DIVERSITY AND CLASSIFICATION OF LIVING ORGANISMS

Scientific classification is the grouping of organisms according to similarities and differences in their characteristics. The branch of science that deals with classification of organisms is known as taxonomy.
Taxonomy involves identification of living organisms as they are discovered, grouping them into various levels and naming of organisms scientifically. This enables scientists to make meaning of the great diversity observed among living organisms. It is thought that humans share the earth with an uncountable number of organisms, which all needed to be classified in order to make meaning out of them. During identification, classification and naming, morphological, anatomical and physiological similarities and differences are considered. Characteristics which change depending on the environment of an organism are not usually considered.

IMPORTANCE OF CLASSIFYING ORGANISMS

Classifying organisms is important for the following reasons:

1) Enables easy identification of living organisms. After discovery of new organisms, they can easy be identified by comparison with already identified organisms.
2) It eases the studying of living organisms by studying them in groups as opposed to studying each individually.
3) Enables scientists to establish evolutionary relationships among living organisms. Related organisms are usually grouped together and unrelated organisms are grouped separately.
4) To assign every species of living organisms a scientific name that differentiates it from the rest. This prevents confusion that may occur with using common names.

TYPES OF CLASSIFICATION

There are two forms of classification basing on the principles used.

a) **Artificial classification**

This involves grouping organisms for the convenience of study of such organisms. Therefore this classification is based on simple easily observable characteristics. Such characteristics may include size, habitat, ways of movement, etc. For example organisms in kingdom *protoctista* are simply placed there due to being eukaryotic and unicellular, though they have no evolutionary relationship between them.

b) **Natural classification**

This is where classification is based on similarities and differences in many external and internal characteristics in order to bring out the natural relationship between organisms. This system of classification uses information from many branches of biology in order to establish the phylogenetic relationships between groups of organisms. A phylogeny is a historical evolutionary relationship among organisms.

CRITERIA OF CLASSIFYING ORGANISMS/ PRINCIPLES OF CLASSIFICATION

When an organism is to be classified, it's obtained and its characteristics observed. Organisms with similar characteristics are placed in the same group while those with differing characteristics are placed in different groups. Modern classification however also seeks to establish the evolutionary relationships between organisms. The following characteristics are therefore considered;

1) **Morphological characteristics**

Morphology is the scientific study of form and structure of plants and animals without regard to function. External morphological characteristics of organisms are usually considered. This includes presence or absence of parts, arrangement of parts, number of parts, etc.

2) **Anatomy of the organisms**

This is the study of the external and structures of living organisms, but also relating them to their functions. Organs with a similar anatomy use the same structure for the same function.

3) **Physiology**

This is the study of the functioning of organs, tissues and cells of living organisms. It includes the study of all the metabolic processes that occur in organisms. The study of physiology is closely related to anatomy. Physiological processes important in classification include photosynthesis, nutrition, reproduction, growth, etc.

DICHOTOMOUS KEY

During collection of organisms to be identified, they are carefully observed. The characteristics seen are then noted down, and identification keys may be constructed to ease the identification process. The most common identification key is the dichotomous key.
A dichotomous key is a key consisting of statements about the characteristics of organisms with each with each step having only two possible alternatives.

Procedure of constructing a dichotomous key

The following steps are followed;

a) Organisms to be identified are carefully observed and external observable characteristics are noted.
b) Organisms are then divided into two groups basing on the characteristics noted. The characteristics chosen must be perfect opposites of each other.
c) The two groups obtained above are also each divided into two smaller groups.
d) The above step (step C) is repeated until each group eventually consists of only one organism.

A flow chart may then be made with each step having two branches or a dichotomous key may be written directly.

Example:

Given 5 insects with following characteristics of legs and mouth parts,

Organism	**Characteristics of legs**	**Characteristics of mouth parts**
A	Spines on tibia	Has mandibles
B	Smooth legs	Has mandibles
C	Hairy legs	Has a proboscis
D	Smooth legs	Has a proboscis, piercing stylets
E	Hairy legs	Has mandibles

Construct a dichotomous key to identify the above insects.

<u>A dichotomous key to identify specimens A, B, C, D and E</u>

1 a) Organism with appendages on legs (A, C, E) ……………………………. go to 2
b) Organism without appendages on legs (B, D) …………….……..…..… go to 4

2 a) Organism with spines on tibia …………………………………………..... A
b) Organisms with hairs on tibia (C, E) ………………………………....... go to 3

3 a) Organism with a proboscis ………………………………………….....… C
b) Organism with mandibles …………………………………………….…. E

4 a) Organism with piercing stylets ……………………………………...... D
b) Organism without piercing stylets …………………………………………. B

Question: Collect five insects from the environment around the school. Using only their features of wings and mouth parts, construct a dichotomous key to identify the specimens.

LEVELS OF CLASSIFICATION

During classification, scientists place living organisms into seven major levels known as taxa (singular taxon). Each taxon contains organisms sharing certain common characteristics which also indicate ancestry. The seven taxa in descending order of size are Kingdom, Phylum, Class, Order, Family, Genus and Species.

The kingdom is the largest level of classification containing many organisms with few general characteristics that are common to all of them.

A species is the smallest level into which organisms are classified and includes organisms that are so similar to each other. A species is defined as *a group of similar organisms that can successfully interbreed to produce viable offspring.*

The modern system of classification places all living organisms into five kingdoms. Each of these kingdoms is split into several phyla with each containing several classes. Classes are then split into orders which are also split into families. Each family contains many genera and each genus contains one or several species.

The table below shows classification of three organisms; human, domestic dog and cassava plant into the seven taxa.

Taxon	**Human**	**Domestic dog**	**Cassava**
Kingdom	Animalia	Animalia	Plantae
Phylum	Chordate	Chordate	Spermatophyta
Class	Mammalia	Mammalia	Dicotyledonae
Order	Primates	Canivora	Malpighiales
Family	Hominidae	Canidae	Euphorbiaceae
Genus	Homo	Canis	Manihot
Species epithet	sapiens	familiaris	*esculeta*

BINOMIAL NOMENCLATURE

When assigning scientific names to organisms, each species of organisms is assigned two names. This form of nomenclature is known as binomial nomenclature and was first proposed by a Swedish scientist Carl Linnaeus.

The first name to be written is the genus name starting with a capital letter, and the second name is the species name (specific epithet) written starting with a small letter. The whole name is then underlined or italicized. E.g. the scientific mane of a domestic dog is *Canis familiaris*.

Question: using information in the table above, write down the scientific names of a human and cassava plant.

Scientific names are used in order to eliminate the confusion that arises due to use of common names. Common names may differ from one place to another and from one language to another.

KINGDOMS OF ORGANISMS

There are five kingdoms into all organisms are placed. These are;

1. Monera
2. Protoctista
3. Fungi
4. Plantae
5. Animalia

When dividing organisms into kingdoms, the following are considered:

- **Cell structure:** this considers whether the cells are prokaryotic or eukaryotic. It also looks at the cell organelles present
- **Chemical composition:** this examines the chemical compounds present in the various cell structures such as cell walls, granules in the cytoplasm
- **Level of cell organization:** whether the organism is unicellular or multicellular

N.B: Viruses are not placed in any of the above kingdoms. This is because they are considered non living but rather a simple collection of molecules. However, they posses some characteristics of living organisms and affect living organisms hence they are of much interest to biologists.

VIRUSES

These are particles consisting of genetic material surrounded by a layer of proteins that are capable of invading other cells.

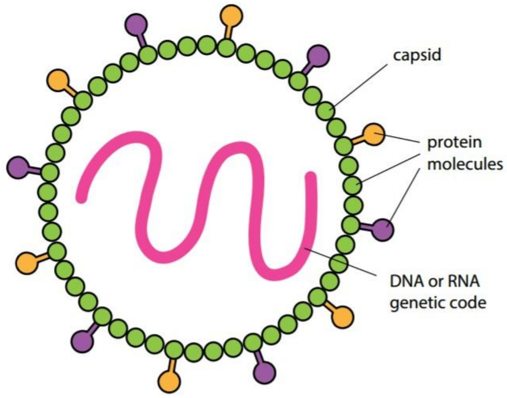
General characteristics of viruses

1) They are much smaller than bacteria or eukaryotes.
2) They can only survive inside host cells i.e. they are obligate parasites.
3) They use the host cell machinery for their own metabolism.
4) Their particle consists of mainly a genetic material (DNA or RNA) surrounded by a protein coat, having no definite cell structures and organelles i.e. they are acellular.
5) They can be crystallized when outside host cells and stored for long periods of time.
6) When inside a host cell, they take control over their metabolism.
7) They only reproduce using the host cell machinery.

Reasons why viruses are considered non living things

1) They cannot survive outside host cells, except as crystals
2) They can only carry out metabolism using the host cell machinery
3) Thy only reproduce when inside host cells
4) They have no cellular components and organelles

Structure of a virus



A virus particle consists of a genetic material surrounded by a protein coat known as a capsid. The genetic material may be DNA or RNA and maybe single stranded or double stranded.
The capsid has surface proteins which act as receptors to the host cell. Some viruses have an additional coat of lipids for protection. Viruses are known as **akaryotes** because they don't have cell organelles.

TYPES OF VIRUSES

Viruses are classified according to the nature of genetic material they have or type of life cycle. They are not classified according to their own characteristics because their characteristics are related t the host organism.

The common types according to genetic material are;

a) Single stranded RNA viruses
b) Double stranded RNA viruses
c) Single stranded DNA viruses
d) Double stranded DNA viruses

According to lifecycle, the types are;

a) Lytic viruses, which burst their host cell during reproduction for the new virus particles to come out E.g. Ebola virus
b) Lysogenic viruses, which just bud off from the host cell when new virus particles are coming out of the host cell, leaving the host cell alive. E.g. influenza virus
c) Retroviruses, these are viruses that change their genetic material from RNA to DNA during the life cycle. E.g HIV

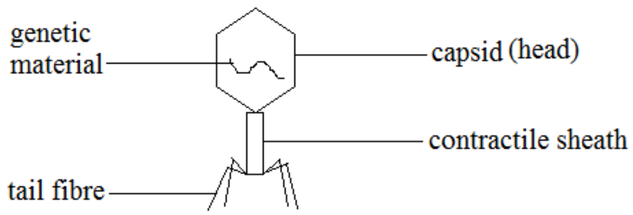
N.B: since all viruses are obligate endoparasites, viruses cause diseases in kingdoms of organisms by infecting their cells. In animals they cause diseases such as AIDS, Ebola, Yellow fever, influenza, polio, foot and mouth disease, Rabies, new castle disease. etc.
In plants, viral diseases include cassava mosaic, tomato bush stunt disease, tobacco mosaic, etc.

Question: Outline methods of preventing the spread of viral diseases.

Lifecycle of a Bacteriophage

A Bacteriophage is a virus that infects bacteria. It's an example of a virus with a simple lifecycle.

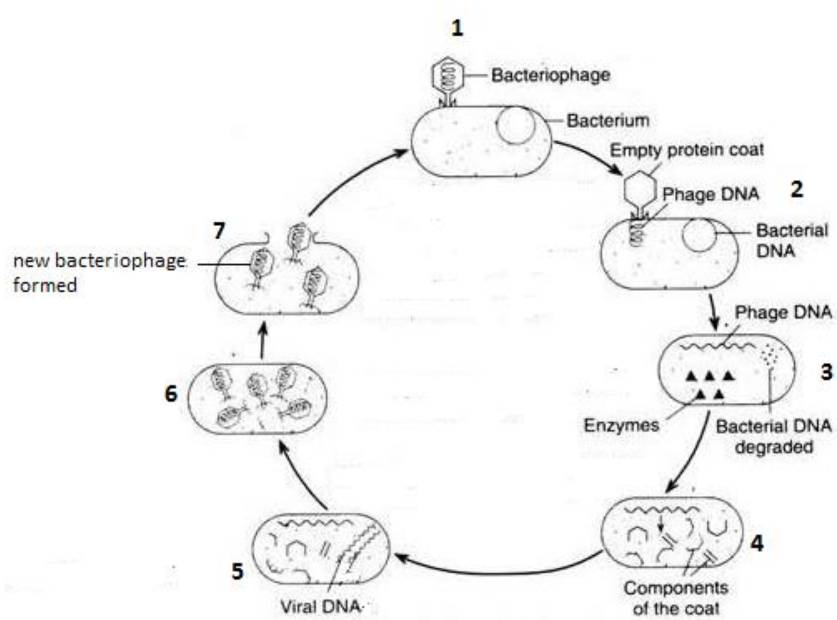
Structure of a Bacteriophage



Its lifecycle begins as follows;

1. The Bacteriophage approaches the bacteria and attaches to its surface (the cell wall) using receptors in the tail fibers.
2. The Bacteriophage then drills through the bacteria's cell wall using pins at the base of the contractile sheath and injects its genetic material.
3. The virus DNA (phage DNA) is then used to synthesize hydrolytic enzymes that breakdown the DNA of the bacterium. The virus DNA then takes control of the bacterium.
4. The viral DNA codes for the synthesis of virus components such as the surface proteins, sheath and tail fibers.
5. The virus DNA replicates forming many copies of its self.
6. The virus components are assembled to form new copies of the Bacteriophage.
7. Due to breakdown of the bacterial cell wall by enzymes and increase in internal osmotic pressure, the cell wall bursts releasing the new Bacteriophage particles into the surrounding medium. The released particles then attack other bacteria.

Illustration



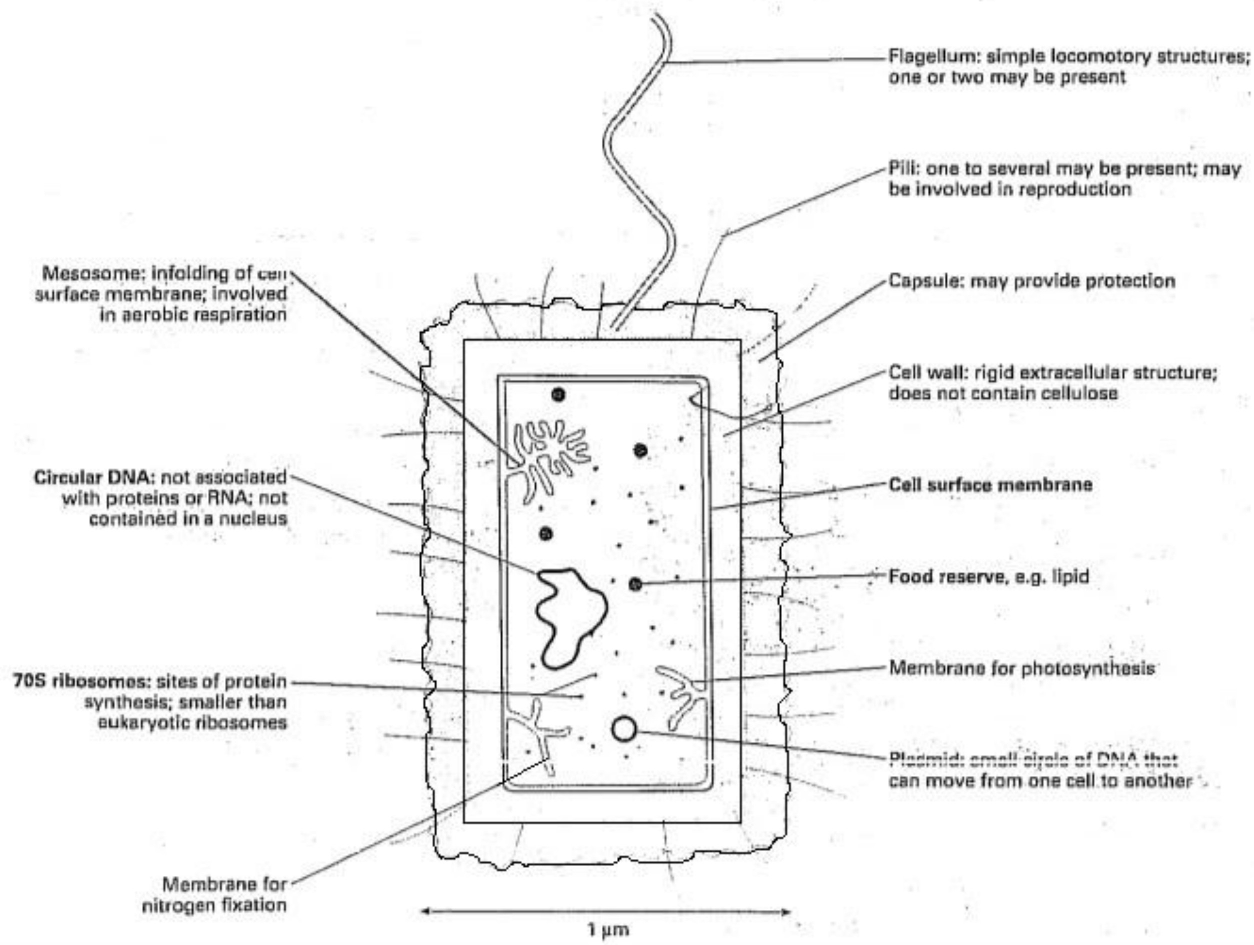
KINGDOM MONERA

This is a kingdom of prokaryotic organisms consisting of bacteria and blue-green algae. These organisms are much smaller than eukaryotes, but much bigger than viruses.

Characteristics of bacteria

i. They have no nucleus in their cells
ii. They have circular DNA in their cells and its always naked (not associated with histones)
iii. Lack double membrane bound organelles such as mitochondria, golgi bodies, etc.
iv. Have smaller 70s ribosomes
v. Cells have cell walls, made up of peptidoglycans
vi. Cells divide by binary fission
vii. They exist as single cells (unicellular) or small groups of cells (colonial).

Drawing of a bacterial cell



The structures that are present in all bacteria are cell wall, cell membrane, cytoplasm, 70s ribosomes and circular DNA.

Question: state the differences between prokaryotic and eukaryotic cells.

DOMAINS OF BACTERIA

Bacteria fall into two groups depending on the characteristics of their cells. These are;

a) **Archaea bacteria:** these are ancient bacteria that inhabit extreme environmental conditions such as hot springs. They differ from the true bacteria by not having peptidoglycan in their cell walls and having 70s ribosomes with features similar to those of eukaryotes.
b) **Eubacteria:** these are the true bacteria having all the characteristics of bacteria. Eubacteria are considered more advanced than archaea.

Although all bacteria share some basic characteristics, they vary widely in size, shape and mode of nutrition.

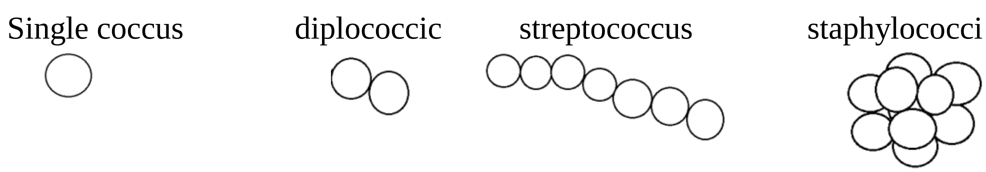
TYPES OF BACTERIA

1. According to shape, bacteria are of the following types

a) Round shaped bacteria (cocci)

These are bacteria with a circular shape usually without flagella. They may occur singly, in pairs (diplococcic), in clusters (staphylococci) or chains (streptococci).

Examples of cocci bacteria Diplococci pneumoniae causing pneumonia, streptococci pyogens



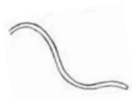
b) Rod shaped bacteria (bacilli)

These are bacteria with a cylindrical shape. They may occur singly or in chains and may have one to several flagella. Examples are Bacillus anthracis and Azotobacter.

c) Spiral shaped bacteria (spirilla)

These are bacteria whose shape is curved like a spring.

Examples include helicobacter pylori and treponema pallidum.



Some spirochetes are shaped like a comma and these are known as vibrios. E.g vibrio cholerae

2. According to mode of nutrition, bacteria are of the following types

a) Autotrophic bacteria

These are bacteria that are capable of manufacturing their own food from simple inorganic compounds and elements. These are also subdivided into;

i. Photoautotrophic bacteria: these use sunlight energy trapped by bacterial chlorophyll to manufacture organic compounds. Examples are cyano bacteria and purple sulphur bacteria.
ii. Chemoautotrophic bacteria: these are bacteria that use energy from oxidation of chemicals to synthesize their own food. Examples include nitrobacter, nitrosomonas.

b) Heterotrophic bacteria

These are bacteria which depend on already manufactured food compound by other organisms. They are subdivided into;

i. Free living saprotrophic bacteria which obtain energy by breaking down dead decaying matter. In so doing they speed up the decomposition process hence recycling nutrients.
ii. Parasitic bacteria which depend on other living organisms causing harm to them. All disease causing bacteria are parasitic bacteria. Examples of bacteria diseases in plants and animals are; plague anthrax, pneumonia, cholera, food poisoning, typhoid, gonorrhea, meningitis, tuberculosis, etc.
iii. These include bacteria in root nodules, bacteria in guts of ruminants and non ruminants. Mutualistic bacteria which live with other living organisms with both organisms benefiting.

ECONOMIC IMPORTANCE OF BACTERIA

Due to their nature and mode of nutrition, bacteria are of great economic importance.

Question: state the economic importance of bacteria

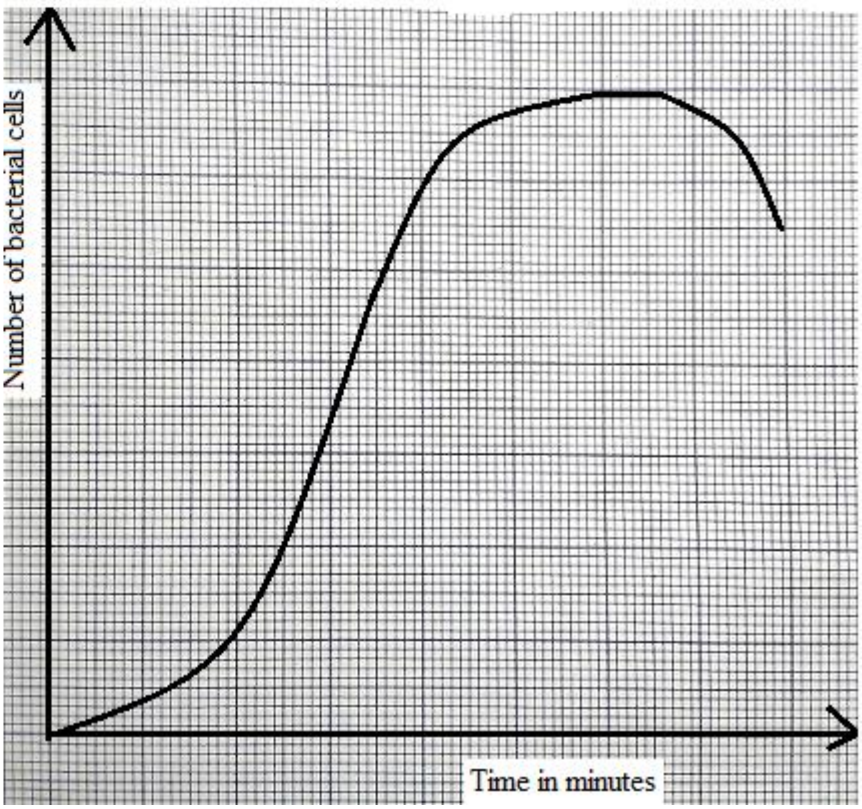
FACTORS THAT AFFECT BACTERIAL GROWTH

Bacteria can easily be cultured/ grown in the laboratory by placing a small amount of them into a medium with nutrients and conditions essential for their growth. The following factors affect the rate at which the bacterial population would grow by affecting the rate of bacterial cell division.

1. Availability of nutrients: bacteria require nutrients such as glucose and mineral ions for them to grow. Large quantities of such nutrients favor rapid bacterial growth.
2. Availability of oxygen: aerobic bacteria require oxygen for respiration hence its presence favors rapid population growth of such bacteria.
3. Temperature: increase in temperature increases the rate of bacterial population growth rate up to about $40^{o}C$ beyond which the rate of growth reduces. This is because temperature affects the activity of bacterial enzymes.

4. Availability of moisture: bacteria easily thrive and reproduce in an environment that contains relatively high levels of moisture.
5. Accumulation of toxic waste products: these include carbon dioxide, lactic acid. They reduce the rate of bacterial growth when their concentration increases. Accumulation of carbon dioxide lowers PH with affects enzymes.

Graph showing growth of a population of bacteria in a culture



Question: state the differences between bacteria and viruses.

KINGDOM PROTOCTISTA

This kingdom was formerly known as Protista. It includes all single celled eukaryotic organisms such as algae and protozoa. Algae are autotrophic while protozoa are heterotrophic.
These organisms have no common ancestral origin but share some common characteristics among them.

Characteristics of protists

1. They are unicellular or colonial organisms
2. They have a true nucleus an other double membrane bound organelles
3. They reproduce asexually by mitosis.

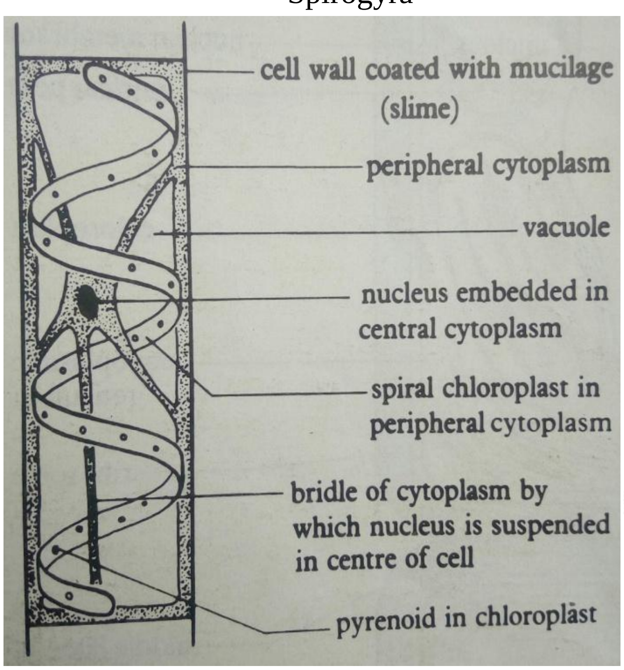
4. They have a cellular level of organization
5. They only stay in aquatic habitats or habitats containing water

Kingdom protoctista is divided into many phyla since the organisms show a great diversity. The common phyla are shown in the table below.

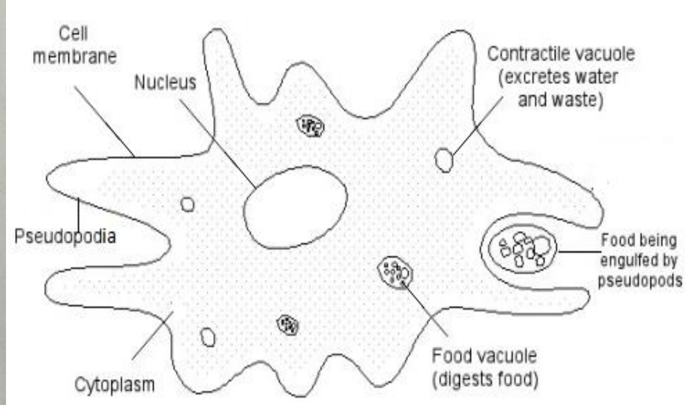
Phylum	Characteristics	Examples
Rhizopoda	• Have pseudopodia for locomotion and feeding	Amoeba, entamoeba
Zoomastigina	• Heterotrophic with cilia for locomotion	Trypanosome
Apicomplexa	• Parasitic organisms that reproduce by multiple fission	Plasmodium
Cilliophora	• Use cilia for movement	Paramecium
Euglenophyta	• Organisms with cilia but autotrophic	Euglena
Chlorophyta	• Plant like photosynthetic organisms	Green algae, e.g. spirogyra
Rhodophyta	• Photosynthetic organisms with red pigments in addition to chlorophyll.	Chondrus

<u>Drawings of common protists</u>

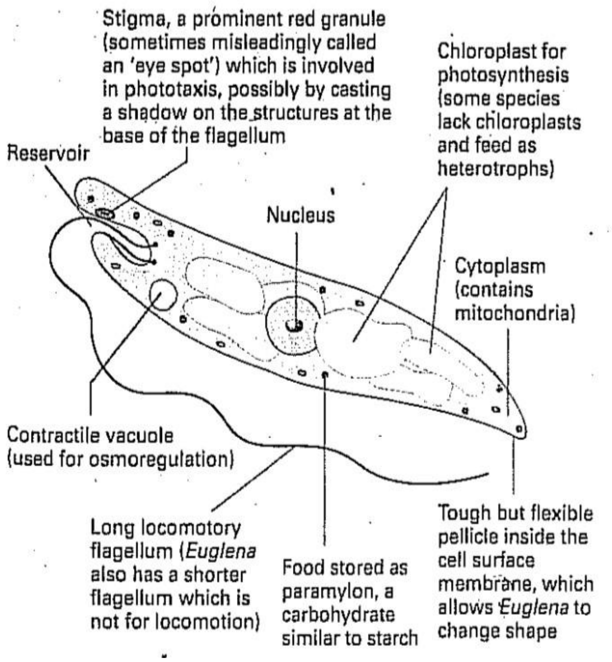
Spirogyra



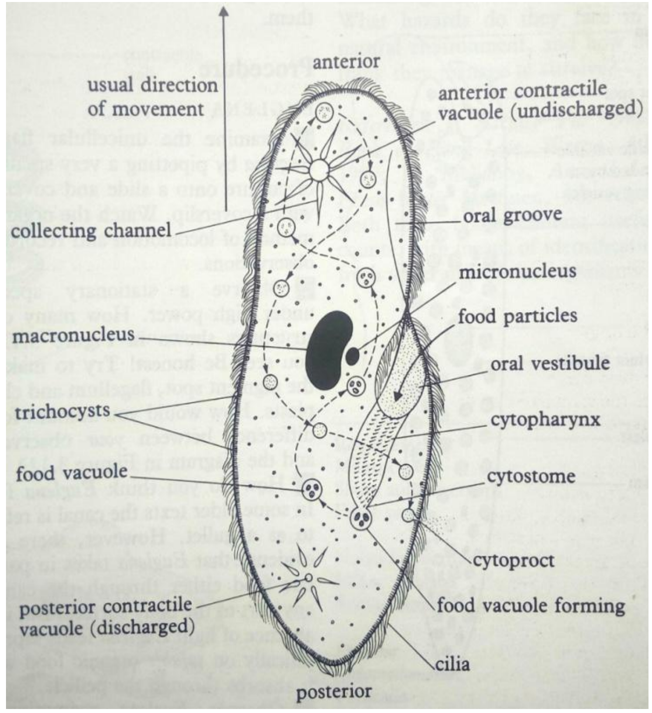
Amoeba



Euglena



Paramecium



ECONOMIC IMPORTANCE OF PROTISTS

1. They cause diseases to plant and animals by living as parasites. They cause diseases like Dysentery, malaria, trypanasomiasis, etc.
2. Some decompose organic matter in the ecosystem
3. Some carryout photosynthesis which produces food and oxygen in the ecosystem.
4. Some have industrial uses.
5. Algal blooms cause pollution in water bodies
6. Some algae are cultivated for animal consumption as a protein source.

Lifecycle of plasmodium parasite

The plasmodium sp. Is a group of four species of parasitic protozoans that cause malaria fever in humans, leading to many deaths world wide. It uses humans and female anopheles mosquitoes as hosts.

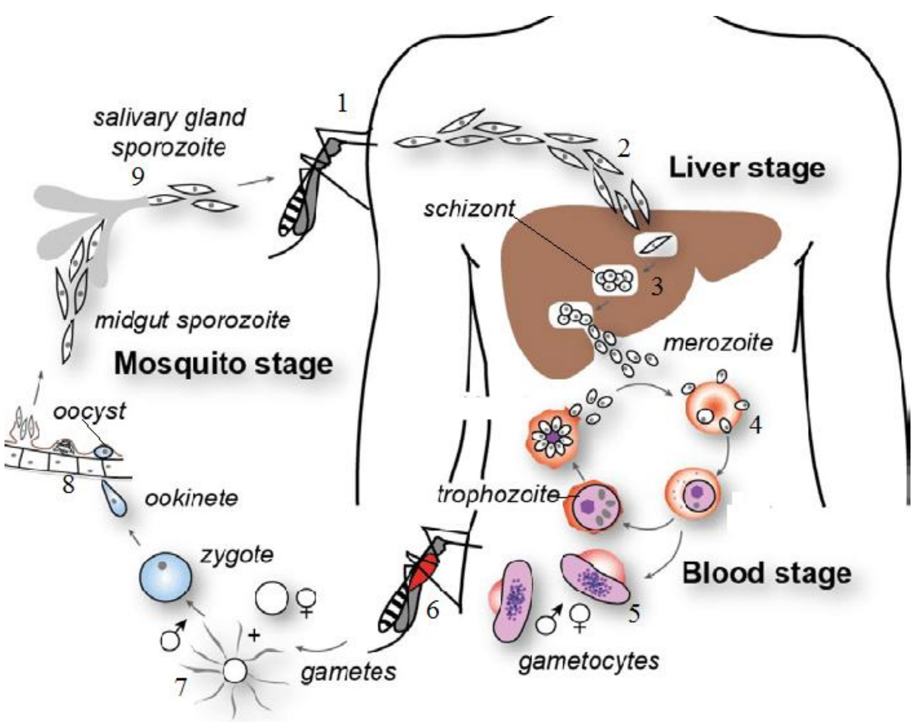
The lifecycle is as follows;

1) An infected mosquito bites a non affected person injecting plasmodium sporozoites into the blood.
2) The injected sporozoites travel through blood and migrate to the liver where they mature to schizonts.
3) The schizonts divide by schizogony to produce many haploid merozoites. The merozoites are released from the liver and enter blood.

4) Merozoites in blood enter red blood cells where they undergo multiple divisions by mitosis to produce more merozoites, and this causes rapture of the red blood cell releasing the merozoites into blood plasma. The released merozoites attack more red blood cells and the process repeats it's self.
5) Some of the merozoites divide and differentiate into gametocytes which stay in blood.
6) When an infected person is bitten by a mosquito, the mosquito sucks blood containing the gametocytes.
7) Male and female gametocytes fuse to form zygotes that mature to ookinetes.
8) The ookinetes mature into Oocysts in the mosquito gut.
9) Oocysts rapture releasing sporozoites which migrate to and stay in the mosquito's salivary glands. The cycle then repeats it's self when the infected mosquito bites a non affected person.

N.B: 1. Rapture of red blood cells when infected by merozoites leads to development of malaria fever. In worse cases the person may become anaemic when the number of red blood cells reduces significantly.
2. The human immune system cannot easily eliminate malaria pathogens from the body because the parasites spend most of their time inside liver cells or red blood cells.
3. There are four species of plasmodium i.e. Plasmodium vivax, P. malarie, P. ovale, P. falcipurum. The most severe malaria causing most deaths is caused by P. falcipurum.

<u>Illustration</u>



LEVELS OF ORGANISATION

The kingdoms Monera and Protoctista consist of unicellular organisms. Such organisms have cellular level of organization with cells existing independently e.g. paramecium. In some cases, the cells loosely interact to form colonies (colonial organization) e.g. staphylococci bacteria. However, the kingdoms fungi, Plantae and Animalia consist of multicellular organisms where cells are organized into specialized tissues (tissue level organization), organs and organ systems (organ level organization).

Advantages of being multicellular

1. The multicellular state allows organisms to increase in size as they grow. This is because growth of an individual cell is limited by the nucleus and therefore in multicellular organisms, cells divide as they grow allowing an increase in size of the whole organism.
2. It allows efficiency of various processes since different cells specialize to carry out different functions.
3. Enables the organism to carryout more sophisticated processes that cannot be carried out by a single cell. This occurs as a result of the cumulative effect of the cells functioning. E.g. feeding on large prey, fast locomotion.
4. Allows the organisms to exploit various habitats which cannot be exploited by unicellular organisms due to development of complex physiological processes. E.g. control of water loss, temperature regulation.

Challenges faced by multicellular organisms

1. Cells lose their independence as they have to depend on other cells for various functions such as provision of nutrients and removing wastes. This limits their functioning by slowing down the rate of their activities.
2. Difficulty in acquisition of resources such as food and oxygen due to reduction in surface area to volume ratio that accompanies the increase in size. When the surface area to volume ratio is small, resources cannot be absorbed over the body surface.
3. Difficulty in control and coordination of the various cell processes in the multicellular state since cell activities are dependent.
4. Difficulty in the internal transportation of materials over long distances in the body of the organism. Materials such as food nutrients have to be transported to all body cells and wastes have to be removed from each cell and processes such as diffusion, osmosis and active transport are no longer efficient.
5. Challenge of support of the increased mass of the body, which may also involve carrying it form one place to another.
6. Finding large amounts of food to provide nutrients to every body cell, since all the body cells require nourishment.
7. Difficulty in loss of heat from the body as the organisms become larger and increase in size. This is because the rate of heat loss is directly proportional to the surface are to volume ratio.

KINGDOM FUNGI

This is a kingdom of unicellular and multicellular eukaryotic heterotrophic organisms that have chitin in their cell walls. Lichens, which are associations between fungi and algae are callsfied according to the fungus present and are hence placed in this kingdom.

