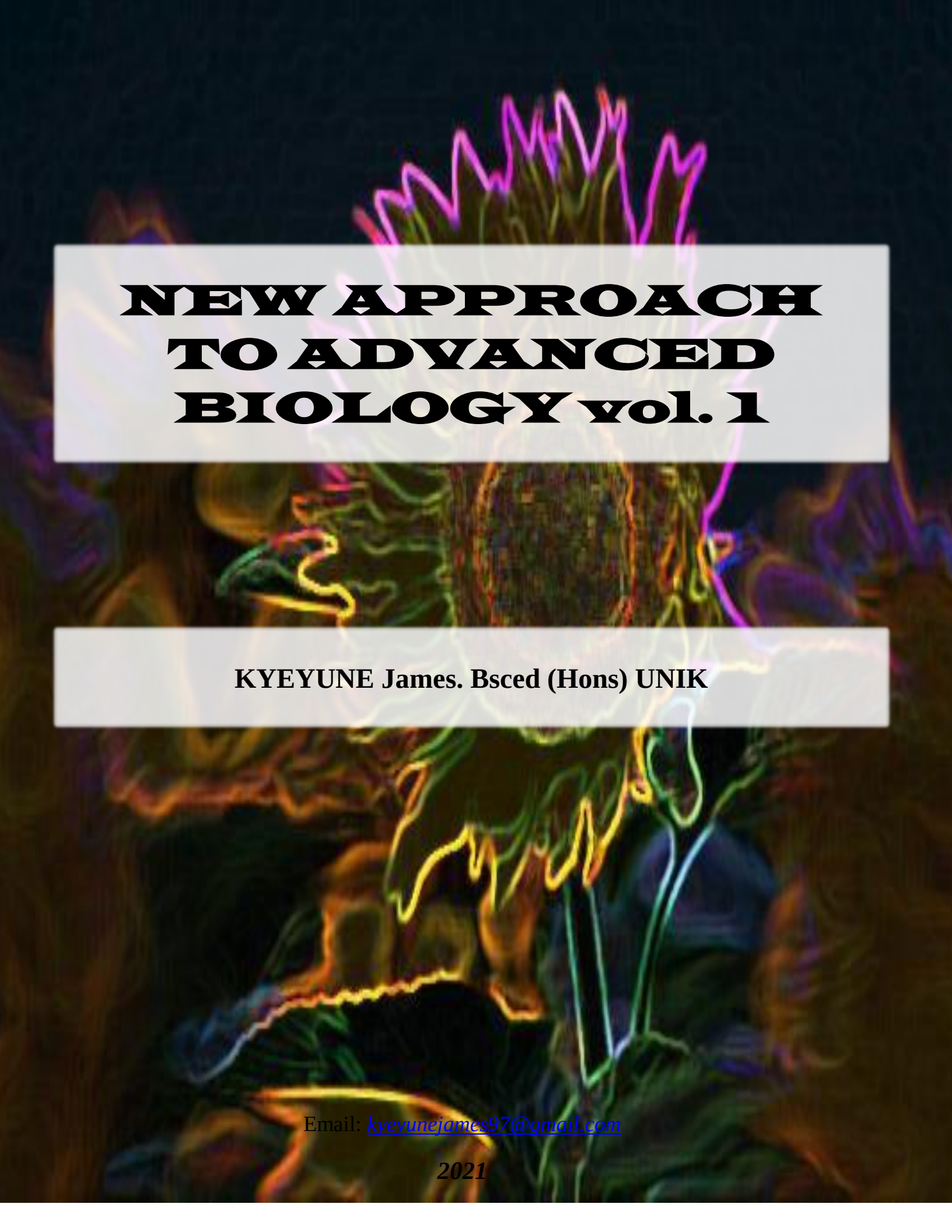




NEW APPROACH TO ADVANCED BIOLOGY vol. 1

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PREFACE

Advanced biology has three papers, papers one and two which are theory papers while paper three is practical. This book aims at guiding and enhancing the teaching and learning strategies for both A' level teachers and learners at secondary schools.

The skills and abilities examined in A' level Biology are hierarchal such that test skills above also test skills at all lower levels. For the theory papers, the test skills may be summarized as follows;

- Recall of knowledge of learned facts, terms and principles.
- Compression of these facts, terms and principles presented in a variety of ways e.g. verbal, graphical or diagrammatic.
This also involves the translation and interpretation of this information.
- Application of the data described above to new situations.
- Synthesis and analysis of data in terms of construction of hypothesis and design of experiments.
- Evaluation of biological information so as to display mastery of data at all levels.

Underlying all the above abilities, you must also be able to communicate knowledge relevantly, logically and clearly.

For practical paper, the skills and abilities to be tested may be summarized as the ability to;

- Observe accurately
- Record observations precisely
- Follow instructions
- Manipulate familiar and unfamiliar biological materials.
- Interpret data
- Pursue logical developments.

The above skills and abilities may be tested in a variety of ways which may involve the use of living and dead organisms, the microscope, and dissection, physiological and behavioral experiments.

Study and revision

There is a need to work steadily and conscientiously throughout you're A' level course. Last minute revision is useful but cannot compensate for poor work earlier in the course. It should not be thought that final revision is unnecessary. You can organize your final revision in such a way that it becomes enjoyable and highly productive.

The following advice should help you with this;

- Obtain an examination syllabus and recent past examination papers.
- Ensure that you are familiar with the form of each paper the style of question.
- Ensure that all your course notes are complete. All the information required for revision should be in your note book. Avoid revising from text books, use them only for revision purposes.
- Work out a plan of revision and keep to it
- Revise the course topic by topic.
- Diagrams should be learned by drawing them several times and looking for patterns in the way they are drawn.
- Complex biological activities which involve many structures and functions can be simplified in form of flow diagrams. Constructing a flow diagram is a valuable way of revising as it helps you to appreciate the interrelationships between structures and functions. It also encourages you to think logically and record information precisely.

Answering essay questions certainly requires the following skills;

- Following your revision of each topic, read the appropriate content noting the definitions and key words. It is vital that you should know that each of the key word, structure, location and how it functions.
Likewise, each key word process should be clearly understood in terms of where it occurs, how it occurs and why it occurs. Concepts and principles too should be identified as they appear.
- Try answering some questions from past papers. Do not aim at speed but aim at answering the questions correctly.

The answers must be relevant, accurate, logically developed and clearly expressed.

When answering questions, remember the following;

- Answer the questions that are set, do not rewrite the questions to suit your self.
- Only give information which is relevant to the question. Do not write down all that you know about the topic as this will not gain marks and will waste your time.
- Answers should be precise
- Present your work in a logically developed way.

I trust that this book will contribute to examination success while engineering a genuine love of biology which stimulates the reader to delve further and deeper into the subject. When revising and reading, use block reading. Block reading involves the grouping of topics with linked information as a single category for example;

Group 1

- Cytology
- Histology
- Cell physiology
- Classification

Group 2

- Ecology
- Evolution and inheritance
- Reproduction
- Growth and development

Group 3

- Nutrition
- Behaviour
- Reproduction
- Evolution

Group 4

- Nutrition
- Transport
- Gaseous exchange
- Respiration

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First and foremost, I thank the Almighty God for his mercies and blessings bestowed upon me and my family.

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STANDARD TEACHING SYLABUS:

The syllabus places emphasis on understanding, application, analysis and evaluation of Biology concepts relating them to everyday experiences. The Biology syllabus comprises 14 topics:

1. *Cell biology or cytology*
2. *Chemicals of life*
3. *Cell physiology*
4. *Levels of organisation and diversity of life*
5. *Ecology*
6. *Inheritance and evolution*
7. *Transport of materials in living organisms*
8. *Nutrition in plants and animals*
9. *Gaseous exchange*
10. *Respiration*
11. *Homeostasis*
12. *Coordination in plants and animals*
13. *Support and movement in plant and animals*
14. *Reproduction, growth and development.*

INTRODUCTION

Biology is the scientific study of life. Although there is no universally accepted definition of life, most biologists agree that all living things share certain basic characteristics such as;

a) Organisation

All living things are made of chemicals which are packaged into highly organized structures. The basic unit of life is the **cell**. Cells themselves contain small organelles that carry out specific functions. A cell may exist on its own or in association with other cells to form tissues and organs. Because of their highly organized structure, living things are called **organism**.

b) Reproduction

This is the ability to produce other individuals of the same species. It may be sexual or asexual. Reproduction involves the replication of DNA, which contains genetic information that determines the characteristics of an organism. Reproduction ensures the continuity of life, and prevents extinction of organisms.

c) Growth and development

All living things must grow and develop to reach the size and level of complexity required to complete their life cycle. **Growth** is a relatively permanent increase in size of an organism. Organisms grow from within by a process which involves the intake of materials from outside and their subsequent incorporation into the internal structure of an organism, **assimilation**.

Development involves a change in the shape and form of an organism as it matures. It is usually accompanied by increase in complexity.

d) Feeding

Living things obtain nutrients (chemicals) that make up their bodies or help them to carry out their biological processes by feeding, either by eating other organisms (**heterotrophic nutrition**) or by making their own food out of simple inorganic chemicals using energy from sunlight or from chemical reactions, **autotrophic nutrition**.

e) Respiration

Living things need energy to stay alive and to do work. Although food contains energy, it is not in a directly usable form and has to be broken down. The energy released during the breakdown is used to make adenosine triphosphate (ATP). ATP is an energy rich molecule that can be used directly to drive metabolic reactions in the body.

f) Excretion

Living things are continuously transforming one form of energy to another. The energy transformations that take place in an organism involve chemical (metabolic) reactions which produce waste products, some of which are poisonous. They are disposed by excretion.

g) Responsiveness

All living things are sensitive to certain changes in their environment and respond in ways that tend to improve their chances of

survival. The degree of responsiveness depends on an organism's complexity.

h) Movement

Responses usually involve some form of movement. Movement of the whole organism from one place to another is called **locomotion**. Plants and other organisms that are fixed in one place do not display locomotion but move parts of their bodies. Movement in living things is active and requires energy.

i) Homeostasis

All living things are to some extent able to control their internal conditions so that their cells have a constant chemical and physical environment in which they can function effectively. The regulation and maintenance of a relatively constant set of conditions within an organism is called **homeostasis**.

j) Evolution

Living things are able to change to new forms of life. This evolution usually takes place gradually over successive generations in response to changes in the environment.

Therefore a living organism can be defined as a self-reproducing system capable of

growing and maintaining its integrity by expenditure of energy.

NOTE

1. *Although non-living systems may show some of the characteristics of living things, life is a combination of all the above characteristics.*
2. *The continued existence of life depends on **reproduction** and this is perhaps the most characteristic feature of life. Reproduction allows both continuity and changes over countless generations and this has allowed species to become well adapted to their environment and life to evolve gradually to complex forms.*

These characteristics can be observed to a greater extent or lesser extent in all living organisms. They are the observable outcome of the all-important property of living material, namely the extraction, conversion and use of energy from the environment. In addition, living material is able to maintain, and even increase in its own energy content. In contrast to this, dead organic matter tends to disintegrate as a result of the chemical and physical forces of the environment.

TOPIC 1: CELL BIOLOGY

SUB-TOPIC 1: CELL STRUCTURE AND MICROSCOPY

SUB TOPIC OUTLINE

- Structure of the animal and plant cell as seen under a light microscope
- Ultrastructure of animal and plant cells
- Functions of the detailed cell structures indicating the interrelationships
- Differences between plant cell and animal cell ultra-structures
- The theory behind the structure of the plasma membrane
- Fluid mosaic model – plasma membrane

CYTOLOGY

Cytology is a branch of biology that deals with the study of the structure of cells using a microscope.

THE CELL

A cell is the basic unit of life. It is the basic functional and structural unit of an organism. All living organisms no matter their size are made of cells. Cells are responsible for carrying out all body processes such as respiration, excretion, osmoregulation, locomotion, circulation etc. in the body of the organism. Cells aggregate (unite) in groups to form body structures.

A cell is thought of as a "bag of chemicals" which is capable of surviving and replicating itself. Inside the bag, the chemicals differ in various ways from those outside it. Without the barrier and the environment the chemicals would mix freely by diffusion and the differences could not be maintained hence life couldn't exist. The barrier is a very thin membrane. All living cells are surrounded by a membrane known as a cell surface membrane to distinguish it from any membranes that occur inside the cell.

When studying the detailed structure of the cell, an instrument called a **microscope** is used. Since most cells are very small, we use the following units of measurements to measure them.

Metric unit	Symbol	Relationship to a meter (m)
Meter	m	10^0 m
Centimeter	mm	10^{-2} m
Millimeter	mm	10^{-3} m
Micrometer	μ m	10^{-6} m
Nanometer	nm	10^{-9} m
Angstrom	$\text{\AA}$	10^{-10} m

The lowest limit of what is visible to a unaided with the human eye is between 50 and 100 μ m. a very fine human hair is about 30 μ m in diameter. Eukaryotic cells vary greatly in size with the largest algal cell about 50 mm in diameter but the average animal cell is about 20 μ m in diameter compared to 40 μ m for an average plant cell.

THE MICROSCOPE

The term microscope is derived from two Greek words; *mikros* meaning small and *skopein* meaning to see or to examine. Most cells are very small, and their structures can only be seen using a microscope.

CHARACTERISTICS OF A MICROSCOPE

Microscopes have two main characteristics namely;

- ❖ Magnification
- ❖ Resolution

a) *Magnification*

Magnification is the number of times an image is made bigger or smaller compared to the object. Magnification can also be defined as the size of the image in relation to the actual size of an object. There is no limit on the amount of magnification but *useful* magnification depends on the resolution of the microscope.

b) *Resolution*

This is the ability of the microscope to distinguish between two separate and very close objects so that they are distinct. It can also be defined as the degree to which the details of the objects are shown or a measure of clarity of the image. If two separate objects cannot be resolved, they will be seen as one object. Resolution is determined by the wavelength of the rays that are being used to view the specimen. The difference between the magnification and resolution of a microscope is that magnification can be

changed (i.e. increased or decreased) while resolution is always the same.

