what remains (Net Primary Production) is used as food by primary consumers, during which only about 5 – 10% of the energy is transferred from producer to primary consumer (a loss of 90 – 95% occurs) because much of plant biomass is indigestible to herbivores. The energy obtained by herbivores through feeding on producers is less than what producers get from the sun because some is lost in egestion, excretion, and not all parts are eaten.

- When carnivores eat herbivores still the energy they obtain is less than what herbivores obtain from feeding on producers, and the trend is maintained even as top carnivores feed on secondary consumers.
- Therefore, with each energy transfer some usable energy is degraded and lost to the environment as low quality heat, thus the energy available to each successive trophic level declines, and the more trophic levels in a food chain or web, the greater the cumulative loss of energy during its flow through the various feeding levels. This limits the number of feeding levels to 3 or 4, or very rarely 5 or 6.



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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 level.

(iii). Primary productivity; is the rate at which energy trapped by autotrophic plants in an ecosystem is stored by them in form of organic substances which can be used as food materials by other organisms.

Or Is the amount of energy and organic material stored in primary producers. Measured in **mass per unit area per unit time** (kilogram per unit area per year, Kg/M^2 /yr.)
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 can as well be called dry mass of the harvest crop**.**
Therefore, **GPP** - **assimilation** (respiration & metabolism) =**N.P.P**
(iv**). Secondary productivity**; is the amount of energy incorporated into the body of consumers

Also known as **Gross secondary 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 lost. 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 ectotherms than in endotherms, because;

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

REPRESENTATIONS OF ENERGY FLOW
<u>FOOD CHAIN AND FOOD WEB</u>.
1. FOOD CHAIN
A linear sequence of energy flow from producers through a series of organisms in which there is repeated eating and being eaten.
Two types exist i.e
i. Grazing food chain
ii. Detritus food chain
Grazing 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 ⟶ Haplochromis ⟶ 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 habitats.
1st trophic level is occupied by a decomposing organic matter

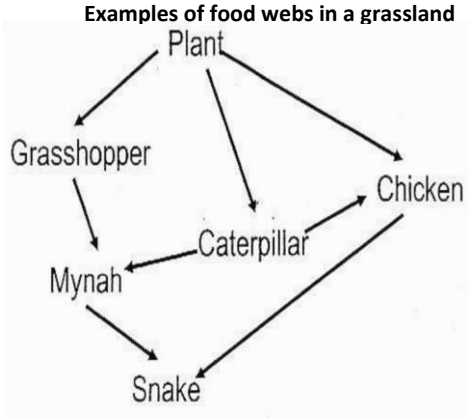
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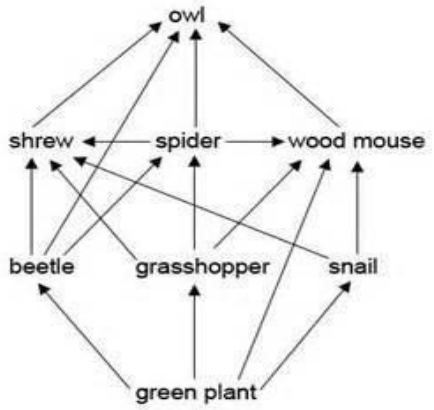
E.g Tree log → woodlice → toad → python

dead animal → maggots → 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

Construct a food web using the following organisms: phytoplanktons, mosquito larvae, small fish, large fish, and crocodiles.

(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 nonliving components of such an ecosystem.

(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 (horizontal bars) that provide information about feeding (trophic) levels in ecosystems. Three types exist i.e

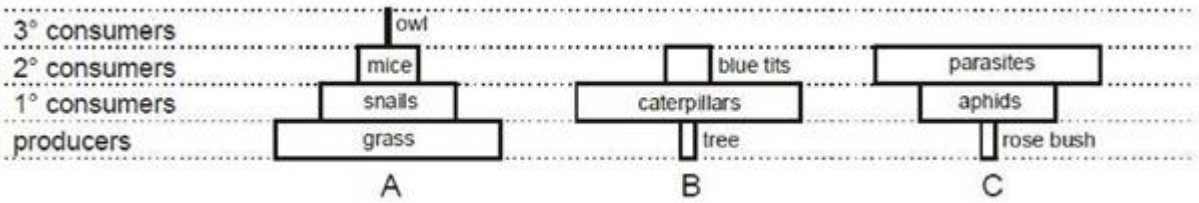
(i).**pyramid of numbers**

(ii).Pyramid of energy

(iii). Pyramid of biomass

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

1. Pyramid of numbers. It is a histogram representing the numbers of different organisms at each trophic level in an ecosystem at any one time.



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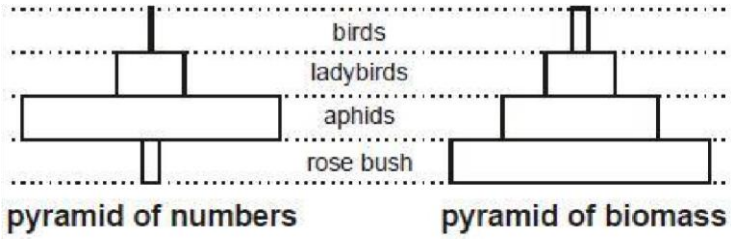
NB:

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

Limitations of pyramid of number

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

2. 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 biomass but with higher productive rate (caused by so rapid turnover rate), therefore capable of supporting a larger biomass of zooplanktons.

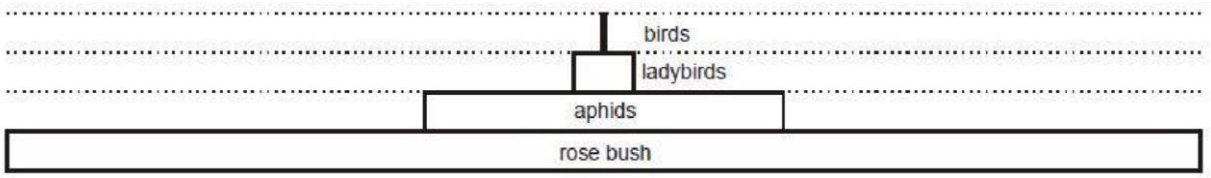
Disadvantages/limitations of pyramid of biomass

- Does not allow for changes in biomass at different times of the year e.g deciduous trees have larger biomass in summer than in 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 many years.
- Impossible to measure exactly biomass of the organisms in an ecosystem, because the sample used may not true representation 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.

3. **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 nor do they have a central bulge.
- More informative than pyramids of numbers and biomass because it shows the amount of energy required to support each 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.

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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)

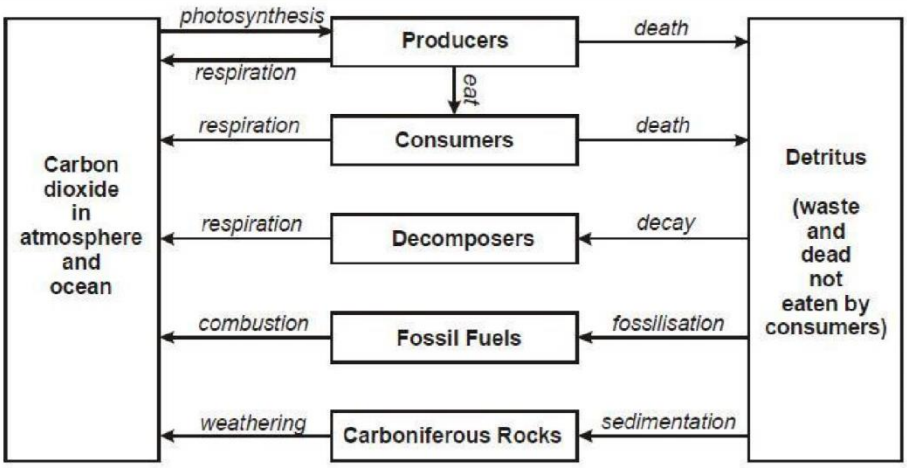
- Process by which chemical compounds of a particular element that constitutes living matter are transferred between living organisms (biotic phase) and non-living environment (abiotic phase).
- Are driven directly or indirectly by incoming solar energy and gravity

(1). **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 form 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 and these ions react with calcium ions to form calcium carbonate ($CaCO_3$) to build their shells and skeletons.
- When the animals with calcium in shells and skeletons die and drift into deep bottom sediments of



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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 CO2 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.

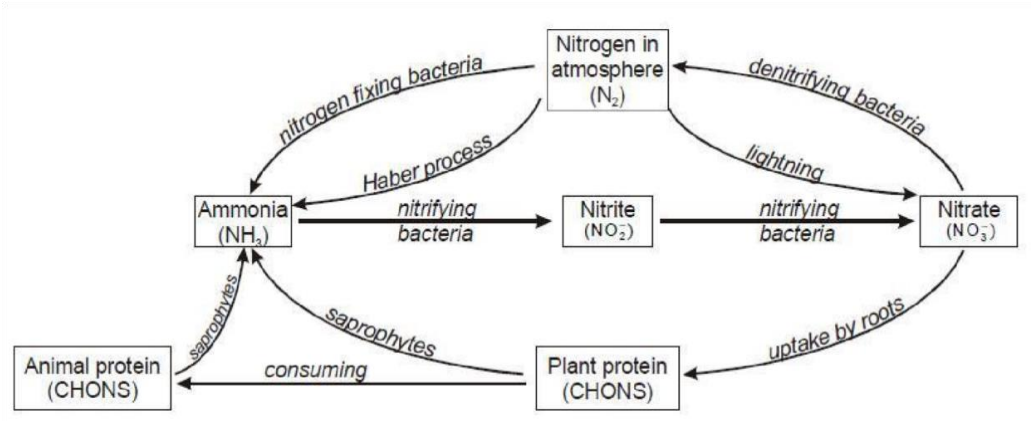
(2) **NITROGEN CYCLE**

- Nitrogen is the atmosphere's most abundant element, with chemically unreactive nitrogen gas making up 78% of the volume of the 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 oxides 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 may 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 ***Nitrosomonas*** **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, amino acids and protein.
- **Denitrification** occurs when mostly anaerobic bacteria e.g. ***Pseudomonas denitrificans*** and ***Thiobacillus denitrificans*** in water logged soil and deep in ocean, lake and swamp bottoms convert ammonia and ammonium ions back into nitrite and nitrate ions, and then into nitrogen gas and oxygen. Nitrogen gas is released into the atmosphere while oxygen is used for the respiration of these bacteria.

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How humans affect the nitrogen cycle

- Burning of fuels forms nitric oxide, which reacts with atmospheric oxygen to form nitrogen dioxide gas that reacts with water vapour to form acid rain containing nitric acid. Nitric acid together with other air pollutants (i) damages trees (ii) corrodes metals (iii) upsets aquatic ecosystems.

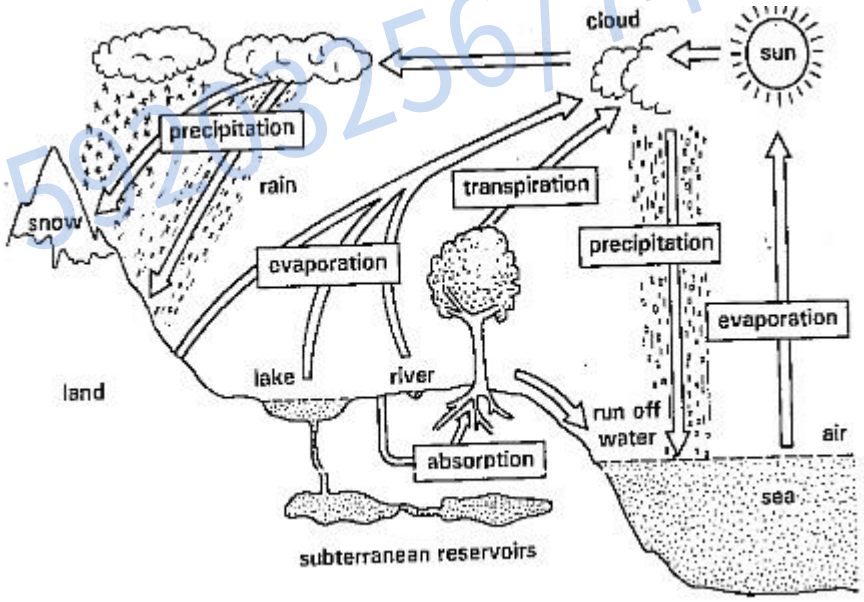
- The inorganic fertilizers applied to soil are acted upon by anaerobic bacteria to release nitrous oxide into the stratosphere, where **it (i)** contributes to ozone depletion **(ii)** contributes to green house effect.
- Nitrogen is removed from top soil when we **(i)** harvest nitrogen-rich crops (**ii)** irrigate crops (**iii)** burn or clear grasslands and forests before planting crops
- Adding nitrogen compounds to aquatic ecosystems e.g. sewage algal blooming, which upon death, their decomposition causes oxygen shortage resulting into death of aerobic organisms e.g. some fish.
- The accelerated deposition of acidic nitrogen containing compounds e.g. **NO_2** and **HNO_3** onto terrestrial ecosystems stimulates growth of weeds, which outcompete other plants that cannot take up nitrogen as efficiently.

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)



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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) mimicry.***

(a) **Human influence**.

- Of all living organisms, humans exert most influence on the distribution and survival of other species through a multitude of 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 limited supply.

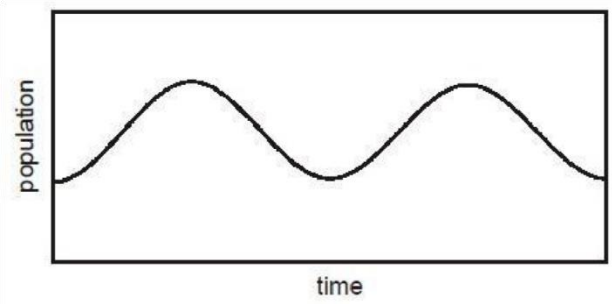
E.g. plants competing for light, carbon dioxide, water, minerals, pollinators, and sites for spores and seeds to germinate while

- Animals compete for food, mates, breeding sites and shelter from predators.

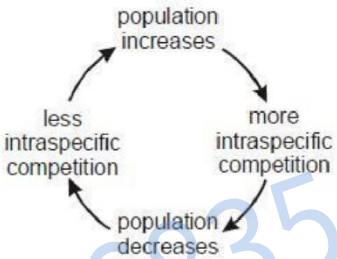
(i) Intraspecific competition Is the competition between members of the same species for the same resources.

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.



Explanation:



(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. ; **or** is the competition among individuals of different species for resources.

Competition is very intense when there is significant overlap of niches, and in this case one of the competing species must;

- Migrate to another area if possible
- Shift its feeding habits or behaviour through natural selection and evolution
- Suffer a sharp population decline or become extinct in that area, otherwise two species can never occupy exactly the same ecological niche.

Co-existence between two species which compete is impossible. To avoid severe/stiff competition and extinction the two different species occupy different ecological niches. This is called ***competitive exclusion principle.***

It states that, "no two organisms can occupy the same ecological niche when they compete for the same resources. If they did so, one would become extinct or will be out-competed thus becomes, extinct"

Organisms develop structural features and behavioral patterns to enable them succeed in the exploitation of natural resources. The successful organism has a **faster rate of reproduction** and a **higher tolerance** to waste materials e.g. seedlings in forests show rapid growth due to competition to gain access to sunlight for photosynthesis.

Consequences of competition

- Weak competitors are eliminated or extinction of species or migration.
- It results in feeding habits/feed on food nutrients which they used not to feed on.
- It affects pollination between certain plants and specific insects.
- Gene loss or change in gene frequency.

Note, competition **will lead to competitive exclusion and resource partitioning**.

Two species (populations) that require identical resources cannot coexist indefinitely in the same habitat.

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Resource partitioning; where two different species share the same resource allow coexistence
So both species survive.

Gausses' competitive exclusion principle; where two different species competing for the
Same resource; cannot co-exist ;so the weaker species is out competed to extinction;

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

Example 1

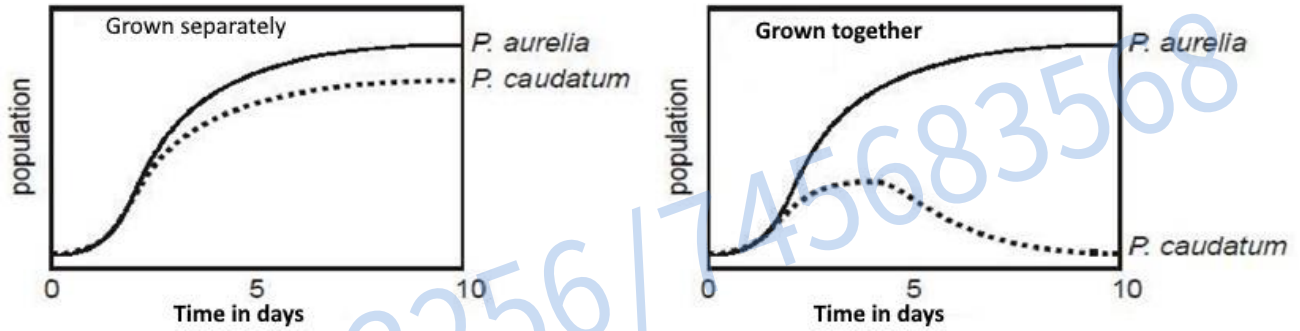
(i). Two species of flour beetles, *Tribolium castenum* and *T. confusum* were kept in the laboratory in bottles of flour acting as a habitat and providing food for them, under variable temperature conditions(24-34) and humid conditions(very humid , 70%RH& 30% RH).

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

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

ii) **Experiments with Paramecium**

Two closely related species of of single-celled bacteria eating paramecium paramecium Aurelia and p.caudatum were grown first separately in the same culture and then **later cultured together.**



Observation

i) When cultured separately each species has maximum population, only coming constant with time due to;

- Presence of toxic wastes which can poison paramecium.
- Heat generated during respiration may kill some paramecium.
- Decrease in food measures.

The research revealed the following;

- Pure population of *Paramecium caudatum* and *Paramecium aurelia* grown in full-strength concentration of food had a high carrying capacity.
- Pure population of *Paramecium aurelia* grown in half-strength concentration of food had a low carrying capacity.
- Pure population of *Paramecium caudatum* grown in half-strength concentration of food had a low carrying capacity.
- Pure population of *Paramecium caudatum* grown in full-strength concentration of food showed a high carrying capacity
- When grown together, *Paramecium aurelia* survived, while the population of *Paramecium caudatum* rapidly decreased.
- At a full-strength food concentration, the decrease in the *Paramecium caudatum* population was approaching exclusion by 16 days but exclusion was not complete.
- At half-strength food concentration, *Paramecium caudatum* had been entirely eliminated by day 16

Other observations

- The maximum population density of *P. aurelia* attained in separate cultures is higher than that of mixed cultures.

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- The rate of population density increase for both organisms is higher in separate cultures than in mixed cultures.
- The initial population density of *P. aurelia* in both experiments is lower than that of Paramecium caudatum.
- The decrease in population density of *P. caudatum* is very gradual in separate cultures in comparison with mixed culture. '
- The population density of *P. caudatum* in mixed cultures decreases to extinction but that in separate culture remains higher even at carrying capacity.
- *P. aurelia* out-multiplied and eliminated *P. caudatum* when grown together.

Note:

a) Experiment 1 each-species grown alone;

(i) Population density of *Paramecium aurelia* increases very gradually for the first 2 days, very rapidly to a maximum on the 9th day, remains relatively constant till the 12th day, then decreases very gradually thereafter. There is rapid growth of population densities of both organisms because of abundance of food and absence of interspecific competition for food. *Paramecium aurelia* Grew faster than that of *Paramecium caudatum*

(ii) Population density of *Paramecium caudatum* increases gradually but later increases rapidly for first 9 days, increases very gradually till the 14th day and then declines very gradually thereafter. Stable populations are established afterwards for both organisms because of intraspecific competition for food.

Population density of *P. caudatum* increased rapidly when compared with *P. aurelia and* remains lower than that of P. *aurelia,* except for the first 4 days. This is because Population density of *P. aurelia* grew faster than that of *P. caudatum* because *P. aurelia* used the available food supply more efficiently than *P. caudatum.*

B) Experiment 2 Species in mixed culture;

(i) Population density of *Paramecium aurelia:* It is lower than that of *P. caudatum* for the first 3 ½ days. Increases gradually for the first two days, very rapidly till day 7 and then gradually thereafter.

(ii) Population density of *Paramecium caudatum:* Remains higher than that of *P. aurelia* for the first 3½ days only. Increases rapidly to a maximum in the first 5½ days, decreases gradually till day 15, and decreases very gradually to extinction at day 17. This is because the population density of *P. caudatum* decreased to extinction because of being out-multiplied and outcompeted for food by P. *aurelia.* This is attributed to the smaller size of P. aurelia.

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 its 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) in 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 or an overlap of their fundamental niches.
- Resource partitioning decreases competition between two species leading to increased niche specialisation

Examples of resource partitioning:

a) When living in the same area, lions prey mostly on larger animals while leopards on smaller ones.
b) Hawks and owls feed on similar prey, but hawks hunt during the day and owls hunt at night.

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c) Each of the five species of common warblers (insect-eating birds) minimizes competition with the others by

(i) Spending at least half its feeding time in a different part of spruce tree branches e.g. some hunt at the extreme top, others at the lower portion, some mid-way etc

(ii) Consuming somewhat different insect species.

d) Different species of eagles in a forest feed at different times of the day e.g. bald headed eagles are most active early mornings and evenings while the white-breasted eagles feed vigorously towards noon.

e) When three species of ground finches of Galapagos Islands occur on separate islands, their bills tend to be the same intermediate size, enabling each to feed on a wider range of seeds, but where they co-occur, there is divergence in beak size to suit each finch species to feeding on seeds of either small, medium or large size, but not all sizes.

f) In an abandoned field, drought tolerant grasses with shallow, fibrous root system grow near the soil surface to absorb moisture; plants with a taproot system grow in deeper soil while those with a taproot system that even branches to the topsoil and below the roots of other species grow where soil is continuously moist. NB: The more that two species in the same habitat differ in their use of resources, the more likely they can coexist.

g) Two species of barnacles do not occupy as much area of the intertidal zone as possible. The upper intertidal zone is the realized niche of the smaller barnacle Chthamalus stellatus since it is drought resistant while the larger Balanus balanoides being poorly adapted to drought lives on the lower intertidal zone. Interestingly C. stellatus can also grow very well in the lower zone only in the absence of B. balanoides, suggesting that Balanus barnacles when present either forces the smaller Chthamalus individuals off the rocks or grows over them. This indicates that the entire intertidal zone is the fundamental niche of Chthamalus, but competition for space restricts it to the upper intertidal zone.

Note:

i) The more two species in the same habitat differ in their use of resources, the more likely they can coexist.

ii) Two competing species also may coexist by sharing the same resource in different ways or at different times.

ii) The tendency for characteristics to be more divergent when populations belong to the same community than when they are isolated is termed ***character displacement*** *e.g* ***Galapagos finches.***

Question.

1a) 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 laboratory

	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.

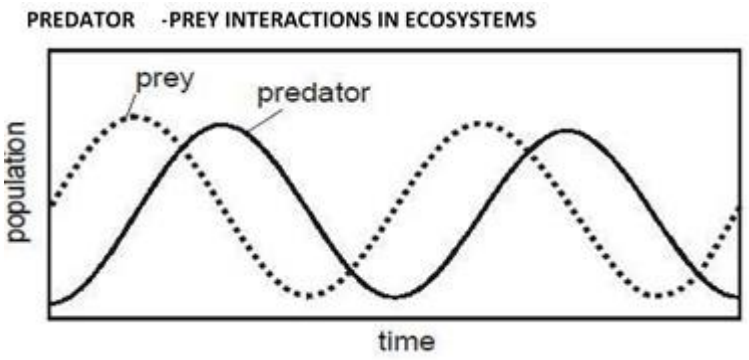
(iv)Offer an explanation for the interaction of the two species when grown together.

(v).Account for the changes in the growth rate between 46 and 60 days for *Lemna trisulca.*

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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 plant 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.



The growth and decline of the population of such organisms depend on the number of each group in an ecosystem. Initially prey population grows at a faster rate than the predator. The predators feed on the prey, thus increasing in production.

A reduced prey population triggers off competition for density dependent factors like food, space, mates among the increased predator population and also increased accumulation of wastes. These will check the increase in predator population hence predator number will start to decrease in number due to starvation. When predator populations decrease, prey will reproduce$_1$ancfinultiply in number and increase. Therefore, large numbers of preys provide food and therefore food becomes available. Thus the population of prey and predator affects each other which bring about fluctuation in the growth of their populations.

Note: normally the numbers of predators tend to lag behind than those of prey because predators being larger have a slower rate of increase.

Question: Explanation for the observed changes in populations:

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.
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.

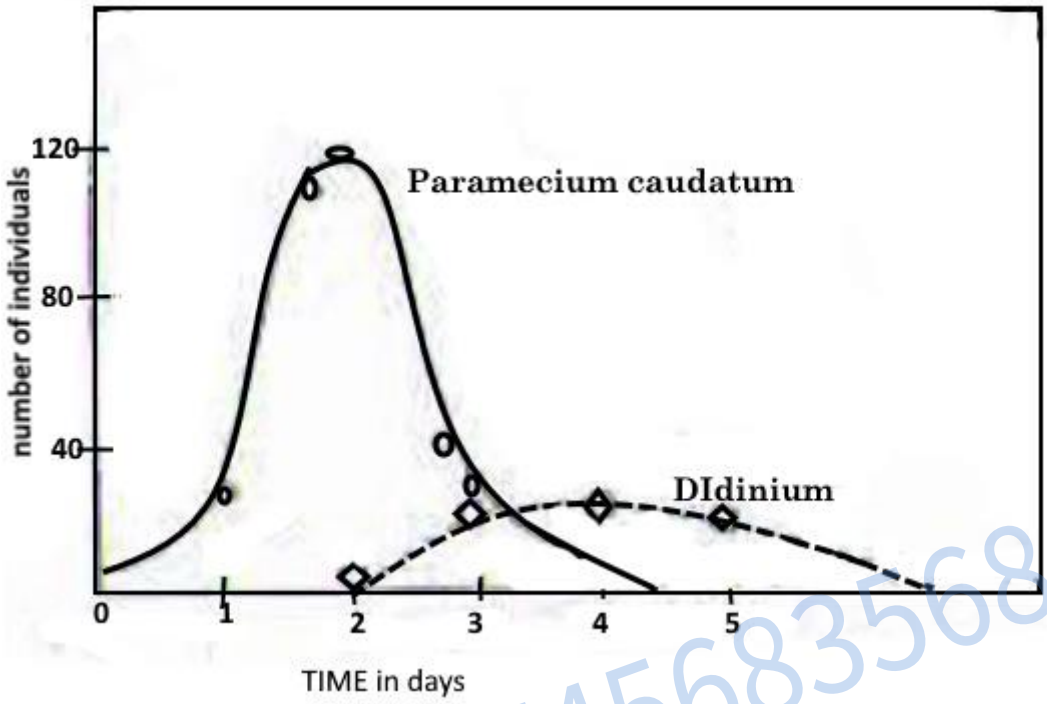
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<u>Evolutionary significance of predator –prey</u>

- 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 longtime survival, thus pass on their good traits to their off springs which can improve their evolution.
- Predation maintains populations within the carrying capacity of their habitats and lessens the sudden explosion of prey species within a population.
- Predation is a mechanism by which excess animal productivity is redistributed by conversion to other animal tissues at higher trophic levels.

Examples

The graph below show the relationship between a predator, Didinium and prey, paramecium in a culture medium.



Description of the trend for;

Paramecium

From o days to 1 days the *Paramecium* population increases gradually

From 1 day to 2 days the *Paramecium* population increases rapidly to a maximum.

From 2 days to 3 days the *Paramecium* population decreases rapidly

From 3days to $4^1/_2$days the *Paramecium* population gradually decreases up to 0

Didinium

From 2 days to 3 days the population of *Didinium* increases gradually

From 3 days to 5 days, the population Didinium remains almost constant

From 5 days to 6 days the population of Didinium gradually decreases up

Explanation

Paramecium population rapidly decreased to extermination because it was being preyed upon by the introduced Didinium on day 2. The gradual increase in Didinium population was supported by food (Paramecium) presence, what resulted was starvation as soon as food depleted.

How are the predators suited for capturing prey?

- Have keen eyes for locating prey eg wolves, African lions hunt in groups.
- Praying mantis, chameleon have cryptic coloration/camouflage that enable them to walk to prey unnoticed.
- Nocturnal predators e.g 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

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- 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?

- Ability to run, swim or fly faster.
- Possession of highly developed sense of sight or smell alerting the presence of predators.
- Possession of protective shells e.g. in tortoise and snails for rolling into armor-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 the 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 making 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 unpalatable or poisonous e.g poisonous frogs, some snakes, monarch butterflies, and some grasshoppers
(ii) **Disruptive colouration/patterning**, works by breaking up the outlines of an animal with a strongly contrasting pattern, thus decreasing detectabilitye.g. Group of zebras
(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. bombardier beetles), foul smelling (e.g. stinkbugs and skunk cabbages) or bad tasting (e.g. monarch butterflies and buttercups)
- Some prey species have evolved warning colouration – contrasting pattern of advertising colours that enable predators to recognize and avoid such prey e.g. the poisonous frogs, some snakes, monarch butterflies and some grasshoppers.
- Some species gain protection to avoid predation by mimicking (looking and acting like) other species that are distasteful to the predator e.g. the non-poisonous viceroy butterfly mimics the poisonous monarch butterfly. **Batesian mimicry** occurs when the palatable species mimics other distasteful species e.g. viceroy butterfly mimics the poisonous monarch butterfly, the harmless hoverfly mimics the painful stinging wasp 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 eggs
- The electric fish Malapterurus (a cat fish) produces high voltage discharge of up to 350v that shocks any predator that makes contact with it.
- Other preys employ alarm signals and calls e.g. ants, various fish, small birds and mammals.
- Group defense, occurring among those that live and feed in herds NB Predation

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Determines distribution and abundance of the prey because

(i) An increase in the number of predators results into decrease 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.

Note: Plants have poor hosts for invertebrate parasites because;

- Plants have strong cellulose cell walls so that are too difficult to be penetrated by parasites as invertebrate parasites lack cellulose enzyme to dissolve such walls
- plants store insoluble food that is undigested e.g. starch yet invertebrates parasites absorb already digested food and so cannot provide suitable conditions for survival
- Plants do not locomote to spread the parasites to other hosts
- Plants have limited cavities where the parasites can be sheltered against climatic extremes
- Some plants are seasonal which limits the dependence of parasites on them

Note: Benefits of predator-prey relationships to both the prey and the predator

- maintains both populations at carrying capacity as they regulate their number interpedently
- They eliminate the weak and aged predators and preys thereby maintaining a healthy populations
- They allow evolution of better adapted predators and preys via natural selection
- They allow nutrient cycling and energy flow
- These relationships avail resources to both predators and preys by maintaining carrying capacity

Benefits of the prey from the predator-prey relationship

- Regulates the prey population thereby minimizing overcrowding, and its effects such as increased competition, overgrazing, increased spread of diseases, enhanced soil erosion, reduced soil fertility, decreased vegetation, which would lead to abrupt collapse of prey population.
- Puts up a selection pressure which favours the well-adapted prey to evolve with mechanisms to survive and multiply in large numbers; while the less adapted are eliminated from the population. This leads into new species formation.
- Obtain food by feeding on the prey for their growth and reproduction
- Increase in the prey population increases the population size of predators, due to increased availability of food in form of the prey, reduced competition among predators, and promotion of predator immigration, while discouraging emigration.
- Regulates the population of the predator at that which can be fully supported by the environment.
- Puts up a selection pressure whereby the poorly adapted predators are naturally selected against, and fail to obtain prey to feed upon, hence their elimination from the population; while the well adapted evolve certain mechanism which enable them efficiently in detect and capture the prey. This can result into formation of new species.

Note: precautions taken before the predator is used for biological pest control

- Careful marching of climatic conditions to ensure that they favour the survival of the predator especially when the prey population is at the peak
- Monitoring of interactions of the natural enemy with native species to ensure that the predator is not preyed upon by other unsuspected organisms. This also allows identification of the prey organisms which may be presented by the predator instead of the targeted prey
- The predators must be released when the prey populations have reached large numbers to provide sufficient food for the predators. Otherwise the predator may get wiped out prematurely via starvation resulting into resurgence of the prey population.

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d) Pollination and dispersal

- ❖ Pollination is an ecological interaction because plants and animals interact with each other. Insects transfer pollen grains from 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 arum 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 organisms 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 and 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 pheromones 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 used 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.

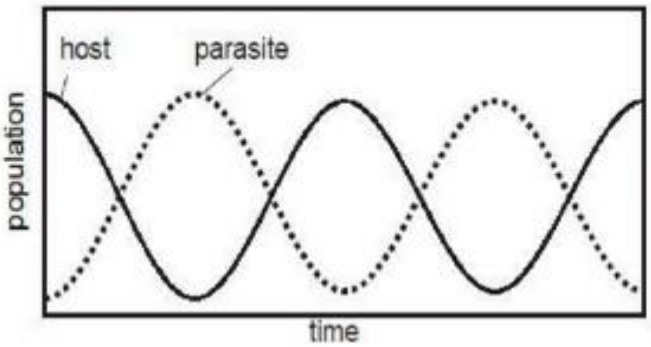
(f) Parasitism: An organism called parasite obtains part or all its nutrients from the body of another organism of different species called host.

The parasite is usually smaller than its host in size.

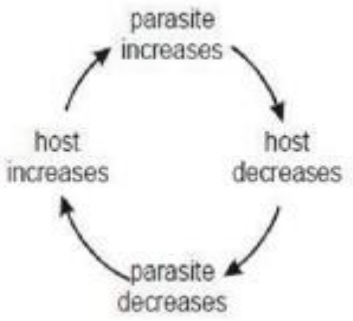
Parasites do not usually kill their hosts, but the host suffers harm.

Many parasites live permanently on (**ectoparasites)** or in their hosts (**endo parasite)** while some visit their hosts only to feed.

Some **parasites are facultative,** live on or in the host for some time e.g. Pythium (a fungus) that causes damping off seedlings, on killing the seedlings, lives as a saprophyte on their dead remains and others are **obligate parasite** which live on or in the host for their entire lives.



Explanation:



Note: In most cases, the parasites don't directly kill the host. However, by weakening its host, a parasite rises the host's susceptibility to other forms of environmental characteristics e.g. a severe fall in temperature during

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winter is more likely to kill parasitized organisms than healthy one, and a predator is more likely to catch parasitized animal than a healthy one.
Parasites which are introduced into a new habitat can cause disastrous effects on their host population e.g they can cause death on the host organism. However, given time, the relationship between a parasite and its host evolves to minimize the harm to the host e.g. when the myxomatosis virus was introduced into Australia, all rabbits died in a short time of infection; however, after some time, infected rabbits were found to survive longer
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, amino acids while bacteria obtains shelter, protection and food
ii. **Leguminous plants** e.g clover and nitrogen fixing bacteria (rhizobium). The plants obtain nitrates while bacteria obtains shelter, sugars, and vitamins.
iii. **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 the root of orchids with the fungi digesting lignin and cellulose in the soil; and passing the end products into the roots of plants.
iv. **Lichens;** 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 and sea anemones,** with the hermit crab (*Eupagurus berhardu) is* 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 another.

(h) **Commensalism** is an association between organisms of different species in which one benefits while the other neither benefits nor its harmed .e.g (i) lichens on the barks of tree ii) cow and white egrets, iii) 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.

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ECOLOGICAL SUCCESSION

Ecological succession is a gradual change in community composition from the initial colonization of an area/habitat to establishing a relatively stable community. ***Or***
Ecological succession is a fairly orderly process of changes of communities in a region or an area.
It involves replacement in the course of time of the dominant species within a given area by other species. ***Or***
It's the establishment of a sequence of different communities in a particular area over a period of time.

A community is a group of interacting populations living in a given area and represents the living part of an ecosystem. Its functions are energy flow and cycling of nutrients. The structure of a community is always built up over a period of time until a stable climax community is established.
Ecosystems are dynamic, constantly changing in response to both physical and biological factors.
Communities succeed each other in an orderly sequence in which such successive stage i.e. it's dependent on the one that precede it.
Succession progresses gradually from a small number colonizing species known as **seres or seral stages** (i.e. communities that replace one another in a given area are called **seres**. These temporary consists the seral stages/seral communities).

Each **sere** has its own community of organisms until the terminal relatively stable and final stage community called climax community.

The climax community comprises of dominant or several co-dominant species which refers to species with the greatest collective biomass/productivity and physical size of individuals in a given area after some time (years).
At climax community the net productivity/biomass tends to remain constant but dependent on species number and population, size.

- This is a long- term directional change in the composition of a community from its origin to its climax through a number of 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 by 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.

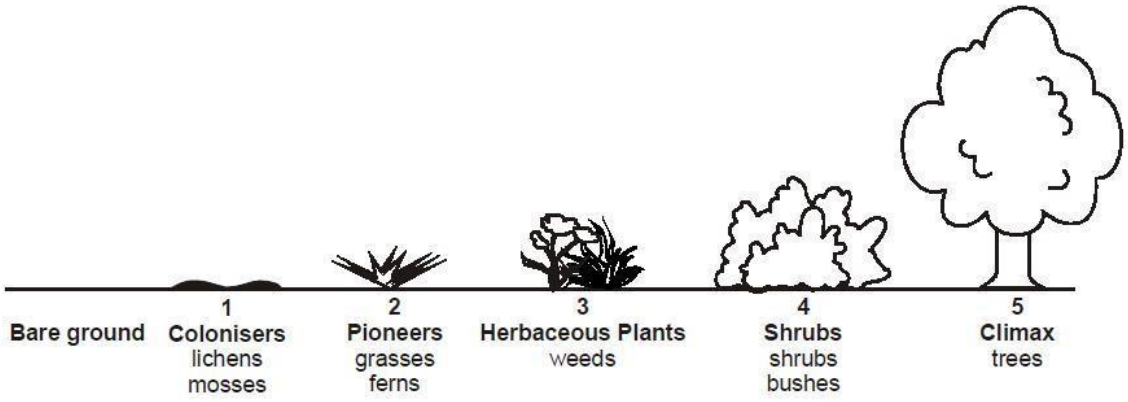
i. **hydrosere**; succession in aquatic environment
ii. **halosere**;succession in salty environment
iii. **xerosere**; succession dry environments e.g. deserts
iv. **lithosere**; succession on a rocky surface

- 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 (i) diverse species (ii) complex feeding relationships and (iii) progressive 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 during the colonization of uninhabited area or where no new life previously existed It occurs on bare rocks exposed by erosion, volcanic islands bare rocks, sand dunes, lake shore, river banks, bare pavements, bare soil surface, dry area devoid of vegetation, newly cooled lava, newly created shallow ponds, Sand dunes, abandoned highway or parking yard.
<u>An example of primary succession on land</u>



An example of succession on a rock:
(i) On a bare rock/bare pavement several seral stages are identified, *lichens* (algae and fungi) are the *pioneer community* to be established first. They are able to utilize the low moisture, nutrients, and ions on rock surface. The hyphae of the fungi penetrate the tiny pores on the rock providing a firm attachment and absorbing inorganic nutrients from the rock while the algae provide food since it is photosynthetic. Bacteria and fungi

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also aided by weathering loosen rock surface by the process of rock decay. Their decaying bodies (algae/fungi and bacteria) add humus to the loosen rocks to form sedimentary soils.

(ii) The loosen rock is now able to be inhabitable by the drought resistance *second colonizers* to support plant life of rhizoids on humus/traps the tiny organic and inorganic debris and water/moisture and further loosen the rock surfaces. Also death of some moss plants add nutrients to the soil due to decay by saprophytic organisms, more soil is formed to support the germination of seeds/grass of the large colonizing angiosperms/vascular plants. Small animals like insects, molasses, earth worms, and rodents break down rocks. The herb seeds germinate to replace proceeding growths and they in tum provide suitable conditions for large woody shrubs to begin to grow in the newly fertile formed soils.

iii) Eventually as a thicker layer of soils develops, shrubs get replaced by deciduous trees with deeper roots that penetrate crevices/cracks. The seeds of the trees become germinated/grow in the created suitable conditions by their parents' previous plants and animal colonizers and the mature forest community develops which becomes self-sustaining.

Note:

As the number of tree species increase, there is increased modification of the micro climates in the habitat e.g. shade increases, making light demanding shrubs to disappear and are replaced by-light tolerant species of trees. The tolerant species of trees finally form the climax vegetation. The savanna grass land and forest ecosystems are the dominant terrestrial ecosystems.

Pioneer species → animals (mosses) → herbaceous perennials (herbs) → shrubs → tree → forest

Summary of the 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 bits of 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 increases nutrients in soil.
- After a long period of time, the soil becomes deep, moist and fertile enough to support the growth of mid successional plant species like herbs, large grasses, low shrubs and small trees that need a lot of sunlight.
- Later 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) **<u>Secondary succession</u>**.

This is the establishment of communities on areas/habitats previously occupied by developed communities but has been disrupted in some ways such as burnt farm, playground fire cleared, forests destroyed by natural disaster like hurricanes, drought, volcanic eruption, floods, human activities like fires, cultivation, fire, overgrazing. Such areas have seeds/spores, organs of vegetative reproduction/propagation rhizomes and abundant nutrients in soil to support life. The successions are called secondary seres. E.g. fires from lightening burn plants stable community living a bare ground. The ground layer plants are killed, the heat destroys hollow roots/seeds and animals burnt in soil.

Often the first green plants on a burnt wood ash are the mosses that form an extensive green carpet. Within carpet the seeds of herbaceous and woody plants germinate.

A new herbaceous layer grows, forming the grasses and followed by shrubs and trees. Each dominant plant community has associated dominant animal population within it. The climax community persists for a long time until when factors that favour that favour invasion of better adapted forms of organisms set in.

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The climax vegetation makes efficient use of resources of the community ensuring indefinite self-sufficiency i.e. a community maintaining itself.
A similar secondary succession takes a short time to reach climax community. This is because the soil is already formed and supports growth of a wide range of plants immediately.
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.

Both primary and secondary succession is affected by the animal (fauna) and flora (plants) of the surrounding environment/areas through dispersal and migration

Characteristics of a succession process

- ❖ A pioneer community which is quite simple in biomass content and composition.
- ❖ A series of intermediate stages/seres
- ❖ Increasing biomass/productivity and species biodiversity

Ends into a stable community which is in equilibrium with its environment called the climax community.

Factors affecting the number and diversity of species reaching an area/colonization

- ❖ Geographical barriers like mountain ranges/ river/lake/rift valley.
- ❖ Ecological barriers like unfavourable habitats separating areas of favourable habitats.
- ❖ Distance over which dispersal must operate
- ❖ Size and nature of invasion areas

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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 trees.
- 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 size: is the number of organisms of the same species sharing the same habitat at a certain time. Population size change as a result of four factors natality (**birth**), mortality (**death**), migration in (**immigration**) and out (**emigration**) of the population.
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). Expressed as the number of individuals born in a given period for every 1000 individual's 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 per 1000 per year e.g. 20 deaths per 1000 people per year)
Environmental resistance
Refers to the sum total of limiting factors, both biotic and abiotic which affect together to prevent the biotic potential from being obtained or all the factors that tend to reduce population numbers, such as predation, food supply, heat, light, space, regulatory mechanisms like intraspecific competition and behavioral adaptation.
Carrying capacity: Maximum number of individuals of a given species that can be sustained indefinitely in a given area of land or volume of water.
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

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Biotic potential.
Is the maximum rate of natural increase in population that can occur under ideal conditions/circumstances.
It varies according to the age structure of a population and is influenced **by male to female ratios.**
i.e. when population density is low and resources are plentiful. Or The maximum rate at which the members of a given population can reproduce given unlimited resources and favourable environmental conditions.
The biotic potential depends on the **age structure** and **male: female** ratio existing in the population. It is also influenced by the age at which the individual first reproduces, the frequency at which reproduction occurs, the reproductive life span and the number of the offsprings the individual is capable of producing.
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 scattered 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 provides uniform factors.
(iii) **Clumped distribution** organisms aggregate into groups to gain better protection, feeding, reproduction etc. Clumped dispersion is the most common pattern of population distribution.

Types of population

(a) Open population

This is the one in which density changes as a result of the interaction of mortality, natality, migration and emigration. It occurs in a natural environment.

(b) Closed population/cultured populations

This is one in which density changes are the result of natality and mortality with neither food nor wastes being allowed to enter or leave the given environment. It occurs in laboratory settings and game reserves/cultured populations

NB. Main characteristics of a population are;

(i) Density

(ii) Dispersion

(iii) Age structure

(iv) Natality

(v) Mortality

(vi) Population size.

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Factors that tend to increase or decrease population the size of a population

a) Factors that cause a population to grow (Biotic potential)

- Favourable light – mostly for plants.
- Favourable temperature.
- Favourable chemical environment (optimal level of critical nutrients and toxic wastes).
- High reproductive rate.
- Adequate food supply
- Ability to compete for resources.
- Ability to hide from or defend against predators.
- Ability to resist disease and parasites
- Ability to adapt to environmental changes.
- Ability to migrate and live in other habitats
- Suitable habitat.
- Generalized niche

b) Factors that cause population size to decrease (Environmental resistance)

- Too much or too little light, mostly for plants.
- Too much or too little temperature.
- Unfavourable chemical environment (too much or too little of critical nutrients and high waste accumulation)
- Low reproductive rate
- Inadequate food supply
- Too many competitors for resources.
- Insufficient ability to hide from or defend against predators.
- Inability to resist disease and parasites
- Inability to adapt to environmental changes.
- Inability to migrate and live in other habitats
- Unsuitable or destroyed habitat
- Specialized niche

Factors that influence of population size.

- Natality or birth rate; this is the rate at which new members are added to a population by reproduction. In any community, the birth of a young one increases the population size.
- Mortality or death rate; the rate are which individuals die out. It reduces population size.
- Immigration rate; the rate at which individuals move into a population from outside increase population size.
- Emigration rate; the rate at which individuals move out of a population reduces population size.
- **Environmental factors** changes in environmental factors affect population size. These can be biotic or abiotic.

Abiotic factors that affect population size include;

- Weather; this includes daily duration of sun light and its intensity, rainfall, humidity and temperature. Most organisms adapt to live in specific weather conditions. Their population increases when conditions are favorable and reduces when conditions become unfavorable.
- Natural calamities such as drought, famine, flood, fire or earthquakes cause large scale deaths or emigrations of population leading to massive population reduction.

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- Food and space are the major limiting factors for animal populations. When food, water and space are in plenty, a population increases in size, otherwise it will reduce biotic factors control population size through producer-consumer relationships and pathogens.
- Predator-prey relationships. Availability of predator reduces the population of prey while reduction of prey reduces predator population and vice versa.
- Interspecific versus intraspecific competition. Increase in population in a given area increases competition for resources among organisms in that area. The more similar the organisms are species, the fiercer is the competition. This reduces the population of the out competed organism.

POPULATION SIZE

Population grows and declines in size. The size of population increase is determined by the reproductive potential of the concerned organism and by environmental resistance

Biotic potential, Is the maximum rate of natural increase in population that can occur under ideal conditions/circumstances. It varies according to the age structure of a population and is influenced by male to female ratios.

Factors affecting biotic potential

- Offspring; the maximum number of off springs per birth.
- Capacity for survival; the chances the organisms' off springs will reach reproductive age.
- Procreation; the number of time per year the organisms reproduces.
- Maturity; the age at which reproduction begins.
- Male to female ratios in the population.
- Age structure; age at which reproduction is high e.g. in man is 45, chances of producing become minimal. Springs will reach reproductive age.
- Procreation; the number of time per year the organisms reproduces.
- Maturity; the age at which reproduction begins.

Environmental resistance: All the environmental factors acting jointly to limit the growth of a population.

Factors hindering biotic potential

- Loss of food.
- Increased predator population.
- High pollution in the environment.
- Fire outbreak; destroys organisms, breeding sites, nest, eggs, slow moving organisms.
- Man's activities of man e.g. encroaching on swamps, wet lands, forests, road construction(separates ecosystems)
- Diseases, parasites and pests.

Environmental resistance: Refers to the sum total of limiting factors, both biotic and abiotic which act together to prevent the biotic potential from being obtained or all the factors that tend to reduce population numbers, such as predation, food supply, heat, light, space, regulatory mechanisms like intraspecific competition and behavioral adaptation.

Mac Arthur and Wilson (1967) estimated population growth using the logistics equation i.e.

Population increase	=	Biotic potential (reproduction per individual)	X	No. of individuals X	Relationship between carrying capacity and resources available

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For sigmoid growth curve

Where:

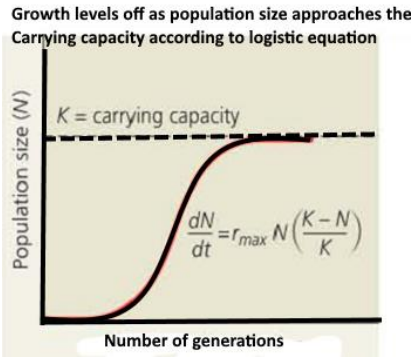
t- Time

r- biotic potential/maximum rate of increase of the population

N- No. of individuals in the population

K- Carrying capacity

I- population change



Where the population is low, the I value is close to **NVR**

When the population increase and resources become depleted, I decrease sharply to zero where **N=K**.

$$I = \frac{rN(K-N)}{K} \quad \text{Or} \quad rN(1-N/K = dN/dt$$

K and r population strategies

Most natural population fall between two extremes called r-selected and K-selected population as were used in the equation for population growth.

Note: r-species/r-strategists species produce rapidly and have a high value of r.

Characteristics of r-selected populations

- They are found in habitat/environments which undergo many changes.
- The individuals are small in size.
- Have a short life span i.e. they attain reproductive potential very early.
- Have a high mortality rate not density dependent.
- Reproduce at a high rate.
- Off springs grow rapidly with little parental care provided.
- Favourable conditions favour rapid explosion of population growth hence no or less competition. Thus selection pressure in such species favours high reproduction rate and short generation.
- A sudden environmental change results in a massive number of deaths. But their rapid birth rate and short life span favour the ability to adapt to a changing habitat e.g. insects, seeds, spores, bacteria, annual plants, paramecium.
- They are opportunist pioneer species of new and disturbed habitats. Migration and dispersal are key factors of their strategy.

K-selected populations

These are associated with specific habitat conditions or fairly stable environmental conditions with fewer fluctuations, relatively undistributed habitats and ever the changes of the seasons are regular and predictable and where competitive ability rather than reproductive speed is a major survival attribute/factor.

They tend to be more typical of the later stages of succession and such species are not very adapted to recover from population densities significantly below their equilibrium level (K-value or carrying capacity).

Characteristics of K-selected population

- Reproduce slowly (low fecundity, long generation time) therefore low value of r.
- Reproduction rate is sensitive to population density, rising rapidly if density falls.
- Population size stays close to equilibrium level determined by K.
- Species are persistent in a given area.

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- Disperse slowly
- Large in size e.g. woody stems and large roots if plants.
- Individuals live long
- Habitats stable and long lived (forests for monkeys).
- Good competitors
- Many become dominant.
- Less resistant to changes in environmental conditions e.g. butterflies, birds, humans and trees.

Comparison between *r*-selected and *K*-selected (equilibria) populations

Characteristic	***r-selected species***	***K-selected species***
Body size	Small	Large
Lifespan	Short	Long
Competitive abilities	Poor	Good
Defensive strategies	Lacking	Well developed
Dispersal	Disperse or migrate widely and in large numbers	Disperse slowly. Species generally persistent in the habitat
Degree of specialisation to the habitat	Poorly specialised (more adaptable to changes in environmental conditions)	Highly specialised (less adaptable to changes in environmental conditions)
Age at first reproduction	Early	Late
Number of reproductions per life time	Usually one	Several
Number of offsprings per reproductive episode	to population density	Few; reproductive rate is density-dependent
Size of offspring/egg	Small	Large
Parental care	None	Extensive
Mortality rate	High	Low
Examples	Bacteria, aphids, flour beetles, annual plants, weeds, cockroaches	Humans, owls, large trees, whales, large marine birds

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POPULATION GROWTH PATTERNS

Natural populations start with small size and gradually increases to a climax/carrying capacity where it is no longer growing/increasing. At this point the population undergoes a number of changes as a result of the changes in the environmental factors.

Carrying capacity of a population refers to the maximum number of the individuals of a population which the resources in a particular environment can support maximally at a given time. At carrying capacity, changes in environmental factors such as food supply decline/reduced rainfall fluctuation in temperature or an outbreak of epidemics, temperature, etc. results in an increased death rate which over powers the birth rate hence leading to a fall in the population. This is known as a decline phase

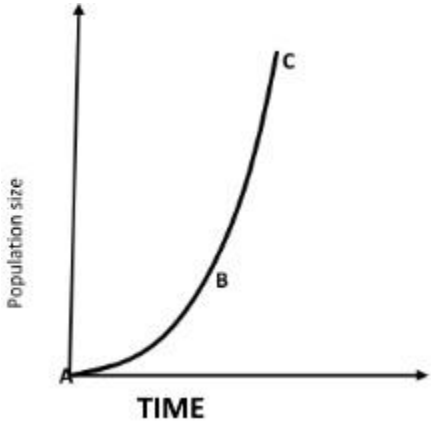
Population grows when(i) natality is greater than mortality (ii) immigration is greater than emigration

Population growth may form a curve which is either (i) exponential population growth curve (J-shaped) (ii) logistic 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

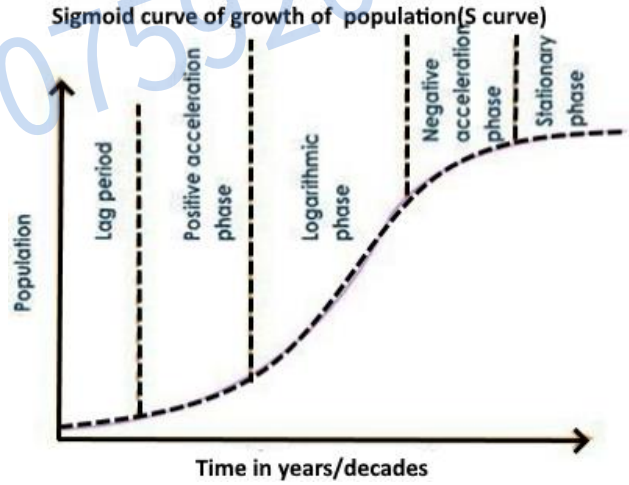
Number of individuals (population) is small. Their number increases gradually/slowly with time along AB. Later thw population size increases rapidly/sharply/drastically with time along CB

Explanation

Initially, the number of individuals increases gradually with time because the population size is small, thus few reproducing 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 off.



- 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 factors. The actual factors responsible for the resistance(any factors that may prevent a population from increasing as accumulation of toxic substances) are expected e.g. predation, parasitism

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

Lag phase:

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This is the period of gradual growth rate because the reproducing organisms are few and the members are still adjusting to the environmental conditions. There is plenty supply of nutrients, space, oxygen and low or few wastes. At this point the decrease in the population is directly proportional to the group members/individuals that are reproducing.
Little growth while yeast starts synthesizing little growth due to small population Individuals may rarely meet, so few matings. Appropriate enzymes for new conditions. Long gestation so few births.
Slow growth because cells are getting used to slow growth because of few reproducing

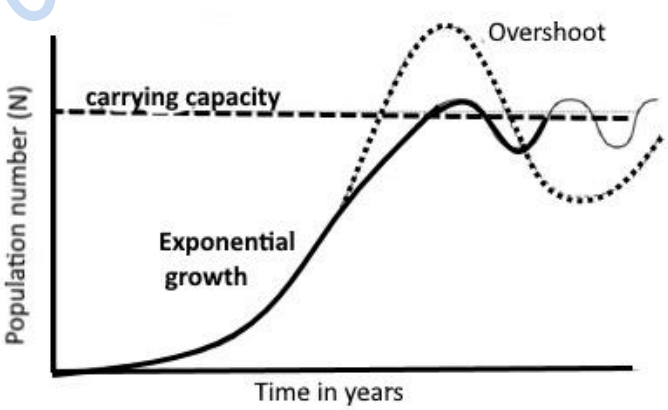
Exponential/log phase:
This is the phase of rapid increase in the population/increased rate of growth because the individuals are used to the environment, majority have reached their reproductive potential and there is no limiting factors such as food, space, oxygen hence the organisms are able to grow and reproduce at fast rate i.e. non environmental resistance.

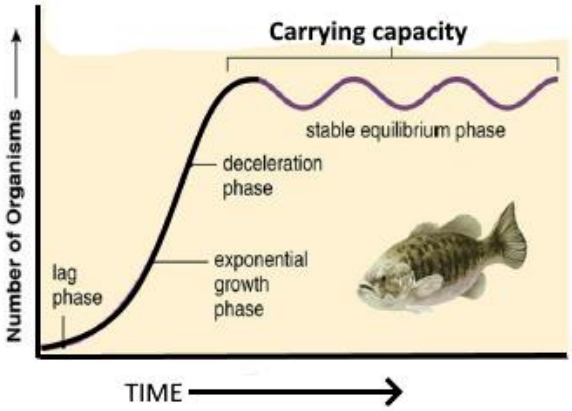
Stationery phase:
This is also called the **equilibrium stage**. This occurs as a result of low growth rate. The birth rate decreases while the death rate increases as a result of shortage of food nutrients, over-crowding, accumulation of toxic waste products, predation and competition for the above resources amongst the death rate and birth rate are equal and the population size becomes stable or attains its climax which is called the stationery phase or **the carrying capacity** of the population i.e. **environmental resistance** is evident.

What happens when population size exceeds the carrying capacity?
The population suffers a dieback or crash, unless the excess individuals switch to new resources or move to an area with more favourable conditions.

Note. When a population reaches equilibrium it does not remain absolutely constant but fluctuates because of variations in the environment resistance. For a give species in a particular environmental situation there is a certain optimum population which the environment can support.

This can be called the **norm** or **set point**. If the population rise above the set point, competition or predation takes place to such an extent that the population falls. If it falls below the set point environmental resistance if temporary relieved so that the population rises again. In the normal course of events populations fluctuate on either side of the set point, but the fluctuations are not excessive a clear





case of **negative feedback**.

Control of the human population

The homeostatic control of the population breaks down if some factor of the environment is suddenly changed. Such factors could be removal of the predators for a given prey or decrease in competition for food, this would shift the set point which would increase the birth rate, reduction in the death rate. All this leads to an exponential increase in the population.
In the case of man, the environmental changes responsible for raising the set point have been created by man himself, and inevitably brings in problems such as food shortage and sheer physical over-crowding. Man's population has exploded due to **(1)** improvement in hunting and food gathering techniques i.e. tool making revolution **(2)** improvements in agriculture i.e. agricultural revolution **(3)** improvement in food production, industry and medicine i.e. the scientific-industrial revolution.
The only human way of curbing the exponential increase in the human population is by **birth control**. This includes behavioural means such as abstinence, the rhythm method, coitus interruptus, contraceptives e.g. condoms, hormonal methods e.g. the contraceptive pill, various intra-uterine devices (IUDs), sterilization of male and female and abortion.

Factors that influence population growth size

Collectively the factors which limit population growth are termed as environmental resistance and are grouped into two.

(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;, parasitism, pollution (accumulation of wastes) diseases, competition for food, light, shelter, etc**. assume** there is a fixed food supply available for the organisms, the larger the population, the less the food available for each individual hence the slower the growth rate of the organism. However, a small population can expand more rapidly or exponentially.

(b) ***Density independent factors,*** are those whose effectiveness is not related to the density of the population. These affect the population regardless of the number of individuals within the community. Any change in the factor affects the same proportion of the population regardless of population density. They include; temperature, rainfall, light, floods, soil nutrients, fires, drought, hurricanes and habitat destruction e.g. clearing a forest or fishing in a wetland, pesticide spraying. They are mainly abiotic factors.

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a) Climatic factors
(1) Light: this affects the population growth and the distribution of organisms move so the plants. It is essential for **(i)** photosynthesis **(ii)** chlorophyll formation **(iii)** stomatal opening, hence gaseous exchange **(iv)** phototropism **(v)** flowering stimulants (**vi**) seed germination (**vii**) broadness of leaves and (**viii**) ripening of fruits. (**ix**) Induces flowering in long-day plants e.g. barley, but **(x)** inhibits flowering in short day plants. In animals light enables (**xi**) hibernation, (**xii**) vision and (**xiii**) migration **(xiv)** Courtship; with some animals preferring light so as to carry out courtship while others prefer darkness (**xv**) Stimulates synthesis of vitamin D in mammals
(2) Water/rain fall.
(i) Habitat for many aquatic organisms e.g frogs, fish e.t.c. **(ii)** Raw material for photosynthesis High thermal capacities **(iii)** cooling agent for terrestrial organisms **(iv)** Agent for fruit, seed, spore, larva and gamete dispersal **(v)** Condition for germination **(vi)** Highly transparent; therefore allowing light to reach aquatic organisms, for photosynthesis; and aquatic predators to locate their prey **(vii)** Important factor in decay and decomposition ; therefore increases in recycling of nutrients in an ecosystem.
(3) Air and wind: wind brings about changes in the weather and it directly affects the organisms.

(i) wind enables seed and spore dispersal **(ii)**wind affects the rate of transpiration **(iii)** determines the distribution of many plant species **(iv)** Because of wind, plants have strong deep roots **(v)** Wind also enables mixing of nutrients and pollutants in water.

(4) Humidity: affects transpiration rates in plants, number of stomata in the leaves and rate of evaporation in animals more so the small invertebrates like earth worms, snails hence distribution of plant and animal populations.

(5) Temperature: **(i)** temperature is vital because it affects the enzymes in plants and animals **(ii)** temperature also enables fruit ripening **(iii)** transpiration rate, wilting of leaves. **(iv)** Low temperatures break dormancy of some plants **(v)** stimulate flowering in some plants e.g cabbage (Vernalisation) **(vi)** In animals it affects humidity and available water in the habitat which factors affect the distribution of organisms.

b. Edaphic factors

These are soil factors such as;

(1)Texture:

This is the proportion of soil particles (sand, silt, clay). It influences the water holding capacity of the soil which in turn influences the number of individuals in a population since plants need water for growth.

(2) Humus:

These are the dead remains and decaying organic matter of living organisms. Humus acts as sponge in retaining water as so to reduce soil erosion, humus also holds soil particles together, further reducing on the rate of soil erosion. Humus decomposes to release minerals which add nutrients to the soil enabling the plant number to increase. Humus is a habitat for some soil organisms. Its dark colour retains heat in the ground.

(3) Air:

Oxygen is required by roots in the soil and most soil animals. Therefore well aerated soils support a number population/community. Water logged soils are due to compacted soil particles like clay has less air which leads to anaerobic conditions and hence cause death of most aerobic plants, animals and fungi hence reducing their population.

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(4) Water:

Water is an important metabolic and a medium of transfer of gametes/dispersal of fruits/seeds thus its availability supports the growth of populations. This explains the presence of xerophytes and halophytes (normal soils) and hydrophytes (aquatic).

(5) Mineral/inorganic salts:

Different species of organisms (plants) require different mineral salts and their qualities and so the distribution and number of any population is pH influence the type of plants in a particular area. It also affects the physical properties and uptake of the mineral salts hence affects growth. Some plants require alkaline soils yet others acidic soils.

(6) Soil organisms:

These are the macro-organisms/population of organisms which influence aeration, drainage tunnels and also soften soil thus exposing the mineral content to plants.

Saprophytes/bacteria/fungi break down plant tissue and dead animals to release humus or mineral salts.

The symbiotic association in the soil such as root nodule bacteria and plant roots enable
fixation of gases/nitrogen in the soil for proper plant growth.