Characteristics of fungi

i. Cells are eukaryotic and have cell walls made of chitin and have no plastids
ii. Body consists of multinucleate hyphae that form a body called 16ycelium
iii. They usually feed saprophytically or parasitically
iv. Carbohydrates in the cells are stored in form of glycogen
v. Reproduction usually occurs by formation of spores.
vi. They inhabit damp places

PHYLA UNDER KINGDOM FUNGI

This kingdom has many phyla but the most important ones are;

- Zygomycota
- Ascomycota
- Basidiomycota

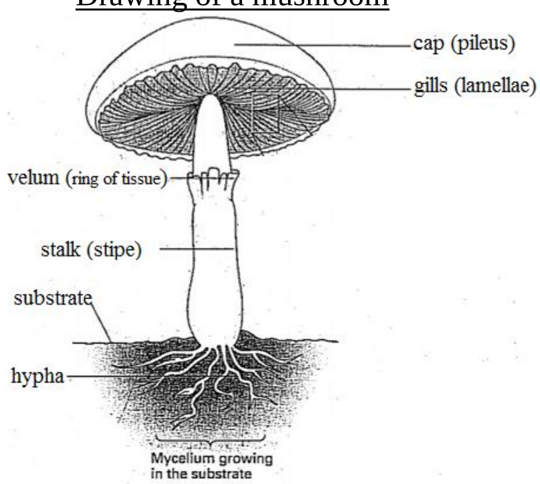
PHYLUM BASIDIOMYCOTA

This includes organisms that produce spores from cap shaped structures called a basidium. They include mushrooms, puccinia, puffballs, toadstools

Characteristics of mushrooms

- Spores are produced asexually
- Sporangia are located in cap shaped structures consisting of many densely packed gills.
- Densely packed mycelium is in soil or supporting medium
- Have septate hyphae

Drawing of a mushroom



PHYLUM ZYGOMYCOTA

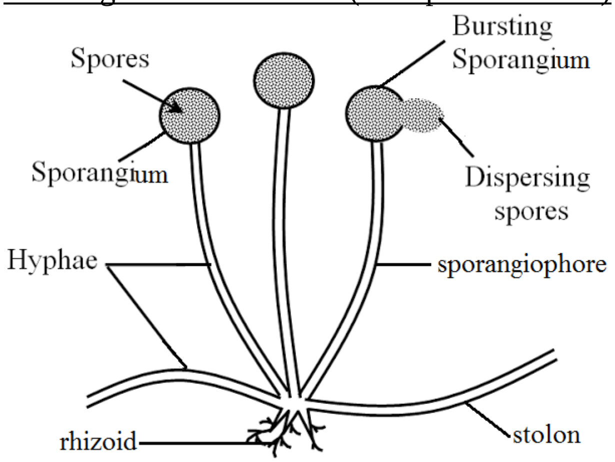
This phylum includes organisms like mucors or moulds (e.g. bread mould) that produce spores from sporangi carried on stalks.

Characteristics of a bread mould (rhizopus sp.)

- Reproduction occurs by production of spores in a sporangium located on top of a stalk called sporangiophore
- Have three types of hyphae, 1.e. rooting hyphae (rhizoids that are root-like), connecting hyphae (stolons), stalk hyphae (sporangiophore)
- Spores may be produced sexually or asexually
- They grow on rooting matter such as bread

Question; describe how a bread mould reproduces by conjugation

Drawing of a bread mould (rhizopus stolonifer)



PHYLUM ASCOMYCOTA

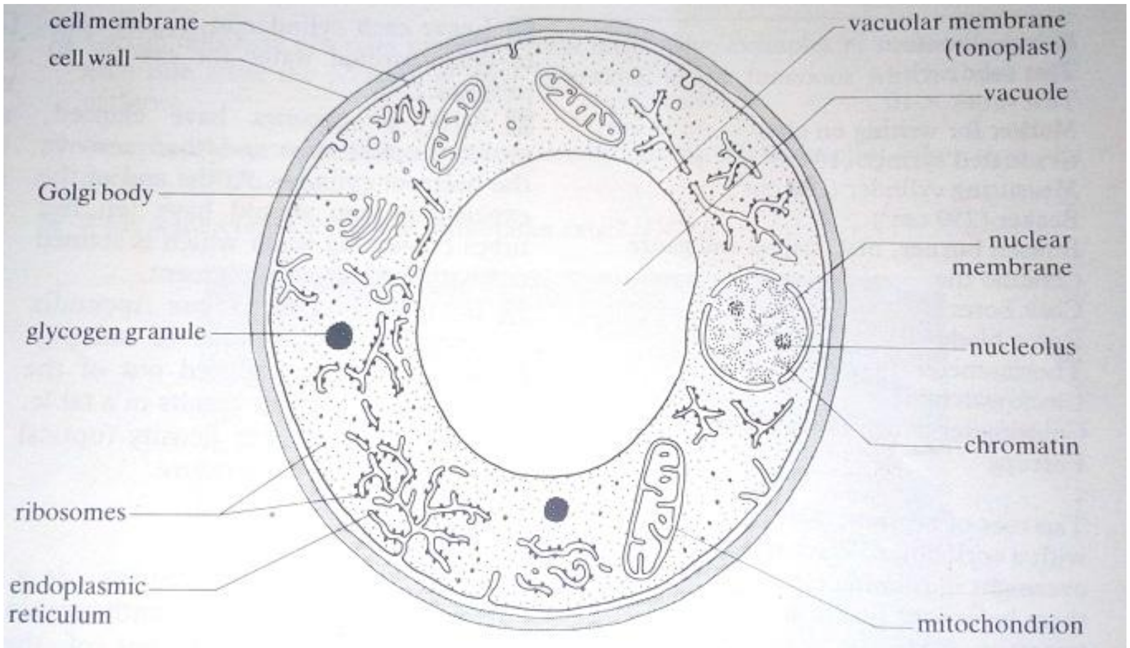
This phylum includes organisms that produce spores in sacs-like structures. They include yeast (saccharomyces) and penicillium.

Characteristics of yeast

- Have oval shaped cells
- It is unicellular
- Reproduces by budding

Question: describe the process of budding in yeast

Drawing of a yeast cell



ECONOMIC IMPORTANCE OF FUNGI

1. They cause decomposition of dead organic matter in the environment which recycles nutrients.
2. Some are used industrially to produce antibiotics e.g. penicilium
3. Some are used industrially in alcohol production by fermentation e.g. yeast.
4. Yeast is used in baking
5. They spoil stored food and spoil materials like leather
6. Some are eaten as food e.g. mushrooms
7. Some are poisonous to humans when eaten
8. Some cause diseases in plats and animals. These include candidiasis, ring worm, powdery mildew.

Question: state methods of preventing the spread of fungal diseases.

NOTE: yeast is used industrially for alcohol production because during anaerobic conditions, yeast breaks down simple sugars to form ethanol and carbon dioxide. Yeast Hs enxymes that break down glucose, fructose, galactose and sucrose rapidily. However yeast breaks down starch slower compared to sugars due to less concentration of amylase.

Yeast does not breakdown lactose due to absence of lactase enzyme.

Carbon dioxide produced by anaerobic respiration raises dough during baking.

KINGDOM PLANTAE

This is a kingdom of multicellular autotrophic organisms that have chlorophyll in their cells.

Characteristics of organisms in kingdom plantae

- They are multicellular eukaryotic autotrophs
- They have chlorophyll in their cells hence carrying out photosynthesis
- Cells have cell walls containing cellulose
- Carbohydrates are stored as starch
- Life cycle shows alternation of generations.

Plants are believed to have evolved from green algae by becoming multicellular and getting adaptations to survive n land.

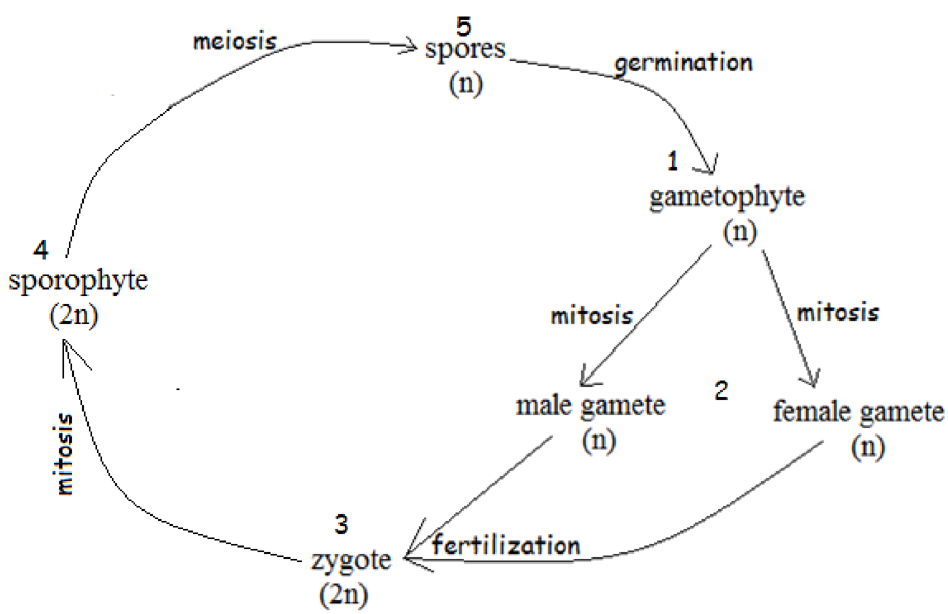
Major characteristics considered in plant classification

a) Presence or absence of vascular tissues (xylem and phloem)
b) Differentiation of the body into roots, stem and leaves
c) The mode of reproduction, whether using seeds or spores
d) The extent to which the life cycle shows alternation of generations
e) The structure of the flowers if present
f) The structure of the leaves and fruits

Alternation of generations

This is a life cycle which has two distinct generations of life that is the haploid gametophyte generation and the diploid sporophyte generation. This kind of life cycle occurs in plants, with the haploid gametophyte producing gametes by mitosis while the diploid sporophyte generation producing spores by meiosis. Alternation of generations enables plants to produce large numbers of offspring in two different generations which increases chances of survival of the species.

Illustration of alternation of generations



Plants are divided into 3 phyla known as divisions. i.e.

- Bryophyta
- Pteridophyta
- Spermatophyta

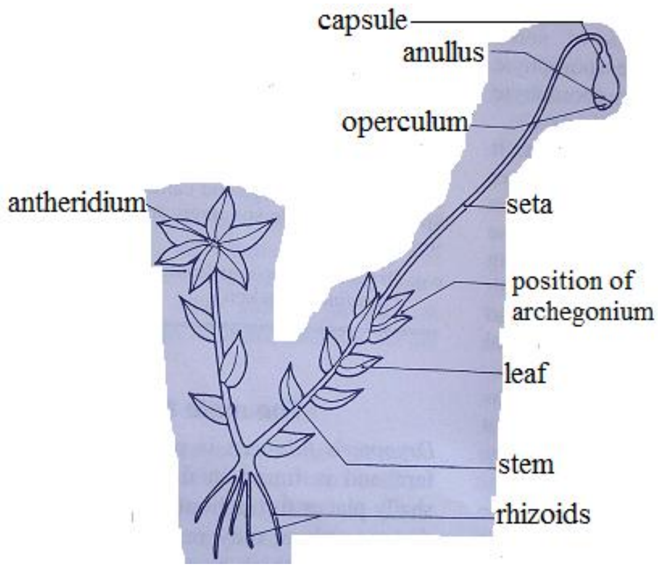
DIVISION BRYOPHYTA

It includes mosses and liverworts. They are considered the least developed organisms in the plant kingdom.

Characteristics of bryophytes

- They have no true roots, stems and leaves. i.e. their body is in form of a thallus
- They have no vascular tissues i.e. no xylem and phloem
- The gametophyte generation is the dominant generation in the life cycle
- The body is anchored to the ground by root-like rhizoids
- They inhabit damp places

Drawing of a moss



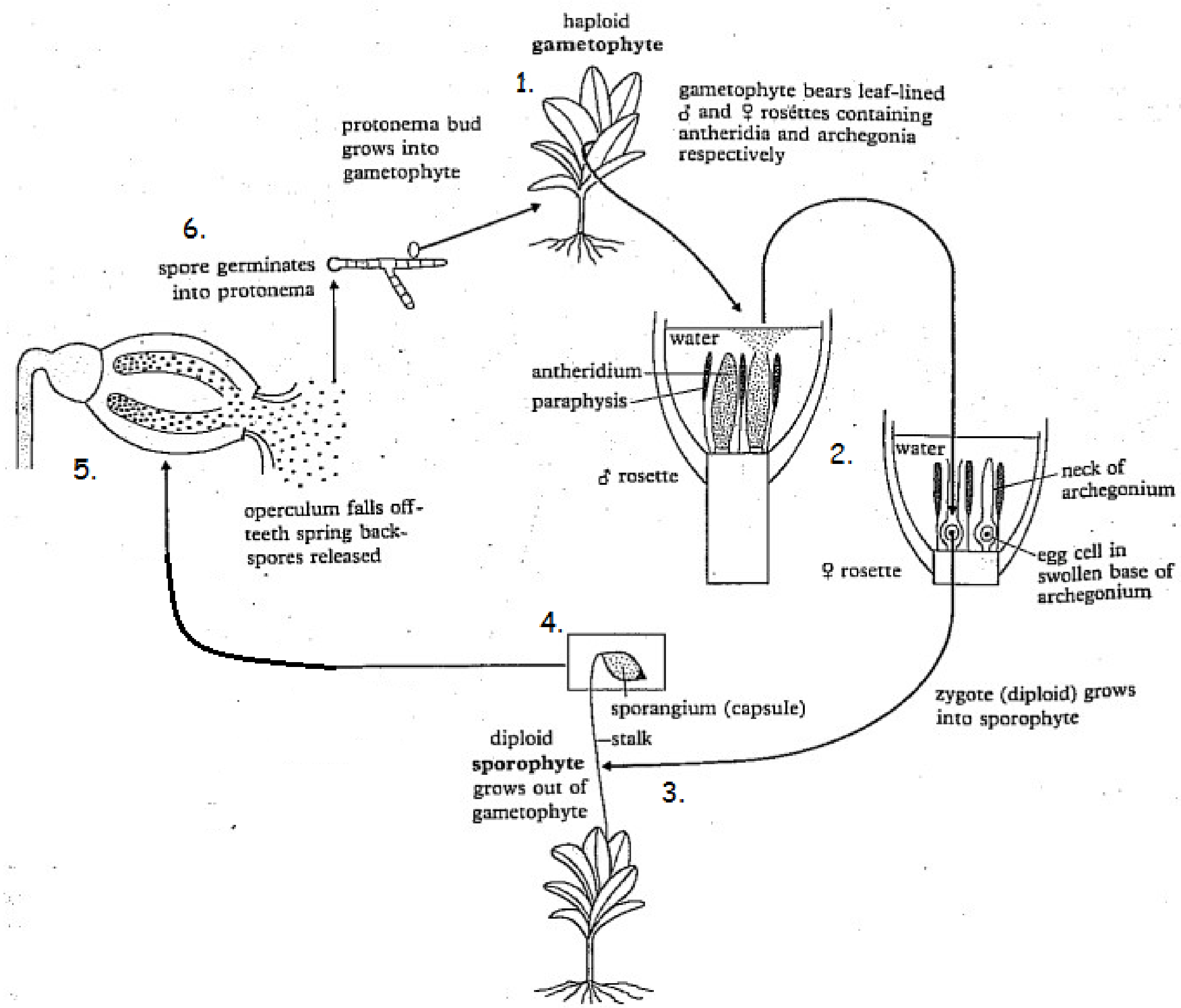
ALTERNATION OF GENERATIONS IN MOSSES

Mosses show alternation of generations with the gametophyte generation being the dominant stage in the lifecycle.

1. The haploid gametophyte produces gametes by mitosis. The male gamete is produced from the antheridium and the female gamete from the archegonium.
2. The antheridium raptures, releasing male gametes (sperms) which swim through water using flagella to the archegonium. The neck of the archegonium opens and sperms enter the archegonium where they fuse with the egg to from a diploid zygote.
3. The zygote undergoes division by mitosis to form a sporophyte that remains attached to the gametophyte and depends on it.

4. In the capsule of the sporophyte, spores are formed by meiosis
5. In dry whether, the capsule operculum opens and spores fall out and are dispersed by wind.
6. When spores fall in a moist environment they germinate to from a protonema. The Protonema then develops buds which grow into new a gametophyte, and the cycle repeats itself.

<u>Illustration</u>



DIVISION PTERIDOPHYTA/ FILICINOPHYTA

This phylum consists of ferns, and fern allies such as club mosses and horse tails.

Characteristics of Pteridophytes

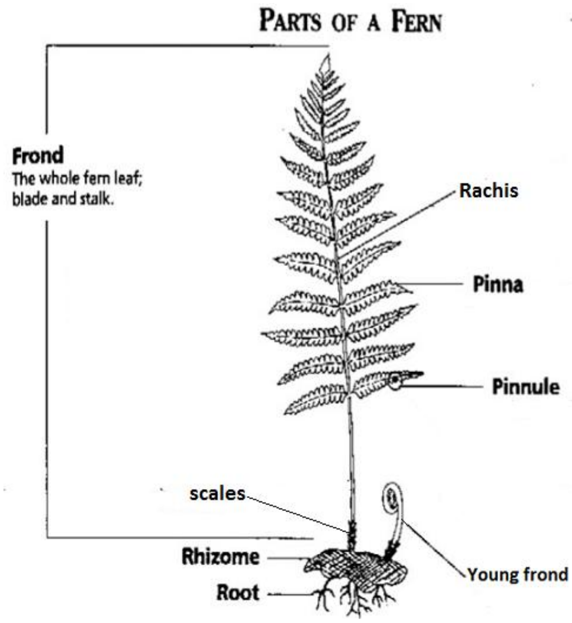
1. They have leaves in form of fronds
2. They show alternation of generations with the sporophyte being the dominant stage
3. Their body is differentiated into roots, stem and leaves
4. They have vascular tissues (xylem and phloem) although the xylem has only tracheids

Ferns are more adapted to terrestrial environments than mosses. This is due to;

- Possession of a waxy cuticle on the fronds which prevents water loss
- Having specialized vascular tissues to transport water and mineral salts
- Having lignin in the vascular tissues which enables support of a large body mass
- Possession of true roots for absorption of water and mineral salts
- Possession of a stem in form of a rhizome which can survive in dry conditions.

However, ferns are less adapted to terrestrial environments compared to conifers and angiosperms. This is because the gametophyte lacks the adaptations possessed by the sporophyte and depends on water for the movement of flagellated sperms hence it's entirely confined to damp conditions.

Drawing of a fern



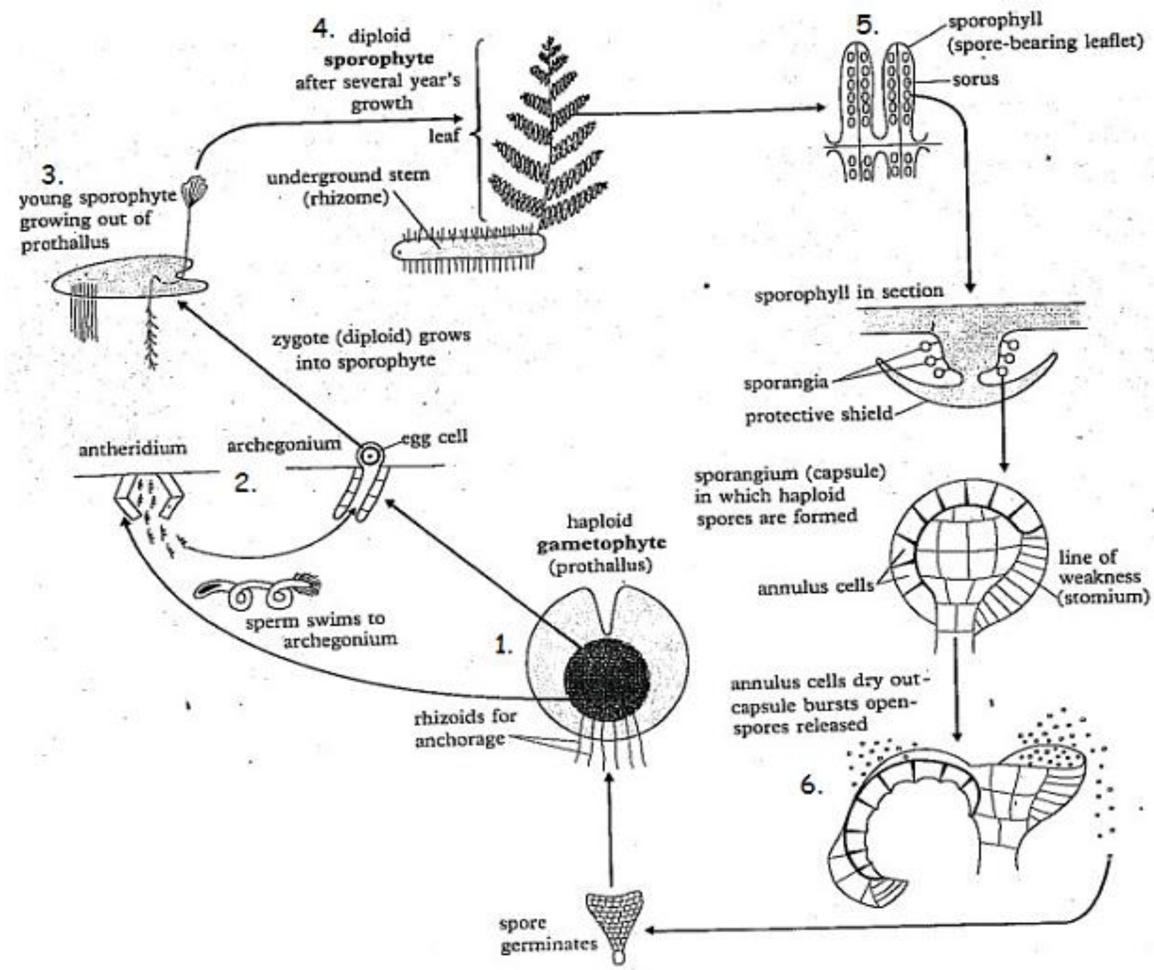
ALTERNATION OF GENERATIONS IN A FERN

The sporophyte is the dominant stage in the lifecycle and the gametophyte is reduced to a structure called a prothallus.

1. The haploid gametophyte (prothallus) produces gametes by mitosis. The male gametes (sperms) are produced from the antheridium, and are flagellated. Female gametes (eggs) are produced from the archegonium.
2. The flagellated male gametes swim from the antheridium to the archegonium where they fuse with the egg cell to from a diploid zygote.
3. The zygote grows into the sporophyte by mitosis. The sporophyte remains attached to the gametophyte for a short time and later separates from it.
4. The sporophyte continues to grow and increases in size, forming a rhizome with adventitious roots and fronds.

5. Spores form in sporangia on the underside of the fronds by meiosis, and the sporangia occur in clusters called sori.
6. The sori rapture releasing spores. The spores are dispersed by wind and when they land in a moist environment they germinate into heart-shaped gametophytes and the cycle repeats it's self.

<u>Illustration</u>



<u>Question:</u> compare alternation of generations in mosses and in ferns.

DIVISION SPERMATOPHYTA

These are seed bearing plants that include gymnosperms (conifers) and angiosperms.

Characteristics of spermatophytes

1. They reproduce by means of seeds
2. They have well developed vascular tissues
3. They have a pronounced sporophyte generation
4. They are well adapted to life on land and hence can inhabit dry environments
5. Reproduction can occur by vegetative means

This phylum is divided into two sub phyla i.e.

- Gymnospermae (the conifers/gymnosperms)
- Angiospermae (the angiosperms/ flowering plants)

GYMNOSPERMS

These are seed bearing plants that produce seeds on cones. They are therefore non flowering. Examples include: pine, cypress, cedar, larch, fir and redwood.

Characteristics of gymnosperms

- They bear seeds and gametes on cones
- They produce naked ovules and seeds (not enclosed in testa or integuments)
- Ovules are not enclosed in ovary
- They mostly have narrow needle-like leaves
- The xylem tissue is made up of only tracheids.

ANGIOSPERMS

These are flowering plants.

Characteristics of flowering plants

- They have seeds enclosed in a testa
- They produce ovules inside an ovary
- They bear flowers from where gametes are produced
- Xylem has vessels and tracheids
- Seeds develop inside fruits

Angiosperms fall into two classes i.e

- ❖ Monocotyledonae
- ❖ Dicotyledonae

Moncotyledonae

This is a group of monocotyledonous plants such as maize, millet, sugar cane, bananas, and palms.

<u>Characteristics</u>

i. Seeds have one seed leaf (one cotyledon)
ii. Vascular bundles are scattered in the stem ground tissue
iii. Floral parts are in groups of 3 or multiples of 3
iv. Calyx and corolla usually fused
v. Have narrow leaves with parallel venation
vi. Leaves have leaf sheaths
vii. Have a fibrous root system
viii. Germination usually hypogeal

Dicotyledonae

This is a class of dicotyledonous plants such as beans, ground nuts, cassava, and sweet potatoes

Characteristics

i. Seeds have two cotyledons (embryo has two seed leaves)
ii. Vascular bundles arranged in a ring in the stem
iii. Floral parts arranged in groups of 4 or 5or their multiples
iv. Have broad leaves with network venation
v. May undergo secondary growth due to presence of a vascular cambium
vi. Leaves have a solid stalk
vii. Have a tap root system
viii. Germination usually epigeal

Adaptations of spermatophytes to life on land

1. They have a well developed vascular system for transportation of water and mineral salts
2. They have a waxy cuticle which prevents evaporation of water from the plant.
3. They do not require water for fertilization since male gametes do not swim
4. Have a pronounced sporophyte generation which is specifically adapted with features such as long strong roots, strong stems and leaves
5. Have seeds with stored food to be fed on by the embryo
6. Gametophyte is entirely dependent on the sporophyte hence getting protection
7. They have lignin in their cell walls which ensures strength for support

Alternation of generations in spermatophytes

Spermatophytes show alternation of generations but to a smaller extent compared to the mosses and ferns. They have a pronounced sporophyte generation, and the gametophyte is much reduced and entirely dependent on the sporophyte.

The male parts of the sporophyte (anther heads or male cones) contain microspore mother cells which produce pollen grains which are the microspores and the female parts of the sporophyte (ovary or female cones) produce ovules which contain the megaspore. When the pollen grain germinates after landing on the stigma, a male gametophyte is formed which releases the sperm nuclei. The ovule is the female gametophyte which produces the egg nuclei.
After fertilization the zygote is formed and is enclosed in a seed, which later is dispersed and germinates to form a new sporophyte.

KINGDOM ANIMALIA

This is a kingdom of animals.

Characteristics of animals

1. They are multicellular eukaryotes
2. Their cells have no cell walls
3. They feed heterotrophyically
4. They are usually motile
5. They at least one opening into the body, such as a mouth
6. They usually have nervous coordination enabling rapid response to stimuli.

Major characteristics considered in animal classification

a) Symmetry: asymmetrical organisms are those which cannot be divided into two equal parts while symmetrical ones are those which can be divided into two equal parts. The important types of symmetry are bilateral symmetry and radial symmetry. Symmetrical organisms easily balance during locomotion or easily detect food and threats from any side.

b) Segmentation: this is the repetition of body sections along the body. This repetition is specifically called metameric segmentation. Segmentation allows specialization of body structures to different functions hence increasing efficiency. In classification, segmented organisms re considered more advanced than non segmented ones.

c) Appendages: these are protruding parts on the body that carry out various functions. The most important appendages are legs, mouth parts, tentacles, antennae, etc. the presence and nature of appendages shows the degree of adaptability to the environment.

d) Skeleton: the nature of the skeleton is very important in animal classification since the skeleton has various functions. The types of skeletons are exoskeleton, endoskeleton and hydrostatic skeleton.

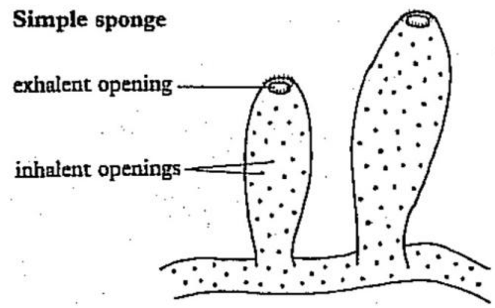
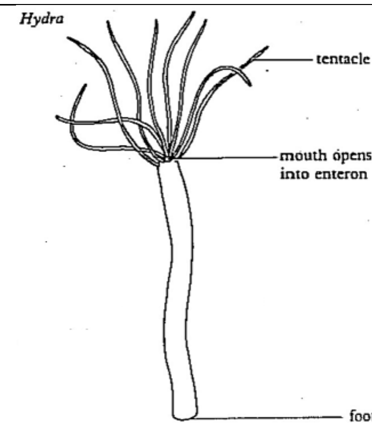
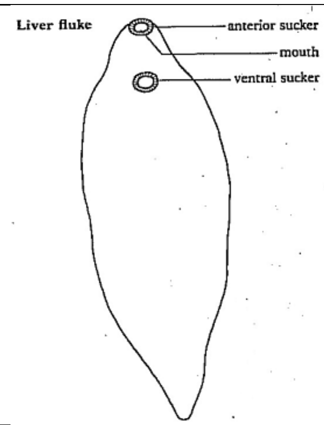
e) Sex: this relates to whether a species of organisms has separate sexes or are hermaphrodites. More advanced organisms usually have separate sexes (dioecious).

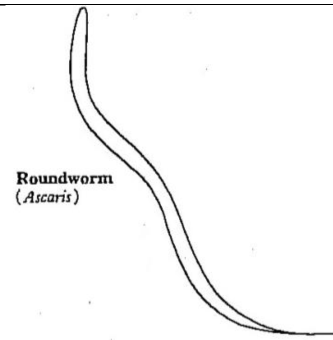
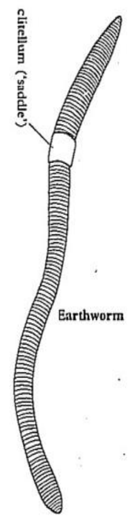
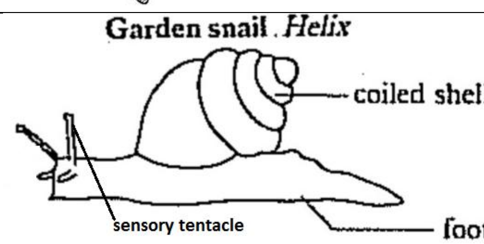
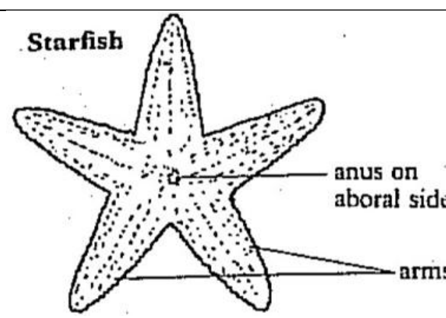
f) Embryonic development: this involves consideration of the mode of egg cleavage, and further changes that occur to the embryo.

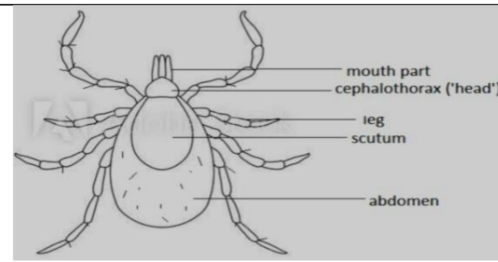
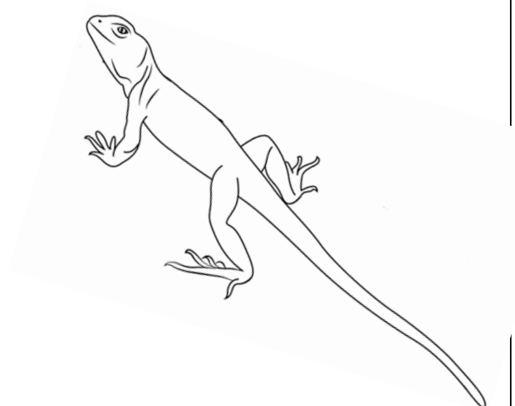
Kingdom animalia is divided into 9 phyla. These are;

1. Porifera	2. Coelenterata	3. Platyhelminthes	4. Nematoda	5.Annelida
6. Mollusca	7. Echinodermata	8. Arthropoda	9. Chordata	

TABLE SHOWING THE DETAILS OF THE ANIMAL PHYLA

Phylum	**Characteristics**	**Drawing**
Porifera - sponges	• Have a body cavity called a spongocoel connected to outside by pores • Have a spicule skeleton made up of calcareous, siliceous or horny plates • They are sessile • Have one layer of body cells • Have no nervous system/ no coordination between cells • They are marine dwellers	
Cnidaria (Coelenterata) e.g. hydra, sea anemone, sea corals, obelia, jelly fish	• Have sac like body with a cavity called the enteron • Have one body opening • They are diploblastic (2 cell layers) • Show radial symmetry • Have nematoblasts that can produce poison in their tentacles • Exist in two forms; polyp and medusa • They are marine dwellers	
Platyhelminthes – flat worms e.g. liver flukes, planaria, tape worms, blood fluke (schistosoma)	• Body dorsal-ventrally flattened • Have one body opening (mouth) • Are hermaphrodites • Have flame cells for excretion • They are triploblastic	

Nematoda – round worms e.g. ascaris, hook worm, pin worms, whip worms	• Hale a long body pointed at both ends • The body is cylindrical • Have two body openings • The body is un segmented	
Annelida – segmented worms e.g. lug worms, earth worms, leeches	• Have an elongated worm like body • The body is segmented • Have two body openings • They are triploblastic • Have a closed circulatory system • Have a well developed nervous system • Use nephridia for excretion • Show bilateral symmetry • They have a coelom (they are coelomates)	
Mollusca e.g. snails, slugs, octopus, squids	• Have a soft muscular foot on ventral side • Have a visceral hump • Have a rasping tongue-like radula • Use gills for respiration • Are always moist, protected by a shell • Have a coelom	
Echinodermata e.g. star fish, brittle star, sea cucumber, sea urchin	• Have an endoskeleton of calcareous plates • Have spins on the body • Show pentamerous symmetry • They are marine dwellers	

Arthropoda e.g. flies, millipedes, ants	• Have an exoskeleton • Have a segmented body • Have jointed appendages Arthropods have advanced features like coelom and triploblastic organization,bilateral symmetry, internal fertilization and thus they are the most advanced among the invertebrates	
Chordata e.g. amphioxus, sharks, cats	• Have an endoskeleton of bone or cartilage • Have a post anal tail • Have pharyngeal gill slits • Have a notochord that may develop into the vertebral column • Have a nerve chord that develops into the central nervous system Chordates are the most advanced among the animal kingdom. They posses other features such a coelom, troploblastic organization, closed circulation, internal fertilization, bilateral symmetry, which adapts them to the environment.	

NOTE:

❖ A Coelom is a body cavity into which visceral organs such as digestive organs are suspended. A coelom separates visceral organs from the rest of the body enabling them to move and grow independently and a ceolomic fluid bathing the organs which supplies nutrients and act as a hydrostatic skeleton.

❖ Diploblastic organisms have only two cell layers in the body i.e. the ectoderm and endoderm. Triploblastic organisms have three cell layers i.e. ectoderm, mesoderm and endoderm. These layers may be differentiated into organs allowing more specialization and increase in size.

PHYLUM ARTHROPODA

This is the largest and most successful phylum in the animal kingdom containing more than 70% of all animal species. It is divided into 5 classes;

- Class Crustacea
- Class Chilopoda
- Class Diplopoda
- Class Arachnida
- Class Insecta

TABLE SHOWING DETAILS OF THE ARTHROPOD CLASSES

Class and examples	Characteristics
Crustacea e.g. woodlice, lobsters, Daphnia, cray fish, crabs, barnacles, shrimps	• Have 2 pairs of antennae • Have two main body parts i.e. cepalothorax and abdomen • Have compound eyes on movable stalks • They inhabit damp or aquatic environments
Diplopoda e.g. millipedes, wire worms	• Have one pair of antennae • Have 2 pairs of legs on each body segment • Body is cylindrical and elongated • They are herbivorous and terrestrial • They have simple eyes
Chilopoda e.g. centipedes	• Have one pair of antennae • Have one pair of legs per body segment • Body is dorso-ventrally falettened • They are carnivorous and terestrial
Arachnida e.g. scorpion, spiders, mites, ticks	• Have 2 main body parts i.e. cephalothorax and abdomen • Have 4 pairs of legs • They have no antennae • Use booklungs for gaseous exchange • Usually carnivorous with sharp appendages for capturing prey
Insecta e.g. cockroaches, silverfish	• Have 3 main body parts • Have three pairs of legs • Have three thoracic segments In addition to the above features, insects also have one pair of antennae and have compound eyes

CLASS INSECTA

This is the largest and most successful class of arthropods. It's divided into several orders. The most important ones are shown in the table below.

	Order and examples	Characteristics
1	**Diptera** e.g. houseflies, mosquitoes	One pair of wings, one pair of haltares, have a proboscis
2	**Dictyoptera** e.g. cockroaches	Two pairs of wings, dorso-ventrally flattened, chewing mouth parts (mandibles, labium, labrum)

3	**Orthoptera** e.g. grasshoppers, locusts, crickets	Chewing mouth parts, 2 pairs of wings, female with long ovipositor
4	**Coleoptera** e.g. beetles, ladybirds	2 pairs of wings with very hard outerwings (elytra), chewing mouth parts
5	**Siphonaptera** e.g. fleas, jiggers	Piercing and sucking mouth parts, no wings, no eyes
6	**Hymenoptera** e.g. wasps, bees	2 pairs of wings which can interlock using hooks, chewing mouthparts and proboscis, social
7	**Isoptera** e.g. ants, termites	Mostly no wings, social insects
8	**Hemiptera** e.g. bedbugs	Piercing and sucking mouth parts,
9	**Lepidoptera** e.g. butterflies, moths	2 pairs of wings, scales on the wings, proboscis present
10	**Odonata** e.g. dragon flies	2 pairs of wings that cannot be folded, chewing mouth parts

Question: state the reasons why arthropods are very successful organisms.

PHYLUM CHORDATA

This is the most advanced phylum of animals having the most adapted organisms.

It is divided into 5 classes i.e. Pisces, Amphibia, Reptilia, Aves, Mammalia

Class	**Examples**	**Characteristics**
Pisces - fish	Sharks, skates, rays. Nile perch, cod, cat fish	• Have jaws on the body • Have scales on the body • Have paired fins • Use gills for gaseous exchange • They are aquatic dwellers • Have homodont teeth • Have a 2 chambered heart • Fertilization is external
Amphibia	toads, frogs, and newts	• Have a moist skin • Live both on land and in water • Use gills, skin and lungs for gaseous exchange • Have a three chambered heart • Show metamorphosis
Reptilia	lizards, snakes, crocodiles, and tortoise	• Have a dry scaly skin • Use lungs for gaseous exchange • Have a four chambered heart • Lay an amniotic egg (cleidoic egg) • Fertilization internal

Aves	ostrich, fowl, doves	• Have feathers on the body • Use lungs for gaseous exchange • Have a 4 chambered heart • Lay amniotic eggs • Are homoeothermic • Fore limbs modified to wings • Mouth modified to horny beak • Sternum expanded • No teeth
Mammalia	rats, porcupines, kangaroos, baboon	• Have glands in skin such as mammary glands • Are homeothermic • Have hair on the skin • Have a diaphragm • Heart is four chambered • Have heterodont teeth

N.B: class pisces is a class of fish. This class is divided into two sub classes i.e.