TYPES OF MICROSCOPES

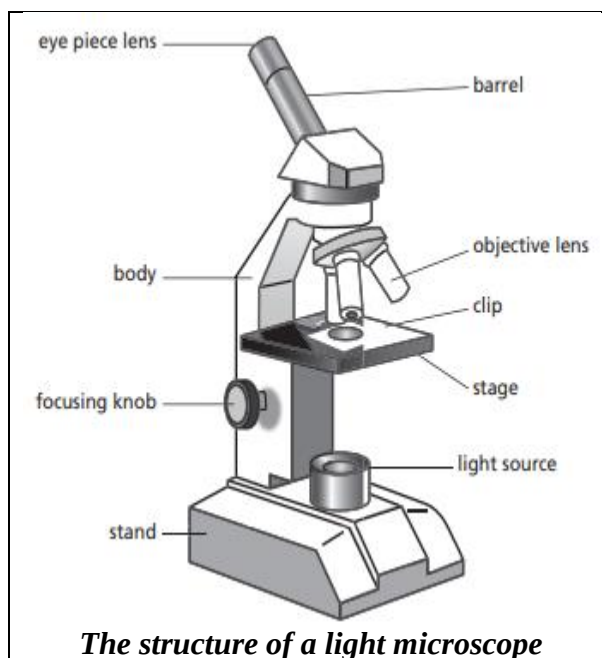
There are two main types of microscopes depending on their source of radiation i.e light and electron microscope.

i) THE LIGHT MICROSCOPE

This type of microscopes uses light to illuminate the specimen under investigation or that has been placed on the stage.

A COMPOUND LIGHT MICROSCOPE

A compound microscope uses two types of lenses i.e. the eye piece and the objective lens. Light from specimen passes through the first lens called objective lens and produces a magnified image. This image acts as the object of the second lens the eye piece which magnifies it further. This produces a magnified image onto the retina of the viewer.



The magnification in a light microscope

The total magnification of a compound microscope is the product of both the objective lens and eye piece lens magnification. The light microscope has a maximum magnification of x1500.

The resolution of the light microscope

The resolving power of the light microscope is always lower (200nm) compared to that of an electron microscope (0.5nm). This resolution is limited by the wave length of the visible light used to illuminate the object. Light is a form of electromagnetic radiation and it can behave like a series of waves. All waves travel at the speed of light but the shorter the wavelength, the greater the energy that the waves carry. It is not possible to view objects smaller than half the wavelength of the radiation used by the user. This is because the object has to be large enough to interfere with the passage of waves. The light microscope can magnify effectively to about 1000 times of the actual specimen since greater magnification above this increases blurredness.

Advantages of a light microscope;

- It is cheaper and easier to operate when compared to the electron microscope.
- It can be used to observe living specimens directly since it does not require a vacuum like the electron microscope.
- It does not result in the destruction of cellular organization like the electron microscope.

Disadvantages of a light microscope;

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

MODIFICATIONS OF THE LIGHT MICROSCOPE

These include;

Dark field microscope

This uses light at right angles to its optical axis and depends on the scattering of light by different particles. It is used to study very small particles about 8nm

Ultra violet microscope

It uses quartz lenses and is used to study chromosome changes during cell division.

Phase contrast microscope

It depends on the refraction of light by parts of the cell based on their refractive indices and is used to study transparent cell parts e.g. cytoplasm.

Polarizing microscope

It uses polarized light and is used to study layer-like structures in the cell e.g. spindle fibres, cellulose in cell wall etc.

ii) ELECTRON MICROSCOPES

In electron microscope, a beam of electrons is used. Electrons are negatively charged particles that can be found in orbit around nucleus of atoms. Under certain circumstances they can behave as waves. They have two great advantages over light i.e.

- ❖ They have extremely short wave length, about the same as X- rays
- ❖ The beam electrons can easily be focused through specimen using electro-magnets. This involves bending the beam of electrons just as glass lenses are used to bend light.

The image produced by the electron microscope cannot be detected directly by the naked eye. Instead, the electron beam is directed on to a screen from which **photomicrographs** can be taken. With electron microscope magnification have x250, 000 are commonly obtained with biological materials and the magnification can be varied by changing the strength of electromagnets. Magnification can be increased but the resolution of the photograph stays the same. The resolution is much greater in electron microscope because electrons have shorter wave lengths, hence greater resolving power than that of light.

TYPES OF ELECTRON MICROSCOPE

There are three types of electron microscopes i.e.

- Scanning electron microscope. (SEM)
- Transmission electron microscope. (TEM)
- Environmental scanning electron microscope.

TRANSMISSION ELECTRON MICROSCOPE (TEM)

The TEM is used to study the ultra-structure of cells. Extremely thin samples of the specimen are needed. Electrons are passed

through the specimen and then the section is treated with heavy metal stains like osmium tetroxide which scatter the electrons in such a way that individual structures can be distinguished. As the molecules in air would absorb electrons, a vacuum has to be created within the instrument where electrons are absorbed by the material, and do not reach the screen, the image appears dark.

Advantages

It has a high resolution (0.5nm).

Disadvantages

Extremely thin sections are used hence a flat image and the natural contouring of the specimen cannot be seen.

SCANNING ELECTRON MICROSCOPE (SEM)

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

Advantages

- ❖ Surfaces of structures are shown.
- ❖ Great depth of field, meaning that a large part of the specimen is in focus at the same time. This gives a very striking three-dimension.
- ❖ Much larger samples can be examined than with TEM.

Disadvantages;

Resolution (0.20nm) is not as great as with a TEM (0.5nm).

ENVIRONMENTAL SCANNING ELECTRON MICROSCOPE (ESEM)

These are microscopes that allow the material on the view to be kept at low vacuum while the region around the electron gun is at a high vacuum. This is achieved by separating the microscope column into a series of chambers each with its own pressure and there is only a minute hole between chambers wide enough to allow tiny electron beam through. A special low voltage detector which can operate at low vacuum is used to detect the scattered electrons, secondary electrons and x-rays which provide the image.

Advantages of electron microscope

- ❖ High resolution (0 – 5nm in practice)
- ❖ It magnifies very tiny objects.
- ❖ High magnification above X300, 000

Disadvantages of electron microscope

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

TECHNIQUES IN MICROSCOPY

1. PREPARATION OF MATERIAL FOR THE MICROSCOPY

Biological specimens may be examined in a living or preserved form. In the preserved form specimens can be sectioned for closer examination and treated with a wide variety of stains to reveal and identify the different structures. Preparations of freshly killed material may be temporary or permanent. Permanent is a form of preparation in the specimen can be prepared and after examination it is stored for future use while a temporary preparation is a form of preparation in the specimen can be prepared once and later discarded after the experiment.

a) Techniques used in permanent preparation

i. Fixation;

This is the preservation of material in its life like state, the tissues are freshly killed and rapidly made sliced/ cut in to small pieces. Chemicals are then used (fixative) to maintain the natural state and this process is called fixation.

ii. Dehydration;

This is the removal of water from the material after being prepared if the specimen is to be viewed when in its dry state. Dehydration is always done gradually and carried out by a series of increasing ethanol or water or promption etc. finished in absolute ethanol.

iii. Clearing;

This is the process of making specimen clear when viewed in the microscope. A clearing agent is then added to specimen that has

been already imbedded in the mounting median. The clearing image makes the image clear and transparent.

iv. Embedding

This is a technique of suspending the specimen in a mounting medium or supporting medium. A light microscope embedding involves impregnating material with more 10 watts and is then allowed to set. A hardened is also used for an electron microscope because thin specimen is used and so move liged support is required when cutting.

v. Sectioning:

This is the technique where specimen is cut in to sufficient light pass through during investigation. It's usually important to cut very small slices of material and this always done using a razor blade or microtone. Hard sectioning is carried out by a razorblade.

vi. Staining:

This is the addition of the staining agent of the specimen that would be originally transparent and hence made coloured in order to view the different parts of the specimen. Examples of staining materials include Methylene blue

vii. Mounting:

This is the way of placing of the specimen on a microscope slide and then covering it with its cover. There are two types of mounting i.e.

- Temporary mounting for temporary preparation.
- Permanent mounting for permanent preparation.

THE CELL THEORY

The cell theory was forwarded by Matthias J. Schleiden, a German botanist and Theodore Schwann in 1839. The cell theory was of considerable biological significance because it suggested that all living organisms have a common denominator (cells) and it unified the nature of organisms.

The cell theory states that:

- All living organisms are composed of cells.
- All new cells are derived from already existing cells.
- Cells contain the hereditary materials of an organism which is passed from the parent to the daughter cells.
- All metabolic processes take place within the cells. The function of the organism as a whole is the outcome activities and interaction of the cells.

CLASSES / TYPES OF CELLS

There are two types of cells namely; prokaryotic and eukaryotic cells. Organisms are also divided in to 2 major groups depending on their type of cells i.e.

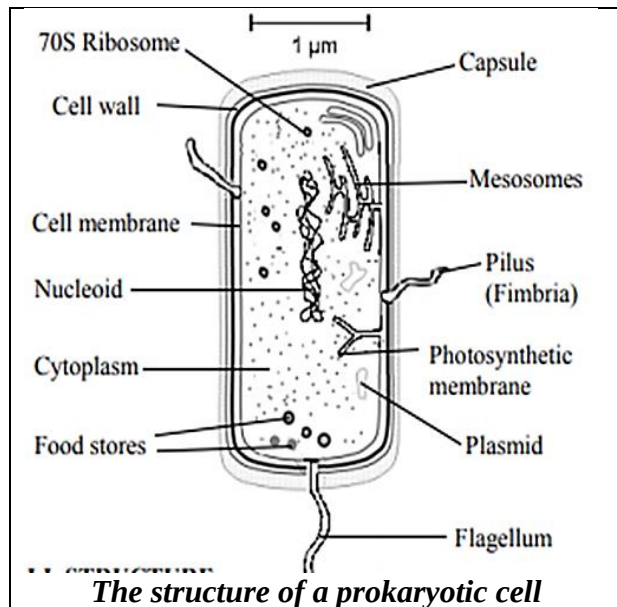
- ❖ Prokaryotes
- ❖ Eukaryotes

PROKARYOTES

These are organisms that contain prokaryotic cells. Prokaryotic cells are cells which have no distinct nucleus and their DNA material is not enclosed with in the nuclear membrane. It lies free in a region of the cytoplasm called the **nucleoid**.

The prokaryotic cell

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



EUKARYOTES

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

The eukaryotic cells

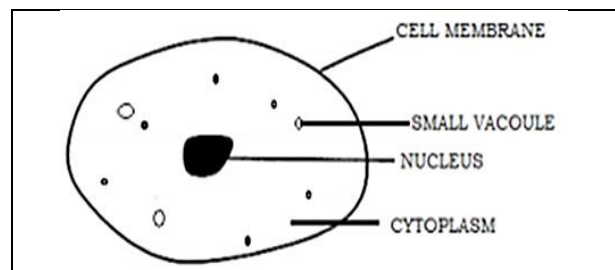
These cells have a true nucleus enclosed a nuclear membrane. These cells evolved from prokaryotic cells. The entire region between the nucleus of the cell and the plasma membrane is called **cytoplasm**. The cytoplasm consists of a semi fluid called **cytosol** in which there are suspended organelles of specialized form and function.

Examples of organisms that contain eukaryotic cells are protists, fungi, plants and animals.

STRUCTURE OF EUKARYOTIC CELLS UNDER LIGHT MICROSCOPE

a) Animal cell

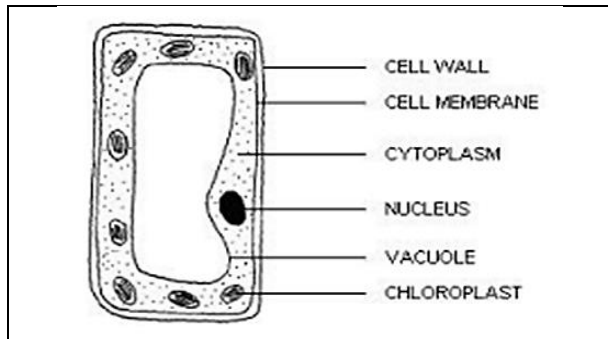
The cell has a diameter of about 20 μm bounded by a *thin plasma membrane* which encloses the protoplasm. The protoplasm consists of the *nucleus* in the centre surrounded by the *cytoplasm*. The cytoplasm appears to be a uniformly homogeneous substance but if stained with special dyes, it shows numerous granules and inclusions. The nucleus is bounded by the nuclear membrane and contains a dense body called the *nucleolus* and the rest is filled by the *nucleoplasm*.



b) Plant cell

Most of the structures found in the animal cell also occur in plant cells. However in a typical plant cell, the centre is taken up by a large vacuole filled with a solution containing sugars and salts, the *cell sap*. The sap vacuole is surrounded by the *tonoplast*. The cell is bounded by a comparatively thick wall made up of cellulose. The presence of the sap vacuole results in the cytoplasm being pushed to the sides of the

cell. In most plant cells, the nucleus is located in this peripheral cytoplasm. In the cytoplasm, there are granules and inclusions (plastids) which include *starch granules* and *chloroplasts*.



WHY CELLS ARE VERY SMALL?

Most cells are microscopic. The size and shape of cells are related to their functions. The size depends on what the cell must do to survive;

- ❖ Cells take in food and other materials through the plasma membrane.
- ❖ Inside the cell, substances must move to the correct locations in the cell where they are converted to other forms.
- ❖ Once the correct molecules are formed they must be transported to proper sites within the cell for use.
- ❖ Waste products from various metabolic reactions must be transported out of the cell before they accumulate to toxic levels.

It is therefore important to note that the distance materials move is very short. This will speed up the cellular functions. Since these materials and waste products have to pass through the plasma membrane, the

larger the surface area the faster a given amount of a substance can pass through it.