Other factors include:

- **Man's activities like immigration, pollution, drainage.**
- ***Predators.***
- ***Epidemic outbreak/diseases.***

- ***Accumulation of toxic substances.***
- ***Migrations in and out.***

POPULATION GROWTH AND SURVIVORSHIP CURVES

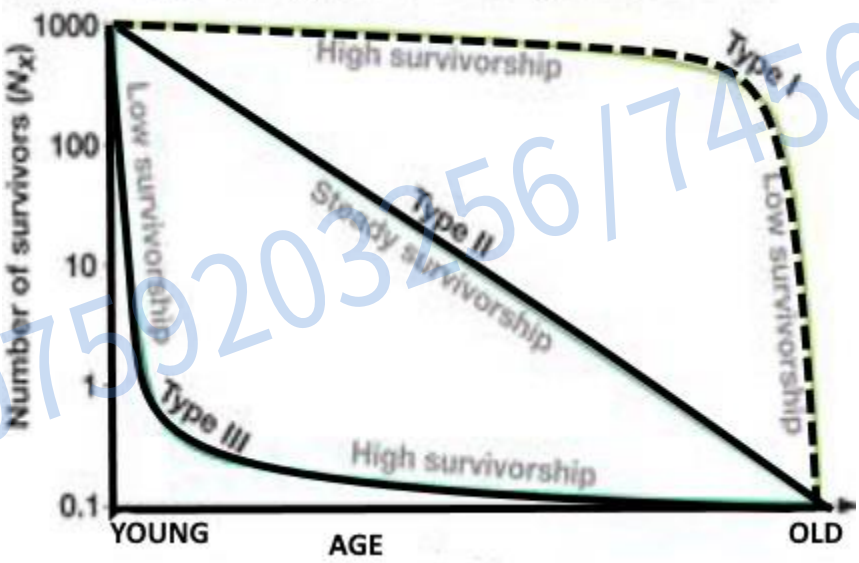
Survivorship curve

This is a graph that shows the proportion or numbers of individuals in a group will still be alive at a given age. For any population size to remain constant at least two off springs from each male and female pair on average must survive to reproductive age.
The percentage of individuals that die before reaching reproductive age, pre-reproductive mortality (infant mortality), is a major factor determining population size. Knowledge of survivorship enables ecologists to study population growth.

For any population size to remain consistent at least two off springs from each male and female pair on average must survive to reproductive age.

Survivorship 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.

a) Three general types of survivorship curves



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i)Late loss curves (Type I)
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) Constant loss (type II)
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.

(IIi)Early loss curves (TYPE III)

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

- These are organisms with a high intrinsic rate of increase.
- They produce many offspring which are poorly cared for resulting into high juvenile mortality.
- There is high survivorship once the surviving young reach a certain age and size.

Most populations have survivorship curves which are a combination of the three types. For example, herring gull starts out with survivorship type III (when newly-hatched chicks are most vulnerable) but once the chicks are independent, the survivorship curve resembles type I.

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.
- Size of organisms under study.
- Facilitation in terms of equipment to be used.
- Behavior of the organism e.g. their level of hostility and excitement when disturbed.
- Topography of the area
- Type of habitat, terrestrial/aquatic.
- Whether the habitat is terrestrial or aquatic.
- Risks expected to be faced during the exercise.
- The duration the exercise is expected to last.
- Seasonal changes and its effect on organisms.

METHODS OF DETERMINING POPULATION SIZE OF ORGANISMS

(a)Total count:

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This is the physical counting of every individual of a population in a specified area of ground. **Examples**
a. census of people after every ten years
b. aerial counting from a low flying aircraft of large, sessile, slow moving animals and mobile but large animals e.g. giraffes, elephants, lions, e.t.c.
c. Accurate results obtained from conducting several aerial counts in the area and then the average is computed and expressed as numbers per unit area of ground.
It is effective for large animals living in unconcealed (exposed) habitats. It includes;

- **Direct counting method** (using a low flying aircraft)
- **Aerial photography**
- **Drive and count**
- **Strip census**
- **Removal method**

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

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Procedure

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

Advantages

- It is quick and more accurate especially for slow moving animals and those that live in herds e.g. antelopes.
- There is reduced likelihood of not counting an animal or counting a given animal more than once.

Disadvantages

- It cannot be applied to aggressive animals e.g. lions, tigers, etc
- Limited to slow moving animals
- Restricted to animals moving in herds

(iv) <u>Stripe census</u>

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 area.

Advantages

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

Disadvantages

- Moving vehicles scare away animals that may run into hiding
- Some animals avoid roads and paths commonly used by man in the park.
- There is increased likelihood of counting fast moving animals more than once.
- Very many counts have to be made so as to come out with a reliable number.

(b) <u>Counting by sampling</u>

- This is when the number of organisms is determined in several sample plots that represent a known fraction of the total area under investigation from which estimation of the total population size of the whole area is made by simple calculations
- Sample counting is applied when the number of the organisms is large, covers a large area or where the behavior of organisms does not allow easy contact.

(i) <u>Capture mark Release recapture method (Lincoln Index).</u>

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

Requirements

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.

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- 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 **N_1.**
- 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 **N_2.**
- A count is made of how many animals captured on the second catch have marks /labels; i.e. those that have been recaptured. Noted as **N_3**.

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
N_1- number of individuals captured on the first occasion.
N_2- number of individuals captured on the second catch.
N_3- 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, 873 were netted of which 129 tilapia had been marked. What is the estimated population size of tilapia? $P = \frac{N_1 \times N_2}{N_3}$

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

P=4230 tilapia

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Exercise 1. 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.

i. What is the approximate size of population of water bugs in the pond? Show your working.
ii. Give three reasons why capture-recapture is unlikely to be an accurate way of assessing the size of water bugs.

Exercise 2. 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 plants

ii) Use of quadrant: 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.
- Total population is got by multiplying the average with the total area under investigation.

Advantages

(i) Its accurate (ii) It enables comparison of different areas and species. (iii) It provides an absolute measure of abundance.

Disadvantages

- Its time consuming.
- It's not suitable for first moving animals.
- It's not suitable for large sized animals.
- Some plants e.g. grass species are indistinguishable and may disturb.

Example:

Three counts of 103, 46 and 20 of a plant species, were made using a quadrant of $25cm^2$. The population density of the plant per m^2 is?

Population density = **$\frac{103+46+20}{3}$ = 56.3**

$25cm^2$ contain 56.3 $1cm^2$ contains **56.325 plants**

$100cm^2$ contain **56.325 x 100 = 225 plant**

Line transect

A line or string is laid along the ground in a straight line between two poles. Sampling is confined to only those organisms touching the line. Line transect is useful in studying transition of one community to another

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.

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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 population is estimated. E.g.

Sample number	Number of organisms in the sample	Cumulative sample size
1	120	120
2	93	213
3	60	273
4	35	328

Exercise 3. 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

Estimating population density

Population size can be estimated in various ways which include;

a) Quadrat method

b) Transect method

c) Capture-mark release recapture method (the Lincoln index)

How population density affects population growth

a) Density-dependent population control; involves factors whose effectiveness depends on the number of individuals present in a unit of space i.e. the more individuals there are in the population, the greater the percentage of the population that dies or fails to reproduce. Examples: Competition for resources like food, disease, predation, parasitism (biotic factors mainly)

b) Density-independent population control; involves factors whose effectiveness is not related to the density of the population. Any change in the factor affects the same proportion of the population regardless of population density. Examples: temperature, rainfall, light, floods, soil nutrients, pollution, fires, drought, hurricanes, habitat destruction e.g. clearing a forest or filling in a wetland, pesticide spraying etc. (mainly abiotic factors)

Kinds of population change curves in nature

a) Stable population growth curve:

Trees in a tropical rain forest where there is little variation in temperature and rain fall from year to year.

b) Irruptive population growth curve:

Some algal populations in freshwater habitats, raccoon and feral house mouse. This is caused by some factor that temporarily increases the carrying capacity e.g. more food, favourable weather, or fewer predators.

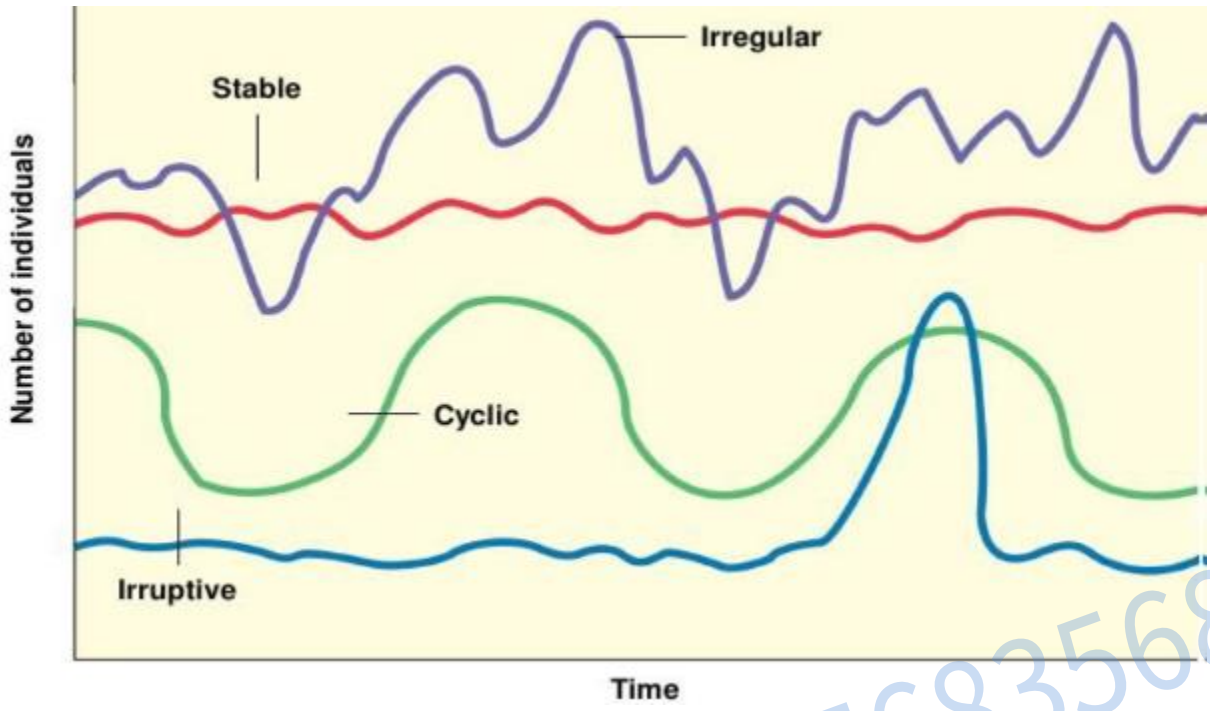
c) Irregular population growth curve

This is partly attributed to chaos in such systems but causes and interactions are not clearly understood.

d) Cyclic population growth curve

Lemmings (small rodents whose populations rise and fall every 3-4 years), grouse, lynx and snowshoe hare (whose populations generally rise and fall on a 10-year cycle). The actual causes are poorly understood, although predators sometimes are blamed.

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Distribution of organisms (population dispersion)

Dispersion refers to the structure/distribution of individuals or organisms within an area

Dispersal is the movement of individuals/organisms or their seeds, parts into or out of the population or habitat to a different locality/area.

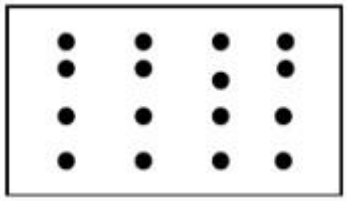
Importance of dispersion in animals

- Individuals acquire a home/nest/habitat within which they can live and breed.
- Individuals are spread out such that resources like food, breeding grounds become enough.
- Chances of obtaining a mate is increased since males attract females into their territories.
- Reduces distances moved away from home to search for food, mate, etc. this saves energy, time and prevents exposure to predators.
- New or depopulated areas are colonized.
- It increases the rate of gene exchange/gene mixing between populations via mating.
- It may prevent extinction and or speed up population growth.
- Natural barriers like rivers and rift valleys restrict animals in particular areas e.g. bush backs, chimps and elephants.

Dispersal mechanism of the population supplements natality and mortality in shaping population growth form and density.

There are 3 forms of dispersion:

1. Uniform/regular distribution



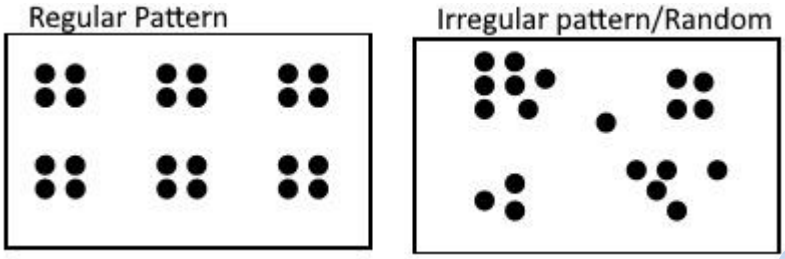
This occurs where intraspecific competition is severe. However, man artificially can induce it through agricultural practices e.g. planting of seeds or birds nesting on a small island

2 Clumped distribution/aggregate/clustered

It's the naturally occurring type of distribution where individuals tend to aggregate at a particular point on the habitat. It's due to;

a) **Distribution of resources** that are not regularly distributed due to climate and soil factors.

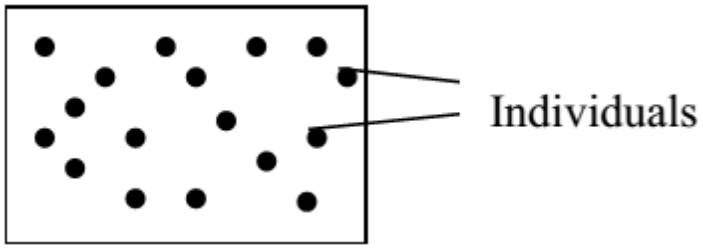
b) **Social behaviour** like termites and bees have division of labour among members, animals that live in colonies like buffalos, baboons, monkeys, etc. clumps could be irregular or regularly distributed.



3. Random dispersion/distribution

This is relatively rare in nature. It occurs where the environment is very uniform in terms of resources and there is no tendency of organisms to aggregate. There is equal and even distribution of resources. There is low or no competition. For example herbaceous plants in a garden

Many communities are dominated by clumped patterns of distribution for several reasons:



a) Effects of parent plant i.e. seeds may not be dispersed far from the parent plant hence plant seedlings are usually found near the parent plant.

b) Distribution of environmental factors. These are not uniform for all areas.

c) Species interrelations i.e. a species may be depending on another directly e.g. epiphytes.

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REGULATION OF POPULATION SIZE

Population size is naturally maintained at their normal carrying capacity depending on the resources in a given habitat. These populations are 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 increase in the number of organisms e.g. predator –prey relationship.

Methods of population control

a) Biological pest control

Control of a pest population using its natural predator, parasite or pathogens.it involves 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.

- Using cats to eat rats.
- Using beetles to feed on the water hyacinth on Lake Victoria
- Placing fish in ponds to eat mosquito larvae.

Biological control aims at bringing the pest population to a level where they are economically unharmful.

Biological control method can be used to;

- control of vector population
- control of parasites
- control of pathogens (bacteria& virus)
- control of some plants e.g. weeds
- Control of pests.

Precautions taken before application of biological pest control

- Careful matching of climatic conditions, to ensure that they favour the survival of the natural enemy of the pest.
- Monitoring of interactions with other native species to ensure that the control agent is not fed upon or killed by unsuspected organisms.
- The control agent should be specific as not to turn against other unintended beneficial organisms.
- Release of control agents should be done at a time when pest populations are large enough to provide sufficient food for the agent, in case the agent is a predator of the pest, so that the agent is not wiped out prematurely.
- Control measures should be put in place to regulate the population of the control agent after pest control.
- Reproductive rate of the control agent should be sufficiently high to effectively regulate the pest population.
- The control agent should not be harmful to humans.
- The control agent should be environmentally friendly and not turn into a nuisance/ pest itself.

Steps involved in biological pest control:

- 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.

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Advantages of biological pest control over use of pesticides

- It is highly specific and only affects the organisms intended.
- It is non-toxic
- Does not cause environmental pollution.
- Organisms used are biodegradable and do not persist in the environment for a long time.
- It is cheap in terms of cost and time.

(a) Chemical method.

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.

Properties of an ideal pesticide:

- Should be biodegradable / non-persistent so that toxic products are not left in or on crop plants.
- Should be specific so that only pest species is killed.
- 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.
- **pest replacement occurs** i.e. since most crop are susceptible to attack by more than one pest species, and the pesticide may be more deadly to one species than another, elimination of one species may simply allow another species to assume major pest proportions.
- **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) may occur. E.g. If Dichlorodiphenyl trichloroethane, DDT is sprayed on plants, to kill green flies, some survive, and absorb the chemical into their bodies. When eaten by small birds, DDT accumulates and when birds are eaten by other predators, e.g birds of prey, the accumulation of DDT reaches a level which burns up and kills the final consumer.

Ecological impact pesticides

- They are nonspecific and may kill other unintended organisms. This reduces the biodiversity of ecosystems.
- Most pesticides are persistent. They accumulate along the food chain and may eventually kill/ damage other unintended organisms at higher trophic levels, including man
- Predators of the organisms targeted by the pesticide may be deprived of their only source of food and therefore upset the food chain.
- Use of broad-spectrum pesticides can lead to pest resurgence after the period of treatment because some pests become resistant yet the pesticide kills the pest and its predator
- Pesticides pollute air, water and soil.

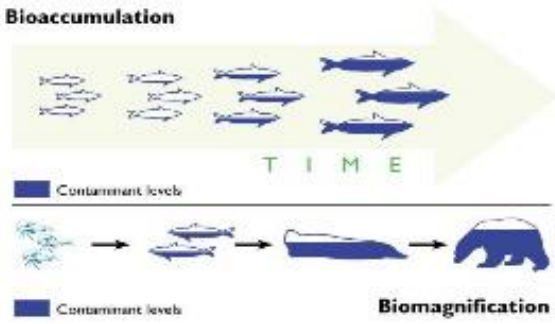
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Effects of DDT

i) Inhibits cytochrome oxidase enzyme.

ii) Limits reproductive success, especially by causing formation of thin eggshells in birds of prey.

iii) Kills organisms.



Effects of other pesticides in general

i) Inhibition of enzyme activity

ii) Kill organisms.

iii Reduce species diversity

iv) It increase productivity at lower levels of the ecosystem

v) It increase productivity at higher levels of the ecosystem

Why human population cannot be controlled by negative feedback mechanisms

- Humans can easily adapt (find solution) to whichever resistance appears to cause population threat.
- Humans have isolated themselves into protected areas where they have no direct predator.
- They are on top of every food chain and exert superiors influence over other organisms.
- They are the only animals that perform sexual intercourse for pleasure. As a result, there are so many unplanned pregnancies and births.

EXERCISE .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.

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 in 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 to carnivorous fish?

c) Explain how a pest sprayed with a pesticide may flourish afterwards?.

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TYPES OF ECOSYSTEMS

There are two major types of ecosystem, namely;

- **Terrestrial/land ecosystem**
- **Aquatic ecosystem**

Each of the two can further be grouped into several habitats.

AQUATIC ECOSYSTEMS

- Aquatic ecosystems support a great diversity of life forms. Water occupies 50% of the earth's surface. Water provides a more constant and protective environment than land (desiccation, less affected by sudden and drastic changes in physical and chemical conditions, some change due to climatic or seasonal variation). It provides support and dissolved oxygen and nutrients to aquatic organisms.
- Aquatic ecosystems are classified as the following depending on the concentration of salts they contain;

-

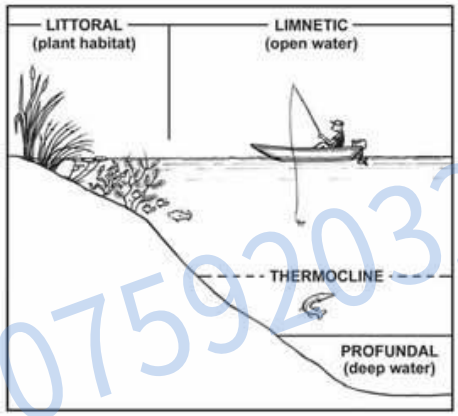
i. **Fresh water ecosystem**
ii. **Marine ecosystems**
iii. **Estuarine ecosystem**

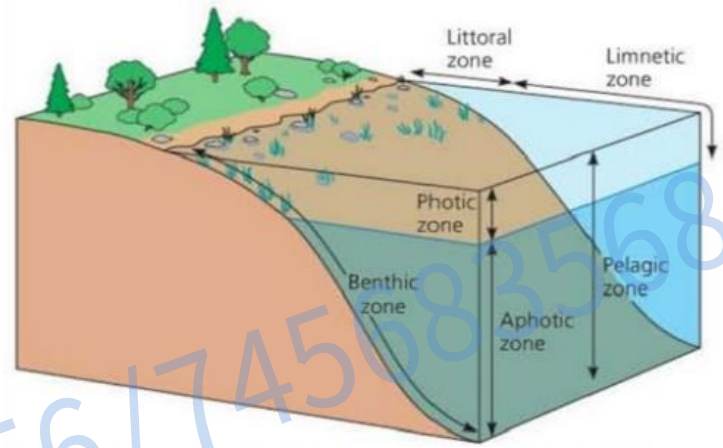
FRESH WATER ECOSYSTEM

- Fresh water habitats occupy a small portion of the earth's surface as compared to marine and terrestrial habitats. However, fresh water habitats are of great importance to man for the following reasons:
- Cheapest source of water for domestic and industrial use
- Provide the cheapest waste disposal systems
- Habour various animals
- Fresh water habitats can be classified into:
- Lotic (running water bodies) e.g. rivers and streams

1) **Lentic (standing water bodies) e.g. pond, lake and swamps**

Structure of a lake/pond (Lake Zonation)





Note: The lake environment (lake zonation) is generally classified on the basis of three physical criteria: light penetration (photic and aphotic zones), distance from shore and water depth (littoral and limnetic zones), and whether it is open water (pelagic zone) or bottom (benthic zone).

i. **Littoral zone**: shallow water region with high light penetration. It has the highest productivity due to high carbon dioxide/oxygen and suitable temperatures.

ii. **Limnetic zone:** it's the open water zone to the depth of effective light penetration. The community here includes phytoplankton, floating insects and algae. Like littoral zone, productivity/net productivity is highest because of high effective light penetration, more dissolved gases, high temperatures at the surface and turbulence due to the high air content/wind so high photosynthesis. Dissolved nitrogen is fixed by nitrogen fixing bacteria and blue-green algae to make proteins. Dissolved carbon dioxide formed carbonic acid which results in formation of H^+, HCO_3^- and CO_3^{2-}.

iii. **Profundal zone:** receives little or no light. Light penetration decreases with depth and also net productivity decreases with depth.

iv. **Benthic zone:** this is the bottom most, receives no light at all, no dissolved gases, aerobic bacteria exists so little productivity. The productivity is due to water currents which tend to mix the upper layers with bottom layer and photosynthesis and chemosynthesis bacteria exist.

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Ecological classification of fresh water organisms

Organisms in water can be classified depending on their life form which is based on their mode of life. The following terms are used:

Neuston:

These are organisms resting or swimming on the surface of water. Such organisms may be supported by the surface film or cling to the surface film from beneath or swim in the upper waters. Examples include pond skaters, air breathing diving beetles, water boat men, floating plants like duck weed, bladder work, etc.

Plankton (floating):

This is a mass of floating small plants (phytoplankton) and animals (zooplankton) whose movements and distribution are more or less dependent on currents. Their powers of locomotion are restricted to small vertical movements or to catching prey. Examples include arolia, Pistoia, water burg, tadpole, etc.

Nekton:

These are free-swimming organisms that can swim against water currents. Some of them are small e.g. swimming insects while others are large e.g. bony fish, amphibians, etc.

Benthos:

These are organisms attached or resting on the bottom or living in the bottom sediments. Most of them feed on fresh water organisms in ponds and lakes. They may also be classified depending on the sub habitat they occupy. **Three zones are generally evident;**

Littoral zone:

This is the shallow-water region with light penetration to the bottom. Such a zone is typically occupied by plants in natural ponds and lakes.

Limnetic zone:

This is the open water zone to the depth of effective light penetration. The community in this zone is composed of plankton, nekton and sometimes **Neuston.** In shallow ponds, this zone is absent. The total illuminated depth including the littoral and limnetic zone is referred to as the euphotic zone.

Profundal:

This is the bottom and deep water area which is beyond the depth of effective light penetration. This zone is often absent in ponds.

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FACTORS AFFECTING PRODUCTIVITY OF THE LAKE

- Temperature
- Nutrient availability
- Salinity
- Water current
- Pollution

Warm temperature provide optimum medium for aquatic organisms distribution as well as enzymes involved in photosynthesis.

Cool temperature of bottom water inactivate enzyme and affect distribution of phytoplankton thus reduced productivity.

Availability of nutrients in water due to decomposition of organic matter like sewage, dead organisms and fertilizers washed off from farm and water would lead to algal blooming or eutrophication of phytoplanktons. This would instead increase productivity since phytoplanktons are many.

Man's activities that harm the environment. With the recent increase in the human population, there has been over exploitation of natural resources.

Limiting factors in fresh water ecosystems

Limiting factors restrict the distribution of living organisms hence preventing the colonization of otherwise favourable environment. The most important limiting factors in fresh waters are:

Temperature:

Water has several unique thermal properties. Although temperature is less variable, it is a major limiting factor. Aquatic organisms have narrow tolerance. Temperature changes produce characteristic patterns of circulation which greatly influence aquatic life.

Light penetration:

Penetration of light is often limited by suspended materials (turbidity). This restricts the photosynthesis zone. Plants cannot survive below the compensation level. Light penetration can be measured using a *Secchi disc*. It consists of a white disc that is lowered from the surface until it just disappears from view. This ranges to about 40 cm in very clear waters.

Water currents:

Currents determine the distribution of vital gases, salts and small organisms. Water current is a limiting factor in fast flowing streams and on shores when it prevents colonization by weak swimming organisms.

Dissolved gasses:

Gases from the atmosphere dissolve in water at the surface. However, some gases are more soluble than the others. E.g. oxygen is 30 times less abundant in water than in air.

This limits the distribution of living organisms. The diffusion of dissolved gases through deep layers of water is very slow. In some places currents and wave action aid the diffusion, but in still waters, very little oxygen is transferred to lower levels. Once the little oxygen available is used up by decomposers, the effects may be disastrous to the whole community.

Dissolved nitrogen is used by nitrogen fixing bacteria and blue-green algae in the manufacture of proteins. Effects of carbon dioxide are complex due to the formation of carbonic acid to form H^+ HCO_3^- and CO_3^{2-} ions. These combine with other dissolved substances in the water.

Dissolved salts:

Fresh water ecosystems show a considerable variation in salt content. This depends on the minerals present in drainage water from the surrounding land mass and activities of living organisms. Deposition of nutrients in water is known as eutrophication.

Nitrate and phosphate are the most limiting factors in fresh water ecosystems e.g. phosphorous is a limiting factor because the ratio of P to other elements in organisms is greater than the ratio in the primary sources of the biological elements. K, Ca, S and Mg may also act as limiting factors.

Biological classification of lakes

Biological classification of lake ecosystems depends on the circulation rates of inorganic plant nutrients in the lake. Three major types are recognized:

i. **Eutrophic lakes:**

These are with waters relatively rich in plant nutrients.

Characteristics

- Have high surface area to volume ratio hence easy circulation
- They are relatively shallow with gentle slopping banks which can support wide belts of marginal vegetation (wide littoral zone).
- Have relatively high phosphates and nitrates, i.e. they are very productive.
- Due to emergent and submerged plants plus a lot of phytoplanktons, upper layers are rich in oxygen. The bottom layers are low in oxygen concentration since it is continuously being used for bacterial decomposition e.g. Lake Kyoga.

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ii. Oligotrophic lakes:

These are with low plant nutrients and they are highly oxygenated.

Characteristics

- They have low surface area to volume ratio, hence limited circulation.
- They are deep with steep rock sides.
- Waters are low in plant nutrient but highly oxygenated.
- Neither have extensive marginal vegetation nor organic bottom deposits which results in their low productivity e.g. Lake Tanganyika.

iii. Dystrophic lakes

These have brown water where the bottom deposits of such lakes consist of unrotten organic matter which accumulates as heat. Productivity of such lakes is very low.

THE POND ECOSYSTEM

The pond ecosystem is complex and is affected by several environmental conditions. The living organism and the nonliving environment are inseparable and the following can be recognized:

Abiotic substances:

These include basic inorganic and organic compounds e.g. water, CO_2, O_2, Ca, N, P, soil, etc. A small portion of the vital nutrients is in soil and available to organisms but much larger portion is held in the bottom sediments and in the organisms themselves. The rate of release of nutrients from the solids, solar input and other environmental factors determine the productivity of the entire ecosystem.

Producer organisms:

There are two major types only;Rooted or large floating plants growing in shallow water e.g. papyrus and Phytoplankton distributed throughout the pond as deep as limnetic zone.

Note: in deep ponds and lakes, phytoplankton is much more important than rooted vegetable in the production of the basic food from the ecosystem (algal blooms)

Macro organisms:

These include animals like insect larvae, crustacean, fish, etc. primary consumers feed on plants or plant remains e.g. zooplankton and benthos (molasses).

Secondary consumers e.g. predaceous insects and fish feed on primary or secondary consumers.

Detritivores e.g. worms, larvae and rotifers consume organic matter from upper layers.

i) Saprotrophic organisms:

Aquatic bacteria, flagellates and fungi are distributed throughout the ponds, but are abundant at the bottom where plant and animal organic matter accumulates.

Dead organisms are rapidly broken down by detritus feeding organisms and microorganisms and their nutrients are released for re-use.

HOW THERMAL STRATIFICATION OCCURS IN LAKES

In warm weather the surface of a lake is heated by the sun. The warmed surface becomes less dense, and so remains at the surface, floating on the colder water beneath. The surface continues to gain heat from the sun, while the bottom water remains cold. If this surface heating continues for some days, without storm winds to stir the lake, a marked temperature difference can develop between the top and bottom water and the following compartments are recognised:

a. **Epilimnion:** upper warmer water, usually well oxygenated.
b. **Metalimnion** (thermocline): middle portion between Epilimnion and Hypolimnion where the rate of temperature change with depth is rapid.

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c. **Hypolimnion:** the deepest portion, with denser and cooler water, usually with low oxygen concentration.

SEASONAL CHANGES THAT OCCUR IN TEMPERATE LAKE

Winter	Late spring/early summer	Late summer	Autumn
During the winter, water is evenly mixed and tends to have the same temperature and chemical composition at all depths.	In the spring, sunshine and warm air temperature melt the ice cover and bring the upper layers of the lake to the same temperature as the lower, about 40C, enabling strong winds to mix the waters of the lake completely (spring overturn)	There is maximum thickness of epilimnion and maximum temperature difference between epilimnion and hypolimnion.	As the lake surface cools by evaporation, convection and radiation, the stability of the stratified system reduces.
If the lake freezes, ice of 0^0C floats over warmer water of 4^0C.	The lake stratifies with a warm epilimnion floating over a cold hypolimnion and a thermocline between.	Epilimnion may be depleted of nutrients and Hypolimnion may be depleted of oxygen.	Strong winds mix the lake water (fall overturn), causing uniform temperatures and chemical composition throughout the water column
The nutrient and oxygen concentrations of the water are high, but oxygen can be depleted under ice in shallow lakes	Phytoplankton bloom in the surface water. Nutrient concentrations begin to fall in the epilimnion and oxygen concentrations begin to fall in the hypolimnion.	In very fertile lakes the hypolimnion may become anoxic and the sediments of the mud/water interface may be chemically reduced.	Bottom mud and water are resupplied with oxygen.
Sediment at the mud/water interface usually will be oxidized.	Sediment at the mud/water interface is still oxidised.	Waters of the Hypolimnion may be nutrient-rich both from solution of particles settling down from the surface water and from solution of nutrients from reduced bottom mud.	Surface water is resupplied with nutrients, which may result in blooming of phytoplankton at the surface.

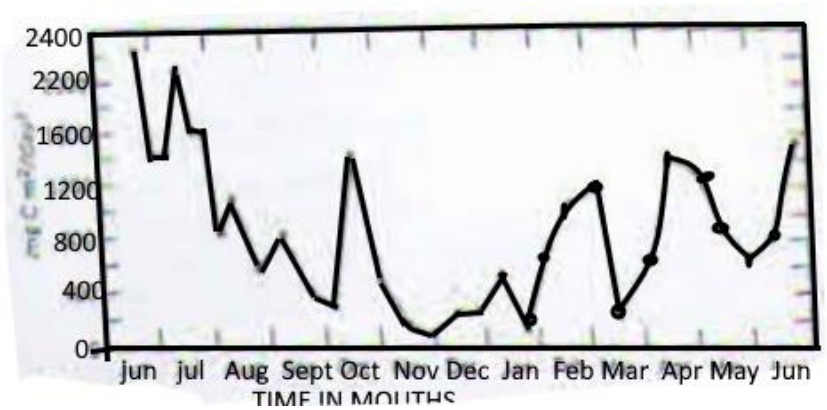
B.O.D (Biological oxygen demand)

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 20^0C for 5 days.

B.O.D indicates the oxygen not available to more advanced organisms. Therefore a high B.O.D indicates anaerobic conditions (low oxygen availability).

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PRODUCTIVITY IN LAKES



Explanation for the observed changes

- Productivity is low in winter due to short days and low temperatures.
- Productivity is high in spring due to proliferation of algae causing blooming because of the warming that precedes summer.
- But the lake then stratifies and the process of exporting nutrients to the hypolimnion via precipitating organic matter proceeds to lower nutrient concentrations in the Epilimnion.
- Productivity then falls during the summer, despite the fact that this is the warmest time of the year with long days. This is because the short-lived algae of the spring bloom are not replaced and the standing crop is lowered, ending the bloom.
- But productivity goes up again with the coming of autumn, despite lowered temperatures. His is because of the fall overturn, which brings to the surface nutrient-charged water formerly held in the hypolimnion.

OXYGEN AND CARBONDIOXIDE AVAILABILITY IN WATER

Oxygen enters an aquatic system from the atmosphere and through photosynthesis by aquatic producers, and isremoved by aerobic respiration of plants, animals and decomposers.

Carbondioxide enters an aquatic system from the atmosphere and through aerobic respiration by plants, animals and decomposers, and is removed by photosynthesising plants. Some dissolved CO_2 forms carbonate ions (CO_3^{2-}), which are stored as calcium carbonate for long periods in sediments, minerals and shells and skeletons of aquatic animals.

STRATIFICATION IN TROPICAL LAKES

In tropical lakes, the range of temperature from top to bottom of the columns of water is not great because the density of water changes more rapidly at higher temperatures.

The hypolimnion in a lowland tropical lake is nearly always without oxygen due to;

- high productivity caused by high temperature
- Biological decomposition of the large inputs of organic matter from productive tropical ecosystems on the banks.

The typical jungle lake therefore, is turbid, murky and opaque with biological activity.

a) MARINE WATER LIFE ZONES

Oceans have two major life zones: the coastal zone and open sea. The coastal zone is the warm, nutrient-rich, shallow water that extends from the high tide mark on land to the gently sloping, shallow edge of continental shelf (the submerged part of the continents).

There is a very high net productivity per unit of area **because of:**

- abundant sunlight that supports photosynthesis
- Abundant nutrients flowing from land and distributed by wind and ocean currents.

Estuaries: are areas where fresh water flowing from land joins with marine seawater.

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BIOLOGICAL ZONES FOUND IN OPEN SEA

This categorization is based on light penetration into seawater:

Euphotic zone: the lighted upper zone where:

i. Photosynthesis occurs mostly by photosynthesis
ii. Nutrient levels are low
iii. Dissolved oxygen levels are high.
iv. Large, fast-swimming predatory fish such as sharks, Bluefin tuna and swordfish inhabit.

Bathyal zone: dimly lit middle zone that does not contain photosynthesising producers due to lack of light. Various types of zooplanktons and smaller fish, many of which migrate to feed on the surface at night inhabit this zone.

Abyssal zone: dark lower zone that is (i) Very cold (ii) Has enough nutrients of dead and decaying organisms on the ocean floor to support life of microscopic decomposers and scavengers such as crabs and sea urchins.

Hypsographic curves summarizing changes in temperature, salinity, density, nutrients and oxygen in oceans

<u>Adaptations of hydrophytes to aquatic life</u>

Hydrophytes are plants that grow in water or in soil covered with water.

They are categorized as:

a) submerged – if completely under water e.g. *Elodea*, *Vallisneria*
b) floating e.g. *Pistia*, *Lemna*, *Eichorhnia*, *Nymphaea*
c) Amphibious - if growing in shallow and muddy waters e.g. *Typha*, *Alisma*.

They show the following **adaptations:**

- Development of tissues with large intercellular spaces for floating.
- Poor development of roots coupled with lack of root hairs.
- Absence of cuticle to allow much water loss.
- Poor functioning of stomata.
- Poor development of mechanical tissues.
- Dimorphism of leaves i.e. some submerged plants bear under water leaves that are thin while the leaves above water are broad for floating.
- Formation of coiled pedicels and petioles to keep flowers and leaves above water surface.
- Development of water proofing waxy cuticle to avoid decay.

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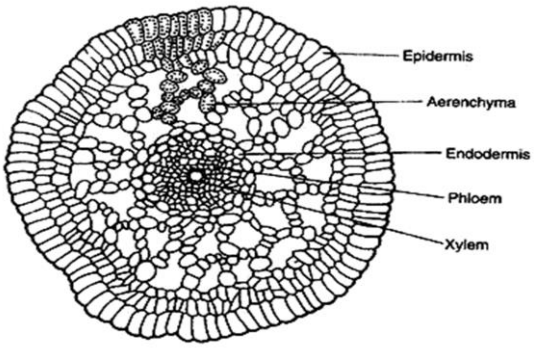


Fig. 8.8. T.S. of *Hydrilla* stem.

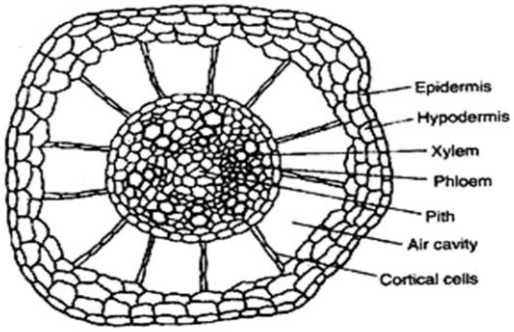


Fig. 8.16. T.S. of stem of *Jussiaea*.

Regional climates interact with regional biota and substrate to produce large recognizable community units called biomass. A biome is identical with a major 'plant formation' but it is a total community unit in which both animals and plants are considered. The six major biomass of Africa include:

- **Tropical rain forest**
- **Tropical savanna and grass land**
- **Desert**
- **Sahel region (semi-desert)**
- **Mountain forests**
- **Temperate region**

The above form the major terrestrial ecosystems.

TROPICAL RAIN FOREST ECOSYSTEM

This is characterized by high temperatures of 25^0C and 35^0C and a high monthly rain fall distributed over 10 months of the year i.e. 200 and 400 cm^3 of rain fall annually. They are dominated by broad leaved evergreen trees which occupy low altitude zones near the equator (amazon, Congo, Malaysia, etc.).
Seasonal changes in breeding and other activities of plants and animals in a tropical rain forest are largely related to variations in rain fall and to a certain extent temperature.
Forest communities are well structured and contain specific plant and animal populations that interact in a complex fashion.
Trees in the forest form three layers (stratification):

a) **Emergent layer:**

This consists of scattered, very tall emergent trees (80-100m) that project above the general level. They have wide spread, umbrella shaped crowns and huge buttresses. Examples are the *Chlorophora excelsa* (Mvule), mahogany, mbizia, etc.

Canopy layer:

This forms a continuous evergreen carpet 50-80m tall. The crowns of such trees are small compared to the emergent and buttresses are narrow.

b) **Under Stoney layer:**

This includes relatively short trees 1-1, 20-40m tall and young trees of the emergent and canopy layers. Ferns e.g. platycerium spp is common as an epiphyte high on trees. Other epiphytic plants include figs and orchids.

c) **Ground layer:**

This includes shrubs, herbs, lianas, shade loving plants with broad leaves and thallophytes e.g. lichen, mosses, liverworts and shade loving animals.
A much large proportion of animals live in the upper layers of the vegetation. These include birds, mammals, amphibians and others. Some animals are ground dwellers e.g. ants, butterflies, moths, snakes and other reptiles.
Tropical rain forests are rich in flora and fauna species e.g. a six square mile area can contain 20,000 species of insects. A tropical rain forest is the only major vegetation type which does not burn i.e. fire is not an ecological factor.
Variation in environmental factors (temperature, light, moisture) caused by the stratifications creates micro-habitat conditions.
The ground layer receives light of low intensity approximately 10% of the total value received by the emergent. Ground layer plants are therefore adapted to such conditions.

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The shade effect of the canopy layer cuts off the sun's rays, thus relatively lower temperatures are experienced in the lower layers.

Moisture is influenced by temperature as it increases rates of evaporation and transpiration. Underground plants are in a region of lower rates of evaporation and transpiration than those above them.

Crowded leaves on the upper layer of tree branches act as wind breaks so the interior of the forest is not windy. The relative humidity inside is relatively constant to the upper layers.

Adaptations

- Emergent and canopy layer trees prevent excessive transpiration by having leathery surface and adequate deposits of cuticle.
- Plants of the undergrowth have large thin leaves.
- Animals on the ground use the soil for protection against extreme condition.
- Arboreal animals possess special features that enable them to climb e.g. specialized feet in squirrels and the monkeys' prehensile tails.
- Some animals use camouflage for protection against predators.

GRASS LAND ECOSYSTEM

Tropical savanna (grassland with scattered trees or clumps of trees) forms the grassland ecosystem in Africa. Grasslands are characterized by hot weather with a moderate temperature range. Rainfall is about $120cm^3$ per annum which falls in one period, followed by a long period of drought.

Grassland ecosystems are dominated by grasses such as guinea grass, elephant grass, spear grass, and palms.

Animals include a variety of numerous hooted mammals e.g. antelopes, elephants, zebra, giraffes which graze or browse on the vegetation. Others include predators like lions, cheetahs, scavengers like hyenas, jackals and culture insects most abundant during the dry season which include grasshoppers, termites, ants and locusts. Reptiles are abundant during the dry season and these include snakes, lizards, chameleons, tortoise, etc.

In the **savanna grassland** ecosystem, seasons are determined by rainfall. Other two factors include herbivore and fire. Trees and grass present must be resultant to drought and fire. This explains why the number of species in the vegetation is not large.

Grazing mammals are important in determining the flora composition of the community. Some species of grasses and other plants are more sensible to grazing pressure than others.

During the dry season, fire is a major ecological factor. It destroys non-resistant plant species like grasses but it also stimulates those with underground parts to grow. Trees develop a dense and shady canopy and grasses grow to high heights during the short rainy season.

Adaptations

- Savanna trees grow long tap roots and develop thick barks which enable them to survive the long dry season and resists fires. They have umbrella shaped canopies which shade the ground and limit loss of soil moisture. The leaves have thick surfaces which minimize the loss of water by transpiration.
- Grasses have durable roots which remain underground when the tops have been burnt away after a fire. They sprout again with the onset of the first rains in the following year.
- Animals usually migrate and hibernate.

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Benefits of co-existence of plants and animals in a terrestrial ecosystem

Benefits from animals to plants.

- Obtaining mineral nutrients from decomposition of dead organic matter of animals.
- Obtaining carbon dioxide for their photosynthetic activities from the respiratory activities of animals.
- Being dispersed by animals which minimizes their overcrowding, competition and spread of disease; and enables them colonize new habitats.
- Being pollinated, leading to sexual reproduction
- Their population size being regulated by animals, by feeding upon them
- Co-evolution of both plants and animals; Co-evolution involves development of flowers with attractive shape, colour , and smell, for the insects to visit the flower, and pollinate it; and at the same time the insects evolve sense organs,. and mouth parts ,specialized for quickly locating and extracting nectar from particular species of insect-pollinated flowers

Benefits from plants to animals.

- Obtaining food manufactured by the plants
- Obtaining oxygen for their respiratory activities produced as a by-product of photosynthesis by the plants
- Obtaining shelter from the plants
- Co-evolution of both plants and animals
- Camouflaging against the plant background /hiding against their potential enemies for their survival.

WHAT IS BIODIVERSITY (BIOLOGICAL DIVERSITY)?

The different life forms and life-sustaining processes that can best survive the variety of conditions currently on earth. **Kinds of biodiversity**

Genetic diversity – variety in the genetic makeup among individuals within a species.

Species diversity (species richness) – number of species present in a habitat.

Ecological diversity – the different biological communities e.g. forests, deserts, lakes etc.

Functional diversity – biological and chemical processes or functions such as energy flow and matter cycling needed for the survival of species and biological communities.

Species abundance refers to the number of individuals of each species

Term	**Definition/ explanation**
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 scattered 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.

FACTORS THAT AFFECT SPECIES DIVERSITY ON LAND AND IN WATER

a. **Latitude (distance** from equator) in terrestrial communities; species diversity decrease steadily with distance from the equator toward either pole, resulting in the highest species diversity in tropical areas e.g. tropical rain forests and lowest in polar areas such as arctic tundra. The main effect of latitude is on temperature, which later affects life.

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b. **Depth in aquatic** systems; in marine communities, species diversity increases from the surface to a depth of 2,000 metres and then begins to decline with depth until the deep-sea bottom is reached. This change is attributed to light penetration which affects photosynthesis, availability of oxygen and availability of dead organisms at the sea bottom.
c. **Pollution in aquatic** systems; increased pollution kills off or impairs the reproductivity of various aquatic species hence reducing species diversity and abundance.
d. **Increased** solar radiation increases species diversity in terrestrial communities.
e. **Increased** precipitation in terrestrial communities increases species diversity.
f. **Increased** elevation decreases species diversity.
g. Pronounced seasonal changes increase species diversity.

FACTORS THAT AFFECT SPECIES DIVERSITY IN AN ISLAND ECOSYSTEM

Robert MacArthur and Edward O Wilson (1960s) studied communities on islands after which they proposed the species equilibrium model or the theory of island biogeography.

According to this model, the number of species found on an island is determined by a balance between two factors:

a) The rate at which new species immigrate to the island and
b) The rate at which species become extinct on the island.

- The model predicts that at some point the rates of immigration and extinction will reach an equilibrium point that determines the island's average number of different species (species diversity)
- The model also predicts that immigration and extinction rates (and thus species diversity) are affected by two important features of the island;

a) Size of the island.
b) Distance of the island from the nearest main land.

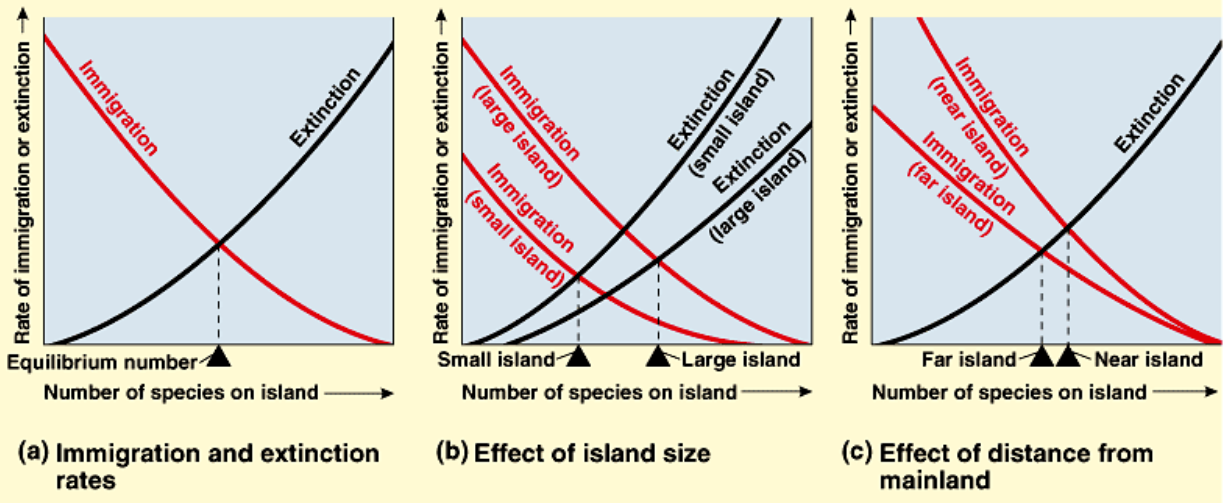
Size of the island: Larger islands tend to have higher species diversity than Small islands because of two reasons:

i. Small islands generally have lower immigration rates since they are a smaller target for potential colonizers
ii. Smaller islands should have a higher extinction rate because they generally have fewer resources and less diverse habitats for colonizing species.

Distance of the island from the nearest main land:

For two islands of about equal size and other factors, the island closest to the main land source of immigration species will have the higher immigration rate and thus a higher species diversity (assuming that extinction rates on both islands are about the same.

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EXPLANATIONS FROM THE OBSERVATIONS MADE FROM THE GRAPHS

a) **Immigration and extinction rates**

- The rate of immigration decreases with increase in species number, while the extinction rate increases with increase in species number on the island.
- The equilibrium number of species on the island is reached when immigration rate and extinction rate equal.
- Extinction rate increases with increasing species number because of interspecific and intraspecific competition.

b) Effect of island size on immigration and extinction rates

- The rate of extinction increases with increase in species number on the island on both small and large islands, but it is higher on small islands than on large islands. The higher extinction rate on small islands is because of the fewer resources and less diverse habitats for colonizing species.
- The rate of immigration decreases with increase in species number on both small and large islands, but with a large island having a higher immigration rate than a small island. Small islands have lower immigration rates because they are a smaller target for potential colonizers.

c) Effect of distance from mainland on immigration and extinction rates

- For both near and far islands, immigration rate decreases with increase in species number, but immigration rate is higher on near island than on the distant island. The higher immigration rate on near island is because of the easy reach by organisms enabled by its proximity to the main land.
- Since extinction rate increases with increasing species number that exert interspecific and intraspecific competition, extinction rate is far higher on small islands due to the fierce competition caused by the higher immigration rate because of easy reach by organisms enabled by its proximity to the main land.

Explain the rate of Immigration of new species on an island that is near to the shore and one that is far from the shore

- At first almost every organism arriving on the island is a new species, so the rate of immigration of new species on each island is high.
- As the number of species on the island increases, many of the organisms arriving belong to already present species, so the rate of immigration of new species on each island reduces.

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- As the number of species on the Island increases, species diversify and abundance increases, this increases interspecific competition for the reducing number of available habitants and ecological riches to occupy. This discourages the immigration of new species to the island due to reduced availability of occupiable ecological; riches.
- An island near to the shore is reached more easily by mainland species than that which is far a way, so the immigration rate of new species is higher on an island that is near to the shore than one that is far away.
- Even at the beginning of the colonization, fewer species reach the island that is far away from the shore, and the rate of immigration to the far away island is much lower than that which is near to the shore, due to the presence of more barriers to the arrival of speed, spores and other propagules, such as air currents, water currents, maintains the long distance and wave action.
- Immigration of flying species to the far away island may also be hindered by the high energy requirements of long-distance travel, mountain barriers, absence of food along the resting, interference by distractions and strong air currents.

Explain the rate of Extinction of species on a small island and on a large island

The rate of extinction of species on each island rises as the number of species on the island increases.

- This is because if there are only a few species on the island each attains a large population size (species abundance) and the level of competition is low so that the rate of extinction is also low.
- As the number of species on the island increases the population size of some species decreases due to increased intraspecific and interspecific completion for space and the decreasing resources, during which the less well-adapted species are out-competed, fails to obtain space and resources, and either emigrate from the island or die out due to failure to survive or reproduce, hence increasing the rate of species extinction.
- The rate of species extinction on a large island is lower than that for a small island, since there is more space and greater abundance of resources creating more room for many large viable species populations to occupy the greater diversity of habitats and ecological riches available thereby reducing the rate of species extinction for the same number of species on a large island.

Explain the rate of Immigration and extinction of species on an island.

When the number of species on an island is small the rate of immigration will exceed the rate of species extinction due to a low level of inter specific competition resulting from a greater abundance of resources and space creating a large abundance of habitats and riches to occupy encouraging immigration and reducing extinction.

As the number of species increases the rate of immigration reduces and the rate of extinction increases due to increased competition for the reducing resources and decreasing space, habitats and fewer ecological riches to occupy.

Eventually the number of species on the island reaches a point of equilibrium, when the rate of immigration equals the rate of species extinction.

When the number of species is greatest the rate of immigration is lowest whole the rate of extension is highest due to stiff competition for the available resources, space and riches which discourages immigration and causes reduced species abundance, restricts species ecological ranges and hence increases the rate of extinction of species.

<u>The number of species on an island is balanced/determined by:</u>

- The size of the island
- The distance of the island from the share of the mainland.

- The number of barriers to species immigration
- The availability of resources, space, habitants and different ecological riches.
- The number of reproducing individuals belonging to the component/existing species.
- The level of interspecific competition between the component species
- The mechanisms of dispersal of species

Describe how factors other than those depicted in the information provided, may affect the immigration of new species on an island.

Other factors that affect the immigration of new species include:

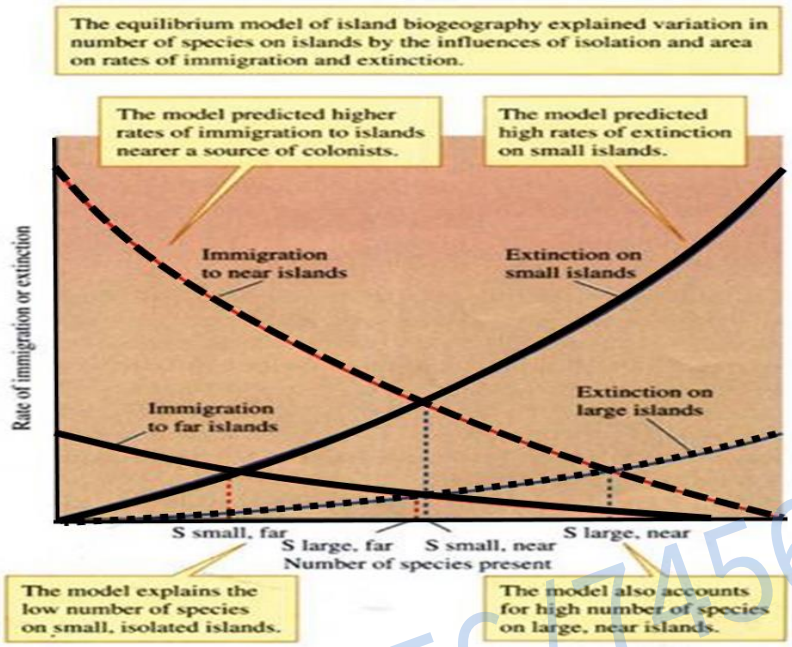
- Evolution of new species by mutation, genetic drift and adaptive radiation can increase the number of component species without immigration making it harder for new species to successfully colonies the island.
- The diversity of habitants and ecological riches on the island determines the number of species that can successfully immigrate to the island. For instance a small island with a greater riche and habitat diversity may attract more species than a large less diverse island.
- Physical environmental factors such as light, temperature, wind, water currents, tidal action, and mineral salts will determine the availability of resources for the species.
- Biotic factors such as parasitism, predation herbivory, pollination, antibiotics, mutualism, and territorial behavior and so on may determine the number of species that can successfully immigrate to an island.
- The physical and biotic conditions on the shore of the mainland such an increased competition, increased parasitism and predation, low availability of resources, unfavorable environmental conditions may act as push factors encouraging the emigration of species from the mainland and immigration onto the island.
- The effect of mainland seasonal changes may encourage increased immigration from the mainland shore to the island.

Factors that cause immigration of new species to a virgin island include;

- Availability of resources such as food, fresh water, mineral salts on the island.
- Overcrowding on the mainland forcing some species to seek more spacious habitats.
- Conducive environmental conditions such as light, temperature, weather may encourage immigration of species to a virgin island.
- Availability of better breeding sites on the virgin island may encourage species to colonise the island.
- Reduced human interference may encourage immigration to a virgin island.
- Low levels of competition, predation, parasitism, antibiosis, disease prevalence may create encourage increased immigration to an island.
- Seasonal and environmental changes on the mainland may cause emigration of species from the mainland may cause emigration of species from the mainland and onto the virgin island.
- The presence of species with good mechanism of dispersal and a wide range of tolerance to environmental resistance can encourage increased immigration to an island.
- Territorial behavior of mainland species may encourage intending mates to seek new territories on a virgin island.
- Territorial behavior of mainland species may encourage intending mates to seek new territories on a virgin island.
- Proximity of the virgin island to the mainland increases chances of species immigration.

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- The nature of prevailing air and water currents may cause increased immigration of species to an island by promoting dispersal of fruits, seeds, spores, flying animals, nektonic and plank tonic species onto the island.
- A reduced number of physical and biotic barriers to species dispersal onto the island may promote immigration of new species.



Term and definition	Examples and/or comments
(i) ***Sustainable yield*** The highest rate at which a renewable resource can be used indefinitely 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 species, pollution, water logging and salt build up in the soil
(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

Further terms associated with natural resource.

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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) through natural processes as long as the usage is not faster than the replacement.	(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).

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, and modern crops.

Conservation of natural resource

Ecosystems contain natural biological resources which are useful for **(1) food** (2) **medicine** (3) r**aw materials for industrie**s (4) **biological control of pests and diseases** (5) **biogeochemical cycling** (6) **pleasure i.**e. ecotourism.

Some of the conservation methods employed include;

(a) **Restricting** urban and industrial development
(b) **Implementin**g recycling programs
(c) **Legislating** the protection of endangered and keystone species, and enforcement of the law
(d) **Carrying out** breeding programs and establishing sperm/seed banks to maintain high biodiversity
(e) **Implementing** sustainable development programs
(f) **Establishing** conservation areas such as national parks, zoos, botanical gardens, nature reserves and sanctuaries
(g) **Effective** pollution control methods, especially when wildlife species are vulnerable to pollutants
(h) **Creating corridors** that connect habitat fragments
(i) **Bioremediation** i.e. using organisms e.g. fungi and prokaryotes to detoxify polluted ecosystems

EFFECTS OF HUMAN ACTIVITIES ON ECOSYSTEMS

POLLUTION

It is the release of substances or energy into the external environment in such quantities and for such duration that may cause harm to living organisms or their environment.

Pollutants include; noise, heat and radiation as different forms of energy, many chemical compounds and elements and excretory products.

The parts of external environment affected include air, water and land.

Harm cause by pollutants.

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- 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 natural physical, chemical and biological processes.
Biodegradation: is the breakdown of complex chemical pollutants into simpler chemicals by living organisms (usually specialised bacteria) 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. plastic bags.
c) Non-degradable pollutants: these cannot be broken down by natural processes e.g. the toxic elements lead, mercury, arsenic, selenium

Causes of nutrient deficiencies in soils.

- Soil exhaustion due to over cropping without intervals of resting of the soil.
- Leaching of nutrients to deeper soil layers
- Excessive use of fertilizers
- Water logging
- Soil pollution
- Burning causes loss of non-metallic nutrients e.g. carbon.
- Mono-culture

How plants living in soils deficient in nitrogen and phosphorus overcome the problem.

- Living in symbiotic relationship with organisms that are capable of producing such minerals. For example, association of leguminous plants with rhizobium bacteria in their root nodules helps them to obtain nitrogen because the bacteria fix nitrogen from the atmosphere into nitrates which can be used by the plants.
- Adopting a parasitic mode of feeding so that such nutrients can be obtained from such plants that can easily obtain nutrients from deeper soil layers. This is the case with the epiphytes.
- Sponsored by: The Science Foundation College +256 753 80209
- Developing deeper roots so that they can absorb these nutrients that have leached to deeper soil layer.
- Adopting carnivorous behaviours in order to obtain such minerals from non-soil sources. For example, the pitcher plant, which is insectivorous, can obtain nitrogen and phosphorous from the small insects it traps.

TYPES OF POLLUTION

- **AIR POLLUTION**
- **WATER POLLUTION**
- **LAND POLLUTION**

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AIR POLLUTION

Pollutant	Source(s)	Effects/ consequences	Control measures
(i)Carbon monoxide	(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 in industry an homes(ii) Avoid smoking.(iii) Vehicle exhausts gas 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 units 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) quarrying (iv) mining, etc	i)Lung diseases(ii) stomatal blockage iii) Stunted growth of plants.(iv) Smog –	i)Installation of dust precipitators in industrial chimneys.

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		forms when temperature inversion occurs (layer of warm air traps cool air containing dust and smoke close to the earth' surface)	Efficient combustion. 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, (ii0 reduction in combustion of fossil fuels by relying on alternative sources of energy e.g. solar energy.
(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)Chlorofluoro c arbons 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 excessive 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

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GREENHOUSE EFFECT AND GLOBAL WARMING

Greenhouse effect: Is where short wavelength solar radiation entering the earth's atmosphere is reflected from the earth's surface; as longer infra-red wavelength which are retained in the earth's surface; resulting into warming/increase in temperature of the atmosphere;

This is a description of the condition which results when greenhouse gases i.e. gases in the troposphere (atmosphere's inner most layer extending about 17km above sea level) like carbon dioxide, water vapor, methane and nitrous oxide allow mostly visible light, some infrared radiation and ultraviolent radiation from the sun to pass through the troposphere to the earth, which transforms this 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, which causes a warming effect of the earth's surface and air.

The tropospheric gases act like a glass of large green house surrounding the earth. Global warming
This is the observed average global temperature rise of 0.8oC since 1900 as result of the enhanced natural greenhouse effect.

The origins/sources 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.

How human activities have contribute to greenhouse effects

Humans have greatly contributed to the enhanced greenhouse effect through the many activities which release greenhouse gases; such as carbon dioxide/nitrogen monoxide/water vapour/methane/CCF; into the atmosphere.

- Burning of fossil fuels; in cars/industries/homes;
- Massive cut down of trees/ forests removes the plants that would take up carbon dioxide for photosynthesis; also the gap created in the canopies allows in light to the forest floor which then enhances
- decomposition of litter; thereby adding more carbon dioxide to the atmosphere
- Increased rearing of animals at the expense of growing crops adds more carbon dioxide
- Use of CFCs in refrigeration/aeriosprays

Practical remedies to greenhouse problems

- Use of alternative energy sources e.g. solar/wind power
- Use of nuclear power to run industries
- Massive tree planting/afforestation
- Nutrient enrichment of oceans/lakes; so as to reduce usage of wood/fossil fuels;
- Law enforcement
- Sensitization/education programs
- Reduction in overstocking
- Recycling of plastic materials

Global warming

This is the observed average global temperature rise of 0.8^{o}C since 1900 as a result of the enhanced natural greenhouse effect.

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.

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- 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 acid and nitric acid, which make up acid rain.

Effects of acid rains

- Hydrogen ions bound to soil particles are displaced into runoff water by the $SO4^{2-}$ ions from sulphuric acid, causing formation of soft exoskeletons, which results into death of invertebrates.
- Aluminum ions are displaced from soil by SO_4^{2-} ions into water where it interferes with gill functioning in fish causing their 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 lamella 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 products 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.

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 carried 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 the abiotic and biotic components.

Some of these changes are due to specific chemical pollutants (e.g. heavy metals such as cadmium from industrial processes, and pesticides from agriculture, with the effects varying according to the chemicals present in the discharge.

Component description from the point of discharge and explanation

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a) Dissolved oxygen and B.O.D (Biological oxygen demand)

BOD is the 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 1dm3 of water stored in darkness at 200C 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).