- **Chondrichthyes** that have a cartilaginous skeleton. Modern cartilaginous fish are known as elasmobranches. E.g. sharks, skates, rays.
- **Osteichthyes** that have a bony skeleton. Modern bony fish are called teleosts e.g. tilapia, nile perch, cod, cat fish

Among the animal and plant groups, some organisms are aquatic while some are terrestrial. More advanced organisms are usually terrestrial.

Challenges faced by organisms living on land (terrestrial organisms)

1. Difficulty in support and locomotion
2. Desiccation due to dry air
3. Reproduction without water
4. Varying environmental temperature

Adaptations of animals to overcome challenges on land

1. Some have skeletal systems made up of strong materials such as bone which provides a framework for support
2. Some have muscle cells specialized for producing a strong force for movement and locomotion
3. Possession of internal gaseous exchange surfaces which reduces the amount of water that evaporates
4. Having a skin covered with scales preventing evaporation of water
5. Having a keratinized skin which is impermeable to water hence reducing evaporation

6. Having internal fertilization which protects the gametes and zygote from desiccation
7. Laying of a cleidoic egg which is covered by a hard shell that prevents water loss and mechanical damage
8. Having a high metabolic rate and being endothermic which minimizes temperature changes in the body
9. Excreting urea and uric acid which require little water to be removed
10. Possession of specialized locomotory structures such as wings and legs which ais rapid locomotion

Achieving of large surface area to volume ratio in large organisms

As a result of the multicellular state and increase in size, large organisms would have a small surface area to volume ratio and hence would not be able to exchange materials with the environment efficiently. Due to this, large organisms have evolved in various ways in order to increase the surface are to volume ratio. This has been achieved as follows;

1. Having a flattened body as in flat worms which exposes most of the cells on the body surface
2. Having respiratory surfaces that are highly folded or branched which increases the surface are for exchange of gases
3. Having folded absorptive surfaces of the digestive system such as the ileum which increases the surface area
4. Having body extremities that are flattened, such as ears of elephants which increases the are available for heat loss
5. Organizing body cells into sheets such as in diploblastic organisms such as sponges which presents a large surface area
6. Having flattened body organs such as leaves of plants which presents a large surface area
7. Having highly branched organs and tissues such as roots or blood capillaries that increases the surface area for exchange of materials.

THE END

CHEMICALS OF LIFE

These are compounds needed by the body to maintain life.

The study of these chemicals and the reactions they undergo is called biochemistry.

TYPES OF CHEMICALS OF LIFE

The bio-chemicals fall in two broad categories, namely:

- ✓ Inorganic chemicals of life; these are simpler molecules needed for cellular metabolism. Examples include carbon dioxide, water, acid and bases, mineral salts etc.
- ✓ Organic chemicals of life are usually large sized complexes of carbon. They are needed for storage, structural and some (DNA and RNA) for informational functions. Examples include carbohydrates, proteins, lipids, vitamins and nucleic acids

NOTE: Both organic and inorganic chemicals of life are made up of elements; Hydrogen, carbon, oxygen and nitrogen (in that order) being the most abundant in the body. They make up to 99% body weight and their significance is largely due to their valencies and ability to form stable covalent bonds.

The chemicals of life are taken into the body as nutrients and are needed to varying quantities. Macro nutrients are needed in large quantities like water, proteins, carbohydrates etc; while micro nutrients are needed in smaller quantities like mineral salts and vitamins.

INORGANIC CHEMICALS OF LIFE

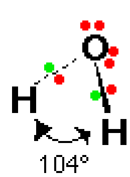
WATER

Water is the most important and abundant inorganic chemical; making up to 80% of cells and more than 60% of the whole body. It is important as a reactant, medium for chemical reactions and a habitat.

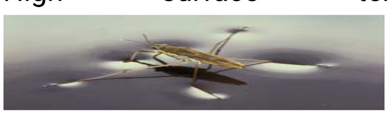
The versatile importance and abundance of water is mainly due to the unique features of the water molecule; these include:

- ✓ Ability to form hydrogen bonds
- ✓ Small size of the water molecule
- ✓ Polarity of water molecules

A water molecule is made up of 2 hydrogen atoms covalently bonded to an oxygen atom; forming a V shape as shown below.



THE FUNCTIONAL PROPERTIES OF WATER

Property and description	Significance
It is a liquid at room temperature	Provides a suitable medium for transportation of materials in plasma and lymph
High SHC; much heat is absorbed/lost to cause a temperature change	Provides a stable habitat with low temperature fluctuations. Maintains a constant body temperature as the body gains/loses heat slowly
High L_v; water absorbs much heat for evaporation to occur	Provides a suitable habitat as water bodies don't easily dry out Evaporation of water in sweat or transpiration causes cooling Minimises dehydration of organisms on hot days.
High L_f; Water loses much heat to turn to ice	Provides a suitable habitat which can't easily freeze on cold days Provides a suitable component of plasma which does not easily freeze
The solid form (ice) is less dense than the liquid form (water)	During winters, ice floats on water and insulates deeper waters to prevent further loss of heat. This makes water a suitable habitat
High surface tension 	Water molecules form a strong continuous layer on the surface that enables small animals to walk on water.
High cohesive forces; Water molecules do not easily pull apart under tension	Water molecules stick together in a continuous flow during uptake in the xylem
High adhesive forces; water molecules cling onto surfaces	Water molecules adhere to the walls of xylem during uptake in the plant
Water is colourless and transparent	This allows for penetration of light to photosynthetic organisms in deeper layers of water bodies It also aids visibility of animals in search for food and escape predators
It is incompressible; Its volume	It makes a good component of the hydrostatic skeleton in lower

remains the same under pressure	animals Osmotic water uptake leads to turgidity of plant cells; thus providing support and opening stomata.
Water is a universal solvent; It dissolves more substances than any other liquid	It provides a suitable medium for chemical reactions in the body Also dissolves substances for transportation in blood
Low viscosity; It provides little resistance to movement of materials	Provides a good habitat where organisms can move about freely Provides a good medium for transportation of materials in the body using minimum energy

Note the following

- ✓ Given the high latent heat of vaporisation; evaporation of water from the body causes cooling. This is because during evaporation, water molecules with high kinetic energy and therefore much heat energy are lost into atmosphere which causes a cooling effect on the body.
- ✓ As water solidifies to ice; adjacent water molecules are held by strong hydrogen bonds in a stable crystalline lattice. This creates large air spaces leading to an overall increase in volume which makes ice less dense than water.

Biological functions of water

- It is a component of cells
- It is a solvent and a medium of transportation of materials
- It is a reagent in hydrolysis reactions
- It facilitates fertilization by swimming gametes
- It is important in seed and fruit dispersal
- Osmotic uptake of water leads to turgidity which provides support and opening of stomata.
- Loss of water by transpiration leads to cooling.
- It is a medium for translocation in plants.
- Water initiates seed germination by activating enzymes and softening the testa
- It is involved in Osmoregulation in animals
- Water provides a medium for transportation of materials in blood and lymph

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

Question: ***how do the properties of water relate to its biological role?***

ACIDS AND BASES

An acid is a compound which when dissolved in water forms hydrogen ions as the only positively charged ions. Such substances are considered as proton (hydrogen ion) donors.

A base is a compound which reacts with an acid to form a salt and water only. Bases are also called proton acceptors. They mainly include oxides and hydroxides.

An alkali is a substance which when dissolved in water forms hydroxyl ions as the only negatively charged ions. All alkalis are basic but not all bases are alkaline.

Acids and bases are important in providing suitable pH media for enzyme-catalysed reactions. Acids are also important components of the first line of body defence.

The balance between acids and bases influence the distribution of plants in the soil as well as aquatic life.

BUFFERS

A buffer is a solution which resists changes in pH even on addition of small quantities of acid or base. They therefore maintain a constant pH

Buffers usually consist of a weak acid in equilibrium with its salt. When a base is added, hydroxide ions react with the acid to form water. When an acid is added, the protons combine with the salt to regenerate the acid hence maintaining the pH constant

Examples of buffers include:

- ✓ Carbonic cid buffer system
- ✓ Phosphate buffers
- ✓ Proteins like Haemoglobin.

MINERAL SALTS

These are needed for proper metabolic functioning of all living cells. They are needed in varying amounts by plants and animals. Though needed in small amounts, shortage of mineral salts in the body leads to serious deficiency diseases.

Basing on the quantities needed, mineral salts are grouped into two;

- ✓ Major/macro-elements which are needed in relatively large quantities. They include nitrogen, calcium, sodium, carbon etc
- ✓ Minor/micro-elements which are needed in small quantities. They are also called trace elements which together with vitamins (also needed in small amounts) are called micronutrients. They include copper, zinc, manganese etc.

GENERAL FUNCTIONS OF MINERAL SALTS

1) They are components of smaller molecules e.g. phosphorus is contained in ATP and iodine is contained in thyroxin, etc.
2) They are constituents of large molecules e.g. nitrogen in amino acids, proteins, chlorophyll etc.
3) They are components of pigments e.g. haemoglobin and cytochromes which contain ion, chlorophyll contain magnesium
4) They are metabolic activators e.g. calcium ions activate ATPase enzyme during muscle contraction.
5) They determine the anion/cation balance across cell membranes e.g. Na^+, K^+ and Ca^+ are important in transmission of impulses.
6) Mineral salts are important in osmotic uptake of water by living cells. Eg root hair cells and water reabsorption in kidney tubules
7) They are constituents of structures in cell membranes, cell walls, bones, enamel and shells.

THE TALE BELOW SHOWS DIFFERENT MINERAL NUTRIENTS AND THEIR FUNCTIIONS

MACRO ELEMENTS		
Element	**Function**	**Deficiency**
Nitrogen	-Component of chlorophyll -Component of proteins, nucleic acids	-Chlorosis Kwashiorkor
Phosphorous	-Synthesis of proteins, ATP and nucleic acids -Used in respiration to phosphorylate sugars -Constituent of bones and enamel -Formation of cell membranes by phospholipids	Stunted growth in plants
Sulphur	A component of proteins and coenzymes like coenzymeA	Chlorosis
Potassium	-Maintains electrical potentials and anion/cation balance across	Yellow edged

	membranes -Needed by sodium/potassium pump to transport materials across membranes. -Important component of the cell sap -A cofactor in photosynthesis and respiration (glycolysis)	leaves
Sodium	-Maintains electrical potentials and anion/cation balance across membranes -Needed by sodium/potassium pump to transport materials across membranes. -Important component of the cell sap	Muscular cramps
Chlorine	-Maintains electrical potentials and anion/cation balance across membranes -Needed by sodium/potassium pump to transport materials across membranes. -Important component of the cell sap -Formation of Hydrochloric acid in gastric juice -Involved in the chloride shift in carbon dioxide transportation	Muscular cramps
Magnesium	-Component of chlorophyll -Component of bones and teeth -An activator of enzymes like ATPase	Chlorosis
Calcium	-A component of bones, teeth and egg shells -Activates ATPase enzyme during muscle contraction -Needed in blood clotting -Important in formation of plant cell walls (pectate)	Rickets in animals Stuntedness in plants
	TRACE ELEMENTS	

Manganese	-Needed for bone development -Activator of enzymes like phosphatases	Poor bone development
Iron	-Constituent of oxygen carriers like Hb and Myoglobin -Component of cytochromes which are the electron carriers in respiration and photosynthesis -A constituent of catalase enzyme and peroxidases	Anaemia Chlorosis
Copper	It is a component of; -Haemocyanin, an oxygen carrier in invertebrates -Cytochrome oxidase, the last electron carrier in ETS -Plastocyanin, an electron carrier in photosynthesis -Tyrosinase, needed for melanin production	Albinism
Zinc	A constituent of: -Carbonic anhydrase, needed in CO_2 transportation in vertebrates -Alcohol dehydrogenase for alcohol fermentation in plants	
Iodine	Formation of thyroxin hormone in vertebrates	Goitre/creti
Cobalt	Component of vit. B_{12} for formation of RBC	P. anaemia

NB: As Iodine is needed in animals but not plants; boron is needed by plants only for normal cell division.

<u>ORGANIC CHEMICALS OF LIFE</u>

These are complex molecules of carbon. They are giant molecules known as polymers (macromolecules). A macromolecule (polymer) is a giant molecule made up of many repeating units of small molecules (monomers).

The table below summarises the common organic chemicals and their features

Macromolecule	**Building blocks**	**Bonds present**

Carbohydrates	Monosaccharides	Glycosidic bonds
Proteins	Amino acids	Peptide bonds
Lipids	Fatty acids and glycerol	Ester bonds
Nucleic acids	Nucleotides	Phosphodiester bonds

All macromolecules are formed by a combination of many small units (monomers) via a condensation reaction. Condensation refers to the combination of small sized molecules to form a large sized molecule by elimination of a water molecule. When water is lost, a covalent bond is formed between the monomers as shown in the above table. Such bonds can be broken by addition of water; a reaction known as hydrolysis. Hydrolysis therefore is the reverse of condensation. When a macromolecule is hydrolysed; the constituent building blocks (monomer units) are released.

CARBOHYDRATES (SACCHARIDES)

These comprise of a large group of organic compounds which contain C,H and O and conform to the general formula $C_X(H_2O)_Y$. They are called so because hydrogen and oxygen are present in the same proportion as in water.

All carbohydrates are ketones or aldehydes with several –OH groups. These determine the chemical properties of carbohydrates

Main functions of carbohydrates

- They are a primary source of energy being oxidized in the body to release energy.
- They are components of body structures e.g. cellulose and chitin in cell walls.
- They are determinants of osmotic potential of body fluids therefore maintain blood pressure.
- Carbohydrate chains in cell membranes act as recognition sites for hormones and antibodies.
- Some are important forms of food storage in the body e.g. starch and glycogen.

CLASSES OF CARBOHYDRATES

Carbohydrates fall in three classes basing on the number of constituent units.

- Monosaccharides (single unit sugars)
- Disaccharides (double unit sugars)
- Polysaccharides (several unit sugars)

MONOSACCHARIDES $(CH_2O)_n$ Where n=3-7

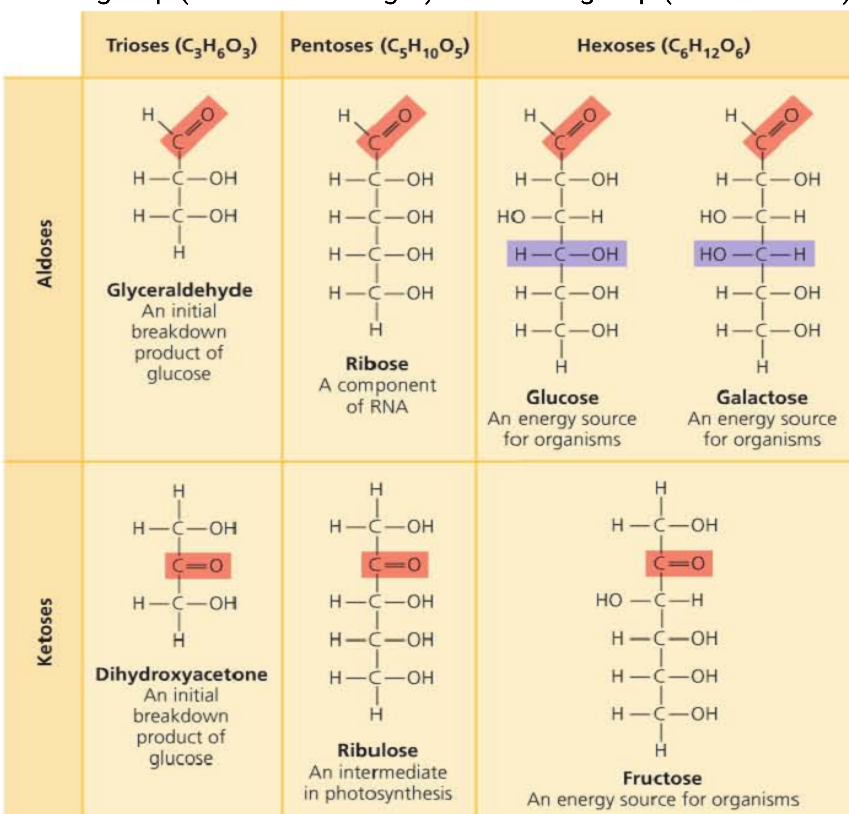
These are single sugars. Their names end in –ose; e.g. glucose, fructose, ribose etc.

Properties of monosaccharides

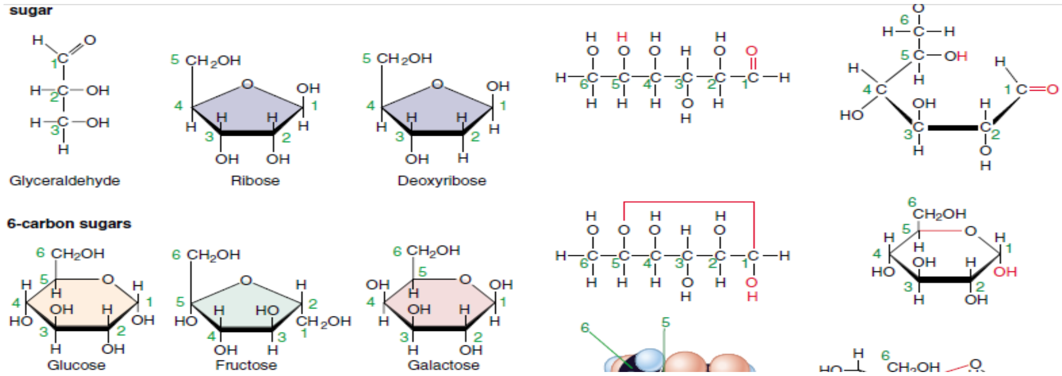
- ✓ They are sweet to taste
- ✓ They are water soluble
- ✓ Are crystalline
- ✓ They are strong reducing agents (can be oxidised)

Basing on the number of carbon atoms present, monosaccharides are further classified as Trioses, troses, pentoses, hexoses and heptoses; hexoses being the most common.

Monosaccharides are either ketones or aldehydes with several –OH groups. For each monosaccharide, all carbon atoms except one carry an –OH group. The remaining carbon atom is either part of a keto group (for a ketose sugar) or an aldo group (for an aldose)



Monosaccharides also occur in closed ring structures, especially in aqueous solutions. Rings formed by pentoses are called furanose rings while those formed by hexoses are called pyranose rings. Hexose ketones like fructose also form furanose rings.



Alpha and β isomers

The ring structures of glucose occur in two structural forms; glucose in which the –OH group on carbon1 is below the ring and β glucose in which the group is above the ring. This seems so simple but the basis of the functional differences between starch as a storage polysaccharide and cellulose as a structural polysaccharide. Also such minor differences are important in biological systems which involve specific recognition by enzymes, hormones and antibodies.

NB:

- Monosaccharides occur in many forms which may have different structures but similar molecular formulae. This is known as isomerism and such structures are called isomers.
- Keto sugars like fructose can isomerise in solution to produce aldehyde groups; this explains their reducing properties.
- Tetroses are very rare but commonly found in bacteria.

GENERAL FUNCTIONS OF MONOSACCHARIDES

- ✓ They are intermediates in respiration and photosynthesis e.g. DHA and GAL
- ✓ Important components of N.As like DNA and RNA
- ✓ Used in synthesis of ATP
- ✓ Synthesis of coenzymes like NAD, FAD, NADP
- ✓ Formation of polysaccharides. Polysaccharides formed by pentoses are called pentosans while those formed by hexoses are called hexosans
- ✓ Ribulose bisphosphate is a CO_2 acceptor in photosynthesis.
- ✓ They are good sources of energy to body cells like glu, fru, gala etc.
- ✓ Used to synthesise disaccharides like maltose, sucrose

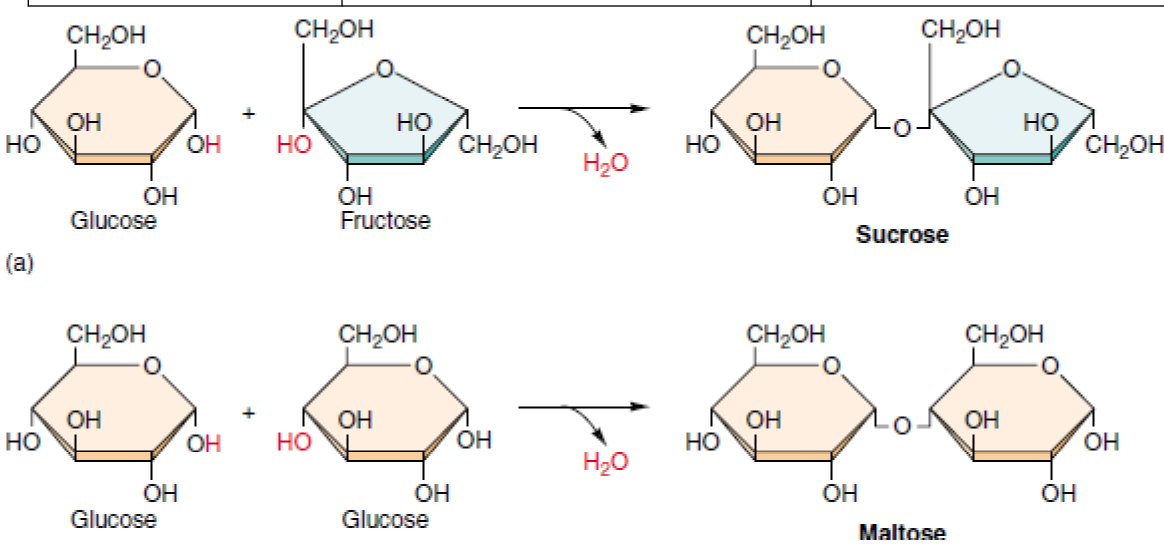
COMPARING KETOSE AND ALDOSE SUGARS

ALDOSES	KETOSES
Have an aldo group	Have a keto group
Functional group found at the terminal end(carbon1)	Found in the middle of the molecule (Usually carbon2)
Functional group carbon carry oxygen and hydrogen atoms	Functional group carbon atom carries only an oxygen atom

DISACCHARIDES

Disaccharides are double sugars that are formed by combination of two monosaccharides units via a condensation reaction. There are three commonly occurring disaccharides in nature.

Disaccharide	Constituent monosaccharides	Notes
Maltose (Malt sugar)	Glucose + Glucose	Common in germinating seeds
Sucrose (cane sugar)	Glucose + Fructose	Form of translocation in phloem
Lactose (milk sugar)	Glucose + Galactose	Exclusively in milk



NB:

All disaccharides contain glucose as one of the monosaccharides.

Adult mammals stop synthesizing lactase, an enzyme that breaks down lactose. When given un treated milk; the undigested lactose builds up in the stomach which encourages bacterial growth. This may lead to stomach upset and diarrhea.

Just like monosaccharides, disaccharides are also sweet, crystalline, soluble in water and can be oxidized. The sweet nature of monosaccharides and disaccharides is the reason they are called sugars

Reducing sugars

All monosaccharides and disaccharides, except sucrose are reducing sugars. The reducing ability of sugars depends on the presence of aldehyde groups for aldoses and keto with primary alcohol groups for ketoses. These groups are not present in non reducing sugars like sucrose and polysaccharides as they are linked up in glycosidic bonds.

Functions of disaccharides

- ✓ They are used for temporary food storage e.g. maltose
- ✓ They are the main forms of food transportation in plant phloem (sucrose)
- ✓ Disaccharides are needed to maintain osmotic gradients for stomatal opening.

NB: Sucrose as a form of food transportation in phloem is highly soluble for easy transportation even at high concentrations and it is chemically less active. It is therefore not easily used up during transit.

POLYSACCHARIDES $(C_6H_{10}O_5)_n$; where n=300-1000

These are large complex carbohydrates, consisting of long chains of repeating monosaccharide units. Such monosaccharide units combine via condensation reactions and are known as **residues**.

The structure and function of a polysaccharide depends on the constituent monosaccharides and the way they are linked. Functions of polysaccharides are usually either storage or structural

Properties of polysaccharides include:

- ✓ They are all large sized (macro) molecules
- ✓ Are not sweet to taste
- ✓ Are insoluble in water
- ✓ They are non crystalline
- ✓ Are all non-reducing sugars

Properties of storage polysaccharides like starch and glycogen

- ✓ They are insoluble in water thus not easily lost in solution
- ✓ They exert no osmotic pressure hence do not alter osmotic properties of cells
- ✓ They can fold into compact shapes; occupying little space
- ✓ They can easily be converted to constituent monosaccharides by hydrolysis when needed.
- ✓ They are chemically inert thus not easily used up in storage organs
- ✓ On hydrolysis, sufficient amounts of energy are released

STARCH

It is a polymer of alpha glucose. It is made up of two components; amylose and amylopectin. Amylose is a straight chain of alpha glucose residues joined by 1,4-glycosidic bonds; while amylopectin is a branched chain of alpha glucose residues joined by 1,6-glycosidic bonds

(Pectins are branched polysaccharides).
Both components coil into helices, with –OH groups oriented inwards giving compact shapes. Starch is the major form of carbohydrate storage in plants; found in large vacuoles called starch grains. It is closely related to, and plays the same role as glycogen in animals.

GLYCOGEN

It is the major storage carbohydrate in animals (and fungi), abundantly found in the liver and muscles. Here it provides a useful energy reserve.

Glycogen is made or highly branched chains of glucose residues joined by 1, 6-glycosidic bonds (amylopectin). It is closely related to starch only that the former is shorter and more branched. It is also more soluble than starch and this explains why it can be stored in the cytoplasm (glycogen granules).

CELLULOSE

It is a tough structural polysaccharide made of straight chains of beta glucose residues joined by 1,4-glycosidic bonds. It is the chief constituent of cell walls and the most abundant organic compound on earth. It is also found in fungi and some ancestral invertebrates.

NB: During formation of cellulose; every other glucose residue is first rotated through 180^0; with –OH groups projecting outwards at alternating positions of the chain (alternating heads up and tails down). These groups allow for H-bonding between adjacent chains, forming cross-linkages that are responsible for structural properties of cellulose.

The chains associate in parallel groups to form microfibrils, which in bundles form macrofibrils. These together with hemicelluloses and pectins form a strong structure called cell wall.

NB:

- ✓ Despite its strength, cellulose is fully permeable to water and solutes. It is hydrophilic and its matrix is riddled with water channels through which diffusion occurs
- ✓ Cellulose is not an available source of nutrients for most animals like humans. This is because they lack cellulose enzyme which catalyses the breakage of beta glycosidic bonds. It is only prokaryotes (bacteria) and some fungi that secrete this enzyme and are important in recycling of nutrients.
- ✓ In starch, all suitable –OH groups face the same side and project inwards in the helical structure. There is no cross-linkage formation and starch has no structural properties

Uses of cellulose

- ➢ Rayon produced form cellulose extracted from wood is used in the manufacture of tyre cords.
- ➢ Cotton is used in the manufacture of fibres and closes.

- Cellophane used in packaging is produced from cellulose.
- Paper is a product of cellulose.
- Celluloid used in photographic films is also a derivative of cellulose.

Question: ***how does the structure of cellulose relate to its roles***

OTHER POLYSACCHARIDES

Chitin:

This is closely related to cellulose in structure and function only that the –OH group on carbon 2 is replaced with an aminoacetyl group (-$NHCOCH_3$). Chitin therefore is a polymer of beta-aminoacylglucose which is formed when glucosamine combines with an acetyl group. It forms long straight chains cross-linked by hydrogen bonds to adjacent strands as shown below.

Chitin is the major component of fungal cell walls and exo skeletons of arthropods and crustaceans

Murein

This is also a structural polysaccharide similar to chitin in containing nitrogen. It consists of long parallel polysaccharide chains cross-linked at intervals by amino acids. It is an important strengthening material of bacterial cell walls

Lignin

It is a polymer of amino acids and various sugars that are deposited between cellulose molecules of plant cells, making the cell wall rigid, strong and impermeable. Lignified cells become dead as they can no longer absorb water and nutrients and the plant tissue is transformed into wood. Xylem cells are lignified and transformed into hollow impermeable tubes for transportation of water and mineral salts.

S.q. Give the structural features of carbohydrates that account for the wide variety of polysaccharides

Polysaccharides are formed by condensation of monosaccharides, usually pentoses like ribose, ribuose or hexoses like glucose to form long chains. These sugars may occur as ketones or aldehydes, pentoses and hexose ketones form 5-sided (Furanose) rings while hexoses form 6 sided (pyranose) rings. A polysaccharide may contain one monosaccharide as in starch, glycogen or two different monosaccharides e.g. in murein.

Occurrence of alpha and beta isomers that are responsible for structural differences between starch and cellulose. Ability of these isomers to form a variety of bonds. These mainly include 1,4 and 1,6 glycosidic bonds, these allow for formation of straight chains as in amylose and branched chains as in amylopectin. This occurs due to presence of several chemically reactive groups like keto, aldo, hydroxyl groups that are involved in formation of bonds between monosaccharides and with other substances like amino acids as in chitin.

LIPIDS

These are large sixed organic compounds made up of fatty acids bonded to glycerol. They are mainly made up of carbon and hydrogen and a very small proportion of oxygen.

Lipids are classified as fats and oils; the former beings solids at room temperature e.g. butter fat while the latter are liquids at room temperature. Fats are mainly used as storage compounds in animals while oils are commonly stored by plants in seeds, fruits and chloroplasts, though may also occur in animal tissues. Oils abundantly occur in coconuts, ground nuts, sunflower, castor oil etc.

CHARACTERISTICS OF LIPIDS

The characteristics of lipids depend on the nature of fatty acids present as these make up the largest of the molecular mass.

- ✓ They are made up of C, H and a very small proportion of O
- ✓ All lipids consists of fatty acid chains bonded to glycerol
- ✓ They are insoluble in water but highly soluble in organic solvents
- ✓ They are less dense than water (Buoyant in water)
- ✓ They occur as fats or oils at room temperature

FATTY ACIDS ($C_nH_{2n}O_2$); where commonly n=14 to 22.

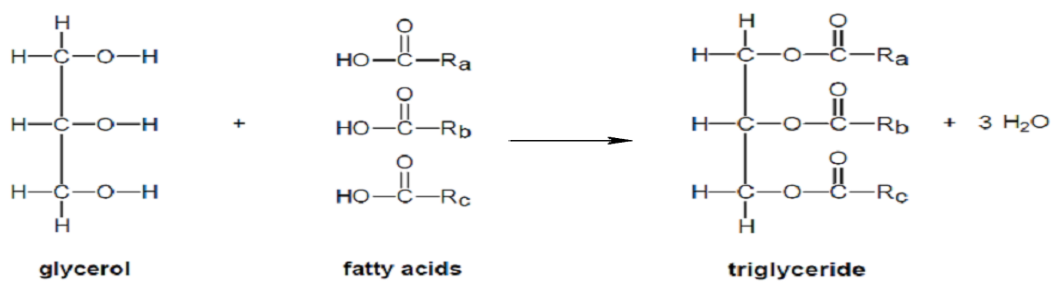
These consist of a long hydrocarbon chain (tail) attached to a carboxyl group (head), this is the functional group. The carboxyl group is the most reactive and determines the chemical properties (like acidity) while almost all physical properties are determined by the hydrocarbon chain. These include solubility and melting point.

All fatty acids (and therefore lipids) are insoluble in water because of the non-polar nature of the hydrocarbon chain that makes it hydrophobic; but highly soluble in organic (nonpolar) solvents

Fatty acids may be saturated (have no double bonds) or unsaturated fatty acids (have one or more double bonds). Saturated fatty acids form straight chains that fit together more closely leading to a higher melting point. These occur as solids at room temperature while unsaturated fatty acids form bent (kinky) chains that fit together loosely leading to a lower melting point, they occur as oils at room temperature. Oleic acid (olive oil, $C_{17}H_{33}COOH$) is unsaturated and melts at 13.4^0C whereas stearic acid ($C_{17}H_{35}COOH$) is saturated and melts at 69.6^0C. Poikilotherms and aquatic animals have a higher proportion of unsaturated fatty acids to maintain the fluidity of membranes even at lower temperatures.

<u>**FORMATION OF LIPIDS**</u>

Glycerol is a 3-carbon alcohol with 3 OH groups, each of which links to the carboxyl group of a fatty acid to form an ester bond via a condensation reaction. Lipids are therefore esters of three fatty acids and glycerol, also called triacylglycerols or simply triglycerides, as shown below.



NB: Some fatty acids can be synthesised by the body, usually from carbohydrates and proteins (Non essential fatty acids). Essential fatty acids cannot be synthesised by the body and must be obtained from diet. Deficiency of fatty acids (and therefore lipids) may lead to retarded growth, kidney failure and reproductive deficiency.

PHOSPHOLIPIDS

Phospholipids (Phosphogycerides) are formed when one of the fatty acids in a triglyceride is replaced by a phosphate group (Phosphoric acid). These lipids form the major component of plasma membranes

The presence of the phosphate group creates a hydrophilic part (Head) which makes them amphoteric, i.e. have both hydrophilic and hydrophobic properties. This is important in formation of membranes, when phospholipids are added to water; they assemble into double-layered aggregates which exclude the water. Hydrophilic heads face outwards in contact with water while the hydrophobic tails face inwards (due to hydrophobic iinteractions) and exclude water.

WAXES

These are formed by combination of fatty acids with long chain alcohols other than glycerol.

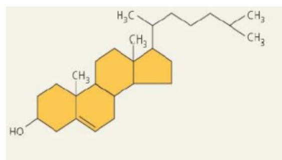
They are used as water-proofing materials in plants and animals

They are also used as additional protective layers in cuticles and bee wax.

STEROIDS

These do not contain fatty acids but are classified as lipids basing on substances used to synthesise them.

All steroids conform to a general formula composed of five fused rings onto which side groups are attached. Different steroids vary in the side chains attached to this general formula, cholesterol being the most common steroid from which other steroids (Commonly hormones) are synthesised. It is synthesised in the liver and is an important component of cell membranes.



FUNCTIONS OF STEROIDS

- ✓ Manufacture of bile
- ✓ Cholesterol is used as a precursor for synthesis of other steroids
- ✓ They are used in formation sex hormones like progesterone, testosterone
- ✓ They are used in formation of other hormones like the ecdysone hormone, aldosterone etc. Such hormones are manufactured in the cortex and are called cortical steroids (Adrenocortical hormones)
- ✓ Vitamin D is promotes absorption of Calcium and phosphates in the ileum
- ✓ Some are used as cardiac poisons like digitalis used in heart therapy

FUNCTIONS OF LIPIDS

The major function of lipids is storage of energy. This relates to their high calorific value as compared to carbohydrates.

Structural

- ✓ They are the major components of the plasma/cell membrane.
- ✓ They form subcutaneous fat in the dermis of the skin hence insulating the body since they are poor conductors of heat.
- ✓ Used in formation of waxy cuticles which are waterproofing materials in plants and insects that minimise water loss.

- ✓ They form the myelin sheath of nerves hence playing a role in the transmission of impulses.
- ✓ They protect delicate body organs from mechanical damage e.g. the heart and kidney from injury. This is due to their spongy nature that they can act as cushion to these organs
- ✓ They coat on fur of animals and feathers of birds enabling it to repel water which would otherwise wet the organism. This is the oil produced from sebaceous glands in the skin

Physiological:

- ✓ They provide energy through oxidation.
- ✓ They are solvents for fat soluble vitamins (ADEK).
- ✓ They are oxidised to release metabolic water. This explains why fats are stored in humps of camels and eggs of birds and reptiles.
- ✓ Oxidation of fats releases heat which is important in thermoregulation. This is mainly brown fat stored in adipose tissues
- ✓ Lipids are less dense that water hence provide buoyancy to aquatic animals and seeds during dispersal
- ✓ They speed up nerve impulse transmission in myelinated neurons
- ✓ Steroids are important in formation of hormones like sex hormones and other corticosteroids.
- ✓ They also insulate the body against heat loss which is important in thermoregulation

Other functions:

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

Question: ***what properties do lipids posses as storage compounds?***

PROTEINS

Proteins are the most abundant organic compounds in cells, making up to more than 50% of the total dry mass. They are complex organic compounds made up of long chains of amino acids joined by peptide bonds. They are mainly composed of C, H, N and O and sometimes S and P

CLASSIFICATION OF PROTEINS

Given their high level of complexity and diversity of function, it is not very easy to classify proteins according to a single criterion.

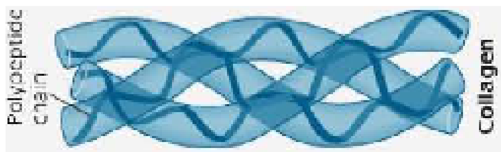
According to composition; proteins are classified as simple and conjugated proteins

SIMPLE PROTEINS

These are made up of one or more polypeptide chains that are made up of only amino acids. E.g. albumins, globulins, histones and scleroproteins

Simple proteins are further classified according to structure as fibrous, intermediate or globular proteins.

FIBROUS PROTEINS consist of long bundles of parallel polypeptide chains, cross-linked at intervals to form fibres. They are mainly formed by the secondary protein structure, insoluble in water and physically tough with physical properties.