ULTRASTRUCTURE OF CELLS

The organisation in an individual cell as revealed by the electron microscope is known as its fine structure or **ultrastructure**. The specific entities making up this organisation are called **organelles**. In cells, specific functions are carried out in certain parts of the cell, and all these functions being integrated in an orderly manner.

THE STRUCTURES OF THE CELL

1) CELL MEMBRANE.

This is an outer surface which covers the cytoplasm of the cell; it consists of lipids and proteins together with carbohydrates. It is a protein covering of a structure for the purposes of enclosing and protecting the cell structure and its contents. The total thickness of the cell membrane is approximately 7.0 nm.

Cell membranes do not simply behave like semi permeable membranes that only allow the passage of water and other small molecules such as gases but they are *differentially permeable* since other substances such as glucose, amino acids, fatty acids, glycerol and ions diffuse slowly through them and they also exert a measure of active control over what substances they allow through. Various structures are associated with the cell membrane and these include *pinocytic vesicles*; flask like invaginations of the plasma membrane. An animal cell may contain numerous small vesicles which are constantly being formed by pinocytosis. Certain animal and protist

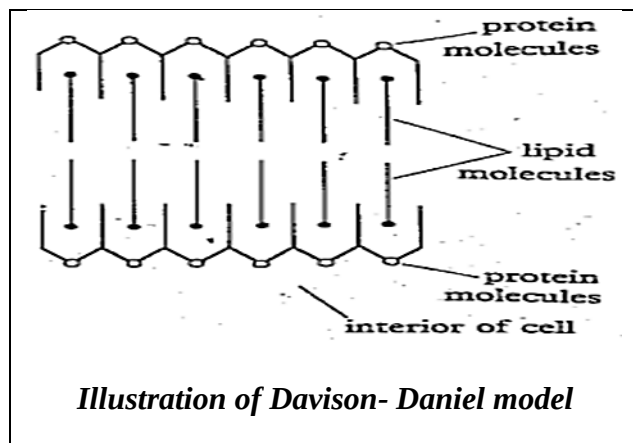
cells also contain food vacuoles which are derived from phagocytosis.

STRUCTURE OF THE CELL MEMBRANE

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

H. Davison & J. Daniel (1935).

These suggested the molecular model of the cell membrane and in this model a phospholipid bilayer is arranged between two layers of globular proteins, with the lipids at right angles to the surface. They also predicted that the lipid layer was about 6.0 nm in thickness and each of the protein layers about 1.0 nm, giving a total thickness of 8.0 nm.



Problems with Davison-Daniel model;

It generalizes all cellular membranes as identical. This was challenged by the development of the electron microscope. The plasma membrane is 7-8 nm thick while the inner membrane of mitochondria is only 6nm thick and it has a substantially greater loss of proteins than the plasma membrane.

There are differences in the specific kinds of lipids and other lipids present. It also follows that membranes with different functions differ in chemical composition and structure.

Placement of the proteins is disputed. Unlike the proteins dissolved in cytoplasm, membrane proteins are not very soluble in water. They are amphipathic as their phospholipids partner in membranes if proteins were layered on the surface of the membrane, their hydrophobic part would be in an aqueous environment. Secondly, this arrangement the proteins separates the hydrophilic heads of the phospholipids from water.

S.J Singer and G. Nicolson (1972)

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

According to this model;

- ❖ A mosaic of protein molecules floats in a fluid lipid layer. Some protein molecules appear to be attached to the surface of the membrane while others penetrate into it to varying extents; some of them extend right through it and stick out on the other side. The membrane is thought to be far less rigid than was originally thought and due to this fluidity and mosaic arrangement of the protein molecules, the model is called fluid mosaic model.

The membrane also contains cholesterol that distort the close packing of phospholipids to keep them more fluid; Cholesterol also increases stability and flexibility of the

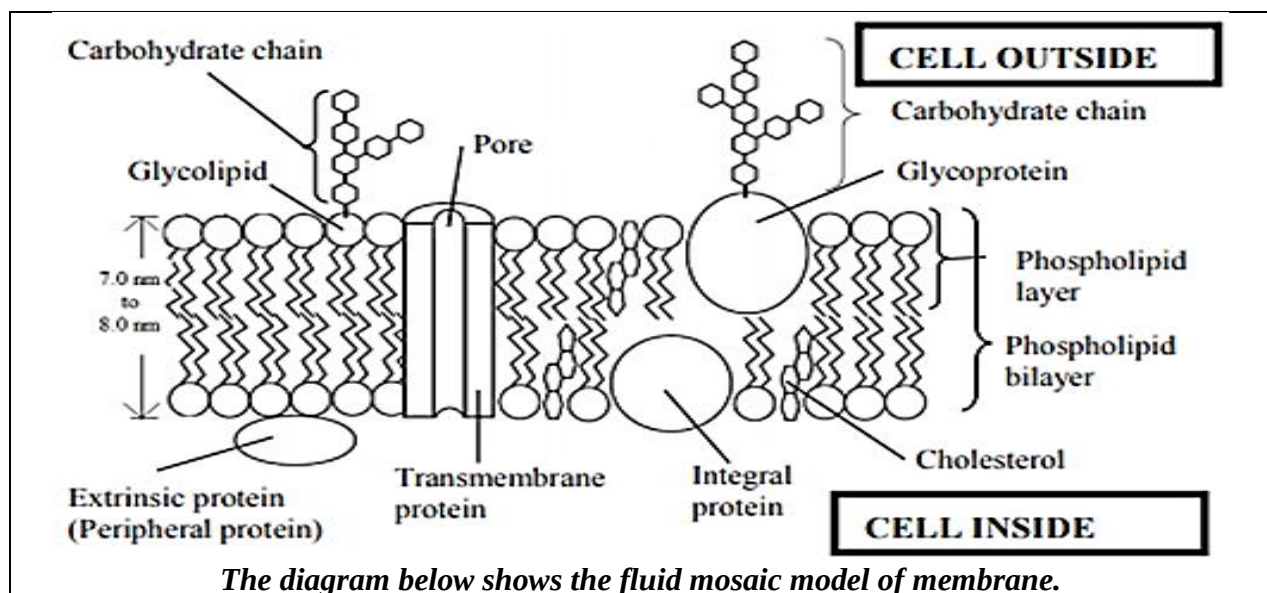
membrane so that in its presence; the membrane cannot breakup. The two sides of the membrane can differ in composition and function.

NOTE;

1. The fluid mosaic model is thought to apply to all biological membranes.
2. The proteins are present not to give it strength but to serve as enzymes

catalyzing chemical reactions within the membrane and as pumps moving things across it.

3. The plasma membrane of a cell and membranes of the various organelles have unique connections of proteins. These proteins are dispersed and immersed in the phospholipids bilayer in an irregular arrangement.



COMPONENTS OF THE PLASMA MEMBRANE

The plasma membrane is made up of phospholipids, glycolipids, proteins and carbohydrates.

a) LIPIDS

These are made up of phospholipids, glycolipids, cholesterol and sterols.

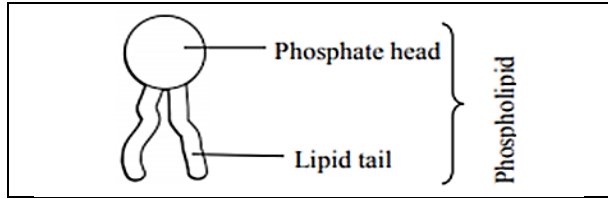
i) Glycolipids

These are found on the outer surface of the plasma membrane. They are composed of short polysaccharide chains attached to the

phospholipids. The composition and branching pattern of the surface polysaccharide vary from one type of cell to another. Glycolipids are involved in cell-to-cell recognition e.g. ABO blood system is as a result of different glycolipids on the cell membrane of red blood cells.

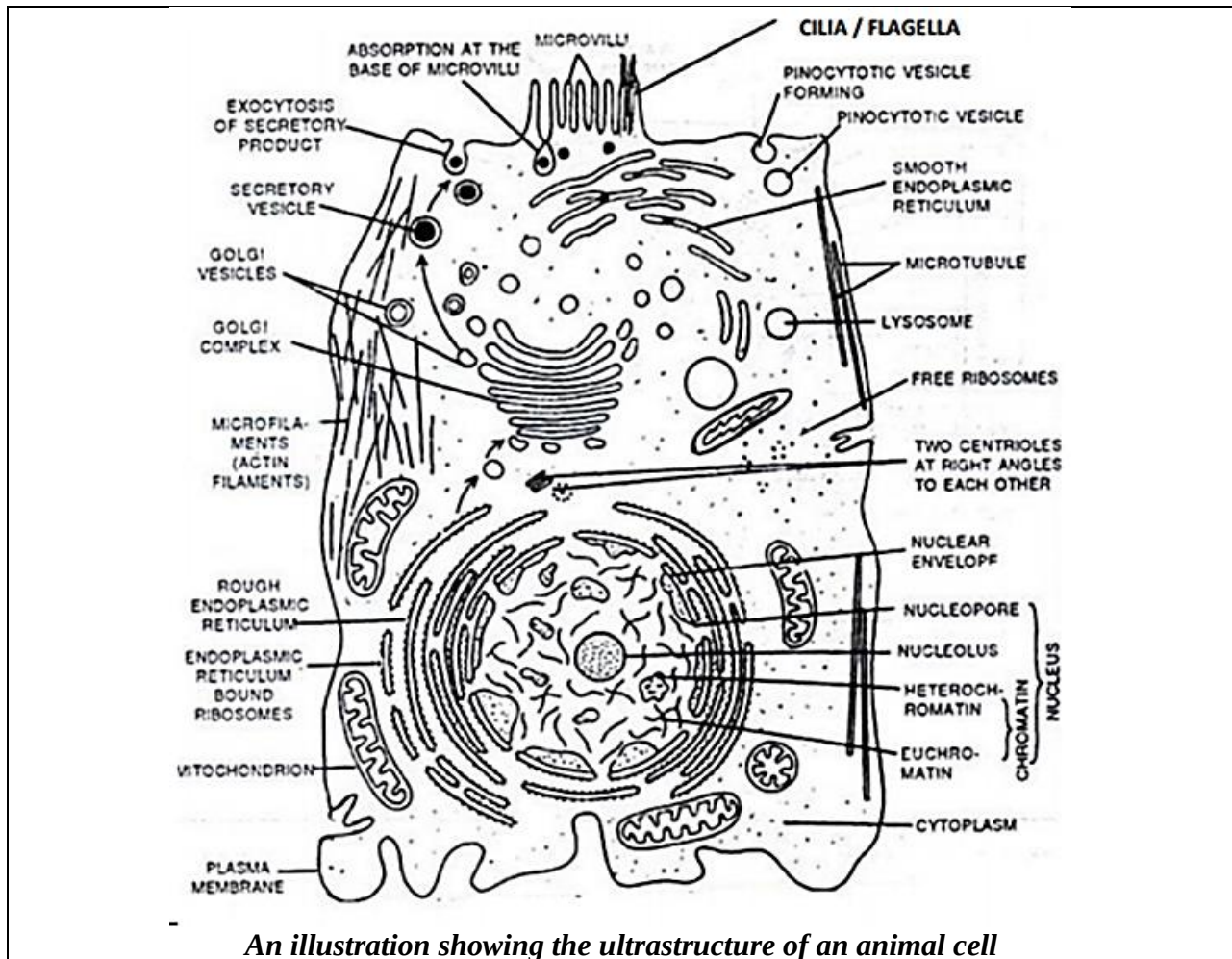
ii) Phospholipids

They have a polar head and two non-polar tails. The head is composed of glycerol and phosphate group while the tail is made from two fatty acids, which could be saturated or unsaturated fatty acid

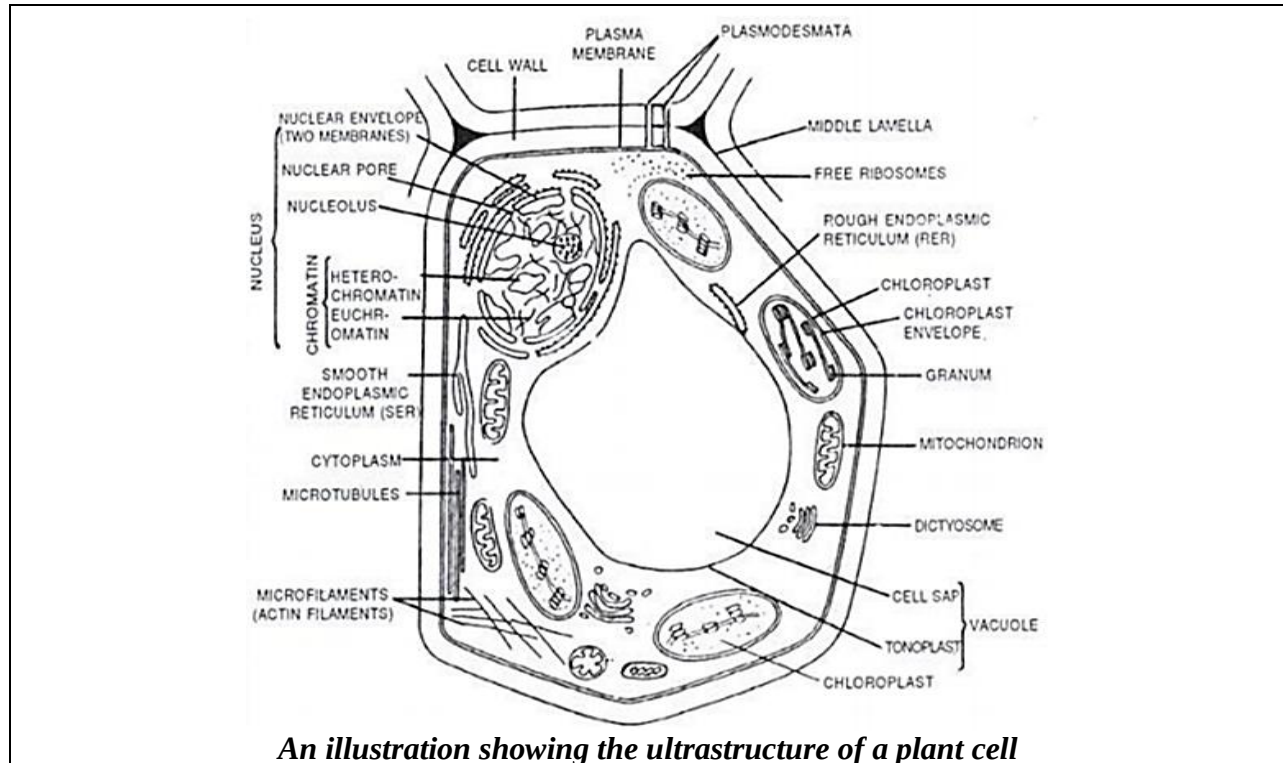


If a thin layer of polar lipid is spread over a surface of water, the molecules orientate themselves into a single monomolecular layer with the nonpolar hydrophobic tails projecting out of water whilst the polar hydrophilic heads lie in the surface of water.