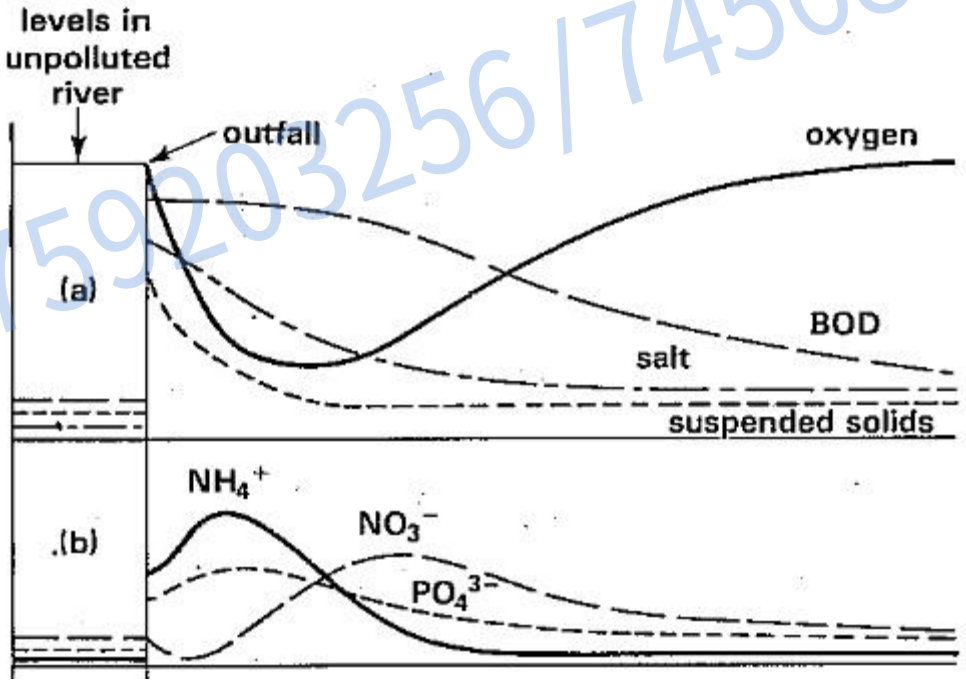
Dissolved oxygen level is high in unpolluted water but decreases rapidly at sewage outfall (discharge) to the minimum and then increases gradually downstream, returning to a normal level further downstream

- B.O.D is very low in unpolluted water, increases rapidly at outfall then decreases gradually downstream.
- Decomposition of organic components of sewage by aerobic bacteria coupled with reduced photosynthesis because of low illumination caused by suspended solids in sewage rapidly reduce oxygen (cause oxygen sag) and create a high BOD at outfall.
- The gradual increase of oxygen downstream is because of increased photosynthesis and dissolution from atmosphere.
- The death of aerobic bacteria due to reduction in organic substances decreases BOD down stream

Suspended solids

- Suspended solids are very few before outfall, increase rapidly at the sewage discharge but progressively decrease downstream
- Sewage discharge adds decomposable organic matter into the water at the point of discharge, the progressive decrease downstream is due to bacterial consumption and dilution by water.

NH_{4+}, NO_{3-} and PO_{43-}(Ammonium, nitrate and phosphate ions)



b) NH_4^+, NO_3^- and PO_4^{3-}ion concentration is very low before outfall

- **NH_4^+ions** increase rapidly at discharge, then very 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.

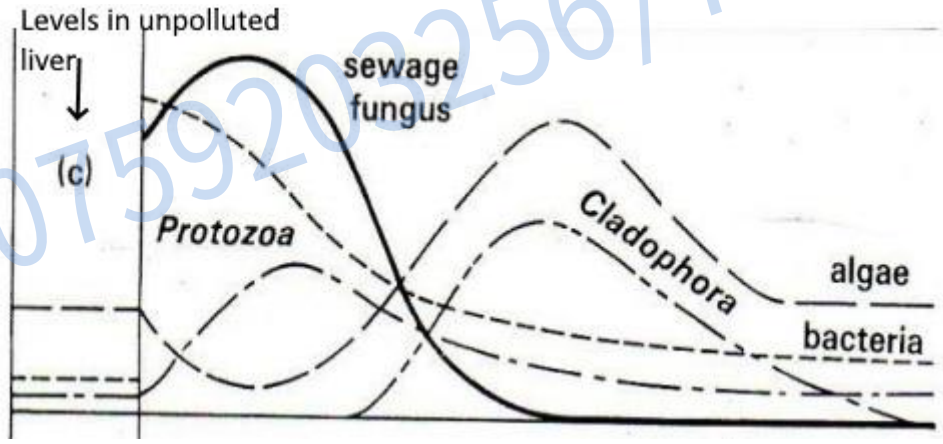
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- **$PO4^{3-}$ ion** concentration increases **(1)** rapidly at discharge, **(2)** gradually just after outfall to a maximum, then decreases gradually to a very low level downstream.
- Sewage contains NH_4^+ions. Putrefying (ammonifying) bacteria convert organic nitrogen-containing compounds in sewage to NH_4^+ just after outfall. Downstream, NH_4^+ions are converted to NO_3^- by nitrifying bacteria and further downstream there is dilution by water.
- **NO^{3-} ion**s first decrease due to consumption by sewage fungus abundant at outfall, then gradually increase because NH_4^+ions are converted to NO^{3-} by nitrifying bacteria, then decrease gradually due to consumption by plants and algae.
- Sewage contains **PO_4^{3-} ions** from **(1)** detergents and **(2)** decomposition of organic matter, yet the consumption by autotrophs is very low at outfall, accounting for the high PO43- 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.

Ecological impact of artificial fertilizers

- Fertilizers applied to crop plants are lost in surface run-off water and pollute soil and water resources.
- Increase in crop yield.
- Decrease in nutrient content in the soil.
- Decrease in the number of microorganisms in the soil such as saprophytic bacteria.
- Nitrogen and phosphate-based fertilizers leach into ground water and increase its toxicity leading to water pollution.
- They change the chemical composition of soil.

c) Aerobic bacteria, sewage fungus, algae and higher plants

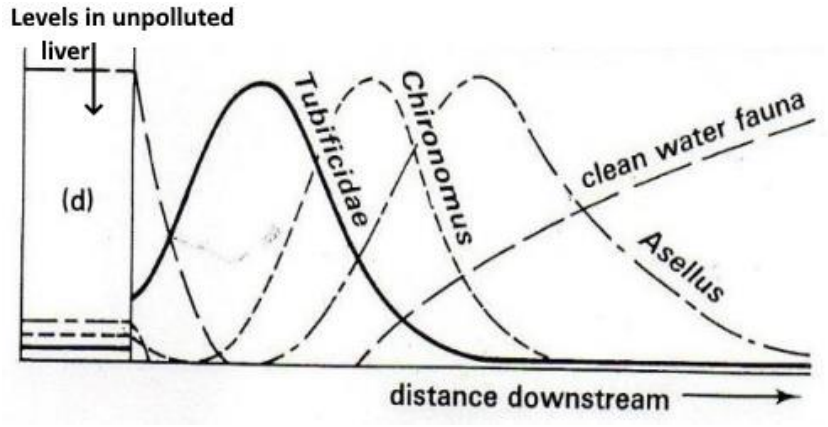


- **Aerobic bacteria** are very few before, but very many at outfall, then their population decreases rapidly immediately and gradually after out fall downstream.
- Sewage fungus is contained in sewage population, increases to a maximum immediately after outfall, but decreases rapidly downstream to very 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 feed on organic substances, but population falls as availability of oxygen and nutrients diminishes.
- Population increases at outfall because the sewage fungus thrives in anaerobic conditions and is very tolerant of high ammonia concentrations.

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- The rapid decrease in populations results from reduced photosynthesis because of the turbidity caused by suspended solids, the rapid increase is because of the high concentrations of NO_3^- (nitrate) ions and increased illumination because suspended solids reduce and water becomes clearer

d) Clean water fauna (e.g. stonefly nymphs, may fly larvae, perch, trout), Asellus (fresh water louse), Chironomus (bloodworm), rat tailed maggot and Tubifex



- The populations of clean water fauna are high before outfall, decrease rapidly to zero at outfall only appearing and increasing to normal with distance downstream.
- **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. Rat tailed maggots' population increases rapidly to a maximum a short distance after outfall and then decreases rapidly downstream and
- **Chironomus** population increases rapidly to a maximum at a slightly longer distance from outfall and then decreases rapidly downstream.
- Clean water species cannot tolerate anaerobic conditions at outfall, populations increase downstream because oxygen and food become available.
- **Asellus** cannot tolerate anaerobic conditions at outfall and therefore dies and/or migrates to the relatively less polluted water downstream where it shrives. The decrease thereafter is due to consumption.
- **Tubifex,** rat tailed maggots and Chironomus are **(i)** relatively inactive to reduce oxygen demand and **(ii)** have respiratory pigments with very high affinity for oxygen enabling them to be tolerant to anaerobic conditions. The increase in their population downstream indicates the level of pollution in the water.
- Tubifex, is the most tolerant to anaerobic conditions, followed by rat tailed maggots and Chironomus. The decrease in population downstream is partly due to predation.

Note:

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;

i**) Volume of incoming degradable wastes in sewage**

ii) Flow rate of the river

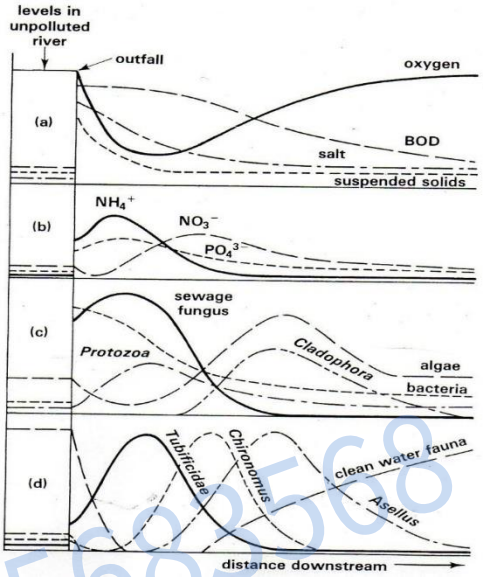
iii) Temperature of the water

iv) PH level of the water

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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.



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) *temperature 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 provide information about the environment e.g. can be used in ecological investigations to find out about both the present and past conditions of soil and climate.*

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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 protoctists (algal blooming/dramatic first growth of algae) (ii) Reduces light penetration in water leading to (iii) Death and decay of algae, which depletes water of dissolved oxygen, killing fish and other 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 baby syndrome").
(ii) Sediment	soil 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 fill 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.

(B) ***ADDITION OF INORGANIC CHEMICALS, PLANT NUTRIENTS AND SEDIMENTS INTO LAKES.***

C. ***HEAT (THERMAL) POLLUTION***

Main human sources

Use of water as a coolant in industrial processes e.g. electricity generating plants.

Harmful effects

- Lowers dissolved oxygen levels since solubility of most gases reduces with temperature.
- Make aquatic organisms more vulnerable to disease, parasites, and toxic chemicals.
- When a power plant shuts down for repair or opens, fish and other aquatic organisms adopted to a particular temperature range can be killed by the abrupt change in water temperature. This is known as thermal shock.
- Some aquatic animals may migrate to water with favorable temperature.

Note: **Effects of eutrophication are more severe in water bodies where thermal pollution occurs because of;**

- Increased decomposition of organic matter and metabolism, which raise the demand for oxygen by higher organisms.
- Reduced dissolved oxygen levels in water.

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 more sensitive and representative reflection of environmental conditions. Chemical monitoring all the time can only be done for small water courses 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**.**

Several human activities which directly destroy the environments are:

1. Deforestation; forests are important for:

Have most species and diverse wild life communities. Their destruction will lead to extinction of numerous species and less of genetic variety and potential resources.

Forests protect the soil. Deforestation leads to soil erosion, clear water supply are destroyed and silting of reservoirs.

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Timber harvest, poles, food, fuel, honey, fruits and herbs
Forests catch large amounts of rain and release the water slowly into streams and rivers. Their destruction cause floods in areas down-hill.
Forests release large amounts of oxygen and absorb carbon dioxide (lock it up) during photosynthesis. Deforestation has led to increased global carbon dioxide hence causing global warming.
Forests influence the amount and frequency of rain fall received in an area.

2. Poor agricultural methods:
These include Monoculture, shifting cultivation, use of artificial fertilizers and pesticides. Excess fertilizers and pesticides leads to eutrophication of water bodies giving rise to build up of toxic by-products by leaching and draining. Pesticides/herbicides/fungicides draining away from fields enter water ways are connected through the food chain. This leads to poisoning of top carnivores.

3. Poor methods of mining; such as open cast mining destroy habitats. Mineral elements mined cause destruction of the environment around the mine. Heavy metals like lead and mercury drain into water bodies causing severe destruction of aquatic fauna, poison water for human consumption; sulphides destroy vegetation altering the structure of plant and animal communities.

4. Urbanization/human settlement; e.g. aggregation of people, food and water supply, garbage disposal.

5. Fires; burning of fossil fuel

6. Cement manufacture

Ecological impact of over fishing

- Extinction of some species of fish.
- Reduction of the population of adult reproductive fish, leaving a population of mainly young individuals because fish are caught as soon as they reach catchable size.
- It may lead to rapid increase in the numbers of fish prey organisms.
- May lead to reduction or even extinction of some aquatic fish predator organisms which may then encroach on terrestrial habitats near water bodies. For example, crocodiles may start hunting terrestrial animals that come close to the water bodies including man.
- Disruption of aquatic food chains.

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TOPIC 6: INHERITANCE AND EVOLUTION – GENETICS

SUB-TOPIC 1: GENETICS

Genetics: This is the study of the mechanism by which characteristics (traits) are transmitted from parents to the offsprings. This transmission occurs via gametes during fertilization in sexually reproducing organisms.

Therefore genetics can also be referred to as the study of inheritance characteristics of the parents by the offsprings. The characteristics of organisms are controlled by internal factors called genes located on chromosomes.

A GENE is a section of DNA that determines a particular characteristic in an organization or a section of DNA that controls the production of a polypeptide chain in an organism.

HEREDITY is the transmission of characteristics from parents to offsprings (progeny). Such characters are also called traits. In humans, characters like hair texture, height; skin colour, body build and hair colour are inheritable characters.

THE IMPORTANCE OF GENETICS

- It is used in genetic engineering where better breeds and varieties of plants and animals are produced. This is intended to increase production and improve resistance of diseases and pests. This can be done locally through cross breeding.
- It is used in the legal profession to determine the paternity of the child i.e. genetics is used to settle paternal disputes by confirming who the father of the child is. This can be proved through use of blood groups as these groups are genetically inherited and can therefore be used to prove the rightful father of the child. If the blood groups fail to prove then DNA analysis can be used.
- They are used in blood transfusion. Genetic principals are used during blood transfusion so that blood being transfused is compatible to avoid blood clotting (Agglutination) in the recipient.
- It is used in the control of the transmission of genetic diseases. These diseases are genetically engineered e.g. hemophilia, colorblindness, acandroplasia e.t.c. can be eliminated from the human population by following the principles of genetics as these diseases are genetically inherited.
- It can be used in crime investigation i.e. use of the DNA finger prints to identify criminals
- It is used in molecular biology to manufacture artificial enzymes, hormones and vaccines.
- It enables humans to choose the right partners during marriage by choosing those with characteristics for reproduction.

TERMINOLOGIES INVOLVED IN GENETICS

Chromosomes

A chromosome is a thread-like long and coiled structure found in the nucleus of the cell on which the genes are located or carried. Most chromosomes occur in pairs and each pair of such chromosomes which are similar in structure but chemically different is known as a pair of **homologous** chromosomes.

Genes

A gene is a unit of DNA that is usually located on a chromosome and that controls the development of one or more traits and is the basic unit by which genetic information is passed from parent to offspring.

Alleles. These are alternative forms in which the gene can exist but control contrasting features of characteristics. Alleles exist in pairs e.g. consider a gene for height. This gene can be expressed inform of allele as T (for tallness) and t (for shortness). Therefore these two alleles can exist as **TT and tt.**

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 allele. A dominant allele is the one that can express its self phenotypically in both homozygous and heterozygous forms. Such genes are always represented by capital letters when performing a genetic cross.

Recessive allele. This is an allele that can only express itself phenotypically in the homozygous form as it is suppressed by the dominant allele in the heterozygous form. Recessive genes are always represented by small alphabetical letters in a genetic cross

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**.

Heterozygous. This is a condition where an individual possess non-identical alleles for a particular gene e.g. Tt, Bb

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Pure breeding (breeding true). This is where the individuals crossed are homozygous and therefore produce consistently the same characteristic, generation after generation. A pure breed should therefore be a homozygous individual when considered for a particular characteristic.

Hybrid. This is heterozygous individual obtained from crossing two parents with contrasting characteristics but when these parents are pure breeding e.g**. tt X TT**

Note: Recessive alleles are presented by small letters (lower case) while dominant alleles are represented by capital letters (upper case)

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.

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.

Heterozygous individuals are genetically called carriers of the recessive characteristic. Recessive characteristics can only be expressed when two carriers make an organism which is phenotypically recessive appears e.g. the sickle cell anemia individuals, albinos, hemophiliac e.t.c.

Crossing (X). This refers to the mating of the male and female organisms under a consideration.

First filial generation (F1). This refers to the set of offsprings obtained from crossing two pure breeding parents with contrasting characteristics. These individuals are therefore heterozygous or hybrids.

Second filial generation (F2). This refers to the set of offsprings that are obtained from crossing mature hybrid of parents of the first filial generation.

Selfing. This refers to the crossing of offsprings of the same parents.

Test cross. This is the mating of a phenotypically dominant individual with a recessive individual so as to determine the genotype of the phenotypically dominant individual. This is due to the fact that a phenotypically dominant individual can either be heterozygous or homozygous. If the homozygous offsprings resemble the dominant parent then the dominant parent is said to be homozygous and if the offsprings formed from the test cross shows a phenotypic ratio of 1:1, then the parent with an unknown genotype is heterozygous.

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 phenotypes of the same characteristics are interchanged among the parents during a genetic experiment.

MENDEL'S GENETIC EXPERIMENTS AND MONOHYBRID INHERITANCE

This is the inheritance of a single pair of characteristics from the parent to offsprings.

Examples include, height, blood groups, albinism, sickle cell anemia, and sex linked characteristics e.t.c.

This mechanism of inheritance was discovered by a scientist called **Gregory Mendel** who carried out a number of genetic experiments using the garden pea plants. He also observed many sexually reproducing organisms and found out that they had variations among themselves despite being of the same species.

In these experiments, Mendel carried out cross pollination between tall pea plants and short pea plants he had grown in his garden. In order to carry out a proper cross, Mendel covered the stigma of all flowers of one group of pea plants in order to have male pea plants.

He also removed all the anthers from the flowers of another group of pea plants in order to have female pea plants. Using a brush he transferred pollen to tall pea plants from short pea plants. He observed the

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F1 offsprings were all tall. He then selfed the F1 pea plants to get F2 which was found to be a mixture of tall pea plants and short pea plants.

In order to perform good genetic experiments, Mendel used a garden pea plant because such plants have good characteristics for genetic experimentation which included the following;

- They have many contrasting characteristics without any intermediates such as tall and short stems, smooth and wrinkled seeds, yellow and white flowers i.e. a good genetic organism must show many discontinuous variation characteristics
- They produce large numbers of offsprings which provide a large sample for experimentation so as to get reliable results.
- It is possible for them to undergo controlled pollination.
- They are so small that they can be conveniently handled.
- They have a short life span and they can be reproduced very quickly before the end of the life span.

Mendel was successful in his genetic experiment because;

- He had a systematic approach to his work. This is because he dealt with a single characteristic (monohybrid inheritance) and then later long he considered two characteristics simultaneously (di-hybrid inheritance).
- He was very patient during his experiments so that he was able to reproduce the garden peas for several generations.
- He used a very a good experimental organism, the garden peas.

Conclusions from Mendel's experiments

About the actual mechanism of inheritance

1. The phenotypic characteristics are under the control of internal factors (these factors were later named genes).
2. It is these factor that are transmitted from the parents to the offsprings i.e. (from one generation to the next).
3. For each character, an organism inherits from the parents two alleles (internal factors), one from each parent and it is these factors which account for variations in inherited characters.
4. The factor which phenotypically appears in F1 generation is dominant to the one which fails to phenotypically in F1 but instead appears in the F2 generation.
5. During sexual reproduction the egg cell and the sperm makes equal contribution to each of the characteristics of the offspring such that the offspring has both male and female parental characteristics. This is because the two alleles for a heritable character separate or segregate during formation of gametes in meiosis and end up in different gametes.
6. Always in F2 generation, the dominant and recessive offsprings appear in a phenotypic ratio of 3:1. The results, using proportions only, are summarised in the table below;

Character	**Type of cross**	**F1 generation**	**F2 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

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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

MENDEL'S FIRST LAW OF INHERITANCE

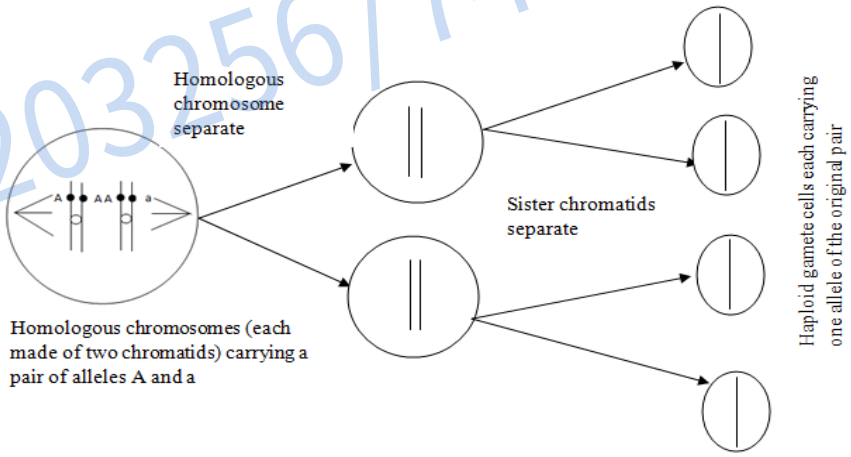
From this experiment about monohybrid inheritance he suggests the law of genetics which is known as the law of segregation.

This law states that in diploid organisms each characteristic is controlled by a pair of alleles but during gamete formation the alleles separate so that each gamete possesses a single allele.

Explanation of Mendel's first law of inheritance

This law is explained by meiosis which halves the chromosome number in that each characteristic of an organism is determined by a pair of alleles located on the pair of homologous chromosomes in the nucleus of the cell of an organism. Each allele of the pair for a characteristic is therefore carried by a single chromosome of the homologous pair when homologous chromosomes segregate and move towards opposite pole of the cell during anaphase I of meiosis. This results into each gamete carrying one allele of the gene pair due to the separation of a pair of chromatids during anaphase I.

Diagram



COMPLETE

DOMINANCE: is a condition where one allele suppresses the effect of another allele in heterozygous condition.**E.g.** Inheritance of Height, appearance of seed **Testa, colour of unripe pod and colour** of cotyledon in Garden pea plant.

Example

1. In a garden pea plant there are two forms of heights i.e. tall and short. When a pure breeding tall pea plant was crossed with a short pea plant all the offsprings obtained where tall when the offsprings were selfed a phenotype ration was obtained in F2.

a. Using suitable genetic symbols, workout the genotypes and phenotypes of the F2 generation

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b. What are the phenotypic and genotypic ratios of the F2 generation

c. Explain how you would determine the genotype of F1 tall pea plants formed

d. Suppose 300 pea plants where produced in the F2 generation

i. How many were tall?

ii. How many were short?

Solution

(a)

*Let **T** represent the allele for tallness*

*Let **t** represent the allele for shortness*

Parental phenotype (2n): tall pea plant X short pea plant

Parental genotype; TT X tt

Meiosis

Gametes (n): All T All t

Fertilization:

F_1 genotypes (2n): All Tt

F_1 genotypes (2n) are all tall pea plants.

Selfed: F_1 X F_1

Parental phenotypes (2n): tall pea plant X tall pea plant

Parental genotype: Tt X Tt

Meiosis

Gametes (n) T t T t

Fertilization

F_2 genotype (2n) TT Tt Tt tt

F_2 phenotype Tall pea plants Short pea plant

F_2 genotypic ratio 1TT:2Tt:1tt

F_2 phenotypic ratio: 3tall:1short

(c) In order to determine the genotype of F_1 pea plants, carry out a test cross, by crossing the F_1 tall pea plants with short pea plants.

Parental phenotype: tall pea plant X short pea plant

Parental genotype (2n): Tt X tt

Meiosis

Gametes (n) T t All t

Fertilization

Test cross offspring genotype: Tt tt

Test cross phenotypic ratio 1tall:1short

This shows that F_1 tall pea plants were heterozygous

(d)

i. Homozygous tall

$$= \frac{homozygous\ tall}{total} \times 700 = \frac{1}{4} \times 700 = 175 \text{ plants}$$

ii. Homozygous

$$\text{short} = \frac{homozygous\ short}{total} \times 700 = \frac{1}{4} \times 700 = 175 \text{ plants}$$

iii. Heterozygous =

$$\frac{heterozygous}{total} \times 700 = \frac{1}{2} \times 700 = 350 \text{ plants}$$

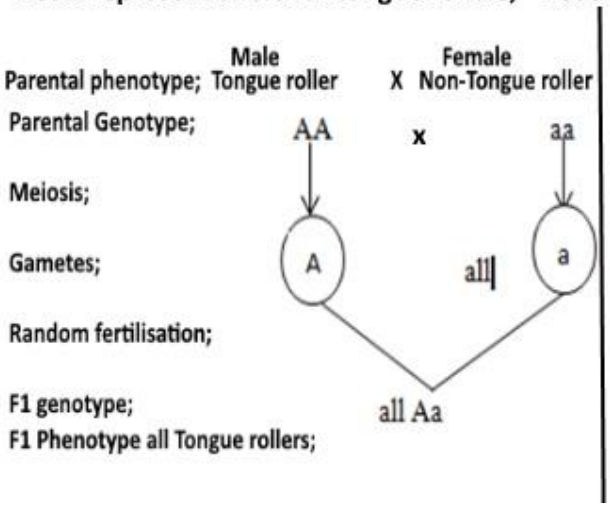
Example 2 : Suppose a man who is a tongue roller marries a woman who is a non-tongue roller and all the children obtained in F_1 are tongue rollers.

(a) Work out the phenotypic and genotypic ratio as obtained in F_2 generation.

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(b) What is the probability that the 4th born is a non-tongue roller?

Let A represent allele for tongue rollers; Let a represent allele for Non-tongue roller



Selfing F1 offsprings

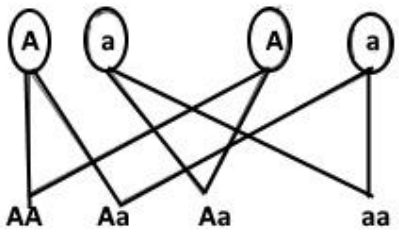
Parental phenotype; Male Tongue roller X Female Non-tongue roller

parental genotype; Aa X Aa

Meiosis;

Gametes;

Fretilization;



F2 genotype; AA Aa Aa aa

Genotypic ratios: 1AA: 2Aa: 1aa

Phenotypic ratios: 3tongue rollers: 1non-roller

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

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EXAMPLES OF MONOHYBRID INHERITANCE IN MAN

- Sickle-cell anaemia; normal allele is dominant
- Albinism; Normal allele is dominant
- Achondroplasia; Normal allele is recessive
- Achondroplasia is a genetic disorder that results in dwarfism. In those with the condition, the arms and legs are short, while the torso is typically of normal length
- Cystic fibrosis;
- Phenylketonuria. Normal allele is dominant.

- Phenylketonuria (PKU) results in decreased metabolism of the amino acid phenylalanine, leading to its increase in blood. Untreated, PKU can lead to intellectual disability, seizures, behavioural problems and mental disorders.
- Huntington's disease. Abnormal allele is dominant.
- It is an inherited disease that causes the progressive breakdown (degeneration) of nerve cells in the brain.

EXCEPTIONS TO MENDEL'S LAWS

These are referred to as **exceptions to Mendel's laws of inheritance** because they never produce the **3:1** ratios of phenotypes in monohybrid.

FACTORS WHICH MODIFY OR AFFECT MENDEL'S MONOHYBRID 3:1 AND 1:2:1 RATIOS

1**. LETHAL GENES:**

These are genes that lead to the death of the bearer lethal genes are divided into 3 major categories;

a. **Gametic lethal genes**. These are genes which kill the gametes and therefore prevent fertilization.

b. **Zygotic lethal genes**. These are genes which kill the zygotes and embryos before birth e.g. the gene that determine coat color in mice.

c. **Infantic lethal genes.** These are genes which kill individuals between birth and reproductive stages e.g. the gene that determines chlorophyll formation in maize, sickle cell anemia in man e.t.c.

Lethal alleles: This is a combination of alleles which result into death of offspring before birth

Lethal genes in mice

The gene that determines coat color in mice is a zygotic lethal gene. In mice, there are two colours determined by these genes i.e. yellow and grey (agouti). If two yellow mice are crossed they produce both yellow and grey offspring however these offspring appear in a phenotypic ration of two yellow; 1 grey instead of 3:1.

This is because the homozygous dominant yellow mice die in the uterus which reduces the phenotypic ratio. The yellow mice produced are always heterozygous and this changes the monohybrid genotypic ratio from 1:2:1 to 2:1

Let Y represent the allele for yellow coat color

Let y represent the allele for grey coat color.

Parental phenotype (2n) : yellow mouse x yellow mouse

Parental genotype (2n): Yy X Yy

Meiosis

Gametes (n) Y y Y y

Fertilization

Offspring genotype (2n): YY Yy Yy yy

YY dies before birth and therefore the offspring phenotype will be 2 yellow: 1 grey

Some genes are lethal when both alleles are present. Lethality can occur before or after birth

Huntington's disease in humans is caused by a lethal allele, death occurs later in life

Other examples:

- **Mouse coat color (yellow),**
- **Creeper legs in chickens,**
- **Manx Cats (no tails)**

An example is the "creeper" allele in chickens, which causes the legs to be short and stunted.

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Creeper is a dominant gene, heterozygous chickens display the creeper phenotype
If two creeper chickens are crossed, one would expect to have (from Mendelian genetics) 3/4 of the offspring to be creeper and 1/4 to be normal
Instead the ratio obtained is 2/3 creeper and 1/3 normal.
This occurs because homozygous creeper chickens die.

	P	p
P	PP lethal	Pp creeper
p	Pp creeper	pp normal



Manx Cats
Cats possess a gene for producing a tail. The tailless Manx phenotype in cats is produced by an allele that is lethal in its homozygous state. The allele interferes with normal spinal development, in heterozygous cats this results in lack of a tail.

Show the cross between a Manx cat and a normal cat.

There is a phenotype in chickens called the creeper condition. This phenotype is caused by an autosomal mutation and displays as a chicken that has short and stunted legs. Chicken embryos that are homozygous for the creeper condition have severe developmental problems and never hatch from their eggs. What is the inheritance pattern? What are the different phenotypes and the associated phenotypic and genotypic ratios from a cross of two chickens with the creeper condition? Show your work with a Punnett square.
Note:
a) Dominant lethal genes are very rare in a population because they are usually manifested easily in growth and development of the offspring at an early age and hence easily eliminated.
b) A pleiotropic gene is the one which controls more than one aspect or characteristic in the metabolism of an organism e.g. **the Y gene** in mice is controlling both viability and coat colour, for viability the Y gene acts as a recessive gene since homozygous YY mice dies in the uterus and since **Yy** mice are yellow this phenomenon is called pleitrophy.

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2. CO-DOMINANCE

CO-DOMINANT: This is a condition whereby when two genes co-exist in heterozygous state both equally express themselves to produce a phenotype which is intermediate of the two parents.

This is a phenomenon whereby the alleles controlling a particular characteristic have equal powers of expressing themselves in the phenotype in the heterozygote. Therefore the offsprings produced will have a mixture of the two parental characteristics in the phenotype.

Co-dominance is taken to be a form of incomplete dominance since no allele suppresses the phenotypic expression of another. In co-dominance which use capital letter to represent all the two alleles each letter corresponding to each of the two characteristics.
Examples of co-dominance include the following;
a. The gene that determines coat color in cattle
b. Inheritance of blood group AB in man
c. Inheritance of sickle cell trait
Inheritance of coat colour in cattle.

Consider a cross between a red bull and a white cow whose F1 offsprings are selfed. Workout the genotypes and phenotypes in F1 and F2 generation stating in each case the ratios

When the F1 roan offspring are selfed, the F2 offspring will be red, roan and white in the ratio 1 red: 2 roan: 1 white as shown below

Let R represent the allele for red coat color

Let W represent the allele for white coat color.

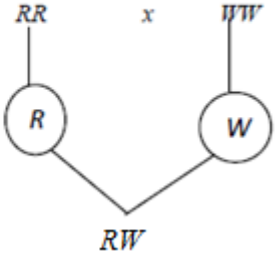
Parental phenotype (2n): red bull x white cow

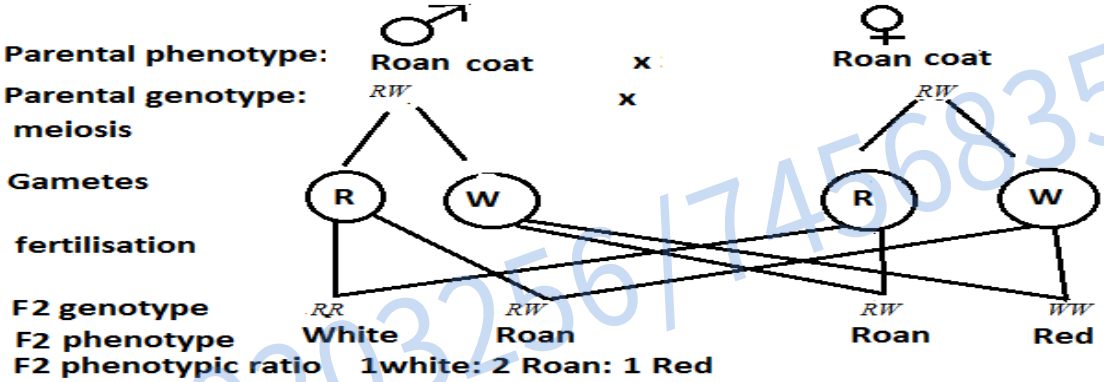
Parental genotype (2n): RR x WW

Meiosis

Parental gametes
Ramdomfertilasation

F1 generation





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**

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INHERITANCE OF SICKLE CELL ANAEMIA

This is an abnormal condition in which the red blood cells collapse into a sickle shape under low oxygen concentration due to the presence of abnormal haemoglobin (Hbs) in the red blood cells. The normal haemoglobin is found in red blood cells with a bi concave disc shape.

How does abnormal haemoglobin arise in the human population

The DNA cistron for the β-haemoglobin gene situated on chromosome 11 which codes for the beta amino acid chain in haemoglobin undergoes a base substitution mutation whereby the base adenine replaces thymine, leading to formation of the DNA code CAC on the DNA cistron instead of CTC.

During transcription the mRNA produced has the triplet codon GUG coding for the amino acid valine, instead of GAG for glutamic acid.

Translation of GUG results into formation of the amino acid valine instead of glutamic acid in the beta haemoglobin polypeptide chain on position 6, giving abnormal haemoglobin.

	NORMAL	MUTANT
DNA code	CTC	CAC
mRNA codon	GAG	GUG
tRNA anticodon	CUC	CAC
Amino acid	Glutamic acid	Valine

Genetic crossing illustration

Sickle cell anaemia is caused by a substitution mutation, in which an amino acid known as ***glutamic acid,*** responsible for the formation of normal haemoglobin is replaced by another amino acid called ***valine*** which leads to the formation of **HbS** in the red blood cells.

Haemoglobin is made of four polypeptide chains, two α-chains which are 141 amino acids long and two β-chains which 146 amino acids long. The substitution mutation occurs at the sixth amino acid in the β-chain, this results in wrong amino acid, valine, being incorporated into two of the β-polypeptide chains. **Valine** is non-polar and hydrophobic which makes its presence in the haemoglobin (**HbS**) less soluble when deoxygenated. Therefore when HbS loses its oxygen, the molecules come out of solution and crystallise (solidify) into rigid rod-like fibres. These change the shape of the red blood into a sickle shape.

Effects of sickling red blood cells

a. Anaemia this is occurs because the sickle cells are destroyed which lowers the amount of oxygen to be carried leading to acute anemia. This leads to;

- Fatigue (weakness)
- Poor physical development
- Dilation of the heart which may lead to heart failure
- Infections which lead to frequent illness

b. Interference with circulation of blood because the cells get jammed in capillaries and small arteries. This leads to;

- Heart damage which leads to heart failure
- Lung damage which leads to pneumonia
- Muscle and joint damage which leads to rheumatism and pain
- Gut damage which leads to abdominal pain
- Kidney damage which leads to kidney failure
- Liver damage

c. 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.

Note: The allele that erythrocytes to have a distorted form in sickle-cell anaemia also causes these blood cells to rupture easily, thereby inducing anaemia. This gene can also be described as pleiotropic since it has more than one effect in an organism.

In heterozygous individuals, half the molecules made are HbS and HbA i.e. the alleles HbA and HbS are co-dominant and the faulty gene is not recessive. Heterozygous people are not affected except at unusually low oxygen concentrations, such as when flying in an unpressurised aircraft or climbing at high altitude. Then some of the cells sickle. The **heterozygous** condition is known as **sickle cell trait.**

These individuals have a **selective advantage** over non carriers because they are far less susceptible to malaria (the malaria parasite multiplies inside normal red blood cells) so are more likely to survive in malaria infested areas, and pass on their genes to the next generation. A single copy of the sickle-cell allele increases resistance to malaria. The final frequency of the gene in the population varies according to the amount of malaria.

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Consider a normal man marrying a sickle cell anaemia woman. Consider another man who is a carrier of sickle cell anaemia of the same disease. Work out the phenotypic and genotypic ratios arising from these two marriages.

Example

Consider a normal man mating with a woman with sickle cell anemia to obtain F1 offsprings which will be phenotypically normal but carriers, if the two carriers mate to form F2 the phenotypic ratio will ***be 1:2:1***

Solution

Let Hb^A represent the allele for normal red blood cells

Let Hb^S represent the allele for sickle celled red blood cells.

Parental phenotypes: normal man x sickler woman

Parental genotypes (2n): $Hb^A Hb^A$ x $Hb^S Hb^S$

Meiosis

Gametes (n): all Hb^A all Hb^S

Fertilization:

F_1 genotype (2n): $Hb^A Hb^S$

F_1 phenotype: All are carriers

Parental phenotype: sickler man x sickler woman

Parental genotype (2n): $Hb^A Hb^S$ x $Hb^A Hb^S$

Meiosis

Gametes (n): Hb^A Hb^S Hb^A Hb^S

Fertilization

$Hb^A Hb^S$ $Hb^A Hb^S$ $Hb^A Hb^S$ $Hb^A Hb^S$

*F2 genotypic ratio: **1 $Hb^A Hb^S$: 2 $Hb^A Hb^S$: 1 $Hb^S Hb^S$***

***F_2 phenotypic** ratio: **1**normal: **2** carrier for the sickle cell trait: **1** sickle cell anaemia*

Carriers (heteozygotes) of sickle cell anemia show the sickle cell trait, a co-dominant condition, in which most of the red blood cells have normal hemoglobin and only about 40% of the red blood cells have abnormal haemoglobin ***S***. This produces mild anemia and prevents carriers of the sickle cell trait from contracting malaria. This is because when the plasmodium that causes malaria enters a red blood cell with haemeoglobin **S,** it causes extremely low oxygen tension in the cell which leads to the cell sickling in heterozygotes. These sickled cells are quickly filtered out of the blood stream by the spleen, thus eliminating the parasites.

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Fully explain the effect of the gene for abnormal haemoglobin in humans.

Inheritance of the gene for abnormal haemoglobin in the **homozygous state** causes **sickle cell anaemia**.

A sickler has abnormal haemoglobin in all the red blood cells, called haemoglobin-S, containing abnormal beta polypeptide chains where the glutamic acid in the beta polypeptide chain on position 6 is replaced by valine

Glutamic acid carries a negative charge and is polar, while valine is non-polar and hydrophobic.

Presence of valine makes deoxygenated haemoglobin-S less soluble, so when haemoglobin-S loses its oxygen the haemoglobin-S molecules come out of solution, and crystallize into abnormal rigid long fibres, which change the shape of the red blood cell from a flat biconcave circular disc shape.

Sickle red blood cells cause: severe anaemia, blockage of blood capillaries and small blood vessels, deprivation of organs of oxygen; pain in the arms, legs, back and stomach; stiff and painful joints, swollen hands and feet, poor growth and development, increased risk of infection

Inheritance of the gene for abnormal haemoglobin in the **heterozygous state** causes **sickle cell trait**, which results in mild anaemia.

Heterozygotes have red blood cells with half the molecules HbA and half HbS, since the alleles are codominant.

But incomplete dominance at phenotypic level causes heterozygotes to have 30% to 40% sickle cells, the rest being normal; so can only suffer anaemia at unusually low oxygen tensions, such as when flying in an unpressurised aircraft and climbing at high altitudes.

However sickle cell trait sufferers are resistant to severe attacks of malaria, which increases their chances of survival in malaria-endemic areas, because Plasmodium cannot easily invade sickle cells, because its metabolism is aerobic , and only multiplies inside normal red blood cells, which have sufficient amounts of oxygen, constituting a heterozygote advantage and a genetic load in such human populations

3. INCOMPLETE DOMINANCE; Is a type is inheritance where two alleles forming a gene pair, neither of them dominate the other, part contribute equally to determine a particular character.

This is a condition whereby the characteristics of the alleles blend together to form an F1 Offspring phenotype which is intermediate between the two parental phenotypes. Therefore the F1 individuals do not resemble any of the parents.

It can also be defined as a situation with by the heterozygote shows a phenotype intermediate between the parental phenotypes.

In incomplete dominance no gene dominates the other in the phenotype but instead forms intermediate phenotypes and are therefore represented using capital letters.

Example In a snap dragon plant, when a red flowered is crossed with a white flowered plant, all the F1 plants obtained are pink flowered. When the F1 are selfed, the F2 phenotypic ratio is 1:2:1 instead of 3:1. Using suitable genetic diagrams, explain the above results.

Let R represent the allele for red flower colour

Let W represent the allele for white flower colour.

Parental phenotype (2n): red flowered x white flowered

Parental genotype (2n): *RR* x *WW*

Meiosis

Gametes (n) all *R* all *W*

Fertilization

F_1 genotype (2n): *RW*

F_1 genotypic ratio: all RW

F_1 phenotypic ratio: all pink flowered plants

When selfed F_1 x F_1

Parental phenotype: pink flowered plant x pink flowered plant

Parental genotype (2n): *RW* *X* *RW*

Meiosis

Gametes (n) *R* *W* *R* *W*

Fertilization

Offspring genotype (2n): *RR* *RW* *WR* *WW*

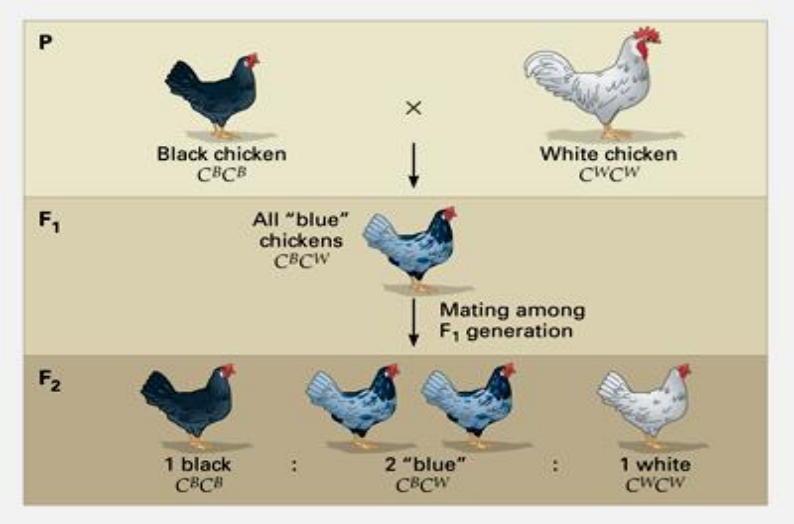
F2 genotypic ratio: 1RR: 2RW : 1WW

F_2 phenotypic ratio: 1Red: 2pink : 1White

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

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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.



DIHYBRID INHERITANCE

Is the inheritance whereby two characteristics, each controlled by a different gene at a different locus.

When Mendel considered the inheritance of two characteristics simultaneously, he concluded that these characteristics are inherited independently and each pair of alleles separates during meiosis and during fertilization each of the alleles combines randomly with either alleles of another pair. From this conclusion **Mendel made his second law of inheritance which states that; "**each characteristic in diploid organisms is controlled by a pair of alleles which separate so that each allele randomly combines with any other allele of another pair."

From this law Mendel also described it as the law of independent assortment.

This law is explained by meiosis as follows.

During gamete formation, during meiosis, the distribution of each allele from a pair of homologous chromosome is entirely independent of the distribution of alleles of other pairs. During metaphase I of meiosis homologous chromosomes lineup on the equator of the spindle and subsequently separate (segregate) independently during metaphase I and move to opposite poles independently during anaphase I which leads to a variety of allele recombination in the gametes formed, as long as each gamete has one allele for each gene.

For instance, in one of his experiments; Mendel crossed pure breeding **tall pea plants with red flowers** with pure breeding **dwarf plants having white flowers**. All in the F1 progeny were **tall with red flowers**. This showed just like Mendel had discovered before that the alleles for tallness and red flowers were dominant to those for dwarfness and white flowers respectively.

Mendel went ahead to self-pollinate the F1 plants and obtained an F2 progeny, this comprised of a variety of phenotypes as summarised in the table below.

- 315 Tall with red flowers
- 101 Tall with white flowers
- 108 Dwarf with red flowers
- 32 Dwarf with white flowers

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These give the respective phenotypic ratios as **9:3:3:1.** This is known as Mendel's Dihybrid ratio; the ratio of phenotypes in the F2 generation for a Dihybrid cross.

From this and many other similar crosses, Mendel was able to make the following observations:

- Both phenotypes/characters (height and flower colour) combined in the F1 but separated and behaved independently in the F2.
- Two of the F2 phenotypes resembled one or the other of the parental phenotypes WHILE two new combinations of phenotypes appeared in the F2; (Tall/white and Dwarf/red). These are known as recombinants.
- The allelomorphic pairs of characteristics (controlled b different alleles of the same gene) occurred in a phenotypic ratio of 3 dominants: 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 of another pair"

Below is a full genetic explanation of the 9:3:3:1 ratio of phenotypes in the F2generatioon of a dihybrid cross.

Example: In the garden pea plant, the gene controlling flower color is located on the same chromosome with that controlling height. Suppose a pure bleeding tall red flowered plant is crossed with a white short flowered plant, the F1 offsprings obtained are tall red flowered plants. If the F1 offsprings are selfed,

a) What would be the phenotypic ratio in the F2 generation?

b) If 700 pea plants are formed in F2 generation, what would be number of pea plants in each phenotypic class?

c) How would you experimentally determine the genotypes of the F1 plants?

Solution

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*Let **T** represent allele for tallness*
*Let **t** represent allele for shortness*
*Let **R** represents allele for red flower color*
*Let **r** represents allele for white flower color*
*Parental phenotype: **tall red flowered pea plant x short** flowered*

Parental genotype (2n): TTRR x ttrr
Meiosis
Gametes (n) all TR all tr
Fertilization
Offspring genotype (2n): TtRr

F1 phenotype: all tall red flowered plants

F1 parental phenotype: tall red flowered pea plant x tall red flowered pea plant

F1 parental genotype (2n): TtRr x TtRr

Meiosis

Gametes (n): TR, Tr, tR, tr | TR, Tr, tR, tr

	TR	Tr	tR	tr
TR	TTRR Tall & red	TTRr Tall & red	TtRR Tall & red	TtRr Tall and red
Tr	TTRr Tall & red	TTrr Tall & white	TtRr Tall & red	Ttrr Tall & white
tR	TrRR Tall & red	TtRr Tall & red	ttRR short & red	ttRr short & red
Tr	RtRr Tall and red	Ttrr Tall & white	ttRr short & red	ttrr short & white

F2 genotypic ratio: 9T_R_:3T_rr: 3ttR_:1ttrr

F_2 phenotypic ratio: **9** tall red flowered: **3** tall white flowered: **3** short red flowered: **1** short white flowered

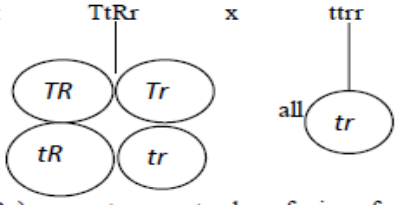
(c) By carrying out a test cross between F1 tall red flowered pea plant with short flowered pea plants

Test cross phenotypic ratio: 1 tall red flowered: 1 tall white flowered: 1 short red flowered: 1 short white flowered. This ratio proves that the F1 plants were heterozygous (TtRr).

Parental phenotype: tall red flowered pea plant x short whit flowered pea plant
Parental genotype: TtRr x ttrr

Parental genotype (2n): TtRr x ttrr

Meiosis



Gametes (n)

Test cross genotypes (2n): punnet square to show fusion of gametes to for genotypes and phenotypes

Punnett square to show fusion of gametes to form F_2 genotypes and phenotypes

	TR	Tr	tR	Tr
tr	TtRr Tall & red	Ttrr Tall & white	ttRr short & red	ttrr short and white

Test cross phenotypic ratio: 1 tall red flowered: 1 tall white flowered: 1 short red flowered: 1 short white flowered. This ratio proves that the F_1 plants were heterozygous (TtRr).

Note: in dihybrid inheritance, some of the offsprings formed in the F2 have a mixture of the two parental phenotypes that gave rise to F1 and such offsprings are known as recombinants while other offsprings in F2 resemble one of the two parental phenotypes that gave rise to F1 and such offsprings are known as parentals.

Recombinants arise when crossing over takes place during the formation of gametes in meiosis which leads to the mixing of the two parental characteristics. The number of recombinants in F2 is usually smaller than that of the offsprings which resembles the parental phenotypes (parental offsrpings). This is because crossing over occurs by chance which reduces the number of recombinants formed

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

9 tall red flowered: 3 tall white flowered : 3 short red flowered: 1 short white flowered
(parental offsprings) (recombinant offsprings): (parental offsprings)

- 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).

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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.

MODIFICATION OF 9:3:3:1 PHENOTYPIC RATIO

This ratio is mainly modified by the inheritance of lethal genes, linkage of genes and epistasis.

1. EPISTASIS:

This is a form of gene interaction in which one gene suppresses the effect of anther gene that is situated at a different locus on a chromosomes. Or

This refers to a condition in which non-allelic genes interact during which the epistatic allele of the epistatic gene on one locus suppress the phenotypic expression of the hypostatic allele of the hypostatic gene on another locus.

An epistatic allele is the one which suppresses the action of another allele in the phenotype though they are not located on the same locus and the suppressed gene or allele at another locus is the hypostatic one.

There are different types of epistasis which include the following;

- **Dominant epistasis**
- **Recessive epistasis**
- **Duplicate dominant genes**

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(a) Dominant epistasis (12: 3: 1):

This is the type of epistasis where the epistatic allele is dominant such that is presence suppresses the phenotypic expression of the recessive allele on another locus. This type of epistasis changes the phenotypic ratio from **9:3:3:1 to 12:3:1.**

When dominant allele 'A' masks the expression of 'B' 'A' is epistatic gene of 'B'. A can express itself only in the presence of 'B' or b allele. Therefore it is called dominant epistasis. B expresses only when 'aa' is present. Therefore, in **9: 3: 3: 1** ratio both 9 and 3 are expressing the 'A' gene the ratio is now **12: 3: 1.**

Example:

Complete dominance at both gene pairs, but one gene, when dominant, epistatic to the other.

Fruit colour in summer squash:

Gene pair A: White dominant to colour 12/16 white

AaBb × AaBb

white | white

♂ \ ♀	AB	Ab	aB	ab
AB	AA BB White	AA Bb White	Aa BB White	Aa Bb White
Ab	AA Bb White	AA bb White	AA Bb White	Aa bb White
aB	Aa BB White	Aa Bb White	aa BB Yellow	aa Bb Yellow
ab	Aa Bb White	Aa bb White	aa Bb Yellow	aa bb Green

AB-9 White, Ab- 3 White } 12 WHITE
aB- 3 Yellow
ab- 1 Green

Gene pair 'B' – Yellow dominant to green 3/16 yellow
Green – 1/16 both recessive **aabb**
Dominant white hides the effect of yellow or green.

(b) Recessive epistasis (9:3:4):
This is the type of epistasis where the epistatic allele is recessive, such that its presence in homozygous condition, suppresses the phenotypic expression of the dominant allele located on another locus. This type of epistasis changes the dihybrid phenotypic ratio from **9:3:3:1 to 9:3:4.**

Recessive alleles at one locus **(aa)** mask the phenotypic expression of other gene locus (BB, Bb or bb) such epistasis is called recessive epistasis. The alleles of 'B' locus express themselves only when epistatic locus 'A' has dominant allele like **AA or Aa.** The phenotypic ratio is **9: 3: 4.**

Example 1:
Complete dominance at both gene pairs, but one gene, when homozygous recessive, is epistatic to the other. In Mouse coat colour.
Gene pair **A:** coloured dominant over albino/white.
Gene pair '**B**' agouti colour dominant over black.
Interaction: homozygous albino is epistatic to agouti and black.
Agouti 9/16
Black 3/16
Albino 4/16

Agouti (Grey) × white albino
AABB ↓ aabb
Aa Bb × Aa Bb
Agouti Agouti

	AB	Ab	aB	ab
AB	AABB Agouti	AABb Agouti	AaBB Agouti	Aa Bb Agouti
Ab	AABb Agouti	AAbb Albino	AaBb Agouti	Aabb Albino
aB	AaBB Agouti	AaBb Agouti	aaBB Black	aaBb Black
ab	AaBb Agouti	Aabb Albino	aa Bb Black	aabb Albino

9 A_B_ = 9 Agouti
3 aaB_ = 3 Black
3 A_bb = 3 Albino } 4 albino
1 aabb = 1 Albino }

Aguoti: Black: Albino
9 : 3 : 4
9/16 3/16 4/16

Example 2
In oats the inheritance of color is controlled by the epistatic gene which has two alleles, one allele being dominant for color appearance while the other allele is for no color formation (white or albino) i.e. the hypostastic gene is responsible for color deposition or type of color. Where by black is dominant over white Consider a cross between homozygous black oat plant with a homozygous white oat plant and then the F1 plants are selfed to get F2.
a. Were out the phenotypic ratio of the F2 generation

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b. How many individuals are found in each of the phenotypic classes obtained in F2 if 130 individuals were found in F2?

Let G represent the allele for color formation (epistatic)
Let g represent the allele for no color formation (albino\ white)
Let B represent the allele for black
Let b represent the allele for grey

Parental phenotype: black oat plant x white oat plant

Parental genotype (2n): GGBB x ggbb

Meiosis

Gametes (n) all GB all gb

Fertilization

Offspring genotype (2n): GgBb

F_1 phenotype: all black oats

F_1 parental phenotype: Black oat plant x Black oat plant

F_1 parental genotype (2n): GgBb x GgBb

Meiosis

Gametes (n): GB, gB, Gb, gb | GB, gB, Gb, gb

Punnett square to show fusion of gametes to form F2 genotype and phenotypes

♂ \ ♀	GB	Gb	gB	gb
GB	GGBB Black oats	GGBb Black oats	GgBB Black Oats	GgBb Black oats
Gb	GGBb Black o	GGbb Grey o	GgBb Black o	Ggbb Grey oats
gB	GgBB Black o	GgBb Black	ggBB white oats	ggBb white oats
gb	GgBb Black o	Ggbb Grey o	ggBb Wite o	ggbb white oats

F_2 phenotypic ration: 9 black oats: 3 grey oats: 4 white oats.

Black oats= $\frac{\text{black oats}}{\text{total}} \times 480 = \frac{9}{16} \times 130 = 73.125$ plants = 73 plants

Grey oats= $\frac{\text{grey oats}}{\text{total}} \times 480 = \frac{3}{16} \times 130 = 24.375$ plants =24 plants

White oats= $\frac{\text{white oats}}{\text{total}} \times 480 = \frac{4}{16} \times 130 = 32.5$ plants =32 plants

Compiled by: Robert Bandikubi 077-2-582-857(watsup) /0704-728-546(roba3k@gmail.com)

(c) Duplicate recessive gene (9: 7):

If both gene loci have homozygous recessive alleles and both of them produce identical phenotype the F2 ratio 9:3:3:1 would be 9:7. The genotype **aaBB, aaBb, AAbb, Aabb and aabb** produce same phenotype. Both dominant alleles when are present together only then they can complement each other. This is known as complementary gene.

Examples:

Complete dominance at both gene pairs, but either recessive homozygote is epistatic to the effect of the other gene.

In sweet pea flower colour:

Gene **pair 'P'** – Purple dominant over white (**p**).

Gene pair 'C' – Coloured dominant over Colourless/white **(c).**

Interaction: Homozygous recessive of either gene A or B produce white

9/16 Purple
7/16 White
White flowers White flower
CCpp × PPcc
CcPp × CcPp
Purple Purple
CP = 9 Purple
Cp = 3 White
cP = 3 White
cp = 1 White
9 : 7
Purple White

	CP	Cp	cP	cp
CP	CCPP Purple	CCPp Purple	CcPP Purple	CcPp Purple
Cp	CCPp Purple	CCpp White	CcPp Purple	Ccpp White
cP	CcPP Purple	CcPp Purple	ccPP White	ccPp White
cp	CcPp Purple	Ccpp White	ccPp White	ccpp White

Example 2: Flowers in sweet pea plants are 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 white. If two plants heterozygous for both genes are crossed, what will be the phenotypic ratio of the offspring be? **(9:7)**

(d) Duplicate dominant genes (15:1):

If a dominant allele of both gene loci produces the same phenotype without cumulative effect, i.e., independently the ratio will be **15:1.**

Example:

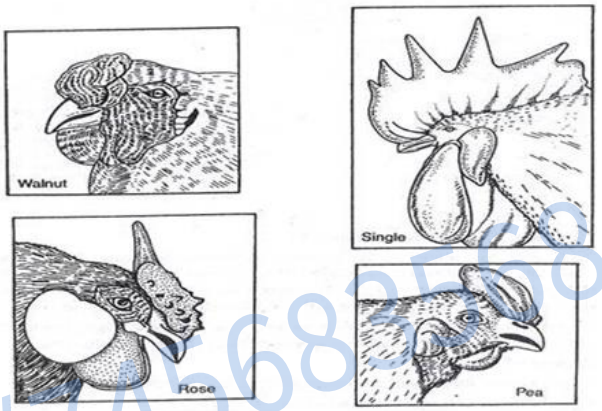
15/16 = Triangular
1/16 = ovoid (topshaped)
AABB × aabb
Triangular Ovoid
AaBb × AaBb
Triangular ↓
AB = 9 = Triangular
Ab = 3 Triangular
aB = 3 Triangular
ab = 1 Ovoid (top shaped)
15 : 1
Triangular : Ovoid

	AB	Ab	aB	ab
AB	AABB Triangular	AABb Triangular	AaBB Triangular	AaBb Triangular
Ab	AABb Triangular	AAbb Triangular	AaBb Triangular	Aabb Triangular
aB	AaBb Triangular	AaBb Triangular	aaBB Triangular	aaBb Triangular
ab	AaBb Triangular	Aabb Triangular	aaBb Triangular	aabb ovoid

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Complete dominance at both gene pairs, but either gene when dominant, epistatic to the other.
Seed capsule of shepherd's purse (Caps ell a bursa-pestoris)
Gene pair 'A': Triangular shape dominant over ovoid (**a**)
Gene pair 'B': Triangular shape dominant over ovoid (double recessive)

NON EPISTATIC INTER ALLELIC GENETIC INTERACTION:
In some cases two pairs of genes determine same phenotype but assorted independently, produce new phenotypes by mutual epistatic interaction. The F2 ratio remains the same as 9:3:3:1.
Example:
Each gene pair affecting the same character complete dominance at both gene pairs, new phenotypes resulting from interaction between dominants, and also from interaction between both homozygous recessives.



Gene Pair A: Rose comb dominant over non rose.
Gene Pair B: Pea comb dominant over non pea.
Interaction:
Dominant of rose and pea produce walnut comb. Homozygous recessive for rose and pea produce single comb.

Rose comb × Pea comb
AAbb (Rrpp) ↓ aaBB (rrPP)
× AaBb (RrPp AaBb(RrPp)
Walnut Walnut

	AB	Ab	aB	ab
AB	AABB Walnut	AABb Walnut	AaBB Walnut	AaBb Walnut
Ab	AABb Walnut	AAbb* Rose	AaBb Walnut	Aabb* Rose
aB	AaBB Walnut	AaBb Walnut	aaBb+ Pea	aaBb+ Pea
ab	AaBb Walnut	Aabb* Rose	aaBb+ Pea	aabb* Single

9/16 = Walnut
3/16 = rose
3/16 = Pea
1/16 = single
AB = 9 = Walnut
Ab = 3 = Rose
aB = 3 = Pea
ab = 1 = Single

9 : 3 : 3 : 1
Walnut Rose Pea Single

According to Bateson and Punnett such result is obtained because by combination of homozygous recessive **genes (bb)** and a homozygous or heterozygous dominant **AA or Aa** the Rose comb is produced; and by combination of homozygous **recessive (aa)** and homozygous or heterozygous dominant condition

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BB or Bb produce pea comb while the single type comb is produced by double recessive **aabb genes. 'A'** gene determines the shape of rose comb and 'B' gene determines the shape of Pea comb, but when both genes combine a new shape Walnut appears. In the cross between two types of Walnut chickens 4 phenotypes appear. The genes here do not determine themselves in the development of character but modify the character determined by a basic gene. These genes are called supplementary or modifying genes.

INHERITANCE OF COMPLEMENTARY GENES

These are two or more genes which interact together in order to control a single characteristic in an organism.

Inheritance of these genes therefore does not agree with Mendel's laws of inheritance. Although these genes control a single characteristic, they show independence assortment. Therefore these genes are passed on from the parents to the offspring in a normal Mendelian fashion. The best example of complementary genes is genes which control the shape of combs in chicken.

In chicken there are four types of combs namely;

i. walnut comb
ii. Single comb
iii. Pea comb
iv. Rose comb

These four types of combs are controlled by the two genes located at two loci situated on different chromosomes and which interact together to give rise to the four comb types. The shape of the combs is controlled by two genes which are represented by two alleles shown below;

Let **P** represent the allele for **pea** comb

Let **R** represent the allele for **rose** comb

The pea comb develops in the presence of the **P**-allele and in the absence of the **R-allele** while the rose comb develops phenotypically in presence of **R**-allele and in the absence of the **P**-allele. When both alleles, **P and R,** are present together a walnut comb develops. A single comb appears only in the homozygous double recessive condition

Consider a cross between a pea comb shaped cock with a rose combed hen whose F1 offspring are then selfed. What is the phenotypic ratio obtained in F2?