Examples include

Fibrous protein	**Function**
Collagen	Strengthening material in connective tissues, like areolar, tendons, ligaments
Keratin	A strengthening material in nails, hair, horns
Myosin	Component of myosin filaments found in muscles
Actin	Component of actin filaments found in muscles
Silk	Used in making spider webs

GLOBULAR PROTEINS; Are formed when polypeptide chains are folded tightly into compact spherical shapes with specific 3-dimensional structures. They easily dissolve in water to form colloids and highly affected by pH and temperature changes. They are formed by the tertiary protein structure and mainly play physiological roles. E.g. enzymes, hormones and antibodies

INTERMEDIATE PROTEINS are fibrous but soluble proteins. E.g. fibrinogen needed for blood clotting

CONJUGATED PROTEINS

These are complex protein molecules consisting of globular proteins tightly bonded to a prosthetic group (Non protein component). They commonly include glycoproteins, lipoproteins, nucleoproteins, chromoproteins, phosphoproteins, Flavoproteins etc. Mucin found in mucus is a glycoprotein

Comparing fibrous and globular proteins

Fibrous proteins	**Globular proteins**
Formed by secondary structure	Tertiary structure
Are insoluble in water	Soluble in water
They are supportive with structural roles	Play metabolic/physiological roles
Consist of long parallel polypeptide chains	Polypeptides folded into spherical shapes
Structure is stable to heat	Very unstable to heat
Have a regular repetitive sequence of amino acids	Have an irregular sequence of amino acids
Amino acid sequence varies slightly between any 2 exaples of a protein	Sequence is highly specific

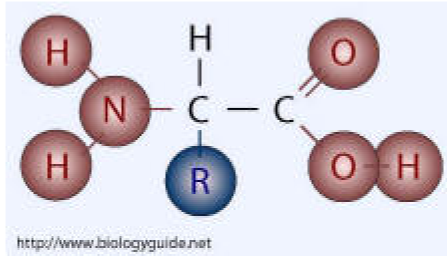
NB: unlike other organic chemicals, proteins cannot be stored by living things except in eggs and seeds.

AMINO ACIDS

These are the building blocks of proteins. There are over 70 amino acids known to occur in cells but only 20 commonly occur in proteins. Unlike plants, animals are incapable of synthesising some of the amino acids they require. These are called essential amino acids and can be synthesised by cells from other amino acids and carbohydrates by a process of transamination. Non essential amino acids cannot be synthesised by the body and therefore must be obtained from diet.

STRUCTURE OF AMINO ACIDS

They consist of a central carbon atom (alpha carbon) to which four groups are attached; these are carboxyl, amino, H and R (residual) groups. The amino and carboxyl groups are respectively responsible for basic and acid properties of amino acids while the R (residual) group/side chain is different for each amino acid and is responsible for unique properties of that amino acid.



NB: All amino acids are alpha amino acids (Amino group attached to carbon 2)

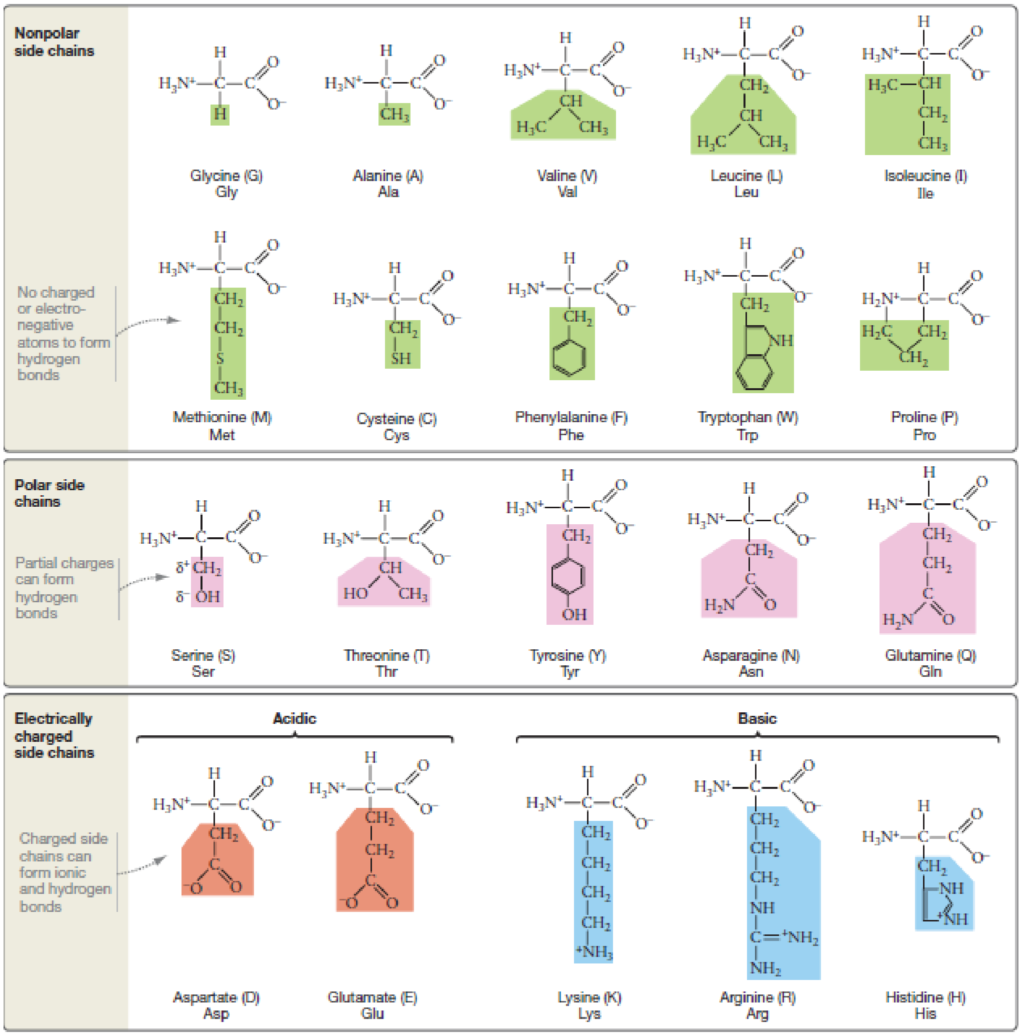
Amino acids can be further grouped into 3 basing on properties of the R group present

- ✓ Non polar amino acids; these have no polar groups in their side chains. E.g. Glycine, Alanine, Phynlalanine
- ✓ Polar amino acids have polar groups in their side chains. This is due to presence of highly electronegative atoms (as in OH or Carbonyl groups) leading to polarised covalent bonds e.g. serine, Tyrosine and glutamine
- ✓ Charged amino acids; these contain extra carboxyl or amino groups which ionise in solution to create negative and positive charges respectively.

Amino acids with extra carboxyl groups form acidic solutions (acidic amino acids) e.g. Aspartate and glutamate while those with extra amino groups form basic solutions (Basic amino acids) e.g. histidine, arginine and lysine

Non polar and polar amino acids form neutral solutions and are called Neutral amino acids.

Some amino acids are known to occur in cells but never proteins. They are known as non-protein amino acids e.g. Ornithine and citrulline which are important intermediates in the ornithine cycle and GABA which is an inhibitory neurotransmitter.



PROPERTIES/XTICS OF AMINO ACIDS (PROTEINS)

- ✓ They form colourless crystalline solids
- ✓ They are soluble in water but insoluble in organic solvents. Proteins/amino acids dissolve in water to form colloidal suspensions. A colloid is a substance that remains dispersed in solution rather than dissolving, settling or floating. It is too large to dissolve but too small to settle under gravity.
- ✓ They are amphoteric (Have both acidic and basic properties). This is due to presence of the carboxyl group which ionises to release protons in solution and amino groups with lone pairs of electrons to accept protons from solution. This enables proteins/amino acids to act as buffers
- ✓ They are amphibious (Carry both positive and negative charges simultaneously). The carboxyl group is acidic and dissociates in solution to release protons which are accepted by the amino group which has a high affinity for protons. This produces a dipolar ion known as a Zwitterion. Such ions have no net charge are formed only at a certain specific pH for each amino acid known as the isoelectric point; which is different for other amino acids. All amino acids exist as Zwitterions in solution

- ✓ They are electrolytes (Due to amphibious nature)
- ✓ They are denatured by heat
- ✓ They are affected by pH changes

Questions: ***how do amino acids act as buffer solutions?***

FORMATION OF PROTEINS

Proteins are formed by a combination of amino acids by a condensation reaction to form a peptide bond between the amino group of one and carboxyl group of another amino acid. Two amino acids form a dipeptide, addition of more amino acids leads to formation of a long polypeptide chain; which is modified by coiling, folding and conjugation to form a functional protein.

BONDS FORMED

There are various types of bonds holding protein structures which include the following

Peptide bonds; they are formed by condensation between the amino group of one and the carboxyl group of another amino acid to form a dipeptide. Continuous addition of amino acids leads to formation of a polypeptide chain

Ionic bonds; are formed between ionised carboxyl and amino groups of amino acids. They are very weak in solution and can be broken by change in pH

Disulphide bonds; are formed by oxidation of adjacent sulphydryl groups. These bonds maybe formed between different polypeptide chains (Inter-chain/sulphur bridges) or the same folded chain (Intra chain bonds). They are very strong and do not easily break

Hydrogen bonds; these are formed as an electrostatic attraction between a highly electronegative atom and hydrogen atoms attached to a highly electronegative atom. They are relatively weak but the overall effect of their frequent occurrence is significant. E.g. silk and hair

Hydrophobic interactions; are formed between non polar R groups of amino acids

PROTEIN STRUCTURES

Proteins show great diversity in structure which is broken down to 4 basic levels of organisation. These include the primary, secondary, tertiary and quaternary structures.

Primary structure refers to the specific sequence of amino acids as held by peptide bonds in the polypeptide chain making up a protein. This is as determined by DNA during translation, unique for each protein and determines not only the overall function but also the basis for secondary, tertiary and quaternary structures. Any slight change in this sequence or substitution changes the overall properties and functioning of the protein. E.g. when glutamate in Hb *(Position 6 of 146)* is replaced by Valine, Sickle cell anaemia results

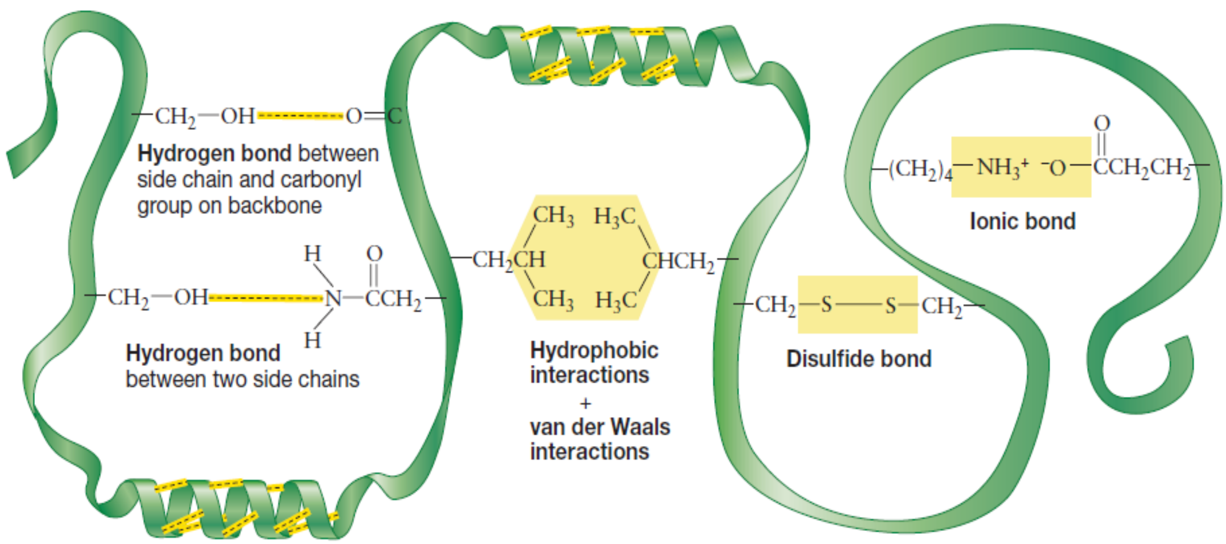
NB; Relationship in amino acid sequence indicates evolutionary closeness among organisms. With the 20 commonly occurring amino acids, there are 20^n possible amino acid sequences where n is the number of amino acids present. This reflects the huge variety of polypeptides that can be produced by cells

The secondary structure is formed by folding and coiling of the polypeptide chain, to form alpha helices or beta pleated sheets; stabilised by hydrogen bonds. These are formed between adjacent carboxyl and amino groups of the chain. This structure is important in formation of fibrous proteins.

The tertiary structure is formed by further coiling and folding into compact spherical shapes with a specific 3 dimensional structures called globular proteins, stabilised by hydrogen and ionic bonds, sulphur bridges and hydrophobic interactions

Quaternary structure is formed when two or more polypeptide chains combine to form a functional protein. These chains may combine with non protein components called prosthetic groups to form a conjugated protein, stabilised by hydrogen and ionic bonds, sulphur bridges and hydrophobic interactions. Haemoglobin consists of 4 polypeptides (tetramer)

(a) Interactions that determine the tertiary structure of proteins



NB: All higher levels of protein structure depend on the sequence of amino acids in the polypeptide chain (primary structure).

Question: ***how does the molecular structure of proteins relate to their roles?***

- Some proteins have a structural function, these are fibrous proteins with a secondary structure insoluble in water and physically tough e.g. collagen in connective tissues, bone, tendons and cartilage. Other structural proteins include keratin in feathers, nails, hair, horns, beaks and skin.

- Metabolically functional proteins have specific globular structures as in hormones and enzymes. Like pepsin, respiratory and photosynthetic enzymes.

- Some proteins functions as respiratory pigment. These are globular proteins with a quaternary structure that increases their surface area for transport or storage of respiratory gases e.g. haemoglobin which transports oxygen in blood and myoglobin that stores oxygen in muscles.

- Some proteins are contractile e.g. they are fibrous with a secondary structure e.g. myosin and actin filaments in muscles.
- Some proteins are insoluble in water e.g. albumin that occurs in egg white, casein in milk, etc.
- Globular proteins form colloidal suspensions that hold molecules in position within cells e.g. proteins in the cytoplasm of most cells where they are soluble in water and have a large surface area.

DENATURATION OF PROTEINS

Protein denaturation refers to the loss of the specific 3 dimensional shape of a protein due to breakage of bonds holding the molecule. Denaturation alters the tertiary structure of the protein leading to loss of the biological function though the primary structure is not affected

Below are examples of protein denaturating factors

Factor	**Explanation**	**Example**
1. Heat	Causes the atoms of the protein to vibrate more thus breaking the hydrogen and ionic bond.	Coagulation of albumen (egg white); making it fibrous.
2. Acids	Acids release protons which combine with carboxyl groups, destabilise ionic and hydrogen bonds. It also reduces the electrical polarity which reduces solubility	Curdling of milk as lactobacillus bacteria produce lactic acid which denatures casein making it insoluble.
3. Alkalis	Reduced number of H^+ in solution and cause amino groups to release more protons. This breaks ionic and hydrogen bonds	
4. Inorganic chemicals (Heavy metals)	Heavy metal ions like Pb, Hg Ag combine with carboxyl groups and disrupt ionic bonds. Electronegative ions like cyanide combine with amino groups which also disrupts ionic bonds	Cyanide inhibits curdling of milk
5. Organic solvents	Interact with hydrophobic groups which disrupt hydrophobic interactions. Some interact with polar groups leading to breakage	Alcohol denatures certain bacterial proteins. This is what makes it useful for

	of hydrogen bonds.	sterilization.
6. Mechanical force	Stretching a protein leads to breakage of hydrogen bonds	On stretching a hair, the hydrogen bonds break

NB: When the denaturating factor is removed, the protein may refold into the original functional structure. This is known as renaturation

General functions of proteins

VITAL ACTIVITY	PROTEIN EXAMPLE	FUNCTION
1. Nutrition	• Digestive enzymes e.g. trypsin, amylase, lipase etc. • Fibrous proteins in grana lamellae	• Catalyses hydrolysis of specific polymers in food into soluble products • Hold chlorophyll molecules in chloroplasts for maximum illumination
2. Storage	• casein • Albumin	• Storage of proteins in milk. • Storage protein in milk
3. Defence	• Mucin in mucus • Antibodies	• Traps foreign particles and pathogens in the body

		• Destroy pathogens in the body
4. Respiration and transport.	• Haemoglobin • Myoglobin • Prothrombin/fibrinogen • Carrier/channel proteins	• Transport of oxygen. • Stores oxygen in muscles. • Required for blood clotting • Needed for movement of materials in and out of cells
5. Support and movement	Actin/myosin	Needed for muscle contraction.
	Collagen	Gives strength with flexibility to connective tissues like tendons and cartilage.
	Keratin	Tough protective protein in scales, claws, nails, hooves, etc.
6. Sensitivity and co-ordination.	Hormones e.g. insulin, thyroxin	Regulate metabolic processes in the body
	Antigens and receptor proteins	Used as receptor site in cell membranes
	Rhodopsin	Visual pigment needed in retinal cells.
7. Reproduction	Hormones e.g. prolactin, oestrogen, progesterone	Regulate the process of reproduction
	Chromatin	Gives structural support to chromosomes.

VITAMINS

ENZYMES

CHEMICAL REACTIONS IN CELLS

There are many metabolic reactions that occur in living cells to maintain life. They are regulated by enzymes and categorised as catabolic and anabolic reactions

Catabolic reactions involve breakdown of molecules usually by hydrolysis or oxidation e.g. digestion and respiration. Most catabolic reactions occur spontaneously to release energy and are also called exergonic reactions. The products of such reactions have much lower energy than the reactants

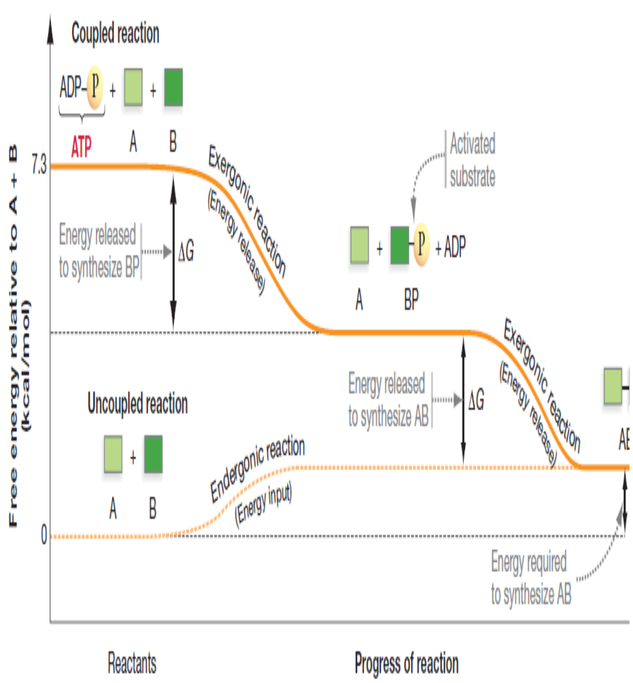
Anabolic reactions involve synthesis of materials by linking up smaller molecules to form a large molecule. They mainly occur by condensation and require energy e.g. photosynthesis and synthesis of nucleic acids, proteins etc. Such energy absorbing (non spontaneous) reactions are called endergonic reactions and the products have much more energy than the reactants.

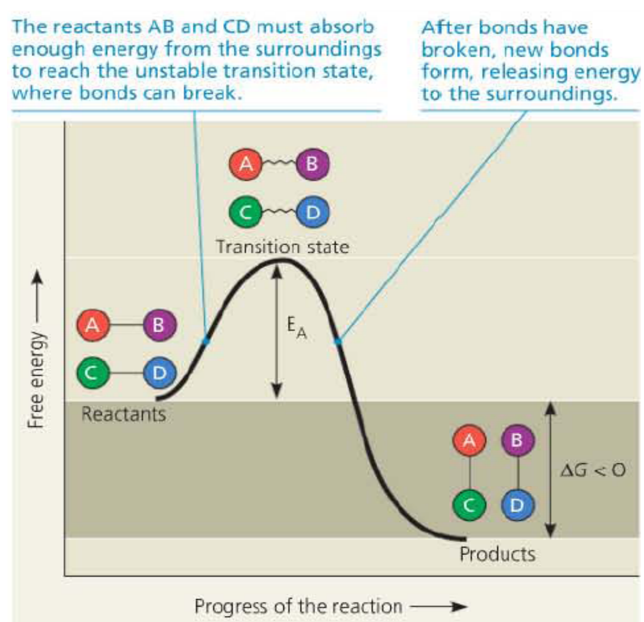
NB: Both anabolism and catabolism are needed to maintain life and are referred to as metabolism; the sum total of chemical processes that occur in the body to maintain life.

ACTIVATION ENERGY

This refers to the minimum amount of energy that must be acquired by reactants before they can be converted to products.

For any chemical reaction, reactants are converted to products via a very unstable intermediate called the transition complex. This state is highly unstable (original bonds are being broken and new ones form) and there for has much potential energy (activation energy). The higher the activation energy, the less likely the reaction to occur





In living cells, enzymes act as catalysts that tend to lower the activation energy of reactions, making them to occur much faster

ENZYMES

Enzymes are biological catalysts, protein in nature that speed up the rate of biochemical reactions in the body but remain unchanged at the end of the reaction.

All biochemical reactions (Endergonic and exergonic) require enzymes to occur. Hydrolysis of sucrose for example is an exergonic reaction and can occur spontaneously. A solution of sucrose can settle for years without significant hydrolysis occurring; yet adding sucrose enzyme can cause this to occur in seconds.

In the absence of enzymes, most biochemical reactions in the body would be too slow to maintain life. Enzymes are able to speed up such reactions by providing an alternative reaction pathway with lower activation energy such that the reaction proceeds faster. The substrates bind to the enzyme active site and form temporary bonds with the active site to form short-lived enzyme-substrate complex. This stabilizes the activated complex thus lowering its activation energy such that the reaction occurs faster. The enzyme may also exert stress on the substrate thus weakening the intermolecular bonds so that they can easily break at lower activation energy

Note that enzymes do not affect the direction or overall free energy change of the reaction and therefore do not affect the nature of products. They also remain unchanged at the end of the reaction and can be used over and over

NOMENCLATURE OF ENZYMES

Enzymes are named by adding a suffix "ase" to their respective substrates.

A substrate is any substance that is acted upon by the enzyme.

Examples of enzymes and their substrates

Enzymes	Proteases	Carbohydrases	Lipases	Sucrase	Cellulase		
Substrates	Proteins	Carbohydrates	Lipids/fats	Sucrose	Cellulose		

NB: Some enzymes however retained their names they had before this convention. Such enzymes include **pepsin and trypsin**. All digestive enzymes catalyse hydrolytic reactions (by adding water) and are called **Hydrolytic enzymes** or simply **Hydrolases**

CLASSIFICATION OF ENZYMES

Enzymes can be classified as intracellular and extracellular enzymes

Intracellular enzymes are produced within cells and catalyse reactions occurring inside cells. E.g.

respiratory enzymes. Extracellular enzymes are secreted from cells of production to catalyse reactions from outside the cells. All digestive enzymes in man are extracellular.

Enzymes are also classified according to the types of reactions they catalyse

Class of enzyme	**Type of reaction**	**Examples**
Oxido-reductase AH_2+ B BH_2 + A	Redox reactions which involve transfer of O and H atoms and Electrons between substances	Cytochrome oxidase, alcohol dehydrogenase
Transferases AB + C AC + B	Transfer of specific chemical groups from one substance to another. E.g. CH_3, Amino, PO_4	Transaminases and phosphorylases
Hydrolases AB + H_2O BOH + AH	Hydrolysis and condensation reactions	All digestive enzymes like Pepsin, amylase
Lyases	Reactions involving breakdown of substances other than hydrolysis (Non hydrolytic breakdown)	Decarboxylase enzymes
Isomerase	Reactions involving changing one substance to another by rearrangement of atoms within the molecule	Mutases
Ligase	Reactions involving formation of larger molecules from smaller molecules using energy from ATP	DNA ligase, Synthetases

PROPERTIES/CHARACTERISTICS OF ENZYMES

- They are all protein in nature.
- They are specific in action i.e. an enzyme can only catalyse one reaction but not the other. Amylase hydrolyses starch only but not proteins
- Their activity is affected by temperature changes. Very low temperatures inactivate enzymes while very high temperatures irreversibly denature enzymes.
- Enzymes work best (optimally) within a narrow range of pH. A slight increase in acidity or alkalinity rapidly reduces enzyme activity
- Enzymes remain unchanged at the end of the reaction. They simply accelerate the reaction rate without taking part in the reaction.
- Their action is affected by inhibitor (poisons) like cyanide

- They are needed in small quantities, only a very small amount of enzyme is needed to convert a large quantity of substrate into products
- Enzymes are very efficient. I.e. work very fast. The speed of enzyme action is expressed as its turnover (The number of substrate molecules converted into products per unit minute). Catalase (Breaks down Hydrogen peroxide in plant cells) is one of the fastest enzymes known
- Enzymes catalyse reversible reactions. They actually work in both directions depending on the relative concentrations of substrates and products (Determines the total free energy)

MECHANISM OF ENZYME ACTION

There are two hypotheses that have been put forward to account for the mechanism by which enzymes speed up biochemical reactions in cells

LOCK AND KEY HYPOTHESIS

Enzymes are large sized molecules with a specific surface configuration called active site in which substrate molecules with complementary shapes fit just like a key in the lock. Temporary bonds are formed between the substrate and the active site forming an enzyme-substrate complex. The enzyme exerts stress onto the substrates, which weakens the intermolecular bonds thus lowering the activation energy. The reaction occurs forming an enzyme-product complex. Products are released from the active site, and the enzyme is freed to bind other substrates.

NB: The lock and key hypothesis can be used to explain a number of observations in enzyme activity

- Specificity of enzymes, only substrates whose structures are complementary to the active site can fit in the active site
- Enzymes can be used over and over again because after forming the enzyme-product complex, products are released thus freeing the enzyme to bind other substrates
- Enzyme controlled reactions depend on substrate concentration. Increasing the number of available substrate increases the number of active sites occupied thus increasing the rate of reaction
- Enzymes can be inhibited competitively by other molecules whose structures are closely related to the actual substrate and therefore can fit into the active site. Non competitive inhibitors bind to enzymes and distort the shape of the active site thus preventing substrates from binding to active site
- Enzymes are easily denatured by external factors like pH changes and high temperatures as these change the shape of the active sites

- It also explains how enzymes lower the activation energy of the reaction so that it can occur faster

THE INDUCED FIT HYPOTHESIS

Recent research indicates that the shape of enzyme active site is not static, but can change slightly so as to fit the substrate more precisely, making the substrate even more reactive. An enzyme-substrate complex is formed in the same way as described in the lock and key above making the reaction occur faster.

FACTORS AFFECTING ENZYME ACTIVITIES

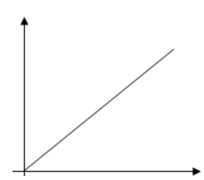
To investigate the effects of a given factor on the rate of enzyme controlled reactions, all other factors should be kept constant at optimum levels so as to obtain accurate results.

The factors affecting the rate of enzyme controlled reactions include the following:

- Concentration of enzyme
- Concentration of the substrate
- Temperature of the medium
- PH of the medium
- Presence of enzyme in inhibitors
- Presence of enzyme activators
- Surface area of reactants

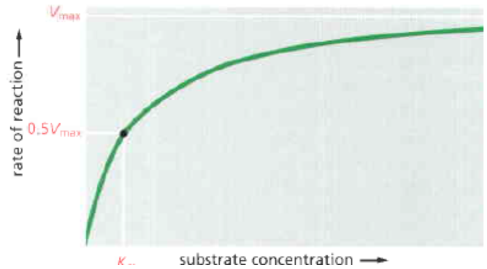
Enzyme concentration

Increase in enzyme concentration increases the rate of enzyme controlled reaction, provided the substrate concentration is not limiting. This is due to increase in the number of active sites that can be occupied by substrates hence increasing the rate of conversion into products leading to increased rate of reaction.



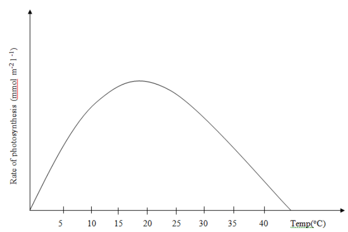
Concentration of substrate

The rate of reaction increases with increase in substrate concentration, up to a maximum value. This is due to increase in the number of active sites occupied by substrates per unit time and increasing the rate of conversion to products. The rates then remains constant with further increase in the substrate concentration as all enzymes available are occupied with substrates (Saturated). At this point, the rate can increase incase enzyme concentration is increased



Temperature of the medium

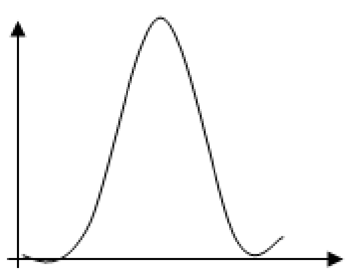
The rate of reaction increases with increase in temperature due to increase in kinetic energy of enzymes and substrate molecules hence increasing the probability of collisions between enzyme and substrate molecules. The rate of reaction increases up to a maximum at the optimum temperature, beyond which the rate of reaction decreases rapidly due to denaturation of enzymes. At very low temperatures, enzymes are inactive and the rate of reaction is low or even stops.



NB: Most of the body enzymes work best at temperatures around 37^{0}C (their optimum temperature. This is because it is the normal body temperature that favours most of the body reactions

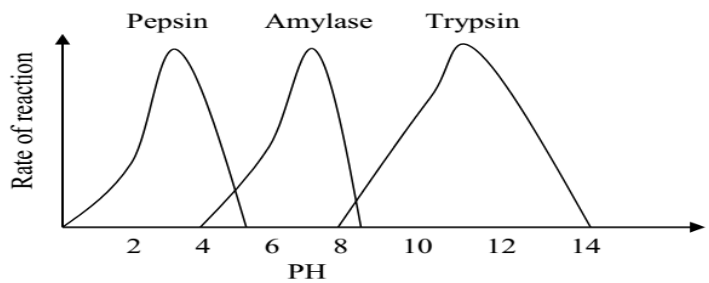
PH of the medium

Each enzyme shows maximum activity at a certain pH value called optimum pH, any increase or decrease in pH leads to a rapid decrease in the rate of reaction. The reaction stops with significant deviations from the optimum pH due to denaturation of enzyme molecules by breaksge of ionic and hydrogen bonds.



Each enzyme has its own optimum pH which may be different from other enzymes. Some enzymes work best in acidic pH while others work best in alkaline pH. E.g. pepsin enzyme in the human stomach has a maximum activity within acidic pH of 1.5 and 2.5 while the enzymes in the duodenum e.g. trypsin work at maximum with in alkaline pH of 8.5 to 9.5.

A graph showing variation of different enzyme activity with PH



Size of substrate molecules (surface area)

The rate of reaction increases with decrease in the size of substrate molecules. This is because smaller substrates present a larger surface area over which enzymes act. Reactions occur much faster when substrates are presented in powder than solid forms due to increase in surface area

This explains the significance of mastication (chewing food by teeth) as it reduces the size of food substances and increases the surface area for digestive enzymes hence speeding up chemical digestion

Enzyme cofactors

These are non protein components that are needed for proper functioning of enzymes. Enzyme cofactors include activators, coenzymes and prosthetic groups

Activators are inorganic ions like ZN, Fe, Mg etc which mould the shape of the active site so that the substrate easily binds to the enzyme. Ca ions are needed by thrombokinase enzyme during blood clotting

Coenzymes are non protein organic molecules that temporarily attach to enzymes between reactions. They are mainly derived from enzymes and serve to carry molecules towards and away from enzyme active sites. E.g. NAD, Coenzyme A, NADP

Prosthetic groups are also non protein organic components that are permanently attached to enzymes and serve to transfer molecules to and from active site sites. E.g. Haem and FAD

Presence of activators

Activators are substances that stimulate enzyme activity. Presence of activators increases enzyme activity and rate of reaction. Examples are Zinc ions that activate catalase enzyme and HCl which activates pepsinogen to pespsin.

Some enzymes catalyse the conversion of their own inactive forms into active forms. E.g. pepsin catalyses the conversion of pepsinogen to pepsin. This is known as Autocatalysis.

Enzyme inhibitors

These are chemical substances that slow down the rate of enzyme controlled reaction

Inhibitors are categorized as **competitive or non competitive**

Competitive inhibitors bind to the active site of enzymes thus preventing substrate molecules from doing so. Such inhibitors are closely related to the true substrate molecules in terms of structure and chemical composition such that they can fit into the active site.

Such inhibitors reduce the probability of substrates to bind to the active site thus reducing the rate of reaction. The degree of inhibition increases with increase in concentration of inhibitors as these will occupy more active sites before substrates do. At a given inhibitor concentration, the degree of inhibition reduces (rate of reaction increases) with increase in substrate concentration. This is due to increase in the probability of substrate molecules to occupy more active sites before inhibitors do. The degree of competitive inhibition therefore depends on the relative concentrations of substrate and inhibitor molecules. The process is actually reversible.

Examples include inhibition of succinate dehydrogenase enzyme which oxidizes succinic acid to fumarate by malonic acid, and inhibition of RuBP carboxylase by oxygen

Non-competitive inhibitors bind to another site on the enzyme other than the active site, preventing it from carrying out catalysis. E.g. cyanide silver arsenic, mercury, DDT, Nerve gass, penicillin

Such enzymes have another binding site called the allosteric site and such inhibitors are called allosteric inhibitors. They bring about change in the shape of the active site making enzymes unable to bind substrates. **Non-Competitive inhibition maybe reversible or irreversible**

Non competitive reversible inhibition is when the inhibitor loosely binds to the enzyme and can be detached when conditions permit. E.g. cyanide binds to cytochrome oxidase

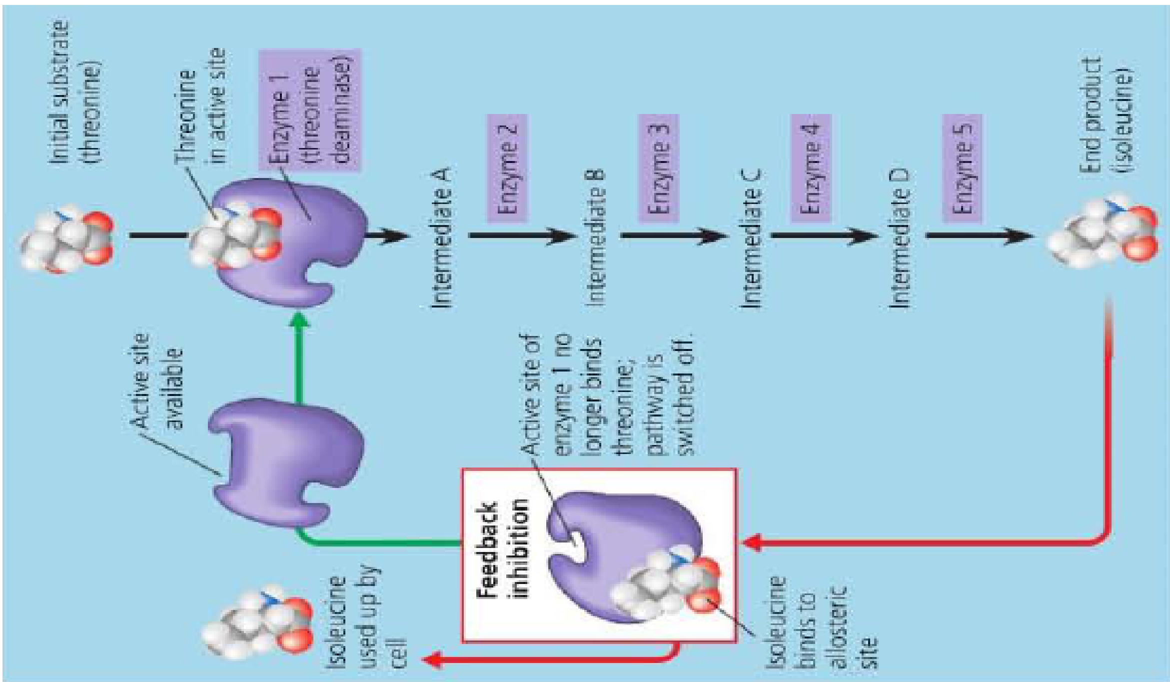
Non competitive irreversible (Or simply irreversible) inhibition is when the inhibitor tightly binds to the enzyme and cannot be detached. E.g. Nerve gas and other toxins

NB:

- Although the degree of competitive inhibition is dependent on substrate concentration, the degree of noncompetitive inhibition is independent of substrate concentration. Regardless of the number of substrate molecules present, none of them can bind to the active site and the rate of reaction will remain constant and very low
- Allosteric enzymes are enzymes whose shape of the active site is changed when a regulator molecule binds to the enzyme at a site away from the active site. This binding site is called an allosteric site, if the binding molecule changes the shape of the active site such that the enzymes works more efficiently, it’s called an allosteric activator/allosteric effector. If the molecule makes the enzyme work less efficiently; then it’s called an allosteric

inhibitor

➢ Most metabolic reactions in the body occur as a series of integrated reactions where the product of one stage acts the reactant (Raw material) for the next stage until the final product is formed. This is known as a metabolic pathway. The final product of a given metabolic pathway may accumulate acts as an allosteric inhibitor of the enzyme catalyzing the initial stage of the metabolic path; this is known as end product inhibition/Feedback inhibition. It is important for self regulation of metabolic processes in cells to prevent over production



Differences

Non competitive inhibition	**Competitive inhibition**
Inhibitor binds to the enzyme away from active sit	Binds to the active site
Degree of inhibition is independent of substrate concentration	Degree of inhibition depends on substrate concentration
Shape of inhibitor is not closely related to that of substrate	Shape of inhibitors is closely related to that of inhibitor
The shape of active site is changed	Shape of active site remains unchanged
Maybe reversible or non reversible	Inhibition is reversible

Importance of enzyme inhibition

- Prevent over accumulation of products by end product inhibition
- Inhibition regulates metabolic reactions such that they occur only in presence or absence of certain substances
- Inhibitors provide information about presence and shape of active sites
- They can also be used to block particular reactions so as to construct metabolic pathways

NUCLEIC ACIDS

Nucleic acids are macro molecules that store the genetic information of an organism and pass it from one generation to the next.