Phospholipids form a bilayer, where the heads face outside the membrane / tails face inside the membrane. The phospholipid layer contains phospholipid molecules that are arranged such that their hydrophobic tails face each other, inwards; and their hydrophilic heads face outwards. Lipids in the plasma membrane prevent close packing of the molecules and make the structure more open and fluid. Being semi-permeable, the bilayer controls movement of substances in and out of the cell.



An illustration showing the ultrastructure of an animal cell



An illustration showing the ultrastructure of a plant cell

b) PROTEINS

Proteins are dispersed and immersed in a phospholipid bilayer which is in a fluid state. Some protein molecules extend into the phospholipid layers up to a certain level (integral or intrinsic proteins); while others penetrate through the membrane (Trans membrane proteins); some protein molecules occur on the surface of the phospholipid layer (peripheral or extrinsic protein molecules); the same surface or peripheral protein molecules have branching carbohydrate portion or chains to form glycoproteins.

Functions of the membrane proteins

Some proteins are carrier molecules, i.e. they transport specific materials across the membrane i.e. proteins that span a membrane may provide selective circulation

and some transport proteins, hydrolyze ATP as energy source to actively pump substance across the membrane (active transport). Hydrophobic pores sometimes occur within a protein or between adjacent protein molecules which allow passage of polar materials through the membrane that would be excluded by the lipid layer.

They also act as enzymes whereby they carry out sequence steps of a metabolic pathway, receptor sites, electron carriers and energy transducers in photosynthesis and respiration.

Some proteins have a carbohydrate chain on their free surfaces which are used as recognition sites for the neighboring cells causing cell-cell adhesion. This enables cells to orientate and ensures that tissues and organs are formed. Glycoproteins also play a

part in the mechanism by which specific hormones and foreign substances recognize and associate with a particular type of cell.

It is an attachment on the cytoskeleton and extra cellular matrix. Although animal cells lack a cell wall they do have an elaborate extra cellular matrix whose main ingredients are glycol-proteins which form very strong fibres outside the cell and these are the advantages of extra cellular matrix; they provide support and they control activities of the genes in the nucleus.

FLUIDITY OF THE MEMBRANE

Membrane fluidity refers to the viscosity of the lipid bilayer of a cell membrane. Membranes are not static sheets of molecules locked rigidly in space. This is because the phospholipids and some of the proteins are held together by hydrophobic interactions that allow the molecules in the membrane to drift about laterally in the plane of the membrane. Flip-flop movement where the phospholipids switch from layer to another is rare but possible.

Lipids move along the plane of the membrane rapidly at an average speed of 2µms. Proteins are much larger than lipids and they move more slowly but some do drift about. Many membrane proteins are unable to move far because of attachment to cytoskeleton. A membrane remains fluid as the temperature rises until finally at same critical temperature, it solidifies. The temperature at which membrane solidify depends on its lipid content or composition. It will remain fluid to a lower temperature if it is rich in phospholipids with unsaturated

hydrocarbon chain which does not allow phospholipids to closely pack together.

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

a) 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.

b) 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.

c) 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.

d) 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°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.

FUNCTIONS OF PLASMA MEMBRANE

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

ADAPTATIONS OF CELL MEMBRANE TO ITS FUNCTIONS

- It has globular proteins which are in constant motion to determine its flexibility.
- It contains some pores particularly in protein molecules to allow passage of materials in and outside. The pores are of particular size to allow only small sized particles and this makes the membrane to be selectively permeable.

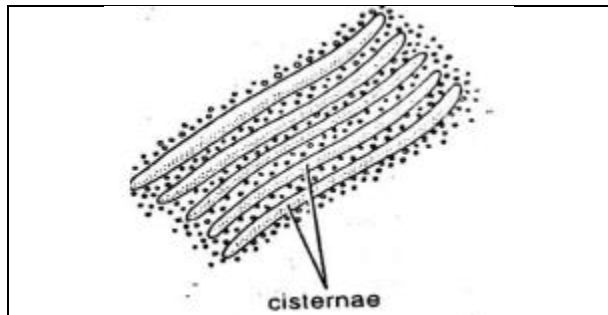
- The membrane is thin and this reduces the distance over which materials diffuse.
- The membrane has a receptor size on its extrinsic proteins recognition by other cells.

Revision question

- Describe the fluid mosaic model of the plasma membrane.*
- Explain how polar and non-polar substances can move across the plasma membrane.*
- Outline four functions of the plasma membrane.*

2) ENDOPLASMIC RETICULUM

This is a network membrane of parallel lines running through the cytoplasm; it is a sheet like structure of flattened membrane band sacs (cavities) called **cisternae**. They are straight tubes; arranged in bundles and parallel; exists more in the pancreas/notochord/brain where they perform synthetic roles.



They are of two types namely;

- Rough endoplasmic reticulum (REM)
- Smooth endoplasmic reticulum (SEM)

Rough endoplasmic reticulum

This is continuous with the nuclear membrane and attached on both sides with ribosomes. It is abundant in cells which participate in protein synthesis like liver cells since the ribosomes provide a large surface area for attachment of messenger RNA (mRNA). This is concerned with synthesis and transport of proteins. It also isolates and transports the proteins which have been synthesized by the ribosomes. Many of these proteins are not required by the cell e.g. digestive enzymes and hormones. A receptor in the membrane of endoplasmic reticulum provides a channel in to which proteins pass in to the end or as the proteins pass through the cisternae, they are modified in the route e.g. converted into glycoprotein which travels to the Golgi body from where they are removed from the cell or passed to other organelle to other cells. It also provides transport of materials between the nucleus and the cytoplasm

Smooth endoplasmic reticulum;

This is a tubular structure that is not embedded with ribosomes on the membrane. SER is found in liver cells, gut cells and gland cells which are responsible for synthesis and transport of lipids and steroids like the sex hormones. E.g. in the epithelium of small intestinal cell, the smooth endoplasmic reticulum synthesizes fats and glycerol absorbed from the gut and passes them to Golgi body.

Muscle cells have specific endoplasmic reticulum called sarcoplasmic reticulum which helps in muscle contraction through storage and release of calcium ions. SER is

also responsible for transporting messages from nerve fibres to cytoplasm in muscle cells. In liver cells, SER also play part in metabolism of carbohydrates, synthesis of cholesterol and de-toxification of drugs, poisons from other cells. They give structural support to the cell organelles and also provide a supporting framework for cells which must maintain shape e.g. receptor cells.

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 enables the transportation of soluble and well packaged substances to their specific destinations and also prevents interference of different metabolic processes taking place in the cell at the same time.
- It contains a variety of enzymes for performing diverse 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

NOTE:

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

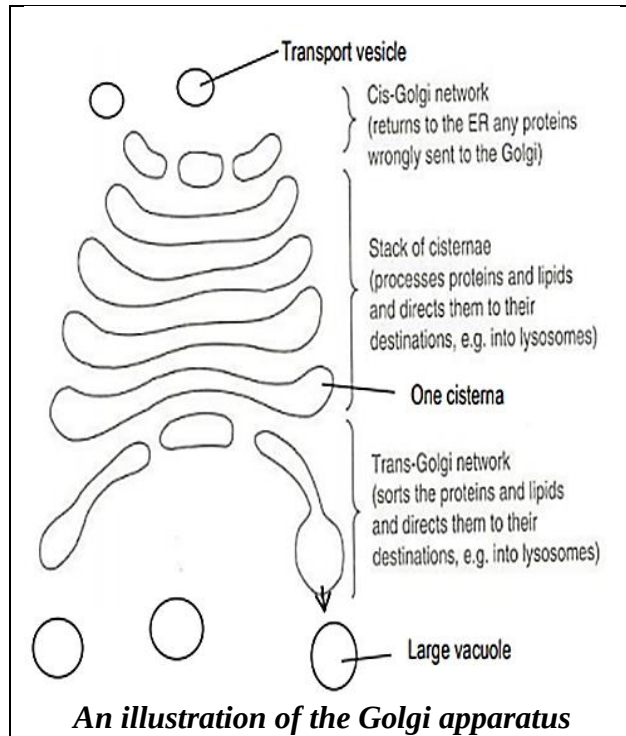
3) GOLGI APPARATUS (PLANTS: DICTYOSOME)

This cell organelle is found in virtually all eukaryotic cells. It consists of stack of flattened membrane bound sacs called **cisternae**, together with a system of associated vesicles called **Golgi vesicles**. One side of the apparatus faces the endoplasmic reticulum that contains cellular products. Its position and size varies from one cell to another but it's well developed in secretory cells, in neurons, muscle cells and in rapidly dividing cells e.g. pancreatic cells, goblet cells, salivary glands, cells in testes and ovaries.

Structure of the Golgi apparatus

All products of the endoplasmic reticulum are passed through Golgi apparatus in a particular sequence; *cis Golgi network* which returns endoplasmic reticulum any protein wrongly exported by it, they then pass through stack of cisternae which modify the proteins and lipids and add labels that allow them to be identified and sorted at the next stage. The *trans Golgi network* where lipids and proteins are sorted and services to their final destination, the opposite side at the Golgi-stack of sacks faces towards the plasma membrane. The cellular membrane are then released that are budded off the sack depending on the nature

of specific products, the vessels that lead to Golgi complex may become lysosomes, storage granules, secretory vesicles in addition to plasma membrane vesicles in addition to plasma membrane.



Functions of Golgi apparatus;

- It secretes carbohydrates e.g. of the new cell walls of cell membrane, such carbohydrates include amylopectin, pectin and cellulose which are important in the formation of cell walls in plants.
- It is involved in production of secretory enzymes produced by pancreatic cells e.g. trypsin.
- Sometimes the Golgi apparatus after budding off have occurred forms lysosomes, containing hydrolytic enzymes for cellular defence.

- It is also involved in the formation and internal secretion of different chemicals such as glycoprotein like mucus.
- It's involved in transporting and transmitting lipids.
- It's involved in packaging and shipping vessels.
- They repair the plasma membrane when vesicles fuse with the plasma membrane as they are emptying their contents to the outside cell surface.

Adaptations of the Golgi apparatus

- Cisternae are enclosed by selectively permeable membranes, which isolate the inside cavity from cytosol for efficient functioning.
- Its tubular structure enables transportation of soluble protein and lipids from the endoplasmic reticulum for modification.
- The apparatus contains a 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

4) LYSOSOME

Lysosomes are found in most eukaryotic cells but are particularly found in animal

cells exhibiting phagocytic activity. They are simple spherical/ sack-like bodies with a diameter between 0.1-1.0 nm and are surrounding a single membrane.

They contain digestive enzymes mostly hydrolytic enzymes such as proteases, nucleases, lipases etc. in acidic region or solution. They isolate enzymes from the remainder of the cell and by doing so; they prevent the enzymes from acting upon other chemicals and organelles from the cell. 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.

Types of lysosomes

A *primary lysosome* is the one that contains only digestive enzymes within an environment that is moved in acidic conditions than that of the surrounding cytoplasm. A primary lysosome may fuse with food vacuole or another organelle to form a secondary lysosome in worn out organelles and the product of phagocytosis can be digested. Enzymes containing the lysosome are synthesized and transport the Golgi in which are budded off as vessel. A *secondary lysosome* is one 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;

- They are used in cellular digestion in some unicellular organisms like

amoeba, bacteria which obtain their food by phagocytosis.

- They also digest out the worn-out organelles within the cell.
- It is used to release enzymes outside the cell into the process called **exocytosis**.
- They release lytic enzyme that resolves the membrane during fertilization.
- Lysosomes are also used in replacement of cartilage by bone during development.
- Leucocytes (WBC) digest foreign particles, bacteria and viruses enabled by lysosomes.

NOTE

*Sometimes lysosomes may destroy the entire cell when the lysosome membrane ruptures and dissolves liberating enzymes which proceed to digest cell organelles hence killing the cell. This process is called **autolysis**.*

5) MICRO BODIES

These are of two types namely;

a) Peroxisomes.

These are also membrane bound organelles with a diameter between 0.5-1.5 nm containing several specific enzymes that promote oxidative reactions and don't have internal structure. They are present in most cells particularly large and active cells. Peroxisomes and lysosomes are similar in appearance, but differ in origin. Lysosomes are formed in the Golgi complex, while peroxisomes self-replicate using protein imported from the cytosol. They contain a variety of enzymes that rid the cell of toxic

wastes e.g. catalase breaks down hydrogen peroxide, liver micro bodies detoxify alcohol and fat-soluble drugs.

b) Glyoxysomes

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

6) VACUOLES

These are fluid filled sacks bounded by a single membrane. They are usually found in plant cells. 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 such as phagocytic vacuoles, food vacuoles, autophagic vacuoles and contractile vacuoles.