Parental phenotype: pea combed cock x rose combed hen

Parental genotype (2n): *PPrr* x *ppRR*

Meiosis

Gametes (n) *all* *Pr* *all* *pR*

Fertilization

Offspring genotype (2n): *PpRr*

F_1 phenotype: all walnut combed chicken

F_1 parental phenotype: walnut combed chicken x walnut combed chicken

F_1 parental genotype (2n): PpRr x PpRr

Meiosis

Gametes (n) PR pR Pr pr PR pR Pr pr

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Punnett square to show fusion of gametes to form F_2 genotypes and phenotypes

O^+\ O	PR	Pr	pR	Pr
PR	PPRR Walnut comb	PPRr Walnut comb	PpRR Walnut comb	PpRr Walnut comb
Pr	PPRr Walnut comb	PPrr Pea comb	PpRr Walnut comb	Pprr Pea comb
pR	PpRR Walnut comb	PpRr Walnut comb	ppRR rose comb	ppRr rose comb
pr	PpRr Walnut comb	Pprr Pea comb	ppRr rose comb	pprr single comb

F2 genotypic ratio: 9P_R_:3P_rr: 3ppR_:1pprr

F2 phenotypic ratio: 9 walnut combed: 3 pea combed: 3 rose combed: 1 single combed

In this inheritance, the genes are usually situated at different loci at different chromosomes from where they interact together and give rise to four distinct phenotypes for a single characteristic.

The walnut comb results from a modified form of co-dominance in which at least one dominant allele of either pea comb or rose comb is present.

This is an incidence where by a 9:3:3:1 phenotypic ratio is obtained for a single characteristic. Although this ratio is this pattern of inheritance differs from the hybrid inheritance because;

a. The F1 progeny (offsprings) resembles neither parents i.e. they are all walnut comb shaped unlike their parents.

b. The F2 progeny also contains two new phenotypes which do not exist in the F1 parents namely walnut and a single comb shaped and these appear in a higher ratio as compared to the rose and the pea comb

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2. LINKAGE

Linked genes are more than two genes located on the same chromosome but controlling different characteristics and are inherited together as a single black.

Linkage is the occurrence of more than one gene on the same chromosome which are inherited together along with the chromosome as a single block. Or

Linkage is the existence of genes determining different characteristics on the same chromosomes such that the two are inherited together.

TYPES OF LINKAGE

1. Total/Complete linkage

This is a condition where two or more genes are located so close to each other on a chromosome that they are inherited together since they pass to the same gamete. No genetic recombination occurs between them. **(No crossing over)**

2. Incomplete linkage

Condition where two or more genes are located relatively further apart on the same chromosome that during crossing over, new genetic recombination occur between them. These genes may not be inherited together.

Linked characteristics are the ones controlled by genes located on the same chromosome and so are transmitted together with the chromosome from generation to generation.

Although these genes occur on the same chromosome, each one controls the specific characteristic irrespective of the other. However, linked genes do not show independent assortment during gamete formation and therefore the phenotypic ratio obtained in F2 **is 3:1** instead of the **expected 9:3:3:1** for the two linked characteristics.

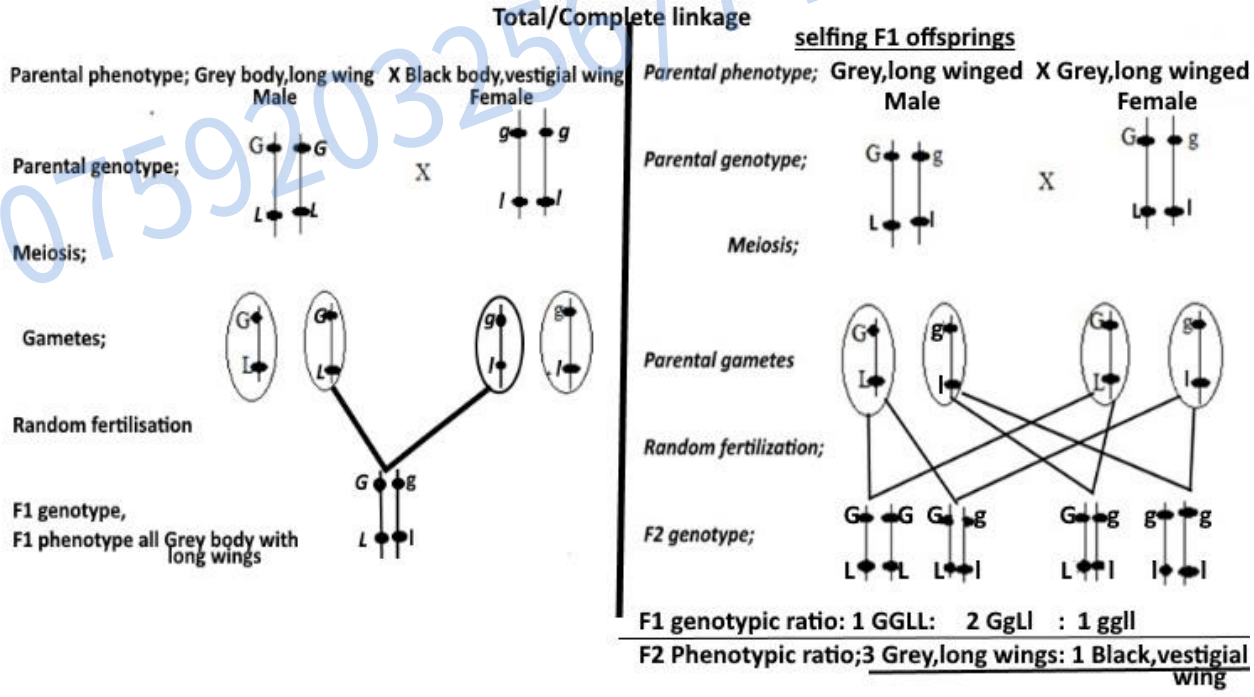
Sometimes crossing over occurs, thereby separating the linked genes on the chromosomes leading to the formation of recombinant gametes during meiosis and this gives an F2 phenotypic ratio of 9:3:3:1 for the linked characteristics.

Total/complete linkage is when the distance between linked genes is not sufficient to allow for successful crossing over.

Example

In drosophila flies the genes controlling body color and the length of wings occur on the same chromosomes and are linked together. Consider a cross between a pure breeding grey bodied long winged fly with a black bodied vestigial winged fly whereby the grey bodied is female while the black bodied is female. If all the F1 flies obtained here grey bodied and long winged what are the phenotypic and genotypic ratios of the F2 flies

Let G represent the allele for grey body
Let g represent the allele for black body
Let L represent the allele for long wings
Let l represent the allele for vestigial wings.



Phenotypic ratio 3 grey bodied long winged flies: 1 black bodied vestigial winged fly

The above results are correct if **no crossing over** during gamete formation.

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In case the genes are not completely linked together and **chromosome crossing over** can occurs between the non - sister chromatids so as to produce recombinant gametes and this gives a phenotypic ratio in F2 of the **9:3:3:1** as shown below.

F2 genotypes: punnet square to show fusion of gametes

F1 SELFED AND CROSSING OVER OCCURED

♀ \ ♂	GL	Gl	gL	gl
GL	GGLL Grey body,long wings	GGLl Grey body,long wings	GgLL Grey body,long wings	GgLl Grey body,long wing
Gl	GGLl *Grey body,long wings*	GGll *Grey body,vestigial*	GgLl *Grey body,long wing*	Ggll *Grey body,vestigial*
gL	GgLL *Grey body,long wings*	GgLl *Grey body,long wings*	ggLL *Black body,long wing*	ggLl *Black body,long wing*
gl	GgLl *Grey body,long wing*	Ggll *Grey body,vestigial*	ggLl *Black body,long wing*	ggll *Black body,vestigial*

9 Greybody,long wings: 3 Grey body,vestigial wings: 3 Black body,long wings: 1 Black body,vestigial wings

F2 phenotypic ratio: 9 grey body long winged flies: 3 grey body vestigial winged flies: 3 black body long winged flies: 1 black body vestigial winged flies.

Two or more genes are said to be linked if recombinant phenotypes occur much less frequently than parental phenotypes.

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**.

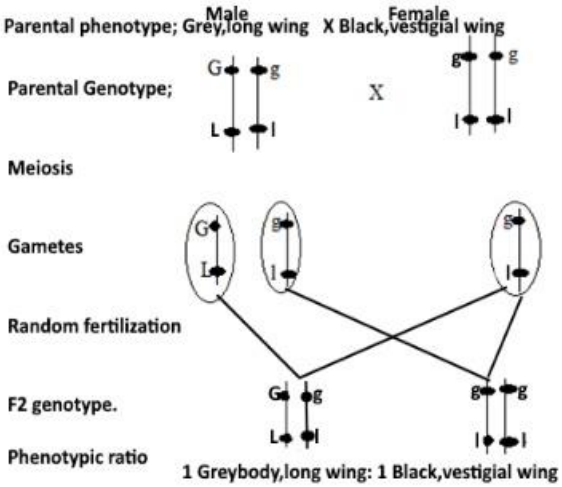
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To his disappointment; even after performing the test cross several times, Morgan never obtained the predicted outcomes. He instead obtained approximately equal numbers of the parental phenotypes with significantly few recombinant phenotypes also in approximately equal numbers as summarised below.

41.5% grey, long winged
41.5% black, vestigial winged
8.5% grey, vestigial winged
8.5% black, long winged

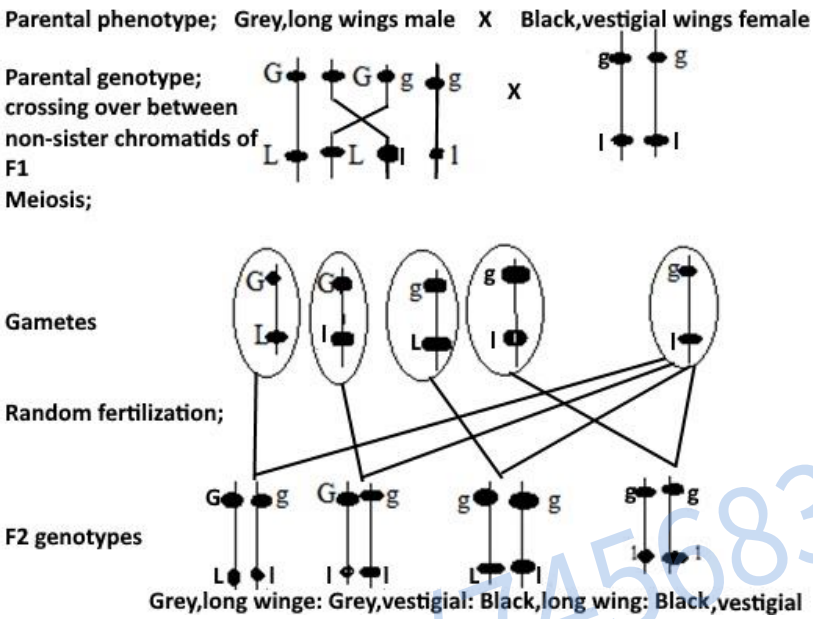
Total/complete linkage

F1 hybrid Test crossed



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.

Test cross between F1 Male and homozygous recessive Female fly



CROSSOVER VALUE AND CHROMOSOME MAPS

The recombinant gametes are formed by crossing over between non-sister chromatids in meiosis I. Such recombinant gametes lead to recombinant offsprings in the phenotypes. Recombinant gametes and recombinant offsprings occur in lower numbers compared to the parental gametes and parental offsprings because crossing over occurs by chance. The percentage of recombinant offsprings in the progeny (total number of offsprings) gives a cross over value which indicates the relative distance between the genes on the chromosomes and the likely hood of undergoing crossing over.

Cross over value (C.O.V) =number of recombinants x 100

Total number of offsprings

The distance between genes on the chromosome is measured in arbitrary units known as map units.

1 map unit = 1 cross over value (C.O.V)

The larger the **C.O.V**, the more separated the two genes are on the chromosomes and the higher the chances of crossing over taking place. The illustration of the distance between the genes on the chromosome gives the chromosome map i.e. a figure that shows a relative distance between the genes on the same chromosomes. The illustration of distance between the genes on the chromosome is the chromosome map.

Example 1: In drosophila flies the genes controlling **body color** and **eye color occur** on the same chromosome and are linked together. In an experiment, a heterozygous female fly for **grey body and**

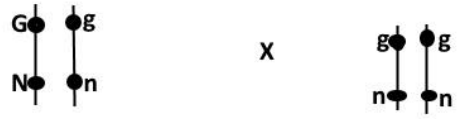
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normal eyes was crossed with a **black body and purple eyed fly**. In these flies, grey body is dominant over black while normal eyes are dominant over purple flies.

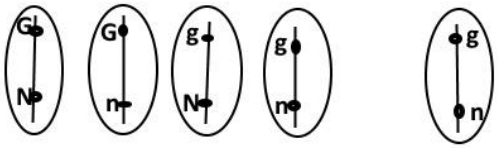
Let **G** represent allele fro grey body; let **g** represent allele for black body

Let **N** represent allele for normal eye colour; let **n** represent allele for purple eye colour

Parental phenotype; Grey body,normal eyed fly X Black body,purple eyed fly

Parental genotype; 

Meiosis;

Gametes; 

Test cross genotype: punnet square to show fusion of gametes **Random fertilisation**

♂ \ ♀	GN	Gn	gN	gn
gn	GgNn Grey,normal eyes	Ggnn Grey,purple eyes	ggNn Black,normal eyes	ggnn Black,purple eyes

Test Cross phenotypic ratio

1 grey normal eyed fly: 1 grey purple eyed: 1 black normal eyed: 1 black purple eyed.

If 1000 offsprings were obtained from this cross s as shown in the table below;

Expected number	Phenotype	Genotype	Number obtained
250	Grey, normal eyes	GgNn	480
250	**Grey, purple eyes**	**Ggnn**	**18**
250	**Black, normal eyes**	**ggNn**	**17**
250	Black, purple eyes	Ggnn	485

The obtained results in the test cross differ from the expected ones because the genes are linked together on the chromosomes and were separated by crossing over which occurs by chance hence resulting into formation of fewer recombinants compared to the parents.

$$\text{Cross Over Value(C.O.V)} = \frac{\text{Number of recombinants}}{\text{Total number of offsprings}} \times 100$$

$$= \frac{18+17}{1000} \times 100$$

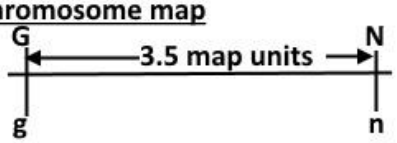
$$= \frac{35 \times 100}{1000}$$

$$\text{C.O.V} = 3.5\%$$

Therefore 3.5% of 3.5 map units

1 C.O.V =1 Map unit

Chromosome map



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Example 2: Further experiment on these flies indicated that the genes for body color, length of wings and eye color are on the same chromosomes. Using the information in the table below calculate the cross over value and illustrate the distance between the genes.

Expected number	Phenotype	Genotype	Number obtained
250	Grey body, long wing	GgLl	400
250	**Grey body, vestigial wing**	**Ggll**	**95**
250	**Black body, long wing**	**ggLl**	**105**
250	Black body, vestigial wing	Ggll	400

Cross Over Value(C.O.V) = $\frac{\text{Number of recombinants}}{\text{Total number of offsprings}} \times 100$

$= \frac{95+105}{1000} \times 100$

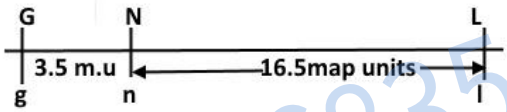
$= \frac{200 \times 100}{1000}$

C.O.V = 20%

Therefore 20% of 20 map units

1 C.O.V =1 Map unit

Therefore new chromosome map



NOTE: Drawing the chromosome map is also called gene mapping where the position of genes are shown on the chromosomes as well as the distance separating with them. Sometimes it is possible to indicate many genes on chromosome and their distances of separation.

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-P = 14%

R-S = 8%

S-P = 6%

Draw the chromosome map to show the position of these chromosomes.

- Insert the positions of the genes with the smallest cross over value in the middle of the chromosome map.
- Examine the next largest cross over value and insert both possible positions of its genes on the chromosomes relative to either S or P.
- Repeat the procedure for all the remaining cross over values until you reach the largest cross over values.

FACTORS THAT AFFECT CROSSING OVER

1) The relative distance between the genes on the chromosome. When the genes are far apart from each other on the chromosome, they have high chances of forming chiasmata in between thereby leading to genetic exchange on the other hand when genes are very close to each other on the chromosome, their chances of forming chiasmata is limited.

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2) The position of the centromere on the chromosome. If the genes are very close the centromere there chances of undergoing genetic exchange are limited. However, if the genes are far away from the centromere, there are high chances that they can be exchanged by crossing over.

3) Temperature. Crossing over decreases with increase in temperature because the process of meiosis requires suitable temperature that can promote efficient crossing over.

4) Age of the organism. Increase in age lowers the chances of crossing over. Meiosis is more efficient in grown up adults before menopause stage in females and before senescence in male.

5) Mutagens. These can decrease or increase the rate of crossing over. The chances of crossing over are greatly reduced by presence of chemical substances that inhibit chiasmata formation thereby preventing cross over e.g. in drosophila flies.

INHERITANCE OF SEX

The sex of an organism is determined by two factors namely; environmental conditions and genetic factors.

Environmental determination of sex

In lower animals, sex can be determined by environmental factors such as temperature, salinity, type of food e.t.c. for example in tadpoles the eggs laid in cool places develop into males while those laid in warm places develop into females.

Genetic sex determination

The sex organs development can be determined by the sex genes or the chromosomes. Under chromosomal sex determination, sex can be determined by;

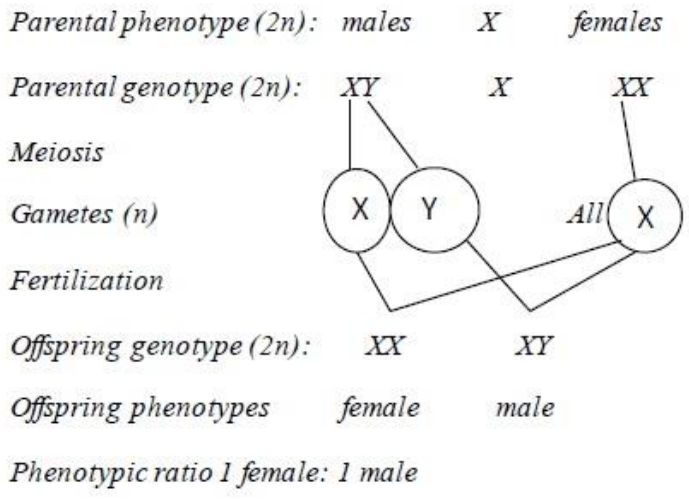
a. The number of chromosomes. e.g. in bees the females are diploid and have 32 chromosomes while the males are haploid and have 16 chromosome. In grasshoppers the females have 24 chromosomes while the males have only 23 chromosomes.

b. The sex chromosomes. In heterogametic organisms there are two sex chromosomes that determine the sex of an individual namely the X and Y chromosomes e.g.

The females are XX and are described as homogametic while the males are XY and are described as heterogametic. Therefore in these organisms it is the presence of the Y chromosome that makes one a male and its absence makes one a female. This implies that it is the type of sperm (whether X or Y) that fertilizes the egg which determines the sex of the offspring.

In birds sex is determined by the X and Y chromosomes except that the females are XY while males are XX.

In grasshoppers sex is only determined by X chromosomes where by the males are XO i.e. they lack only one X chromosome while the females are XX.



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SEX LINKED CHARACTERISTICS

This is the transmission of characteristics (from parents to offsprings) whose genes are located on the sex chromosomes i.e. the genes controlling such a character are transmitted along with those that determine sex on the same chromosome.

Most sex linked characters are controlled by genes located on the X chromosome and very few are controlled by genes located on Y chromosome. Examples of sex-linked characteristics include; haemophilia, Red-green colorblindness, brown teeth, **Duchenne muscular dystrophy (muscular weakness, the disease typically affects boys)** e.t.c.

Sex linked characteristics can therefore be defined as those whose genes controlling them occur on the sex chromosome and yet they do not determine sex.

Sex linked characters are often expressed more in males than females. This is because the males being heterogametic have a non-homologous portion of the X chromosome while the sex linked allele is located and therefore such an allele cannot be suppressed in the phenotype by any other dominant allele. The condition.

WHY SEX-LINKED TRAITS ARE MOST COMMON IN MALES AMONG HUMANS

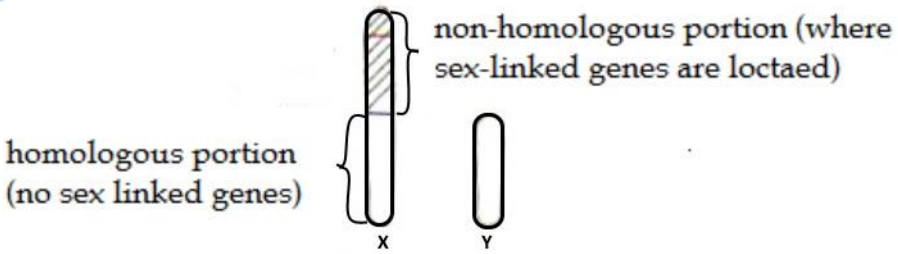
In humans, males have one **X** chromosome and one **Y** chromosome, while females have two X chromosomes.

Most sex-linked traits are determined by recessive genes, carried on the non-homologous portion of the X chromosome, for which the Y chromosome is genetically empty.

In males a recessive allele on the X chromosome is expressed phenotypically, because the Y chromosome cannot carry the dominant allele.

In females a recessive allele on one X chromosome is usually masked/suppressed by the dominant allele on the other X chromosome, such heterozygous females are carriers and phenotypically normal.

Females only express that trait phenotypically in the double recessive state when the recessive allele is present on each of the two X chromosomes. But since the recessive alleles determining sex-linked traits are rare in human populations, this is quite unlikely to occur.



This implies that the genes of the sex linked characters of the males are located in the non-homologous portion and therefore whenever a recessive allele of these characters appears, it has to be expressed in the phenotype since it does not have a counterpart allele that can suppress its phenotypic expression.

In the case of females, the **X** chromosomes are completely homologous to each other and this gives chances of development of carrier females (heterozygous females) for sex linked characters who may never express the characteristic in the phenotype as the recessive sex linked allele would be suppressed by the dominant allele on the counterpart X chromosome.

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Sex linked characters are determined by recessive alleles. However sex linked characteristics undergo a characteristic cross pattern of inheritance i.e. the fathers transmit there sex linked characters to their grandsons through their daughters who are carriers this implies that the father will not transmit the sex linked character to his sons but instead to his daughters. This is because the son only inherits the father's Y chromosome and not the X chromosome that controls the sex-linked characteristics.

Although sex linked characters are mostly carried on the X chromosome there are a few of them which are carried on the Y sex chromosome and these are called holandric characters i.e. development of many hairs in the nostrils and ears.

Why there are more colour-blind individuals than haemophiliacs.

Haemophilia is potentially lethal and therefore is selected against as it has a calling effect sufferers being less likely to survive to sexual maturity and so produce off spring. Colour blindness is not lethal and thus not selected against; sufferers survive to sexual maturity and produce offspring.
Haemophiliacs may choose not to have children knowing the fata risk that their offspring may suffer the disease. Colourblind individuals freely produce children as there is no special risk associated with being colour-blind.
Haemophiliac females rarely survive to child-bearing age due to the special risk associated with menstrual bleeding; hence only carrier females pass on the disease. With colorblindness both (female) sufferers and carriers can pass on the condition

Worked examples

Consider a normal man who marries a female whose father was having haemophilia and the mother was homozygous normal. Using suitable genetic symbols, workout the phenotypes and genotypes of their offsprings. What is the probability that this couple will produce a haemophilic boy?

Parental phenotype: haemophiliac father X Non haemophiliac mother

Parental genotype (2n) X^hY *X* X^HX^H

Meiosis

Gametes X^h Y *all* X^H

Fertilisation

Offsprings genotype X^HX^h X^HY

Parental phenotype: normal man X carrier woman

Parental genotype (2n) X^HY *X* X^HX^h

Meiosis

Gametes X^H Y *all* X^H X^h

Fertilisation

Offsprings genotype X^HX^h X^HX^H X^HY X^hY

Let **H** represent allele for non haemophillic (normal condition)
Let **h** represent allele for haemophilic/abnormal blood clotting.
Offsprings phenotype: normal girl: normal girl: normal boy: haemophiliac boy
Offsprings phenotypic ratio 3 normal: 1 haemophiliac
Male phenotypic ratio; 1 normal: 1 haemophiliac

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Probability = 1/2

Note: Haemophilia is a condition whereby blood takes too long to clot after an injury leading to excessive bleeding of the victim. This makes hemophiliac individuals rear in population as most of them die before reproductive age.

Colour blindness is a condition whereby an individual fails to see the colours or fails to distinguish between particular colours e.g. red, green colour blindness where the red and green cone cells of the eye retina are defective due to some sex linked gene in an individual which does not allow such an individual to distinguish between red and green. Colour blind individuals are more common in the population than haemophiliacs because haemophiliacs have higher chances of dying before reaching reproductive age to pass on their genes to the next generations whereas colour-blind individuals survive and reach reproductive age in most cases which enables them to reproduce and pass on their gene of colour blindness to the next generation which increases their number in the population. Besides, haemophiliac people may bot choose to marry due the lethal gene they have, thereby becoming unable to pass on their genes to the next generation.

SEX LIMITED AND SEX INFLUENCED CHARACTERISTICS

Sex limited characteristics are the ones which occur particularly in one sex. These characteristics occur at a later stage in the life of an organism e.g. in human beings they normally occur at puberty.

In human beings the males have the following sex limited characteristics beard, deep voice, hairs in the ears and nostrils, porcupine characteristics e.t.c. In human females these characteristics include development of breasts, widening of the hip girdles e.t.c.

Sex influenced characteristics are those whose dominancy is determined by the sex of the bearer e.g. baldness of the head occurs in males and not in females because the genes determining it are dominant in males and recessive in females.**MULTIPLE ALLELES**

Multiple alleles is a set of more than two alleles at a single locus on a chromosome that determine a single character. It's another form of co-dominance.

Examples of characteristics controlled by multiple alleles include;

a. Blood groups in humans

b. Coat color in rabbits

Full coat colour **(C)** is dominant to Chinchilla coat (c^{ch}), which is dominant to Himalayan coat (c^{h}), which is dominant to albino allele (**c**). So order of dominance is:

Characteristic	Allele	Phenotypes	Possible genotypes
Full coat colour	**C**	Heterozygous for full coat	**Cc^{ch}, Cc^{h}, Cc**
Chinchilla coat	**c^{ch}**	Heterozygous for chinchilla coat	**$c^{ch}c^{h}$, $c^{ch}c$**
Himalayan coat	**c^{h}**	Homozygous for Himalayan coat	**$c^{h}c^{h}$**
Albino	**c**	Homozygous albino	**cc**

c. Eye color in rabbits and mice

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Inheritance of ABO blood system

The ABO blood group system is controlled by three alleles of a gene I (isohaemogglutinogen) occur at a single locus any time. These alleles are A or IA, B or IB and O or IO. These alleles IA and IB are equally dominant while the allele. IO is recessive to both.

The transmission of thee alleles occurs in a normal Mendelian fashion.

The table below summarizes the possible phenotype and blood group.

GENOTYPE	PHENOTYPE
I^AI^A (AA)	Blood group A (homozygous)
I^AI^O (AO)	Blood group A(heterozygous)
I^BI^B (BB)	Blood group B
I^BI^O (BO)	Blood group B
I^AI^B (AB)	Blood group AB (co-dominant)
I^OI^O (OO)	Blood group O

Inheritance of ABO blood groups in man

ABO blood groups are determined by the multiple alleles **A, B, and O**, of an autosomal gene, whose locus is represented by the symbol I for Isohaemagglutinogen, whereby alleles A and B are equally dominant, while o is recessive to both A and B.

Inheritance of any of the following allelic combinations via fertilization, results in possession of any of the four blood groups; A, B, AB and O.

Blood group A is determined by inheritance of genotype **I^AI^A or I^AI^O** through fertilization, determining production of antigen/agglutinogen A on the red blood cell/erythrocyte cell membrane, and possession of agglutinin anti-B/antibody b in plasma.

Blood group B is determined by inheritance of genotype **I^BI^B or I^BI^O** through fertilization, determining formation of antigen/agglutinogen B on the erythrocyte cell membranes, and possession of agglutinin anti-A/**antibody a** in plasma.

Blood group AB is determined by inheritance of genotype **I^AI^B** through fertilization, determining formation of antigens/agglutinogens **A and B** on the erythrocyte cell membranes, and absence of agglutinins in plasma.

Blood **group O** is determined by inheritance of genotype **I^OI^O** through fertilization, determining absence of agglutinogens on the erythrocyte cell membrane, and possession of both **agglutinins a and b** in plasma.

Physiology of the blood groups in humans

Human blood contains blood group antigens and blood group antibodies. Some of these specifically determine blood groups e.g. allele A determines the production of antigen **A, allele B** determines the production of antigen B and allele O does not code for the production of any antigens. Antigens **A** and B occur on the plasma membranes of red blood cells. These antigens have corresponding protein molecules known as blood group antibodies (agglutinins) in blood plasma. These antibodies can react with the antigens under the lock and key hypothesis should they be similar to the antigens brought into the recipient's blood, leading to the formation of a precipitate or an agglutinate in blood.

Therefore an individual should not have blood group antibodies corresponding or similar to his blood group antigens in order to avoid agglutination. Consequently, individuals should have the following antibodies not corresponding to their antigen to avoid blood clotting.

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Blood group	A	A	B	B	AB	O
Antigen	A	A	B	B	AB	None
Antibody	A	A	B	b	None	a and b

Example

1. A man having blood A marries a woman having blood group AB. What are the possible genotypes and phenotypes of their offsprings if the man is heterozygous for blood group A?

Let I^A represent the allele for formation of antigen A

Let I^B represent the allele for formation of antigen B

Let I^O represent the allele for no formation of antigen A or B

Parental phenotype: blood group A x blood group AB

Parental genotype (2n): I^AI^O X I^AI^B

Meiosis

Gametes (n) I^A I^O I^A I^B

Offspring genotype (2n): I^AI^A I^AI^B I^AI^O I^OI^B

F2 genotypic ratio: $1I^AI^A: 1I^AI^B: 1I^AI^O: 1I^OI^B$

F_2 phenotypic ratio: 2 blood group A: 1blood group AB: 1blood group B

The importance of blood groups

They are important during blood transfusion where they are used to prevent agglutination (precipitation) of blood of the recipient. To avoid agglutination, the donors blood group should be compatible (matching with) to that of the recipient by having the donors blood group antigen that is different from the blood group antibody of the recipient.

When the recipient's gets antibodies from the donor, such antibodies become diluted in the recipient's blood and so cause either minor clotting of blood or no blood clotting at all and so cannot lead to death of the recipient. However, in case the donor introduces an antigen that is similar to the antibody of the recipient, it stimulates the recipient's blood to produce more antibodies which attack and react with the donor's antigen to cause severe blood clotting. Therefore an individual with a specific antigen on the red blood cell membrane does not possess its corresponding antibody in the blood plasma to avoid agglutination.

Blood plasma permanently contains two blood group antibodies a and b which do not correspond with a specific antigen in blood to avoid agglutination e.g. a person with blood group A has antigen A and antibody to avoid agglutination. A person with blood group B cannot donate blood to a person of blood O because antigen B in the donor's blood will be attacked by antibody b in the recipient's blood leading to agglutination. The same applies to blood group A and blood group AB donors to blood group O recipients.

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It is possible for blood group A to donate blood to blood AB, because the donors blood, blood group A, has antigen A which cannot stimulate the recipient's blood group AB to attack antigen A since blood group AB individuals lack antibodies that can attack antigen A to cause an agglutination.

A person of blood group AB cannot donate blood to a person of blood group O. This is because the donor's blood has antigen A and antigen B, which stimulate the recipient's blood to produce corresponding antibodies a and b, which then attack and react with antigen A and B in the recipient's blood.

Blood group AB individuals can receive blood from all other individuals having other blood groups. Therefore individuals with blood group AB are called universal recipients. This is because such individuals have no antibodies in their blood plasma that can react with antigens A and B in the donor's blood.

Individuals with blood group O can donate blood to all other blood groups and are therefore called universal donors.

This is because blood **group O individuals** do not have any antigens in their red blood cells that can react with antibodies in the blood plasma of the recipient to cause agglutination. The table below summarizes the possible and impossible blood transfusions.

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 occurs

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b. They are used in settling court cases about who the father of the child is (i.e. paternity suits). Although blood groups cannot prove below reasonable doubt who the father of the child is it is possible to use their inheritance to show that an individual could possibly by the father of the child.

Consider a mother who is of blood group O having child of blood group O and the child produced also with blood group O. she claims that the father is a man whose blood group is AB. Since the child is blood group O its only possible genotype is $\mathbf{I^OI^O}$ and it must therefore have inherited one $\mathbf{I^O}$ allele from each parents. Since the man is of blood group AB he cannot donate the I^O to the child and therefore he cannot be the father of the child. Even if the father was found to be of another blood group such as blood group A still the evidence will be insufficient because any other man can possess such a blood group and donate the IO allele to the child. Therefore a DNA test should be carried out to confirm who the father of the child is.

c. Blood groups can also be used as an evidence of evolution. This is because organisms of different species having similar blood group systems such as the ABO system are believed to have originated from the same ancestor in the course of evolution for example humans, chimpanzees, gorillas, Baboons e.t.c.

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+)** however **Rh+** allele is taken to be dominant over the rhesus negative (Rh-) allele. The Rhesus factor is controlled by three alleles C, D and E which determine the production of D-antigens on the surface of the red blood cells. Allele mainly determines the production of D-antigens and it is this antigen which is the fundamental determinant of blood grouping under the rhesus blood group system.

Marriage complications of the Rhesus system

If an Rh+ man marries an Rh- woman, most of their children are likely to die immediately after birth or before birth. 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 feotus to cause death. If a mother becomes pregnant after the first child, the Rh+ feotus formed can die due to antibodies of the mother entering the foetal circulation. This is because during the first pregnancy, especially the time of giving birth, the blood of the child which is Rh+ may mix with that of the mother which is Rh-, thereby introducing D-antigens in the mother's blood. Also, some of foetal erythrocytes of the first child with D-antigens in them may cross the placenta and enter the body of the Rh- mother towards the end of the gestation period. D-antigens will then stimulate the mother's blood to produce many antibodies called anti D-agglutinins which attack and react with the D-antigens introduced in the mother's blood if the mother becomes pregnant again and the child is Rh+. These antibodies in the mother's blood will pass via the placenta and enter the foetal blood circulation, where they will attack and react with D-antigens in the child's blood causing the red blood cells of the child to calmp together, this dieases is known as **heamoltyic disease of the new born** (erythroblastosis foetalis). This results into acute anaemia of the foetus which can lead to death of the foetus.

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.

Another blood group system in humans called the MN blood group system is controlled by 2 alleles **M and N** which are co-dominant. M and N alleles also determine the production of antigens respectively. Individuals therefore have the following genotypes if this blood group system **MM, NN, MN.**

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.

Genes and Chromosomes

Each of us has a unique set of chemical blueprints affecting how our body looks and functions. These blueprints are contained in our DNA (deoxyribonucleic acid), long, spiral-shaped molecules found inside every cell. DNA carries the codes for genetic information and is made of linked pieces (or subunits) called nucleotides. Each nucleotide contains a phosphate molecule, a sugar molecule (deoxyribose), and one of four so-called "coding" molecules called bases (adenine, guanine, cytosine, or thymidine). The order (or sequence) of these four bases determines each genetic code.

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The segments of DNA that contain the instructions for making specific body proteins are called genes. Scientists believe that human DNA carries about 25,000 protein-coding genes. Each gene may be thought of as a "recipe" you'd find in cookbook. Some are recipes for creating physical features, like brown eyes or curly hair. Others are recipes to tell the body how to produce important chemicals called enzymes (which help control the chemical reactions in the body).

Along the segments of our DNA, genes are neatly packaged within structures called chromosomes. Every human cell contains 46 chromosomes, arranged as 23 pairs (called autosomes), with one member of each pair inherited from each parent at the time of conception. After conception (when a sperm cell and an egg come together to make a baby), the chromosomes duplicate again and again to pass on the same genetic information to each new cell in the developing child. Twenty-two autosomes are the same in males and females. In addition, females have two X chromosomes and males have one X and one Y chromosome. The X and the Y are known as sex chromosomes.

Human chromosomes are large enough to be seen with a high-powered microscope, and the 23 pairs can be identified according to differences in their size, shape, and the way they pick up special laboratory dyes.

VARIATION

This is the description of the differences in phenotypic and sometime genotypic characteristics shown by organisms belonging to the same species or natural population due to interaction between the genes and the environment.

Variations can be clearly seen among sexually reproducing organisms due to some differences in genetic constitution that occur during meiosis.

Variations are important because they make organisms better adapted to their environment. This is because some variations within the population are favourable (beneficial) to the organisms possessing them making such organisms better adapted or fit to survive in their environment and this gives a selective advantage to those organisms possessing them. Other variations are unfavourable because they are disadvantaged in the environment and organisms possessing such. The first organisms therefore survive, grow and reproduce and pass on their favourable characteristics to the next generation. If this continues for a long time it leads to the emergency of new species in the population having good characteristics and therefore better adapted to the environmental change. Variation is therefore a raw material for evolution during which new species are formed.

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Importance of variation

- To identify and distinguish individuals
- To ensure the survival of a species. Variation introduces differences in an organism which may cause it to be better suited to adapt to changes in the environment.

Examples of variation in humans:

- Height -weight - shape of nose - dimples - eye colour - blood group

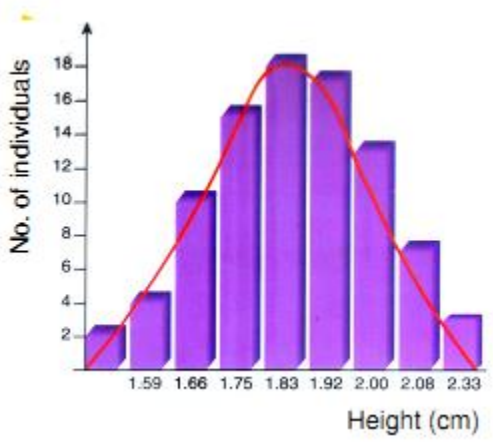
- Skin colour - finger print - ability to roll the tongue - type of ear lobe

Variation can be due to genetic factors, environmental factors or the interaction of both genetic and environmental factors.

TYPES OF VARIATION

There are two types of variation namely;

- Continuous variation
- Discontinuous variation



Continuous variation

This is the type of variation whereby characteristics in a given population show a smooth gradation between two offsprings with the intermediate phenotype being the majority in the population and few individuals being at the extremes of the characteristics. This implies that organisms do not show any clear cut differences among themselves.

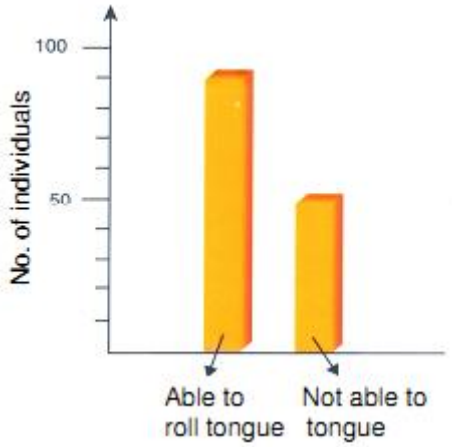
***Characteristics of continuous* Variation**

- They are influence of many genes but can also be influenced by environmental factors.
- They show no clear cut differences among organisms
- its quantitative (its measurable
- They are influenced by both environmental conditions and genetic factors.
- Off springs with the intermediate phenotype being the majority in the population and few individuals being at the extremes of the characteristics.

Examples of **continuous variation** characteristics include **skin color, height, weight, intelligence** e.t.c. These characteristics are quantitative i.e. they can be measured and are controlled by many genes. These characteristics are therefore described as polygenic characteristics i.e. characteristics which are controlled by a number of genes during their transmission i.e. many genes control a single characteristic. These genes are sometimes referred to as multiple genes. Although these genes may determine a single characteristic each of them has its own alleles which occur on different loci.

The transmission of x-tics that are controlled by many genes from one generation to another is called **polygenic** inheritance and such characteristics are known as polygenic characteristics. The statistical analysis of these characteristics gives a normal distribution curve shown below;

The above graph shows that continuous variation characteristics appear in the graded pattern and therefore show a smooth graduation. It also shows that most of the individuals in the population lie along the normal.



Discontinuous variation

This is the type of variation where individuals show clear cut differences among themselves in the population with no intermediate phenotypes between them but instead they are grouped into distinct categories. These characteristics are therefore qualitative and cannot be measured. Such characteristics include **sex, blood groups in man, tongue rolling, e.t.c.**

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Characteristics of discontinuous variation

- They are caused by genetic factors
- They show a clear cut difference
- They are qualitative and cannot be measured.
- Are controlled by a **single gene** and cannot be influenced by environmental conditions i.e. they are purely genetically controlled.

This variation is controlled by a single gene and cannot be influenced by environmental conditions i.e. they are purely genetically controlled.

ROLE OF VARIATION IN EVOLUTION

Variation refers to differences in phenotypic and sometimes genotypic characteristics within members of a species/population; due to the interaction between the genes and the environment.

Some variations within a species population are favourable, and give a selective advantage to those organisms possessing them; other variations are unfavourable because they are disadvantageous in the environment

Individuals with unfavourable characteristics die off, and are eliminated from the population; while those with favourable characteristics naturally and selectively survive, reproduce and pass on their favourable characteristics to the next generation

If this continues for a long period of time over several generations, it will lead to the emergence of new species, with accumulation of new good traits and alleles, and better adapted to environmental change

CAUSES OF GENETIC VARIATION

This is caused by the **gene reshuffling and mutations.**

Reshuffling of genes refers to the random orientation of chromosomes at the equator of the spindle during meiosis which changes the positions of the genes on the chromosomes.

Reshuffling of genes include the following;

I. **Crossing over:** this is the exchange of genetic material between the non-sister chromatids of homologous chromosomes during pachytene stage of prophase I of meiosis. This produces new linkage groups and so provides a major source of genetic recombination of alleles on chromosomes which results into formation of recombinant gametes and leads to variation in the offsprings formed. When the gametes undergo random fertilization, offsprings with different genetic constitution are produced.

II. Independent assortment. During independent assortment in during metaphase 1, chromosomes are distributed randomly at the equator and segregate (separate). It is by pure chance as to which chromosome from each homologous pair ends up in a daughter cell at the end of meiosis and therefore all sorts of allele combinations are possible in the gametes. This reshuffles the existing alleles thereby producing new genetic recombination's in of the gametes and the offsprings formed from these gametes when they fuse randomly during fertilisation.

Independent assortment can therefore be defined as the random orientation of the chromatids of homologous chromosomes (bivalents) on the equator of the spindle during metaphase 1 of meiosis which determines the direction in which the pairs of chromatids move during anaphase 1. This is so because

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after random arrangement on the equator of the spindle the chromosomes subsequently segregate (separate) independently thereby leading to the mixing of genes in addition during metaphase II the orientation of the pairs of chromatids is again random at the equator of the spindle and determines which chromosomes migrate to the opposite poles of the cell during anaphase II.

III. Fertilization. Fertilization occurs randomly between the male and female leading to mixing of genes in different combinations.

IV. Mutation. Mutations change the genotype of an organism with respect to a specific characteristic as it produces new alleles in the population hence making it to vary due to the combination of mutant and non-mutant gametes during random fertilisation.

V. Genetic drift. This refers to a loss of genes from a small population or the change of genes of a small population by chance alone and not natural selection which results into the change of the gene frequency of the small population. This changes the phenotypic appearance of the organisms thereby making them to vary.

VI. Cross breeding. This mixes genes from different individuals resulting into the formation of hybrids (heterozygotes) with improved qualities compared to the parents. Cross breeding can be defined as mating of organisms that are pure breeding in which one has better x-tics than another which results into the formation of the hybrid offspring.

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MUTATION

This refers to the sudden or spontaneous genetic changes which occur in the genetic constitution of an organism. These changes are brought about by mutagens. Mutations change the genotype of an organism with respect to a given characteristic as it produces new alleles in the population. Mutations cause permanent genetic variations unlike reshuffling of genes whose genetic variations are temporary as they can be undone (removed) in subsequent generations due to chromosomes rearranging themselves alongside with their genes.

During mutation, some genetic material may be lost, doubled, inverted, translocated (moved), and mixed, resulting into mutants having different genetic constitution from the non-mutants. The mutants formed transmit these mutated genes to their offsprings through random fertilisation which makes the offsprings become different from the non-mutants.

Individuals or cells resulting from mutations are known as mutants. The sudden changes in the genetic constitution of an organism are brought about by substances called mutagens. The common mutagenic agents include the following;

- Gamma rays
- Alpha and beta particles
- X-rays
- Cosmic rays
- Ultra violet rays
- Excessive heat
- Chemicals such as caffeine and heroin
- DDT and other insecticides
- Colchicine
- Marijuana
- Opium
- Cocaine
- Formaldehyde
- Some food preservatives, color and sweeteners
- Accidents

Characteristics of mutations

- Arise spontaneously in nature
- Most are disadvantageous to the organisms
- Are not directed by the environment, though mutagenic agents can cause them artificially and can accelerate their rate
- Can be reversed, although reversal is rare; thus mutations are almost always permanent
- Are rare but persistent and can occur in any cell at any time
- Do not occur slowly, but occur in a single abrupt stage
- Occur randomly in nature

Causes of mutation.

Ionizing radiation, such as x-rays, γ (gamma) rays and ultra violet rays

- High fluctuations in temperature
- Mutagenic chemicals like nitrous acid, mustard gas, and colchicine
- Certain particles like particles like β- particles.

Note: mutations usually occur in germ cells during gamete production and so lead to the formation of mutant gametes. When these gametes fuse randomly with mutant or non-mutant gametes of another parent, a mutant offsprings is formed which must have unique characteristics compared to the parents. Such mutations are known as gametic mutations. Some mutations may occur in somatic cells and are therefore known somatic mutations e.g. cancer.

Role of mutation in evolution

Mutation is the sudden, spontaneous and unpredictable change in the amount, arrangement, or structure of the DNA of an organism.

Mutation causes change in the amount, arrangement or structure of the DNA of organisms; increasing heterozygosity and the size of the gene pool; and leading to increased genetic and phenotypic variation within the population; and natural selection acting on those increased variations increases chances of evolution; where better adapted variations are selected for, reproduce and persist/survive; and less adapted variations are selected against, fail to survive or reproduce and are eliminated

Mutation leads to increased genetic variation in the gene pool of a population.

Somatic mutations occur in somatic cells that do not produce gametes and are only inherited by daughter cells produced by mitosis and so are lost when the organism dies, and do not contribute to evolution.

Mutations occurring in gamete cells and gamete-producing germ cells are inherited by subsequent generations, and contribution to evolution.

Inheritable mutations increase genetic variation, and those mutations which confer a competitive advantage to mutants/bearers are selected for by natural selection, persist and reproduce more offspring; while mutations which confer a competitive disadvantage to mutants/bearers are eliminated as they fail to survive or reproduce.

The resultant change in allele frequency in the population gene pool from generation to generation leads to evolution.

TYPES OF MUTATIONS

There are two types of mutations (germ mutations) namely;

1. Chromosomal mutations

2. Gene mutations (or point mutations)

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Somatic mutations cannot be inherited while gametic mutations can be transmitted from parents to the offsprings indeed most of the gene and chromosomal mutations are gametic and can therefore be inherited or they are usually recessive.

Chromosomal mutations

This refers to the changes that occur in the chromosome number or chromosome structure but can be transmitted from the parents to the offspring.

Chromosome mutations usually occur during **prophase I** of meiosis where a number of mistakes are made on the chromosome structure i.e. chromosomes break and join wrongly. It can also arise during anaphase I and II where by some chromosomes may fail to separate and move to opposite poles which brings about an increase in the number of chromosomes or polyploidy i.e. an increase in the number of chromosomes beyond the normal diploid number. The process by which chromosomes fail to separate during anaphase I of meiosis is known as non-disjunction.

Chromosomal mutations are divided into the following categories;

a. Mutations that change the chromosome structure.

b. Mutations that change the chromosome number.

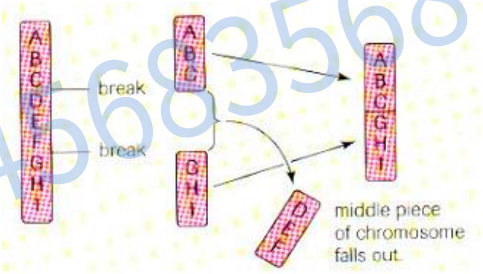
a. **Mutations that change the chromosome structure**

Such mutations include the following;

i. Deletion

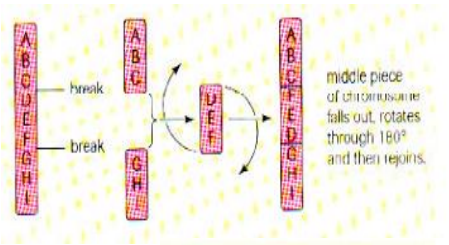
This is a form of mutation where part of a chromosome breaks and gets lost leading to the formation of a number of chromosomes that is shorter than the original chromosome. This is the most dangerous form of mutation because it leads to loss of genes from the chromosome.

In human beings deletion leads to cat cry syndrome where the voice box fails to develop properly.



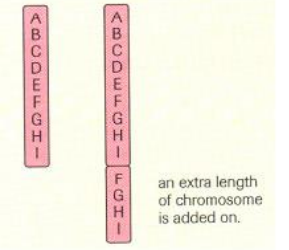
ii. Inversion

This is the form of mutation where part of a chromosome breaks, rotates through 180 degrees and rejoins in the reverse way, this in turn changes the sequence of genes on the chromosomes as well as the sequence of bases on the DNA strand which makes the offspring vary.



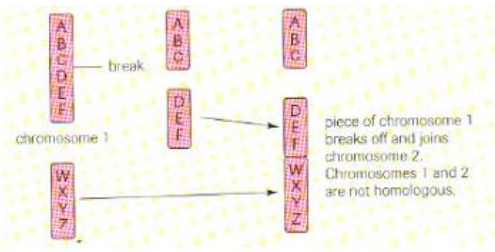
iii. Duplication

This is a form of mutation whereby a portion of chromosomes baring certain gene is doubled. This form of mutation causes over amplification of certain phenotypes whose genes have been duplicated. This form of mutation is of importance in crop and animal husbandry since it increases yields and improves other characteristics.



iv. Translocation

This is a form of mutation whereby a portion of a chromosome breaks and is moved to join a nother chromosome which maybe homologous or non-homologous.



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b. Mutations that change the chromosome number

These are mutations that affect the whole chromosome and change the chromosome number in the cell. This normally occurs during meiosis at anaphase I and II where two of the same type of chromosomes or chromatids fail to separate and are transmitted together into a single gamete leaving the other gamete empty a concept known as non-disjunction. The other chromosomes not affected by non-disjunction are usually distributed normally by meiosis into gametes formed.

Non-disjunction results into formation the formation of gametes either with an extra number of chromosomes **(n+1) (n+2) (n+3)** e.t.c. or a less number of chromosomes (n-1). Therefore, this condition where by half of gametes contain extra number of chromosomes while the other half of gametes formed during meiosis contain a chromosome missing is known as aneuploidy.

If a chromosome is present in triplicate in the fertilised egg (so that the cell has a total of 2n+1 chromosomes), the aneuploidy cell formed is said to be trisomic and if a chromosome is missing, so that the zygote cell formed has 2n-1 chromosomes, the aneuploid cell is said to be monosomic. Mitosis will subsequently transmit this variation to all embryonic cells (somatic cells) leading to the formation of an organism with variation in the form of a set of symptoms caused by the abnormal dose of genes associated with extra or chromosomes missing.

GENE MUTATIONS

Gene mutations are caused by changes to the sequence of nucleotides in DNA.
Addition, deletion and substitution which occur to the sequence of nitrogenous bases in DNA will affect the nature of proteins that are synthesized.
Mutated genes which cause defective proteins / enzymes to be synthesized may cause the death of the organism. Such genes are called lethal genes.

Examples of gene mutations in the human population

Sickle-cell anaemia

The haemoglobin gene undergoes a mutation to form a mutant recessive gene.
The mutant gene produces abnormal haemoglobin, causing the red blood cell to become sickle-shaped.
Sickle-shaped erythrocytes are not efficient in transporting oxygen and the patient suffers from anaemia.
A person who is homozygous recessive (possesses two mutant alleles) will suffer from severe life-threatening anaemia.

Albinism

A condition caused by a mutation to the gene which produces the pigments found in the skin, hair & eyes. Individuals with this condition are called albinos. Due to their lack of pigmentation, albinos are very fair-skinned, have white hair and red eyes.
The gene which causes albinism is recessive and is found on an autosome. Therefore, an individual needs to be fat and homozygous.

Haemophilia

Haemophilia is an inherited blood disease.
The condition is caused by a gene mutation on the X-chromosome.
Haemophiliacs are unable to produce certain blood clotting factors.

Gene mutations (point mutation)

A mutation is a change in the amount, arrangement or structure of the DNA of an organism. A change in the structure of DNA at a single locus is called a gene mutation or point mutation

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This is a sudden change in the sequence of nuclear nucleotides or bases of DNA. These mutations are of the following types;

1. **Substitution**. This type of mutation whereby or more bases of nucleotides may be replaced with wrong nucleotides or basses. Sickle cell anemia in man is an example of a substitution gene mutation where an individual gets abnormal hemoglobin S in the red blood cells. Such individuals have a wrong better polypeptide chain in their hemoglobin due to the substitution where by glutamic acid that causes the formation of normal hemoglobin is replaced by another amino acid called **hyaline** which caused formation of hemoglobin S in sickle cell anemia in individuals.

2. Deletion. This is a form of gene mutation where a section of DNA is lost. This results into wrong transcription and wrong translation processes in protein synthesis. This mutation is dangerous because it leads to absence of certain structures or wrong physiological processes taking place in an organism.

3. Inversion. This is where a group of nucleotides in DNA becomes reversed after rotating through 180 degrees.

4. Insertion. This is where one or more nucleotides may be fixed in a particular DNA strand.

Genetic Problems

Errors in the genetic code or "gene recipe" can happen in a variety of ways. Sometimes information is missing from the code, other times codes have too much information, or have information that's in the wrong order.

These errors can be big (for example, if a recipe is missing many ingredients — or all of them) or small (if just one ingredient is missing). But regardless of whether the error is big or small, the outcome can be significant and cause a person to have a disability or at risk of a shortened life span.

Abnormal Numbers of Chromosomes

When a mistake occurs as a cell is dividing, it can cause an error in the number of chromosomes a person has. The developing embryo then grows from cells that have either too many chromosomes or not enough.

In **trisomy**, for example, there are three copies of one particular chromosome instead of the normal two (one from each parent). Trisomy 21 (Down syndrome), trisomy 18 (Edwards syndrome), and trisomy 13 (Patau syndrome) are examples of this type of genetic problem.

Trisomy 18 affects 1 out of every 7,500 births. Children with this syndrome have a low birth weight and a small head, mouth, and jaw. Their hands typically form clenched fists with fingers that overlap. They also might have birth defects involving the hips and feet, heart and kidney problems, and intellectual disability. Only about 5% of these children are expected to live longer than 1 year.

Trisomy 13 affects 1 out of every 15,000 to 25,000 births. Children with this condition often have cleft lip and palate, extra fingers or toes, foot abnormalities, and many different structural abnormalities of the skull and face. This condition also can cause birth defects of the ribs, heart, abdominal organs, and sex organs. Long-term survival is unlikely but possible.

In **monosomy**, another form of numerical error, one member of a chromosome pair is missing. So there are too few chromosomes rather than too many. A baby with a missing autosome has little chance of survival. However, a baby with a missing sex chromosome can survive in certain cases. For example, girls with Turner syndrome — who are born with just one X chromosome — can live normal, productive lives as long as they receive medical care for any health problems associated with their condition.

Deletions, Translocations, and Inversions

Sometimes it's not the number of chromosomes that's the problem, but that the chromosomes have something wrong with them, like an extra or missing part. When a part is missing, it's called a **deletion** (if it's visible under a microscope) and a **microdeletion** (if it's too tiny to be visible). Microdeletions are so small that they may involve only a few genes on a chromosome.

Some genetic disorders caused by deletions and microdeletions include Wolf-Hirschhorn syndrome (affects chromosome 4), Cri-du-chat syndrome (chromosome 5), DiGeorge syndrome (chromosome 22), and Williams syndrome (chromosome 7).

In **translocations** (which affect about 1 in every 400 newborns), bits of chromosomes shift from one chromosome to another. Most translocations are "balanced," which means there is no gain or loss of genetic

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material. But some are "unbalanced," which means there may be too much genetic material in some places and not enough in others. With **inversions** (which affect about 1 in every 100 newborns), small parts of the DNA code seem to be snipped out, flipped over, and reinserted. Translocations may be either inherited from a parent or happen spontaneously in a child's own chromosomes.
Both balanced translocations and inversions typically cause no malformations or developmental problems in the kids who have them. However, those with either translocations or inversions who wish to become parents may have an increased risk of miscarriage or chromosome abnormalities in their own children. Unbalanced translocations or inversions are associated with developmental and/or physical abnormalities.

Sex Chromosomes

Genetic problems also occur when abnormalities affect the sex chromosomes. Normally, a child will be a male if he inherits one X chromosome from his mother and one Y chromosome from his father. A child will be a female if she inherits a double dose of X (one from each parent) and no Y.
Sometimes, however, children are born with only one sex chromosome (usually a single X) or with an extra X or Y. Girls with Turner syndrome are born with only one X chromosome, whereas boys with Klinefelter syndrome are born with 1 or more extra X chromosomes (XXY or XXXY).
Sometimes, too, a genetic problem is X-linked, meaning that it is associated with an abnormality carried on the X chromosome. Fragile X syndrome, which causes intellectual disability in boys, is one such disorder. Other diseases that are caused by abnormalities on the X chromosome include hemophilia and Duchenne muscular dystrophy.
Females may be carriers of these diseases, but because they also inherit a normal X chromosome, the effects of the gene change are minimized. Males, on the other hand, only have one X chromosome and are almost always the ones who show the full effects of the X-linked disorder.
Note: The zygote produced with odd number of chromosomes in the above cross containing less than the diploid number of chromosomes usually fails to develop. But those with extra sets of chromosomes though odd numbered or even numbered usually develop and in most cases this produces severe abnormalities. In humans, non-disjunction causes the following abnormalities.

1. Down's syndrome (mongolism)

This disease is also referred to as mongolism and it is caused by an extra autosomal chromosome in position number 21 of the homologous chromosome pairs.

Mongolism occurs as result of non-disjunction in chromosome number or during anaphase I of meiosis in gametes formation leading to formation of abnormal gametes with 24 chromosomes. In such a case if a normal gamete fertilizes an abnormal gamete, the zygote formed will have 47 chromosomes instead of the normal 46. This form of syndrome occurs in both males and females. It can take place during sperm production but it's more common during cogenesis.

Mongolism is due to a type of mutation known as translocation in which chromosome 21 is translated or moved to chromosome 14 in most cases or chromosome 22 in some cases.

Most non disjunction occurs in meiosis I where it causes failure of the whole chromosome 21 to separate if it occurs in meiosis II the chromatids fail to separate leading to Down's syndrome.

Mongolism causes miscarriage in mothers and the chances of it to occur increases with age of the females. This form of syndrome results in individuals having the following characteristics;

- They are mentally retarded
- They have a low resistance to infections and therefore have a short life span
- They have frequent saliva flow from the mouth
- They have slit eyed appearance.

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2. HETEROSOME NON-DISFUNCTION

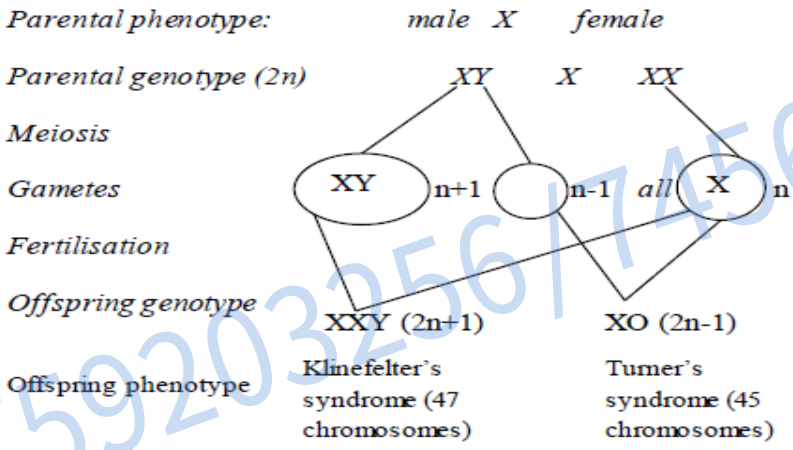
This is non-disjunction of sex chromosomes which produces a variety of aneuploid conditions which include the following;

a. Klinefelter's syndrome (XXY)

This results from non-disjunction of the sex chromosomes pair in either males or females resulting into a male with 47 chromosomes and genotype XXY. It may occur if a normal Y sperm fertilizes an abnormal egg. It may also occur if an abnormal sperm (XY) fertilizes a normal egg (X). This is illustrated below;

Individuals suffering from **Klinefelter's** syndrome have the following characteristics;

- They are infertile (sterile) and therefore they don't produce sperms although erection and ejaculation occurs.
- Their testes are usually very small compared to the normal males i.e. the testes fail to grow to the expected size.
- They have very subnormal intelligence
- They tend to be taller than the average height
- They have little facial hair
- They possess some female secondary sexual characteristics e.g. developed breasts and wide hips.
- Their trunk may show signs of obesity



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b. Turner's syndrome (XO)

This monosomy condition occurs in females resulting into a female with 45 chromosomes and genotype XO. It occurs as a result of non-dysfunction which results into an abnormal egg or an abnormal sperm. If an abnormal sperm fertilizes a normal egg this condition occurs and if an abnormal egg that is empty is fertilized by a normal sperm containing X chromosomes this condition again occurs. Individuals with Turner's syndrome vary from others by having the following characteristics;

They do not show female secondary characteristics such as developed breasts, menstruation, widening of hips e.t.c.

- They are infertile with no ovaries but with a small uterus.
- They have a short height than the women average height.
- They have a webbed neck.
- They are usually of normal intelligence

c. Triple X syndrome (XXX)

This also occurs in females due to non-disjunction which results into formation of an abnormal egg containing XX chromosomes and if such an egg is fertilized with a normal X sperm the triple X female occurs with 47 chromosomes and these individuals have the following characteristics;

- They are fertile females

- They are mentally normal
- They are physically normal
- They have a very high sex libido

d. XYY syndrome

This condition occurs in males with genotype XYY. It occurs in case the Y chromosome undergoes duplication and fails to separate at anaphase I. This may result into production of abnormal sperms containing YY which if they fertilize a normal X egg and XYY syndrome occurs. Individuals with this syndrome vary from other males by having the following characteristics;

They are usually very aggressive and therefore common in prisons and security forces.

- They are fertile males.
- They are giants.
- They are mentally and physically normal

POLYPOIDY

This is a condition whereby cells of organism possess extra sets of chromosomes beyond the normal diploid number. Polyploidy therefore makes the genetic constitution of an organism multiplied to become 3n, 4n, 5n, 6n e.t.c.

Polyploidy is a useful phenomenon in plant bleeding where the chromosome number is increased so as to improve on the vigor (characteristic) of the plant i.e. plants acquire better characteristics such as high yields, high resistance to dieses, quick maturity, high resistance to pests e.t.c. It is more common in plants than animals because the increased number of chromosomes in animal polyploidy causes errors in gamete formation unlike in plants which usually reproduce vegetatively without such errors.

What is meant by polyploidy?

Polyploidy involves cells containing three or more time the haploid number of chromosomes.

Polyploids may be triploid (3n), tetraploid (4n), pentaploid (5n), and so on.

Polyploidy is caused by errors in meiosis or mitosis, such as failure of the cytoplasm to cleave, spindle fibres failing to form, and doubling of the chromosome number after fertilisation.