There are two types of nucleic acids that universally occur in all organisms and all cells, i.e. DNA and RNA. DNA stores coded information that directs and control all activities of an organism (cell). This information passes from DNA to Messenger RNA which in turn directs synthesis of proteins that control all metabolic activities of the organism

GENERAL STRUCTURE OF NUCLEIC ACIDS

All nucleic acids are made up of smaller sub units called nucleotides. These are linked up by condensation to form long chains (polynucleotide chains) that make up the nucleic acid

THE NUCLEOTIDE

These are the building blocks of nucleic acids. Each nucleotide is made up of three major components, namely:

- Phosphate group/Phosphoric acid
- Pentose sugar
- Nitrogen base

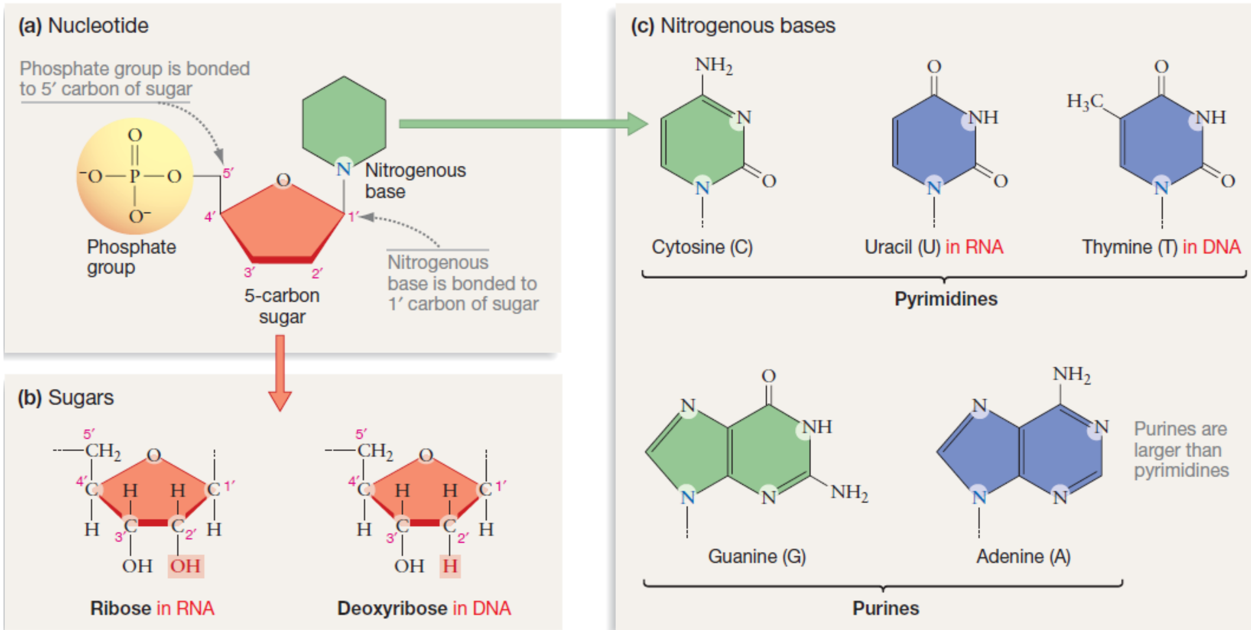
The phosphate group being acidic is responsible for the acidic properties of nucleic acids. It retains the same structure in all nucleic acids as shown below

The pentose sugar is a 5 carbon sugar that links up nucleotides to form a long polynucleotide chain that makes up the nucleic acid. There are two types of pentose sugars known to occur in nucleic acids; Ribose ($C_5H_{10}O_5$) which is found in RNA and deoxyribose sugar ($C_5H_{10}O_4$) which is found in DNA. The latter is actually formed by removal of an oxygen atom from carbon 2 of the ribose sugar (hence its name)

Nitrogen bases (Organic bases) are complex ring structures that are responsible for the overall shape, function and basic properties of nucleic acids. They are composed of carbon and nitrogen and occur in two types, purines and pyrimidines

Purines are double ring compounds, composed of a 5 sided and 6 sided rings. There are two purines known to occur in DNA and RNA; Adenine (A) and Guanine (G)

Pyrimidines are single-ring compounds composed of a 6-sided ring. There are 3 examples of pyrimidines; Cytosine (C), Thymine (T) and Uracil (U). Cytosine occurs in DNA and RNA while Thymine occurs in DNA only and Uracil in RNA only



NB:

- Each nucleic acid contains 4 different nitrogen bases of which 2 are purines and 2 are pyrimidines.
- Nucelotides are known to occur in many other biologically important molecules which include the following

Molecule	**Notice**
Nicotinamide Adenine Dinucleotide (NAD) and Flavin Adenine Dinuccleotid (FAD)	Important electron and H carriers in photosynthesis and respiration
Adenosine TriPhosphate (ATP)	The universal form of energy currency in cells
Cyclic Adenosine MonoPhosphate (cAMP) and Cyclic Guanosine MonoPhosphate (cGMP)	Are second messengers that facilitate hormonal action

<u>Formation of nucleotides and Nucleic acids</u>

A nucleotide is formed by combination of a pentose sugar, nitrogen base and phosphate group via a condensation reaction. The nitrogen base combines to carbon 1 of the pentose sugar, forming a nucleoside. This then combines with a phosphate group at carbon 5 to form a nucleotide, as shown below

Two nucleotides can combine by condensation between the phosphate group of one and the pentose sugar of another, forming a dinucleotide held by a phosphodiester bond between carbon5 and carbon 3. Addition of more nucleotides to the 3' end leads to formation of polynucleotide chain that consists of a sugar-phosphate backbone from which nitrogen bases project; being attached to the pentose sugars as shown below.

Hydrogen bonds can be formed between complementary bases of two different or the same folded polynucleotide chain. This is known as complementary base pairing which stabilises the nucleic acid molecule, giving it the overall 3-dimensional shape

NB:

- For complementary base pairing to occur, the two polynucleotide strands must be antiparallel (Running in opposite directions)
- Complementary base pairing occurs by hydrogen bond formation between a purine and a pyrimidine; specifically with G to C with 3 bonds and A to either T (as in DNA) or U (As in RNA) with 2 bonds.
- Two nitrogen bases that can pair with stable hydrogen bonds are called complementary bases. Two purines cannot form stable hydrogen bonds because the space between them would be too small for stable bonds to be formed. Similarly; the distance between 2 pyrimidines would be two large for stable hydrogen bonds to be formed.

RIBONUCLEIC ACID (RNA)

RNA is a single stranded polynucleotide consisting of a pentose sugar ribose, phosphoric acid and nitrogen bases G, C, A and U. In some RNA molecules, the single strand my fold into a double strand stabilised by hydrogen bonds between complementary bases with G to C (with 3 bonds) and A to U (with 2 bonds).

RNA is found in the cytoplasm of the cell; but may also be found in the nucleus shortly after being manufactured.

Types of RNA

There are 3 forms of RNA all of which are important in the process of protein synthesis. These include;

- Ribosomal RNA (rRNA)
- Transfer RNA (tRNA)
- Messenger RNA (mRNA)

RIBOSOMAL RNA (rRNA)

This is the largest and most abundant form of RNA, making up to 80% of the total RNA in a cell. It forms a large complex structure made of partly single strands and double helices. In eukaryotic cells, rRNA is manufactured by the nuceleolus in the nucleolar organiser. It is then transported to the cytoplasm where it associates with proteins to make ribosomes. These are sites for synthesis of proteins in the cytoplasm.

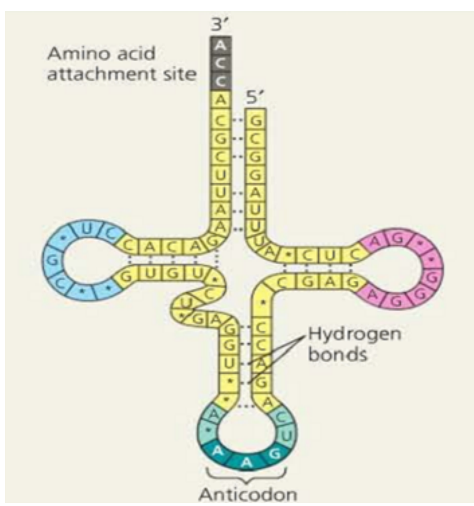
NB: rRNA maintains the same basic structure in all organisms ranging from the simplest bacteria to the most complex. This shows that it is rarely destabilised during continuity of life and can be used to show evolutionary relationships among organisms.

TRANSFER RNA (tRNA)

This is the smallest (About 80 nucleotides) and second abundant form of RNA making up to 15% of total RNA. There are at least 20 different tRNAs in a cell whose role is to activate, attach to and transport specific amino acids from the cytoplasm to ribosomes where protein synthesis is taking place. Activation is catalysed by an amino-acyl tRNA synthatase enzyme forming an amino acid-tRNA complex

Structure

tRNA consists of a single polynucleotide strand made of ribose sugar, phosphoric acid and nitrogen bases G, C, A and U. The strand is folded into a double helical structure with three prominent bulges forming a clover-leaf shape, stabilised by hydrogen bonding between complementary bases; G to C and A to U. The middle loop has a triplet of bases called the anticodon which is specific to each tRNA and base pairs with triplet bases of codons on mRNA. At the 5’ end of the strand is G and at the 3’ end is a CCA base sequence common to all tRNAs, and acts as the attachment site for the amino acid.



MESSENGER RNA (mRNA)

This is the least abundant form of RNA, making up to 5% of the total RNA. It is manufactured by the process of transcription in the nucleus as a complementary base sequence of one DNA strand making up a gene (Cistron). The bases on mRNA occur in triplets called codons. It passes into the cytoplasm where it acts as a template for synthesis of proteins. mRNA serves to deliver the coded information from DNA into the cytoplasm.

NB: Unlike other RNAs, mRNA is temporary and usually broken down by enzymes in the cytoplasm immediately after protein synthesis

Structure

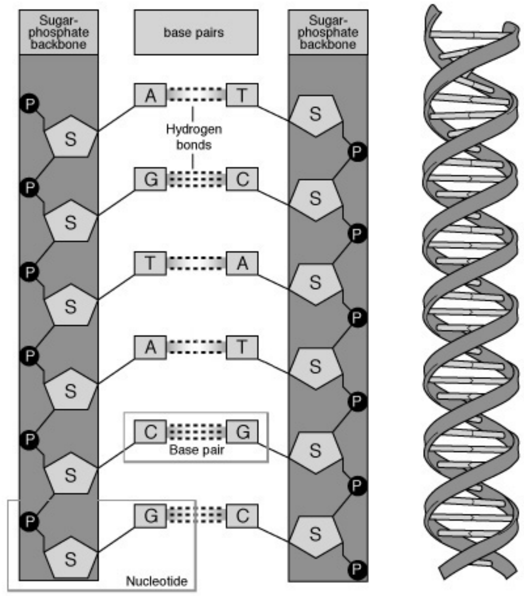
It is a single stranded polynicleotide, consisting of ribose sugar, phosphoric acid and nitrogen bases G, C, A and U. The length of the polynucleotide varies depending on the length of the amino acid chain to be coded for. It coils into an alpha helix as it passes from the nucleus into the cytoplasm.

DEOXYRIBO NUCLEIC ACID (DNA)

DNA is the hereditary material that contains coded instructions for its own synthesis (By replication), synthesis of RNA through which DNA directs synthesis of proteins. In this way, DNA determines the characteristics of an organism. Being capable of self replication, DNA is passed through generations from parents to offsprings; it's therefore called the hereditary material.

STRUCTURE OF DNA

DNA consists of two long, right-handed spiral polynucleotide strands that wind around each other to form a double helix. The strands run in opposite directions hence called antiparallel. Each strand consists of repeating units of a pentose sugar deoxyribose bonded to phosphate groups by phosphodiester bonds, forming a sugar-phosphate backbone. From this backbone, nitrogen bases G, C, A and T project at right angles, being attached to carbon 1 the pentose sugar. The nitrogen bases form hydrogen bonds with complementary bases of the other strand, with G to C with three bonds and A to T with two bonds. This is called complementary base pairing which stabilises the 3 dimensional structure of DNA.



NB:

- Complementary base pairing occurs between antiparallel polynucleotide strands, specifically between a purine and a pyrimidine
- The base sequence along DNA strands vary more among members of different species but slightly among members of the same species
- The ration of A:T or G:C is always 1
- The total number of purine residues (A+G) =the total number of pyrimidines (C+T)
- The ratios of A:G and T:C show considerable variation among different species. This shows that the DNAs have different composition of bases

Similarities between DNA and RNA

- Both are made of long chains of nucleotides (polynucleotide chains).
- Both contain nitrogen bases G, C and A
- Both are formed in the nucleus
- Both of them contain four bases and two purines and two pyrimidines
- Both participate in protein synthesis

Differences between RNA and DNA

DNA	RNA

Made of a pentose sugar deoxyribose	Made up of ribose pentose sugar
Contains a nitrogen base thymine	Contains uracil
Double stranded	Single stranded
Has a much higher molecular weight	Has a lower molecular weight
Found exclusively in the nucleus	Found in the nucleus and cytoplasm
It occurs in one structural form	It Occurs in three structural forms; mRNA, rRNA and tRNA.
Its amount is the same in a non dividing cell	Amount varies in cells from time to time
It is chemically very stable	It is less chemically stable

Properties/Characteristics of DNA as a hereditary/genetic material

- It is capable of self-replication i.e. make exact copies of itself. This allows for transmission of characters from parents to off springs.
- Ability to undergo mutations which creates variation among organisms. This allows for evolutionary change to occur
- DNA is chemically very stable to safely store the genetic information safely without change
- DNA is very long so as to store a lot of information
- Its amount remains constant body cells to store the same information
- Ability to associate with proteins to form chromosomes

Evidence of DNA as a hereditary material

- Ability to replicate accurately
- Association with mutagenes. Occurrence of a mutation in DNA results into change in the phenotypic characteristics of an organism. This indicates that characteristics are determined by DNA
- Association of DNA with chromosomes which are associated with inheritance.

DNA REPLICATION

It refers to the process by which the DNA double helix directs synthesis of a similar copy of DNA in a cell. It occurs in the synthesis (S) sub-stage of interphase as the cell prepares to divide.

PROCESS OF DNA REPLICATION

The DNA double helix unwinds due to breakage of hydrogen bonds between complementary bases by DNA helicase enzyme. The enzyme moves along the replication fork to separate the two strands each of which acts as a template for synthesis of a new polynucleotide strand.

DNA polymerase enzyme attaches to the 5' end of the leading strand and moves in the 5' to 3' direction along the strand. In the process, free nucleotides approach from the nucleoplasm and hydrogen bond with complementary bases in the template strand; with G to C and A to T, this is called complementary base pairing. Polymerase holds adjacent nucleotides in position and catalyses formation of phosphodiester bonds between them. The enzyme continues moving along the template strand in the same direction as the unwinding enzyme until the whole strand is synthesised. This is known as continuous replication

The lagging strand is replicated in small segments called okazaki fragments, in a direction away from the replication fork. This is because polymerase enzyme can only work in the 5' to 3' direction. Another enzyme DNA ligase joins the segments by linking the 3' carbon to the 5' carbon to form a complete strand. This is called discontinuous replication.

The two double strands then coil into double helices; each containing half of the original (parental) DNA molecule. This is called semi-conservative replication

NB: The conservative theory of DNA replication suggests that the double strand remains intact but the nitrogen bases are exposed to direct synthesis of a new double helix. The original DNA double helix is therefore conserved

SIGNIFICANCE OF DNA REPLICATION

- It ensures constancy of the amount of DNA from generation to generation
- DNA replication doubles the amount of DNA prior to cell division which ensures constancy in daughter cells

CHROMOSOMES

Chromosomes are threadlike structures formed by the association of DNA with proteins. A special class of proteins called histone proteins associate with DNA to form chromosomes. These chromosomes uncoil and lengthen into chromatin during interphase.

GENES

A gene is the basic unit of inheritance that determines the characteristics of an organism. Genes are actually small sections of chromosomes called cistrons that code for synthesis of a particular polypeptide chain (Protein). A cistron (Gene) consists of a specific sequence of bases that determine the sequence of amino acids in the polypeptide chain. This is done during the process of protein synthesis.

DNA makes RNA, RNA makes protein

PROTEIN SYNTHESIS

This is the process by which the sequence of bases in a DNA cistron directs synthesis of a polypeptide chain in a cell. The process involves two major processes, Transcription and translation.

TRANSCRIPTION

The process by which the sequence of bases in a DNA cistron is converted into a complementary sequence of bases on mRNA

The process begins with unwinding of the DNA cistron due to breakage of hydrogen bonds between complementary bases by DNA helicase. This recognises the start triplet and moves along DNA up to the stop triplet. RNA polymerase selects and attaches to the template strand (transcribing strand) and moves in the 5’ to 3’ direction along the strand. In the process, free nucleotides approach from the nucleoplasm and hydrogen-bond with complementary bases in the template strand, with G to C and U to A. The enzyme holds adjacent nucleotides and catalyses formation of phosphodiester bonds between them. The process continues in the same direction until the stop triplet is reached.

The mRNA detaches from the template strand, modified and leaves the nucleus via nuclear pores into the cytoplasm where translationoccurs. The cistron rewinds (Zips-up) into a double helix

TRANSLATION

The process by which the triplet sequence of bases on mRNA is converted into a polypeptide chain in the cytoplasm of the cell. It specifically occurs on ribosomes in the cytoplasm.

After transcription**;** the mRNA enters the cytoplasm**;** and attaches to the smaller subunit of the ribosome**;** by the first 2 codons. Meanwhile Amino acids are activated**;** by phosphorylation using ATP**;** and attached to specific tRNAs**;** to form aminoacyl-tRNA complex**;** using aminoacyl-tRNA synthetase enzyme**.** The complexes move to the ribosomes and hydrogen bond**;** by their anticodons to complementary codons on mRNA**.** The complexes are held by the large subunit of

the ribosome which catalyses; formation of a peptide bond; between adjacent amino acids by the peptidyl transferase enzyme.
The ribosome then moves one codon along the mRNA; which frees the first tRNA; and a complementary tRNA complex attracted to the next codon. The process of the ribosome reading and translating the mRNA code continues; until the whole polypeptide is synthesised.

After formation, the polypeptide chain at its primary structure; leaves the ribosome and undergoes modifications; like coiling, folding and conjugation to form a functional protein.

Many ribosomes may attach onto the same mRNA; in form of a polysome; so as to synthesise many polypeptide chains from the same mRNA molecule.

Second mRNA base

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

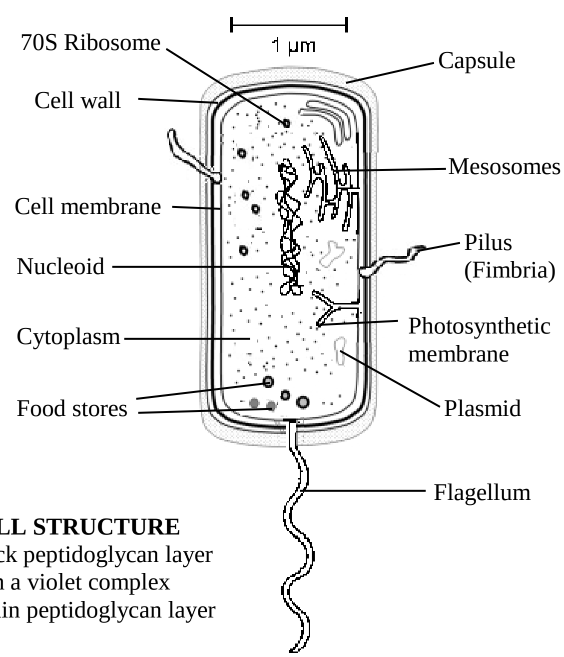
i) The code is non-ambiguous i.e. no one codon can code for more than one amino acid.

CYTOLOGY (CELL BIOLOGY): The study of structure and function of cells of plants and animals.

TERMS IN CYTOLOGY

TERM	DEFINITION	EXAMPLE / COMMENT
1. Cell	Smallest structural and functional unit of an organism capable of carrying out life processes under suitable conditions	***Life processes:*** respiration, nutrition, excretion, movement, reproduction, growth, response
2. Unicellular organism	Organism whose whole body is made of only one cell	Amoeba, paramecium
3. Multicellular organism	Organism whose body is made up of many cells	Animals and plants
4. Cytoplasm	Region within a cell composed of these **three major** elements: **cytosol**, **organelles** and **inclusions**	
(a) Cytosol	The fluid part of cytoplasm not contained within membrane-bound organelles.	
(b) Cell organelle	Separate structure within a cell which performs specific function e.g. mitochondria, chloroplast, etc	
(c) Cytoplasmic inclusion	Insoluble, non-living substance suspended in the cytosol of a cell **not** capable of carrying out any metabolic activity.	●**Glycogen granules** in liver and muscle cells. ●**Lipid droplets** in fat cells. ●**Melanin pigment** in melanocyte cells of skin and hair. ●**Water** filled **vacuoles**. ●**Crystals** e.g. (i) inside sertolli cells and leydig cells of human testes. (ii) calcium oxalate or silicon dioxide in plant cells.
5. Protoplasm	The fluid living part of the cell consisting of plasma membrane and all that it encloses.	***Protoplasm is divided into:*** (i) cytoplasm (ii) nucleoplasm (cell nucleus)
6. Prokaryotic cell	Cell without membrane-bound organelles inside.	Bacteria and cyanobacteria
7. Prokaryote	Organism without membrane-bound organelles in cells	Bacteria and cyanobacteria
8. Eukaryotic cell	Cell having the nucleus and other organelles enclosed within membranes.	Cells of plants, animals, fungi and protists
9. Eukaryote	Organism whose cells have the nucleus and other organelles enclosed within membranes.	Plants, animals, fungi and protists
10. Cytoskeleton	Complex network of fibers throughout the cytoplasm enabling maintenance of cell shape and support.	●Microfilaments ●Microtubules ●Intermediate filaments e.g. keratin.

ULTRASTRUCTURE OF PROKARYOTIC CELL (e.g. ROD-SHAPED BACTERIUM)



Parts **ALWAYS** present

- ●***70S ribosome:*** site of protein synthesis
- ●***Cell wall:*** peptidoglycan layer that protects and maintains cell shape
- ●***Cell membrane:*** phospholipid layer controls entry and exit of substances.
- ●***Nucleoid:*** region of one free strand of DNA
- ●***Food granules:*** glycogen and lipid
- ●***Cytoplasm:*** centre for biochemical reactions.

Parts **SOMETIMES** present

- ●***Mesosome:*** site of respiration, cell wall synthesis
- ●***Flagellum:*** elongated, relatively flexible cork-screw shaped structure that moves the cell
- ●***Capsule (slime layer):*** for protection
- ●***Pili (fimbriae):*** protein filaments that facilitate cell adhesion and conjugation
- ●***Plasmid:*** independent small circle of DNA
  - Offers resistance to drugs
- ●***Photosynthetic membranes:*** where photosynthesis occurs.

DIFFERENCES IN CELL WALL STRUCTURE

(i) Gram positive cells: Have thick peptidoglycan layer that reacts with gram stain to form a violet complex

(ii) Gram negative cells: Have thin peptidoglycan layer that is not stained by gram stain.

COMPARISON OF EUKARYOTIC AND PROKARYOTIC CELLS

Feature	Eukaryotic Cell	Prokaryotic Cell
Examples	Cells of plants, animals, fungi and protists	Bacteria and cyanobacteria

Structural differences

Feature	Eukaryotic Cell	Prokaryotic Cell
Cell size	Much larger (10µm -100µm)	Much smaller (0.2µm -10µm)
Cellularity	Usually multicellular	Mostly unicellular, some cyanobacteria are multicellular
Nucleus	Present with nuclear envelope and nucleolus	Absent
DNA shape	DNA is linear	DNA is circular (has no ends))
DNA composition	DNA complexed with proteins called histones	DNA is naked, without histones
Main organelles	Present	Absent
Ribosomes	Many, larger (80S type) and 70S (in cytoplasm)	Smaller (mainly 70S type) and few **[S: Svedberg]**
Flagella	If present there's 9+2 microtubule arrangement i.e. 9 peripheral doublets surround 2 central singlets.	If present lack 9+2 microtubule arrangement
Cell wall	Chemically simpler. In plants, **cellulose** wall, fungi **chitinous** cell wall, in animals, no wall	Cell wall usually chemically complexed with **peptidoglycan**
Plasma membrane	Sterols and carbohydrates present	No carbohydrates and generally lacks sterols
Glycocalyx	Present in some cells that lack a cell wall	Present as a capsule or slime layer
Cytoplasm	Cytoskeleton present	No cytoskeleton

Functional differences

Feature	Eukaryotic Cell	Prokaryotic Cell
Cell division	Occurs by mitosis	Occurs by binary fission
Sexual reproduction	Involves meiosis	Occurs by conjugation
Cytoplasm activity	Cytoplasmic streaming occurs	No cytoplasmic streaming
Nitrogen fixation	Does not occur	Occurs in some bacteria

Similarities

Both: contain vacuoles, DNA, ribosomes, vesicles, cell wall, cytoplasm, cell membrane.

THE CELL THEORY

While Robert Hooke (1665) initially discovered cells from thinly sliced pieces of cork, it was Matthias Schleiden (1838) and Theodor Schwann (1839) who proposed the cell theory, with modifications by Rudolf Virchow (1858).

Modern ideas of the Cell Theory

1. All known living things are made up of one or more cells (Schwann and Schleiden, 1838-39).
2. The cell is the structural and functional unit of all living things (Schwann and Schleiden, 1838-39).
3. All cells arise from pre-existing cells by division (Rudolf Virchow, 1858).
4. Cells contains hereditary information which is passed from cell to cell during division.
5. All cells are basically the same in chemical composition.
6. All energy flow (metabolism and biochemistry) of life occurs within cells.

EXCEPTIONS (DISCREPANCIES) TO THE CELL THEORY

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

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

FACTORS THAT LIMIT CELL SIZE

Factor	Explanation of how each factor influences cell size
1. Surface area to volume ratio $\left(\frac{\text{surface area}}{\text{volume}}\right)$	●Small cells have large 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***: **(i)** In animals, some large sized cells take in substances in bulk by **endocytosis** and expel bulk substances by **exocytosis** to **supplement** on **simple diffusion**. **(ii)** Some animal cells increase their surface area by forming many tiny projections called **microvilli**. **(iii)** Some cells divide when they reach a certain size to maintain suitable SA : V ratio. ***Note***: ●SA : V ratio particularly **limits the size of bacterial cells**, i.e. prokaryotic cells which are incapable of endocytosis and exocytosis.
2. Nucleo-cytoplasmic 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 which lack cell walls.
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.

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.

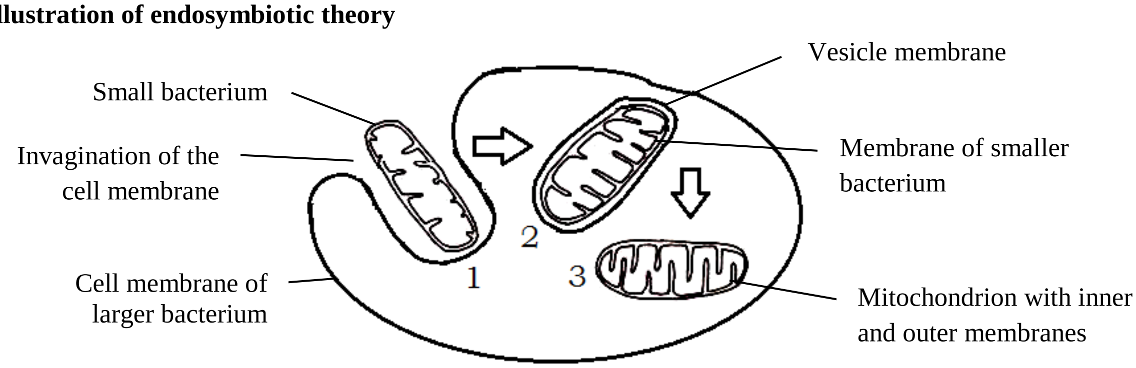
●Larger **anaerobic bacteria** engulfed the smaller bacteria by the process of **endocytosis,** but digestion failed.

●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.*

Illustration of endosymbiotic theory



EVIDENCE FOR ENDOSYMBIOTIC THEORY

1. Mitochondria and Chloroplasts have their own DNA, and divide independently of the cell they live in.

2. There is great similarity between prokaryotic cells and the organelles of eukaryotic cells as shown below.

Feature	**Prokaryotes**	**Eukaryotes**	**Mitochondria of eukaryotic cells**	**Chloroplasts of photosynthetic eukaryotes**
DNA	One circular chromosome	Linear chromosomes	One circular chromosome	One circular chromosome
Replication	Binary fission (1 cell splits into 2)	Mitosis	Binary fission (1 splits into 2)	Binary fission (1 splits into 2)
Ribosomes	"70 S"	"80 S"	"70 S"	"70 S"
Electron Transport Chain	Occurs in the plasma membrane	In mitochondria and chloroplasts	In the membrane of mitochondrion	In the membranes of chloroplast
Approx. Size	~1 µm -10µm	~50 µm - 500 µm	~1 µm -10 µm	~1 µm -10 µm

3. The timeline of life on Earth shows that from fossil evidence of bacterial life, the mitochondria, chloroplasts and eukaryotic cells emerged at about the same time, 1.5 billion years ago.

Feature	**Prokaryotes**	**Eukaryotes**	**Mitochondria of eukaryotic cells**	**Chloroplasts of photosynthetic eukaryotes**
Appearance on Earth	***Anaerobic bacteria:*** ~3.8 Bn yrs ago ***Photosynthetic bacteria*:** ~3.2 Bn yrs ago ***Aerobic bacteria*:** ~2.5 Bn years ago	~1.5 billion yrs ago	~1.5 bn years ago	~1.5 bn years ago

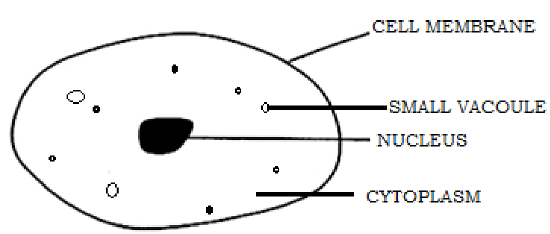
- At about 3.8 billion years ago, the atmosphere of the Earth did not contain oxygen, and all life was **anaerobic**.
- About 3.2 billion years ago, **photosynthetic bacteria** or **cyanobacteria** appeared and accumulated **oxygen** in the atmosphere from their photosynthesis, which killed **anaerobic** cells.
- **Aerobic** cells appeared at about 2.5 Billion years ago, followed by mitochondria, chloroplasts and eukaryotic cells at almost the same time, approximately 1.5 billion years ago.

SEMI-AUTONOMOUS ORGANELLES

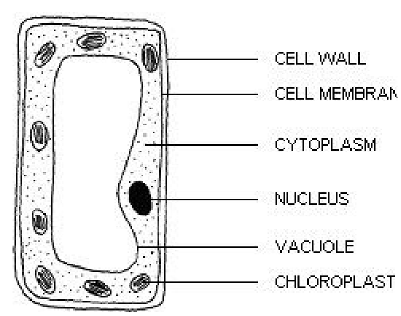
- Mitochondrial DNA and chloroplast DNA is short hence provides only a small part of the **genome** needed for **binary fission,** hence the process in organelles is controlled by the nucleus which contains the larger genome.
- Mitochondrial DNA and chloroplast DNA is short, therefore can only code for a few of the proteins needed, hence some of the required proteins are imported from the cytoplasm of the main cell where the organelle stays.

GENERALISED STRUCTURE OF CELLS AS OBSERVED UNDER LIGHT MICROSCOPE

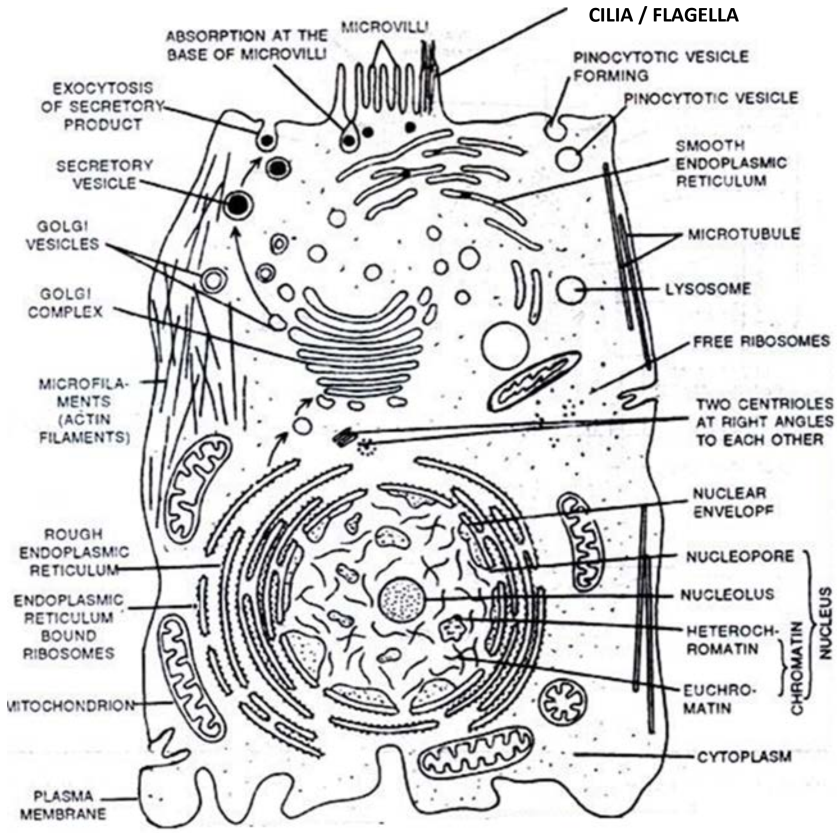
Animal cell



Plant cell



ULTRASTRUCTURE OF CELLS (AS OBSERVED BY ELECTRON MICROSCOPE)



Parts of a typical animal cell

1. Cell membrane
2. Cytoplasm

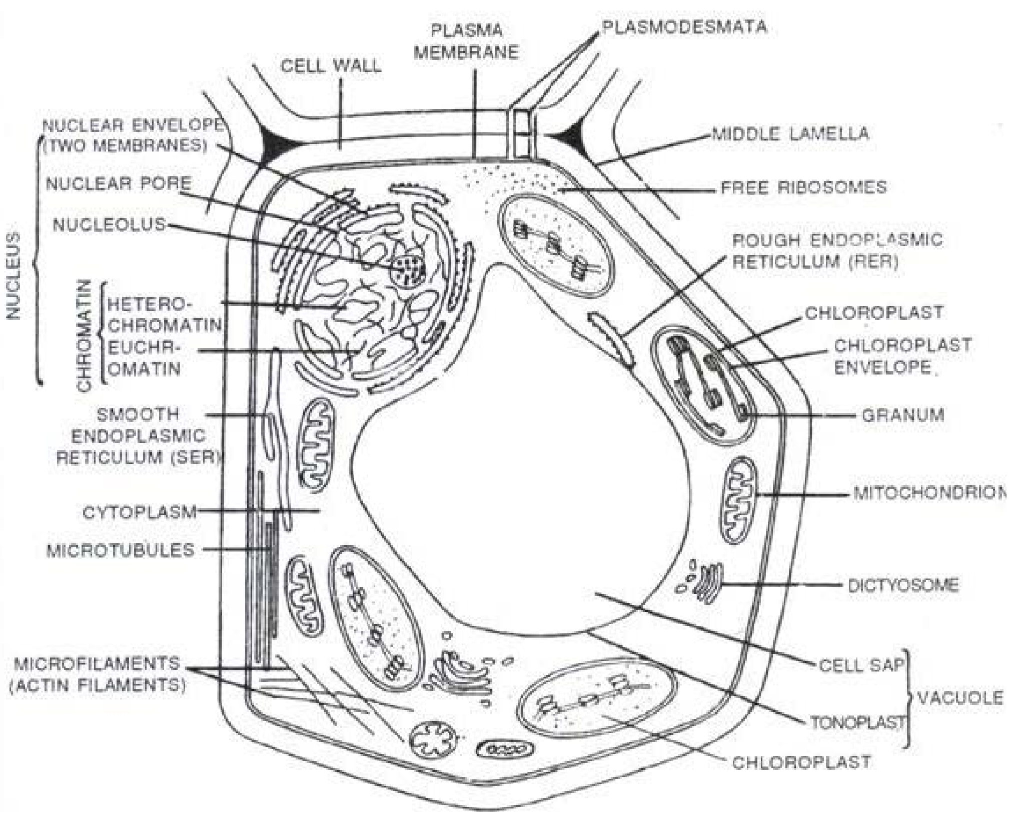
(a) Cytosol
(b) Cell organelles
(c) Cytoplasmic inclusions

Cell organelles

(i) Nucleus
(ii) Ribosomes (free or attached to ER)
(iii) Endoplasmic reticulum (SER/RER)
(iv) Mitochondria
(v) Golgi complex (Golgi apparatus)
(vi) Lysosomes
(vii) Microfilaments
(viii) Centrioles
(ix) Microvilli
(x) Cilia and Flagella
(xi) Microtubules

Cytoplasmic inclusions

(i) Pinocytic vesicles
(ii) Glycogen granules
(iii) Fat droplets



Parts of plant cell

1. Cell membrane
2. Cell wall
3. Plasmodesmata
4. Cytoplasm

(a) Cytosol
(b) Cell organelles
(c) Inclusions

Cell organelles

(i) Nucleus
(ii) Ribosomes
(iii) Endoplasmic reticulum (SER/RER)
(iv) Mitochondria
(v) Dictyosomes
(vi) Microfilaments
(vii) Microtubules
(viii) Vacuole
(ix) Chloroplasts

Cytoplasmic inclusions

(i) Starch grains
(ii) Fat droplets

COMPARISON OF PLANT AND ANIMAL CELLS

Similarities

All plant and animal cells contain the Cytoplasm, Endoplasmic Reticulum (Smooth and Rough), Ribosomes, Mitochondria, Golgi apparatus, Microtubules, Microfilaments, Nucleus, lipid droplets

Differences

Feature	**Animal Cell**	**Plant Cell**
Cell wall	Absent	Present, made of cellulose
Plastids	Absent	Present e.g. ***chloroplasts***
Plasmodesmata	Absent	Present
Cilia	Present on some cells	Most plant cells lack cilia.
Centrioles	Present in cytoplasm	Absent
Cholesterol in cell membrane	Present	Absent
Centrioles	Present in all animal cells	Only present in lower plant forms.
Vesicles	Present	Absent
Shape	Irregular shapes	Fixed shapes
Vacuole	Vacuoles small, many, scattered in cytoplasm	Vacuole is 1, large (90% of cell volume), central position
Food stored	Glycogen	Starch

Note: In plants and fungi, **lysosomes** are called **acidic vacuoles**.