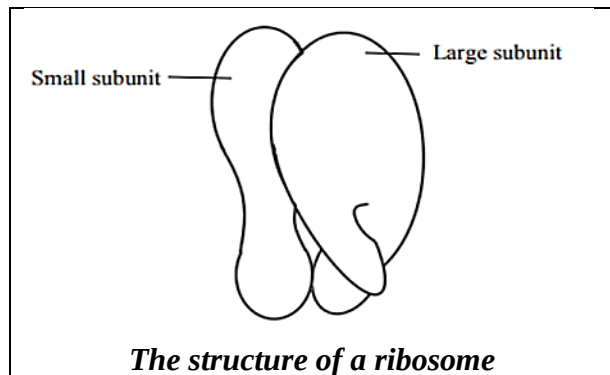
Functions of vacuoles

- The tonoplast isolates the vacuolar sap from the cytosol, enabling vacuolar pathway of water.
- Vacuoles contain coloured pigments in solution called **anthocyanins** which are largely responsible for colours in flowers, fruits, buds and leaves. These are important in attracting insects, birds and other animals for pollination and seed dispersal.
- Many plant cells use their vacuoles as disposal sites for metabolic by-products like tannins that would endanger the cell if they accumulated in the cytoplasm, which are excreted when leaves fall.
- They also serve as stores of reserve food, salts, nutrients, minerals, pigments, proteins, ions etc.
- It maintains cell turgor by osmotic uptake of water since vacuolar sap has a higher solute concentration than cytosol. This enables the cell to gain stability which brings support in non woody plant.
- The plant vacuole has a major role in the growth of the cell which elongates their vacuoles by absorbing water through osmosis enabling the cell to become larger. Vacuoles contain concentrated cell sap which provides an osmotic gradient for entry of water into the cell. In meristematic cells, vacuoles bring about growth by initiating cell elongation.
- Vacuoles are also important in osmoregulation e.g. in fresh water protozoans like amoeba and paramecium, contractile vacuoles regulate the water content of cells.
- Food vacuoles formed by phagocytosis (endosomes) enable bulk intake of food.
- Plant vacuoles contain hydrolytic enzymes and act as lysosomes. After cell death, the tonoplast like all membranes loses its partial permeability and the enzymes escape causing autolysis.

7) RIBOSOMES

Ribosomes are tiny organelles of about 20nm in diameter. They are found in large numbers throughout the cytoplasm of living cells in both prokaryotic and eukaryotic cells

and are also located on the surface of rough endoplasmic reticulum. They are a site for protein synthesis. Ribosomes on rough endoplasmic reticulum form proteins for export out of the cell e.g. hormones, etc. while those that occur freely in the cytoplasm make proteins that remain with cytoplasm e.g. dissolve in solution or form structural cytoplasmic elements.



Ribosomes are made roughly equal amounts of RNA and protein and are termed as *ribosomal RNA* (rRNA) and they are made in the nucleoli. Each ribosome consists of two sub units, one large (protein) and another small (rRNA). There are two basic types of ribosomes i.e. 70s and 80s ribosomes. The 70s ribosomes are found in prokaryotes and the slightly larger 80s ribosomes occur in the cytoplasm of eukaryotes.

8) THE CYTOPLASM

This is a jelly like matrix with in the cell in which cell organelles and structures such as insoluble waste and storage products are suspended. It is about 90% water and forms a solution which contains all fundamental biochemical of life. Such ions and small molecules include salts, sugars, amino acids, dissolved gases etc. others are big molecules

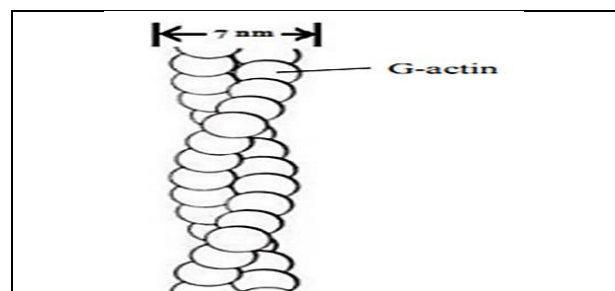
such as proteins fibres in form microfibers and microtubules, nucleus, chloroplasts for plant cell, Golgi apparatus, ribosomes etc. which form colloidal solutions. Its fluid like substance is called **cytosol**. The cytosol is a homogeneous solution but its highly organized structure that surrounds the organelles. Apart from acting as a store of vital chemicals, the cytoplasm is a site of certain metabolic pathways like glycolysis.

9) CYTOSKELETON

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. The microfilaments and microtubules are tube-like structures with a diameter of about 20 nm. They are made of proteins and are widely distributed in the cytoplasm where they occur in singly or in bundles.

a) Microfilaments

The micro filament consists of actin and myosin proteins; the actin filaments are associated with fibre involved in the movement of the cells and its organelle. They nucleate at the plasma membrane, with the cell periphery (edges) having the highest concentration.

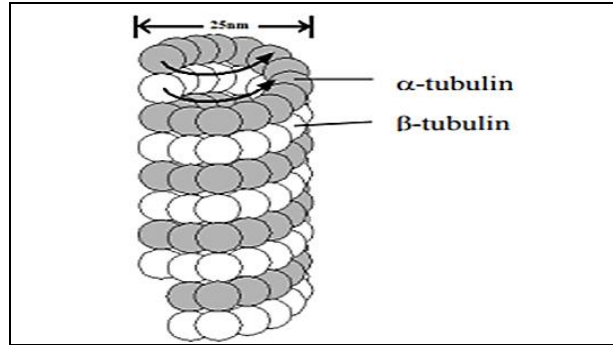


Functions of microfilaments

- They enable a dividing cell membrane to pinch off into two cells.
- Microfilaments are also involved in cell movement e.g. amoeboid movement, phagocytosis, pinocytosis, etc. They occur in the tail of sperm cell where they contract and relax because side by side lashing of the tail in order to propel the cell.
- They support the cell membrane and maintain cell shape.
- Microfilaments exist in sieve tubes of phloem vessels in woody plants. They are associated with cell motility such as cytoplasmic streaming i.e the filaments are in constant motion within the sieve tubes
- Microfilaments are associated with muscle contraction. The myosin filaments move over the actin filament in skeletal muscles in order to cause contraction of the muscle therefore thereby bringing about movement of the different parts of the body.

b) Microtubules

The microtubules consist of 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. They are found throughout the cytoplasm of all eukaryotic cells, forming part of cytoskeleton that gives structure and shape to cells.



Microtubules are easily broken down and reassembled hence they are associated with cellular movements and transport in the cell.

Functions of microtubules

- They serve as conveyor belts moving other organelles throughout the cytoplasm.
- They are the major components of cilia and flagella in cell motility.
- They form spindle fibers during cell division.
- They give shape and mechanical support to the cell.
- They enable vesicles to move during cell wall formation in plants

c) Intermediate filaments

These are a broad class of fibrous proteins whose diameter ranges between 8nm-2nm. They are smaller than microtubules and are made up of myosin proteins. Examples of intermediate filaments include;

- 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.

Functions of intermediate filaments

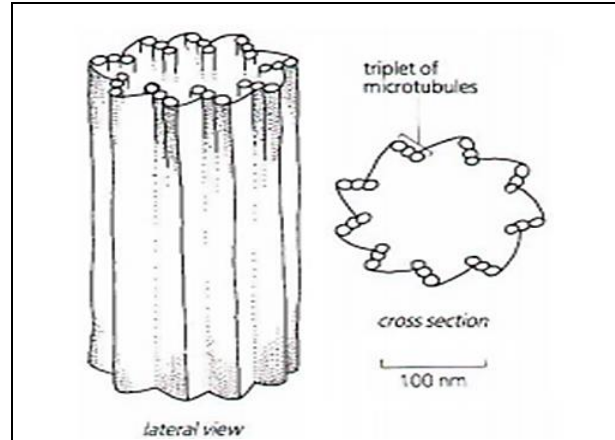
- They are tension-bearing elements that maintain cell shape and rigidity.
- They anchor in place several organelles, including the nucleus and desmosomes.
- They are involved in formation of the nuclear lamina, a netlike meshwork array that lines the inner nuclear membrane and governs the shape of the nucleus.

NOTE

The cytoskeleton is not rigid but capable of quick/ rapid movement and reorganization.

10) CENTRIOLES

They are found only in animal cells, near the nucleus in the centrosome which serves as an organizing centre for microtubules. At cell division, the centrioles replicate and migrate to opposite poles of the cell where they synthesize the microtubules which form the spindle fibres. They are hollow, cylinders, held at right angle to each other, each about $0.3\mu\text{m}$ - $0.5\mu\text{m}$ long and $0.24\mu\text{m}$ in diameter, made of nine triplets of microtubules arranged in a ring in a 9+0 pattern.



Functions of centrioles

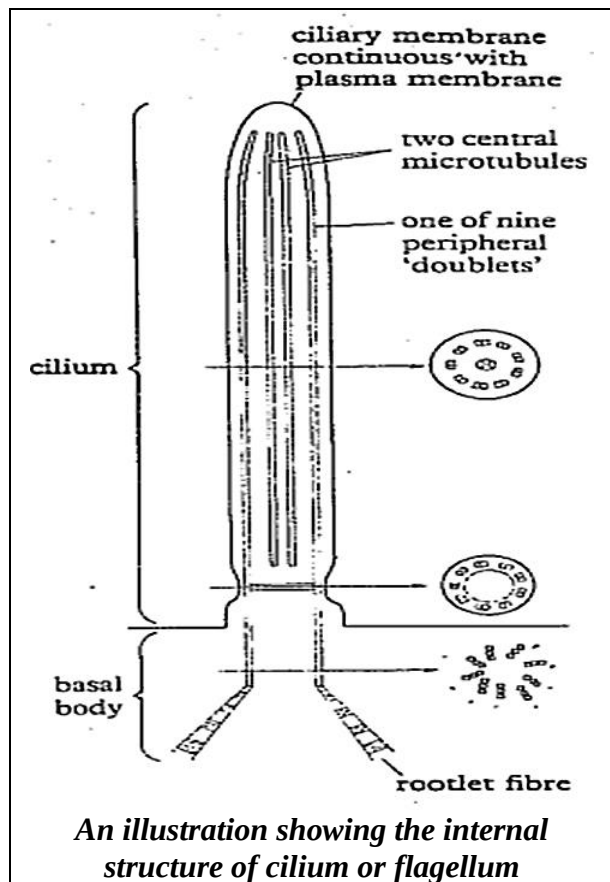
- In animal cell division, centrioles organise microtubules to form spindle fibers which separate chromosomes towards the opposite poles.
- Cellular organization; centrosomes are involved in organizing microtubules, whose position determines position of organelles e.g. nucleus
- Ciliogenesis; In ciliated and flagellated organisms, the mother centriole which becomes the basal body determines the position of these organelles.

11) CILIA AND FLAGELLA

The surface of certain cells is drawn out to form hair-like processes called **cilia** or **flagella** according to their length. Cilia and flagella are organelles that have identical structures, although flagella are longer. The flagella are fairly long with the length of about $150\mu\text{m}$ while the cilia have a length of about $10\mu\text{m}$ with a fine diameter of $0.3\mu\text{m}$

They are out growths from cells which can beat either in one direction (cilia) or like a wave (flagella). They are found in certain cells like in the paramecium which is covered by cilia and euglena which has a single flagellum which aid in the movement of the cell.

Structure of cilia and flagella



Cilia and flagella are covered by a unit membrane, which is an extension of the cell membrane. Both the cilia and flagella arise from a small granular structure called **basal body**. There is a central filament called **axoneme**. Cross sections of a cilium axoneme show that it contains a bundle of microtubules which run longitudinally along its length. These are arranged in a precise

way i.e. they are two in the centre surrounded by a ring of nine pairs called **doublets**. This arrangement is described as 9+2 pattern i.e. 2 central singlets (single microtubules) and 9 peripheral doublets (pairs of microtubules).

At the base of the cilium is an elaborate attachment apparatus consisting of a basal body from which rootlet fibres may be seen to penetrate into the deeper layers of the cytoplasm. The basal body is composed of a ring of peripheral microtubules continuous with those in the cilium itself. However, the two central microtubules are absent and the peripheral microtubules are in threes (triplets).

In animal cells, there are two rod like centrioles situated at right angles to each other which have the same structure to the cilia and flagella. Each rod contains nine triplets of microtubules but no central microtubules arranged in a ring (9+0 pattern). They are responsible for the formation of cilia and flagella.

Functions of cilia and flagella

Cilia and flagella are responsible for movement of cells and materials. For example;

- Cilia in paramecia beat rhythmically to propel the cell in a particular direction. Ciliary movement also enables the paramecium to drive food into its gullet.
- In certain molluscs, ciliary movement facilitates gaseous exchange by passing water currents over the gills

- In echinoderms, ciliary movement enables locomotion by driving water through the water vascular system.
- Cilia lining the respiratory tract of humans beat rhythmically to expel foreign bodies such as microbes and dust particles towards the nose or mouth preventing them from reaching the lungs.
- Cilia in nephridia of annelids e.g. earthworms removes wastes
- Flagella in bacteria, euglena and sperm cells beat side by side to propel the cells forward.
- The oviduct is lined by ciliated epithelial cells whose cilia beat rhythmically to propel mature egg towards the uterus.

12) CELL WALL

This cell organelle is found in prokaryote, fungi and plant cells although their chemical composition differ as prokaryote cells consist of **murein**, fungi cell walls are composed of **chitin** while plant cell walls consists of **cellulose**. The cell wall is secreted by the living cell (protoplast) within the cell. It is tough; usually flexible/bendable/fairly rigid; of variable thickness [1µm-10µm]. The plant cell wall consists of 3 main layers (regions) i.e.

- ❖ Middle lamella; this is the outermost layer and it binds adjacent plant cells together. It is rich in calcium and magnesium, pectates and proteins
- ❖ Primary cell wall; is generally a thin; flexible and extensible. It consists mainly of cellulose, microfibrils, hemicelluloses, pectin, water, and proteins. In plant epidermis it is usually impregnated with cutin and wax; to form an impermeable barrier called **plant cuticle**
- ❖ Secondary cell wall; in some cells there is the secondary cell wall inside the primary cell wall. It 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 coincide 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;

Functions of the cell wall:

- It provides mechanical strength and skeletal support for individual cells and for the plant as a whole.
- Cell walls are fairly rigid and resistant to expansion and therefore allow the development of turgidity.
- Orientation of cellulose micro fibrils limits and helps to control cell growth and shape.
- The system of interconnected cell walls is major path way of movement for water and dissolved mineral salts by the apoplast pathway.
- Cell walls develop a coating of waxy cutin, the cuticle on exposed epidermal surfaces reducing water loss and rise of infection.