There are two forms of polyploidy namely; **autopolyploidy and allopolyploidy**

1. Autopolyploidy

This is where the chromosome number of some individuals in a given species is increased either naturally or artificially by preventing cytokinesis or preventing the formation of spindle fibres during cell division. This can be done artificially using colchicines which prevents formation of spindle fibers thereby increasing the chromosome number. This mutation prevents the tetraploids from successfully interbreeding with the diploid plants of the original population leading to the reproductive isolation. However, the tetraploids can still produce fertile offsprings by self-pollination or by mating with other tetraploids

Autopolyploid can be as fertile as diploids if they have an even number of chromosomes and they can be infertile if they have odd number of chromosomes because they cannot form homologous pairs.

Colchicines and other related drugs have been used in breeding in certain varieties of tobacco and tomatoes whose cells have a large nucleus. **Autopolyploidy** arises when an organism has three or more multiples of the haploid chromosome number derived from the same species.

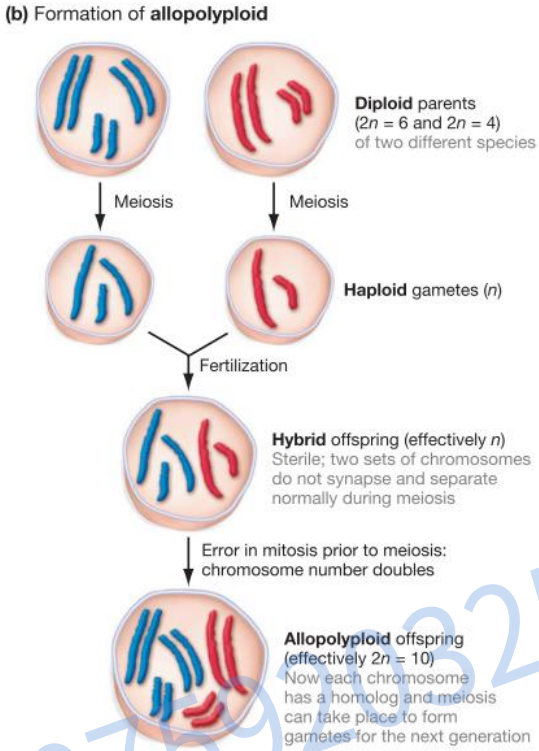
2. Allopolyploidy

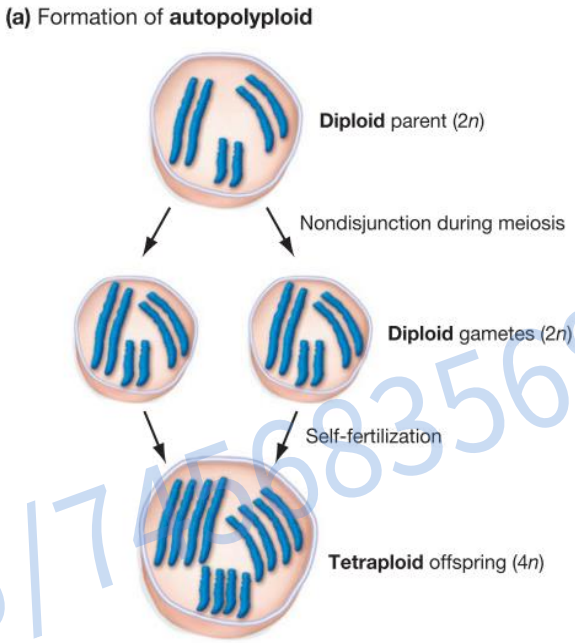
This is a condition which arises when the chromosome number in the sterile hybrids gets doubled and produces fertile hybrids. Sometimes the F1 offsprings formed may be sterile but if these individuals are crossed with another related. **Alloploidy**/allopolyploidy —individual has two or more genomes contributed from different parental species in their ancestral lineage.

During meiosis in F1 hybrids chromosomes from each parent cannot pair together to form homologous chromosomes hence the F1 hybrids produces gametes with a diploid set of chromosomes. This brings about allopolyploid as illustrated below;

The allopolyploid is fertile because homologous pairing of chromosomes can occur in meiosis as the two sets of parental chromosomes are present. Allopolyploid is an example of interspecific hybrid

Polyploid cells and organisms are those containing more than two paired, complete sets of chromosomes. Polyploidy occurs when an error in meiosis or mitosis results in a doubling of the chromosome number, a massive mutation.





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Most naturally occurring polyploids are **alloploids.** Amphidiploids (also called amphiploids) are allotetraploids that contain two sets of genomes from each of two different parents. Amphidiploids are so called because they behave like diploids during meiosis.

Autopolyploid ("same-many-form") individuals are produced when a mutation results in a doubling of chromosome number and the chromosomes all come from the same species as in triploids, tetraploid. It is common in plants.

Allopolyploidy ("different-many-form") individuals are created when parents that belong to different species mate and produce an offspring with two different sets of chromosomes

Euploidy—individual has one or more whole sets of chromosomes with each chromosome represented once in each set. There are three main kinds of euploidy.

Haploidy—individual with half (n=x) of the somatic cell chromosome number.

Diploidy—individual with two sets of the basic, complete genome (2n=2x).

Polyploidy—individual with more than two basic, complete sets of chromosomes in its somatic cells. Among polyploids,

Polyploidy brings about genetic variation with in a population as it results into the formation of new and different genetic combinations within some individuals of the population. This makes some polyploids with in the population better adapted than their original parents and so are favoured by a selection pressure of nature

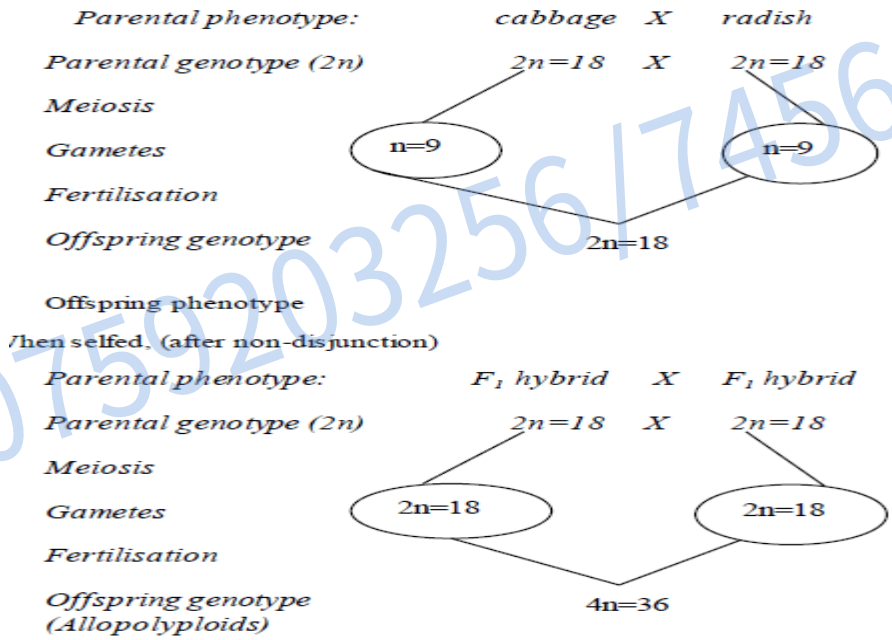
to survive, reproduce and transmit their adaptive variations to their offsprings. However, better adapted polyploids may fail to interbreed with diploid organisms, thereby forming a new specie due to possession of extra sets of chromosomes beyond the diploid number.

Polyploidy also results into formation of new species via **interspecific hybridization**, a process in which the F1 hybrids formed are sterile because their chromosomes cannot form homologous pairs being that they arise from organisms of different species, but when a diploid number of chromosomes of F1 hybrids is doubled due to non-disjunction, tetraploids (4n) can be formed as F2 hybrids which can inter breed among themselves to produce fertile offsprings. The F2 tetraploids formed by **interspecific hybridization** can interbreed among themselves to form fertile offsprings but cannot interbreed with any of the original parents because of having extra sets of chromosomes thereby becoming a new species.

The F2 offsprings formed are described as allopolyploids because they are formed by a type of polyploidy known as halopolypolidy. **Halopolypolidy** is the one which occurs when two different species interbreed and produce a sterile F1 hybrid whose chromosome number gets doubled by non-disjunction thereby changing the sterile F1 hybrids into fertile F2 hybrids. The halopolypolids formed are fertile with each other but cannot interbreed with a diploid parental species. The F1 hybrids are sterile because the set of chromosomes from one species cannot pair during meiosis with another set of chromosomes from another species.

Illustration

Parental phenotype: cabbage X radish



The tetraploids formed is fertile because homologous pairing of chromosomes can occur in meiosis, as the two sets of parental chromosome present in diploid gametes are produced which contain nine chromosomes from the parental cabbage and 9 chromosome of the parental radish.

ROLE OF POLYPLOIDY IN EVOLUTION

Polyploidy is a chromosomal mutation resulting in gametes and somatic cells of organisms with extra haploid sets of chromosomes; and occurs in three forms amphiploidy, allopolyploidy and autopolyploidy

In asexually-reproducing organisms, such as vegetatively-propagated angiosperms, autopolyploidy results in intraspecific speciation sympatrically; while amphiploidy caused by interspecific hybridization can result in interspecific speciation sympatrically if the amphiploids undergo allopolyploidy.

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In plants, polyploidy has the following effects**:** shorter stem length, insensitivity to day length, increased size, increased hardiness, increased resistance to drought, increased yield, increased nutrient content in edible parts, earlier maturation, increased number of flowers, fruits, leaves and storage organs, increased responsiveness to water and fertilizers; arising due to heterozygosity of allopolyploids causing hybrid vigor. Natural selection for these favourable characteristics leads to production of new better adapted species.
In animals, polyploids usually have severe genetic disorders, shorter lives or both

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 population is a group of organisms of one species occupying a defined area and usually isolated to some degree from other similar groups.
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.
The process of natural selection determines which gene passes on to the gene pool of the next generation.
Whereas natural selection happens on individual organisms of a species, its only populations which can evolve.
A gene is the basic unit of inheritance of a particular characteristics. Alleles are the alternative form of the same gene determining contrasting characteristics.
The genetic construction of an organism with respect to particular alleles is called the genotype. The observable characteristic of an organism due to its genotype and sometimes environmental influence is it's phenotype.
Evolution is the process of change in the frequency of gene and alleles in a gene pool or population by a mechanism of natural selection of the fittest genes and alleles.
A population whose gene pool changes consistently from generation to generation is undergoing evolution and is said to be a dynamic gene pool. A population whose gene pool does not change from generation to

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generation does not undergo evolution and is said to be static. A static gene pool represents a species population whose genetic variation is inadequate to cause 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,

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'.

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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. onsidering 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).

The Hardy – Weinberg equation.
Consider a gene which has dominant allele A and a recessive allele a
Let
A = dominant allele
a = recessive allele.
And
p =the frequency of the dominant alleles A.
q = the frequency of the recessive allele a
Crossing dominant homozygotes with recessive homozygotes produces heterozygous offspring.

Parental genotype (2n): AA x aa
Meiosis
Gametes (n) (A) (a)
Random fertilization
F_1 phenotypes: all heterozygous. Aa

Selfing the F_1 to produce the F_2:
F_1 phenotypes: heterozygous.(♀) x heterozygous.(♂)
F_1 genotypes: Aa x Aa
Meiosis
Gametes (n) (A) (a) (A) (a)
Random fertilization using punnet square

	$(A)_{(p)}$	$(a)_{(q)}$
$(A)_{(p)}$	AA (P^2)	Aa (pq)
$(a)_q$	AQ (pq)	Aa q^2

F_2 genotypes 1AA : 2Aa : 1aa
P^2 :2pq : q^2
F_2 phenotypes: homozygous dominant : heterozygous: homozygous recessive

F_2 genotypic ratio: 1 : 2 : 1
Genotype frequency: $\frac{1}{4}$(25%) : $\frac{1}{2}$(50%) : $\frac{1}{4}$(25%)
But $\frac{1}{4}+\frac{1}{2}+\frac{1}{4}$ = 9 and 25% + 50% +25% =100%
Thus AA + 2Aa + aa = 1.0(100%)
And $P^2 + 2pq + q^2$ = 1.0(100%)
So $(p + q)^2 = 1$ and $p + q = 1$

.

The expression $p^2 + 2pq + q^2 = 1$ is called the hardy Weinberg equation.
Note: **p** = dominant allele frequency while **q**= Recessive allele frequency
And to obtain the allele frequency, use the expression p + q =1
p^2= homozygous dominant genotype frequency
2pq = heterozygous genotype frequency.
q^2 =homozygous recessive genotype frequency
And to obtain genotype frequency, use the expression $p^2 + 2pq + q^2 = 1$

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Factors causing evolutionary change in species population.

1. Non-random breeding

Non-random mating is a form of natural selection called sexual selection

Sexual selection occurs when the presence of one or more inherited characteristics increases the chances of successful fertilisation of gametes.

Many structural and behavioural mechanisms in both plants and animals prevent mating from being random e.g.

a) Flowers possessing larger and more brightly coloured petals and greater amounts of nectar are likely to attract more pollinating insects

b) Colour pattern in insects, birds, fish, mammals; and behavioural pattern involving nest building, territoriality and courtship makes animal mating selective.

Sexual selection thus ensures that organisms with more favourable characteristics have an increased reproductive potential so their alleles are passed on to the subsequent generations with increasing frequency. This change in allele frequency causes evolution.

2. Small population size causing genetic drift.

Genetic drift chance events that alter allele frequencies) (the Sewall wright effect)

It is a change in the frequency of alleles in the gene pool when a new population arises from one or a few colonising pioneer individuals.

When a small population becomes split off from the parent population, it will not contain all the alleles of the parent population.

Continuous breeding within the pioneer population produces a gene pool with allele frequency different from that of the original parent population.

Another effect of genetic drift is gene fixation

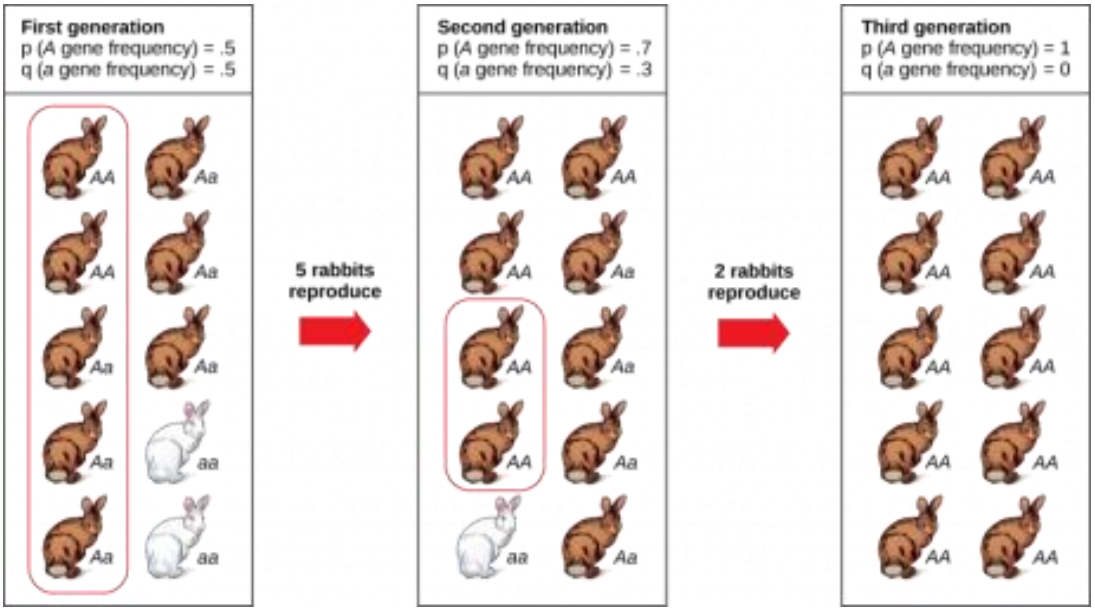
Gene fixation is the establishment of only one allele of a gene in a population as a result of eliminating its alternative alleles. The locus of the gene thus becomes homozygous in all individuals after fixation. Gene fixation may result from the founder effects by genetic drift, or by natural selection against the eliminated alleles.

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Example of genetic drift are;

a) When a population of plants that colonies a newly formed island comes from one pioneer seed dispersed from large mainland plant population.

b) When a breed of a domestic pig is descended from one originally domesticated wild female pig.



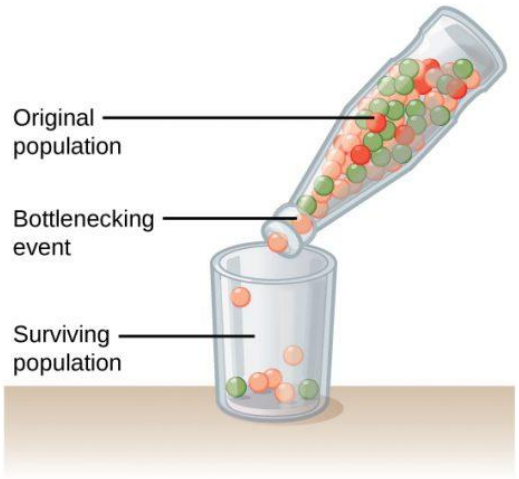


Figure 1. Genetic drift in a population can lead to the elimination of an allele from a population by chance. In each generation, a random set of individuals reproduces to produce the next generation. The frequency of alleles in the next generation is equal to the frequency of alleles among the individuals reproducing.

Genetic drift can also be magnified by natural or human-caused events, such as a disaster that randomly kills a large portion of the population, which is known as the **bottleneck effect** that results in a large portion of the gene pool suddenly being wiped out (*Figure 2*). In one fell swoop, the genetic structure of the survivors becomes the genetic structure of the entire population, which may be very different from the pre-disaster population. The disaster must be one that kills for reasons unrelated to the organism's traits, such as a hurricane or lava flow.

3. Genetic load and heterozygote advantage.

Genetic load refers to the existence within the population of disadvantageous (deleterious) alleles in heterozygous genotypes. This occurs when recessive alleles which are disadvantageous in homozygous recessive genotype are carried in the heterozygous genotype and confer a selective advantage on the heterozygous phenotype in certain environmental conditions this heterozygote advantage maintains and increases the frequency of recessive alleles in the population.

For example, the sickle cell allele carriers are more resistant to malaria than both normal individuals and sickle cell anaemics.

Thus, heterozygote advantage is a situation in which the heterozygote is fitter than either of the homozygotes.

The disease sickle cell anaemia is an example of how a single cell mutant in a gene can have devastating effects and also the role of natural selection in determining the frequency of a gene in a population

Symptoms of sickle cell anaemia

The Red blood cell becomes sickle-shaped at low oxygen concentration. The abnormal haemoglobin molecules tend to crystallize, deforming some of the cells into a sickle shape.

Sickle cells are useless to the body and so they are broken down causing anaemia

Anaemia results into oxygen deficit, leading to frequent illness, weakness and fatigue, poor physical development and dilation of the heart (large heart).

The sickle cells get clogged (jammed) in the capillaries and small blood vessels and prevent normal blood flow. This may cause heart damage causing rheumatism, gut damage causing abdominal pain, kidney damage leading to kidney failure and liver damage.

A combination of heart damage and dilation of the heart may cause heart failure.

The sickle cells collect in the spleen for destruction causing enlargement of the spleen.

Causes of sickle cell anaemia.

Sickle cell anaemia results from a gene mutation in the gene producing haemoglobin as follows:

Haemoglobin is made of four polypeptide chain, two chains which are 141 amino acids long and two b- chains which are 145 long.

The DNA which codes for the sixth amino acids in the b- chain in haemoglobin has a mutant where by the base adenine replace thymine.

This is a substitution mutation.

The mRNA produced has the triplet code GUA (for the amino acid Valine) rather than GAA (for the amino acid glutamic acid).

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The b- chain produced has one glutamic acid molecule replaced by a valine molecule. Glutamic acid carries a negative change and its polar, whereas valine is non- polar and hydrophobic.
The presence of valine makes deoxygenated abnormal haemoglobin called (haemoglobin s or HbS) less soluble.
Thus the low oxygen concentration when HbS losses it's oxygen, the molecules come out of the solution and crystallize into rigid rod – like fibres.
Theses HbS fibres change the shape of the RBC which is normally a flat circular biconcave disc to become crescent (sickle) shaped. These sickle cells are less efficient in carrying oxygen hence cause anaemia and may block small vessels causing permanent organ damage and the possibility of death.
The distribution of the sickle cell allele is evidence of evolution in action.
The distribution of the sickle allele coincides with that of malaria. Malaria is a major source of illness and death in many parts of Africa. Malaria is caused by the blood parasite, plasmodium.
Homozygous recessive individuals usually die before reaching adulthood thereby, eliminating two recessive alleles from the populations. Heterozygotes of the sickle cell allele however are far less susceptible to malaria than normal homozygotes. This is because plasmodium multiplies inside normal Oxygen - rich red blood cells.
Therefore, a number of conflicting selection pressures act on the sickle cell allele;
a) There is a strong selection pressure against the sickle cell allele in the homozygous condition **(HbSHbS)**
b) In malaria, infested areas, there is strong selection pressure for the sickle cell allele in heterozygous condition (**HbAHbS)**
c) People who are homozygous for the normal allele (**HbAHbA**) have a selective disadvantage in malaria infested areas.
The net result of opposing selection pressure is to retain the sickle cell allele in areas where malaria is endemic.
The actual frequency of the allele in the population varies according to the amount of malaria e.g. in some African tribes the genotype frequency is as high as 40% while it is only 10% of the black people in Britain.
This is an example of evolutionary change in action. It highlights the influence of an environmental selection mechanism on changes in allele frequency which causes evolution to occur.

4. Closeness of population and gene flow.

Gene flow refers to the movement of alleles from one population to another as a result of interbreeding between members of two populations. The random introduction of two alleles into the recipient population and their removal from the donor population affects the frequency of both populations and increases genetic variation.
The frequency of gene flow between population depends upon their geographical proximity and the ease with which the organisms or their gametes can pass between the two populations. E.g. flying animals and pollen grain are easily dispersed between two near environments.

5. Natural selection

Natural selection is the process by which those organisms that are morphologically, physiologically, structurally and behaviourally better adapted to the environment, survive and reproduce and pass on their advantageous genes to the next generation, while those that are less well adapted either fail to survive or to reproduce and hence die out. Failure to reproduce constitutes genetic death as it eliminates the organism's gene from the population.
Natural selectin 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.

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The well adapted organisms pass on their successful characteristics (genes and alleles) into the next generation while the poorly adapted do not.
This increases the frequency of the successful genes and alleles in the population.

How does natural selection occur?
When a population increases in size, some environmental resources and conditions become limiting, for instance food availability decreases and the availability of light in plants decreases.
This increases interspecific competition for the limited resources within members of the population.
During the competition, some organisms exhibit phenotypic characteristics which give them a competitive advantage over the others and so they obtain the resources survive and reproduce. Those organisms lacking those characteristics are at a competitive disadvantage and may die before reproducing; and are thus eliminated from the population
Thus, both the environment and the population size act together to produce a selection pressure with varying intensity and direction.
The well adapted phenotypes thus turn their competitive advantage into a selective advantage that confers upon them a reproductive advantage.
And so, natural selection determines which alleles are passed on to the next generation by virtue of the relative selective advantage they confer upon their phenotypes
The selection pressure offers a means of increasing or decreasing the spread of an allele within the gene pool and these changes in allele frequency lead to evolutionary change.
Natural selection therefor acts at the level of the gene or allele and is based upon the existence of genetic variation with in the population.

Evidence for natural selection
Industrial melanism
Moths collections of the 19TH century showed the peppered moth (biston betularia) as a white moth (biston, betularia, typical), while occasional specimens showed a dark mothed form (biston betularia carbonaria).
However, by the end of the 19th century, near the industrial city of Manchester, the dark form had become more common (about 98% of the population)
This change in the frequencies of the two forms of peppered moth is an example of evolution taking place.
This change resulted from natural selection in industrial areas. A phenomenon called Industrial melanism.
In the 19th century before industrial revolution, trees were covered with whitish lichens and walls painted white. This allowed the light form to camouflage against the white background and thus hide from the predatory birds.
The dark form could be highlighted on this white background and thus faced high levels of predation.
By the end of the 19th century, with industrialisation, air pollutants including gasses, smoke and soot killed off the lichens, and darkened the barks of trees and walls of building.
This change in the environment allowed the dark form to camouflage facing less predation hence increasing in frequency. The light form would be highlighted on the dark background and face more predation thus reducing in frequency.
Industrial melanism provides evidence for natural selection, where changes in the environment due to industrialisation caused a change in the selection pressure (predation of the non-camouflaged form)
This natural selection was based on differences in melanin concentration of the two forms guided by industrialization hence the term industrial melanism.

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Types of selection

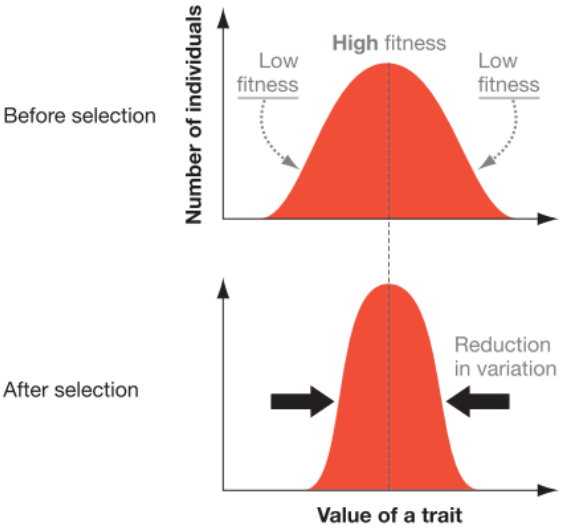
1. Stabilizing selection is selection which favours average phenotypes over either extreme.

It selects for average phenotype and against both the lower extreme and upper extreme. E.g. the optimum birth weight in humans is 3.6 kgs, and babies lighter or heavier than this optimum are at a selective disadvantage and have a slightly increased mortality rate.

Also, average weight and average height humans have a selective and reproductive advantage over the extremely small or shorter and the extremely fat or tall, hence both extremes tend to be unhealthy.

Stabilizing selection pressure do not promote evolutionary change but tend to maintain phenotypic stability with in the population from generation to generation.

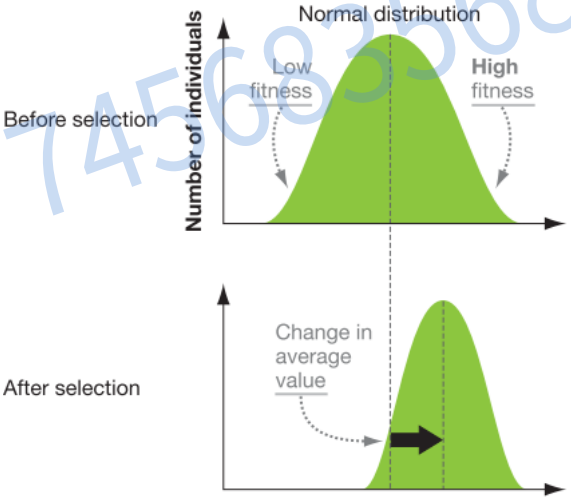
(a) Stabilizing selection reduces the amount of variation in a trait.



Directional selection is the selection which favours the phenotypes at one extreme over the other

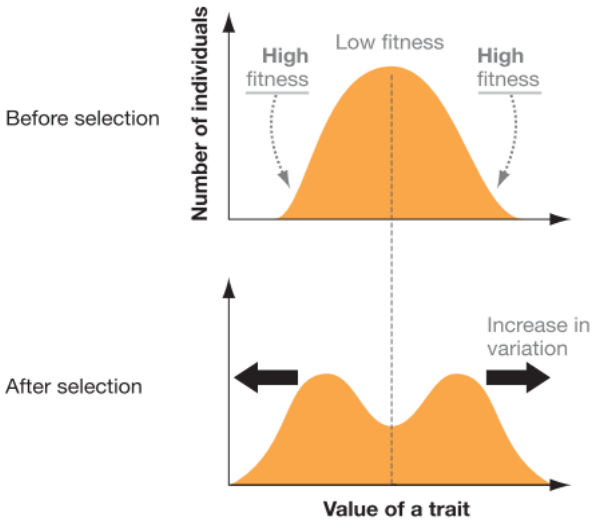
It selects for one extreme and against the other. E.g.
If birds prefer eating big seeds to small ones, there will be selection for small seeds and against big seeds.
Strong lions are selected for, while weak ones are selected against.
Directional selection operates in response to gradual changes in environmental conditions and brings about evolutionary change.

(a) Directional selection changes the average value of a trait.



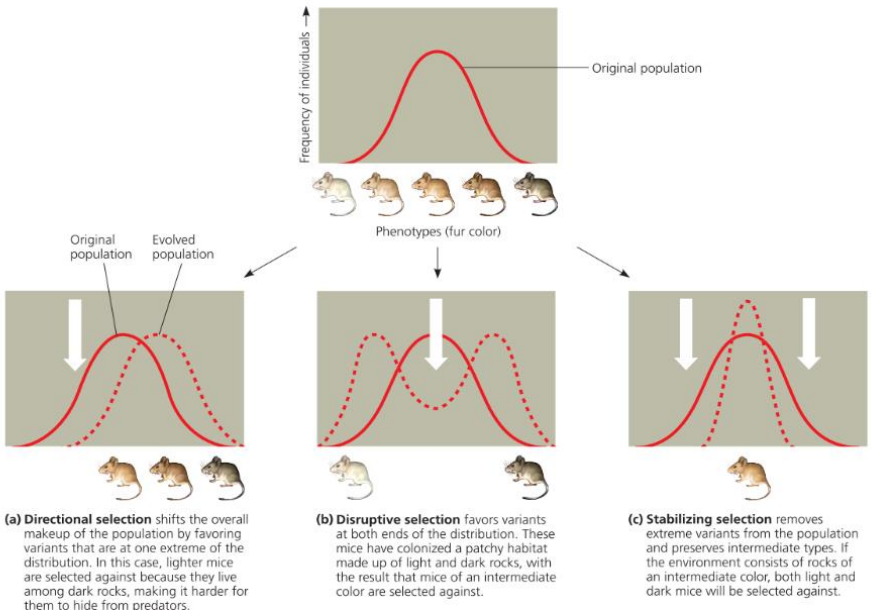
Disruptive selection is selection which favours both extremes and selects against the average intermediates. e.g. if birds prefer to eat intermediate (average-sized) seeds and ignore the very small and very large seeds. Disruptive selection can be very important in bringing about evolutionary change.
Micro – evolution due to disruptive selection may give rise to subpopulations, polymorphs, ecotypes, races, and demes. And if gene flow is prevented between the subpopulations, each subpopulation may give rise to a new species (speciation.)

(a) Disruptive selection increases the amount of variation in a trait.



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An illustration of the effects of 3 types of selection on the normal distribution curves of populations.



ROLE OF NATURAL SELECTION IN EVOLUTION.

Natural selection is the mechanism of evolution where organisms that possess favourable adaptations to the environment, survive, and reproduce and pass on their favourable characteristics, contributing more offspring to the next generation, while those with unfavourable adaptations are selected against and die easily, and their population becomes extinct

If this continues for a long period of time over several generations, it will lead to the emergence of new species, with accumulation of new good traits and alleles, and better adapted to environmental change

The biological significance of natural selection.

1. Offers a mechanism by which species adapt to change in environmental conditions, by allowing the continued survival and perpetuation of only these alleles that better suit the phenotype to the environment.
2. Allows species to extend their geographical range to new different environment by adaptive radiation, thereby reducing risks of species extinction.
3. Leads to change in the frequency of alleles in gene pools of populations thereby causing evolution, which may ultimately lead to the formation of new better –adapted species. (Speculation)

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.

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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

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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 haemoglobin 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
Speciation is the process by which one or more species arise from pre–existing species.
This mainly occurs by a reproductive isolation of a species to form two new species.
The concept of species
A species is a group of closely related organisms capable of interbreeding freely to produce fertile offspring and which are reproductively isolated from other species.
Members of the same species share a unique set of structural and functional characteristics, occupy the same ecological niche, and show close similarity in genetic karyotype.
The process of formation of new species

A single species may give rise to new species, a process called intraspecific speciation, or two different species may give rise to a new species by interspecific hybridisation.
If intraspecific speciation occurs while the population is separated geographically, its termed as **Allopatric speciation.**
If the process occurs when the populations are occupying the same geographical area it is termed as Sympatric speciation.
Intraspecific speciation.

Speciation occurs as a result of the formation of barriers which lead to reproductive isolation between members of the population. The means of producing and maintaining reproductive isolation within a population are called isolating mechanisms. Isolating mechanisms which act before fertilisation are called pre-zygotic mechanisms, while mechanisms acting after fertilisation are called post–zygotic mechanisms.
The pre–zygotic isolating mechanisms are barriers to the formation of hybrids, which include:
i) **Ecological isolation** where two species occupy the same geographical region but have differences in habitat preferences. These never encounter one another and so their gametes cannot fuse, for example Viola arvensis grow in calcareous soils while Viola tricolor prefer acidic soils,
ii) **Seasonal isolation** where two species occupy the same habitat but mate or flower at different times of the year. The reproductive organs mature at different times of the year, preventing fusion of gametes, for example in New York, the wood frogs mate in April while the bull frogs mate in July, in California Pinus radiata flowers in February while Pinus affanuata flower in April.

iii) **Behavioral isolation** where animals of different species exhibit specific courtship patterns and mating only results when the courtship display by one sex leads to acceptance by the other sex. Mismatching of courtship

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displays leads to failure of mating and fusion of gametes is therefore prevented as in certain fish, insects, birds, reptiles and mammals.

iv) **Mechanical isolation** occurs in animals where differences in genitalia prevent successful copulation, for example insect's genitalia work as a clock and key system. In plants, it occurs where related species of flowers have different pollinating animals, for example the calimyra fig is pollinated by only one species of wasp.

The post–zygotic isolating mechanisms are barriers affecting hybrids; a hybrid is the offspring of a cross between different species or breeding lines.

Post–zygotic mechanisms include:

TABLE 27.1 Mechanisms of Reproductive Isolation

	Process	Example
Prezygotic Isolation		
Temporal	Populations are isolated because they breed at different times.	Bishop pines and Monterey pines release their pollen at different times of the year.
Habitat	Populations are isolated because they breed in different habitats.	Parasites that begin to exploit new host species are isolated from their original population.
Behavioral	Populations do not interbreed because their courtship displays differ.	To attract male fireflies, female fireflies give a species-specific sequence of flashes.
Gametic barrier	Matings fail because eggs and sperm are incompatible.	In sea urchins, a protein called bindin allows sperm to penetrate eggs. Differences in the amino acid sequence of bindin cause matings to fail between closely related populations.
Mechanical	Matings fail because male and female reproductive structures are incompatible.	In alpine skypilots (a flowering plant), the length of the floral tube varies. Bees can pollinate in populations with short tubes, but only hummingbirds can pollinate in populations with long tubes.
Postzygotic Isolation		
Hybrid viability	Hybrid offspring do not develop normally and die as embryos.	When ring-necked doves mate with rock doves, less than 6 percent of eggs hatch.
Hybrid sterility	Hybrid offspring mature but are sterile as adults.	Eastern meadowlarks and western meadowlarks are almost identical morphologically, but their hybrid offspring are usually infertile.

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v) **Hybrid viability** where hybrids are formed but fail to develop to reproductive maturity. This occurs because genetic incompatibility prevents normal mitosis after formation of the zygote, for example hybrids formed between the northern and southern races of the leopard frog Rana pipien in northern North America are unviable

vi) **Hybrid sterility** where hybrids form and develop to reproductive maturity, but fail to produce functional gametes. Here, mitosis occurs in the hybrid and the individual develops to reproductive maturity, but meiosis being more sensitive to chromosomal imbalance fails as a result of segregation, resulting in abnormal gametes or compete failure of meiosis, for example the mule (2n =63) is a sterile hybrid of a horse (Equus equuus, 2n = 690) and a donkey (Equus hemionus, 2n = 66)

vii) **Hybrid break down** where there the F1 hybrids are fertile, but the F2 generation and back crosses between F1 hybrids and formed between different species of cotton (genus Gossypium) suffer hybrid breakdown.

THE PROCESSES OF SPECIATION

1. Allopatric speciation (peripatric)

Allopatric speciation occurs as a result of spatial / geographical isolation of a population by a physical barrier splitting it into two or more isolated population. Geographical barriers such as mountain ranges, seas or rivers, deserts may produce barriers to gene flow due to spatial separation. Such barriers may arise due to processes

such as glaciation, volcanic activity, flooding, earthquakes, landslides and continental drift. This inability of organisms or the gametes to meet leads to reproductive isolation.

The geographically distinct regions, differ in environmental resources and conditions such as flood availability and climatic factors. The separated populations are thus subjected to different selection pressures. Each isolated population adapts to its own environment through natural selection leading to changes in allele frequencies of the separated gene pools as a result of adaptive radiation.

The changes may also occur as a result of random genetic drift when a few colonizing individuals become founders of a new species population in a previously unoccupied area such as a newly emerged island, as a result of the founder effect.

The founder effect is the loss of genetic variation that occurs when a new population is established by a very small number of individuals from a larger population

Prolonged separation of the population leads to genetic isolation even when brought together. In this way, new species arise since the separated population can no longer interbreed.

2. Sympatric speciation.

Sympatric speciation involves the development of some form of reproductive isolation mechanism without spatial separation of the population by geographical barriers. Such reproductive isolation usually results from mutation leading to the following isolating mechanisms;

i) **Mechanical isolation** whereby copulation cannot occur due to incompatible genitalia.

ii) Seasonal (temporal) isolation where by the reproductive organs mature at different time of the year and so the organisms mate or flower at different times of the year. This prevents fusion of their gametes.

iii) **Behavioural isolation** where by differences in courtship pattern prevent mating and hence fusion of gametes.

iv) **Ecological isolation** where by differences in habitat preference prevent fusion of gamete even when in the same geographical region.

v) **Gametic isolation**; Failure for the gametes to meet for example sperms may not survive in the female's reproductive tract, or the pollen tube may fail to grow.

Failure of the gametes to fuse as a result of difference in genetic makeup of gametes making the gametes incompatible.

vii) **Hybrid unviability** where by the hybrids produced fail to develop to maturity and so they die off

viii) **Hybrid sterility** where by the hybrids produced are viable but sterile.

Sympatric speciation occurs by polyploidy.

Polyploidy is a chromosomal mutation resulting in gametes and somatic cells having additional haploid sets of chromosomes. There are two forms of polyploidy: autopolyploidy and allopolyploidy.

Autopolyploid involve gamete and somatic cells containing extra sets of the haploid numbers of chromosomes from only one species.

During mitosis for example, the chromosomes undergo replication (interphase) and the chromatids separate normally (in anaphase) but the cytoplasm may fail to clear during cytokinesis, resulting in the formation of a tetraploid cell (4n) with a larger nucleus.

The tetraploid cell will undergo normal mitosis to produce tetraploid daughter cell with large sizes due to increase in volume of the cytoplasm.

When a tetraploid cell under goes normal meiosis, it produces diploid gamete cells (2n). A normal haploid gamete (n) can fuse with a mutant diploid gamete (2n) to produce a triploid, a diploid gamete can fuse with another diploid to form a tetraploid species (4n) and so on

The chemical colchicine can induce polyploidy by inhibiting spindle formation by disrupting microtubules so that the chromatid fail to separate during anaphase; autopolyploid are fertile when they have an even number of chromosomes to give even homologous pairs during meiosis.

A modified form of polyploidy occurs in animals through chromosome replication without cell division, a process called endomitosis, to give polyploidy cells and tissues, for example in the salivary glands of Drosophila and tetraploid cells in the human liver.

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Polyploidy is much more common in plants than in animals this is because.
Most plants are capable of self-pollination and can undergo vegetative propagation.
Mutant polyploid animals usually fail to locate a genetically compatible mate or may be sexually selected against due to their abnormalities
But animal species that are permanently parthenogenetic are certainly polyploidy as in some insects and primitive fish.
Autopolyploidy is a case of intraspecific speciation
Interspecific hybridisation involves amphiploidy followed by allopolyploidy.

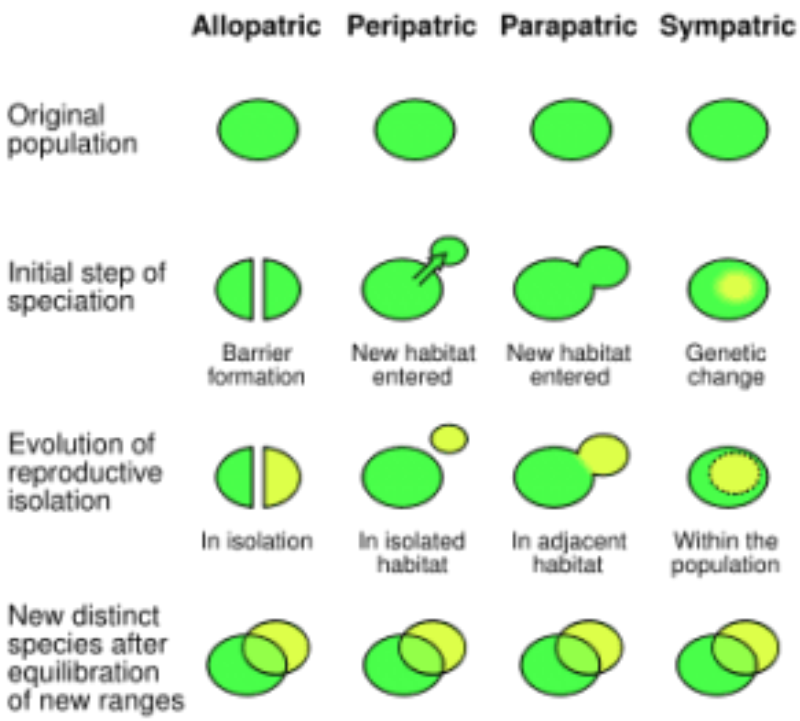
When two individuals of two different but closely related species are accidentally hybridized, the F1 offspring are amphiploid with a diploid set of chromosomes from two different species.

These amphiploid F1 hybrids are sterile as they possess non-homologous chromosomes which cannot pair during meiosis, resulting in failure to produce functional gametes. This is hybrid infertility.
However, all the non-homologous chromosomes of the F1 hybrid can undergo non-disjunction during meiosis. The foundation gametes of the F1 can also occur by autopolyploidy occurring in the sterile amphiploids where the chromosomes replicate but the cytoplasm fails to clear, causing a doubling of the hybrid chromosome number such that F2 offspring are called allopolyploids.
Allopolyploids have double the number of chromosomes of a sterile amphiploid hybrid; and are thus fertile with themselves but infertile with both the F1 amphiploid and the original non-mutant parental species, due to the extra set of chromosomes.
In plants, polyploidy has the following effects: shorter stem length, speciation, increased chance of evolution increased genetic variations, intensity to day length, increased size, increased hardness, increased resistance to drought, increased crop yield, increased nutrient content in edible parts, earlier maturation, increased number of flowers, fruits, leaves and storage organs, increased responsiveness to water and fertilizers. Such advantageous features usually rise due to heterozygosity of allopolyploids causing hybrid vigour. In animals, polyploids, usually have severe genetic disorders, shorter live spans or both

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4. Parapatric Speciation

Peripatric speciation is a form of allopatric speciation that occurs when populations that have become isolated have very few individuals. Through this process, the population goes through a genetic bottleneck. Within the small sub-population, organisms which are able to survive within the new environment may carry genes that were rare within the main population but that cause a slight variation to behavior or morphology. Through repeated matings, the frequency of these, once rare, genes increases within the small population. This is known as the 'founder effect'. Over time, the



characteristic that was determined by the gene becomes fixed within the population, leading to an isolated species that is evolutionarily distinct from the main population.

SPECIES EXTINCTION

The IUCN publishes detailed lists of species at risk of extinction in red data book, which identify 4 categories of risk.

RARE:

Species with small populations and either restricted geographically with localized habitats or with widely scattered individuals. These are at risk of becoming rarer, but they are not in immediate danger of extinction

2. VULNERABLE

These are species under threat of or actually declining in number, or species which have been seriously depleted in the past and have not yet recovered.

3. ENDANGERED

Species with low population numbers that are in considerable danger of becoming extinct.

EXTINCT

Species which cannot be found in areas they recently inhabited nor in other likely habits.

The causes of species extinctions

1. Natural selection

Species that are better adapted to the environment out compete and replaces the less well adopted species which die out.

2. Habitat destruction

Caused by human activity, like timber cutting, industrial and agricultural expansion and urbanization has driven many species to extinction.

3. Competition from humans and their animals

Species restricted to small areas are often unable to compete with influx of humans and their animals for example the giant tortoises in the Galapagos Islands.

4. Overhunting, overfishing and collecting

Humans hunt tigers for sport, crocodiles for their skins, fish are fished transport. Parrots and tamarins are collected for pet trade, and some species are overhunted for food. This greatly reduces the population sites leading to extinction.

5. Destroyed by humans as a health risk

Many species are persecuted because they carry diseases of humans and domesticated species, for example badgers (tuberculosis of cattle) and eland (spiral-horned African antelope.) (various cattle diseases).

6. Pollution

Oil pollution endangers some rare marine bird species. Bioaccumulation of persistent pesticides along food chains endangers predatory birds such as peregrines, falcons and golden eagles.

7. Very little or few variations

Species with very little genetic variation have reduced adaptability (evolutionary plasticity) making them prone to extinction when important environment changes occur.

8. Small population sizes

When the number of individuals belonging to a particular species are too few, the species may be easily wiped out by natural selection/environmental changes, human activity or natural calamities.

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9. Restricted geographical range

If the members of a species, however large, are restricted to a small geographical area, the species is much more likely to face extinction if this area is altered, such as by catastrophes, human activity.

10. Natural calamities

Catastrophes such as volcanicity, earth quakes, glaciations, landslides, floods, fire, meteor showers, cause death and sudden environmental changes, and are therefore very likely to cause mass extinction.

11. Sudden environmental changes

When the environment undergoes rapid and sudden changes, such as due to global warming and glacial activity, species may lack ample time for adapting to such changes, and thus face extinction.

The methods of preventing species extinction

- Establishing game parks, national parks, nature reserves and similar protected areas.
- Planned land use.
- Protecting and restoring species habitats.
- Legal protection of endangered species, for example it is illegal to collect, trade in or kill Koalas in Australia.
- Providing refuge and assisted breeding programmes for endangered species, such as zoos and botanical gardens.
- Removal of endangered plants and animals from areas affected by natural disasters and human activity.
- Controlling and reducing the impact of modern intensive agriculture.
- Control of introduced species to protect indigenous ones
- Ecological study of threatened habitats.
- Establishing sperm banks and seed stores to maintain the full range of genetic diversity of species.
- Controlling pollution such as smoke emissions, oil spillages, over- use of pesticides, fertilizers.
- Recycling materials.
- Education and sensitization to create awareness of importance of biodiversity, prevention of habitat destruction and encouraging of species conservation.
- Restricting urban and industrial development.
- Reclaiming derelict sites, such as mining, water tips
- Prohibiting release of non-native species into an area.
- Limiting the exploitation of renewable resources to sustainable yields.

Note:

1. Oceanic islands

An oceanic island is one which has never had any connection with the mainland, usually formed by a submerged volcanic mountain erupting and pushing up above the surface of the area, for example the Galapagos islands.

The evaluation of fauna of the Galapagos Islands.

Grant Iguana Lizards

The development and distribution of the giant iguana lizards explain geographical isolation, adaptive radiation and divergent evolution. Small terrestrial lizards with the same feet and tail structure colonized the Galapagos Islands.

The giant iguana lizards are more abundant and much larger than main land species, due to lack of competition from large and more dominant, advanced species which were absent from the islands.

Lizards are terrestrial reptiles, but on the Galapagos Islands with two species present, there is one terrestrial and one aquatic species.

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TOPIC 7: TRANSPORT IN ANIMALS

Need for a transport system

Many materials including oxygen, carbon dioxide, soluble food substances, hormones, urea etc. need to be transported from one point to another using a transport network and medium

Multicellular animals have a smaller surface area to volume ratio, higher rate of metabolism, and the distance from the body surface to the center of the body is longer, movement of materials through the many cells is difficult, so they develop transport systems.

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

Unicellular animals are smaller, have larger surface area to volume ratio, lower rate of metabolism, and the distance from the body surface to the center of the organisms is shorter, so materials move by simple diffusion with no need for specialized transport systems.

Multicellular animals may increase surface area to volume ratio by developing hollow body cavities as in coelenterates, flattening of the body as in Platyhelminthes, to eliminate the need for transport systems.

General characteristics of the transport systems of animals

1. A circulating fluid such as blood or lymph
2. A pumping device such as the heart
3. A series of tubes to carry the fluid, such as blood vessels and lymph vessels
4. Valves that ensure that the fluid is flowing in the correct direction

Importance of blood circulatory systems in animals.

1. Tissue respiration

it enables formation of energy in the tissue by transporting water and soluble food substances/metabolites to the tissues to be used as raw materials for respiration and carbon dioxide is also transported away from the tissue mainly inform of bicarbonate ions as byproduct of respiration and taken to the lungs for its removal from the body .

Oxygen is transported inform of oxyhaemoglobin from the respiratory surfaces to the respiring tissues

2. Hydration: by transporting water from the gut to all the tissues

3. Nutrition: by transporting soluble well digested food materials from the gut to body tissue.

4. Excretion: by transporting metabolic products from the tissue to the excretory organs for their removal from the body e.g. urea from the liver is transported to the kidney in order to be removed from the body.

5. Temperature regulation: by the distribution of heat, from the organs, where it is mainly generated e.g. the muscles and liver, evenly throughout the body.

6. Maintenance of constant PH via the maintenance and circulation of the plasma proteins, manufactured, by the liver, which acts as buffers to maintain the PH of the body fluids constant.

7. Growth, development and coordination: by transporting diff metabolites including hormones, needed for growth and development of the body to take place.

8. Defence: some leucocytes phagocytically ingest and destroy microbes

They also help in formation of blood clot around the wound to prevent entry of microbes into the body.

By also use the immune response mechanisms towards infections.

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BLOOD CIRCULATION

Every circulatory system possesses three distinct characteristics

1. A circulatory fluid, generally called **blood**
2. A contractile pumping device to propel the fluid around the body**. This may either be a modified blood vessel or a heart**
3. Tubes through which the fluid can circulate, called **blood vessels.**

Types of circulatory systems in the vertebrates and non-vertebrates

There are two types of vascular systems, the **closed vascular system** and the **open vascular system**.

1. The open vascular system

Blood flow occurs within the body spaces called haemocoel. Instead of blood vessels.

In this system, blood is pumped by the heart into 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.

Characteristics of the open vascular system

- Blood is not confined to blood vessels
- Blood comes into direct contact with the body tissues
- Blood flows into a series of blood spaces called haemocoel
- Blood is pumped by a heart
- Blood flows at a lower pressure
- Blood flows slowly
- Distribution of blood to the body tissues is poorly controlled.
- Blood has no respiratory function
- Present in most arthropods and some cephalop molluscs

2. The closed vascular system

In a closed vascular system, blood flows in blood vessels or sinuses. Blood is pumped by the heart rapidly around the body under sustained high pressure and back to the heart. 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.

Characteristics of closed circulatory system

- Blood is confined to blood vessels
- Blood is not permitted to come into direct contact with the body tissues
- Blood is pumped by a heart
- Blood flows at high pressure
- Blood flows rapidly
- Distribution of blood to different tissues is adjusted, depending on demand
- Blood transports respiratory gases
- The only entry and exit to the system is through the walls of the blood vessels
- Arterial and venous blood are distinctive
- Present in echinoderms, most cephalopod molluscs and all vertebrates

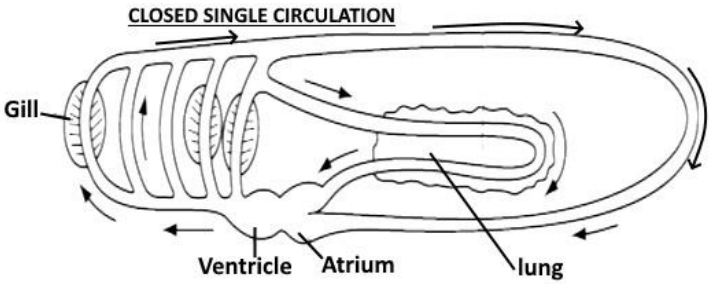
Types of closed circulatory systems

There are two closed circulatory systems: the closed single circulation and closed doubled circulation

A.The closed single circulation is where blood is confined to blood vessels, and passes through the heart only once for every complete circuit of the body, **as in fish.** Fish consists of a two chambered heart.

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When the ventricle of the two chambered heart pumps deoxygenated from the body tissue to the gills, blood becomes oxygenated and flows back to the body tissues, where it loses oxygen. Deoxygenated blood flows from 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.

It also results into sluggish flow of blood in the veins which affects the affects the distribution of oxygen and other metabolites to the tissues due to high resistance towards blood flow by the capillaries of the lungs and the body tissues.

Solution: The sluggishness of blood flow at the venous side is solved by replacing the veins with large sinuses

b) The closed double circulation system where blood is confined to blood vessels, and passes through the heart twice for every complete circuit of the body, as in amphibians, reptiles, birds and mammals.

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

Differences between single closed circulation and double closed circulation

SINGLE CLOSED CIRCULATION	DOUBLE CLOSED CIRCULATION
• Blood passes through the heart once for every complete circuit of the body	Blood passes through the heart twice for every complete circuit of the body
• Heart pumps deoxygenated blood only	Heart pumps deoxygenated blood to the lungs and oxygenated blood to the body
• Blood is oxygenated by gills	Blood is oxygenated by lungs
• Occurs in fish	Occurs in amphibians , reptiles, birds, and mammals

Demerits of the open blood circulation

I. The blood moves slowly between the tissues under very low pressure and percolates gradually back into the heart
II. Blood takes relatively longer to circulate round the whole body

Merits of a closed blood circulation

I. Blood flows under high pressure and rapidly round the body and back to the heart
II. Blood takes relatively shorter time to circulate round the whole body
III. The volume of blood flowing through a tissue can be controlled by the contraction and relaxation of the smooth muscles of the arteries

The comparative advantage of double circulation over single circulation

I. In single circulation the resistance created by the fine network of blood capillaries in the gills and the body tissues causes drop in the blood pressure, leading to sluggish flow of blood

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II. In double circulation blood is returned to the heart passing through the lungs and then pumped to the rest of the body, sustaining a high blood pressure, causing more rapid circulation. Rapid blood circulation sustains high metabolic activity. This explains why birds and mammals are homoeothermic, since endothermy requires a high metabolic rate.

The open circulatory system of insects

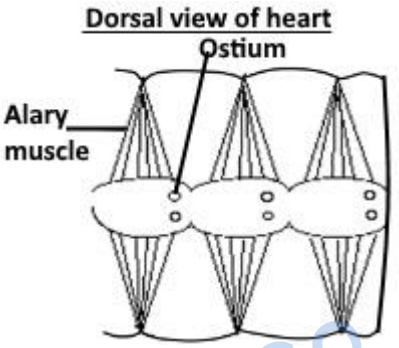
In open circulation blood is pumped out by a long, tubular heart into spaces in the body cavity called **sinuses,** where it bathes the body organs directly, but under **very low pressure**. From the body organs the blood re-enters the heart through openings controlled by **valves** and is **recirculated.**

The only blood vessel is the heart which is tubular and perforated by tiny holes called **Ostia.**

The heart is suspended by slender ligaments attached to the pericardial membrane on one end and the body on the other end.

The heart extends from the abdomen to the thorax and is expanded to form a chamber in each segment

At positions corresponding to these chambers of the heart in the pericardial membrane are muscles called **alary muscles**, which cause expansion of the heart after its contraction.

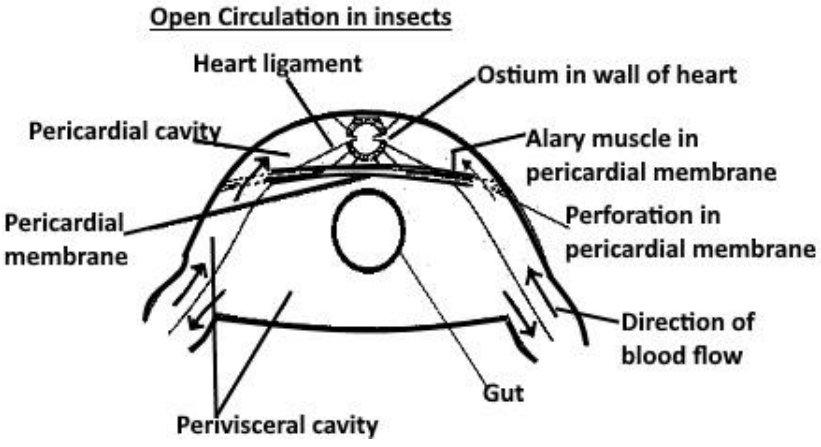


The functioning of the insect open circulatory system

Blood flows through the tubular 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 circular muscles of the heart contract, stretching the heart ligaments, the alary muscles relax, the pericardial membrane is pushed upwards, the volume of the heart decreases, the pressure in the heart increases and exceeds pressure in the haemocoel, the pressure in the **perivisceral cavity** decreases below that in the **pericardial cavity**, so blood is pumped from the heart into the haemocoel, through the aorta and into arteries that open into the haemocoel.

During diastole, the circular muscles of the heart relax, the alary muscles contract, increasing the tension on the heart ligaments, and pulling the pericardial membrane downwards, the volume of the heart increases, the pressure in the heart decreases, and fails below the pressure in the pericardial cavity, the pressure in the perivisceral cavity increases above that in the pericardial cavity, sucking blood into the heart via the open Ostia from the perivisceral cavity through the pericardial cavity, which has a lower pressure than the perivisceral cavity. The backflow of blood is prevented by the **valves** found between the **Ostia,** which allow blood to enter, but not to leave, the heart through them.



THE CLOSED SINGLE CIRCULATORY 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

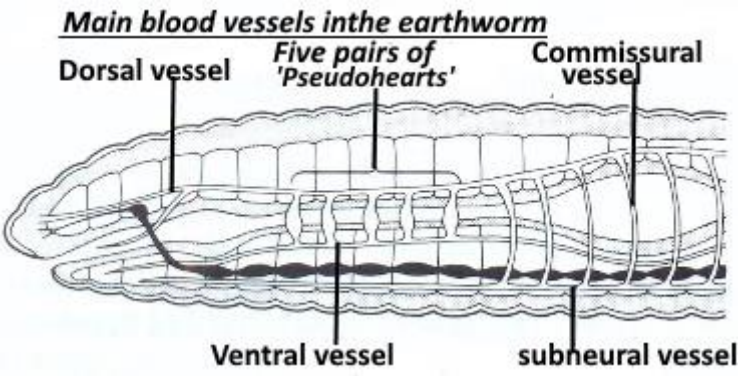
The largest vessel is the longitudinal muscular-walled dorsal vessel and it is above the alimentary canal (gut). The peristaltic contraction from the posterior end of the vessel drives blood forward to the anterior end of the

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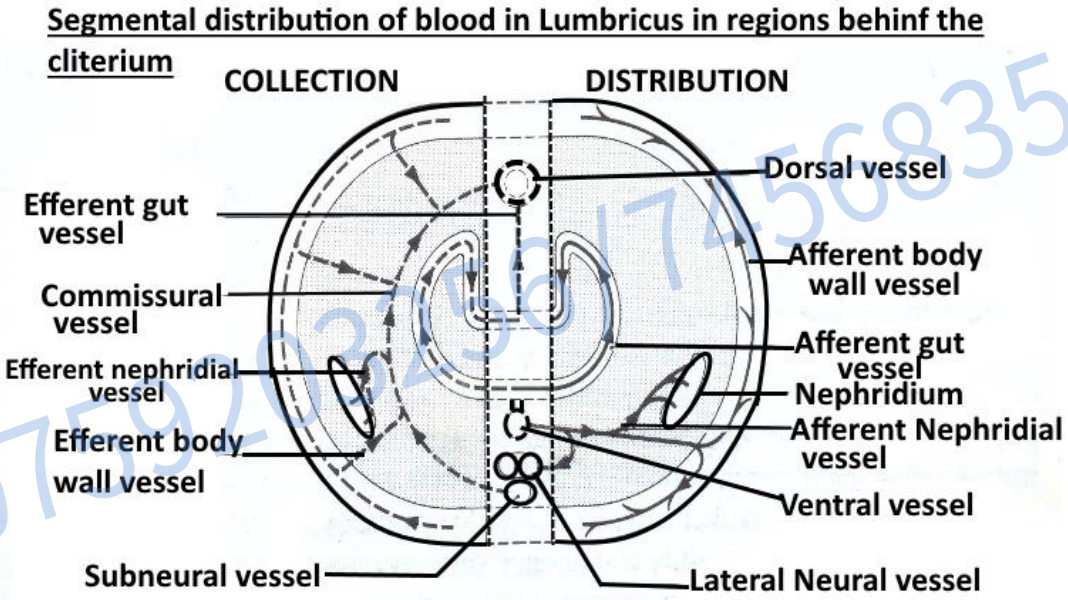
animal. The backflow of blood is prevented by valves. Each valve originates from a fold of an internal membrane or tissue of any blood vessel that is called an endothelium.

The dorsal vessel collects and receives blood from the body wall, the gut, the nerve cord and the nephridia via blood capillaries. The dorsal 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 dorsal vessel for its flow to the anterior side due to the peristaltic movement of the dorsal vessel. **The blood is red in colour with haemoglobin**



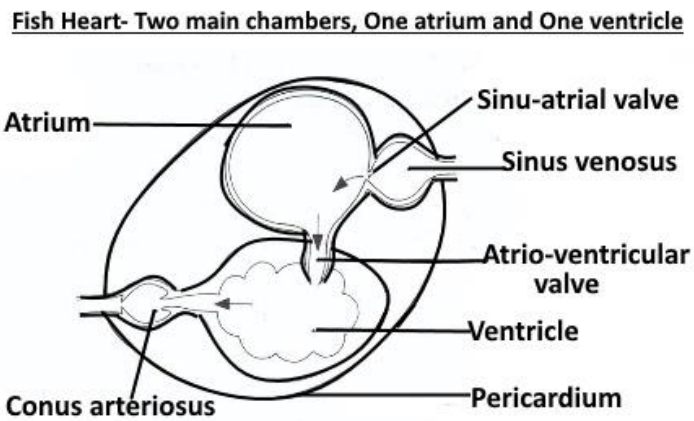
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Hearts of vertebrates

1. Pisces

Fish have a two-chambered heart, with one atrium and one ventricle. This simple heart facilitates a closed single circulation.

Blood from the general body circulation enters a thin walled chamber, the **sinus venosus,** which proceeds the heart. From here it passes into the weakly muscular atrium by negative pressure developed in the surrounding **pericardium**.it is passed on to the thicker, more muscular ventricle. When it contracts, blood is pumped via the **conus arteriosus** into a ventral aorta. Valves



between the atrium and ventricles and the ventricles and conus arteriosus prevent backflow of blood. The conus arteriosus is highly elastic and easily stretched by the pressure of the blood leaving the ventricle.
In turn its elastic walls act on the blood and force it forwards at a more uniform speed, thus enhancing a continuous flow of blood in the ventral aorta.

2. Amphibia (frog)

Incomplete double circulation

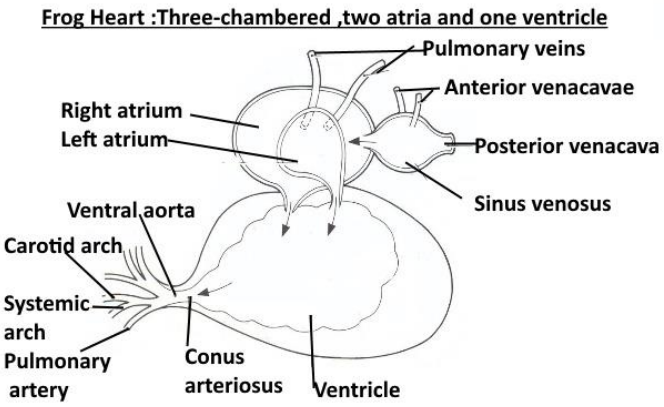
Amphibians have a **three chambered heart** with two atria and one ventricle. The atria are completely partitioned by a septum

Blood flows through three chambered heart twice for each complete circuit of the body occurs in frogs.