STRUCTURE OF THE CELL MEMBRANE

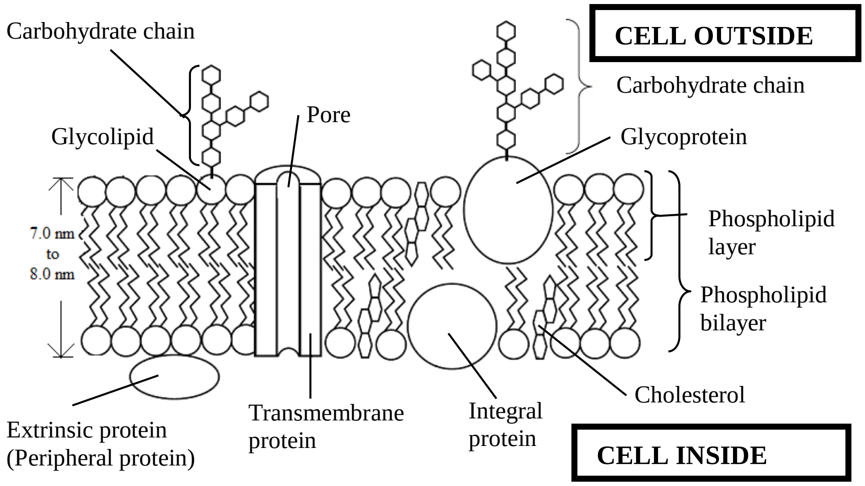
According to **S. J. Singer** and **G. L. Nicolson (1972)**, the structure of the cell membrane is a **fluid-mosaic model.**

It is described as:

- **Fluid** because the individual phospholipid and protein molecules can move laterally, giving the membrane a flexible structure that is constantly changing in shape.
- **Mosaic** because the proteins that are embedded in the phospholipid bilayer vary in size, shape and pattern of arrangement.

The main components of the cell membrane are: **1.** Phospholipids **2.** Proteins **3.** Carbohydrates **4.** Cholesterol

Fluid mosaic model of the cell membrane



Description fluid mosaic model

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

NOTE: **The cell membrane is supported by intracellular microfilaments at the inner surface which act as cytoskeleton**

RESEARCH QUESTION: (a) Describe SIX roles of cell membrane proteins.
(b) How is the cell membrane SUITED for its functions?

OTHER TOPICAL QUESTIONS: See last page (page 20)

CELL MEMBRANE FUNCTIONS

Component	Function
1. General	Forms a protective barrier between the inside and outside of the cell and determines cell shape.
2. Proteins	●Glycoproteins work as antigens in immunity. ●Channel proteins allow diffusion of polar ions and molecules across the membrane. ●Transport proteins move ions or solutes by active transport e.g. sodium ions or by facilitate diffusion e.g. glucose, amino acids across the membrane ●Membrane proteins provide sites for cytoskeleton filaments to anchor to support and maintain cell shape. ●Membrane proteins join cells together forming tissues which perform specific functions. ●Glycoproteins are involved in cell-to-cell recognition by cells of complimentary sites e.g. specific hormones. ●Cell surface receptor proteins are involved in signal-transduction by converting an extracellular signal to an intracellular one. ●Some membrane proteins have enzymatic properties e.g. ATP synthase for ATP synthesis. ●Some membrane proteins work as electron carriers in electron transport chains
3. Glycolipids	Are involved in cell-to-cell recognition
4. Cholesterol	Stabilizes membrane structure by preventing phospholipids from closely packing together
5. Lipid bilayer	Being semi-permeable, it controls movement of substances in and out of the cell

MEMBRANE FLUIDITY

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

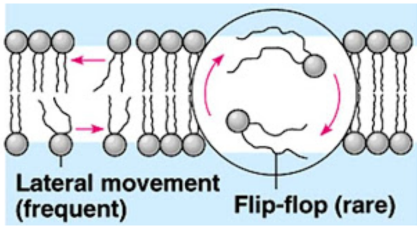
Importance of regulating membrane fluidity

- Membranes must be fluid to work properly.
- Biological processes stop when the bilayer fluidity reduces too much e.g. membrane transport and enzyme activities.

Factors that affect membrane fluidity

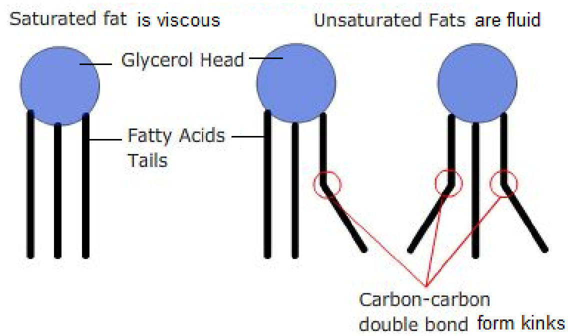
Factor	How the factor influences membrane fluidity
1. Temperature	●Low temperature decreases membrane fluidity because lipids are laterally ordered, the lipid chains pack well together, mobility reduces to allow many stabilising interactions. ●Increase in temperature increases membrane fluidity because lipids acquire thermal energy to become mobile and reduce stabilising interactions.
2. Length of lipid tails	●Lipids with shorter chains are more fluid because they quickly gain kinetic energy due to their smaller molecular size and have less surface area for Van der Waals interactions to stabilise with neighboring hydrophobic chains. ●Lipids with longer chains are less fluid because their large surface area enables more Van der Waals interactions hence increasing the **melting temperature**.
3. Lipid saturation	●Lipid chains with double bonds (unsaturated fatty acids) are more fluid because the kinks caused by double bonds make it harder for the lipids to pack together. ●Lipids that have single bonds only (saturated fatty acids) have straightened hydrocarbon chain which pack together to reduce membrane fluidity.
4. Presence of cholesterol e.g. in membranes of animal cells	●At low temperatures, cholesterol increases membrane fluidity by preventing fatty acid hydrocarbon chains from coming together and crystallizing there by inhibiting the transition from liquid to solid (decreases the membrane freezing point). ●At warm temperature (e.g. $37^{0}C$) cholesterol decreases membrane fluidity by interacting with lipid tails to reduce their mobility, thereby increasing the melting point. ●At high concentrations, cholesterol also prevents fatty acid hydrocarbon chains from coming together and crystallizing. **(The ratio of cholesterol to lipids in a membrane can be as high as 1:1)**

Effect of lipid tail movement

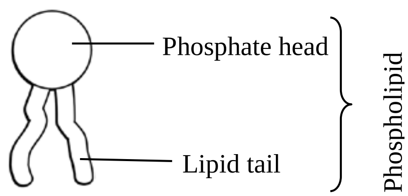


Note
1. Most of the lipids and some proteins drift laterally
2. Rarely does a molecule flip-flop transversely across the membrane.

Effect of *fatty acid unsaturation*



Structure of phospholipid



- The phosphate head is composed of glycerol and phosphate
- Tail made from two fatty acids, which could be saturated or unsaturated fatty acid

Arrangement in membrane
- Phospholipids form a bilayer, where the heads face outside the membrane / tails face inside the membrane

How phospholipid properties maintain cell membrane structure
- Phospholipids are held together by hydrophobic interactions
- Phospholipid layers are stabilized by interaction of hydrophilic heads and surrounding water
- Phospholipids allow for membrane fluidity/ flexibility
- Fluidity/ flexibility enables membranes to be functionally stable
- 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)
- Phospholipids can move about / move laterally (horizontally) / "flip flop" (move transversely) to increase fluidity
- Hydrophilic / hydrophobic layers restrict entry/ exit of substances.

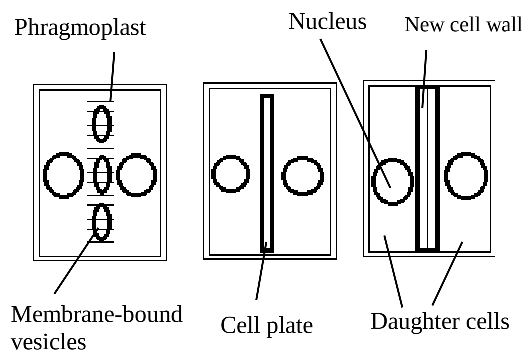
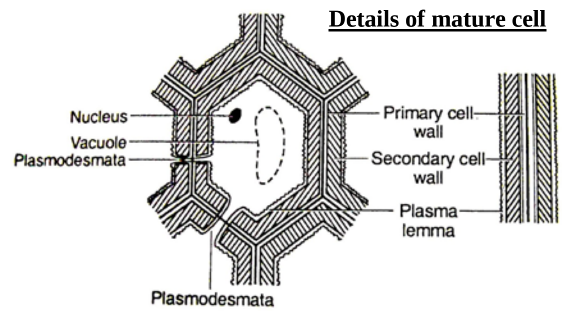
DISTRIBUTION AND FUNCTION OF MEMBRANES OF CELLS

Membranes of cells DOES NOT only include the **cell membrane (plasma membrane)**, which forms the cell boundary plus its **various modifications**, BUT ALSO all **other membranes** enclosing **some organelles** and some **cytoplasmic inclusions** within cells.

Distribution	Function
Plasma membrane	● Forms a protective barrier between the cell inside and outside. ● Determines cell shape and provides cell stability. ● Selectively regulates entry and exit of substances.
Nuclear envelope	● Separate nuclear contents from cytoplasm hence limits DNA within the nucleoplasm but allows exit of RNA. ● Controls flow of information to nucleus and DNA that are carried by the macromolecules.
Outer mitochondrial membrane	● Allows entry of ATP, NADH and from glycolysis
Inner mitochondrial membrane	● Contains electron carriers in electron transport chain
Rough Endoplasmic Reticulum	● Intracellular transport and sites for ribosome attachment
Smooth Endoplasmic Reticulum	● Intracellular transport
Outer chloroplast membrane	● Allows photosynthetic products out and substrates in
Thylakoid membranes of chloroplasts	● Store photosynthetic pigments e.g. chlorophyll ● Contains electron carriers
Golgi complex membrane	● Storage of glycoprotein ● Synthesis of polysaccharides e.g. cellulose in plants
Lysosomes	● Isolates autolytic enzymes from unnecessary digestion of cell components
Tonoplast	● Limits cell sap within the vacuole
Membranes surrounding vesicles	● Limit the contents of the vesicles within until when ready for exit e.g. calcium ions and neurotransmitters in neurones, undigested materials in phagocytic vesicles, etc.
Neurilemma of neurones	● Contains protein pumps for Na+ and K+ which bring about impulse propagation
Myeline sheath membrane	● Insulates nerve fibre to increase transmission speed.

STRUCTURE OF PLANT CELL WALL
NOTE*:** Plant cell wall is an **extracellular component** of plant cells. ***Others: glycoprotein and basement membrane.

- The cell wall consists of **3** main layers (regions) i.e. **middle lamella; primary cell wall;** and **secondary cell wall**
- It is tough**;** usually flexible/bendable/fairly rigid**;** of variable thickness [1 µm - 10µm] **;** surrounding plant cells**;**
- The outermost layer (middle lamella) cements (binds/glues) adjacent plant cells together**;** and is rich in **calcium** and **magnesium pectates** and **proteins;**
- The next layer (primary cell wall)**;** is generally a thin**;** flexible and extensible**;**
- It consists mainly of **cellulose microfibrils; hemicelluloses; pectin; water; and protein;** In plant epidermis it is usually **impregnated** with **cutin** and **wax;** to form an impermeable barrier called **plant cuticle;**
- The various chemical components are tightly (closely) bound together**;**
- In **some cells** there is the secondary cell wall inside the primary cell wall**;** It is **thick/** has **3 layers;** and contains several **proteins;** and **polymers** like: **cellulose**, **hemicelluloses** and **lignin** in ***WOOD*** and ***XYLEM*; suberin** in ***CORK*** and ***ROOT CASPARIAN STRIPS*; silica crystals** in ***GRASS*;**
- Certain small areas of the cell wall remain unthickened to form **pits;** which concide in adjacent cells to form pit pairs in which the two cells are separated only by the middle lamella and through which **plasmodesmata** (**cytoplasmic strands**) pass**;**

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

Functions of plant cell wall
- Maintaining / determining **cell shape.**
- **Provides support** and **mechanical strength** to the cell against gravity.
- Pathway for water and dissolved mineral salt movement by the **apoplast** pathway.
- Prevents excessive entry of water to the cell in a hypotonic medium (*i.e.,* resists turgor pressure of the cell)
- Has a **metabolic role** *i.e.,* some of the proteins in the wall are enzymes for transport and secretion.
- In **suberized cells**, acts as **physical barrier** to: (a) pathogens; and (b) water loss.
- **Carbohydrate storage** - components of the wall can be reused in other metabolic processes, like in seeds.
- allows turgor pressure/high pressure to develop inside the cell;

QUESTION
Eukaryotic cells have intracellular and extracellular components. State the functions of one named extracellular component. *(Any one of: cell wall/Glycocalyx/basement membrane/bone matrix, etc.)*

How the plant cell wall is suited for functioning

STRUCTURE	FUNCTION
• 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**
• The relatively thick multiple wall layers	**provide mechanical support**
• Secondary walls may be cutinized / suberinised	**for preventing water loss**
• 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**
• The extreme rigidity of secondary wall	**provides compression strength**
• Deposition of cellulose fibrils in alternating layers	**enables some degree of flexibility**
• semi-permeable nature	**Allows exchange of water, dissolved salts and small protein molecules**

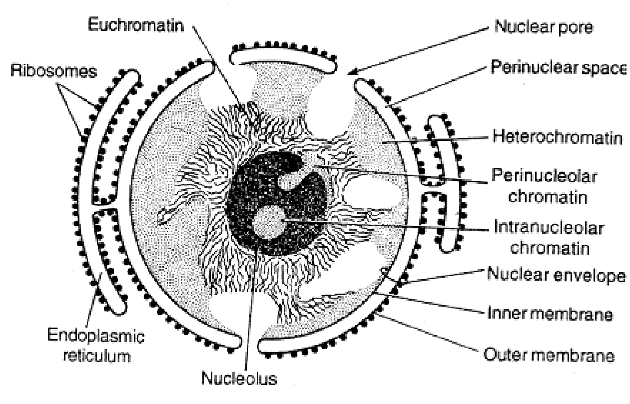
COMPARISON OF PLANT CELL WALL AND PLASMA MEMBRANE

Differences

CELL WALL	PLASMA MEMBRANE
• Number of main layers / regions varies (2 or 3)	• Number of main layers / regions constant
• Skeleton mainly made of carbohydrates / polysaccharides	• Skeleton mainly made of phospholipids
• More permeable to molecules	• Less permeable to molecules
• Lacks transmembrane proteins	• Transmembrane proteins present
• Plasmodesmata present	• Plasmodesmata absent
• May be lignified and suberinised	• Lacks lignification and suberinisation
• Has middle lamella	• Lacks middle lamella
• Secondary thickening occurs	• Lacks secondary thickening

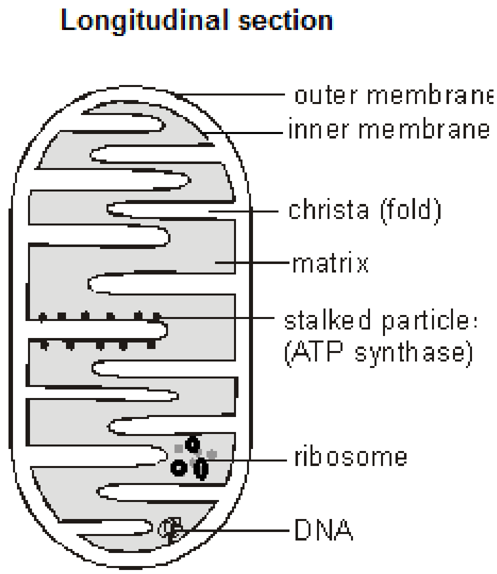
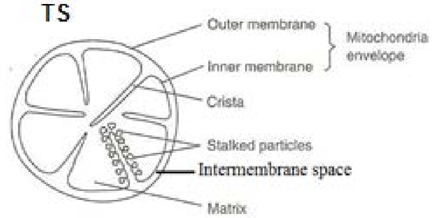
TASK: Outline the similarities between cell wall and cell membrane

NUCLEUS

Description of nuclear structure	Drawing of the nucleus	Adaptations of nucleus
●Cell nucleus is enclosed / bound by a double-layered nuclear membrane (nuclear envelope); ●Outer membrane is connected to the endoplasmic reticulum; ●A fluid-filled space (perinuclear space) exists between the two layers of a nuclear membrane. ●Nuclear membrane is perforated by nuclear pores ~50 nm in diameter ●Enclosed within the inner membrane are the nucleoplasm (karyoplasm), nucleolus and chromosomes (chromatin); ●Nucleolus is a dense, spherical-shaped structure; ●Chromosomes (chromatin) are thread-like. (i) **Heterochromatin:** stain darkly, genetically inactive, tightly coiled. (ii) **Euchromatin:** loosely packed, genetically active and enriched	 **Functions of the nucleus** **(i)** Controls the heredity features of an organism. **(ii)** Controls protein synthesis, cell division, growth and differentiation. **(iii)** Stores DNA, the heredity material **(iv)** Stores proteins and RNA in the nucleolus. **(v)** Site for transcription in which messenger RNA are produced for protein synthesis. **(vi)** Nucleolus produces ribosomes, which are the protein factories	●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; enables production of ribosomes which are protein factories; ●Nuclear envelope; isolate nucleus from interference by processes in cytoplasm; ●Nuclear pores are narrow; regulate entry and exit of substances

MITOCHONDRION

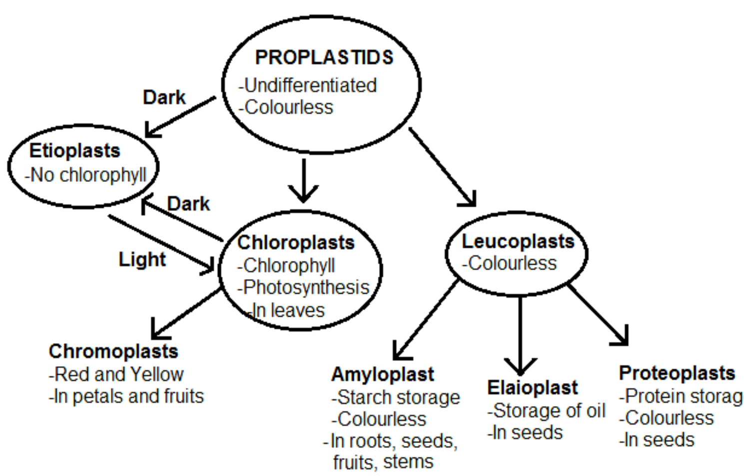
Function**:** It is the site for aerobic respiration for production of ATP that powers cell activities.

Description of structure	Drawings of mitochondrion from LS and TS	Adaptations of mitochondrion
●Mitochondrion has a diameter of about 0.5 µm – 1µm, length of 2.0µm - 7µm; and variable shape (may be spherical /rod shaped / filamentous); ●It is double (2) membrane bound; outer membrane is entire; inner membrane folds into the mitochondrial matrix to form cristae; and in-between the two membranes is the intermembrane space. ●Mitochondrial matrix is fluid filled, with several enzymes, small sized ribosomes and circular DNA ●Each membrane is a phospholipid bilayer, with variable phospholipid compositions and protein-to-lipid (PTL) ratios. **The PTL ratio for the outer membrane is about 50:50 while that of the inner membrane is about 80:20**	 TS 	●Double membranes isolate the mitochondrion from interference by processes in the cytoplasm ●Small size gives large surface are to volume ratio for rapid uptake / release of materials ●Matrix contains enzymes of Krebs cycle. ●Inner membrane forms cristae to increase the surface area for electron transport chain ●Inner membrane contains stalked particles that make ATP ●Narrow intermembrane space enables H^+ ion concentration gradient to be rapidly established for chemiosmosis to occur ●Inner membrane contains molecules for electron transport pathway ●DNA is present to act as genetic material for synthesis of some protein ●Many ribosomes for protein synthesis to reduce on importing proteins from cytoplasm.

PLASTIDS FAMILY OF ORGANELLES

These are small organelles in the cytoplasm of plant cells, containing pigments or food

Examples of plastids



Proplastid: Undifferentiated organelle which develops into **plastid**.

1. Etioplasts – colourless in absence of light, turn into chloroplasts on exposure to light

2. Chloroplasts (*chloros* - green) manufacture carbohydrates by photosynthesis.

Chloroplasts form chromoplasts

Chromoplasts (*chromos* - color) contain xanthophyll or carotenes, hence the yellowing in fruits, vegetables, and leaves.

3. Leucoplasts are colourless and include:

(a) Amyloplasts: form and store starch in tubers of roots and stem.

(b) Elaioplasts: Form and store oil.

(c) Proteoplasts (*Proteinoplasts***)**: Store crystalline proteins in plant seeds.

CHLOROPLASTS

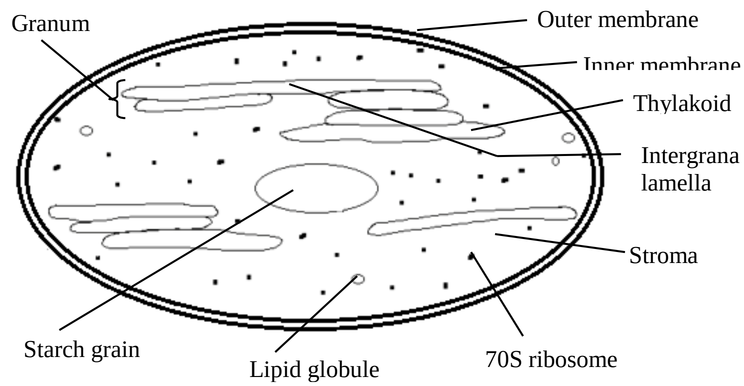
***Main function*:** It is the site for manufacture of food by the process of **photosynthesis**.

Other functions:

(i) Ribosomes enable amino acid and protein synthesis.
(ii) They produce fatty acids
(iii) They store starch, but only temporarily
(iv) Produce new chloroplasts and pigments

CHLOROPLAST STRUCTURE

- Chloroplast shape and size vary from biconvex in higher plants with length of ~5 µm to filamentous in algae, spherical, ovoid, etc.
- It is enclosed by an envelope of double membranes; outer membrane is semi-permeable.
- Inner membrane surrounds the stroma, regulates entry and exit of materials to the chloroplast, and is a manufacturing Centre for fatty acids, lipids and carotenoids.
- Intermembrane space is narrow, ~10 nm-20 nm in between the outer and inner membranes.
- Stroma is semi-gel-like fluid, alkaline, rich in protein (e.g. enzymes), with chloroplast DNA, 70S ribosomes, starch granules, lipid globules and thylakoid membrane system.
- Thylakoids are interconnected, membranous sacs, with chlorophyll in the membranes.
- At intervals, thylakoids form piles (~10-20) known as **grana**.



Adaptations of chloroplast for its functions

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

COMPARISON OF CHLOROPLAST AND MITOCHONDRION

Similarities:

Both: are enclosed by double membrane, contain DNA, contain 70S ribosomes, have electron transport chain, produce ATP by chemiosmosis, contain ATP synthase /ATPase

Chloroplast	**Mitochondrion**
● Site of photosynthesis	● Site of respiration
● Contains thylakoid membranes	● Lacks thylakoid membranes.
● Contains photosynthetic pigments that absorb light	● Lacks photosynthetic pigments.
● There is light generated ATP production	● ATP production by oxidation of organic molecules
● H+ gradient across thylakoid membrane	● H+ gradient across inner membrane
● Cristae absent	● Cristae present
● Larger size	● Smaller size

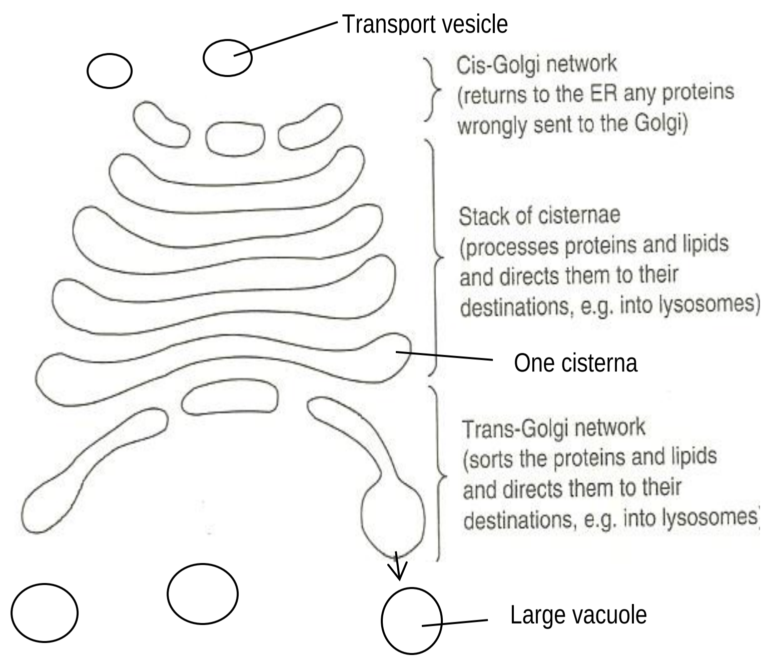
GOLGI COMPLEX (PLANTS: DICTYOSOME)

Note:

1. Golgi is abundant in **secretory** cells and in rapidly **dividing** cells e.g. pancreatic cells, goblet cells, salivary glands, cells in testes and ovaries.
2. Golgi complex is the cell's **"post office"** or **"shipping department"** where molecules are packaged, labelled and sent to different parts of the cell.

STRUCTURE OF GOLGI COMPLEX

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



The *cis* face is adjacent to the endoplasmic reticulum and the **trans** points towards the plasma membrane.

FUNCTIONS OF GOLGI APPARATUS	**ADAPTATIONS OF GOLGI**
●To modify, sort and package proteins that are made at the rough endoplasmic reticulum for secretion (export) or for use within the cell. ●To form carbohydrates e.g. polysaccharides are attached to a protein to form **proteoglycans** present in the extracellular matrix of the animal cell. ●Transport of lipid molecules around the cell. ●Formation of lysosomes containing hydrolytic enzymes. ●Formation of peroxisomes. ●In plant cells, Golgi produces vesicles that join to form cell plates during cell division. ●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 ***Note***: Golgi complex is the cell's **"post office"** or **"shipping department"** where molecules are packaged, labelled and sent to different parts of the cell.	●Cisternae are enclosed by selectively 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

FUNCTIONING OF GOLGI APPARATUS

THE SECRETORY PATHWAY

● Proteins made at Rough Endoplasmic Reticulum (RER) have, as part of their amino acid sequence, a signal that directs them where to go, just like an address directs a letter to its destination.

(i) Proteins arriving at *cis*-Golgi but having RER retention signal (were wrongly sent), are repackaged into vesicles then returned to RER.

(ii) Soluble or properly folded macromolecules (proteins, lipids and polysaccharides) from RER enter *cis*-Golgi network via transport vesicles

● Within *cis*-cisternae, macromolecules are partly modified i.e. carbohydrates are added to proteins (**glycosylation**), phosphate is added to protein (**phosphorylation**) etc.

● After partial modification, coated vesicles bud (pinch) off the swollen ends of *cis*-cisternae and fuse with ends of *medial* cisternae.

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

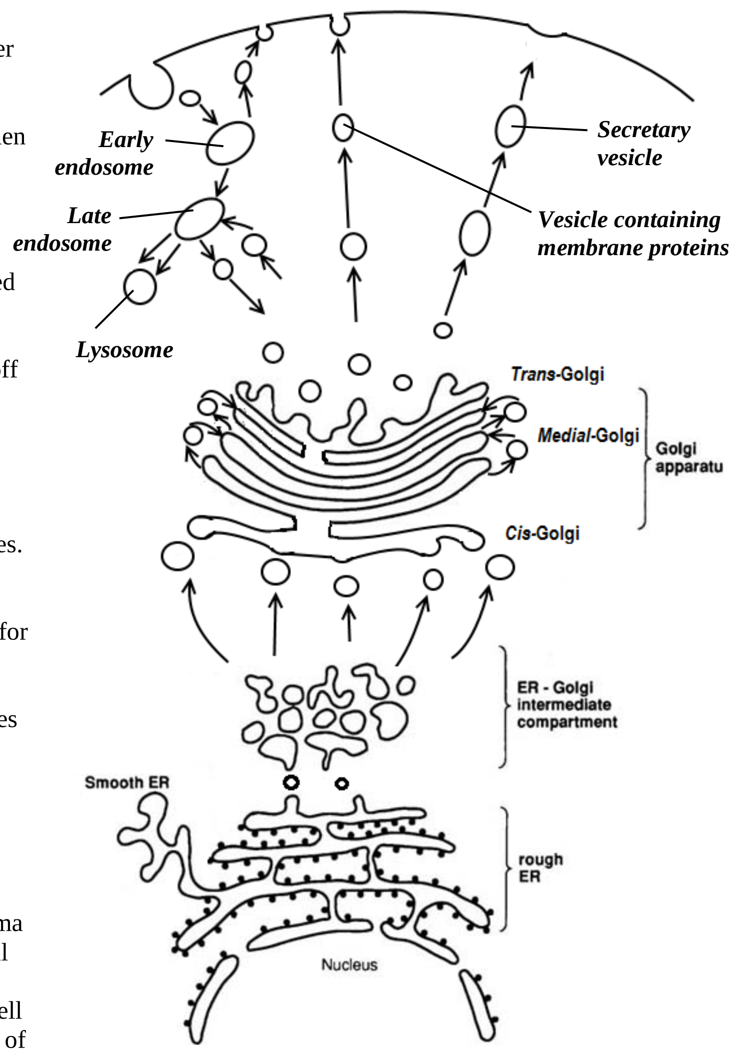
● After further modification within the *medial*-cisternae, coated vesicles bud (pinch) off the swollen ends of the *medial*-cisternae and fuse with the ends of *trans*-cisternae for further transformation.

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

(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.



ENDOPLASMIC RETICULUM

This is a membrane-bound organelle which forms a network of tubules, vesicles and cisternae within eukaryotic cells, except mammalian red blood cells.

TYPES OF ENDOPLASMIC RETICULUM

● Rough Endoplasmic Reticulum (RER), studded membrane-bound ribosomes.
● Smooth Endoplasmic Reticulum (SER), without ribosomes attached.

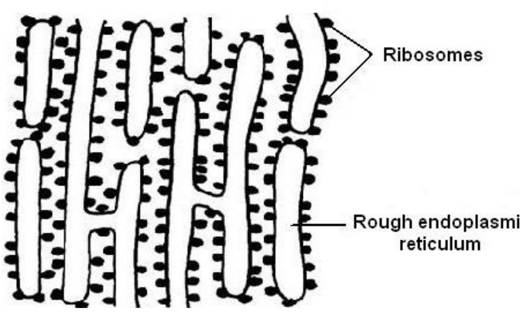
RER is more prominent in cells concerned with protein synthesis e.g. liver cells.
SER is prominent in cells concerned with the production of lipids

NOTE:
1. The rough and smooth endoplasmic reticulum can transform from one type to another, depending on especially the enzymatic needs of the cell.
2. The transformation happens through the embedding of proteins.

FUNCTIONS OF ENDOPLASMIC RETICULUM

Specific functions by RER	General functions by SER and RER	Specific functions by SER
● Production and processing of specific proteins at ribosomal sites, that are later exported ● Folds proteins into three dimensional shapes e.g. haemoglobin for further processing e.g. carbohydrates may be added. ● Transports ready proteins to the sites where they are required. ● Checks the quality of proteins formed, especially correct ordering and structure.	● Transporting proteins and carbohydrates to other organelles like lysosomes, Golgi apparatus, and plasma membrane. ● Form part of the cell's skeletal framework. ● Offer increased surface area for cellular reactions. ● Form the nuclear membrane during cell division.	● Synthesis of lipids and other steroids like cholesterol, progesterone and testosterone. ● Synthesis and repair of membranes by producing cholesterol and phospholipids, ● For metabolism of glycogen in the liver e.g. glucose-6-phosphatase enzyme in SER converts glucose-6-phosphate to glucose. ● Contains enzymes that detoxicate lipid-soluble drugs, alcohol and metabolic wastes from the liver. ● SER attaches receptors to cell membrane proteins in plant cells ● Sarcoplasmic reticulum regulates muscle contraction through storage and release of calcium ions.

STRUCTURE OF ENDOPLASMIC RETICULUM

Rough Endoplasmic Reticulum (RER)	Smooth Endoplasmic Reticulum (SER)
● RER is an extensive membrane network of **cisternae** (sac-like structures), which are held together by the cytoskeleton. ● A phospholipid membrane encloses a space, the lumen from the cytosol, which is continuous with perinuclear space. ● The surface of the rough endoplasmic reticulum is studded with ribosomes, which give it a rough appearance hence the name **rough endoplasmic reticulum**. ● A part of RER is continuous with the nuclear envelope 	● The SER is a folded structure composed of a network of interconnected disc-like sacs and tubules called **cisternae** which are held in their place by the cytoskeleton. ● The SER is bound by a phospholipid membrane enclosing a fluid-filled space known as **cisternal space** or **lumen**. ● The lumen or cisternal space is continuous with the perinuclear space. ● A part of SER is continuous with the nuclear envelope, some other part may be at the periphery of the cell. 

ADAPTATIONS OF ENDOPLASMIC RETICULUM

- The interconnected network provides the cell with skeletal framework.
- Forming an extensive network increases the surface area for metabolic reactions e.g. protein synthesis at RER.
- *The endoplasmic reticulum membrane compartmentalizes the cytoplasm (isolates lumen from cytosol), which:*

(i) Enables transporting soluble and well packaged substances to their **specific** destinations.
(ii) Prevents interference of different metabolic processes taking place in the cell at the same time.

- Contains a variety of enzymes for performing diver roles in cell metabolism.
- The SER is modified into sarcoplasmic reticulum storage and release of calcium ions.
- The membrane has a variety of proteins that offer unique properties including signal reception.
- The RER membrane has sites for attachment of many ribosomes for protein synthesis

LYSOSOMES

●These are tiny spherical sac-like structures surrounded by a single membrane containing **powerful** hydrolytic **enzymes**.
●They are mostly abundant in secretory cells e.g. epithelial cells, in phagocytic cells e.g. liver cells and kidney cells.
●Lysosomes are also referred to as **"suicide bags", "digestive bags", "cell garbage disposal system"**, etc.

STRUCTURE OF LYSOSOMES

●Irregular / spherical, sac-like structure enclosed by a single membrane, about 1 μm in diameter.
●A single lysosome contains over **50 different enzymes** known collectively as **acid hydrolases,** in an acidic medium (about pH 4.8 to 5).
●Lysosomal membrane has a protein complex that is highly **glycosylated** forming a continuous **glycoprotein layer**, whose structure consists of a **mucin-like** domain that resists break down by enzymes within the lysosome.

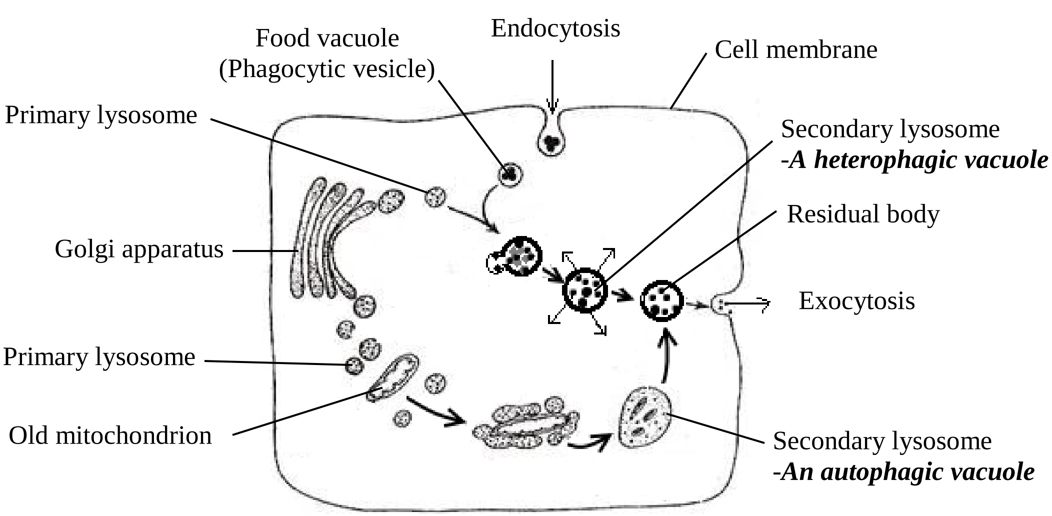
MAIN TYPES OF LYSOSOMES

●***Primary lysosome:*** This is the lysosome produced at the Golgi complex, containing many hydrolytic enzymes.
●***Secondary lysosome:*** This is the lysosome formed by the combination of a primary lysosome with a food vacuole, in which **lysis** takes place through the activity of **hydrolytic enzymes**.

FUNCTIONS OF LYSOSOMES

Function	Explanatory notes
1. Autophagy	**Primary lysosome** fuses with worn-out cellular components like mitochondrion to form **autophagic vacuole** in which digestion occurs by lysosomal enzymes into end products which leave by **diffusion** or with the aid of **specialized transporters** into cytoplasm while undigested materials (**residual body**) is released outside by **exocytosis**.
2. Heterophagy (Cellular digestion)	**Primary lysosome** fuses with food vacuole engulfed by **endocytosis** to form **digestive vacuole (heterophagic vacuole)** in which digestion occurs by lysosomal enzymes into end products which leave by **diffusion** or with the aid of **specialized transporters** into cytoplasm while undigested materials (**residual body**) is released outside by **exocytosis**.
3. Autolysis	Primary lysosome releases hydrolytic enzymes within a dead cell to digest the **whole** cell.
4. Development processes	●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.
5. 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.
6. Role in immunity	Leucocytes (WBC) digest foreign particles, bacteria and viruses enabled by lysosomes.
7. GERL system	Golgi, Endoplasmic Reticulum and Lysosome system regulates the secretory activities of the Golgi and ER as well as modification of secretory products.