- The walls of xylem vessels and sieve tubes are adapted for long-distance translocation of materials.
- The cell walls of root endodermal cells are impregnated with suberin that forms a barrier to water movement. Suberin also acts as physical barrier to pathogens; and water loss.
- Some cell walls are modified as food reserves as in storage of hemicelluloses in some seeds.
- 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.

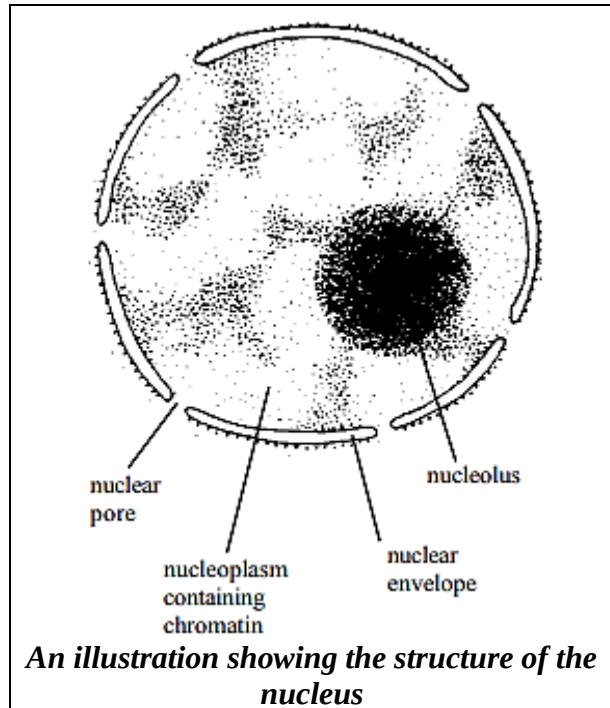
Adaptations of the cell wall to its functions

- Its 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, and cell wall maturation.
- The extreme rigidity of secondary wall provides compression strength

- Deposition of cellulose fibrils in alternating layers enables some degree of flexibility
- Its semi-permeable nature allows exchange of water, dissolved salts and small protein molecules

13) NUCLEUS

This is a prominent organelle that's oval in shape with a diameter of about 10 µm. It is surrounded by a double membrane called the **nuclear envelope** which is continuous with endoplasmic reticulum. It is perforated by **nuclear pores** which allow exchange of substances between the nucleus and the cytoplasm. The nuclear pore has a definite structure formed by fusion of the outer and inner membrane of the envelope and controls the passage of molecules through the passage. Enclosed within the inner membrane is the **nucleoplasm** (karyoplasm), **nucleolus** and **chromosomes** (chromatin). The nucleolus is a dense, spherical shaped structure; Chromosomes (chromatin) are thread-like and are grouped into two i.e. **Heterochromatin**: stain darkly, genetically inactive, tightly coiled and **Euchromatin**: loosely packed, genetically active and enriched. The nucleus is found in all eukaryotic cells except in mature phloem sieve tubes and mature red blood cells. Normally a cell contains one nucleus except in some protozoa like paramecium which possess two nuclei i.e micronucleus and macronucleus.



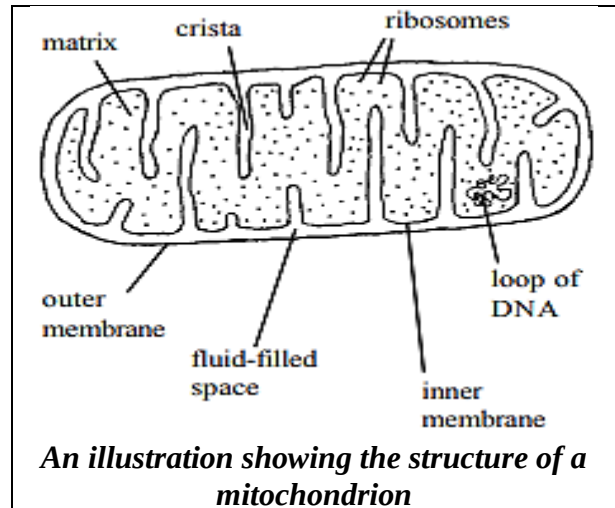
Functions of nucleus:

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

14) MITOCHONDRIA

These are embedded in the matrix of the cytoplasm and are found in all eukaryotic cells. Their shape and size vary but generally they are sausage shaped with a diameter of about $0.5\text{ }\mu\text{m}$ – $1\text{ }\mu\text{m}$, length of $2.0\text{ }\mu\text{m}$ - $7\text{ }\mu\text{m}$. Cells which require large amounts of energy contain large numbers of mitochondria which are often packed

together in the part of the cell where energy is required. They are found mostly in spermatozoa, liver cells, contractile fibrils in muscles e.g. flight muscles in birds and insects, and on the surface of cells where active transport take place.



Each mitochondrion is bounded by two membranes, the outer being separated from the inner by a narrow space called **intermembranal space**. The inner membrane is highly folded giving rise to a number of partitions called **cristae** which project into the interior. The cristae increase the surface area and provide space for the components of the respiratory chain located in the membrane. The inside of the mitochondria is made up of an organic matrix consisting of numerous chemical compounds like phosphate granules and co enzymes for energy release in form of ATP, small sized ribosomes, proteins, lipids and traces of the circular DNA. The matrix is a site where reactions of the Krebs' cycle occur and act as a sight for oxidative phosphorylation and electron transport system. The mitochondrion has

mitochondrial ribosomes and is capable of self-replication since it has its own DNA and synthesis of its own proteins.

Functions of the mitochondria;

The mitochondrion is an organelle where a process of respiration takes place particularly around its cristae. Some of the reactions take place in the matrix of the mitochondrion while others occur in the inner membrane.

Adaptations of mitochondria to its functions;

- The inner membrane of mitochondria is highly folded to cristae where by increasing the surface area for electron transport chain for production of large amount of energy (ATP). It also contains stalked particles that make ATP
- Mitochondria contain many enzymes, hydrogen acceptors and electron transport system that are used in energy production. Enzymes such as sillinale dehydrogenase etc. realize energy production within the matrix.
- Mitochondria contain small ribosomes which carry out protein synthesis by providing a firm support to messenger RNA to reduce on importing proteins from cytoplasm.
- 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

- Narrow intermembranal space enables H^+ ion concentration gradient to be rapidly established for chemiosmosis to occur
- DNA is present to act as genetic material for synthesis of some protein.

15) PLASTIDS

These are small organelles in the cytoplasm of plant cells, containing pigments or stored food material. These include;

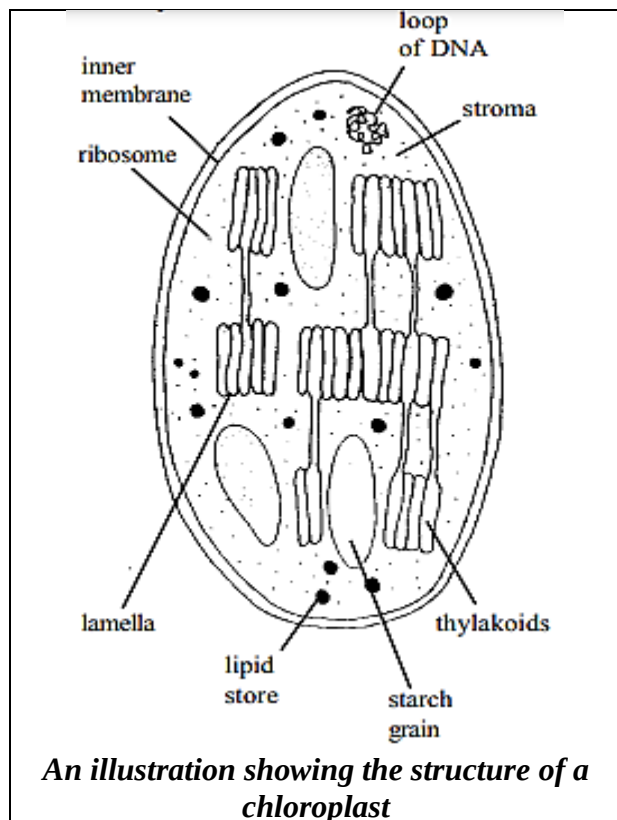
- a) **Proplastid:** these are undifferentiated organelle which develops into plastid.
- b) **Etioplasts;** these are colourless in absence of light, turn into chloroplasts on exposure to light
- c) **Chloroplasts** (*chloros* - green); these manufacture carbohydrates by photosynthesis. Chloroplasts form **chromoplasts** contain xanthophyll or carotenes, hence the yellowing in fruits, vegetables, and leaves.
- d) **Leucoplasts** are colourless and include: **amyloplasts** that form and store starch in tubers of roots and stem, **elaioplasts** that form and store oil and **proteoplasts** that store crystalline proteins in plant seeds.

CHLOROPLASTS

This is a double membrane bound organelle found mostly in a plant cells and eukaryotic algae cells.

Chloroplast shape and size vary from biconvex in higher plants with length of about 5 μm to filamentous in algae, spherical, ovoid, etc. It is enclosed by an

envelope of double membranes; the outer membrane is semipermeable while the inner membrane regulates entry and exit of materials to the chloroplast, and is a manufacturing centre for fatty acids, lipids and carotenoids. The intermembranal space is narrow between 10 nm-20 nm in between the outer and inner membranes.



Inside the chloroplast are numerous structures called **thylakoids**. Each thylakoid consists of interconnected, pair of membranous sacs with a narrow space between them containing chlorophyll. The thylakoids are distinguished into two regions namely;

- a. **Granum** which is a group of adjacent thylakoids neatly aligned in a group form piles (~10-20). It is

rather like a stack of coins with a diameter of about 600 nm. The grana also give structural support and determine the shape of the chloroplast.

- b. The **intergranal lamella** occurs between two or more grana which are slightly further apart.

The thylakoid membrane possesses chlorophyll and other pigments that absorb light and increase the surface area for light trapping. It also holds the chlorophyll molecules at right positions to trap maximum sunlight. The thylakoids are embedded in a semi-gel like, alkaline matrix called **stroma** which contains the enzymes responsible for the reduction of carbondioxide, chloroplast DNA, 70S ribosomes and numerous starch granules. The light dependent stage of photosynthesis occur on the thylakoid membrane where enzymes catalyzing light are found and light independent reactions occur in the stroma where carbondioxide is reduced to starch.

Function of chloroplast;

It's an organelle where process of photosynthesis takes place producing sugars and other substances from carbondioxide and water.

Adaptations of chloroplast to suit its function;

- It's surrounded by transparent membrane to allow light pass through.
- It has a ground matrix called stoma where the dark stage of photosynthesis takes place. It

possesses abundant enzymes that catalyse photosynthetic reactions in the stroma.

- The stoma contains starch granules which acts as temporary store for starch.
- The thylakoids are also numerous in numbers to increase surface area where the light stage of photosynthesis takes place. Its thylakoids also contains a green pigment called chlorophyll which traps sunlight.
- The grana are inter-connected with intergranal lamellae to increase the surface area for trapping sunlight for the process of photosynthesis.
- Its outer membrane is semi-permeable to regulate entry and exit of substances for maintaining internal chloroplast environment.
- The narrow intermembranal space enables H^+ ion concentration gradient to be rapidly established for chemiosmosis to occur
- 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

16) MICRO VILLI

Micro villi are minute finger like projections. Each micro villus is a very thin finger- like process about 1.0 μm long and 0.08 μm wide. It is lined with the plasma membrane and filled with cytoplasm which is continuous with the main body of the cell.

Cells that bare micro villi are responsible for material absorption. It has already been mentioned that one function of the plasma membrane is to permit the entry of materials into the cell hence the greater the surface area of the plasma membrane, the greater the exchange of materials across it. The micro villi increase the surface area for absorption of sufficient amounts of materials. Some of the micro villi contain microfilaments and undergo squeezing, worm-like movements, thereby creating a pumping effect which aid absorption. They are found on the membrane of certain cells such as those of the epithelium and proximal convoluted tubules of the kidney nephron responsible of absorption of materials. However microvilli are not invariably associated with absorption.

CELL SIZE

There is a limit to the size of an individual cell with a single nucleus. The size of the cell is limited by the ratio of the surface area of the cell membrane and the nuclear membrane to the cell volume.

FACTORS THAT DETERMINE CELL SIZE

The following are the factors that determine the cell size;

a) Surface area to volume ratio; exchanging materials

A living cell is constantly exchanging substances with its environment. The speed at which substances diffuse in and out depends on the cell surface area but the amounts of those substances that are needed depend on the cell volume since the volume

increases more rapidly than its surface as the cell becomes large.

A cell that grows indefinitely can reach at a point at which it uses substances more quickly than it can obtain hence cellular activities could stop or slow down. This places the upper limit on the size of the cells. Above that size, the number of molecules required by the cell could not be transported into the cell fast enough to sustain its needs. Hence:

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

b) Nucleo-cytoplasmic ratio

The same limitation applies to the size of the nucleus which exchanges substances with the cytoplasm across the nuclear membrane. 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. If the nucleus stayed the same size while the cytoplasm grew larger, there would be problems of controlling the outer regions of the cytoplasm distant from the nucleus. This problem can be overcome by the cell having several nuclei i.e becoming **multinucleated** / **coenocyte** e.g. skeletal muscle cells and fungal hyphae.

c) 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

d) 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 plus maintaining the cell shape.