There is minimized mixing of oxygenated and deoxygenated blood using ridges along the walls of the ventricles which separate oxygenated and deoxygenated blood.

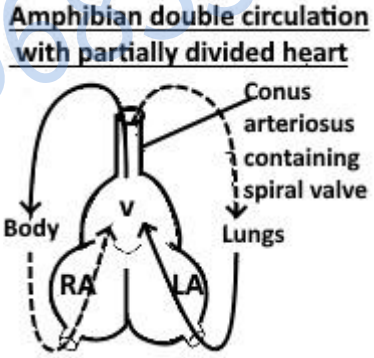
The mixing is also minimized by the spiral valves with in **conus arteriosus**.

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This heart facilitates a double circulation.

Blood which has been oxygenated at the lungs is returned to the left atrium via the pulmonary vein while deoxygenated blood from the body is passed to the right atrium via the sinus venosus by the anterior and posterior venacave. However both atria contract at the same time and deliver their blood to the single ventricle.



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 inner surface of the dorsal and ventral walls of the **ventricle is built up into ridges which prevent mixing** of the blood to some extent and enhances the separation of deoxygenated blood from oxygenated blood.

When the blood passes from the ventricle to the conus arteriosus mixing is further **prevented by a spiral valve** which incompletely divides the conus into two distinct corridors.

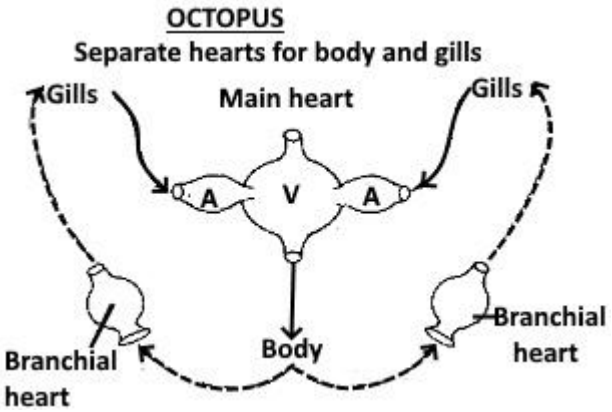
The closed single circulation in octopus and squids

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.

They tend to apply the branchial hearts to pump oxygenated blood from the body tissues to the gills

The branchial heart assists the main heart so as the increase the pressure.

Body tissue provides resistance to the flow of blood due to the presence of capillaries.



Note: in amphibians the mixing of oxygenated and deoxygenated blood is prevented by ridges and folds of the ventricles surface

Compiled by: Robert Bandikubi 077-2-582-857(watsup) /0704-728-546(roba3k@gmail.com)

The spiral valves which incompletely divides the conus arteriosus such that oxygenated blood is passed to the body and deoxygenated blood to the lungs.

3. Reptilia

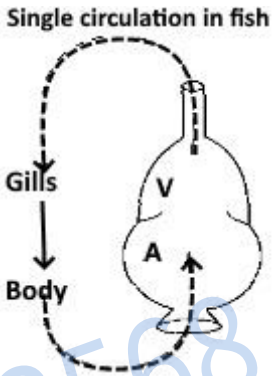
Reptiles have an incompletely four chambered heart with two atria and two ventricles. The atria are completely divided by a septum, but the ventricles are only partially divided.

Note: The exception is crocodilians which possess a complete four-chambered heart.

4. Aves and mammals

Birds and mammals have a completely four-chambered heart with two atria and two ventricles. Both the atria and ventricles possess complete septa

The closed single circulation in fish



The closed single circulatory system of fish has a two chambered heart with **one atrium and one ventricle**

Deoxygenated blood from the body is pumped by the muscular ventricle of the heart into the aorta which takes blood to the gills.

The blood gets oxygenated when it passes over the gills and then continues to flow to various parts of the body before returning slowly to the heart.

The deoxygenated blood collects first in the **sinus venosus** from where it flows into the atrium.

The complete double closed circulation in mammals

Blood flows through a four chambered heart twice for each complete circuit of the body.

One circulation is between the heart and body organs except the lungs; called the **systemic circulation**, and the other circulation is between the **heart and lungs** called the **pulmonary circulation**

Pulmonary circulation

Involves flow of deoxygenated blood from the right ventricle pumped to the lungs through pulmonary artery via the open semi- lunar valves at a high pressure due to contraction of the walls of the right ventricle.

The blood is transported to the lungs to the where it picks oxygen and loses carbon dioxide.

The oxygenated blood flows from the lungs into the bicuspid valve of the left atrium and then into the left ventricle of the heart.

Oxygenated blood enters the left atrium due to decrease in its pressure due to relaxation of its cardiac muscles

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Systemic circulation

Involves flow of oxygenated blood from the left atrium of the heart into the left ventricle and then pumped to the rest the body tissues via aorta and the return of deoxygenated blood from the body tissues back to the heart.

The walls of the left ventricle contract power full, thereby reducing the ventricular volume and increasing the ventricular pressure which forces the oxygenated blood to flow from the ventricle through the open aortic valves into aorta at a high pressure.

The aorta branches into arteries, the arteries into arterioles and the arterioles into a network of blood capillaries in the tissues where exchange of gases and materials occurs.

Finally the deoxygenated blood from the tissues flows through venules and then to veins

The blood returns to the right atrium through the venacava

This blood is distributed all over the body tissues by the arteries which branch from the aorta

These arteries include

- Renal artery which supplies the kidney
- Hepatic artery which supplies the liver
- Gastric artery which supplies the stomach
- Subclavian artery which supplies the hands

- Coronary artery which supplies the heart
- Carotid artery which supplies the head
- Femoral artery which supplies the hind limbs

Deoxygenated blood flows from the body tissues via different veins into the venacavae which transport it back to the right atrium of the heart

Vein drains the lower limb include,

- Hepatic vein drains the kidney
- Rena vein drains the kidney
  Veins which drain the upper limb
- Subclavian vein drains the upper limbs (arms)
- Jugular vein drains the head

Importance of double circulation

1. Paramount control of ever distribution of oxygen to the body.
2. A high metabolic rate can be realized by the body
3. Fast distribution of oxygen and other metabolites at a high pressure
4. Ensures separation of oxygenated from deoxygenated blood.

Factors which maintain flow of blood within the body.

- **The pumping action of the heart** forces blood into the arteries and aorta at high pressure then into blood capillaries. Also the pumping action of the heart forces blood through the **thin walled veins**.
- **Contraction of skeletal muscles** during the normal movements of a muscles squeeze blood in the thin walled veins, increasing the pressure of blood within them to flow towards the heart.
- **Presence of valves** in the veins prevent backflow of blood and allows blood flow in one direction. **This** ensures that the pressure in the veins directs blood back to the heart.
- **Inspiratory movements of the thorax (rib cage) creates a negative pressure in the thoracic cavity hence blood flow towards the heart**.
  When breathing in, the pressure in the thoracic cavity is reduced which helps draw blood towards the heart within the thorax.
- **Gravity** causes blood in organs above the heart to flow towards the heart.

The closed double circulation in mammals

This is composed of the tubular channels **called blood vessels,** a pumping organ called the **heart** and a circulating fluid called **blood.**

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. the deoxygenated blood is separated from oxygenated blood 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

The heart consists of **atrioventricular valves**/ pocket valves and semi lunar valves.

The atrioventricular valves include the following;

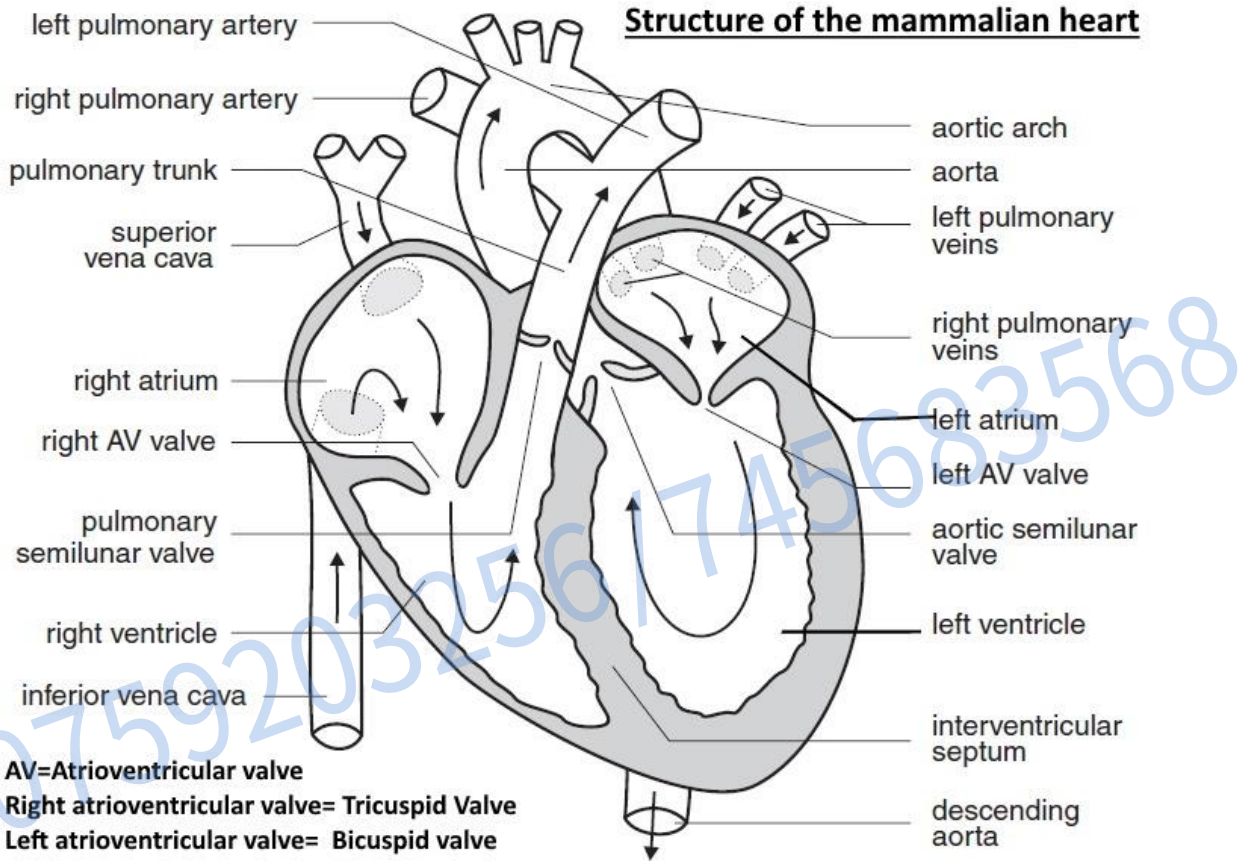
The three (3) flapped **tricuspid valves** found between the right atrium and the right ventricle

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**

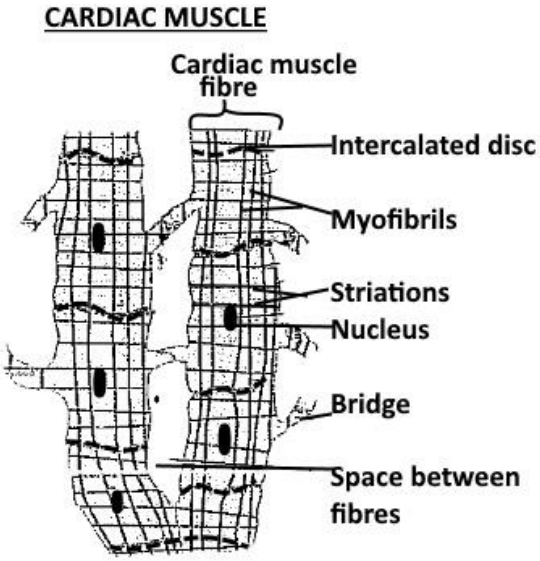
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The heart linked with four blood vessels which include the following;
The venacava which transports deoxygenated blood from body tissues through the right atrium of the heart.
The pulmonary artery which transports deoxygenated blood from the right ventricle of the heart to the lungs.
The pulmonary vein which transports oxygenated blood from the lungs into the left atrium of the heart.
The aorta which is the biggest vessel and it transports oxygenated blood from the left ventricle of the heart to the body tissues.
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.



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Structure of the heart muscle (myocardium)
Consists of numerous muscle fibres called **myofibrils** with cross striated muscle cells called cardiomyocytes, with one large centrally placed nucleus, surrounded by a sarcoplasmic reticulum, myobrils branched and joined to one another by dark bands known as **intercalated discs**, with a cytoplasm containing numerous large mitochondria and glycogen grannules



Innervation and function of the cardiac muscle
Cardiac muscle is myogenic meaning its contractions develop within the muscle
The rate of contraction can be influenced by the autonomic nervous system
Interconnections between the fibres ensure a rapid and uniform spread of excitation

Have rhythmic rapid contractions and relaxations with long refractory period and so do not fatigue as contraction is not sustained

Need a constant supply of large amounts of energy

A small number of cardiac muscle fibres and a few nerve endings from the autonomic nervous system; a sinoatrial node located near the opening of the venacava which stimulates heartbeat on their own

Adaptations of the cardiac muscle to its function

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

The cardiac cycle (Sequence of the heart beat

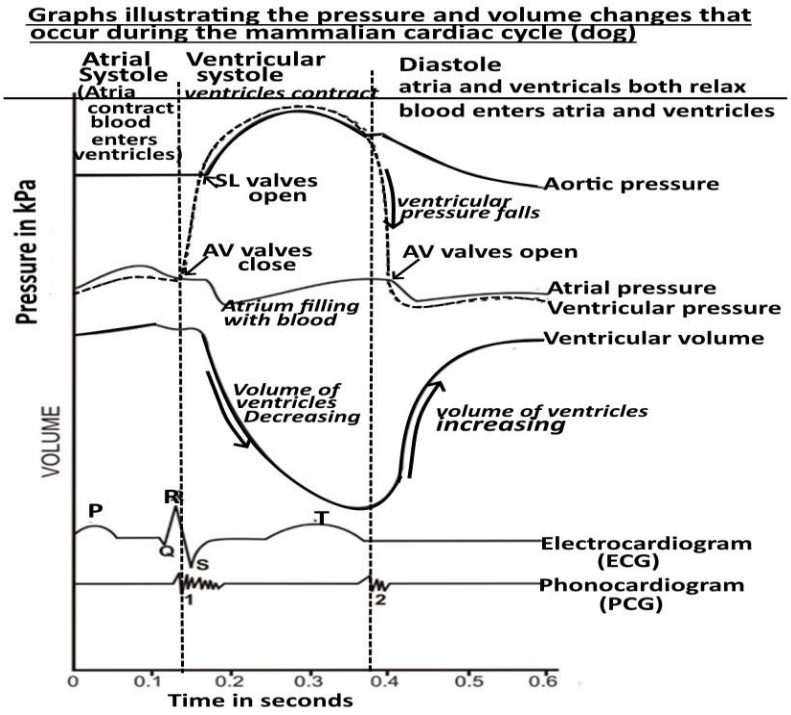
This is the sequence of events of heart beat by which blood is pumped around the body. ***OR it refers to the sequence of events which take place during the completion of one heartbeat.*** The pumping action of the heart consists of alternate contractions of heart muscles (cardiac muscles) called **systoles** and relaxations called **diastoles**. The term cardiac output refers to the volume of blood pumped from each ventricle.

Description of the cardiac cycle

During atrial diastole the cardiac muscle in the walls of both atria relaxes; atrial volume increases ,atrial pressure decreases and falls below the pressure in the great veins, so oxygenated blood flows into the left atrium from the pulmonary vein, and deoxygenated blood enters into the right atrium from the venacava.

Atrial systole

When filled with **blood atria** undergo systole, whereby the cardiac muscle in the walls of both atria contracts, atrial volume reduces, atrial pressure increases and exceeds ventricular pressure in the relaxed ventricles, forcing the **atrioventricular valves** to open, so blood is pumped from the atria



into the relaxed ventricles, thus oxygenated blood is pumped from the left atrium into the left ventricle via the open bicuspid valve and deoxygenated blood from the right atrium into the right ventricle via the open tricuspid valve.

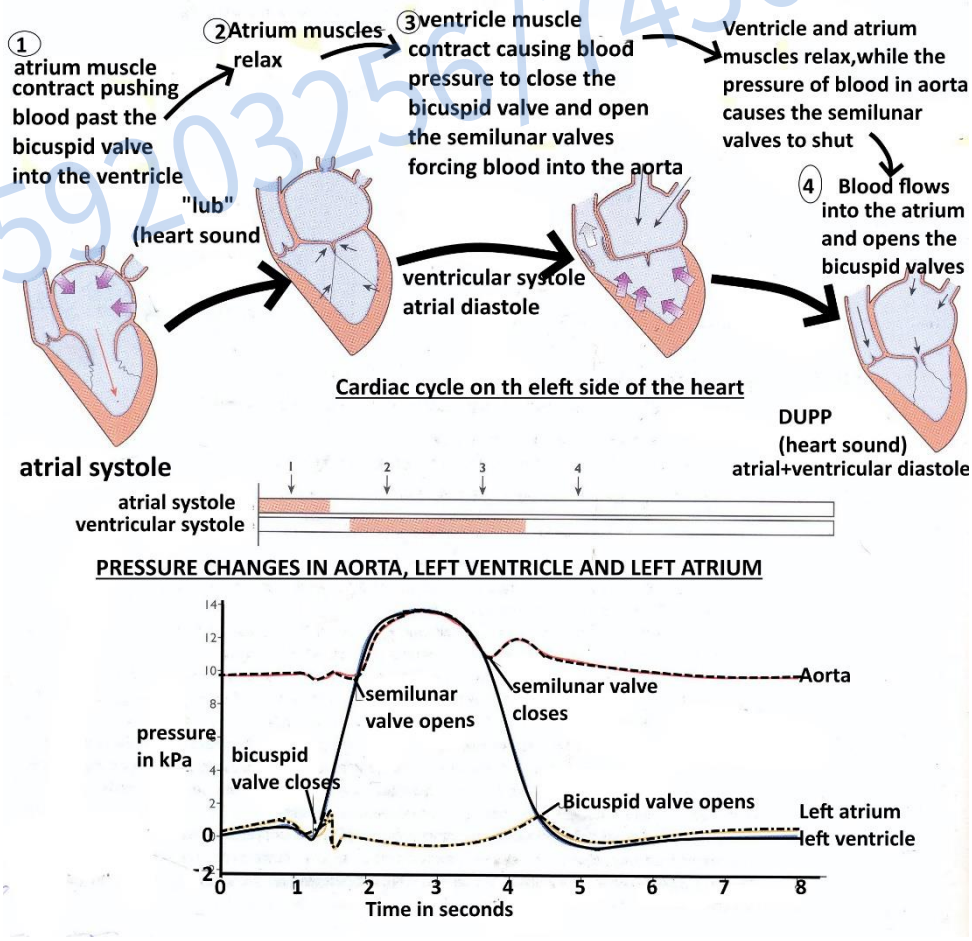
Ventricular systole

When filled with blood both ventricles undergo ventricular systole, whereby the cardiac muscle in the walls of both ventricles contracts more powerfully than the less muscular atrial walls, ventricular volume deceases, ventricular pressure increases and exceeds atrial pressure, forcing the atrioventricular valves shut, preventing back flow of blood into the atria, producing the first heart sound described as the **"lub".**

The ventricular pressure increase further, and exceeds the great arterial pressure forcing the semi-lunar valves at the bases of the great arteries open, thus deoxygenated blood is pumped from the right ventricle into pulmonary artery through the open pulmonic valve, and oxygenated blood is powerfully pumped from the left ventricle into the aorta through the open aortic valve.

The left ventricle being thicker and more muscular contracts more powerfully than the right ventricle thereby generating the higher pressure which forces blood to travel for longer distances to all body tissues.

After ventricular systole, there is a brief period of simultaneous atrial and **ventricular diastole**, whereby the cardiac muscle in the walls of both ventricles relaxes; ventricular volume increases; ventricular pressure decreases and coupled with the increased pressure in the aorta and pulmonary artery, due to elastic recoil of the elastic great arterial walls, great arterial pressure exceeds ventricular pressure forcing the semilunar valves in the bases of the aorta and pulmonary artery to close, preventing backflow of blood into the heart, and producing the second heart sound; described as the '**dub";** so the blood flows in one direction away from the heart in the great arteries.



Summary

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a) Atria in a state of diastole and filling with blood

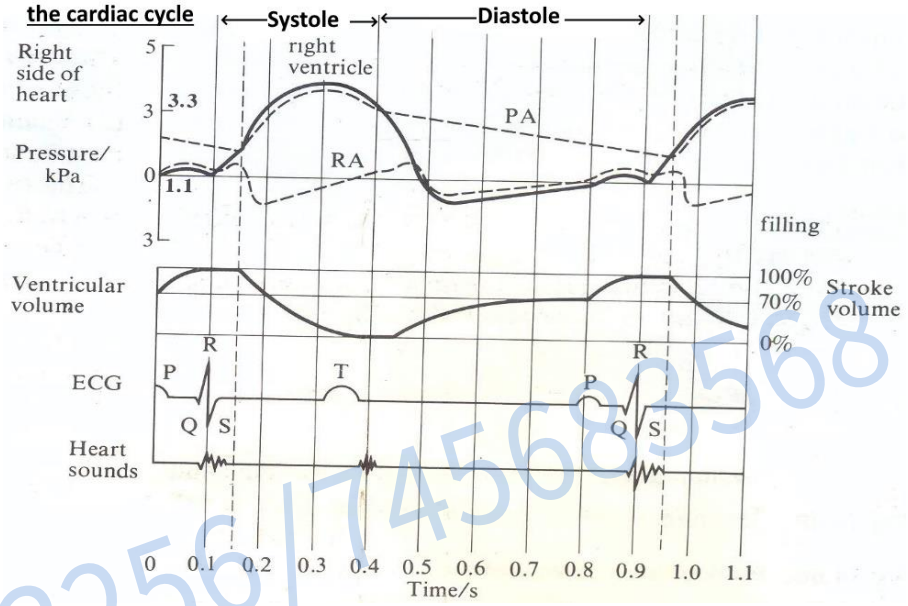
Deoxygenated blood under low pressure enters the right atrium and oxygenated blood enters the left atrium. These chambers gradually become distended. Initially the bicuspid and tricuspid valves are closed but as pressure in the atria rises, as they fill with blood, it eventually exceeds that of the ventricles and the valves are pushed open and some of the blood flows into the relaxed ventricles. This resting period of the heart chambers is called **Diastole.**

b) Atrial systole forces blood into ventricles. Bicuspid and tricuspid valves open. Sphincters of venacavae and pulmonary veins closed.

c) Atria relax, ventricles contract/ventricular systole, bicuspid and tricuspid valves closed. During ventricular systole blood is forced against the closed atrio-ventricular valve produces the first **heart sound ('lub').** Ventricular pressure rises and exceeds the blood pressure in the aorta and pulmonary artery, forcing the semilunar valves open. Blood propelled into aorta and pulmonary artery.

d) Semilunar valves/pocket valves of aorta and pulmonary artery close due to high pressure developed in the aorta and pulmonary artery to prevent back-flow of blood. The impact of this backflow against the valves causes the second **heart sound ('dub').** Atria begin to refill. Ventricles in state of diastole

The sequence of events in the cardiac muscle of the right side of the heart during the cardiac cycle

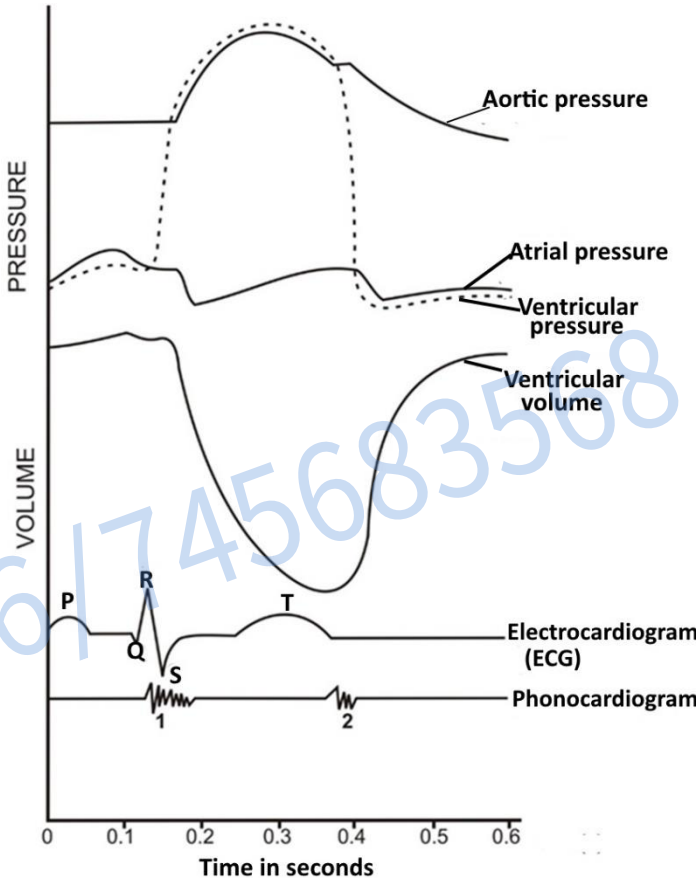


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Adaptation of the internal structure of the heart to its functioning

- Cardiac muscle fibres interconnected to form a network of fibres to ensure rapid and uniform spread of excitation throughout the walls of the heart
- Heart divided into 4 chambers to enable differential generation of pressure
- Ventricles have thicker walls than atria to generate higher pressure to pump blood over long distance into more elaborate circulation to the lungs and to all body tissues
- Walls of the left ventricle are thicker than those of the right ventricles to generate pressure to pump blood to longer distance in the systemic circulation
- Longitudinal septum which separates the heart into two halves to prevent mixing of oxygenated and deoxygenated blood
- Valves to prevent back flow of blood
- Valves have strands of connecting tissue called tendinous chords to prevent them from being pushed inside out when ventricles contract Cardiac muscle cells are highly branched terminally and connected to each other by special interdigitating processes called intercalated discs to form a network that allows rapid spread of waves of electrical excitation from cell to cell, so that linked cells rhythmically and simultaneously for fast heartbeat.
- Dense supply of blood capillaries ensures adequate supply of oxygen and nutrients for fast production of adequate ATP, for continuous rapid muscle contraction, and rapid excretion of carbon dioxide and other metabolic wastes

- Numerous large mitochondria and glycogen granules rapidly provide adequate energy in form of ATP by aerobic respiration, for continuous rapid contraction without fatigue
- The Sino-atrio node (SAN) which emits waves of electrical excitation that initiate continuous and rhythmic contraction without fatigue for continuous heartbeat
- Has cross striations for mechanical strength to support its fast and continuous contractions
- Undergoes rapid rhythmic contractions and relaxations with long refractory period, and thus does not fatigue as contraction is not sustained.
- Well-developed T-system for rapid transmission of impulses; thus rapid contraction and relaxation
- Branched muscle fibres offer a large surface area for fast spread of waves of electrical excitation, for continuous contraction hence continuous heartbeat



(a) Describe the changes in:

(i) **Changes atrial pressure**

From 0 seconds to 0.08 seconds atrial pressure increases gradually to a peak.
From 0.08 seconds to 0.14 seconds atrial pressure decreases gradually.
From 0.14 seconds to 0.16 seconds atrial pressure remains almost constant.
From 0.16 seconds to 0.19 seconds atrial pressure decreases rapidly.
From 0.19 seconds to 0.4 seconds atrial pressure increases gradually to a peak
From 0.4 seconds to 0.44 seconds atrial pressure decreases rapidly.
From 0.44 seconds to 0.58 seconds atrial pressure increases gradually to a peak
From 0.58 seconds to 0.6 seconds atrial pressure decreases gradually

(ii) Ventricular pressure

From 0 seconds to 0.08 seconds ventricular pressure increases gradually to a peak.
From 0.08 seconds to 0.14 seconds ventricular pressure decreases gradually.
From 0.14 seconds to 0.16 seconds ventricular pressure increases rapidly.
From 0.16 seconds to 0.28 seconds ventricular pressure increases rapidly to a peak.
From 0.28 seconds to 0.38 seconds ventricular pressure decreases gradually.
From 0.38 seconds to 0.42 seconds ventricular pressure decreases rapidly.
From 0.42 seconds to 0.58 seconds ventricular pressure increases gradually to a peak.
From 0.58 seconds to 0.6 seconds ventricular pressure decreases gradually.

Explain the effect of the changes in atrial, aortic and ventricular pressures on blood flow during the cardiac cycle.

From 0 seconds to 0.14 seconds the cardiac muscle in the wall of the left atrium contracts during **atrial systole, the** atrial volume decreases while atrial pressure increases and then it exceeds ventricular pressure forcing the bicuspid value open, so oxygenated blood flows from the left atrium into the relaxed left ventricle through the open bicuspid valve.

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From 0.14 seconds to 0.38 seconds the cardiac muscle in the wall of left ventricle contracts more powerfully than the atrial wall during **ventricular systole, the** ventricular volume decrease whereas ventricular pressure increases, exceeding the atrial pressure at 0.14 seconds forcing the bicuspid valve shut/close preventing backflow of oxygenated blood into the left atrium and ventricular pressure increases further and exceeds aortic pressure at 0.16 seconds forcing the semilunar/aortic valve of the aorta open and so oxygenated blood, is powerfully pumped from the left ventricle into the aorta.

From 0.38 seconds to 0.6 seconds the cardiac muscle in the wall of the left ventricle relaxes during **diastole** ventricular volume increases whereas the ventricular pressure decreases which falls below aortic pressure at 0.38 seconds forcing the semilunar/aortic valve of the aorta shut/close preventing backflow of oxygenated blood into the left ventricle and so oxygenated blood flows in a single direction away from the heart through the aorta to the rest of the body and ventricular pressure decreases further and falls below atrial pressure at 0.4 seconds forcing the bicuspid valve open, and oxygenated blood flows from the left atrium into the left ventricle.

Differences in changes in ventricular pressure and ventricular volume

From 0.14 seconds to 0.16 seconds ventricular pressure increases rapidly, while ventricular volume increases gradually.

From 0.16 seconds to 0.28 seconds ventricular pressure increases, while ventricular volume decreases.

From 0.38 seconds to 0.42 seconds ventricular pressure decreases, while ventricular volume increases.

From 0.42 seconds to 0.5 seconds ventricular pressure increases gradually, while ventricular volume increases rapidly.

Ventricular pressure attains a peak later at 0.28 seconds, while ventricular volume attains a peak earlier at 0.16 seconds.

Explain the pattern of:

(i) Electrical activity

P wave corresponds to the wave of electrical excitation spreading over the atria during atrial systole/contraction.

QRS wave corresponds to the wave of electrical excitation spreading over the ventricles during ventricular systole/contraction.

T wave corresponds to the wave of electrical excitation spreading over the ventricles during ventricular diastole/relaxation.

(ii) Pattern of Sounds on the phonocardiogram

1 is the first heart sound produced by the sudden closure of the atrioventricular valves during ventricular systole **[described as the 'lub']**

2 is the second heart sound produced by the sudden closure of the semilunar valves of the aorta and pulmonary artery during diastole [**described as the 'dub']**

NOTE;

One complete **heartbeat (cardiac cycle) consists** of one systole and one diastole, and lasts about **0.8 seconds**

In each cardiac cycle there is a louder "lub" sound during ventricular systole and a fainter "dub sound" during ventricular diastole

The heart beat is myogenic, because the rhythmic beating of the heart is stimulated by a specialized group of muscle fibres within the heart itself

The heart rate is the number of **times the heart beats per minute**

The average adult human heart rate is **72** beats per minute at rest

The arterial pulse is the wave of distention followed by constriction experienced in the arteries as a result of ventricular systole and diastole

Blood pressure is the force developed by the blood pushing against the walls of the blood vessels

Blood pressure is measured using a sphygmomanometer

Cardiac output is the product of **heart rate and cardiac frequency**

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Control of the rate of heart beat

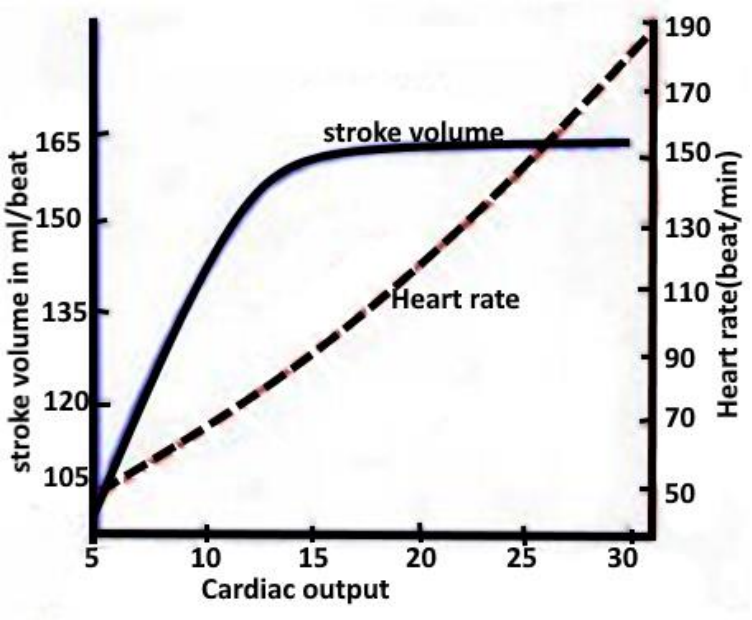
Heart rate is the number of times the heart beats per minute

Cardiac output is the volume of blood pumped by the heart, over a given period of time.

Stroke volume is the volume pumped by the heart per beat .this is the volume of blood dispatched through the pulmonary circulation (to the lungs) and through the systemic circulation (to the rest of the body) with every heartbeat. The stroke volume can and does change, e.g it increases with exercise.

Cardiac output is determined by the heart rate and stroke volume as shown below.

Cardiac output =**stroke volume x heart beat**



Myogenic stimulation 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 a specialized network of fine cardiac muscles and a few nerve endings from the autonomic nervous system found inside the wall of the right atrium close to the entrance of blood from the venacava into the right atrium, called the **Sino-atrial Node (SAN**).

The SAN can stimulate the heart beat on its own, but the rate at which it beats can be varied by stimulation from the autonomic nervous system.

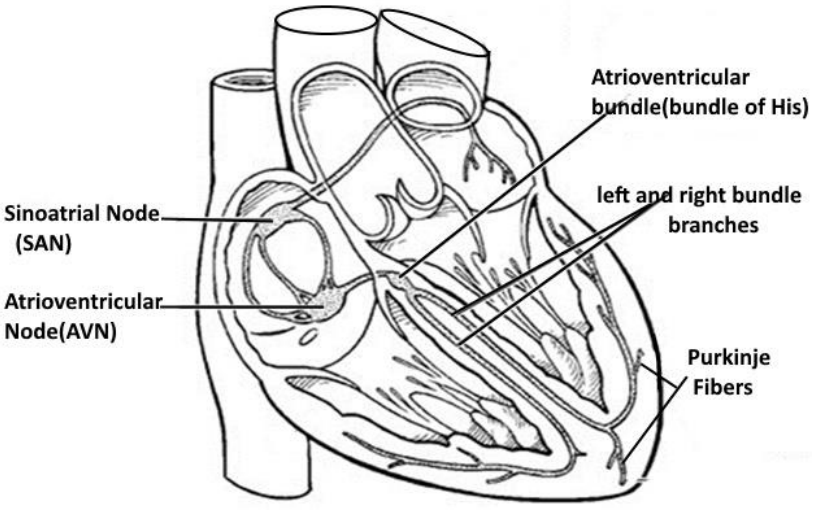
The cells of the SAN slowly become depolarized during atrial diastole, and at a certain point an action potential is set up in the cells.

A wave of excitation similar to a nerve impulse passes across the muscle fibres of the heart as the action potential spreads from the SAN

The **SAN is a pacemaker** because each wave of electrical excitation begins here and acts as a stimulus for the next wave of excitation.

The atrial muscle fibres are completely separated from those of the ventricles by a layer of connective tissue called the atrio-ventricular septum, except for a region in the atrium **called the atrio-ventricular node (AVN)**

The structure of the AVN is similar to that of the SAN and is connected to a bundle of specialized muscles fibres the **AV bundle** which provides the only route for the transmission of the wave of excitation from the atria to the atria to the ventricles.



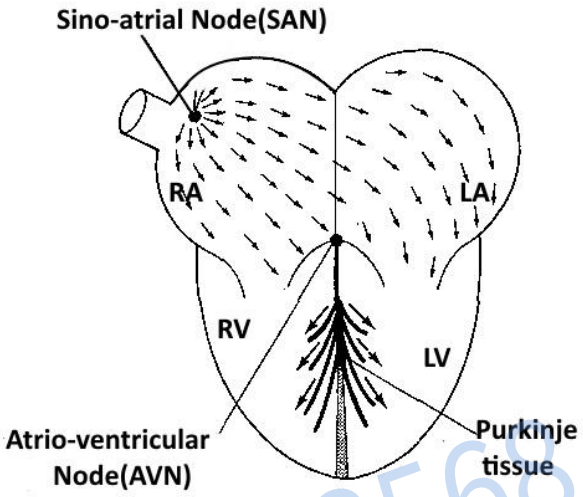
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There is a delay of 0.1s in the conduction from the SAN to the AVN which means atrial systole is completed before ventricular systole begins
The **AV bundle** is connected to the bundle of his, a strand of modified cardiac fibres which gives rise to finer branches called **purkyne tissue.**

Initiation of the heart beat

The rhythmic contraction of the cardiac muscles is initiated by the **Sino-atrial Node(SAN)** a specialized network of fine cardiac muscles and a few nerve endings from the autonomic nervous system found inside the wall of the right atrium close to the entrance of blood from the venacava into the right atrium, which sets up the pace at which the heart beats.
The cells of the SAN slowly become depolarized during atrial diastole, and at a certain point an action potential is set up in the cells, and the wave of excitation similar to a nerve impulse passes across the muscle fibres of the heart as the action potential spreads rapidly from the SAN in the right atrium to the left atrium, so both atria contract more or less simultaneously.

Diagram showing how waves of electrical excitation spread from the SAN



The wave of excitation is picked by the **atrio-ventricular node**, a region in the right atrium and transmitted to the AV bundle, which conveys it to the **Bundle of His**.
The Bundle of His conducts the wave of excitation to its finer branches called **Purkyne tissue,** spreading from the apex of the ventricle upwards, so both ventricles contract simultaneously from the bottom upwards

The PCG (phonocardiogram) is a recording of the sound the heart makes
The **ECG** (electrocardiogram) is a recording of the electrical activity of the heart
There are characteristic waves of the electrical activity marking each phase of the cardiac cycle

Control of rate of 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 heart beat.
When the rate of heart beat increases beyond the normal rate, the vagus nerve (parasympathetic nerve) is stimulated such that it lowers back to normal 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.
During intense muscle activity the muscles contract strongly, increasing the volume of blood flowing through the venacava, **stimulating stretch receptors** in the wall of the venacava, sending sensory impulses to the **cardiac accelerator Centre** in the medulla, which sends motor impulses via the sympathetic nerve of the sympathetic nervous system, which releases **noradrenaline** at the neuromuscular junction with the SAN increasing rate of depolarization in the SAN and AVN, increasing the heart rate

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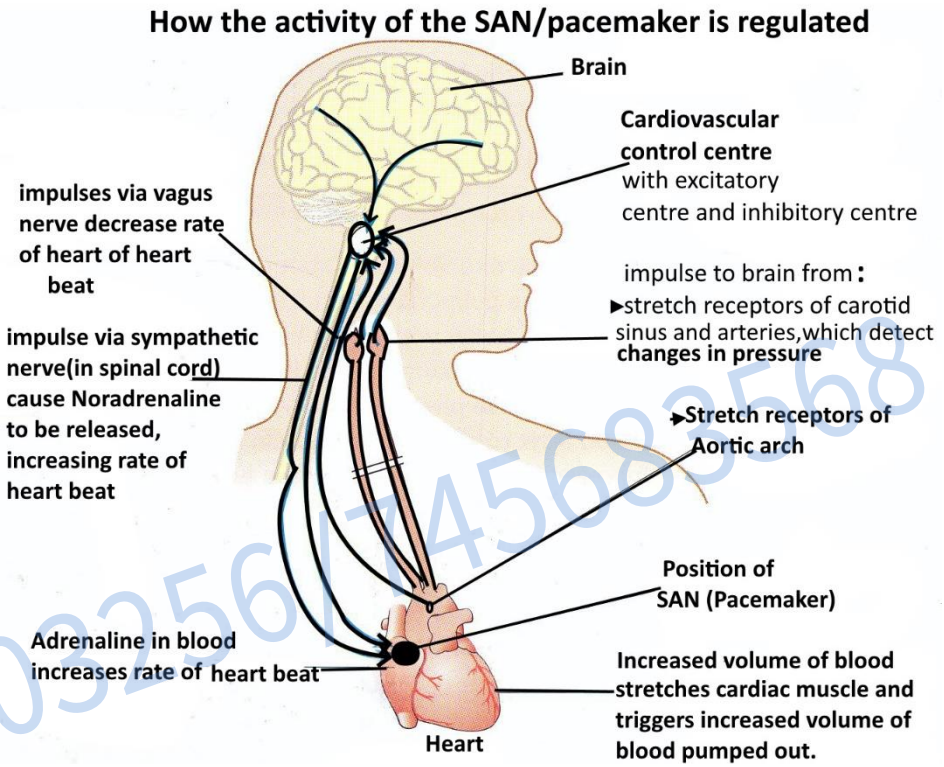
Increase in heart rate increases the volume of blood flowing through the aorta, **stimulating the stretch receptors in the wall of the aorta** and carotid sinuses, sending sensory impulses to the **cardiac inhibitory Centre in the medulla**, which sends motor impulses via the vagus nerves of the parasympathetic nervous system, which release **acetylcholine** at neuromuscular junctions with the SAN, AVN, and bundle of His decreasing the rate of depolarization of SAN and AVN, decreasing the heart rate.

At the same time increased blood flow to the heart places the cardiac muscle of the heart under increased pressure, the cardiac muscle responds autonomically (no nerves involved) to this pressure by contracting more strongly during systole and pumping out an increased volume of blood(stroke volume is increased)

This relationship between the volume of blood returned to the heart and cardiac output was named after the English physiologist Starling and is known as **Starling's law. It states that the power of cardiac contraction is directly related to the length of the cardiac muscle fibre.**

The increased stroke volume stretches the aorta and carotids which in turn, via stretch reflexes, signal the cardiac inhibitory Centre to slow the heart rate.

Therefore there is an automatic fail safe mechanism which serves to prevent the heart from working too fast, and enable it to adjust its activity in order to cope effectively through it at any given time.



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Effect of carbon dioxide concentration on the heart beat

In addition, increased muscular activity increases carbon dioxide concentration lowering pH below the norm, stimulating the **chemoreceptors in** the carotid artery and aorta, sending sensory impulses to the cardiac accelerator Centre in the medulla, which sends motor impulses via the sympathetic nerve of the **Sympathetic nervous system**, which releases noradrenaline at the neuromuscular junction with the SAN, increasing the rate at which it emits waves of electrical excitations, increasing the rate of the contraction of the cardiac muscles of heart. Hence increasing cardiac out, blood pressure and speed of blood flow to the muscle with excess carbon dioxide to remove it away from the muscles to the lungs.

And decreased carbon dioxide tension, raises PH below the norm, stimulating chemoreceptors in the carotid body and aortic body, sending sensory impulses to the cardiac inhibitory center in the medulla which sends motor impulses via the **vagus nerves** of the **parasympathetic nervous system** which releases acetylcholine at the neuromuscular junctions with the SAN, AVN, and bundle of His. This reduces the rate of electrical excitation emission by SAN, thereby reducing the rate of cardiac muscle contraction hence reducing the rate of heart beat.

Hormonal control of the heart rate

A number of hormones affect the heart rate directly or indirectly

Adrenaline

Cerebral cortex fires impulses along the cardiac acceleratory Centre of the cardio-vascular of medulla oblongata which fires impulses along the sympathetic nerves of the sympathetic nervous system which fire impulses to the adrenal medulla.
Adrenal medulla secretes adrenaline and noradrenaline into the blood stream which stimulate the SAN to increase the rate at which waves of electrical excitation are emitted to the cardiac muscle hence increase in the heart rate.
Both hormones stimulate the heart, although adrenaline is more effective. Cardiac output and blood pressure are increased by increasing the rate. The two hormones also have effects on the body which prepare the body for action ('flight and fight" response)
Thyroxine, produced by the thyroid gland, raises basal metabolic rate.
Thyroxine can directly increase the heart rate by stimulating the SAN to increase on the rate at which it emits waves of electrical excitations to the cardiac muscle hence increasing the rate of heart beat.
Indirectly by increasing the basal metabolic rate, which increases the breakdown of glucose to form energy. Thereby increasing the oxygen demand by the muscles which stimulates an increase in the rate of heart beat.

Increased metabolic activity, leads to greater demand for oxygen and production of more heat and as a result, vasodilation (dilation of blood vessels) followed by increased blood flow occurs.
This in turn Leads to increased cardiac output.
A summary of factors determining the rate of heart beat

1. **Age:** Heat rate is faster in younger mammals than in adults, because younger mammals have higher metabolic rates
2. **State of health**: Infection and diseases can change the rate of heart beat
3. **Level of physical exercises**; A higher level of exercise increases the metabolic rate and hence the heart rate
4. **Body size:** Smaller animals have higher metabolic rate and hence higher rate of heart beat
5. **Hormonal level:** A number of hormones such as adrenaline, noradrenaline and thyroxine increase the heart rate
6. **pH:** High pH decreases the heart rate, while **low pH/rise in CO_2** tension in blood directly affects the cardio-acceleratory Centre resulting into increased heart rate.
7. **Temperature:** When the body temperature is low then the rate of heart beat is low and when the body temperature is high, the rate of heart beat is high. High temperature accelerates the heart rate due to increased metabolic activity.
8. **Emotional state of an animal**: A variety of emotions such as excitement, embarrassment, anger, fear and anxiety increase the heart rate **while** feelings of grief and depression may slow the heart rate down.

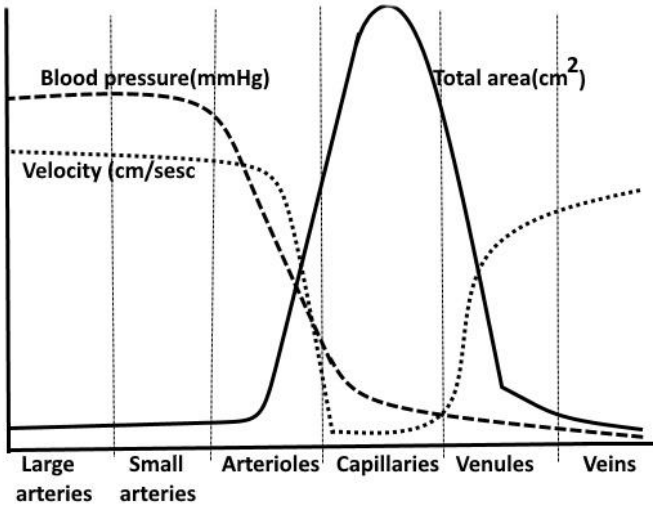
Blood flow velocity
The speed of blood flow reduces as it moves from arteries to arterioles and then to capillaries. Each artery conveys blood to so many capillaries that the total cross-sectional area is much greater in capillary beds than in the arteries or any part of the circulatory system. The result is an increase in velocity from the arteries to capillaries than in the aorta.
The reduced velocity of blood flow in capillaries is critical to the function of the circulatory system. Capillaries are the only vessels with walls thin enough to permit the transfer of substances between the blood and interstitial fluid. The slower flow of blood through these tiny vessels allows time for exchange to occur. After passing through the capillaries, the blood speeds up as it enters the venules and veins, which have smaller total-sectional areas

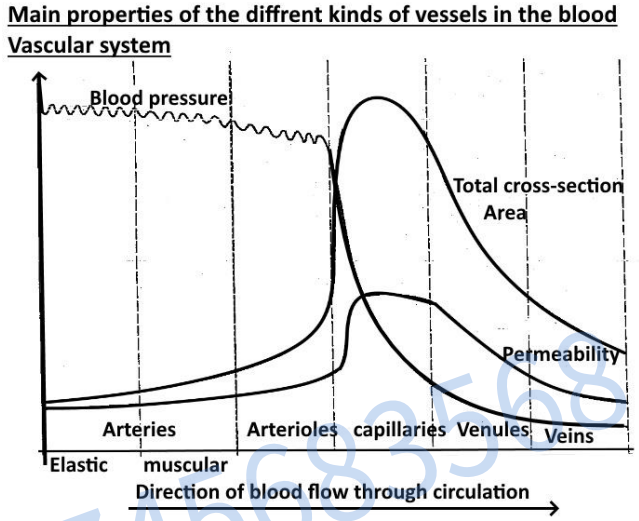
Blood pressure: This is the force developed by blood against the walls of blood vessels mainly due to pumping action of blood by the heart.

Blood pressure is the force developed by blood against the Walls of blood vessels during contraction and relaxation of the ventricles.

Contraction of the heart ventricle generates blood pressure, which exerts a force in all directions. The force directed lengthwise in arteries causes the blood to flow away from the heart, the site of highest pressure. The force exerted against the elastic wall of an artery stretches the wall, and the recoil of the arterial wall plays a critical role in maintaining blood pressure, and hence blood flow, throughout the cardiac cycle. The numerous arterioles and capillaries offer resistance to blood flow hence reducing the blood pressure. **Ventricular systole causes a blood pressure of 120mmHg**

Ventricular diastole causes a blood pressure of 80 mmHg

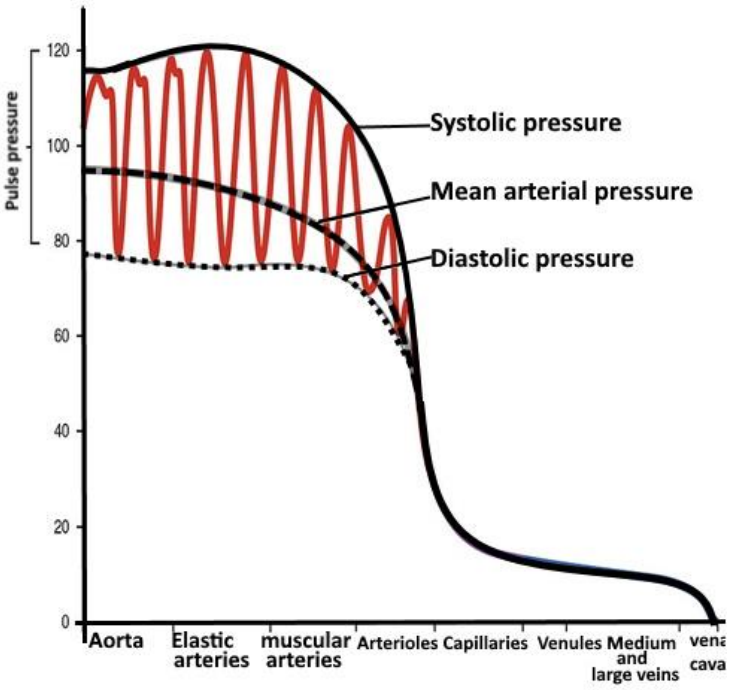




Changes in blood pressure during the cardiac cycle

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. Arterial blood pressure is highest when the heart contracts during ventricular systole, this is systolic pressure. This is also due to the narrow openings of arterioles impeding the exit of blood from arteries. Hence, when the heart contracts, blood enters the arteries faster than it can leave, and the vessels stretch from the rise in pressure

During diastole, the elastic walls of the arteries snap back. As consequence, there's a lower but still substantial blood pressure when ventricles are relaxed (diastolic pressure). Before enough blood has flowed into the arteries to completely relieve pressure in the arteries, the heart contracts again. Because the arteries remain pressurized throughout the cardiac cycle blood continuously flows into arterioles and capillaries.



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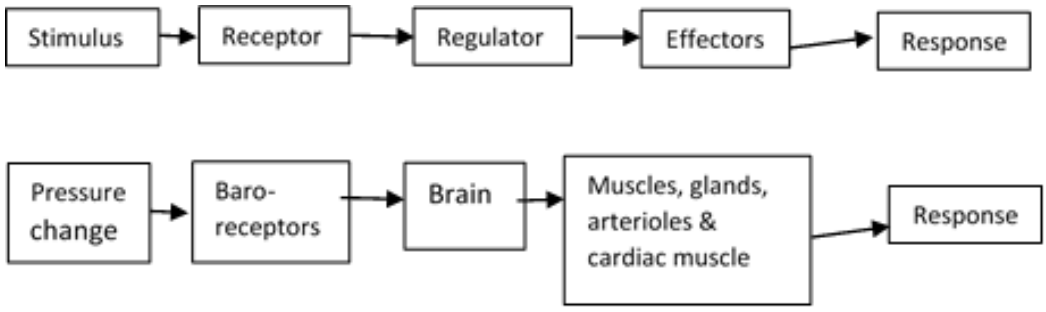
Compiled by: Robert Bandikubi 077-2-582-857(watsup) /0704-728-546(roba3k@gmail.com)

NOTE:

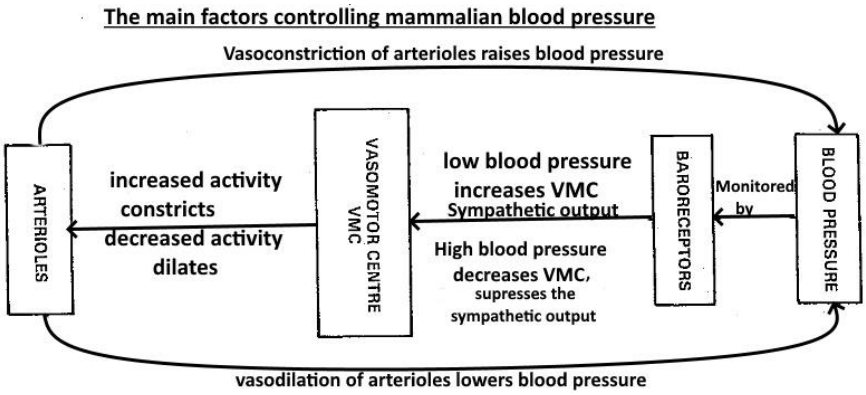
Blood is expelled from the heart only when it contracts. Blood flow through the arteries is therefore *intermittent,* the blood flowing rapidly during systole and slowly during diastole. However, by the time the blood reaches the capillaries it is flowing evenly. The gradual change from intermittent to even flow is made possible by the elasticity of the of the arterial walls which contain elastic tissue and smooth muscles

CONTROL OF BLOOD PRESSURE

Blood pressure is controlled via control of heart rate and cardiac output together with the control of peripheral resistance towards blood flow by the blood vessels, mainly the arteries.
When the arterioles constrict (the smooth muscles of their walls contract), there is increased resistance towards blood flow which results into increase in blood pressure.
When the arterioles undergo vasodilation (the smooth muscles of their walls relax), the resistance towards blood flow reduces which in turn reduces blood pressure.
Vasomotor Centre of medulla oblongata controls blood pressure. Small receptors which are sensitive to stretching, called **baroreceptors** are found in the walls of aortic arch, 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 **cardiovascular Centre** found in the medulla oblongata of the brain via the afferent nerves (sympathetic nerves). The cardiovascular Centre sends impulses to the heart via the efferent nerves (vagus nerves), which results into reduction of the **cardiac output.**
When blood pressure is above the normal baroreceptors in aorta and carotid sinuses detect changes in blood pressure and become stimulated to fire impulses to the vasomotor Centre of medulla oblongata which suppresses sympathetic output**. The vasomotor Centre** sends impulses via the parasympathic system to the arterioles, causing them to undergo **vasodilation. Their resistance to blood flow is reduced thereby** lowering the blood pressure.
A rise in blood carbon dioxide concentration also causes a rise in blood pressure. This increases the speed with which blood is delivered to the lungs and so helps remove the carbon dioxide more quickly.
When the **blood pressure lowers** below the norm, the **baroreceptors** stop being stimulated and this leads to impulses being fired from the cardiovascular Centre to heart. The cardiac output is then increased.
If blood pressure falls below the normal, the vasomotor Centre of the medulla oblongata fires/sends impulses along sympathetic nerves to the arterioles. By secreting noradrenaline from their endings the nerves bring about contraction of the smooth muscles in the walls of the arterioles, resulting in narrowing of the arterioles called **vasoconstriction and their resistance towards blood flow increases** hence increasing the blood pressure back to normal.



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NOTE: When the arterioles constrict (vasoconstriction) blood pressure is raised and when they dilate (expand) the blood pressure decreases.

The brain includes the vasomotor, cardiovascular centre and the medulla oblongata.

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 pressure depends on the following factors;

1. Blood volume
2. Blood vessel radius/ diameter of the lumen
3. heart rate
4. stroke volume
5. heart strength
6. peripheral resistance of blood flow by mainly the arterioles
7. chemicals like adrenaline and thyroxine increase heart rate hence increase blood pressure
8. Concentration of CO_2 and O_2. when CO_2 Concentration is high ,it causes local vasodilation of the arterioles
9. Accumulation of lactic acid also stimulates local vasodilation of arterioles so that the lumen widens so as to let a large volume of blood move to the tissues for the expulsion of CO_2 from the body.

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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** $\alpha \frac{1}{r^4}$). 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.

NOTE:

Blood is expelled from the heart only when it contracts. Blood flow through the arteries is therefore ***intermitten***t, 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 arterial walls which contain elastic tissue and smooth muscles.

BLOOD VESSELS

There are three main types of blood vessels; **arteries; veins and capillaries**

Arteries: transport blood from the heart

Transport oxygenated blood from the heart to tissues except the pulmonary artery which carries deoxygenated blood from the heart to the lungs

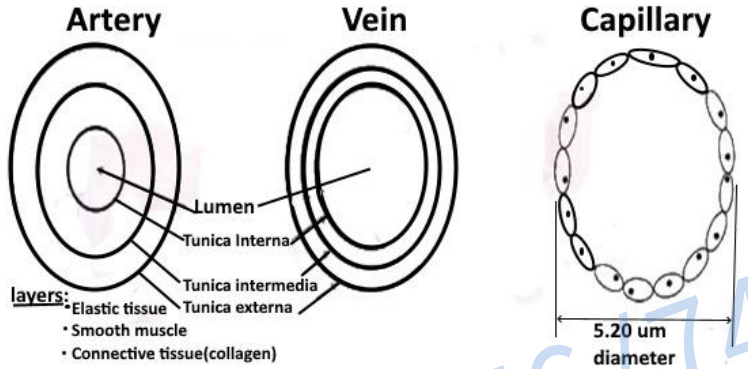
Pulse: Is the wave of dilation of the walls of arteries, during flow of blood through them at a high pressure.

Pressure in capillaries is very low due to high resistance and inform of a dense network with a large surface area to carry a large volume of blood.
Each artery and vein consists of three basic layers, namely;

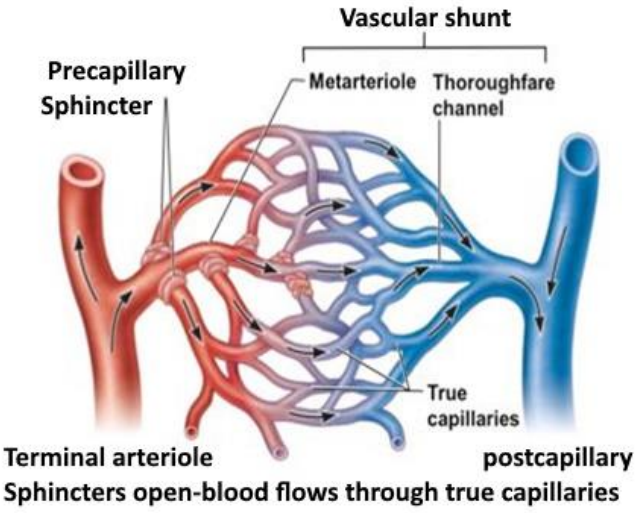
1. **Tunica externa (outer most layer)**
2. **Tunica media (middle layer)**
3. **Tunica interna (inner most layer)**

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.
Blood capillaries consist of only the endothelium

A comparison of the structure of blood vessels



Capillaries are sites of exchange of materials between the blood circulation and the tissues
Precapillary sphincter regulates the amount of blood flowing into capillary network.
Arterio-Venous shunt vessel/vascular shunt regulates the amount of blood passing through the capillaries.
Capillaries are in direct contact with the body tissues, this reduces the diffusion distance of materials so that they can easily diffuse into the tissues
They have a thin (a single celled membrane), this reduces diffusion distance of materials for their fast diffusion if materials into the tissues.
By branching into a dense network and numerous in number provides a large surface area for maximum diffusion and exchange of materials.
Capillaries are in close contact with the body cells to reduce the diffusion distance of materials for their fast diffusion
The lumen is very narrow thereby providing maximum resistance towards blood flow resulting into sluggish flow of blood through them, this maximizes the diffusion and exchange of materials
Red blood cells being flexible squeeze themselves through the narrow lumen and this slows down the speed of their movement there by maximizing the diffusion of oxygen and exchange of respiratory gases



Increases membrane surface area for respiratory gases between the capillary and red blood cells thereby increasing their rate of diffusion.

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Similarities

- All are tubular, hence have a lumen
- All have an inner lining endothelium
- All transport blood

Differences

Arteries	Veins	capillaries
Have thick muscular walls	Have thin muscular walls	Have no muscle
Have much elastic fibre	Have little elastic fibre	Have no elastic fibres
Have a small lumen	Have a large lumen	Have the largest lumen
Have no semi lunar valves except at the bases of the aorta and pulmonary artery	Have semi lunar valves throughout their length	Have no semilunar valves
Can constrict	Cannot constrict	Cannot constrict
Not permeable	Not permeable	Permeable
Transport blood away from the heart	Transport blood towards the heart	Link arteries to veins
Transport oxygenated blood except the pulmonary artery	Transport deoxygenated blood except in the pulmonary vein	Blood changes from oxygenated to deoxygenated
Blood flows under high pressure	Blood flows under low pressure	Blood flows at moderate pressure
Blood moves in pulses	Blood moves with no pulse	Blood moves with no pulse
Blood flows rapidly	Blood flows slowly	Blood flows slowing
Low blood volume	Highest blood volume	High blood volume

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 have 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.

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Functional differences

Artery	Vein	Capillaries
Carry blood away from the heart	Carry blood towards the heart	Carry blood to and from the heart
Carry oxygenated blood except pulmonary artery and umbilical artery	Carry deoxygenated blood except pulmonary vein and umbilical vein	Carry both oxygenated and deoxygenated blood
Blood flow at high pressure(flow in pulse)	Blood flow at low pressure	Blood flow at intermediate pressure
Blood flow in pulse	Blood does not flow in pulse	Blood does not flow in pulses

Structural differences

Artery	Veins	Capillaries
Have thick walls with smooth muscles	have thin walls with smooth muscles	Have thinner walls with smooth muscles
have more elastic fibres	Have few elastic fibres	Do not have elastic fibres
Have smaller lumen relative to diameter	Have a wider lumen relative to diameter	Have largest lumen relative diameter
Have no valves except at the base of aorta	Have valves throughout their length	Have no valves

The functioning of blood vessels

(a) Arteries carry blood away from the heart

Adaptations of arteries to their function

- Large arteries near the heart (aorta, subclavian and carotids) have thick muscular walls with much elastic tissue, enabling them to stretch (dilate) and not rapture when the heart contracts and forces blood into them at high pressure.
- Between heart beats the arteries undergo elastic recoil and contract smoothing out the flow of blood along their length.
- Smaller arteries further away from the heart are supplied with neurons from the sympathetic nervous system, where nervous stimulation regulates the diameter of these arteries and thus controls the flow of blood to different parts of the body.
- Arterioles possess circular muscle fibres called sphincters at the point where they enter the blood capillaries, and contraction of the sphincters prevents blood flowing into the blood capillary beds networks, enabling regulation of the quantity of blood flowing into blood capillary beds according to the needs of the body
  Note: Following contraction of sphincters the blood shortcuts from arterioles to venules through cross connections called shunt vessels
- The bases of the aorta and pulmonary artery contain semilunar valves which prevent back flow of blood into the heart.

b. **Blood capillaries** link arteries to veins and function as the site for the exchange of materials between blood and tissues.