ILLUSTRATION OF AUTOPHAGY AND HETEROPHAGY IN THE ANIMAL CELL



NOTE:
Endocytosis forms **endosomes** (membranes surrounding food particles) of various sizes:

1. **Pinocytosis** forms **vesicles** (less than 100nm in diameter)

2. **Phagocytosis** forms **vacuoles** (more than 100nm in diameter)

RIBOSOMES

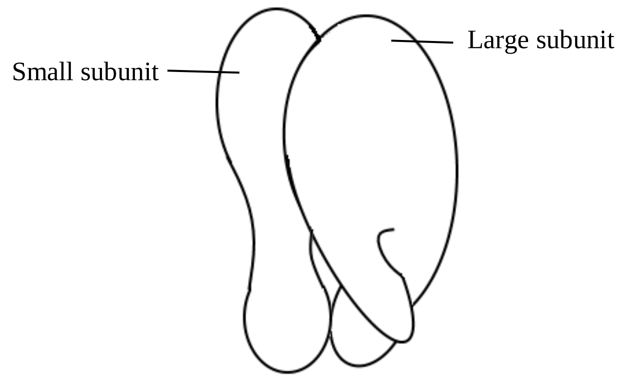
These are small (diameter of 20 nm -30nm), non-membranous particles made up of a large and small subunits, present in large numbers in all living cells.
Function: Site of protein synthesis.

- Ribosomes are made of large (protein) and small (rRNA) subunits.
- Ribosomes on rough endoplasmic reticulum form proteins for export out of the cell e.g. hormones, etc.
- Ribosomes that occur freely in the cytoplasm make proteins that remain with cytoplasm e.g. dissolve in solution or form structural cytoplasmic elements.
- Prokaryotes have 70S ribosomes (small subunit of 30S and large subunit of 50S) while Eukaryotes have mainly 80S ribosomes which are larger and more complex, each consisting of small (40S) and large (60S) subunit.

S stands for the Svedberg unit for sedimentation velocity

- The ribosomes share a core structure which is similar to all ribosomes despite differences in its size

STRUCTURE OF ONE RIBOSOME



MICROBODIES

Examples:
(i) **Peroxisomes**, which contain a variety of enzymes that rid the cell of toxic wastes e.g. catalase breaks down hydrogen peroxide, liver microbodies detoxify alcohol and fat-soluble drugs.

- Peroxisomes and lysosomes are similar in appearance, but differ in origin. Lysosomes are formed in the Golgi complex, whiles peroxisomes self-replicate using protein imported from the cytosol.

(ii) **Glyoxysomes**, which contain enzymes that degrade lipids into sugars during seed germination.

CILIA AND FLAGELLA

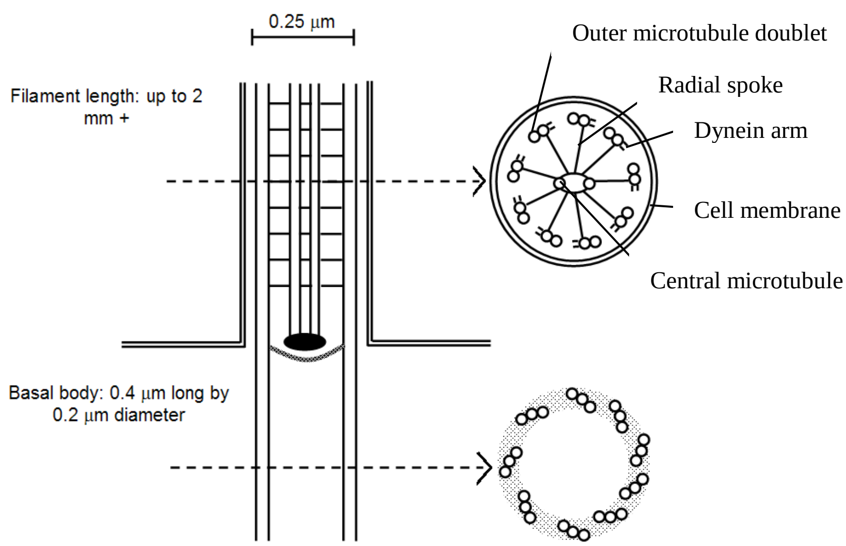
Cilia and flagella are structurally identical structures.

Cilia	**Flagella**
Numerous	Less in number
Short and hair-like organelle (about 10μm)	Long whip-like organelle (about 150μm)
Occur throughout the cell surface	Presence at one end
Beat in coordination	Beat independently
Show sweeping movement or pendular stroke	Undulatory movement

STRUCTURE OF CILIA AND FLAGELLA

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

Note:
Each centriole is made of nine triplets of microtubules arranged in a ring (9+0 pattern)



FUNCTIONS OF CILIA AND FLAGELLA

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

CYTOSKELETAL ELEMENTS

Cytoskeleton is the network formed by **microtubules, microfilaments** and **intermediate filaments**.
The **cytoskeleton** connects to every organelle and every part of the **cell membrane**, giving structural support and maintaining shape.

1. MICROFILAMENTS (ACTIN FILAMENTS)	**2. MICROTUBULES**
Structure: ●Two strands of **actin**, (a globular protein) twist around each other to form a **solid**, right-handed, long helical-shaped rod, about 5nm-9nm in diameter (***see figure next page***) ***Functions:*** ●They enable a dividing cell membrane to pinch off into two cells ●Are also involved in cell movement e.g. amoeboid movement, phagocytosis, pinocytosis, etc. ●Associate with **myosin** to cause muscle contraction. ●Support the cell membrane and maintain cell shape. ***Location:*** They nucleate at the plasma membrane, with the cell periphery (edges) having the highest concentration.	***Structure:*** ●Two alternating strands of ***alpha*-tubulin** and ***beta*-tubulin** (globular protein) bind together in a helical shape to form a **hollow**, straight cylinder with length of 200nm-25μm and diameter of about 25nm. (***see figure next page***) ***Functions:*** ●Serve as conveyor belts moving other organelles throughout the cytoplasm. ●Are the major components of cilia and flagella in cell motility ●They form spindle fibers during cell division. ●Give shape and mechanical support to the cell. ●Enable vesicles to move during cell wall formation in plants. ***Location:*** Found throughout the cytoplasm of all eukaryotic cells, forming part of **cytoskeleton** that gives structure and shape to cells.

3. INTERMEDIATE FILAMENTS

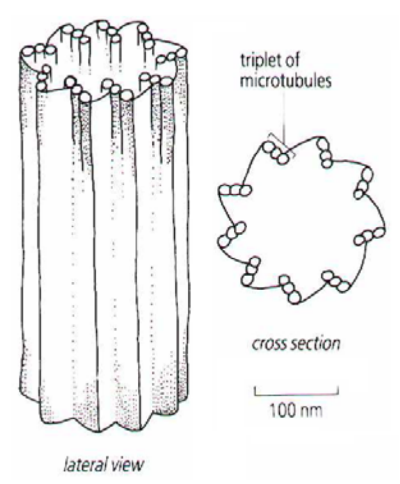
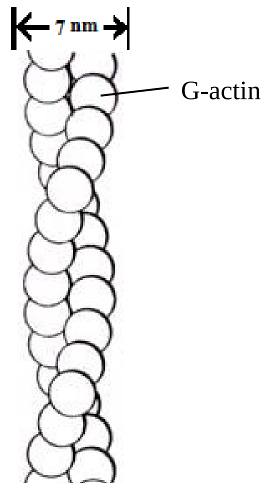
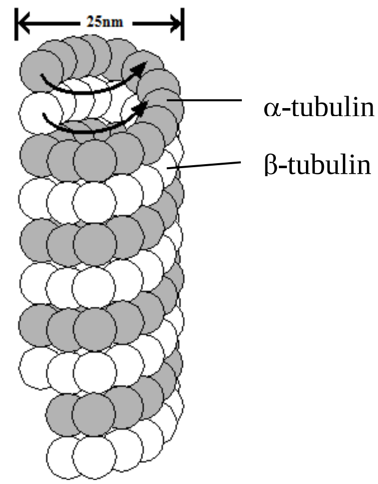
These are a broad class of fibrous proteins whose diameter ranges between 8nm-2nm.

Examples of intermediate filaments	**Functions of intermediate filaments**
(i) **Keratins** in animal epithelial cells (ii) **Desmin**, which integrates sarcolemma, Z-disc and nuclear membrane in sarcomeres of muscle cells. (iii) **Peripherin and neurofilaments** in neurons (iv) **Nuclear lamins** inside the nucleus, which attach the chromosomes to nuclear membrane and provide anchorage points for nuclear pores.	●They are tension-bearing elements that maintain cell shape and rigidity. ●They anchor in place several organelles, including the nucleus and desmosomes. ●They are involved in formation of the **nuclear lamina**, a net-like meshwork array that lines the inner nuclear membrane and governs the shape of the nucleus.

CENTRIOLES

Location: Are found only in animal cells, near the nucleus in the **centrosome** which serves as an organizing centre for microtubules. ***Structure:*** Two cylinders, held at right angle to each other, each about 0.3μm-0.5μm long and 0.24μm in diameter, made	***Functions:*** ●In animal cell division, centrioles organise microtubules to form spindle fibers which separate chromosomes. ●Cellular organization - centrosomes are involved in organizing microtubules, whose position determines position of organelles e.g. nucleus ●Ciliogenesis- In ciliated and flagellated organisms, the mother

of nine triplets of microtubules arranged in a ring in a **9+0 pattern**.	centriole which becomes the basal body determines the position of these organelles.

CENTRIOLE STRUCTURE	MICROFILAMENT	MICROTUBULE STRUCTURE
		

VACUOLES

●Plant vacuoles are large, sac-like structures in which a single membrane called **tonoplast** encloses a fluid called **cell sap**, containing water and various dissolved substances. ●In animal cells, vacuoles, when present are smaller in size.

Formation of plant vacuole

●A newly formed plant cell lacks sap vacuole. ●As the cell matures, vesicles that pinch off Golgi apparatus and RER enlarge into small vacuoles. ●Smaller vacuoles fuse together to form a large vacuole.

Functions of vacuoles

(i) The tonoplast isolates the vacuolar sap from the cytosol, enabling vacuolar pathway of water.
(ii) Vacuoles in some flowers have coloured pigments that give petals bright coloured for attracting pollinators.
(iii) Serve as stores of reserve food, secretory products or waste product.
(iv) It stores salts, nutrients, minerals, pigments, proteins etc.
(v) It maintains cell turgor by osmotic uptake of water since vacuolar sap has a higher solute concentration than cytosol.
(vi) In meristematic cells, vacuoles bring about growth by initiating cell elongation.
(vii) Serve as stores of waste products like tannins, which are excreted when leaves fall.
(viii) In fresh water protozoans like amoeba and paramecium, contractile vacuoles regulate the water content of cells.
(ix) Food vacuoles formed by phagocytosis (endosomes) enable bulk intake of food.

TOPICAL QUESTIONS FOR PAPER 2 (P530/2)

Qn. 1. (a) Distinguish between **cell organelle** and **cytoplasmic inclusion** (3 marks)
(b) Describe the fine structure of the following:
(i) Golgi complex (ii) Nucleus (iii) Mitochondrion (12 marks)
(c) How are the structures in (b) above suited for functioning? (5 marks)

Qn. 2. (a) Describe the **structure** of any two named **cytoskeletal elements**. (10 marks)
(b) State the **roles** of each of the named cytoskeletal elements in (a) above to cells. (10 marks)

Qn. 3. (a) What are the main ideas of the **cell theory**?
(b) Discuss possible exceptions to the **cell theory.**
(c) Explain how **surface area to volume ratio** and **nucleo-cytoplasmic ratio** influence cell size.

Qn. 4. (a) Describe the functioning of Golgi apparatus in animal cells.
(b) Explain the role of lysosomes in animal cells.

Qn. 5. By stating differences in structure and function, distinguish between
(a) Rough endoplasmic reticulum and Golgi apparatus
(b) Cell wall and cell membrane
(c) Cilia and flagella

Qn. 6. Give an account of
(a) Fluid mosaic model of cell membrane structure (6 Marks)
(b) The different functions of the membranes of cells. How do these functions relate to the structure of the membrane? (14 marks)

Qn. 7. (a) Describe the structure of plant cell wall (10 Marks)
(b) Compare the structures of plant cell wall and plasma membrane (07 Marks)
(c) How is the plant cell wall suited for functioning? (3 Marks)

Qn. 8. (a) Describe the structure and function of TWO eukaryotic membrane-bound organelles other than the nucleus.
(b) Prokaryotic and eukaryotic cells have some non-membrane bound components in common. Describe the function of TWO of the following and discuss how each differs in prokaryotes and eukaryotes:
(i) DNA (ii) Cell wall (iii) Ribosomes.
(c) Explain the **endosymbiotic theory** of the origin of eukaryotic cells, and discuss one example of evidence.

Qn. 9. Membranes are essential components of all cells.
(a) Identify THREE macromolecules that are components of the plasma membrane in a eukaryotic cell and discuss the structure and function of each.
(b) Explain how membranes participate in each of the following biological processes
(i) Muscle contraction (ii) Fertilization of the egg (iii) Chemiosmosis production of ATP

Qn. 10. Describe the structural arrangement and function of the membranes associated with each of the following eukaryotic organelles:
(a) Mitochondrion (b) Endoplasmic reticulum
(c) Chloroplast (d) Golgi apparatus

Qn. 11. (a) Describe the structure of a **generalized eukaryotic** plant cell.
(b) Indicate structurally how a **non-photosynthetic prokaryotic cell** differs from a generalized eukaryotic plant cell.

Qn. 12. Membrane are important structural features of cells.
(a) Describe how membrane structure is related to the transport of materials across a membrane.
(b) Describe the role of membranes in the synthesis of ATP in either cellular respiration or photosynthesis.

Qn. 13. (a) Compare the structure of chloroplast and mitochondrion in relation to function.
(b) Eukaryotic cells have intracellular and extracellular components. State the functions of one named extracellular component.

HISTOLOGY (Study of tissues)

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

Characteristics of tissues

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

ANIMAL TISSUES

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

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

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

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

EPITHELIAL TISSUE

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

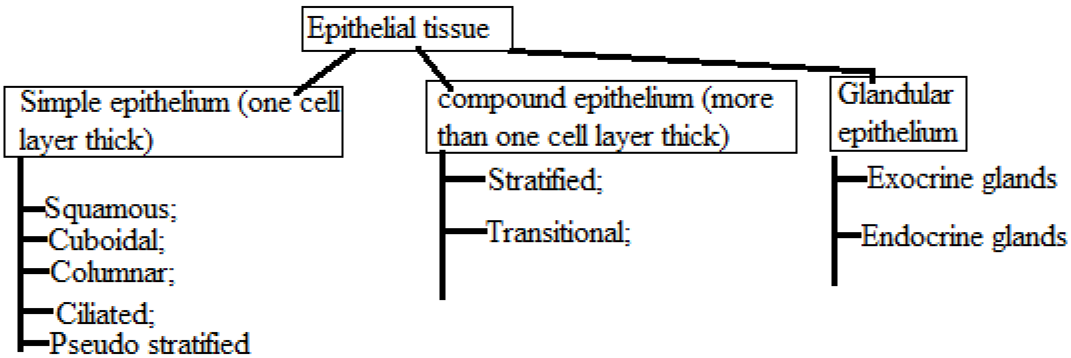
Characteristics of epithelial tissue

1. Epithelial tissue consists of **tightly packed cells** that are firmly attached to each other with little intercellular material between them. Epithelial cells are held firmly together by small amounts of carbohydrate cementing substances and by special intercellular junctions between the cells.
2. The bottom of epithelial cells rest on a **basement membrane** composed of a network of fibres which include collagen. The portion of epithelial cells attached to the basement membrane is called the **basal surface,** the opposite end facing the external environment or the lumen of the body cavity is called the **apical surface/free surface.**
3. There are **no blood vessels** in the epithelial tissues hence the tissue lacks vascularity. As the epithelial cells are not supplied with blood vessels, **they rely on diffusion** of nutrients and oxygen from lymph vessels which run through nearby intercellular spaces. However, nerve endings may occur in the epithelium.

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

CLASSIFICATION OF EPITHELIAL TISSUES

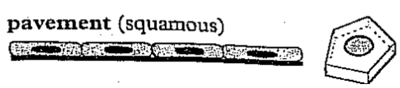
Epithelial tissues are classified according to the number of cells/layers and the shape of the individual cells.



SIMPLE EPITHELIAL TISSUES

A. **Simple squamous/pavement epithelium**

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



Functions

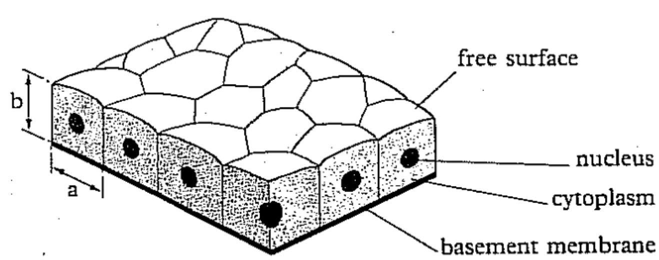
- Diffusion of materials
- Exchange of gases

Adaptations

i. Thin flattened cells to reduce the distances across which materials diffuse.
ii. Possesses smooth lining to allow relatively friction free passage of fluids and materials through the hollow structures.

B. **Simple cuboidal epithelium**

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



Distribution

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

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

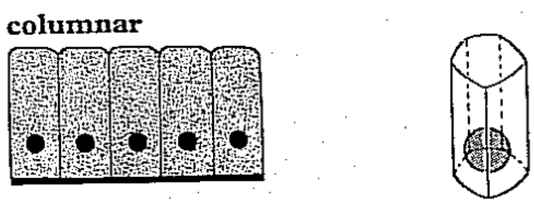
The functions include: **Protection, excretion, absorption and secretion**

Adaptations

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

C. **Simple columnar epithelium**

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



Distribution

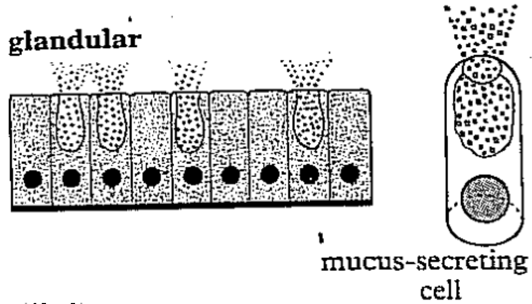
- ✓ Lining of the stomach, small intestines, gall bladder, and kidney ducts.
- ✓ Lining of the gastric glands, intestinal glands, mammary glands, thyroid glands, salivary glands.

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

Adaptations

i) Possess fingerlike projections called microvilli which increase the surface area for absorption such as digested food in the intestines.
ii) Possess mucus secreting cells which secrete mucus. The mucus protects the gastric walls from hydrochloric acid and digestive enzymes.
iii) Mucus from goblet cells also lubricates the passage of food in the intestines.

Illustratiion of secretory columnar/glandular epithelium



D. Ciliated epithelium

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

Distribution

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

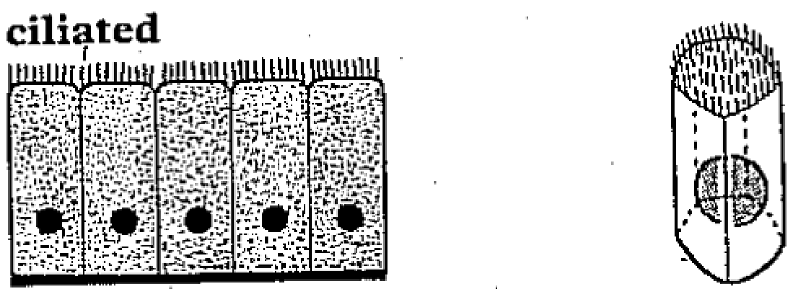
Functions

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

Adaptations

i) Interspersed with goblet cells which secrete mucus to protect the lining of the gut from enzyme and acidic action.
ii) Possess cilia which set up currents that move materials from one direction to another.
iii) Possess goblet cells which lubricate the passage.

Illustration



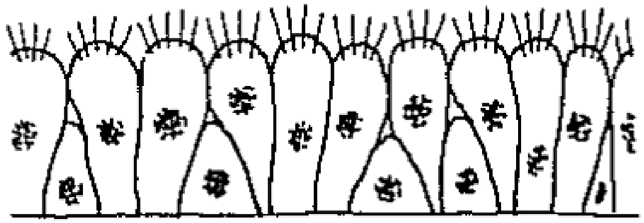
E. Pseudostratified epithelium

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

Most cells are columnar, thus usually named pseudostratified columnar epithelium. Where the cilia appear at the free surface (trachea, bronchi, bronchioles), it is called pseudo stratified columnar ciliated epithelium.

Pseudo stratified epithelium also lines the urinary tract and ducts of large glands (non-ciliated pseudo stratified).

Pseudo stratified ciliated columnar



COMPOUND EPITHELIAL TISSUES

1. STRATIFIED EPITHELIA

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

a) **Stratified squamous epithelium**

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

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

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

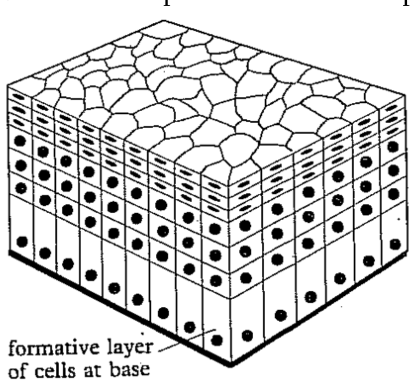
b) Stratified cuboidal epithelium

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

c) Stratified columnar epithelium

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

ILLUSTRATION



2. TRANSITIONAL EPITHELIUM

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

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

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

Adaptations of the transitional epithelium to its function

- **i)** By changing its shape, the transitional epithelium allows expansion of the organ such as the urinary bladder. This increases the volume of the organ.
- **ii)** Transitional epithelium is composed of many layers of cells making it impermeable to water from blood to urine.
- **iii)** Due to its thickness, it prevents urine from escaping to the surrounding tissues.

GLANDULAR EPITHELIUM

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

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

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

a) Merocrine glands

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

b) Apocrine glands

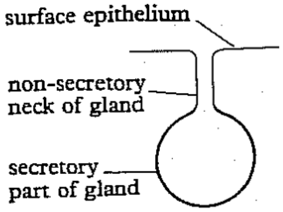
Here, the glandular epithelia shed their secretion by the top part of the cell loaded with the secretion breaking away from the rest of the cell eg mammary glands. The cell loses part of the cytoplasm while releasing its secretion.

c) Holocrine glands

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

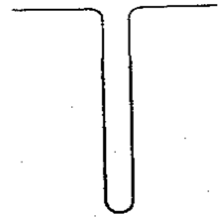
An epithelium containing goblet cells is called a mucus membrane. Multicellular exocrine glands exist in various forms which include;

1. Simple saccular/alveolar gland



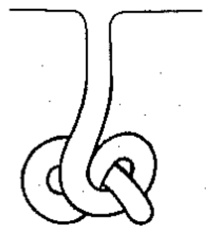
Simple saccular gland e.g. mucus glands in the skin of the frog and other amphibia.

2. Simple tubular gland-



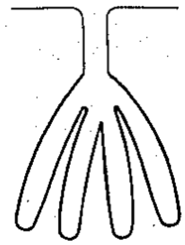
Simple tubular gland e.g. crypts of Lieberkühn in the wall of the mammalian small intestine.

3. Simple Coiled tubular gland



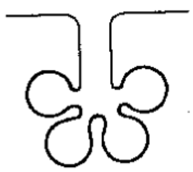
Coiled tubular gland e.g. sweat glands in the skin of humans

4. Simple branched tubular gland-



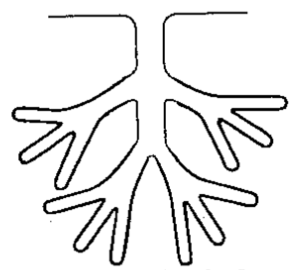
Simple branched tubular gland e.g. Brunner's glands in the wall of the mammalian small intestine and gastric glands in the wall of the

5. Simple branched saccular gland-



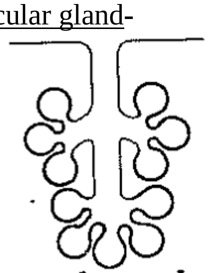
Simple branched saccular gland e.g. oil- secreting sebaceous glands in mammalian skin.

6. Compound tubular gland-



Compound tubular glands e.g. salivary glands.

6. Compound saccular gland-



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

Functions of the epithelial tissue

1. **Protection;** Epithelial tissue basically protects the underlying tissue from injuries by chemicals, pressure abrasion and infection.
2. **Secretion;** A number of epithelial cells are modified to produce secretions such as mucus, hormones etc.
3. **Excretion;-** The epithelial cells of the kidney tubules and sweat glands remove excessive and toxic metabolic wastes from the body thus helping the body in excretion.
4. **Absorption;-** Cuboidal and columnar epithelia are modified for absorption.

5. **Exchange of materials and gases-** Squamous epithelium is extremely thin and flattened promoting exchange of materials and gases by diffusion such as the alveoli of the lungs.
6. **Sensory-** epithelia bearing sensory cells and nerve endings are specialized to receive stimuli as in the skin and retina of the eye.
7. **Movement of materials-** Epithelia may be modified to aid movement of materials e.g Ciliated columnar epithelium lining the inside of the oviduct, ventricles of the brain, spinal canal and respiratory passages bears numerous cilia at their free surface. These are associated with mucus secreting goblet cells producing fluids in which the cilia beat up rhythmically setting up currents which move materials from one location to another.

CONNECTIVE TISSUES

Connective tissues are derived from the embryonic mesoderm.

Functions of connective tissues

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

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

- **Connective tissue proper** which is further divided into **loose** and **dense connective tissue**.
- **Special connective tissues** which include; **cartilage**, **bone** and **blood**. Cartilage and bone form the **skeletal tissue**.

LOOSE CONNECTIVE TISSUES

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

Areolar connective tissue

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

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

I) Collagen fibres

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

II) Elastic fibres

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

The cells within the matrix include;

a) Fibroblasts

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

b) Macrophages/histocytes

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

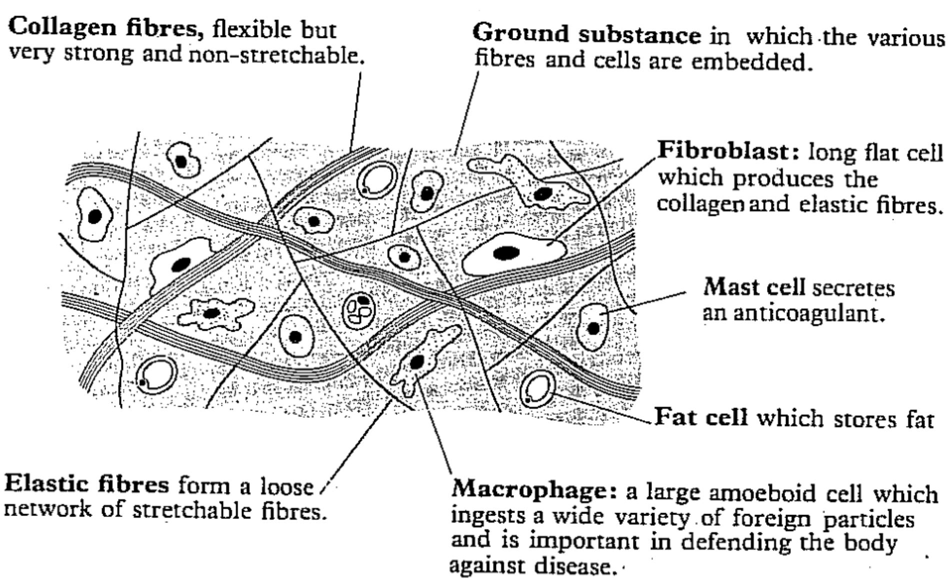
c) Mast cells

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

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

d) Fat cells

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



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

Functions of the areolar connective tissue

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

Adipose tissue

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

Recticular connective tissue

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

DENSE (FIBROUS) CONNECTIVE TISSUE (DCT)

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

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

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

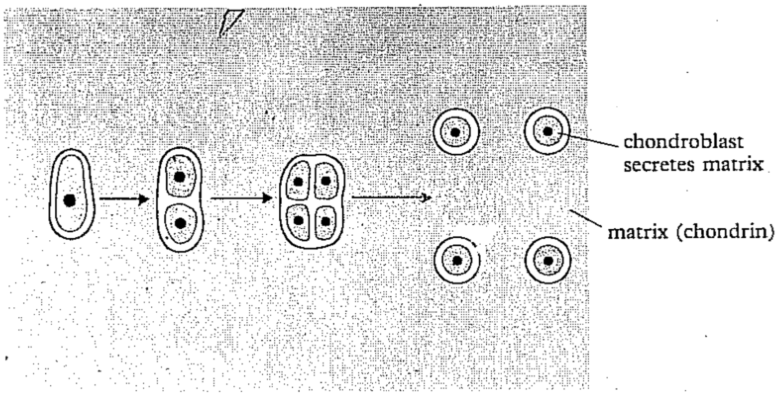
SPECIAL CONNECTIVE TISSUES

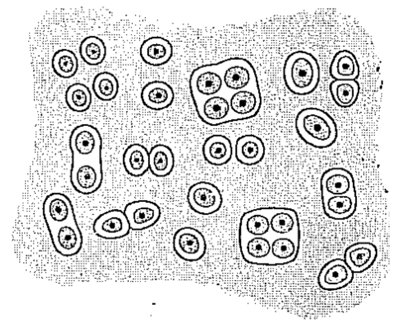
SKELETAL TISSUES

CARTILAGE/GRISTLE

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

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





Hyaline cartilage as it appears in a microscopical preparation.

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

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

Types of cartilage

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

Hyaline cartilage

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

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

Yellow elastic cartilage

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

It is located in the external ear, in the epiglottis and cartilages of the pharynx

White fibrous cartilage

In addition to chondrocytes in the matrix, there are large bundles of densely packed collagen fibres. This gives the tissue a greater tensile strength than hyaline cartilage as well as a small degree of flexibility.

It is located in the discs between adjacent vertebrae which provide a cushioning effect and the ligamentous capsules surrounding the joints.

BONE

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

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

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

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

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

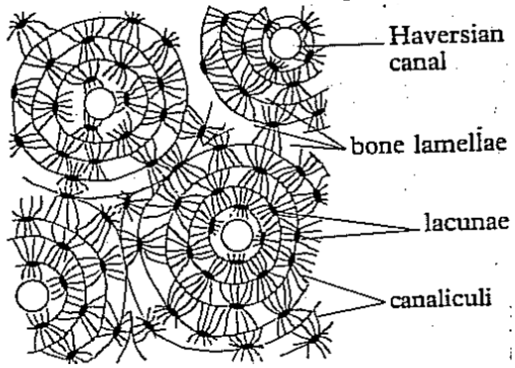
Types of bone

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

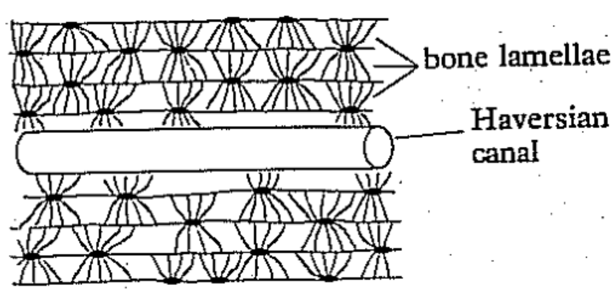
Compact bone/dense bone

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

A transverse section of a compact bone



Longitudinal section of a compact bone



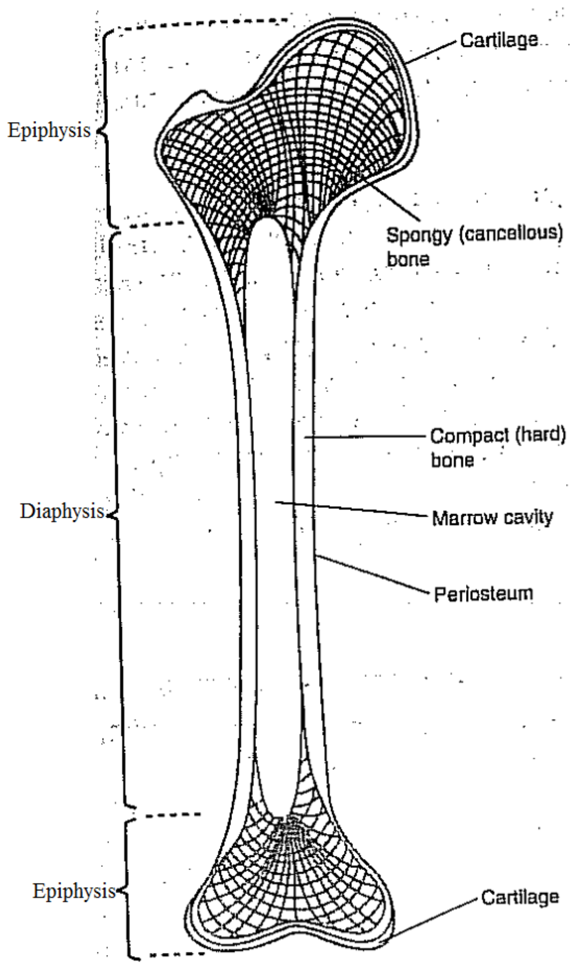
Spongy/cancellous bone

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

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

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

Longitudinal section through a Long bone



The development of bone (ossification)

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

Intramembranous ossification

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

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

Endochondral ossification

Endochondral ossification is the process of replacement of cartilage by bone. The skeleton of the vertebral embryo consists of mainly hyaline cartilage. Each cartilage element is surrounded by a layer of dense connective tissue, the perichondrium.

Ossification of bones (such as the long bones of the arms and legs) begins when blood vessels penetrate the perichondrium of the cartilage midway along the shaft/diaphysis of the cartilage model.

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

A primary ossification centre appears inside the shaft and is progressively invaded by a proliferating number of blood vessels and osteoblasts. The matrix of the cartilage tends to become calcified by deposition of calcium and phosphate, but is eroded by the osteoclasts leaving spaces which eventually fuse to form the **marrow cavity.**

Working in small groups, osteoclasts tunnel through the bone leaving cavities which are invaded by blood capillaries and new bone forming osteoblasts. Within the tunnel, osteoblasts lay down a new bone matrix in concentric rings forming an arrangement called haversian system.

Cartilage continues to grow at either end producing an increase in length. Most of the cartilage is later replaced by a spongy bone.

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

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

Adaptations of bone to its function

a) A tough fibrous layer of dense connective tissue called periosteum provides a tough and hard covering that surrounds the bone and protects the inner cells.
b) Bundles of collagen fibres from the periosteum penetrate the bone giving more mechanical strength, providing an intimate connection between the underlying bone and the periosteum and acting as a firm base for insertion of tendons, which contribute to movement and locomotion.
c) Osteoblasts are arranged in concentric rings around a series of haversian canals in compact bone thus lay down the matrix in a similar rigid and dense regular pattern to provide uniform mechanical strength.
d) Bone lamellae contain numerous lacunae containing living bone cells called osteoblasts which secrete the matrix of the bone.
e) Mature less active osteoblasts called osteocytes can be reactivated quickly regaining the structure of active osteoblasts and depositing bone matrix, when structural changes in bone are required.
f) Bone cells are embedded in a firm bone matrix which is rendered hard by deposition of calcium salts and other inorganic ions.
g) Bone cells called osteoclasts responsible for dissolving of the matrix as it is laid down enable reconstruction and remodeling of the bone during endochondral ossification.
h) An artery, a vein and a lymph vessel pass through a haversian canal of a compact bone allowing the passage of nutrients, respiratory gases and metabolic wastes towards and away from the bone cells.

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

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

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

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

Differences between a cartilage and bone

Cartilage	Bone
No process extended from each lacuna into the matrix.	Lacuna possesses canaliculi that extend into the matrix.
No blood vessels and nerves in the tissue.	Blood vessels and nerves run through the haversian canal.
Exchange of material between chondrocytes occurs by diffusion.	Osteoblasts exchange materials by help of blood capillaries passing through the canaliculi into the lacunae.
Elastic and compressible	Relatively incompressible as the matrix is highly composed of minerals e.g calcium ions, magnesium ions.
Matrix is relatively semi-transparent with hyaline cartilage and semi opaque in yellow elastic cartilage.	Matrix is opaque
The matrix is not calcified.	Matrix is calcified with greater quantities of Mg^{2+}, Na^{+}, Ca^{2+} etc.
No concentric layers of lamellae and no haversian canals present.	Consist of concentric layers of lamellae surrounding the haversian canal.
Rather inactive.	An active tissue with metabolic activity.
Matrix secreting cells are called chondroblasts.	Matrix secreting cells are called osteoblasts.
It is differentiated into hyaline, white fibrous and yellow elastic cartilage.	It is structurally differentiated into compact and spongy bones
It is flexible due to relatively soft and flexible matrix called chondrin.	It is rigid due to solid matrix called osteon.
It is less strong.	It is stronger.
Chondroblasts are randomly scattered in the matrix and occur in singles, pairs or fours.	Osteoblasts are in concentric layers around the haversian canal.
It is mostly found in areas where cushioning is required.	It is located in areas where maximum support is needed.

MUSCLE TISSUE

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

Basic structure of a muscular tissue

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

VOLUNTARY/ SKELETAL /STRIATED OR STRIPED MUSCLE

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

Distribution of skeletal muscles

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

Gross structure of a skeletal muscle

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

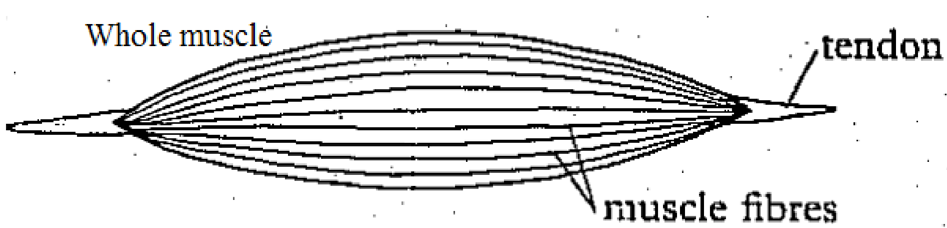
The skeletal muscle is attached to a bone in at least two places namely; the **origin**, a fixed non-moveable part of the skeleton and the **insertion**, a moveable part of the skeleton.