SUB-TOPIC 2: DIVERSITY OF SPECIALISED CELLS AND TISSUES

SUB TOPIC OUTLINE

- *Levels of organisation: cell, tissue, organ and organ system*
- *Advantages and disadvantages of being unicellular*
- *Advantages of a multicellular state*
- *Function and adaptations of epithelial tissues*
- *Specialised cells and tissues: xylem, phloem, tracheids, sclerenchyma, collenchyma, parenchyma, connective tissue and skeletal tissue.*

DIVERSITY OF CELLS AND SPECIALIZATION

Although cellular structures like chromosomes, mitochondria, endoplasmic reticulum and ribosomes are virtually common to all cells, all cells are not identical. The shape, form and content of the individual cells show much variation as seen between different species and within single species. The structural characteristics of a particular cell are correlated to its functions. Cells are structurally specialized to perform particular tasks. In extreme case, specialization may entail loss of protoplasm or some important constituent of it but in most cases it involves the modification of the shape and form of the cell, its basic features remaining unchanged.

However, most organisms adopted another solution to the transport problem of being large, their bodies consist of more than one cell, and they become **multicellular**. Being multicellular not only enables organisms to become larger, it also enables their cells to become specialized. Each cell can no longer have the ability to carry out all the activities necessary to sustain life. Cells may become specialized in feeding, support or defence.

Advantages of specialization in cells

- This division of labour among cells makes multicellular organisms more efficient and enables them to exploit modes of life not available to single celled organisms.
- Specialization also allows increase in the size of an organism and development of more developed organs like muscles and bones in animals.
- More specialization also means more sophisticated physiological mechanisms can be developed which allow a constant body temperature to be maintained independent of the surrounding environment.

Disadvantages of specialization in cells

Specialization often makes individual cells to lose their ability to carry out some functions for example a mature human red blood cell; specialized to carry oxygen lacks a nucleus. This means that it cannot reproduce. Therefore cells of multicellular organisms lose some of their independence.

TYPES OF LEVELS OF ORGANISATION

There are four levels of organisation in organisms which include;

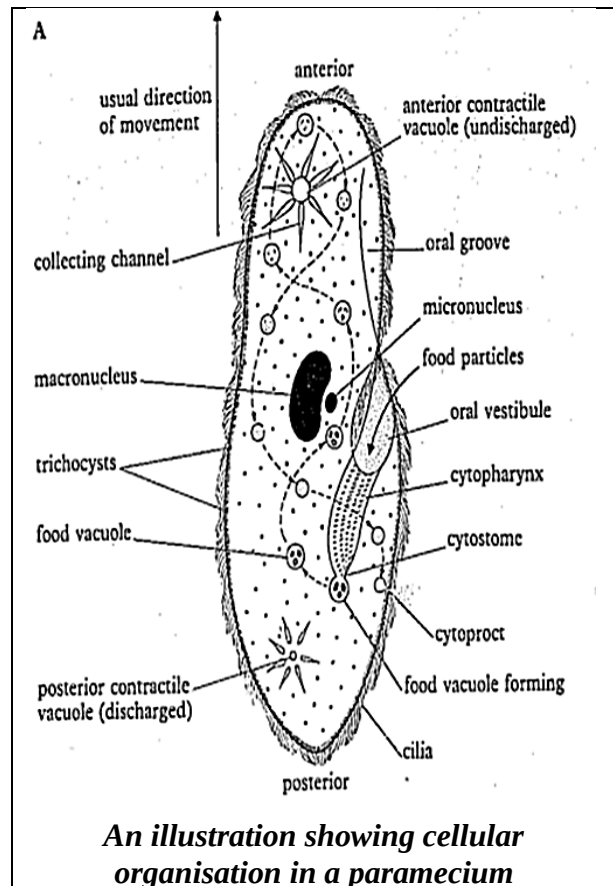
- Unicellular organisation
- Tissue organisation
- Colonial organisation
- Organ and organ system

UNICELLULAR ORGANIZATION

In unicellular organisms, the single cell has to carry within itself all functions. The cell contains many organelles; each organelle has its own role, involving its own specialised structure and chemistry. The cell itself is divided into compartments. This compartmentation is often achieved by membranes. Most organelles are surrounded by membranes so that each membrane-bound organelle can have its own particular unique set of chemicals and chemical reactions.

Organelles in unicellular organisms e.g. paramecium take over the functions carried out by organs in multicellular organisms. The cilia are responsible for movement and sweeping food into the oval vestibule and food vacuoles formed at the base of the **cytopharynx**. Digestion occurs in the cytoplasm and undigestible remains are expelled through the **cytoproct**. The contractile vacuole carries out osmoregulation while the **trichocysts** contain needle-shaped threads that are for defense. The macronucleus exercises control over metabolic functions including growth, whilst the micronucleus is necessary for sexual reproduction. Therefore, the organization of

the body of paramecium tends to be as efficient as the organ level of multicellular organization.



Advantages of unicellular level of organisation

- Their small size enables living in a variety of habitats
- There is less food intake
- There is no need for the development of complex excretory organs since they take in less food.
- No necessity for development of complex circulatory and gaseous exchange structures since simple diffusion combines with their large surface area to volume ratio

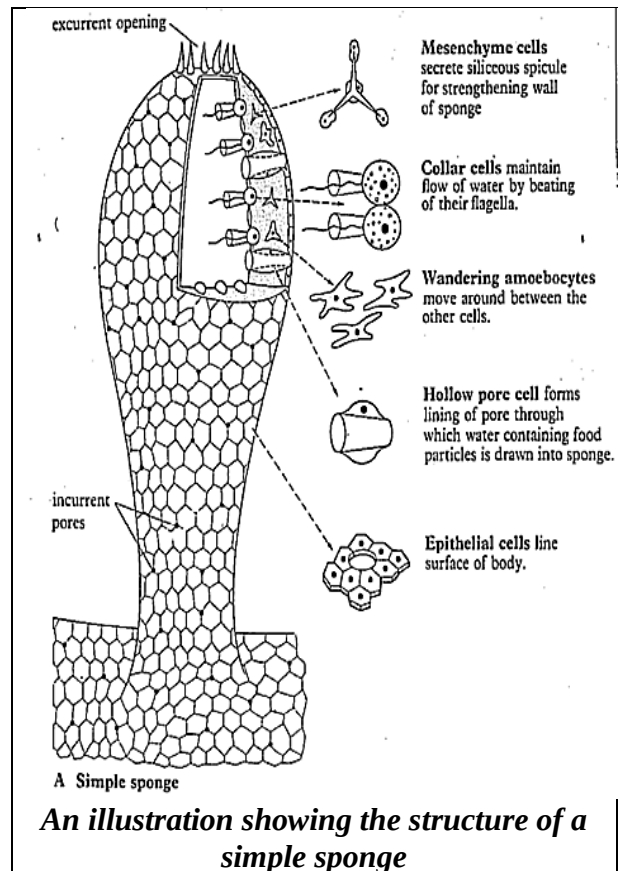
- There's no need for development of complex support systems like cartilage, bones, xylem e.t.c.

COLONIAL ORGANISATION

Some animals must have more than one cell but when this occurs independently it is referred to as a colony of single cells e.g. in sponges. The first colonies may have risen when individual cells failed to separate after cell division. Within colonies, each cell is capable of carrying out all the essential life processes. If separated from the colony, any cell is capable of surviving independently.

If each cell in a colony loses its ability to carry out a vital process, it can only survive by relying on other cells in the colony to perform the process on its behalf. The loss of one function however may permit the cell to perform one or other of its functions efficiently because the energy and resources required by the missing function could be directed towards the remaining ones. In this way, the individual cell in the colony could have different from one another in both functions and structure, a process called **differentiation**. Further changes of this type finally result in cells performing a single function (specialization). With increasing specialization, and the consequent loss of more and more functions, any cell becomes increasingly dependent on others in the colony for its survival. This interdependence of cells must be highly organized and coordinated so that the colony carries out its activities efficiently, a process called **integration**. Once cells become so dependent on each other, they are no longer capable of surviving independently. Then

the structure is no longer a colony but a **multicellular organism**.



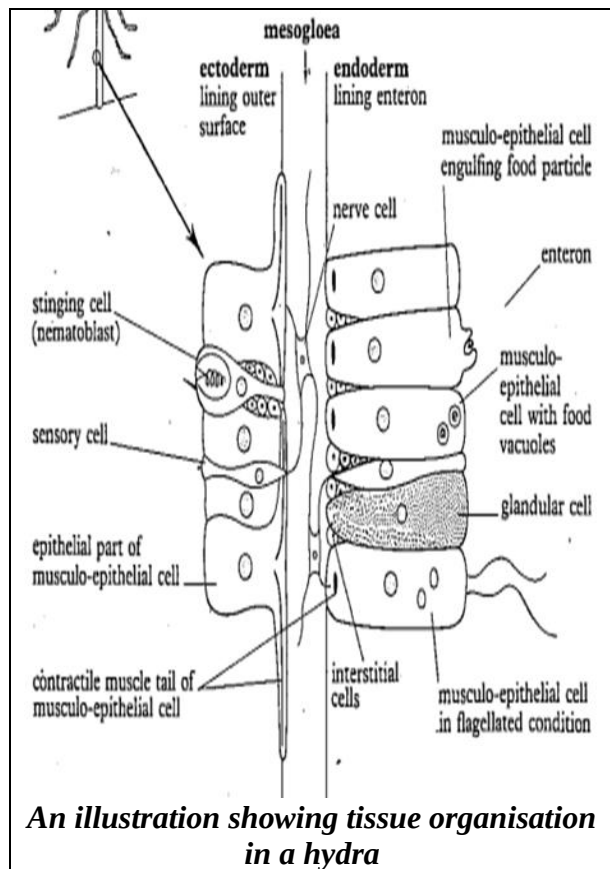
A simple sponge consists of five types of cells: flattened **epithelial cells** and hollow **pore cells** at the surface, numerous **flagellated collar cells** lining the internal cavity, spicule-secreting **mesenchyme** cells and **amoeboid** cells which move about in spaces between the other cells.

TISSUE ORGANISATION

In most multicellular organisms, groups of cells of the same type associate together to form **tissues**. A tissue is a group of similar cells along with any intercellular substance which performs a particular function. Working as a group of cells is often more

efficient than working individually. Animals that fall under tissue level of organization include cnidarians such as hydra, sea anemone. Apart from reproductive organs, these organisms have few organs as such; physiological processes are carried out mainly by isolated cells and tissues.

Structure of a hydra



Hydra represents a group of primitive multicellular organisms. The wall of hydra's simple sac like body is composed of seven different types of cells arranged in two sheet-like layers, the **ectoderm** and **endoderm**. Most of the cell types particularly the **musculo-epithelial cells** and nerve cells are integrated to form tissues. It has a few types of cells which engulf food

and carries out movements and the stinging cell (**nematoblast**) for defense and killing their prey. These cells are connected by nerve cells and therefore coordinating its activities. The **nerve cells** are used for detecting and recognizing changes in the environment. The contractile musculo tails of musculo-epithelial cells are used as muscles to bring about movement. The **glandular cells** secrete mucus for attachment onto objects and also secrete enzymes for digestion of food.

ORGAN AND ORGAN SYSTEMS

An organ is a structural and functional unit of a plant or an animal. It comprises of a number of tissues which are coordinated to perform a variety of functions although one major function often predominately. Organs are structurally distinct parts of the body made up of several types of tissues performing a particular function e.g. the kidney contains blood, smooth muscles, connective tissues and several types of epithelial tissues all combined to carryout excretion.

Most organs do not function independently but in groups. Several organs which perform a specific function form an **organ system**, for example, the digestive system is made up of the gut and various accessory glands like pancreas and the liver. Sometimes an organ belongs to more than one system like the pancreas is found in the digestive system playing an important role in digestion and also in the endocrine system. Animals have elaborate organs and organ systems as compared to plants; however the plants have the leaves as organs for photosynthesis and

flowers as reproductive organs. Other organs include the bulbs and corms which are storage or vegetative organs.

Advantages of multicellular level of organisation

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

Disadvantages of multicellular level of organisation

- They require large quantities of food
- They require specialised locomotory structures to enable motion
- They produce a large quantity of waste products hence a necessity for development of complex excretory systems
- They have a small surface area to volume ratio that requires development of transport systems since simple diffusion cannot supply enough nutrients to satisfy the needs of each individual cell.

HISTOLOGY

Histology is the study of tissues. A tissue is a group of cells linked together to perform a particular function. In multicellular organisms, cells of one or more types are generally massed together to form **tissues**. The cells in a tissue act together to perform a common function because working together as a group is often more efficient than working independently.

A tissue may combine with other tissues to form an **organ** for example muscle tissue, nerve tissue and connective tissue work together in the heart. An organ is a group of tissues that carry out a particular function.

CLASSIFICATION OF TISSUES

There are two main types of tissues i.e. plant and animal tissues.

ANIMAL TISSUES

There are 4 major groups of animal tissues i.e.

- i) Epithelial tissue
- ii) Connective tissue
- iii) Muscular tissue
- iv) Nervous tissue

EPITHELIAL TISSUES

They are comprised of a single or several shifts of cells held together by intercellular substances. The individual cells are firmly attached to a **basement membrane** made up of collagen fibres and have a free surface. The basement membrane is produced by the epithelial cells themselves and consists of a mesh-work of protein fibres embedded in a

jerry like “cement”. The epithelium on the surface of the body comprises of the **epidermis**. In some animals e.g. arthropods the epidermis secretes a protective cuticle of varying thickness and hardness.

Epithelial cover inner and outer surfaces where they always have a protective function against mechanical injury such as abrasion or pressure. The cells may be linked by keratin to resist abrasion and divide rapidly to replace cells that are worn out. Other epithelia protect against water loss.