Adaptations of blood capillaries to their functions

- Blood capillary walls consist only of an endothelium which is one cell thick, and are therefore permeable to water and dissolved substances.
- The blood capillaries are so numerous and form a dense network which provides a large surface area for exchange of material between blood and tissues.

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- Blood flows slowly through the blood capillaries because in total they have a very large cross-sectional area, allowing ample time for sufficient exchange of materials.
- Some capillaries have a bypass arterio-venous shunt vessel which links the arterioles and venules directly so as to regulate the amount of blood which flows through the capillary network e.g. in the capillaries of the feet, hands, stomach etc.
- The capillary network offers maximum resistance to blood flowing through them hence decreasing the speed of blood flow which allows the maximum diffusion and exchange of materials between blood and the tissues. 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

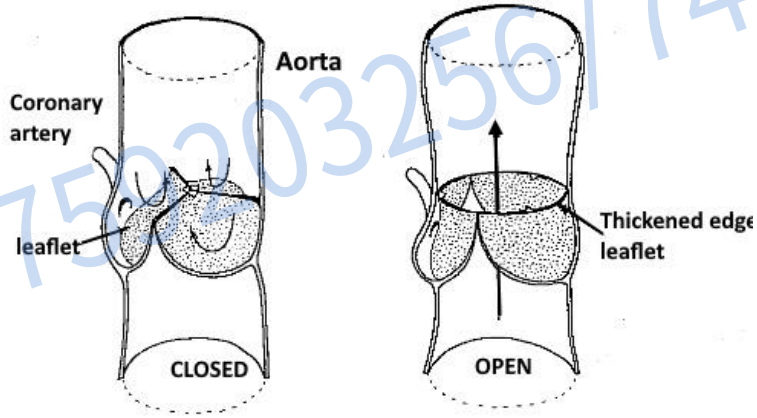
a) Veins

Veins transport blood towards the heart

Adaptations of veins for their function

- Veins have a large lumen which provides enough space for the mass flow of large volumes of blood back to the heart.
- They have wide lumen to encourage flow of blood at low pressure.
- They have thinner walls than arteries which are adequate to withstand low pressure.
- They have valves at intervals along their length which prevent blood from flowing backwards / maintain flow of blood in one direction.
- Veins possess semilunar valves formed from folds of the inner walls of the veins, which prevent the back flow of blood, ensuring one-way flow of blood.

An illustration of the action of a semilunar valve



A number of veins are located between the large muscles of the body, as in the arms and legs, and when these muscles contract they exert pressure on the veins and squeeze them flat, thereby helping the flow of blood to the heart.

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

Importance 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

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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. **Defense.** Blood defends the body against diseases through the following ways;
9. **By using some white blood cells** (leucocytes) which phagocytotically ingest and destroy pathogens that cause diseases.
10. **By formation of a blood clot** around the wound so as to prevent entry of microbes or pathogens into the body.
11. By use of the immune response mechanism towards infection e.g. by use of the different types of antibodies to destroy the microbes

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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 in the blood serum that all the different soluble materials are dissolved e.g. urea, hormones, soluble food substances, bicarbonate ions etc.

The plasma proteins are manufactured by the liver and include the following;

1. Fibrinogen. This protein is important for normal blood clotting by changing into fibrin in the presence of thrombin enzyme.

Fibrinogen (soluble) ⟶ **Fibrin (insoluble)**

2. Prothrombin. This is the inactive form of the proteoltyic enzyme, thrombin, used in converting fibrinogen to fibrin during the clotting of blood.

3. 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.

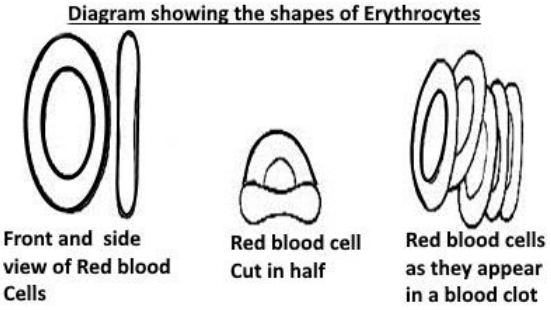
4. Blood cells. There are three main types of blood cells which include;

- **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.

Diagram showing the shapes of Erythrocytes



Front and side view of Red blood Cells | Red blood cell Cut in half | Red blood cells as they appear in a blood clot

Adaptations of red blood cells to their function

- Lack nuclei when mature giving them a circular, biconcave disc shape. The shape results in a large surface area to volume ratio which increases the area over which gaseous exchange can occur.
- Thin membranes thus allowing the efficient diffusion of gases across its surface.
- Circular biconcave disc shape makes them flexible allowing them to squeeze through capillaries whose internal diametres are smaller than their own by bending into shapes like umbrella shapes
- Numerous about 5million per mm^3 of blood. They thus make up about have the volume of blood giving blood enomous oxygen carrying capacity about 20cm3 of oxygen per $100cm^3$ of blood.
- Packed with haemoglobin the oxygen carrying pigment which gives blood its red colour. Each haemoglobin molecule can carry a maximum of 4 oxygen molecules forming oxy-haemoglobin.
- Lack nuclei providing more room for the packing of haemoglobin
- Lack mitochondria which also make more room for the packing of haemoglobin.
- Lack of mitochondria means red blood cells respire anaerobically and thus do not use up any of the oxygen they carry.
- Haemoglobin combines reversebly with oxygen to form oxy-haemoglobin in areas of high oxygen concentration/ low carbon dioxide tension and releases the oxygen in regions of low oxygen concentration/high carbon dioxide tension, this ensures that oxygen is taken up readily at the respiratory surface where carbon dioxide concentration is low and oxygen concentration is high.
- Contain the zinc containing enzyme **carbonic anhydrase** which catalyses the dissociation of carbonic agid into protons and bicarbonate ions, which process is important in the transport of carbon dioxide.
- Contain various glycolytic enzymes such as dehydrogenases, phosphokinases, isomerases, enolases and co-enzymes such as **NAD, Mg2+, K+,** necessary for anaerobic respiration which provides them with energy.
- Rate of destruction and replacement of red blood cells is partly determined by the amount of oxygen in the atmosphere. If the quantity of oxygen being carried in the blood is low, the bone marrow is stimulated to produce more red blood cells than the liver destroys. This allows acclimatization to lower oxygen levels at high altitude. When the oxygen content of the blood is high, the situation is reversed.

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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 $7000/mm^3$ of blood. They are mainly manufactured by the bone marrow. They are classified into two main types which include;

Granulocytes (polymorph nuclear 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%)

A granulocytes (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;

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 etc.

Eosinophils (1.5%) possess anti-histamine properties and their number increases in people with allergic reactions such as high fever, asthma etc. 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.

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

- They have enzymes in their cytoplasm to digest the engulfed micro organisms
- They do not have a fixed shape and hence the amoebic movements used to engulf pathogens.
- They have an irregular shaped nucleus which allows them to squeeze through the narrow capillaries
- They have a large nucleus which contains many genes for the control of antibody production.

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.

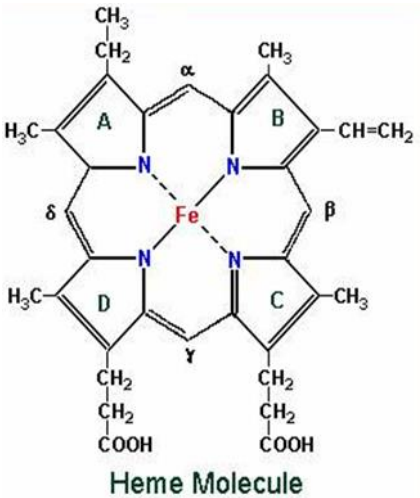
TRANSPORT OF OXYGEN

The equation below shows how haemoglobin combines with oxygen.

As shown by the equation above, each haem group combines with one oxygen molecule and therefore 1 haemoglobin molecule carries four oxygen molecules.

$$Hb + 4O_2 \leftrightarrow HbO_8$$

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, a**nd 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



Heme Molecule

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.**

Other oxygen carrying pigments

There are several other groups of blood pigments and they differ mainly in the nature of prosthetic group. Chlorocruorin and haemoerythrin both contain iron, and haemocyanin contain copper. These three pigments are confined to invertebrate groups, particularly annelids and mollusks.

Pigments differ in their oxygen-carrying capacities and are located in different areas

	Haemoglobin	**Chlorocruorin (some annelids)**	**Haemocyanin (snails and crustaceans)**	**Haemoerythrin (some annelids)**
Colour of pigment	Red	Green	Blue	Red
Metal in prosthetic group	Iron	Iron	Copper	Iron
Molecule of oxygen carried per atom metal	1:1	1:1	1:2	1:3
Location in blood	Cells or plasma	Plasma	Plasma	Cells or plasma

CARRIAGE OF OXYGEN

Oxygen is carried from the lungs to the tissues in form of oxyhaemoglobin.

Oxygen diffuses into the red blood cell across its thin permeable membrane and combines with the haemoglobin to form oxyhaemoglobin.

Each of the four iron-containing haem groups in the haemoglobin molecule can combine with a molecule of oxygen.

$$\underset{\text{Haemoglobin}}{Hb} + 4\,\underset{\text{oxygen}}{O_2} \underset{\text{Tissues}}{\overset{\text{lungs}}{\rightleftharpoons}} \underset{\text{Oxyhaemoglobin}}{HbO_8}$$

The oxygen is loosely attached to the haemoglobin in the lungs and equally readily detached in the tissues.

Haemoglobin has a high affinity for oxygen in that it readily combines with it and the combination of oxygen with haemoglobin to form oxyhaemoglobin, occurs under conditions when partial pressure of oxygen is high such as in the lung alveolar capillaries.

When partial pressures of oxygen is low as in capillaries supplying the respiring tissues, the bonds holding oxygen to haemoglobin became unstable and oxygen is released to the tissue. This diffuses in solution into the surrounding cells.

The affinity of haemoglobin for oxygen is reduced in an environment where oxygen partial pressures is low e.g. in the capillary of respiring tissues because of high carbon dioxide concentration there and the affinity of haemoglobin for oxygen is high in the lungs because of low carbon dioxide partial pressures.

Summary of the structure of haemoglobin and oxygen carriage

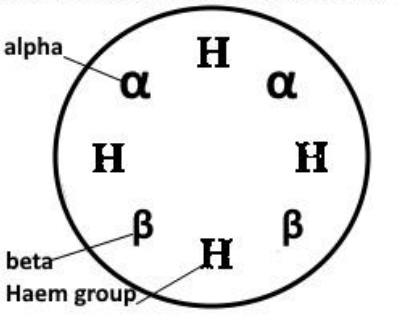
Haemoglobin is a conjugated protein

Each haemoglobin molecule consists of four non- protein prosthetic groups called **haem** which consists of an atom of iron enclosed in a ring structure.

Each haem group is associated with polypeptide chains either alpha or beta chains. I.e. Each polypeptide chain is combined with a non-protein prosthetic group called **Haem**

Each haem group can combine with one molecule of oxygen in the process called **Oxygenation. Not oxidation** (because the iron does not lose any electrons and is not chemically oxidized)

Across section of haemoglobin molecule



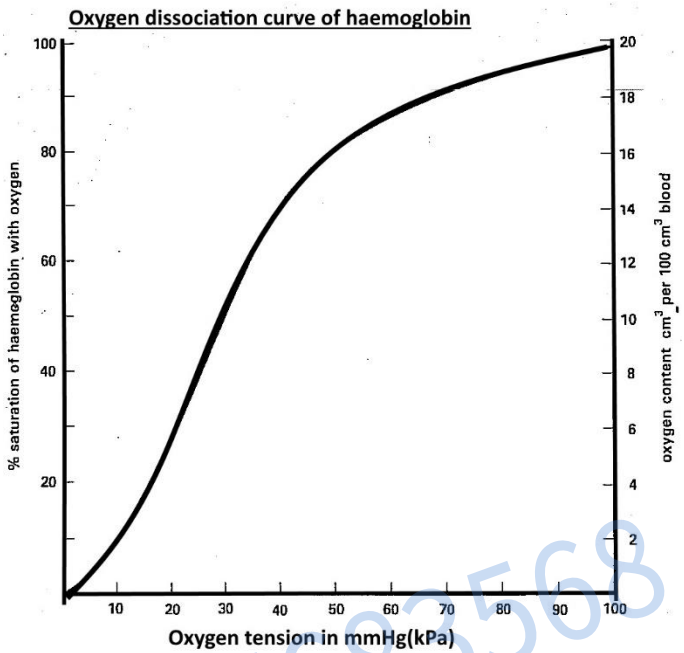
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Each molecule of haemoglobin can therefore combine with a maximum of four molecules of oxygen.

$$\underset{\text{Haemoglobin}}{Hb} + \underset{\text{oxygen}}{4\,O_2} \longrightarrow \underset{\text{Oxyhaemoglobin}}{HbO_8}$$

Oxygen dissociation curve



- The sigmoid shape of the curve reflects the high affinity of haemoglobin for oxygen, whereby a slight increase in oxygen partial pressure leads to a large increase in the percentage saturation of haemoglobin with oxygen.
- At the lowest partial pressure of oxygen of 0 kPa the percentage saturation of haemoglobin with oxygen is 0 %, because there is no oxygen bound to the haemoglobin.
- As partial pressure of oxygen increases slightly the percentage saturation of haemoglobin with oxygen increases gradually, because the first oxygen molecule to combine with the haem group does so with the greatest difficulty, because the polypeptide chains are tightly bound together, making it difficult for an oxygen molecule to gain access to the iron atoms of the haem groups.
- Thereafter, as partial pressure of oxygen increases slightly further, the percentage saturation of haemoglobin with oxygen increases rapidly, because the remaining haem groups combine with oxygen with increasing ease, due to distortion of the structure of the haemoglobin molecule when the first haem group combines with the first oxygen molecule, exposing iron in the haem groups to oxygen, because as one molecule of oxygen becomes bound to one haem group the polypeptide chain opens up, exposing the other three haem groups of the haemoglobin molecule to oxygen.
- As partial pressure of oxygen increases further the percentage saturation of haemoglobin with oxygen increases gradually, because most binding sites of haemoglobin are already occupied by oxygen molecules
- At very high partial pressures of oxygen the percentage saturation of haemoglobin with oxygen remains constant at a maximum, because all binding sites of haemoglobin are already occupied by oxygen molecules

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 millimeters 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 on the right.

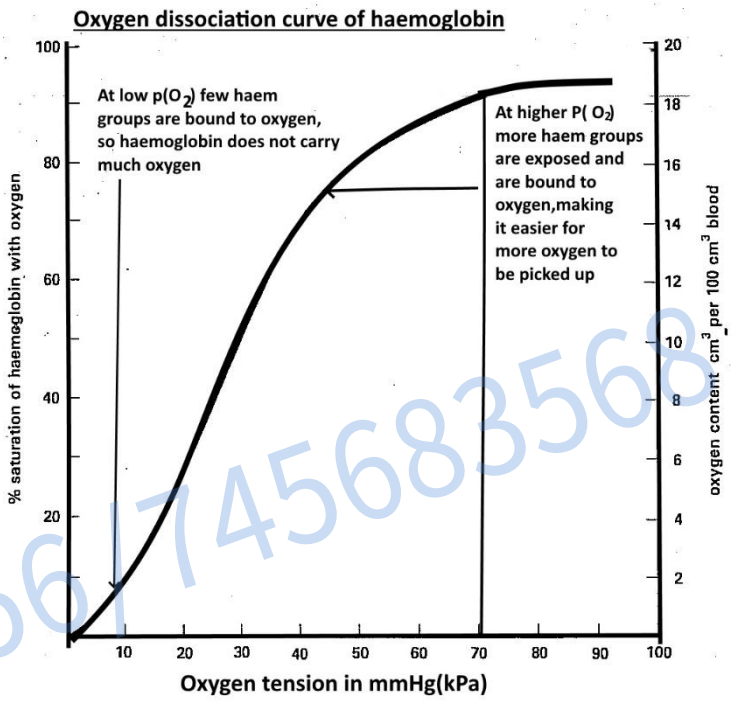
Oxygen dissociation curve shows the degree of haemoglobin saturation with oxygen plotted against different valves of oxygen partial pressures.

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The curve indicates that a slight increase or a small increase in the partial pressure of oxygen leads to a rapid 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 subsequent and 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 supplying blood to respiring tissues.

The oxygen supply can be distributed according to the requirements of different times, with skeletal muscles getting more during exercise or the intestinal tract getting 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).

Note: loading tension is the partial pressure of oxygen at which 95% of the pigment is saturated with oxygen, and the unloading tension is the partial pressure at which 50% of the pigment is saturated with oxygen.

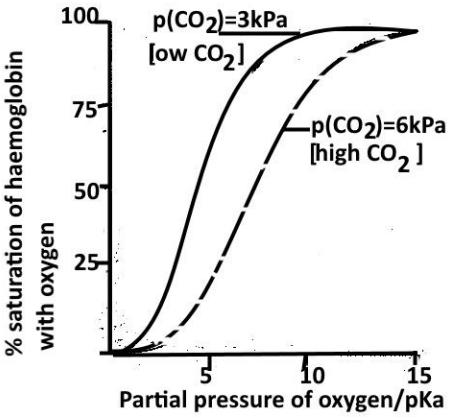
Effect of carbon dioxide on the oxygen dissociation curve (Bohr's effect)

Within tissues there is a high concentration of carbon dioxide produced during aerobic respiration

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

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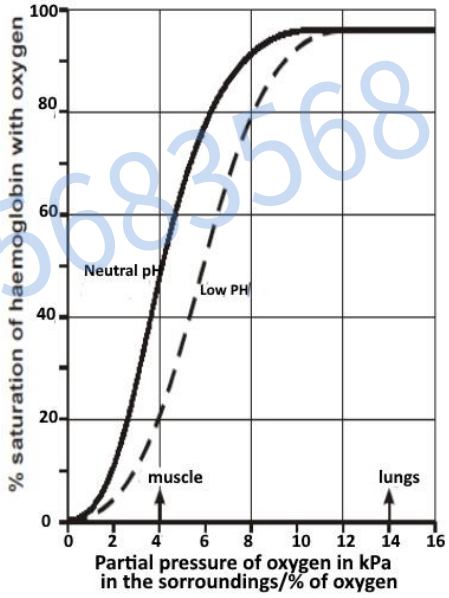
Increase in carbon dioxide concentration decreases the affinity of haemoglobin for oxygen, by making the pH of the surrounding medium more acidic (low). Thereby shifting the oxygen dissociation curve to the right. This shifting of the curve to the right is **known as Bohr's effect** i.e.



The shifting of the oxygen dissociation curve to the right due to 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.

Bohr shift: movement of the oxygen dissociation to the right due to higher carbon dioxide partial pressures, making the haemoglobin less efficient at taking up oxygen but more efficient at releasing it to the actively respiring tissues/cells



As carbon dioxide partial pressure increases the oxygen dissociation curve of haemoglobin shifts to the right and downwards, because increased partial pressure of carbon dioxide reduces the affinity of haemoglobin for oxygen, since carbon dioxide diffuses into red blood cells where it reacts with water forming carbonic acid under catalysis of carbonic anhydrase, the carbonic acid dissociates into protons and hydrogencarbonate ions, the hydrogencarbonate ions diffuse out of the red blood cell, (and chloride ions diffuse into the red blood cell to maintain electrical neutrality), and the protons left inside displace the oxygen molecules from the haemoglobin binding sites/ protons reduce the affinity of haemoglobin for oxygen by increasing acidity, thereby inducing dissociation of oxyhaemoglobin into haemoglobin and oxygen, which can hardly recombine to regenerate oxyhaemoglobin, but instead leading to formation of haemoglobinic acid

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From the dissociation curves above, 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

Why human haemoglobin saturation with oxygen occurs in the lungs.

At high partial pressure of oxygen and low partial pressure of carbon dioxide due to ventilation mechanism in the lungs, the affinity of haemoglobin for oxygen is high, so haemoglobin readily associates with oxygen to form oxyhaemoglobin, and the oxyhaemoglobin formed does not dissociate to give haemoglobin and oxygen

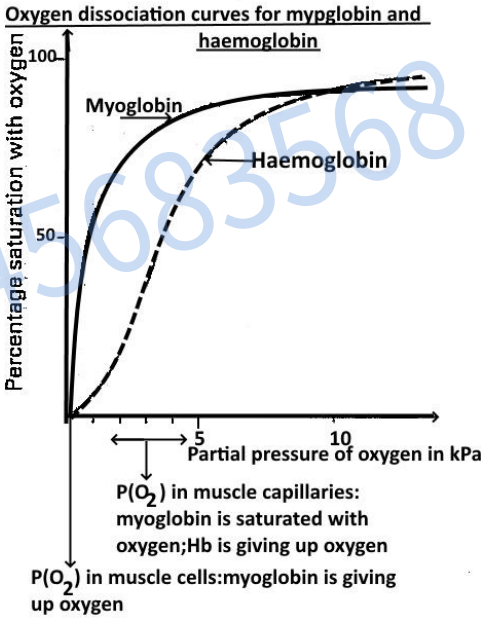
Why human haemoglobin releases oxygen when it reaches the tissues.

At low partial pressure of oxygen and high partial pressure of carbon dioxide in the tissues, due to respiring cells consuming oxygen and releasing carbon dioxide, the affinity of haemoglobin for oxygen is low, so oxyhaemoglobin readily dissociates to give oxygen and haemoglobin, and the haemoglobin does not associate with oxygen to form oxyhaemoglobin

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
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 o**xymyoglobin** and only releases the oxygen it stores only when oxyhaemoglobin has been exhausted i.e. mainly during vigorous muscular activity.
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.**



There are respiratory pigments mostly found in lower animals which include **haemocyanin** which consists of copper and commonly found in some snails and crustaceans
Haemoerythin which contains iron and found in some annelids, **chlorocruorun** which contains iron and found in **some annelids.**
Note;

- **High affinity** refers to low rate of dissociation of oxyhaemoglobin to release oxygen and a higher rate of association of haemoglobin with oxygen.
- **Low affinity** refers to higher rate of dissociation of oxyhaemoglobin to release oxygen and a lower rate of association of haemoglobin with oxygen.

Comparison between the oxygen dissociation curve for Lugworms' haemoglobin and that of Man

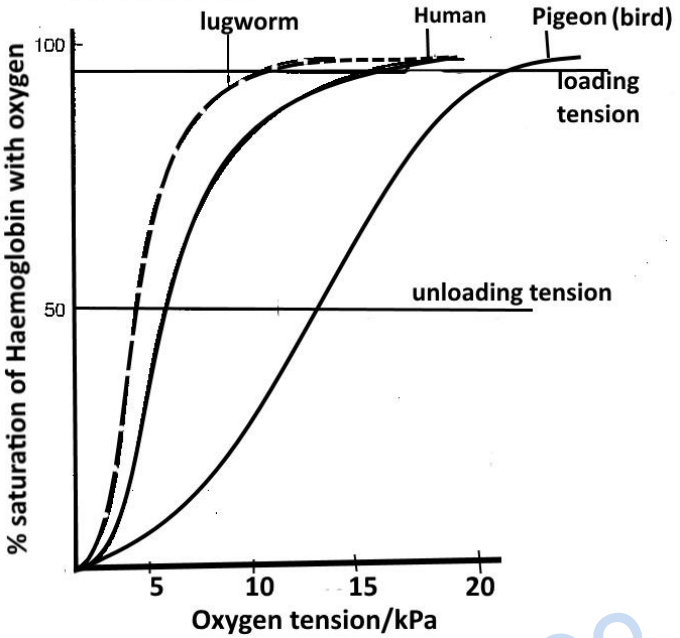
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The oxygen dissociation curve of the **lugworm's** haemoglobin lies on the left of that of man's haemoglobin as shown in the graph besides

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 oxyhaemoglobin does not easily dissociate to release oxygen to its tissues compared to that of man which makes the lugworm less active than man, who releases much oxygen more easily and rapidly to the tissues.

Oxygen dissociation curves for the Hb of three animals from different groups

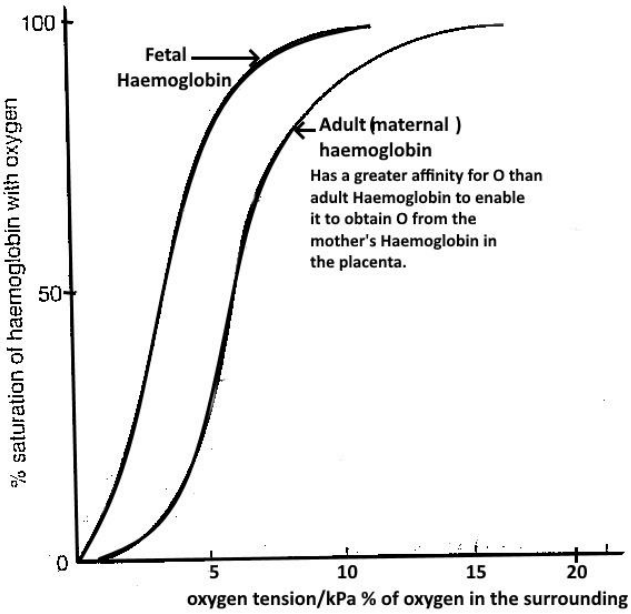


Pigeon: The oxygen dissociation curve of the pigeon's haemoglobin lies on the right of that of man's haemoglobin.
This indicates that the haemoglobin of the pigeon has a lower affinity for oxygen than that of man. This is because as flight muscles demands much energy, birds have a higher metabolic rates. To supply oxygen to the active tissues rapidly their haemoglobin must release it more readily. With an oxygen tension of 21kPa the air still saturates the haemoglobin with oxygen despite its lowered affinity for it.

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Comparison between the oxygen dissociation curve of maternal haemoglobin and that of the foetal haemoglobin

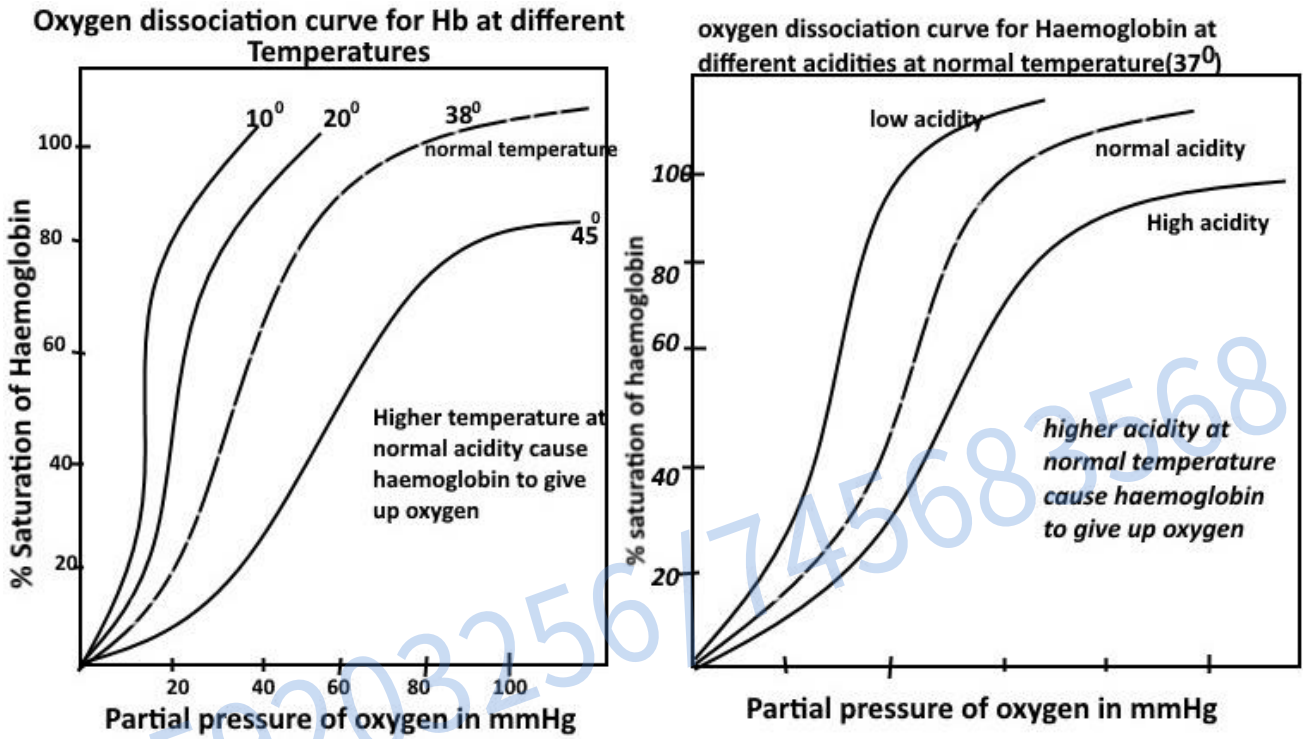
The oxygen dissociation curve of foetal haemoglobin lies to the left of maternal haemoglobin as shown in the diagram above;
This indicates that the foetal hemoglobin has a higher affinity for oxygen than that of the mother. This enables the foetal haemoglobin to pick sufficient oxygen from the mother 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.



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.

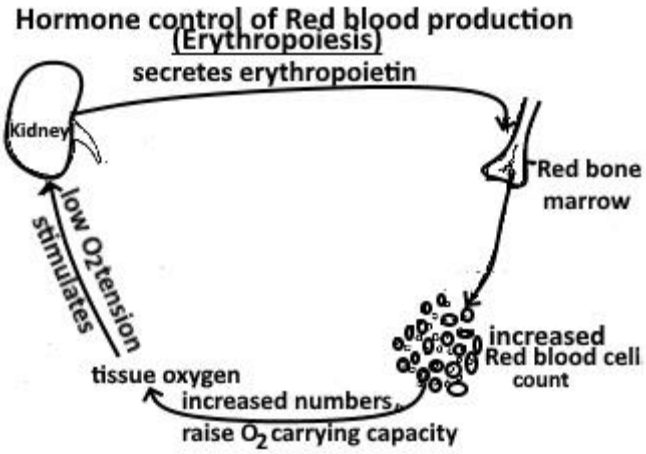


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Effect of changing altitude on oxygen carriage

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.

Acclimatization involves:

1. Adjustment of blood pH: reduced loading of haemoglobin leads to deeper breathing; **hyperventilation** in an attempt to compensate for lack of oxygen in the blood. This leads to excessive removal of carbon dioxide and raised **blood pH**. Nervous responses are triggered causing reduced depth of breathing.

In acclimatized individuals the hydrogen carbonate ions are removed by the kidney, restoring blood pH to normal

2. Increased oxygen uptake: More oxygen is absorbed by the lungs a result of an improved capillary network in the lungs and deeper breathing

3. Increased transport of oxygen to the tissues: This is the result of;

- **Increased red blood cell concentration, this may rise from 45% to 60% of the total blood volume**
- **Increased haemoglobin concentration in red blood cells -this may rise by 20%**

4. Changes in haemoglobin affinity for oxygen: The oxygen dissociation curve is shifted to the right to facilitate release of oxygen to the tissues. Above **3500m** this advantage is offset by the reduced affinity of haemoglobin for oxygen in the lungs and so is not shown by those living at these altitudes, where a shift to the left favours survival.

5. Increased myoglobin levels in muscles: with its higher affinity for oxygen this facilitates the exchange of oxygen from the blood to the tissues

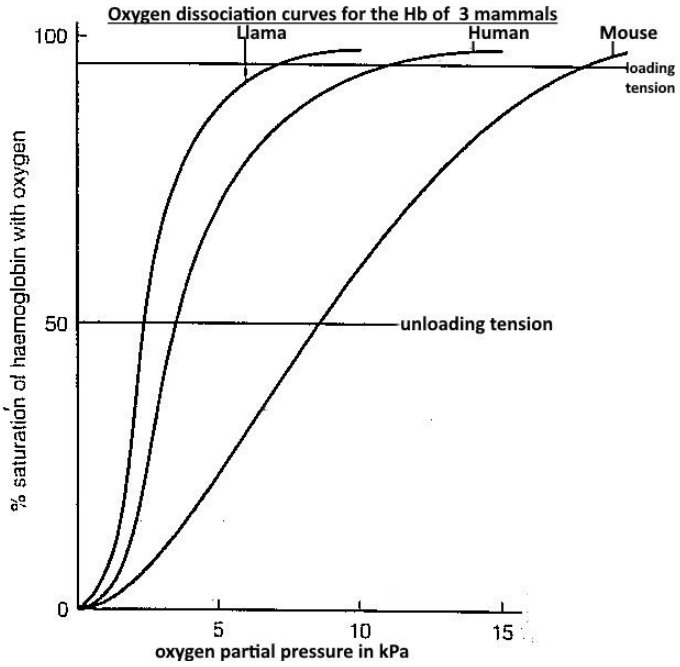
The graphs below show the oxygen dissociation curves of people living at sea level and at high altitude

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. **Llama**

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Llama: an animal living at high altitude where the reduced pressure of the atmosphere makes it difficult to load haemoglobin. The Llama's Haemoglobin therefore has a higher affinity for oxygen to compensate for this. This explain why the oxygen dissociation curve of the haemoglobin of the llama lies to the left of that of other mammals at sea level.

Mouse: being small it has a large surface area to volume ratio and therefore loses heat rapidly. To compensate for this it has a high metabolic rate to help generate heat. To keep tissues supplied with oxygen, the haemoglobin of the mouse has a lower affinity for oxygen and therefore unloads it easily to the active tissues. The reduced affinity for oxygen does not adversely affect the loading of haemoglobin as the oxygen tension of air is 21kPa more than enough to fully saturate the haemoglobin.



NOTE:

1. The more the oxygen dissociation curve of a particular pigment is displaced to the right, the less readily it picks up oxygen, but the more easily it releases it

2. The more the oxygen dissociation curve of a particular pigment is displaced to the left, the more readily it picks up oxygen, but the less readily it releases it

Mammals living at high altitudes

- These possess an improved capillary network in the lungs which coupled with their deeper breathing (hyperventilation) insures increased oxygen uptake.
- They have an increased red blood cell which increases the amount of oxygen transported by blood.
- Increased haemoglobin concentration in the red blood cells which improves the amount of oxygen transported by the blood.
- Changes in haemoglobin affinity for oxygen. Here the oxygen dissociation curve is shifted to the right to facilitate release of oxygen to the tissues. This particularly occurs at relatively lower altitudes.
- Mammals living at altitudes about 3500m have their oxygen dissociation curves shifted to the left this favors their survival by promoting an increased affinity for oxygen by haemoglobin.
- 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.

Diving mammals e.g. seals, dolphins and whales.

1. 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.
2. Have high concentration of myoglobin in their muscles. Myoglobin is an oxygen storing protein.
3. 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.
4. Store oxygen in their blood as oxyhaemoglobin and this they achieve by having concentration of haemoglobin.

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5. Blood supply to muscles is restricted and completely cut off during the longest dives hence encouraging anaerobic instead of aerobic respiration.
6. In this way, the muscles use sparingly oxygen stored in their myoglobin.

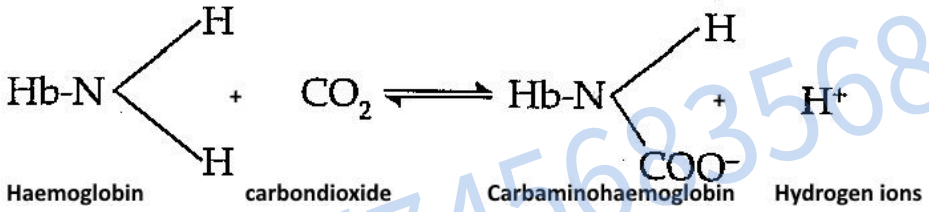
TRANSPORT OF CARBON DIOXIDE

Carbon dioxide is transported from the body tissues mainly inform of bicarbonate 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. **In aqueous solution:** A small amount, about **5%** of carbon dioxide is transported in physical solution in blood plasma. 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. **In combination with haemoglobin**: About 10% of carbon dioxide combines with the amino group of haemoglobin to form a neutral compound known as **carbaminohaemoglobin ($HbCO_2$).** If less oxygen is being carried by haemoglobin molecule, then more carbon dioxide is carried in this way as $HbCO_2$.

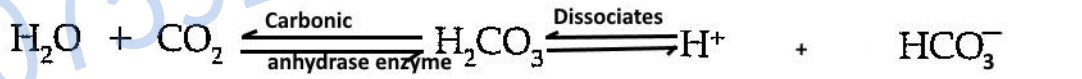


c. **Transportation of carbon dioxide inform of hydrogen carbonate ion**

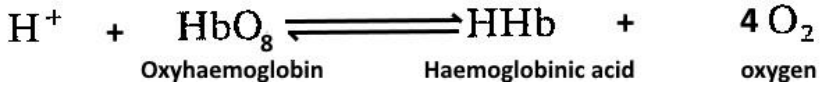
When carbon dioxide is formed during respiration, it diffuses from the tissues into the erythrocytes, via their thin and permeable membrane.

Inside the erythrocytes/red blood cells, carbon dioxide reacts with water to form carbonic acid catalysed by the zinc-containing enzyme **carbonic anhydrase.**

The formed carbonic acid then dissociates into hydrogen ions and hydrogen carbonate ions



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 and free oxygen molecules. I.e. the hydrogen ions which stay in the red blood cells cause the release of oxygen from oxyhaemoglobin



The free oxygen molecules diffuse into the tissues to be used in respiration. The free haemoglobin molecules take up the hydrogen ions (H^+) inside the red blood cells to form a very weak acid known as **haemoglobinic acid/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 ions from the dissociation of sodium chloride 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

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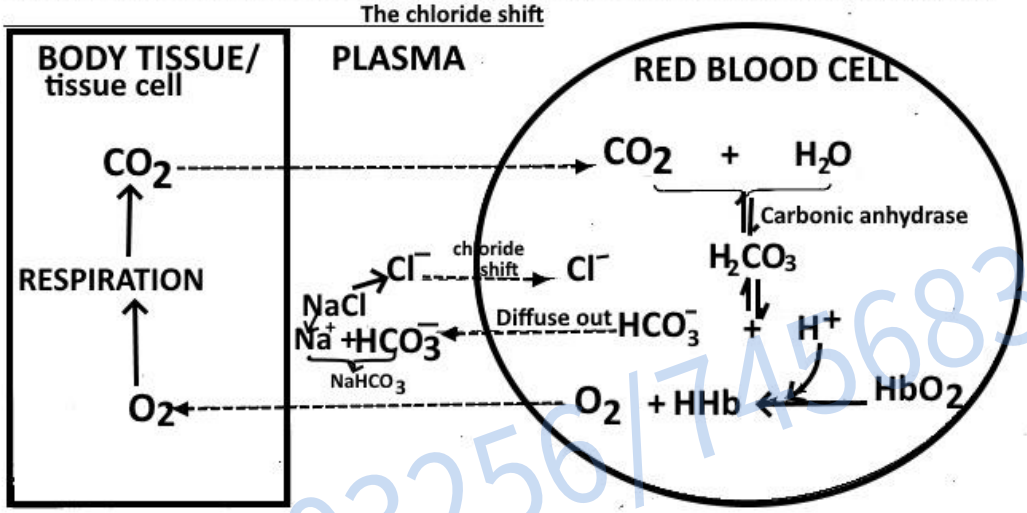
neutrality, to remove this imbalance in the red blood cells, chloride ions from the dissociation of sodium chloride diffuse from the plasma into the red blood cells, a phenomenon known as the **chloride shift**

It is largely in this form that the carbo dioxide is carried to the respiratory surface where the processes are reversed, releasing carbon dioxide which diffuses out of the body.
When the hydrogen carbonate ions reach the lungs, they react with H^+ to form carbonic acid which in presence of carbonic anhydrase, carbonic acid dissociates into water and carbon dioxide.

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

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

Summary of the chemical events that take place in red blood cell on reaching the body tissue/ The chloride shift



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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;

- **Clotting of blood**
- **Phagocytosis**
- **Immune response to infection**

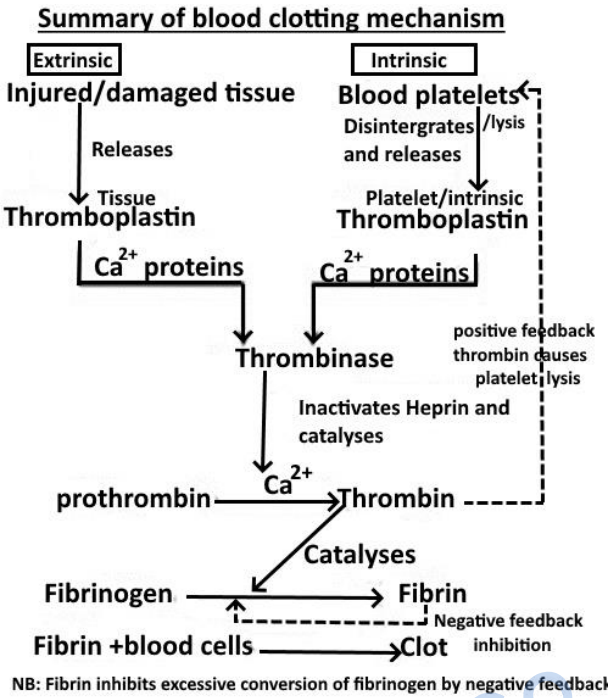
Clotting of blood

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 rupture/disintegrate and release an enzyme called **thromboplastin or thrombokinase**, which in the presence of calcium ions and vitamin K Cause the inactive plasma protein, prothrombin to become converted to its active form ,thrombin.

Thrombin is a proteolytic enzyme that hydrolyses another **soluble** plasma protein called **fibrinogen** into an **insoluble protein** called **Fibrin** which forms a meshwork of threads/fibres at the wounded area.

Within the fibrous network of fibrin blood cells become trapped, thereby forming a fibrin clot or a blood clot. These dry o form a clot beneath which repair of the wound takes place.



The clot not only prevents further blood loss, but also prevents the entry of bacteria and other microbes which might otherwise cause infection.

Note:

1.Clotting of blood is prevented by substances such as oxalic acid, which precipitate out the calcium ions as calcium oxalate

2. Heparin is an anticoagulant which inhibits the conversion of prothrombin to thrombin thereby preventing blood clotting.

3. Burst platelets also release a substance called **serotonin** which causes vasoconstriction of blood vessels which may be enough to stop blood loss from arterioles. The stoppage of blood flow is called **haemostasis**

Apart from blood clotting, the entry of microbes into the body can be prevented by the following;

- Using impermeable skin and its protective fluid called sebum (oily secretion in the skin)
- Using mucus and cilia to trap the microbes and then remove them
- By using hydrochloric acid in the stomach
- By using lysozyme enzyme in the tears and nasal fluids
- By vomiting and sneezing

Why blood does not clot in the vessels

Connective tissue plus the liver produce chemical, heparin, which prevents the conversion of prothrombin to thrombin, and fibrinogen to fibrin.

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.

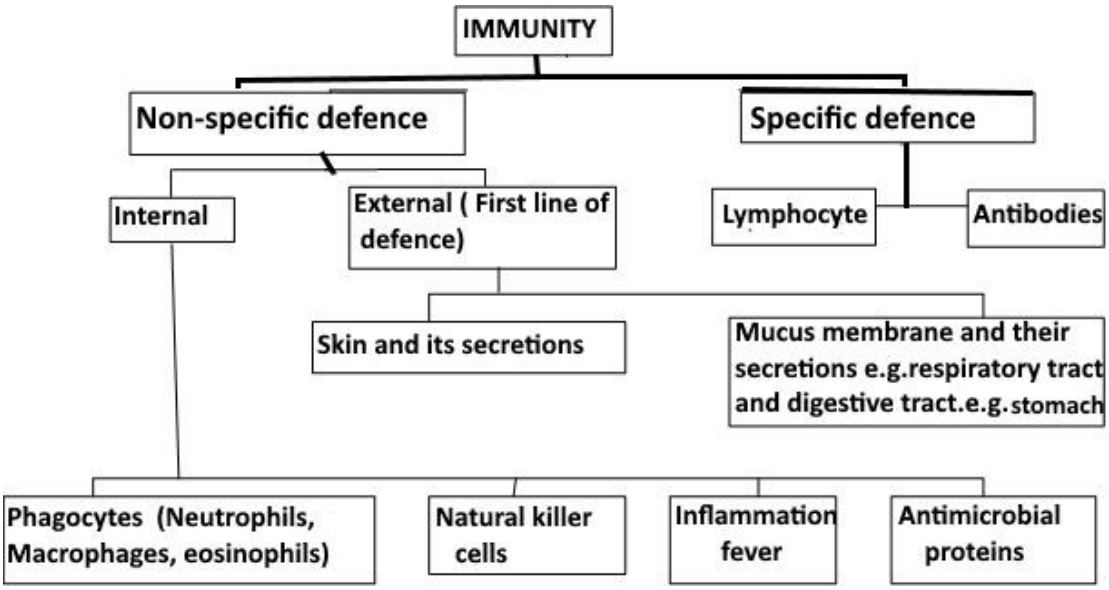
BODY DEFENCE SYSTEM AND MECHANISM IN MAMMALS (HUMANS)

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.

Immunity is the ability of an organism to resist disease, which involves the recognition of foreign material and production of chemicals which can destroy it. The chemicals are called **antibodies** which are produced by **lymphocytes**

A summary of defence mechanisms in an animal's body

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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**.

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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.

NON SPECIFIC DEFENCE MECHANISM

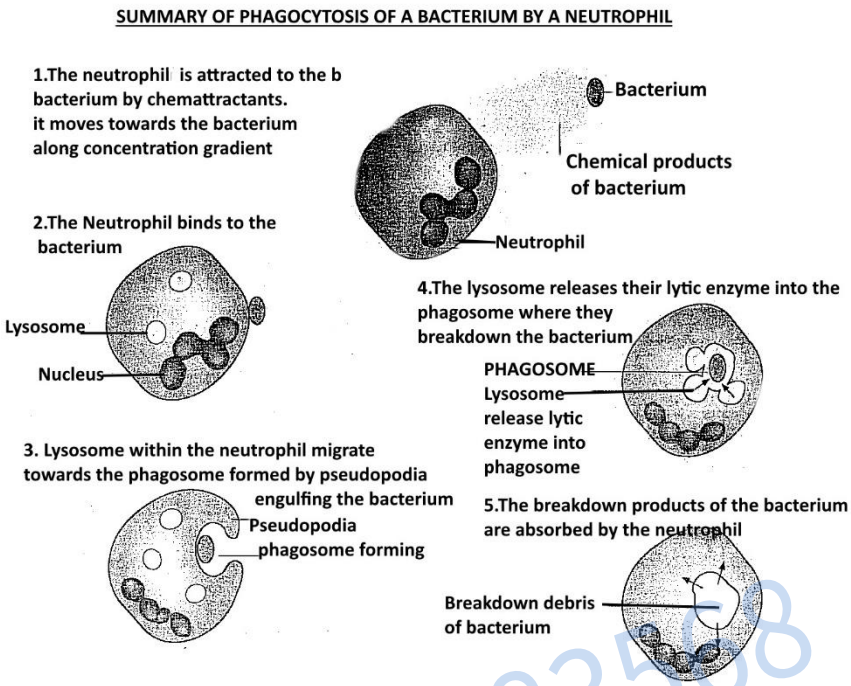
The non-specific defence mechanism act in 6 ways i.e

1. **Through physical barriers e.g. skin.**
2. **Phagocytosis.**
3. **Natural killer cell.**
4. **Anti-microbial proteins.**
5. **Inflammation.**
6. **Fever**

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.



- In protecting against infection the phagocyte is attracted to chemicals produced naturally by bacteria.
- The recognition is aided by the presence of **opsonins**-plasma proteins which attach themselves to the surface of the bacteria.
- The phagocytes have specific proteins on their surface that bind to these **chemoattractants.** This causes the phagocyte to move towards the bacteria possibly along a concentration gradient.
- The phagocyte strongly adheres to the bacterium on reaching it.
- This stimulates the formation of pseudopodia which envelop the bacterium forming a vacuole called **Phagosome.**
- Lysosome within the phagocyte migrate towards the phagosome into which they **release hydrolytic enzymes** that breakdown of the bacterium.

Note: The breakdown products are finally absorbed by the phagocyte. Phagocytosis causes **inflammation** at the site of infection. **Inflammations** are painful swellings of an infected or mechanical damaged part of the body due to increase in the blood supply as a result of vasodilation of small blood vessels. The **hot and swollen area** contains many dead bacteria and phagocytes which are known as **pus.** Inflammation results when **histamine** is released as a result of injury or infection. This causes dilation of blood capillaries from which plasma containing antibodies, escapes into tissues.

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 .

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

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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 lysozyme** 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.

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.

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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 cell

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.

TYPES OF LYMPHOCYTES

1. B-CELLS (B-LYMPHOCYTES)- perform antibody immunity

These are lymphocytes that produce antibodies when stimulated. They are produced and mature in the bone marrows from the stem cells. They have glycoprotein receptors on their cell surface membranes which bind specific antigens. Mature B-cells become plasma cells and memory cells produce much more antibodies in terms of quantity and effectiveness than plasma cells.

2. T-CELLS (T-LYMPOCYTES)

The T-lymphocytes regulate the immune response (in case of TH-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

a. T4 cell which have the CD4 receptor cites

b. T-helper cells.

When T lymphocytes are activated by an antigen, three types of cells are recognized in a clone;

i. **Killer T-cells (T-cytotoxic cells)**

These kill body cells which have become invaded by viruses/bacteria causing the cells to burst terminating the replication of the virus. Since the virus require host cells to reproduce, the bursting of the invaded body cell effectively prevents multiplication of the virus.

Killer T-cells attach to invading cells and secrete hormone-like chemical substances called **lymphokines** such as **interferon** which prevent viral replication.

Cytotoxic T cells bind to infected body cells/cancerous cells and destroy them by puncturing a hole in their cell membrane.

The cytotoxic T cells can also be triggered directly by foreign antigens bound to a cell that has been attacked by a virus.

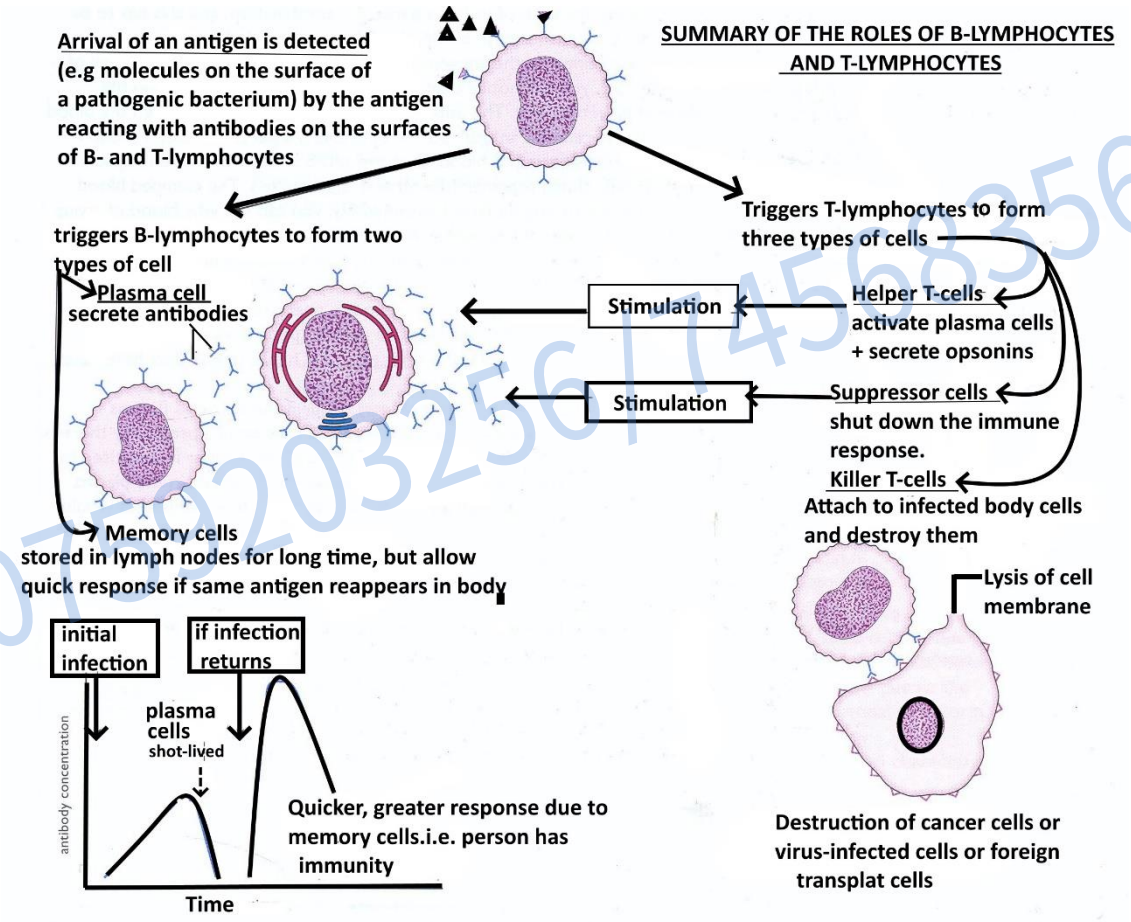
ii. **Helper T-cells**

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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.
They secrete chemicals which activate other macrophages/phagocytes to engulf harmful material.
The chemicals (called **opsonin**s) attach themselves to the foreign material (on bacterial cell) and so label them as requiring phagocytosis by other white cells.
They also activate B-lymphocytes to divide to produce plasma cells as well as assisting the T-killer cells to destroy pathogens.i.e. They stimulate the activity of T-cells and B lymphocytes by releasing chemicals.

iii. **Suppressor T-cells**

These suppress the activities of the killer T-cells and B-cells after the microbes/infection has been eliminated from 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. I.e. ***Suppressor cells switch off the immune response once the invasion has been overcome and so maintain control of the immune system.***



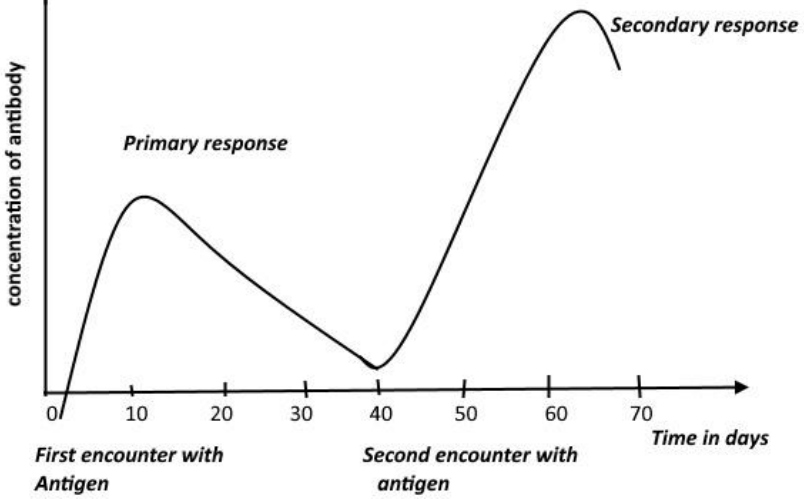
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COMPARISON OF PRIMARY RESPONSE AND SECONDARY RESPONSES

Similarities

In both the primary and secondary response the concentration of antibody increases rapidly following encounter with the antigen.
In both the primary and secondary response the concentration n of the antibody attains a peak.
In both the primary and secondary response the concentration of antibody decreases following attaining a peak.

Graph showing changes in the concentration of antibodies in blood of an individual twice injected with antigen.



Differences

Primary response	Secondary response
Initially the concentration of antibody is zero	Initially the concentration of antibody is above zero
Primary response triggered by the first encounter with the antigen	Secondary response triggered by the second encounter with the antigen
Concentration of antibody increases rap[idly on encounter with antigen	Concentration of antibody increases more rapidly on encounter with antigen
Concentration of antibody attains a lower peak	Concentration of antibody attains a higher peak
Concentration of antibody decreases gradually after the peak	Concentration of antibody decreases rapidly after the peak
Concentration of antibody attains a peak in 10 days after encounter with antigen	Concentration of antibody attains a peak in 18 days after encounter with antigen
Concentration of antibody decreases to a lower value after the peak.	Concentration of antibody decreases to a much higher value after peak

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Explaining the differences in the primary and secondary responses

In the primary response following the first encounter with the antigen on day 0, each antigen binds to a specific B cell/B lymphocyte which has the appropriate antibody/immunoglobulin in its cell surface membrane.

The cell surface membrane of the B cell/lymphocyte contains antigen receptors whose specific shape is identical to the antibodies/immunoglobulin's that the cell can make,
A **B cell/**lymphocyte to which the antigen (molecule) binds is stimulated/activated to divide repeatedly by mitosis, producing a large clone/population of identical B cells/lymphocytes, in a process called clonal proliferation, all of which can produce identical antibodies against the antigen.
Many of the cells in the clone become plasma cells/effectors (B) cells.
Each plasma cell quickly develops extra endoplasmic reticulum and ribosome's, amounts of the particular antibody hence the rapid increase in concentration of antibody within the first 10 days.
The antibody molecules bind with the antigens, leading to the destruction of the antigen-bearing structure particular nu phagocytic cells.

As plasma cells live for only few days, the concentration of antibody decreases gradually as the antigen-bearing structures are destroyed from q0m days to 40 days.
However some B cells in the clone stop dividing and secreting antibody, and become memory cells which survive for long periods of time.
In the secondary response following the second encounter with the antigen on day 40, the large numbers of memory cells formed in the primary response are stimulated/activated to divide and produce a large population of B cells.
In turn theses B cells produce clones of B cells that produce a much larger concentration of antibody rapidly increasing from day 40 to day.
In addition to being more numerous, antibodies produced in the secondary response have greater affiniting for the antigen than those secreted in the primary immune response, this explains why the secondary response is faster greater and more effective.

SIGNIFICANCE OF PRIMARY AND SECONDARY RESPONSES IN IMMUNITY AND DISEASE CONTROL

On the first encounter with an antigen, the infected individual may become ill as it takes days to produce enough B cells to produce enough antibodies to eliminate the antigen from the body in the primary response.
Eventually, however, the antibody concentration may increase sufficiently and effectively eliminate the antigen from the body, and the symptoms of the disease subside and eventually disappear.
On the next encounter with the same antigen, the antigen elicits a secondary immune response which is faster, greater and more effective, such that the invading antigen has no chance to multiply and make the individual ill. The individual is thus immune to the disease caused by the antigen.

During vaccination, antigens from a potential pathogen are modified in some way, so that they stimulate a primary response from the individual's immune system that the normal pathogen would, without making the individual ill. This ensures immunity against the disease on exposure to the normal pathogen, enabling disease control by vaccination.
However pathogens which mutate regularly and rapidly, changing their surface antigens to a level of antigenic shift, and those that avoid the immune system by antigenic concealment are difficult to vaccinate against. As the effectiveness of the vaccine depends on the antigenic properties of the pathogen involved.

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REASONS FOR FAILURE OF VACCINATION TO ERADICATE SOME DISEASES

If a pathogen mutates regularly and rapidly, largely changing its surface antigen by antigens variation to a level of antigenic shift, so that the pathogen is effectively different to that the individual; was vaccinated against as n the case of the influenza virus in red blood cells, out of reach of T cells and lymphocytes and Vibria cholera lives in the wall of the intestine bathed in intestinal juices, unlikely to be reached by antibodies in the blood and lymph.
When vaccination against highly contagious diseases is not extensively administered to then whole population of the same time, there is failure of the population to develop herd immunity.
Individuals with inherited defective immune systems, or whose immune system is weakened by disease or malnutrition, may not respond at all to vaccination

IMMUNE RESPONSE OF THE BODY TOWARDS INFECTIONS.

- When microbes enter into the body
- The membrane receptor of the B-cells and T- lymphocytes detect them and the lymphocytes are stimulated to undergo rapid mitotic proliferation to produce numerous T –cells and B – clone cells
- T cells differentiate into helper T- cells (T4), suppressor T- cells, killer T- cells / T-cytotoxic cells

- The helper T cells with the aid of macrophages, identifies the microbes and secrete lymphokines which prevent viral replication.
- Stimulates the killer T- cells to destroy the viruses by puncturing holes into the cell membrane of the infected body cells / canerous cells
- Stimulates helper T-cells to give of chemicals that cause the plasma cells produced by B-lymphocytes to secrete antibodies
- Stimulates the suppressor cells to secrete their lymphokines which inhibit the activities of B and T – lymphocytes, phagocytes, killer T – cells after the microbes have been cleared from the body to prevent auto/ self destruction.
- Stimulates the B – lymphocytes to manufacture antibodies.
- The B clone cells differentiate into effector / plasma cells which secrete antibodies and also into the memory B- cells for secondary immune response of the body towards the microbes whereby they retain the ability to identify the microbes and stimulate for rapid production of numerous antibodies towards the microbes on re- infection in order for them to be eliminated from the body before they register a significant damage.

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

Antibody

This is an immunoglobin specific protein produced by the plasma cells which recognizes and binds to specific antigens. Antibodies either neutralize antigens or tag cells that are antigens for easy attack by macrophages.

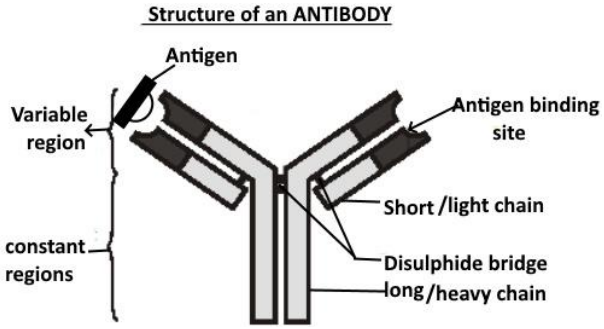
Structure of an Antibody

It consists **of a Y** – shaped immunoglobin protein

It's a large protein molecule comprising of four polypeptide chains where by two are long, heavy chains and hinged and another two/pair are light chains and shorter.

They are arranged in a **Y-**shape and the chains are linked together by disulphide bonds

At the end of the chains, are **antigen binding site** is and each chain has both constant and variable regions.



Antibodies defend the body against infections in different ways which include -:

Some – **opsonins** attach themselves on the microbes and enable the phagocytes to identify the microbes, engulf them and destroy them phagocytically.

Lysis: Some – **lysins** cause breakdown of the pathogen by bursting and rupturing of the microbes.

Agglutination: Some – **Agglutins** cause clumping together of the pathogens/microbes for their fast destruction by making them more vulnerable to attack from other types of antibody.

Precipitation: Some- **precipitins bind together** the soluble antigens into large units which are thus precipitated out of solution.as such they are more easily ingested by phagocytes. .

Neutralization: Some antibodies bind to toxic molecules produced by a pathogen and so neutralize their harmful effects. **I.e. antitoxins** neutralize the toxins / poison produced by the microbes.

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.