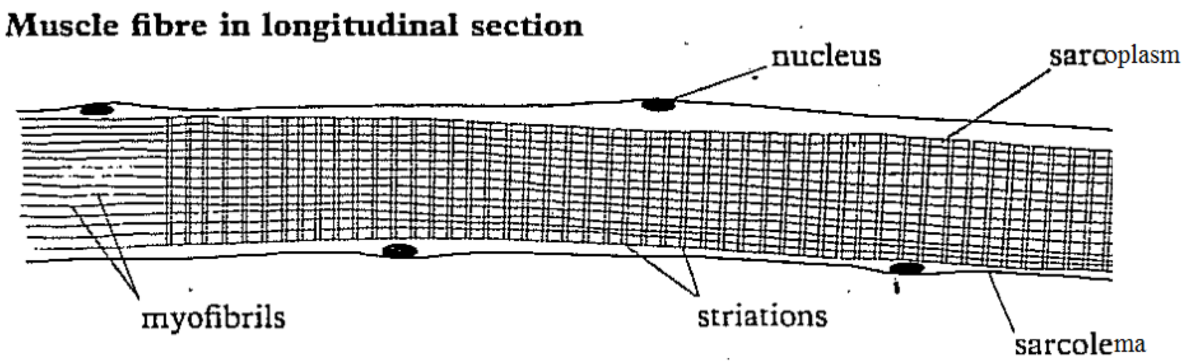
Attachment is by a means of tough relatively inelastic tendons made up of almost entirely collagen fibres. At one end, the tendon is continuous with the outer covering of the muscle while the other end is of the tendon combines with the outer layer of the bone called **periosteum** and forms a very firm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

Histology of a striated muscle (skeletal muscle)

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

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





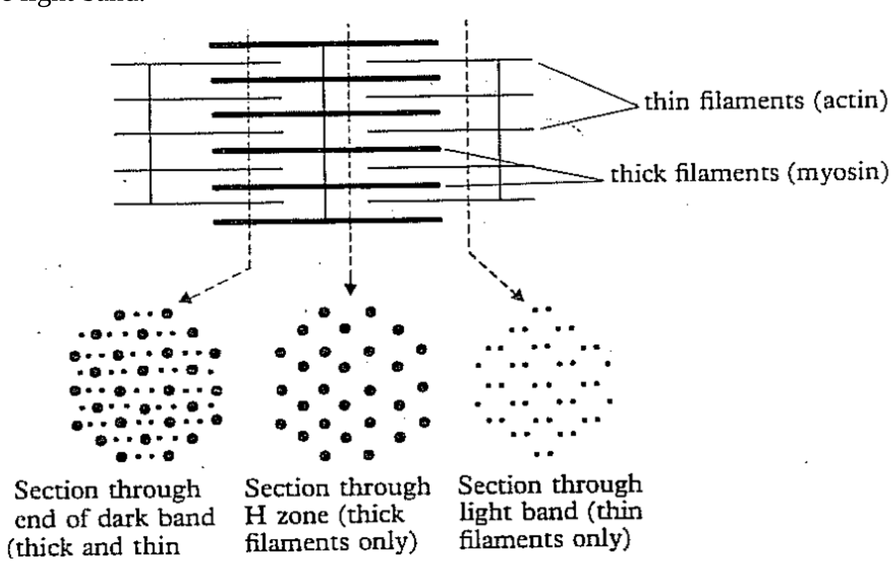
Fine structure of a striated muscle

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

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

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

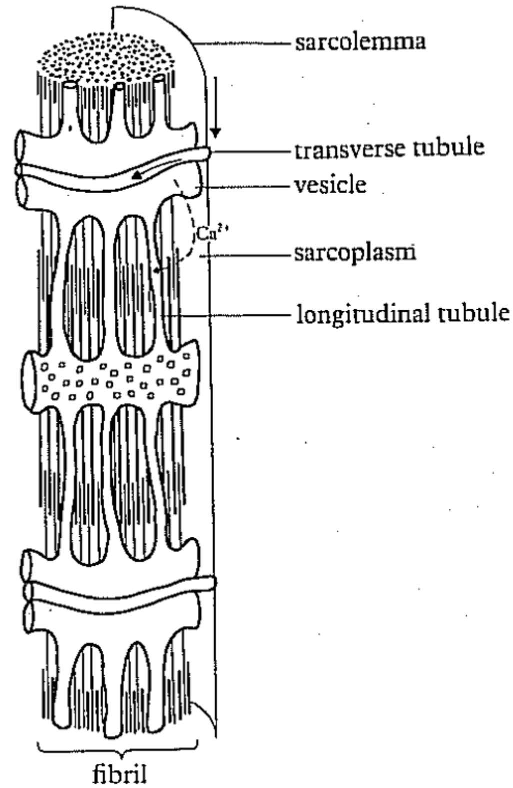
The darker segments on either side of the H- zone are due to both thick myosin and thin actin filaments **overlapping**. The H-zone consists only thick myosin protein filaments. The thin actin filaments alone are found in the light band.



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

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

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



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

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

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

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

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

VISCERAL/INVOLUNTARY/UNSTRIATED/UNSTRIPED/SMOOTH MUSCLE

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

Innervations and activity of the smooth muscle

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

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

Functions of the smooth muscle

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

ii. The pyloric sphincter controls passage of food from the stomach to the duodenum.
iii. Small sphincter muscle surrounds some blood vessels to control the distribution of blood and regulation of blood pressure.
iv. Control movement of materials with the body visceral organs.

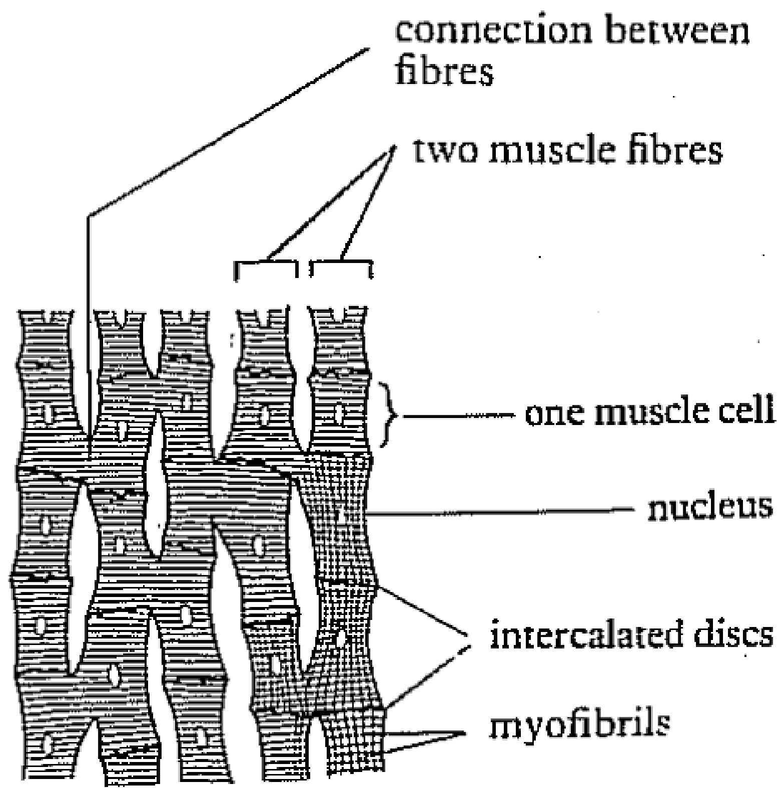
CARDIAC MUSCLE

It is found only in the heart.

The structure of a cardiac muscle

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

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



- Cardiac muscle is myogenic meaning that the contractions are developed within the muscle.
- The rate of contraction can be influenced by the autonomic nervous system.
- Interconnections between the fibres (intercalated discs) ensure a rapid and uniform spread of the excitation.
- Have rhythmic rapid contractions and relaxation with a long refractory period and so do not fatigue as contraction is not sustained.
- Need a constant supply of large amounts of energy.

- A small number of cardiac muscle fibres and a few nerve endings form the Sino atrial node (SAN) located near the opening of the vena cava which stimulates heart beat on their own.

Adaptations of the cardiac muscle to its function

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

A comparison of voluntary, involuntary and cardiac muscles (similarities and differences)

Feature	Striated muscle	Smooth muscle	Cardiac muscle
Names	Striated, striped, voluntary muscle	Unstriated, unstriped, smooth, involuntary, non-striated muscle	Heart muscle, cardiac muscle
Specialization	Most highly specialised	Least specialised	More specialised that smooth muscle
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	Interconnected to form a network.
Nucleus	Multinucleated myofibrils with peripherally located nucleus.	Uninucleated 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 but less mitochondria.	Numerous large mitochondria
	Prominent smooth endoplasmic reticulum forming a network of tubules. T- System well developed.	Individual tubules of smooth endoplasmic reticulum.	Poorly developed SER consisting of a network of tubules.

	Glycogen granules and some lipid	Glycogen granules present.	Glycogen granules present.
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 the voluntary nervous system.	Under control of the autonomic nervous system.	Myogenic, but rate of contraction can be influenced by the autonomic nervous system.
Contractions	Powerful rapid contraction with short refractory period (rest period).	Shows sustained slow and rhythmic contractions and relaxation with a long refractory period.	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 the walls of intestines of genital, urinary and respiratory tracts, in walls of blood vessels.	Only in the walls of the heart.
Energy	Large amount of energy needed at once.	Much energy needed but constant supply required.	Needs a constant and good energy supply.
Sarcolemma	Present	Absent	Present
Mode of working	Voluntary	Involuntary	Involuntary

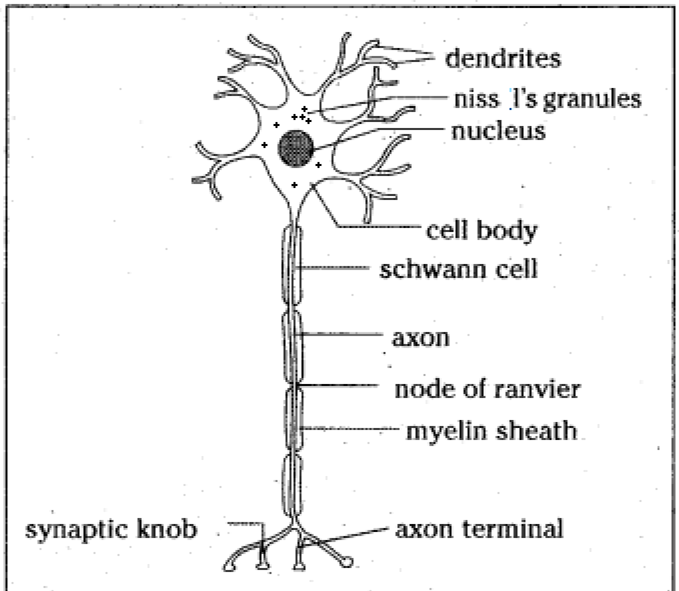
NERVOUS TISSUE

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

Structure of a neuron

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

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



Nerve cell

General functions of the parts of a neuron

1. Cell body; this consists of a nucleus surrounded by a mass of cytoplasm. The nucleus controls all activities of the neuron.

2. Axon; this is one or more long cytoplasmic extensions running from the cell body. Axons carry impulses over long distances in the body. Each axon is filled with cytoplasm called **axoplasm**.

3. Myelin sheath; this is a fatty material that covers the axon. The myelin sheath is secreted by cells called **Schwann cells**. The myelin sheath insulates the axon and speeds up transmission of impulses. It also protects the axon from any injuries especially which may be as a result of contraction from muscles.

4. Dendrites; these are fine structures on the neuron that link up nerve cells to form a complex network of communication.

5. Schwann cell; this is a cell which secretes the myelin sheath.

6. Nissl's granules; these are groups of ribosomes responsible for protein synthesis.

7. Node of Ranvier; this is the space on the axon between two adjacent myelin sheaths. It speeds up nervous transmission.

8. Cytoplasm; this is a site for chemical reactions in the neuron.

9. Dendrone; it is a branch through which impulses are transmitted to the body.

POLARITY OF NEURONES

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

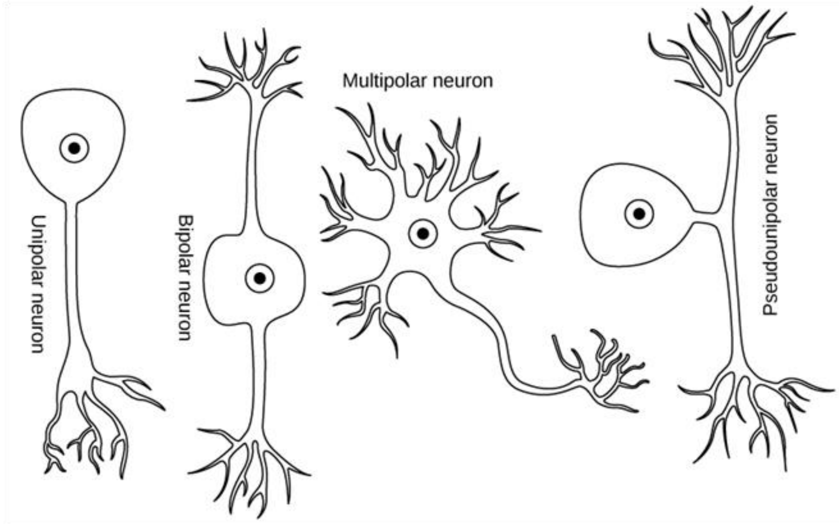
Unipolar:-It is a neuron with the axon as the only large branch from the cell body e.g arthropod motor neuron.

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

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

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

DIAGRAMS



Types of neurons/nerve cells

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

Diagram of a motor neuron

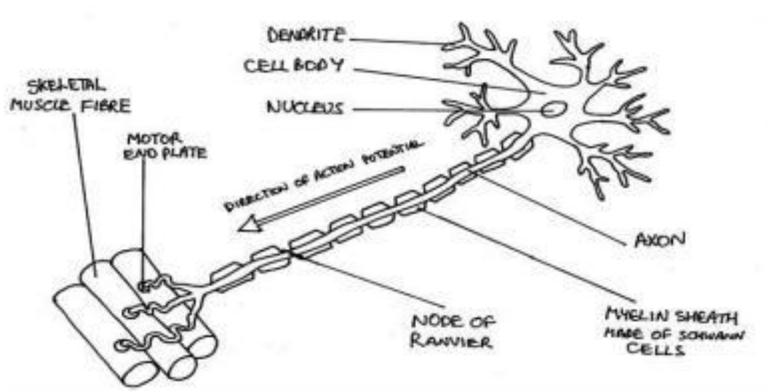


Diagram of a sensory neuron

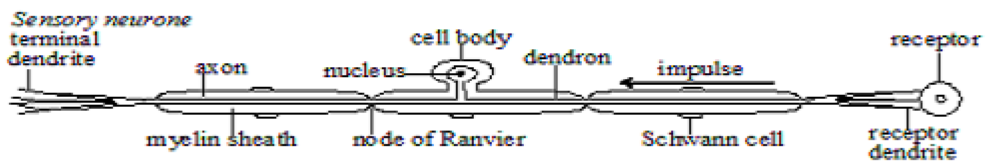
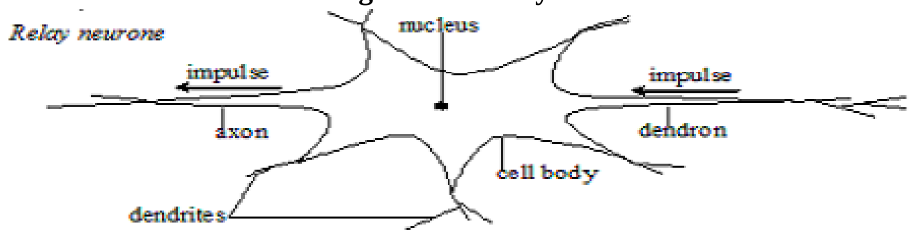


Diagram of a relay neuron



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

Assignment: *Compare the structure of a motor neurone and a sensory neurone.*

PLANT TISSUES

1) MERISTEMATIC TISSUE

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

Meristem

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

Types of meristems

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

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

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

SIMPLE PLANT TISSUES

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

2) PARENCHYMA

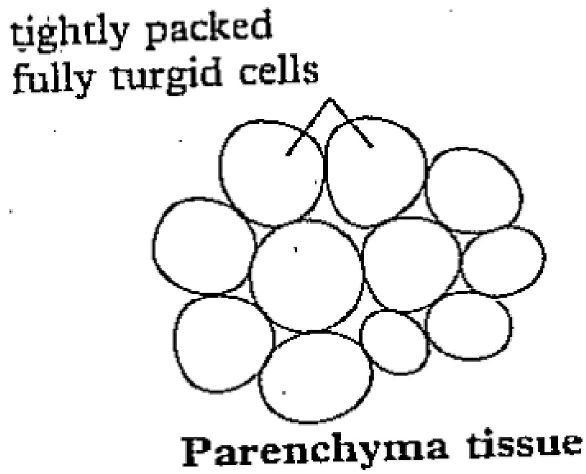
It consists of living cells which are relatively undifferentiated. The cells are either roughly spherical or elongated. The cells have thin cell walls made up of cellulose, pectins and hemicelluloses. The cells also have large sap vacuoles with dense but peripheral cytoplasm.

Parenchyma tissue is located in the cortex, pith and medullary rays of wood. It also serves as a packing tissue in xylem and phloem

Functions of the parenchyma tissue

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

Transverse section of a parenchyma tissue



Relationship between structure and function of the parenchyma tissue

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

r) Cell walls contain cellulose, pectins and hemicelluloses for support.
s) The cells have chromoplasts such as in petals to provide bright colour to attract insects for pollination.

Modified parenchyma

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

a) Epidermis/epidermal cells

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

Functions

- ✓ The basic function is to protect the plant body from desiccation and infection. This is achieved by secreting cutin and forms the cuticle that is impervious to water.
- ✓ Specialized epidermal cells (the guard cells) bound/guard the stomata and are important in opening and closing of stomata.
- ✓ Hair like structures on cuticle (epidermis) serve various purposes for example, root hairs increase on the surface area for absorption of water and mineral salts by the roots.
- ✓ Hooked hairs of climbing stems prevent them from slipping off their supports.
- ✓ Glandular cells on the cuticle secrete sticky substance that traps and kills insects and they may also secrete scent.
- ✓ The epidermal hairs of leaves reduce water loss from the plant as well as reflecting the sun's radiations.
- ✓ Being transparent, the epidermis allows passage of light in the mesophyll cells for photosynthesis.

Qn. ***State the various modifications of the epidermis to serve different functions***

b) Mesophyll cells (chlorenchyma)

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

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

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

Adaptations of the mesophyll to its function

i. Palisade mesophyll cells are column shaped with numerous chloroplasts in a thin layer of cytoplasm to carry out photosynthesis.
ii. Palisade mesophyll cells are tightly packed together forming a continuous layer that traps incoming light.

iii. The chloroplasts within the mesophyll cells can move towards light allowing them to be in the best positions to receive light.
iv. Spongy mesophyll cells are irregularly shaped hence fit together loosely leaving large air spaces to allow efficient gaseous exchange via the stomata.
v. The mesophyll cells contain numerous amyloplasts for storing starch.

c) Endodermis

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

Functions of the endodermis

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

Adaptations of the endodermis to its functions

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

d) Pericycle

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

Functions of the pericycle

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

Adaptations of the pericycle to its function

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

e) Companion cells

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

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

Functions of the companion cells

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

Adaptations of the companion cells to their function

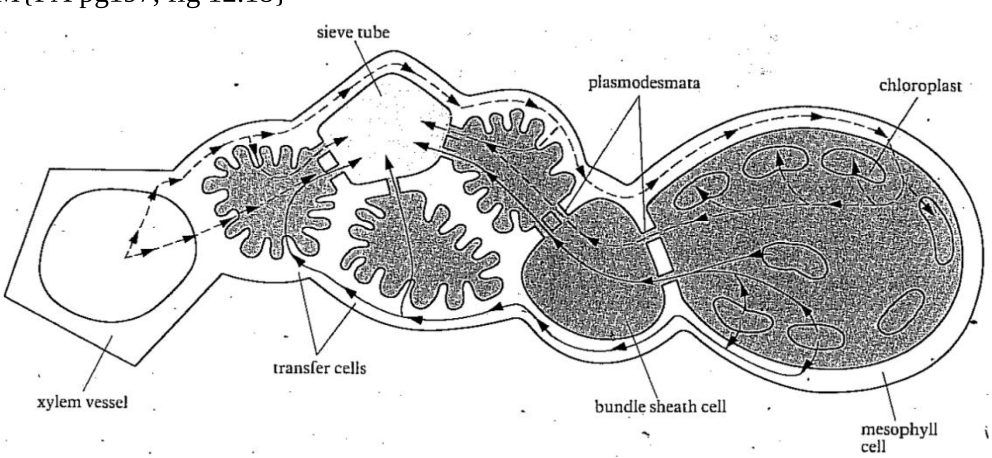
- Plasmodesmata connect sieve elements with companion cells allowing communication and exchange of materials between companion cells and sieve tube elements.
- Companion cells have large nucleus to effect metabolic activity of both companion cells and sieve tubes.
- Companion cells contain numerous mitochondria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

f) Transfer cells

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

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

DIAGRAM{FA pg197, fig 12.18}



Adaptations of transfer cells to their function

- ✓ Numerous internal projections of the cell wall and cell membrane increase the surface area and bring the cell membrane to closer association with the cytoplasm.
- ✓ Numerous mitochondria in their cytoplasm provide energy for active transport of organic solutes such as sugars from neighbouring cells.
- ✓ Have a large amount of starch granules which are broken down to glucose for aerobic respiration.

3) COLLENCHYMA

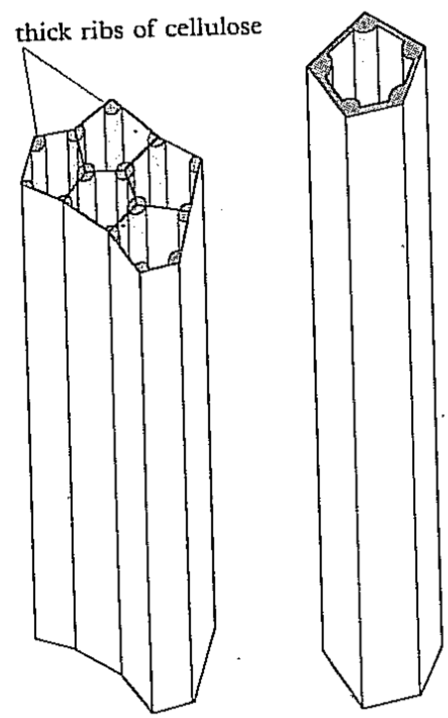
Collenchyma consists of living cells modified to give support and mechanical strength. The collenchyma is the first mechanical tissue to develop in the primary plant body.

Structure of collenchyma tissue

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

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

Diagram of Collenchyma tissue cells



Distribution and functions

Collenchyma cells which are relatively flexible provide support for plant organs allowing them to bend without breaking.

It is mainly found in young plants, herbaceous plants and in organs such as the leaves in which secondary growth does not occur.

In the leaves, they are mainly found in the midribs of dicotyledonous leaves.

They are also located at the periphery of the organs usually under the epidermis.

Adaptations of collenchyma to its function

- ✓ Deposition of extra cellulose at the corner of the cells leads to development of unevenly thickened cell walls to provide support and mechanical strength.

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

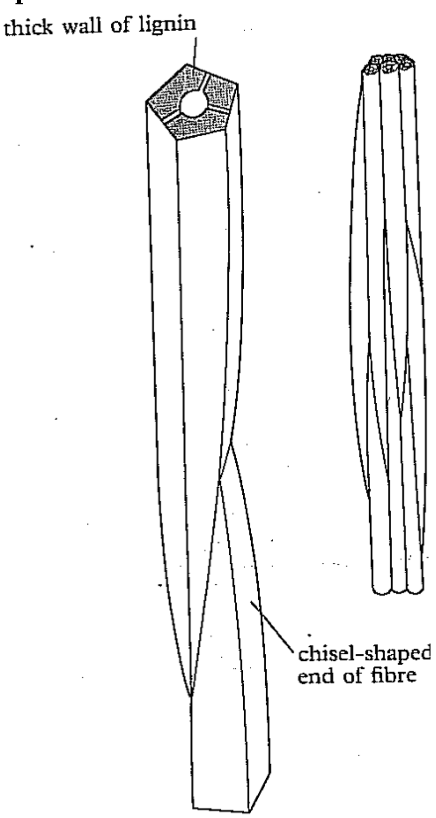
4) SCLERENCHYMA

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

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

<u>Fibres</u>

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



Sclerenchyma fibre

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

Adaptations of sclerenchyma to its function

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

XYLEM

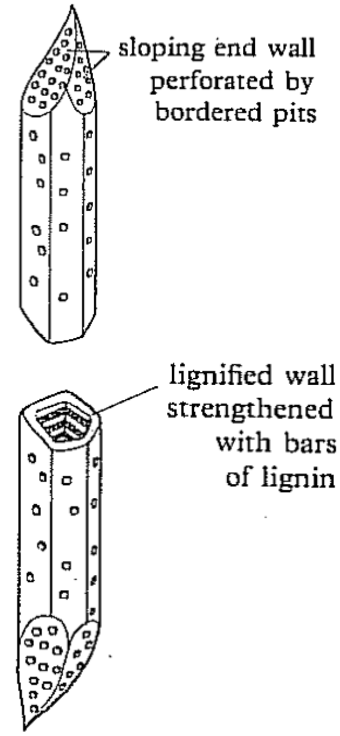
It is a vascular tissue with two main functions; conductance of water and mineral salts and providing mechanical support to the plant. The xylem consists of four types of cells; tracheids, vessels elements, parenchyma and fibres.

Tracheids

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

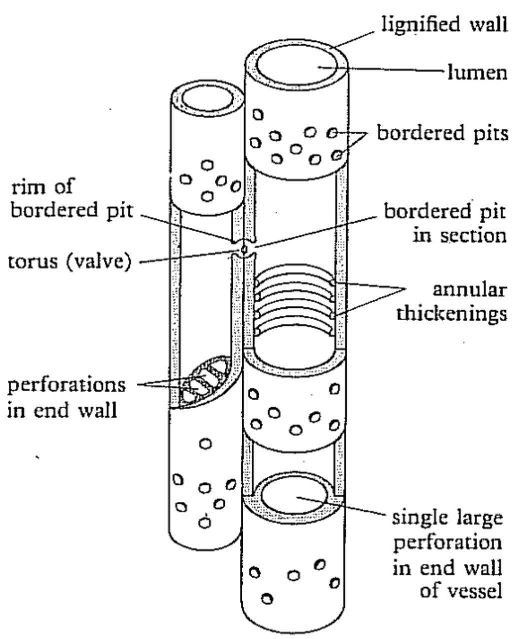
The tracheids represent the original primitive water conducting cells of vascular plants. They are the only cells found in the xylem of the more ancestral vascular plants and are the only conducting elements in conifers.

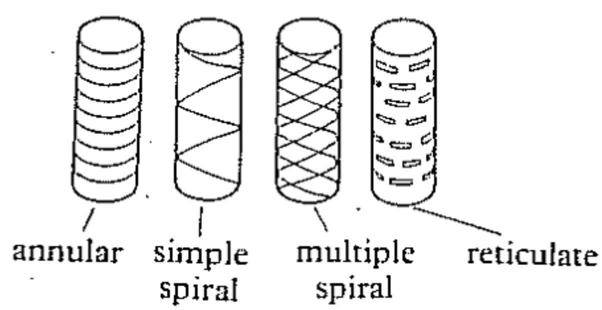
Structure of a tracheid



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

The xylem vessel elements of higher plants





Differences between vessels and tracheids

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

Protoxylem and metaxylem

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

NB:

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

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

Adaptations of xylem to its functions

1. Xylem vessels and tracheids consist of long cylindrical cells joined end to end, hence are continuous with each other ensuring continuous flow of water in a continuous unbroken column.
2. Endwalls of the xylem vessels are completely broken down to form continuous tubes that allow uninterrupted flow of water.
3. Tracheids are perforated with numerous cellulose bordered pits that allow water to pass from one cell to another in lateral directions.
4. During development, the protoplasmic contents of vessels and tracheids die and disappear leaving empty hollow lumens, permitting uninterrupted flow of water without obstruction by living content.
5. Impregnation of cellulose walls with lignin increases adhesion of water molecules to walls thereby facilitating the rise of water by capillarity.
6. Lignifications of walls confer rigidity preventing walls from collapsing under large tension forces set up by the transpiration pull.
7. Narrowness of lumens of vessels and tracheids increases the rise of water by capillarity.
8. Xylem fibres have extremely thick walls which are heavily lignified and with narrow lumens to provide additional mechanical strength and support to the xylem.

5) PHLOEM

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

Sieve tubes

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

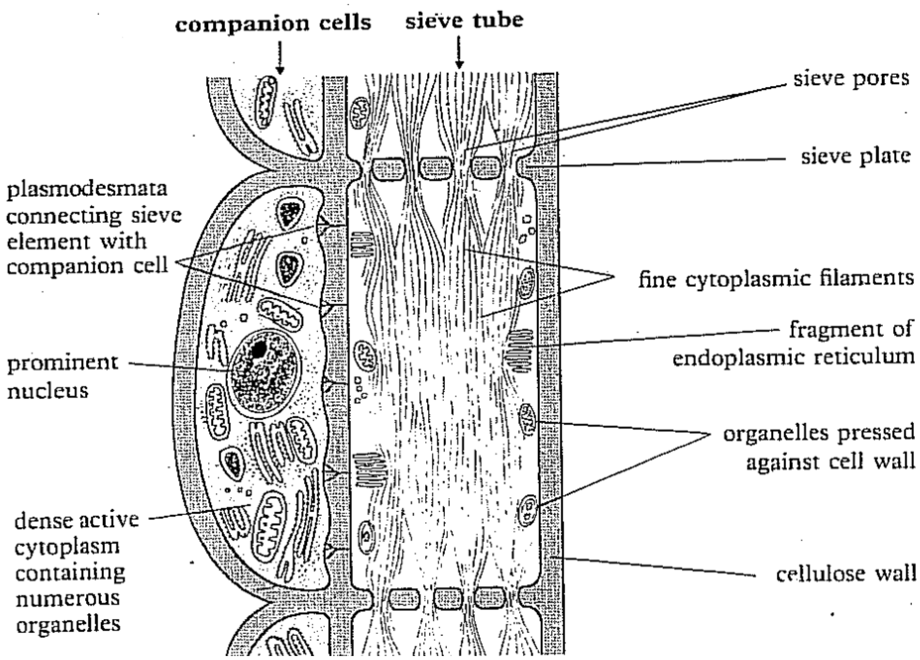
The cytoplasm is confined to a thin layer around the periphery of the cell. Sieve elements are living but metabolically depend on adjacent companion cells. In between the sieve tube elements are **sieve plates**, formed from the two adjoining end walls of neighbouring sieve elements.

The sieve plates are perforated by sieve pores formed by enlargement of plasmodesmata. The sieve plates are made up of a polysaccharide called **callose.**

Companion cells

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

Diagram of a sieve element and its companion cell



Protophloem and metaphloem

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

Adaptations of the phloem to its function

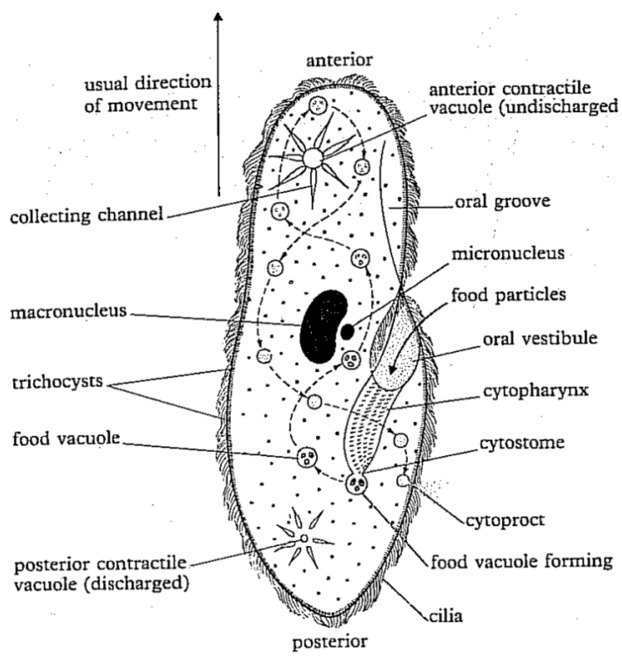
- Sieve tube elements are joined end-to-end; their walls are perforated with sieve pores in sieve plates allowing passage of materials unimpeded from one cell to another.
- Sieve elements lack nuclei and possess a thin cytoplasm pushed to the sides of the cell, creating room for passage of organic materials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

LEVELS OF ORGANISATION

1. **Unicellular level of organization**

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

Paramecium structure



The paramecium has the following main parts and their functions.

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

Advantages of unicellular organization

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

Disadvantages

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

Advantages of small size

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

Disadvantages of small size

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

Advantages of big size

- i. It allows the organism to have a low metabolic rate hence eats less relative to body size.
- ii. The organism loses less heat because it has a small surface area to volume ratio.

iii. The organism can easily intimidate/scare the predator/enemy.
iv. A large organism cannot easily be consumed, only parts of it can be consumed.

Disadvantages of big size

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

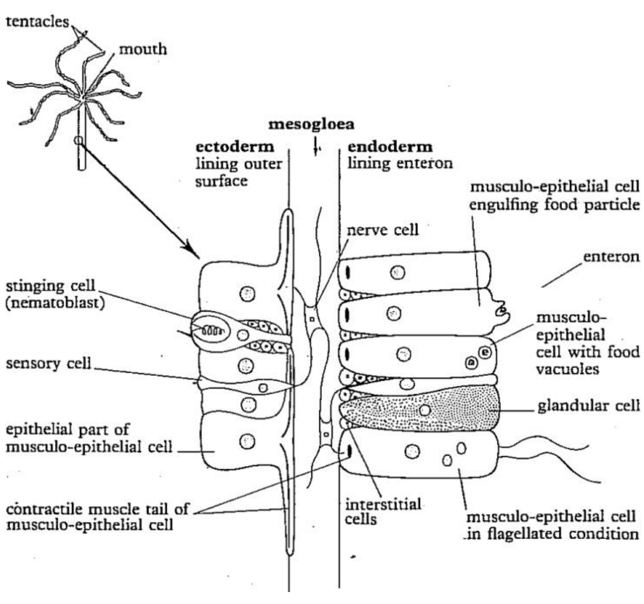
2. <u>Tissue level of organization</u>

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

HYDRA

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

Structure of the wall of the hydra



The wall of the hydra

It is composed of seven different types of cells arranged in two sheet like layers called **ectoderm** and **endoderm**. The ectoderm lines the external surface whereas the endoderm lines the body cavity/enteron.

Between the ectoderm and endoderm is an intersurface called the **mesogloea** in which there are nerve cells that are interconnected to form a nerve net. Each of the different cells performs a specific function as stated below.

- **<u>Musculo epithelial cells</u>-** These are cells lining the upper surface in the ectoderm and are mainly for protection.
- **<u>Nematoblasts</u>-** (stinging cells). It contains a thread which contains a toxic fluid. It is used in the piercing and poisoning of prey.
- **<u>Sensory cells</u>**- They are for detecting changes in the surrounding environment and pass impulses to the nerve cells.
- **<u>Nerve cells</u>-** They are interconnected to form a nerve net. They are connected to the contractile muscle tail of the musculo epithelial cell. Therefore, their role is to pass on the information ie conducting impulses to those muscle tails of the musculo epithelial cells.

- **<u>Muscle tails</u>-** They are contractile muscles at the base of each musculo epithelial cell. They are concerned with bringing about the movement or beating of the tentacles and flagella when they contract.
- **<u>Glandular cells</u>-**They secrete enzymes that carry out digestion in the enteron.
- **<u>Phagocytic musculo epithelial cells</u>-** For taking in small particles from the enteron so that digestion is completed intracellularly.
- **<u>Flagellated musculo epithelial cells</u>-** Are important for effective movement of materials eg food materials and stirring it up in the enteron.
- **<u>Interstitial cells</u>-** For generation or production of new cells.

Feeding mechanism in a hydra

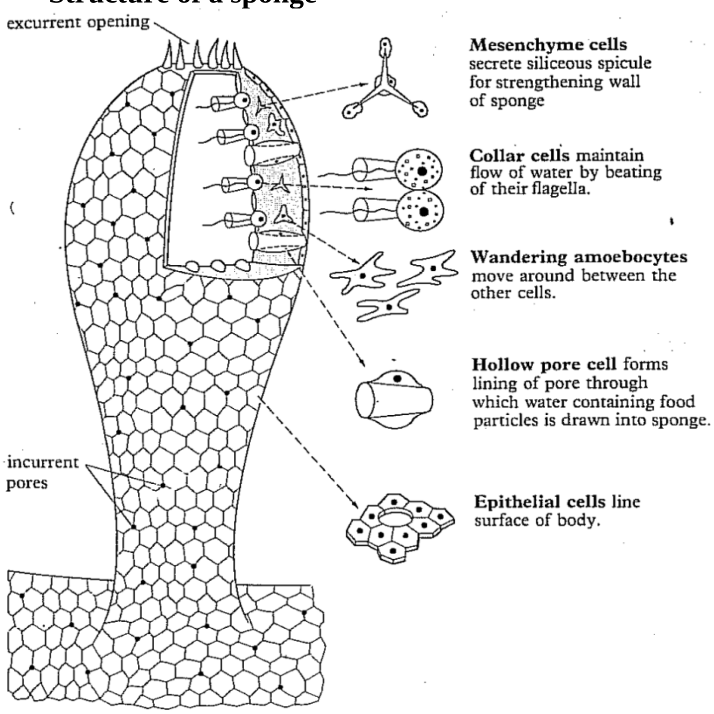
Food of a hydra is usually water fleas. The water fleas are immobilized by the stinging cells and pulled to the mouth by the tentacles under the influence of the contraction of the muscle tails which are controlled by the nerve net in the mesogloea.

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

3. **<u>Colonial organization</u>**

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

Structure of a sponge



4. <u>Organ level of organization</u>

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

Advantages of being multicellular

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