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Opsonisation

- Coating of bacteria with proteins substance called **opsonins**
- Phagocytes have receptors in their cell surface membrane which match the opsonins and enable them to recognize, blind and then engulf the bacteria.
- A phagocytic vacuole is formed
- Small lysosomes fuse with the phagocytic vacuole, forming a phagosome
- Lysozyme and other hydrolytic enzymes together with acid, are poured into the phagocytic vacuole from the lysosomes and the bacteria are digested
- The soluble products of bacteria digestion are absorbed into the surrounding cytoplasm of the phagocyte.

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.

Cytokines (**lymphokines**)

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**

Complement system.

This is a group of about 20 proteins found in blood plasma and other body fluid. These are inactive until the body is exposed to antigens e.g. histamines.
Some of these **proteins are enzymes** which cause the breakdown of the pathogens.

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**.

a. 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.
Antibodies 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.

b. 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

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population is stimulated by a specific antigen and response synthesizing and secreting the appropriate type of antibody.

c. 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.

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

Types of immunity

Active immunity

This is when the body is stimulated to manufacture its own antibodies to protect itself from infections. Active immunity may be **natural** result of an injection or artificial

1. Natural active immunity

It is when the body is stimulated to manufacture its own, antibodies due to the presence of microbes i.e. its primary response towards infections)

After the microbes have been cleared memory B ells remain with the capacity to stimulate for rapid production of numerous antibodies on reinfection which clear out the microbes with greater speed and efficiency before they cause a significant damage to the body.

This makes the body to rarely suffer from the same infection (i.e. its level of immunity against infections is increased) and secondary response is also a basis for vaccination.

2. Artificial active immunity

This involves introduction of a small amount of harmless antigens from a disease-causing organism either by infections (intravenously) or by mouth into the body of an individual to stimulate the body's immune system to produce antibodies against the antigen.

Because the process involves the formation of the memory B-cells which retain the ability to recognize the microbes and stimulate rapid production of many antibodies when the body is infected by the living and active microbes they are curbed down before they register a significant damage to the body.

Vaccination:-*process by which harmless antigens from a disease-causing organism are introduced into the body either by injection or orally/by mouth in order to stimulate the body's immune system to make antibodies against the antigen.* Vaccination works because it induces the production of memory lymphocytes which persist in the body.

Providing immunity artificially *is called i**mmunization***

This is the basis of immunization (vaccination) of which there are a number of different types depending on the form the antigen takes.

1) Living attenuated microorganisms: - living pathogens which have been treated, e.g. by heating, so that they multiply but are unable to cause the symptoms of the disease. They are therefore harmless but nonetheless induce the body to produce appropriate antibodies. e.g measles, tuberculosis, poliomyelitis and rubella(German measles)

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ii) **Dead microorganisms:-** pathogens are killed by some means and then injected. Although harmless they again induce the body to produce antibodies in the same way it would had they been living. e.g .typhoid, cholera and whooping cough are controlled by this means

iii) Toxoids: - the toxins produced by some diseases e.g. .diphtheria and tetanus are sufficient to induce antibody production by an individual.to avoid these toxins causing the symptoms of the disease they are first detoxified in some way. e.g. by treatment with formaldehyde and then injected.

iv) **Extracted antigens**:-the chemicals with antigenic properties may be extracted from the pathogenic organisms and injected. E.g influenza vaccine is produced in this way.

v) **Artificial antigens:-** through genetic engineering it is now possible to transfer the genes producing antigens from a pathogenic organism to a harmless one which can easily be grown in the laboratory. Vaccines used in the treatment of hepatitis B can be produced in this way

Artificial immunity

It is when the preformed antibodies in an organisms are injected into the body of animals of another organism to offer it temporary immunity against infection.

Artificial passive immunity

This involves extracting of antibodies from the body of an individual and inject them into the body of another individual of the same or different species, to offer it with temporary immunity

e.g. the antibodies cultured in the body of the horses are injected into the human body to offer it with temporary immunity against tetanus and diphtheria.

TYPES OF ACQUIRED IMMUNITY

There are two types of acquired immunity namely:

1. **Active acquired immunity.**
2. **Passive acquired immunity.**

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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.

Passive immunity is the result of antibodies being passed into an individual rather than being produced by the individual itself. It's the Immunity that develops after a person receives immune system components, most commonly antibodies from another person. it may occur naturally in mammals when antibodies pass a cross the placenta from a mother to her fetus or are passed to the new born baby in the mother's milk.

Passive immunity provides immediate protection against an antigen, but does not provide long-lasting protection.

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 newborn's immune system is not fully operative and depends on the mother's immune system. Certain antibodies are also passed from the mother to her nursing infant in breasts milk especially in her colostrum or fast secretions. ***Passive immunity is short-lived because the transferred antibodies are soon destroyed in the liver.***

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

a. 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.

b. 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.

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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.

a. Neutralization

Here the antibody blocks certain sites on an antigen or toxins making it effective. Antibodies neutralize a virus by attacking to the sites the virus uses to bind to its host cell. Also bacterial toxins become coated with antibodies hence getting neutralized, eventually, phagocytic cells (macrophages) destroy these antigen-antibody complexes.

b. 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

c. 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.

d. Opsonisation

Here, the antibody molecule oats the surface of a microbe making it easier for phagocyte leucocytes to engulf it.

e. Complement fixation

Here, the antibodies activate the complement proteins which then leads to lysis of foreign cells.

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 Histocompatibility 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.

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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.

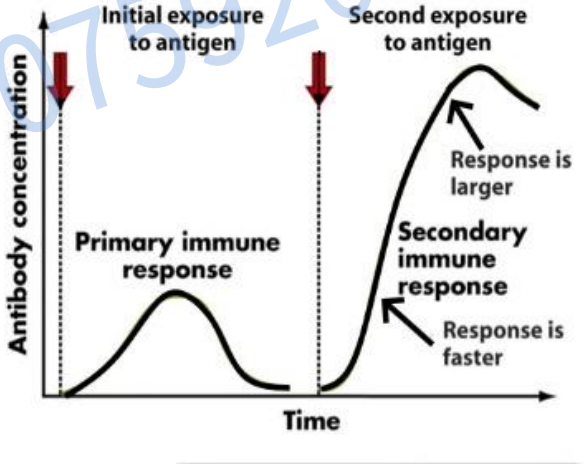
Secondary immune response is the rapid response that results in faster production of effector Tcells and antibody molecules when the body is exposed to subsequent infection of the same antigen that has ever invaded the body.

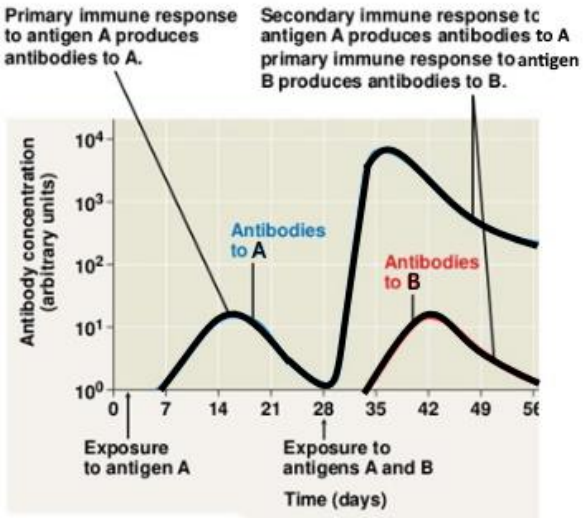
Antibodies produced during the secondary immune response are more effective in binding to the antigen than those produced during the primary immune response.

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.

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Graph to illustrate changes in antibody concentration during primary and secondary immune responses to antigens





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.**

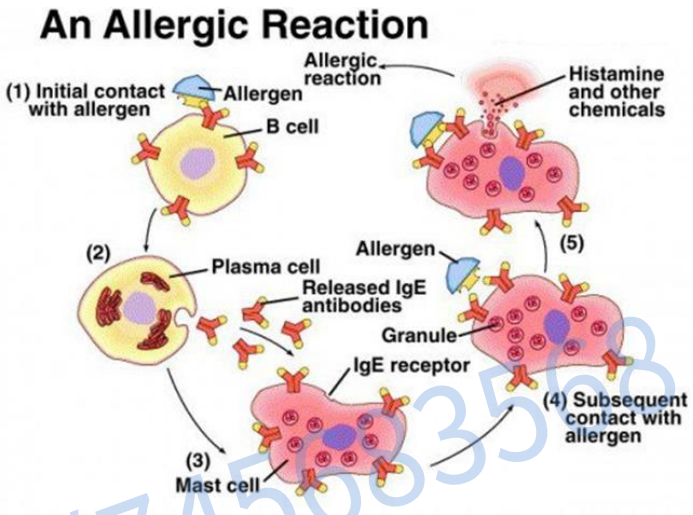
AUTO IMMUNE DISEASES.

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 pancreas. Rheumatoid arthritis is a crippling auto immune disease in which inflammation damages the cartilage and bone of joints. Rheumatic fever is an auto immune condition in young adults where antibodies produced in response to streptococcal 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.



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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.

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

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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 antigen B 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 occurs

Individuals with blood group AB posse 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 **erythroblastosis foetalis** (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.

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Adaptation of mammals to oxygen deprivation.
Diving mammals e.g. seals, dolphins and whales.

- 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 enriched with oxygen.
- Have high concentration of myoglobin in their muscles. Myoglobin is an oxygen storing protein.
- 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.
- Store oxygen in their blood as oxyhaemoglobin and this they achieve by having concentration of haemoglobin.
- Blood supply to muscles is restricted and completely cut off during the longest dives hence encouraging anaerobic instead of aerobic respiration.

In this way, the muscles use sparingly oxygen stored in their myoglobin.

Mammals living at high altitudes.

- These possess an improved capillary network in the lungs which coupled with their deeper breathing (hyperventilation) insures increased oxygen uptake.
- They have an increased red blood cell which increases the amount of oxygen transported by blood.
- Increased haemoglobin concentration in the red blood cells which improves the amount of oxygen transported by the blood.
- Changes in haemoglobin affinity for oxygen. Here the oxygen dissociation curve is shifted to the right to facilitate release of oxygen to the tissues. This particularly occurs at relatively lower altitudes.
- 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.
- 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.

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TRANSPORT IN PLANTS

Plant cells, like animal cells, need a regular supply of oxygen and nutrients. All plants are multicellular, and some of them are very large. Most plants, however, have a much more branching shape than animals, and this provides a much larger surface area to volume ratio for exchange with their environment than in an animal of the same body mass.

The requirements of plants differ from those of animals in several ways, both in the nature of the nutrients and gases required and the rate at which these need to be supplied.

•**Carbon dioxide**: Photosynthesizing plant cells need a supply of carbon dioxide during daylight. They obtain this from the air. Aquatic plants get carbon dioxide from the water that surrounds them

•**Oxygen:** All living plant cells need oxygen for respiration. Cells that are actively photosynthesizing produce more than enough oxygen for their needs. Cells that are not photosynthesizing have to take in oxygen from their environment, but they do not respire at such a high rate as mammals and so they do not need such a rapid oxygen supply.

•**Organic nutrients**: Some plant cells make many of their own organic food materials, such as glucose, by photosynthesis. However, many plant cells do not photosynthesize and need to be supplied with organic nutrients from photosynthetic or storage cells.

•**Inorganic ions and water:** All plant cells require a range of inorganic ions and also water. These are taken up from the soil, by roots, and are transported to all areas of the plant.

NOTE: The energy requirements of plant cells are, on average, far lower than those of cells in a mammal. This means that their rate of respiration and, therefore, their requirement for oxygen and glucose are considerably less than those of mammals. Plants can therefore manage with a much slower transport system.
One of the main requirements of the photosynthetic regions of a plant is sunlight. Plants have evolved thin, flat leaves which present a large surface area to the Sun. This also makes it easy for oxygen and carbon dioxide to diffuse into and out of the leaves, reaching and leaving every cell quickly enough so that there is no need for a transport system to carry gases.

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 however can be lost from the mesophyll cells into sub-stomatal air chambers and then eventually lost into the atmosphere of water vapor through tiny pores called "stomata" by a process known as transpiration
Adaptations of root hairs for their functions

- They are numerous in number so as to provide a large surface area for the maximum absorption of water by osmosis.
- They are slender and flexible for easy penetration between the soil particles so as to absorb water.
- The lack a cuticle and this enhances the passive osmotic absorption of water without any resistance
- They have a thin and permeable membrane which allows the absorption of water by osmosis.
- They have a water potential lower than that of the soil solution which facilitates a net osmotic flow of water from the soil

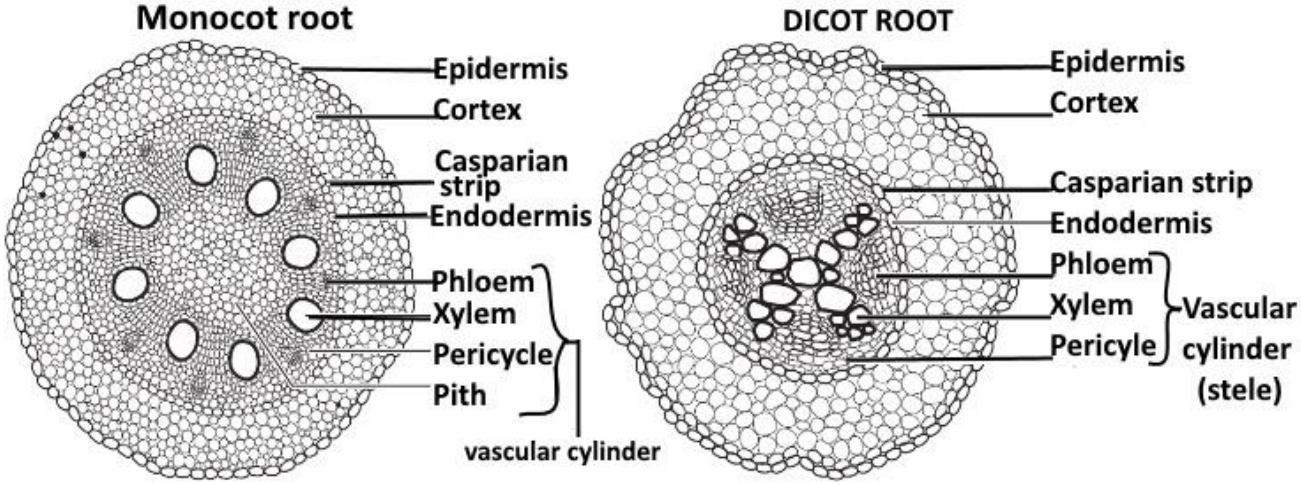
Adaptations of roots for water absorption

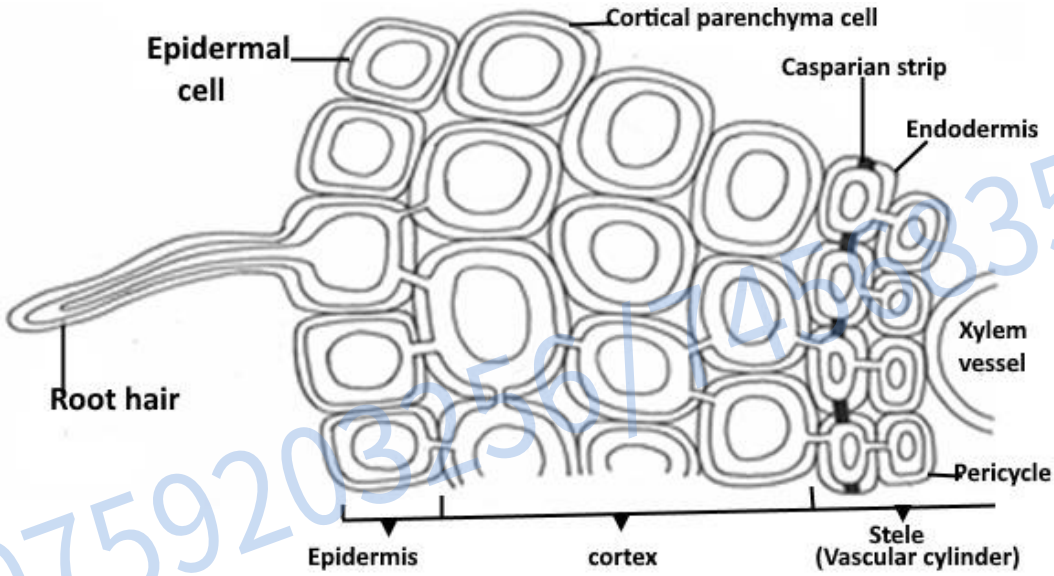
- They are numerous in number to provide a large surface area for maximum absorption of water, by osmosis.
- They are slender and flexible for easy penetration between the soil particles for water absorption.
- They lack cuticle, and this enhances the passive osmotic absorption of water without resistance
- They have a thin and permeable plasma membrane which allows maximum absorption of water by osmosis.
- They have a water potential lower than that of the soil solution, which facilitates a net osmotic flow of water from the soil.

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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 form the peliferous layer and are so called because it is formed 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 **epiblema,** to become the functional outer layer.
Next to the epiblema 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





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Sources of water available to plant roots

(i). Metabolic water from metabolic reactions
(ii).Soil water solution between soil particles
(iii).Surface water surround soil particles

Mechanism of water uptake by the roots

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. **I.e.** water moves through cell walls from one cell to another without ever entering the cells.

The apoplast path way does not occur within the endodermal cells because they possess the impermeable **casparian strip** which prevents water and solute 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.* It also 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 salts (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.

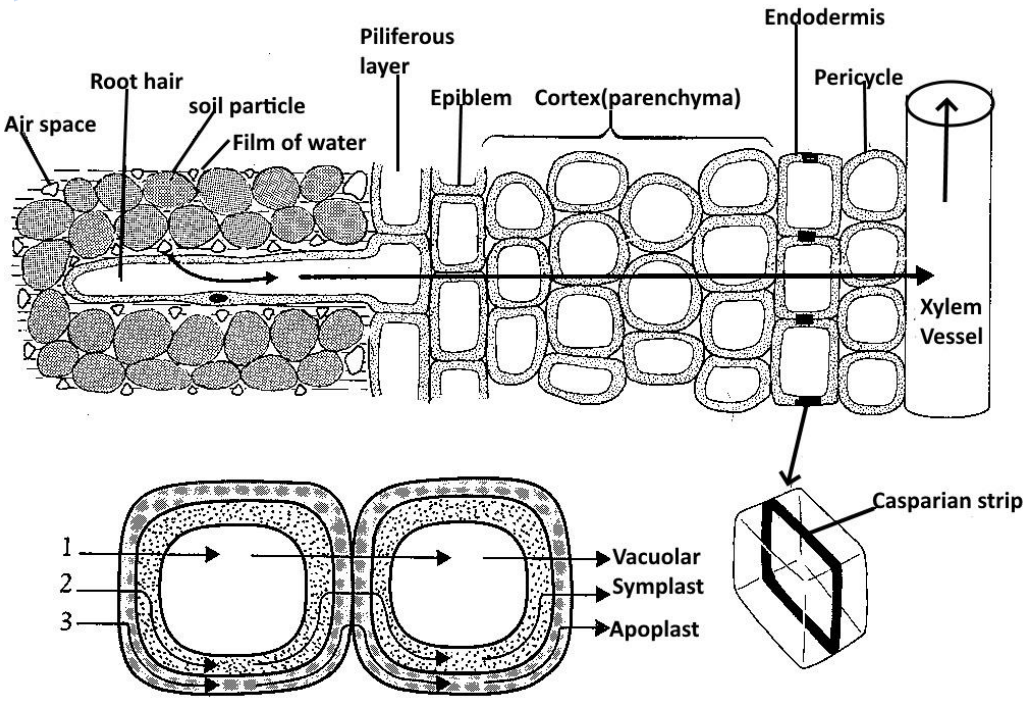
In this way the water potential gradient from the root hairs to the xylem is high with the xylem vessels having a lower water potential relative to the neighboring endodermal cells.

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.



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Summary of water movement from the soil into the xylem of the root.

The water potential of soil is higher than that of the root hair cells due to a higher solute concentration in root hairs, so water enters the root hairs by osmosis down a water potential gradient.

The root hairs are numerous and increase the surface area for water uptake.

From the root hair cells to the cortical cells of the main root water moves by osmosis, diffusion and cytoplasmic streaming/mass flow through cytoplasm in **symplast,** through cell walls in the **apoplast,** and through vacuoles in the **vacuolar** pathway.

But the most important pathway is the **apoplast pathway.**

When water reaches the endodermal cells it is forced through the **symplast path way** but not the apoplastic route, due to the presence of suberin in the casparian strips within their cell walls.

Mineral salts are actively pumped into the root xylem from the cytoplasm of the endodermal cells lowering the water potential in the xylem. Hence water flows into the root xylem by osmosis down a water potential gradient.

ROOT PRESSURE AND UPTAKE OF WATER IN THE XYLEM

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 than that in the endodermal cells.

The steep water potential gradient between the endodermal cells and xylem tissues, results into rapid osmotic flow of water from the endodermal cells into the xylem tissues and its upward movement through the stem xylem tissue to the leaves.

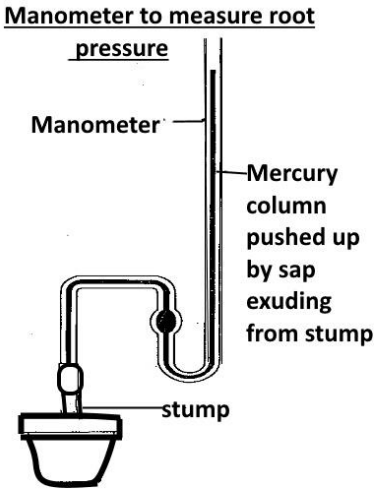
The active pumping of salts into the xylem tissues also prevents leakage of salts out of the xylem tissue.

In some plants, root pressure may be large enough to force the liquid water, through the pores called hydathodes of the leaves, a process **called guttation.**

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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.



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.

NOTE: Root pressure can be measured using **a mercury manometer** whose diagram is shown below
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;

1. **Root pressure**
2. **Transpiration pull(cohesion force)**
3. **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.
The root pressure is a force that pushes up water and salts into xylem. It is probably caused by the endodermis. The endodermis cells possess a **casparian strip**, a band of corky material which runs round each cell in its radical and horizontal walls. Unlike the rest of the cell wall, the casparian strip is impermeable to water. Therefore, when water reaches the endodermis, it cannot enter the vascular cylinder via the radical and horizontal walls of the endodermis cells. That is, water cannot move through the apoplast at this point and must be diverted through the symplast. Also, the endodermis is believed to actively secrete salts into the vascular tissues thereby creating relatively low water potential in them.
As a result, water is drawn into the vascular tissues by osmosis across the selectively permeable membranes of endodermal cells. In this way, the roots behave like an osmometer, generating a force (root pressure) that pushes water into the vascular tissues.

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 neighboring water molecules which in turn attract their other neighbors 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

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by means of mass flow and water enters the base of these columns from neighboring 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.

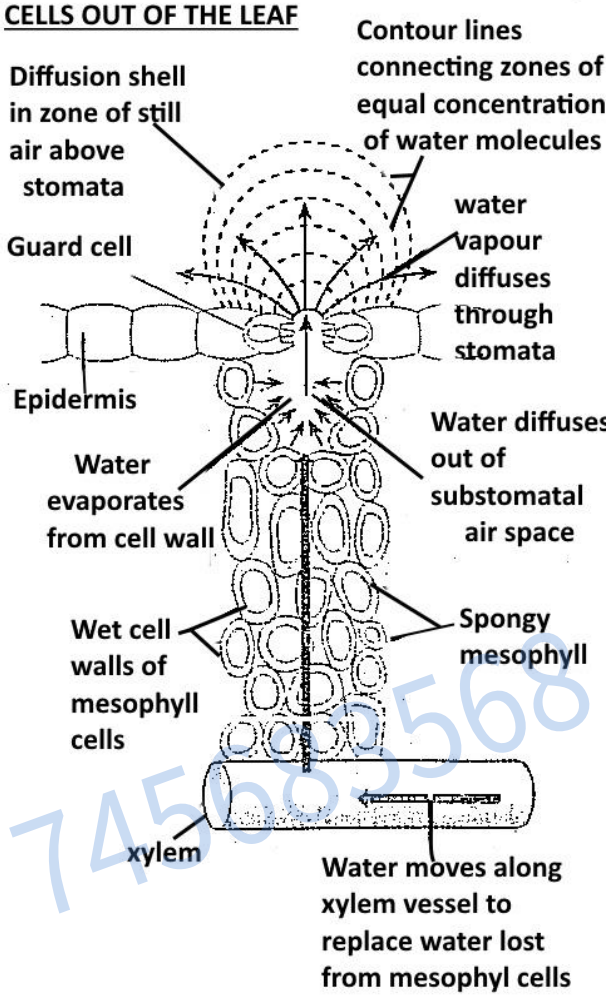
Capillarity

This is the upward movement of a liquid through narrow tubes water movement is facilitated by capillarity, through the stem, in that as the xylem vessels are narrow, the flow of water is maintained without breaking, by both cohesive and adhesive forces.
The continuous mass flow of water, through the xylem vessels, from the roots to the leaves, in a continuous stream, without breaking; due to the transpiration pull is called a transpiration stream.

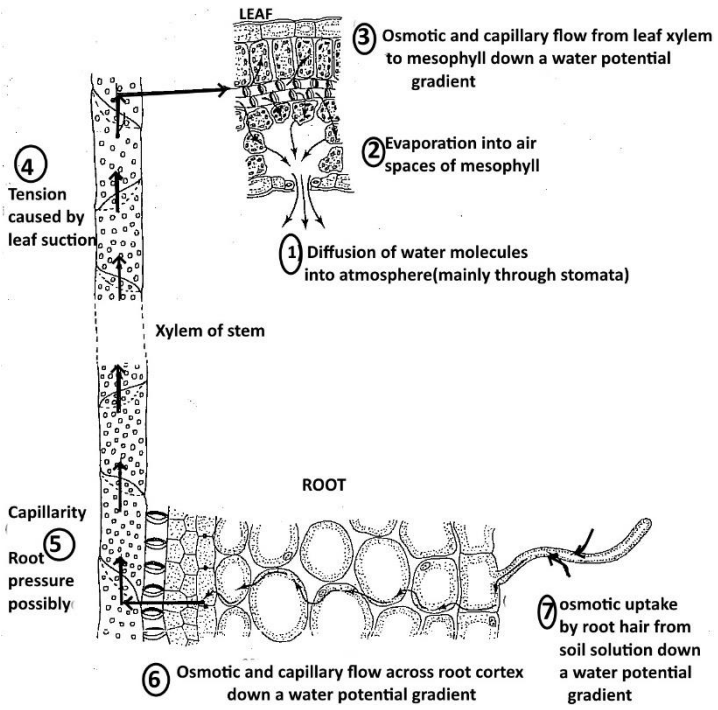
Summary of water movement through the xylem in the stem of a plant.

The active pumping of ions into the xylem from the endodermis rapidly draws water into the xylem by osmosis down a water potential gradient, causing a build-up of **root pressure** which forces water up the xylem in the stem.
In addition, **evaporation** of water from the leaf cells reduces the water potential in the cells next to the xylem.
Water then enters these cells from the xylem sap by osmosis down a water potential gradient through the cell walls of the xylem vessels. Lowered water potential of the leaf xylem vessels draws water from stem xylem vessels by osmosis into the leaf xylem to replace lost water.

DIFFUSION OF WATER FROM THE MESOPHYLL CELLS OUT OF THE LEAF



SUMMARY OF WATER UPTAKE AND MOVEMENT IN A FLOWERING PLANT



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As water leaves the xylem vessels, a **tension** is set up in the water column, which is transmitted back down the stem xylem all the way to the root xylem by **cohesion** of the water molecules to each other forming an unbroken water column, and **adhesion** of the water molecules to the xylem walls.
As such water moves up the xylem in the stem in a continuous stream called the **transpiration stream** by **mass flow** in an unbroken column due to the **transpiration pull**.
Also the narrow lumen of the xylem vessels cause | to rise up the stem of the plant by **capillarity**.

Note: The lowered water potential creates a tension *between water molecules due to cohesion force between water molecules which is transmitted through the stem xylem to the root xylem which lowers their water potential below that of soil causing water uptake from the soil by osmosis*

Transpiration is regulated *by controlling the size of the stomata pore surrounded by guard cells whose inner cells are thinner and the outer cells are thicker; adjacent to epidermal cells from which they absorb water to become turgid to open the stomata while on loss of water they become flaccid to close the stomata.*

UPTAKE AND TRANSLOCATION OF MINERAL IONS
Mineral salts are required by plants for the metabolism.
The main source of minerals is the soil solution.
Plants absorb mineral salts using root hairs of younger roots because the older roots walls contain suberin, and are hence impermeable.
Within the cell membrane and tonoplast, there are transmembrane proteins which function as channels, carriers or pumps which move minerals into the cell, and also from cell to cell.

Translocation is the movement of mineral salts and chemical compounds within a plant.

There are two main processes of translocation which include;

1. The uptake of soluble minerals from the soil and their passage upwards from the roots to the various organs via the xylem tubes.
2. The transfer of organic compounds synthesized by the leaves both upwards and downwards to various organs via the phloem tubes

Adaptations of root hairs to absorption of mineral ions

- Thin to reduce the distance over which ions move.
- Cell surface membrane is (selectively) permeable to ions to permit entry of required ions.
- Slender and flexible, penetrating between soil particles to come into intimate contact with the film of soil solution on them.
- Lack cuticle making the permeable to ions
- Numerous to increase surface area for absorption of ions.
- Cell surface membrane possesses channel and carrier proteins for facilitated diffusion and active transport of ions.
- Metabolically active to produce much energy in form of ATP for active uptake of ions.

Mechanism of mineral ion uptake
Minerals such as nitrates, phosphates, sulphates etc. may be absorbed either **actively or passively.**
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).

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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.

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.

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 utilized called **sinks** by diffusion and active transport i.e. the minerals move laterally (sideways) through pits in the xylem tissue to the sinks by diffusion and active transport.

Evidence to show that most mineral ions are absorbed actively by the root hairs

1. 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
2. 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
3. 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.

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Evidence for supporting the role of the xylem in transporting minerals

1. The presence of mineral ions in the xylem sap i.e. many mineral ions have been found to be present in the xylem sap.
2. 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.
3. There's evidence that other solutes e.g. **the dye, eosin,** when applied to the plant roots, it is carried in the xylem vessels
4. 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 **mycorrhiza**.

TRASLOCATION OF ORGANIC MOLECULES

Translocation is the movement of organic products of photosynthesis through the phloem of the plant.
The main materials transported are, **sucrose, amino acids and hormones**.
The contents of the phloem are generally called sap and the transport medium is water.
Generally the **movement of sap** is from the source to the sink.
A source is a plant organ where sugar is manufactured, such as, the leaf or one where stored food is mobilized from, such as a storage root
A sink is a plant organ where sugar is used or stored, such as a root.
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.**
The transfer of sucrose from a source into the phloem is called **loading,** while the transfer of sucrose from the phloem to the sink is called **unloading.**
Sucrose travels to the phloem sieve tubes through two routes, the **apoplast** and **symplast pathways.**
Loading is done by modified companion cells called **transfer cells**, specialized for high volume transport of materials for a short distance.

How loading is done

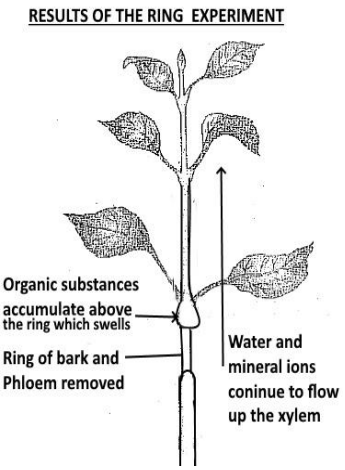
Loading of sieve tubes is by **cotransport**.
A uniport proton pump generates a hydrogen ion gradient across the membrane of the transfer cell by active transport.
The proton gradient is then used to drive the transport of sucrose by coupling sucrose transport to the facilitated diffusion of hydrogen ions back into the cell by a symport carrier.
The sucrose then passes into the sieve tubes through the plasmodesmata.
To prove that loading requires energy, a plant is supplied with respiratory poison or subjected to high temperature which stops/ slows down the loading of sucrose into sieve tubes.

How unloading of sieve tubes is done in the sink

In the sink, two proton pumps work together to accumulate hydrogen ions in the root vacuoles in the root cells.
One of the proton pumps hydrolyses ATP and uses energy to transport protons into the vacuole against a concentration gradient.
Another proton pump which is also a sucrose transporter uses a hydrogen gradient to transport sucrose against its concentration gradient.

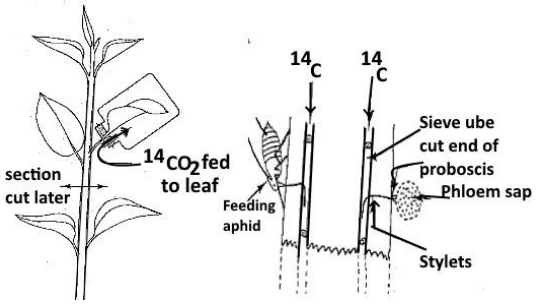
Evidence to support that organic molecules of photosynthesis are transported in the phloem

1. 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 swelling of the stem above the ring.
2. When the **phloem is cut,** the sap which exudes out of it is rich in organic food materials especially sucrose and amino acids.
3. 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



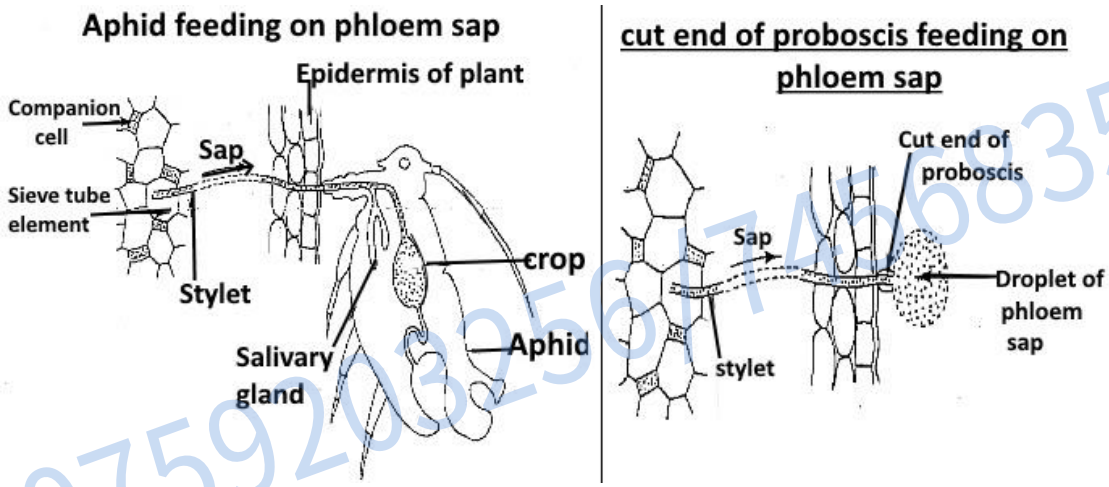
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4. The **use of radioactive tracers**. If radioactive **carbon dioxide-14** is given to plants as a photosynthetic substrate, the sugars later found in the phloem contain carbon-14. When the phloem and the xylem are separated by waxed paper, the carbon-14 is found to be almost entirely in the phloem sap.



5. **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.



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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.

a. **The mass flow or pressure flow hypothesis (i.e. Munch's hypothesis)**
b. **Electro-osmosis**
c. **Cytoplasmic streaming**

Mass flow or pressure flow hypothesis

The pressure flow hypothesis

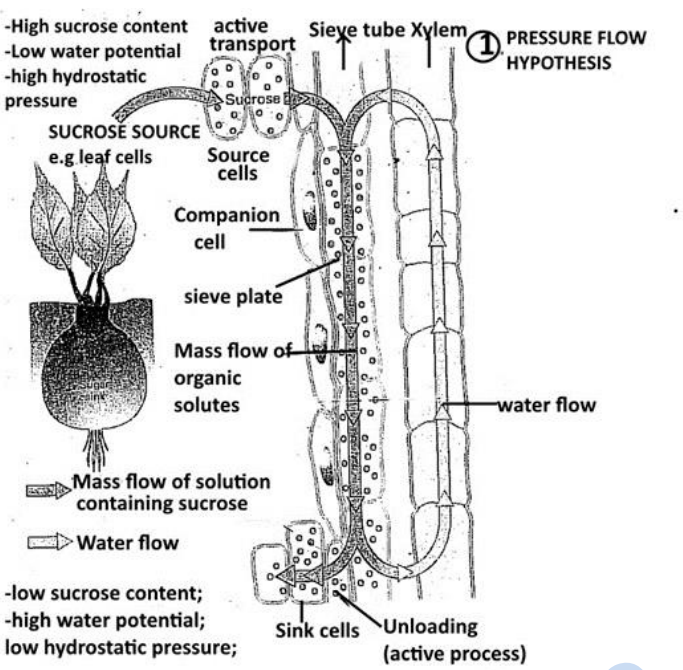
This hypothesis suggests that phloem and sap freely flows from a region of high hydrostatic pressure to a region of low hydrostatic pressure. The pressure having been created by active loading of sucrose by transfer cells into sieve tubes and the unloading of the same sucrose at the sink.

Mass flow is the bulk 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 sieve tube elements.

There are four things in this hypothesis:

- The active loading of sugar in the phloem from a source, such as a leaf mesophyll cell, increases the solute concentration. This increases the solute concentration and lowers water potential gradient inside the sieve tube cell. This causes the sieve tubes to take up water from the surrounding tissues by osmosis.
- The water absorbed creates a hydrostatic pressure which forces the sap to move along the sieve tubes.
- The gradient of pressure in the sieve tube is reinforced by the active unloading of sugar and consequent loss of water by osmosis at the sink.
- The water lost at the sink is transferred to the xylem which moves it from where it moves in the transpiration stream and part of it returns to the source.

Evidence in support of pressure flow hypothesis

1. A concentration gradient has been found to exist in many plants between the source and the sink.
2. It has also been demonstrated that phloem fluid flows under high hydrostatic pressure. This has been done using aphids
3. (a) Radioactively labeled molecules applied to illuminated leaves are trans located to the sink

(b) Radioactively labeled molecules applied to shaded leaves are not found in the sink

(c) Increase in light intensity has been shown to increase sucrose concentration in leaves and in the phloem.

Evidence against the pressure flow hypothesis

1. The hydrostatic pressure measured in phloem sieve tubes has been found to be insufficient to transport organic salts.
2. The presence of sieve plates is considered to be a barrier to mass flow

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The hypothesis proposes that the flow of sap in the sieve tubes is passive, yet it requires living cells and energy is used at different rates and sometimes different directions simultaneously in the same sieve tubes

MUNCH'S MASS FLOW HYPOTHESIS

Munch put forward a purely physical hypothesis to explain how mass flow might be brought in sieve tubes.

Two semi permeable reservoirs cell **A** and **B** are joined by a tube

Cell A contain a concentrated sugar solution, while **cell B** contains more dilute sugar solution.

The two reservoirs are immersed in water as show in the diagram below.

Water is draw into **cell A** by osmosis and the solution flows from **cell A to cell B**, due to the developed pressure potential in **A**.

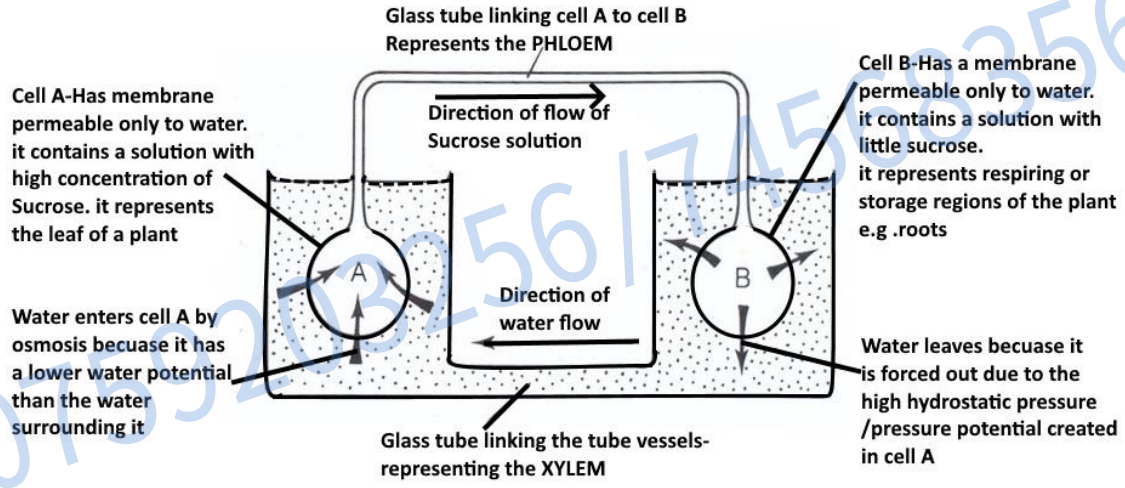
Water is forced out of bulb B by the hydrostatic pressure so developed.

The flow will cease when the concentrations in **cell A and cell B** are equal.

The water which is forced out of B can return to **A** via the interconnecting tubes of the two beakers, as it is forced from **sink cells**, to the sources, via the xylem.

In other words , **cell A** represents the source (mesophyll) cells with a high solute concentration , and **cell B** represents the sink (storage and growth cells) where the solutes move from **A to B** , via the phloem , due to pressure potential gradient (i.e. higher in A and lower B)

Physical model to illustrate the mass flow theory of translocation in phloem



Provided sucrose is continually produced in A (leaf) and continually removed at B (e.g. root) the mass low of sucrose from cell A to Cell B continues

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

- 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.

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- The phloem has a relatively high rate of oxygen consumption which this theory does not explain.
- When a metabolic poison such as potassium cyanide enters the phloem, the rate of translocation is greatly reduced, implying that translocation is not a passive process, but an active one.
- The mass flow hypothesis does not mention any translocation of solutes with influence of transfer cells and Indole Acetic Acid (IAA) hormone that loads the sugars or solutes into the sieve tubes and also unload it into the cells of the sink.
- The sieve plates offer a resistance which is greater than what could be overcome by the pressure potential of the phloem sap. This implies that the pressure would sweep away the sieve plates during this transport.
- Higher pressure potential is required to squeeze the sap through the partially blocked pores in the sieve plates than the pressure which has been found in the sieve tubes

NOTE: The mass flow theory is considered to be the most probable theory in conjunction with electro-osmosis

Differences between Munch's mass flow hypothesis and the pressure flow hypothesis

1. Munch's mass flow hypothesis is a purely physical explanation and so does not explain why sieve tubes must be living and metabolically active.
2. It also does not explain the observation that the leaf cells are capable of loading sieve tubes against a concentration gradient, that is, the fact that the solute potential of the sieve tubes is more negative than that of the leaf cells

The hypothesis has therefore been modified to include an active loading mechanism of solutes into the sieve tubes.

The osmotic and hydrostatic pressure gradient therefore starts in the tubes rather than in the photosynthetic cells.

It is also believed that unloading at the sinks is an active process.

The modern version of Munch's hypothesis is known as the **pressure flow hypothesis.**

Electro-Osmosis

This is the passage of water across a charged membrane.

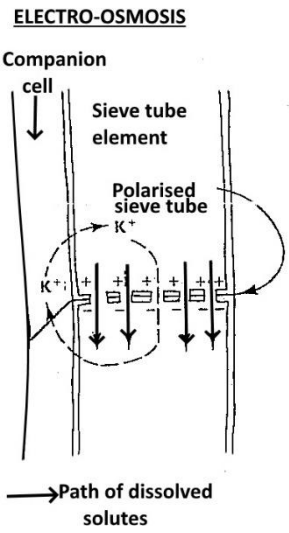
This membrane is charged because positively charged ions e.g. K^+ ,actively pumped by the companion cells across the sieve plate into the sieve tube element using energy from ATP of the companion cells.

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 si eve 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 pores, to enter the lower cell.



Evidence to support the electro-osmosis theory

1. K^+ ions stimulate the loading of the phloem in the leaves with sugars during photosynthesis.

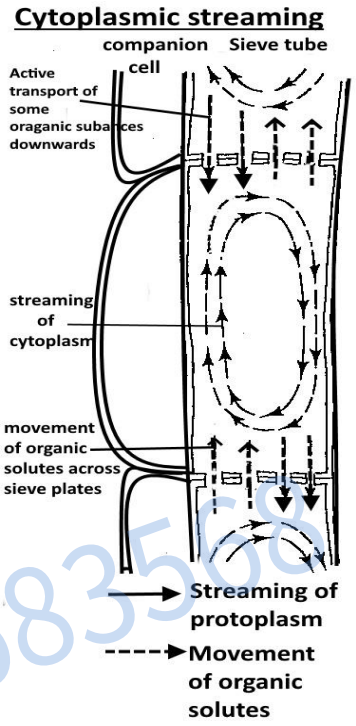
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2. Numerous mitochondria produce a lot of energy for translocation, an indicator that translocation is an active process. If however, the phloem tissues are treated with a metabolic poison, the rate of translocation reduces.
3. potassium uptake is promoted by indolaacetic (IAA)

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.



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.
2. The rate at which the protoplasm streams is far slower than the rate of translocation

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TRANSPIRATION

This is the process of water loss inform of water vapor to the atmosphere from the plant mainly through the stomata pores. **Or** is the loss of water in form of vapour from the aerial parts of the plant through the stomata, lenticels and the cuticle.

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 vapor 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 vapor can pass and also there's little resistance to the movement of water vapor through the stomatal pores.

In addition, leaves also have a large surface area over which water vapor can evaporate rapidly to the atmosphere.

Cuticular transpiration

This is the loss of water vapor 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 vapor molecules.

Lenticular transpiration

This is the loss of water vapor 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 vapor 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 thiocyanate** 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 thiocyanate paper changes to pink, i**ndicating 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

b) 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

c) 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 is equivalent to 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

$$\text{Total area of leaves} = \text{Number of complete squares} + \text{Number of incomplete squares} \times \frac{1}{2}$$

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.

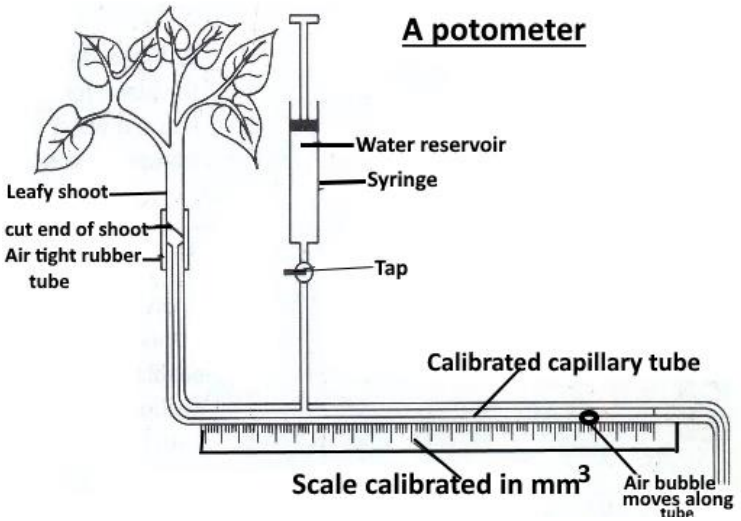
How to use a potometer

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.

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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.



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

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

- 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.
- It facilitates the uptake of the absorbed mineral salts within the xylem vessels from roots to leaves
- It brings about the cooling of the plant since as water evaporates to the atmosphere, excessive heat is also lost as heat of vaporization, which results into the cooling of the plant
- 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
- It is important for cloud formation via evapotranspiration hence resulting into rainfall

Disadvantages of transpiration

- It causes wilting of plants in case of excessive transpiration
- It may eventually cause death of the plant, when the plant loses water excessively due to excessive transpiration

Explain the role of transpiration to flowering plants.

- Cools the leaves in hot conditions
- Transpiration stream makeup for the water lost in transpiration; acc. water absorption.
- Provides pathway through which mineral contents are transported in the plant

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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**

Humidity is the amount of water vapor in the atmosphere**.**

The humidity of the atmosphere affects the gradient of water vapor between the sub-stomatal air chamber and the atmosphere around the leaf i.e. it affects the rate of diffusion of water vapor.

Low humidity (low water vapor pressure) outside the leaf increases the rate of transpiration because it makes the diffusion gradient of water vapor from the moist sub-stomatal air chamber to external atmosphere steeper, enabling water vapor to rapidly diffuse out of the sub/stomatal air chambers down a water vapor gradient to the external environment hence increasing the rate of transpiration.

When humidity is **high** in the atmosphere, the diffusion gradient or the water vapor 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.

Differences between transpiration and guttation

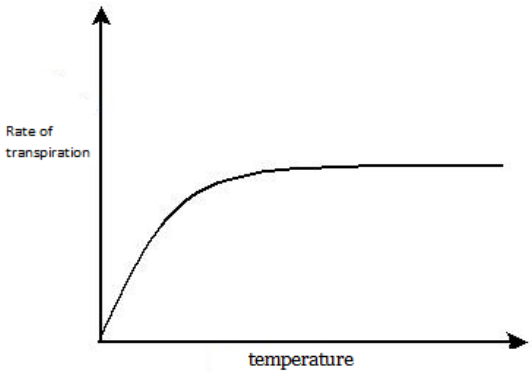
Transpiration	Guttation
▪ Water is lost in the form of water vapour	Water is lost in form of water droplets
▪ Occurs through the stomata cutical and lenticels	Occurs through special pores called hydathodes
▪ Occurs during bright lights and high temperatures	Occurs during deem light such as at night and at low temperature.
▪ Enhanced by low humidity	Enhanced high humidity
▪ Water lost is pure water and does not contain minerals	Water lost in minerals water it contains sugars, salts and amino acids.
▪ Increased transpiration leads to wilting	Increased guttation is related to low transpiration and high root pressure and does not cause wilting.

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.

An increase temperature increases latent heat of vaporization of water molecules and therefore encourages faster evaporation water molecules from the mesophyll cells/ when the air around the leaf is warmed, its capacity for water vapor intake increases/latent heat of vaporization causes more water from the plant to turn into water vapour so increases transpiration rate.

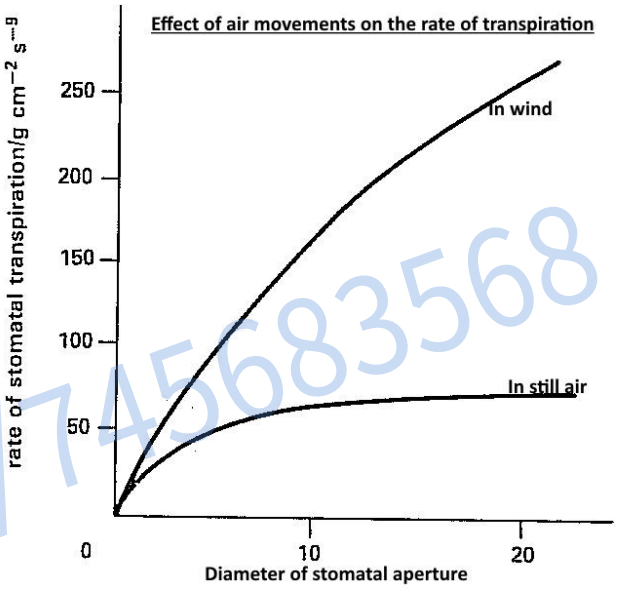
This is because increase in temperature increases the kinetic energy and movement of water molecules hence the water molecules evaporate rapidly and accumulate in the sub-stomatal air chambers and eventually escape through stomata into the atmosphere.



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 vapor from the leaf. The layers of highly saturated water vapor 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 creating a steep diffusion gradient which keeps the rate of transpiration high.

4. Atmospheric pressure

Water vapor and the atmospheric pressure decreases with increasing altitude.

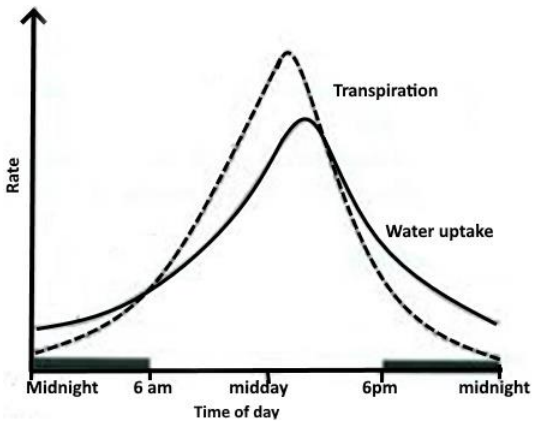
The lower the atmospheric pressure the greater the rate of evaporation of water from the sub-stomatal air chamber. This implies that plants growing on a mountain have a higher rate of transpiration than those growing in low land areas.

However, when the atmospheric pressure is high e.g. in the lowland areas, the evaporation of water vapor from the sub-stomatal air chamber to the atmosphere decreases, thereby increasing the rate of transpiration.

5. Water availability

For water vapor 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 degree of stomatal opening and closure. The stomata of most plants open full in bright sunlight/daylight hours to allow evaporation of water to the atmosphere. Therefore sunlight increases the rate of transpiration.

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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.

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.

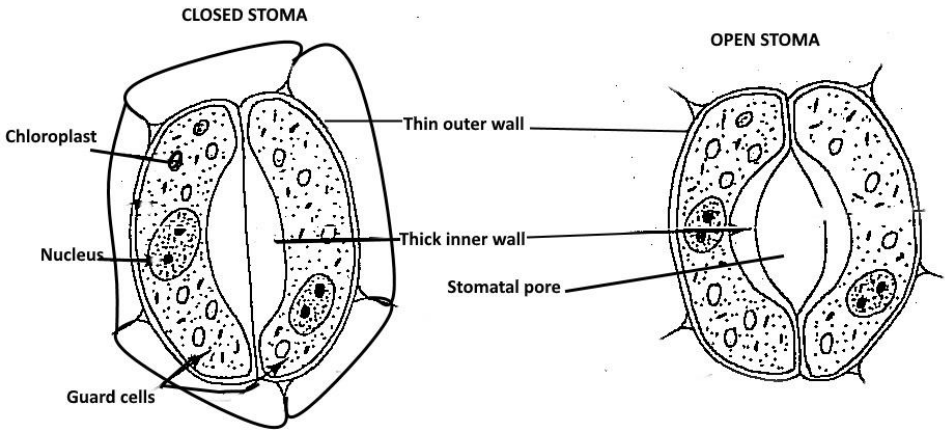
The number of stomata in leaves vary from one plant species to another. They are normally absent in submerged leaves of water plants.

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STRUCTURE OF THE STOMA

Each stoma consists of a stomatal pore is 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.

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.

THEORIES TO EXPLAIN HOW THE LIGHT INTENSITY INFLUENCES THE OPENING AND CLOSING OF STOMATA.

1. Photosynthesis by guard cells

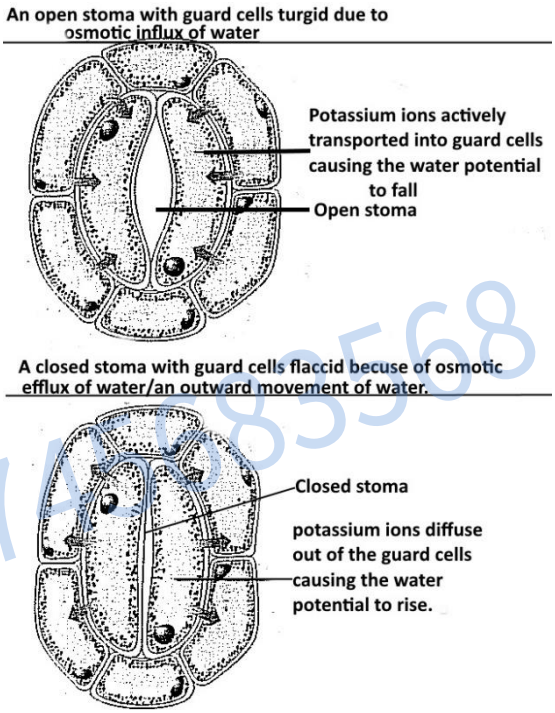
Guard cells have chloroplast that are involved in the formation of sugars by photosynthesis in the guard cells. During day light, the chloroplast carry out photosynthesis producing water soluble sugar which lower the water potential of the guard cells.

The sugar also increases the osmotic pressure of the cell sap which causes water to move by osmosis into the guard cells from neighboring epidermal cells down a water potential gradient.

This results in 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 epidermal 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

Criticisms

- Some guard cells don't contain chloroplast and yet they open and close
- The rate of photosynthesis is too slow to explain the rapid response of stomata to light
- Some plants have their stomata which open at night and close during day. These are succulent plants in the desert therefore the above theory doesn't accurately explain the stomatal opening and closure.

2.Potassium ion (K^+) mechanism (mineral ion concentration)

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.

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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.

3. Starch-sugar interconversion

The starch-sugar interconversion in guard cells is catalysed by a group of enzymes

Leaf mesophyll cells contain an enzyme known as **carbonic anhydrase** which catalyses the reaction between carbon dioxide and water to form carbonic acid. The carbonic acid dissociates into **hydrogen ions** and hydrogen carbonate ions.

H_2CO_3 ⟵ carbonic anhydrase ⟶ HCO_3^- + H^+

Carbonic acid — **Hydrogen carbonate ions** — **hydrogen ions**

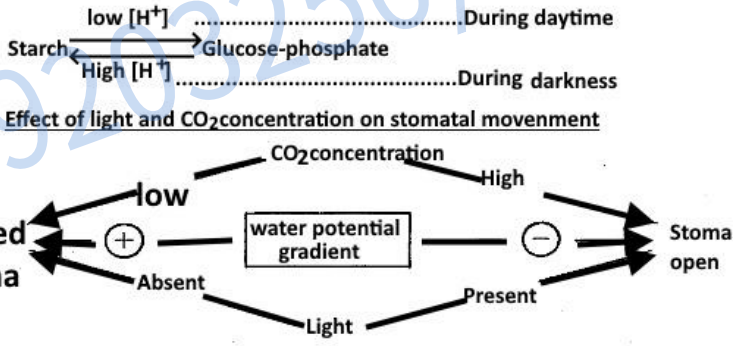
During the day time/at high light intensities photosynthesis, uses up carbon dioxide. This lowers the concentration of hydrogen ions in leaf cells during the day time and therefore creates a high pH in the guard cells. Like most enzyme-catalysed reactions, the high pH favors conversion of starch to glucose phosphate by the **enzyme starch phosphorylase**.

The accumulation of sugars **during** daytime lowers water potential of guard cells, the guard cells take in water down a water potential gradient from the nearby **epidermal cells by osmosis. The resultant increase in pressure potential causes the stomata to open**. Also increase in turgidity of the guard cells cuases thin outer expand while the thick outer is pulled apart resulting into opening of the stoma.

At night carbon dioxide produced in respiration causes its accumulation in the intercellular spaces of the leaf, and this raises the concentration of carbonic acid, lowering **the pH**. The resulting drop/fall in pH favours the conversion of sugar to starch by enzyme **starch phosphorylase** in the guard cells, thereby raising their water potential, hence the guard cells lose water by osmosis and causing the stoma to close.

In the morning the resumption of photosynthesis lowers the concentration of carbon dioxide.

As a result the level of carbonic acid falls, the pH rises, starch is converted to sugar, and the water potential of the guard cells decreases and the stoma opens.



Stomata opening

- Stomata opening is promoted by high light intensity and low mesophyll carbon dioxide levels. Guard cells generate ATP by photophosphorylation during photosynthesis.
- Blue light is absorbed by blue-light photoreceptors which activate a proton-pump (H^+-ATPase) in the cell membrane of the guard cell
- ATPs generated by the light-dependent reaction of photosynthesis are hydrolyzed to provide energy to drive the proton-pump. As protons (H^+) are pumped out of the guard cells, the cells become increasingly negatively charged. Potassium channels are activated and K^+ ions diffuse from subsidiary cells through the channels down this electrochemical gradient into guard cells. Chloride ions (Cl^-) then enter to balance the charge.
- **In some plants the starch is converted to malate**.

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- 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 neighboring subsidiary cells into the guard cells. The guard cells become turgid.
- The outer wall of the guard cells is thinner and more elastic than the thicker inner wall. There are cellulose micro fibrils which are radially arranged around the cell wall and the ends of the two guard cells are joined
- The increased turgor pressure therefore causes the guard cells to curve outward and the stoma opens

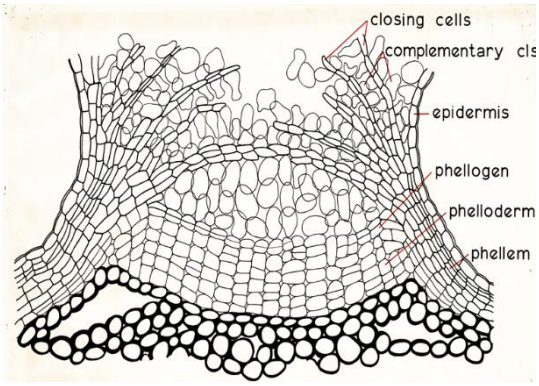
Stomata closure

- Stomata closure can be triggered by water stress, high temperature, increasing carbon dioxide levels in the leaf mesophyll and low light intensity (night time)
- The hormone abscisic acid (ABA) is secreted by plant cells when transpiration rate is high and soil water is low.
- ABA binds to receptors at the cell membrane of the guard cells. This increase the permeability of calcium channels in the cell membrane. Calcium ions (Ca^+) enter into the guard cell. The influx of calcium ions also triggers the release of Ca^+ from the cell vacuole into the cytosol.
- Potassium ions (K^+) move out of the guard cells into the subsidiary cells
- In some plants (Cl^-) and certain organic ions e.g. malate ions also move out of the guard cells
- The water potential in the guard cells increase. Water diffuses out to neighboring subsidiary cells by osmosis. The turgor pressure in the guard cells decreases, the cells become flaccid and the stoma closes.
- At night the chloroplasts in the guard cells do not photosynthesize, less ATP is produced and there's no active uptake of K^+ ions. Instead, the K^+ ions diffuse out of the guard cells. The cells become flaccid and the stoma closes.

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LENTICELS

A small extent 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.



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.

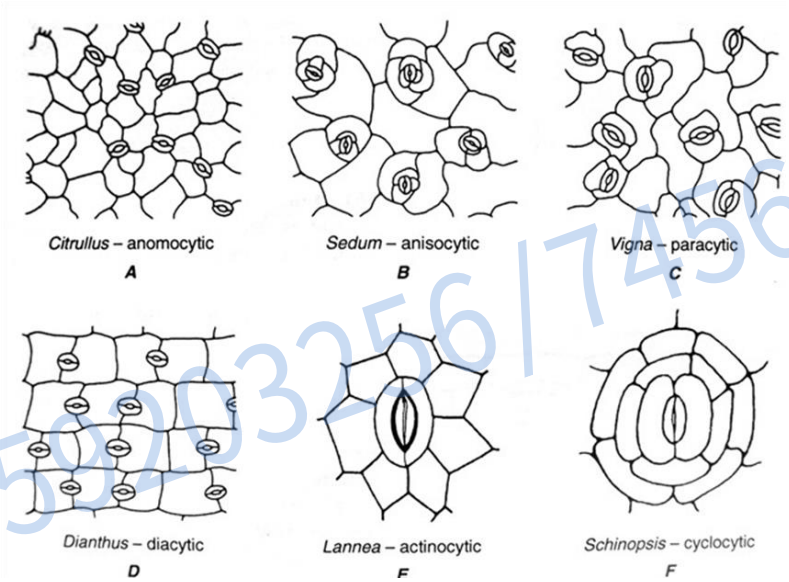
Others like rice and water lilies are partially submerged in water. Their aerial parts obtain carbon dioxide and oxygen in the same manner as terrestrial plants. The submerged parts may face the problems of obtaining adequate oxygen for their respiratory requirement. However such plants have large air 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 commelina. 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



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END OF VOLUME ONE LOOK OUT FOR VOLUME TWO
SUCCESS

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