Classes of epithelial tissues

Animal epithelial tissues may be classified in various ways; by the shape of cells, or by the number of cells layers present. There are two groups namely;

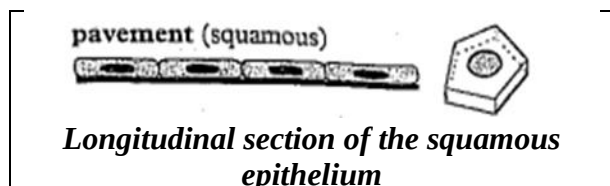
- Simple epithelial tissues
- Compound epithelial tissues

SIMPLE EPITHELIAL TISSUE

Simple epithelial tissues are one cell thick. They include:

1. Squamous epithelial

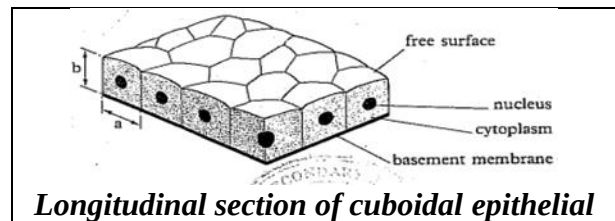
Cells form a single layer attached to a basement membrane. In surface view, the cell outlines are irregular and closely packed. The cells are thin, shallow and flattened. Adjacent cells may be joined by strands of cytoplasm.



Such epithelia form structures and surfaces over which diffusion can occur hence are important in the alveoli of the lungs, Bowman’s capsule and in capillary walls. Their smooth surface provides a friction free lining for blood vessels.

2. Cuboidal/cubical epithelial

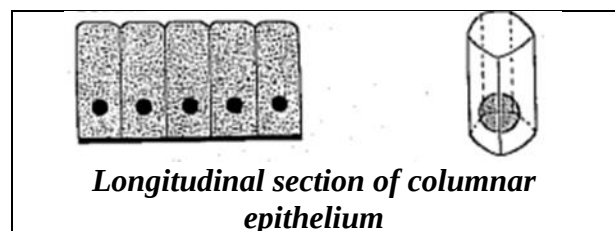
Its cells are cuboidal and form a single layer attached to a basement membrane.



Such epithelium has a secretory function in glands like thyroid, sweat and salivary glands. It also has a non-secretory function e.g. the lining of the kidney collecting tubules, proximal and distal convoluted tubules, pancreatic ducts, etc.

3. Columnar epithelium

Columnar epithelium consists of elongated at right angles to the basement membrane. The cells are tall and narrow with a nucleus near their base. Their surface area is increased by micro villi at the free end.

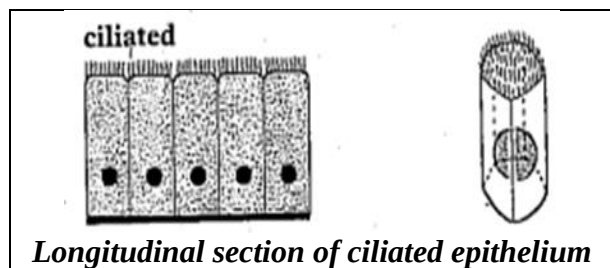


Such cells are mostly found in areas that have an absorptive role. Secretory goblet cells are found within the columnar cells.

This tissue is found lining the digestive system where secretion of mucus and absorption of food takes place. It is also found lining the kidney ducts and the thyroid glands.

4. Ciliated epithelium

It comprises of columnar cells with cilia at their free edges capable of beating rapidly and rhythmically. They have many mucus secreting goblet cells present.



The combination of mucus and cilia allows substances to move through ducts e.g. in the oviduct, trachea, spinal cord, bronchus and bronchioles where it moves materials from one location to another. In some animals like the flatworms, the cilia play an important part in locomotion.

5. Pseudostratified epithelium

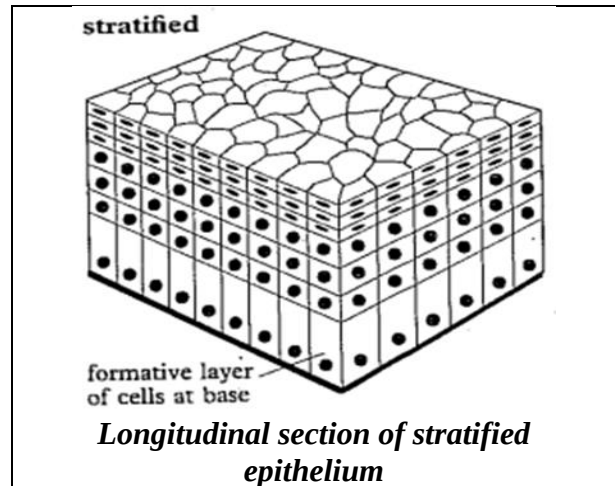
The nuclei of this type of epithelium appear to be at several different levels because not all the cells reach the free surface. Nevertheless, the epithelium is still one layer or one cell thick with each cell attached to a basement membrane. It is found lining the urinary tract and respiratory passages e.g. bronchi.

COMPOUND EPITHELIAL CELLS

Compound epithelial cells are more than one cell thick. They include;

1. Stratified epithelium

It is made of many layers of cells and therefore thicker than the simple epithelium and forms a germinating layer and they undergo cell division. As new cells form, older ones are pushed near to the surface changing shape and flattening to form squamous.



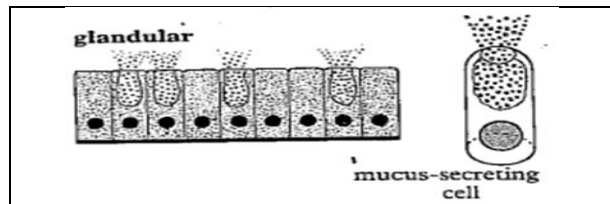
The squamous may remain un keratinized as in the oesophagus or may be heavily thickened with keratin (**cornified**) e.g. the skin where there is a dead layer of cells, and are continuously replaced from below like those found lining inside the mouth and vagina. Therefore they are for protection from abrasion to areas exposed to wear and tear.

2. Transitional epithelium

It is found in structures which must stretch e.g. the urinary bladder and parts of the kidney. It comprises of 3 or 4 layers of cells which may be flattened towards the surface which are not shed like those of the stratified epithelium. Transitional epithelium lacks a basement membrane.

GLANDULAR EPITHELIUM

This is where epithelial cells are interspersed with secretory cells. Glandular epithelia secrete materials into the cavity or space which it happens to be lining. In the intestines, the columnar epithelial cells are large numbers of cells which secrete mucus into the lumen. The mucus is protective and its lubricating action facilitates the movement of solid matter along the intestine.



In epithelial cells there may be individual glandular cells which aggregate forming a **multi-cellular gland** whose sole function is secretion. Such epithelia may be folded to increase the surface area from which secretion takes place. Some glands have ducts through which their secretions are released to the surface of the epithelium (exocrine glands) while others are ductless and their secretions are released directly into the blood stream (endocrine glands). The cells making up a gland may be **mucocytes** producing mucus or **celocytes** producing a fluid containing enzymes. A mixed gland has both types of glandular cells.

Glandular epithelium shed their secretions in different ways e.g

- Mucus and sweat are released from the free surface of the cells
- Some glandular epithelia shed their secretions by the top part of the cell,

loaded with the secretion breaking away from the rest of the cell e.g in mammary glands.

- In some few cases e.g sebaceous glands in the skin, the entire secretory cell disintegrates and is shed from the epithelium.
- Sometimes, the membranes between adjacent cells break down resulting in the formation of a thin multinucleate sheet of tissue known as **syncytium** e.g in skeletal muscle fibres.

GLANDS

In case of glands, the glandular epithelium invaginates to form a sac which may show various levels of branching. Branching in glands has the effect of increasing the surface area from which secretions can take place

CLASSIFICATION OF GLANDS

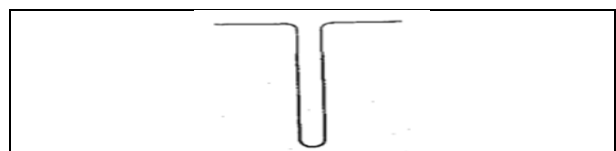
Under this classification, the glands are either simple or compound.

(a) SIMPLE GLANDS.

These have got a single unbranched duct. They include;

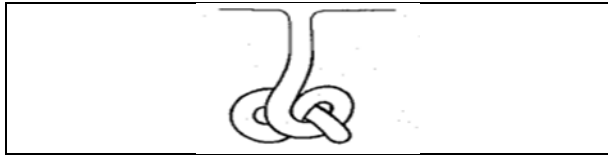
(i) Simple tubular glands

These have got single straight and tubular secretory portion e.g crypts of lieberkuhn in the walls of the ileum and large intestines.



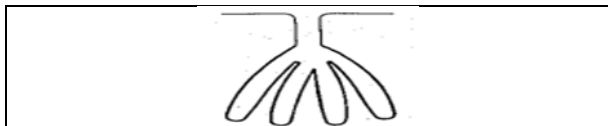
(ii) ***Simple coiled tubular glands***

Each gland consists of a simple tube which is highly coiled e.g sweat glands in the skin of man.



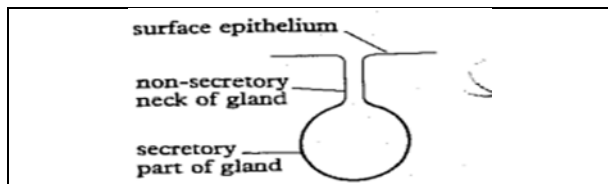
(iii) ***Simple branched tubular glands***

Each gland consists of several tubular proteins which converge in to a single branched duct. For example, Brunner's gland in the wall of the small intestines in mammals, gastric glands in the wall of mammalian stomach.



(iv) ***Simple alveolar (secular) glands***

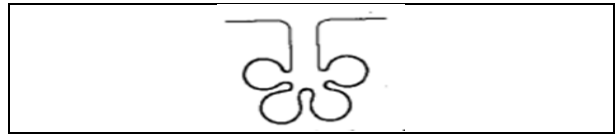
Here each gland is a secretory portion and is round or like sac-like e.g mucus secreting glands in the urethra of the penis and mucus glands in the skin of the frog.



(v) ***Simple branched alveolar glands***

Each gland consists of several secretory acids which empty into a simple excretory

duct. Examples include sebaceous gland in a mammalian skin.



(b) **COMPOUND GLANDS**

These are exocrine glands with a branched duct system. Their secretory portions have similar structural forms to those of the simple glands and tubular forms may be found together draining into the same duct system, they include;

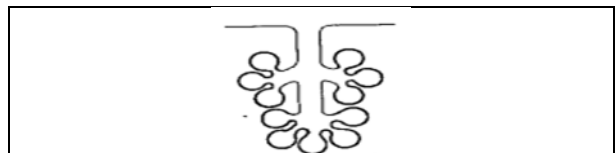
(i) ***Compound tubular gland.***

The secretory portions of these are of tubular form which is branched e.g salivary glands, Brunner's glands in mammalian bodies.



(ii) ***Compound adnar (secular) glands***

Have round secretory units which drain in to a branched duct. E.g. mammalian glands, exocrine gland of pancreas.



(iii) ***Compound tubulo-alveolar glands***

These are got in secretory ducts which consist of branched tubular components,

branched alveolar components with alveolar end piece.

ENDOCRINE / DUCTLESS GLANDS

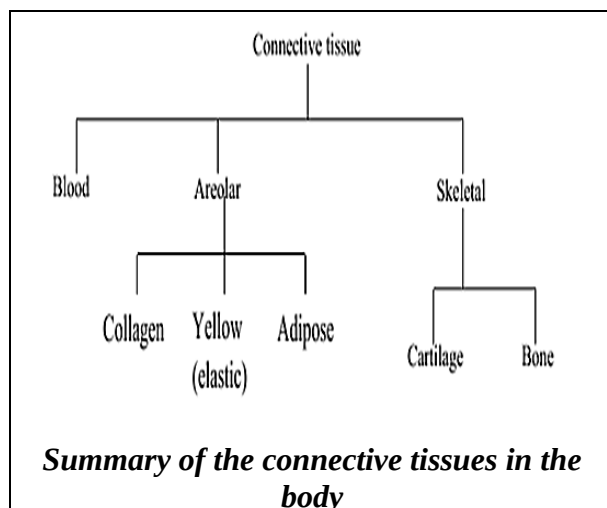
These are glands without ducts. Their secretions are released directly in to the blood stream. These glands consist of clumps of secretory cells surrounded by a network of blood capillaries. The secretory products are released into the extra cellular fluids surrounding the capillaries from where they are absorbed in to the blood stream e.g thyroid gland ovaries, testis, islets of Langerhans of pancreas, placenta, parathyroid glands attached to the thyroid gland etc.

Revision question

Explain how epithelial tissue is adapted to its functions.

CONNECTIVE TISSUE

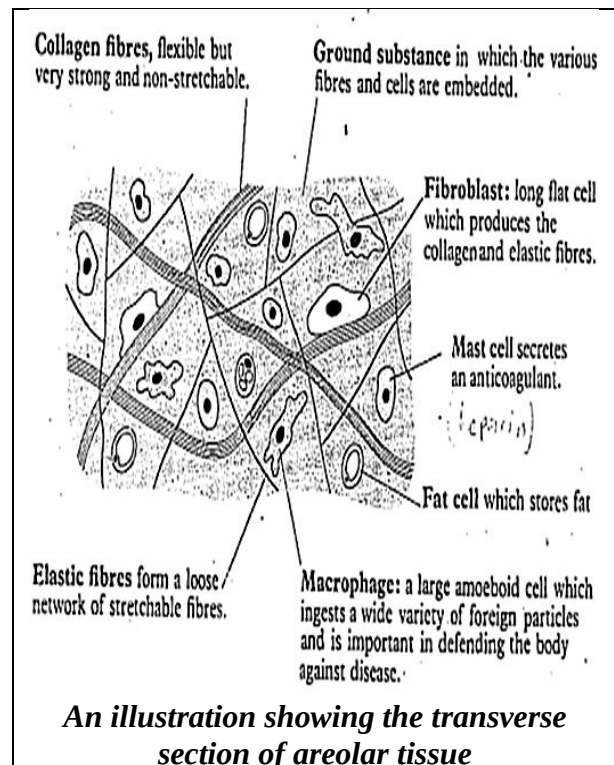
It is composed of a variety of cells embedded in a large amount of intercellular substance called **matrix** or **ground substance** in which a variety of structures may be embedded.



Connective tissues develop in the embryonic mesoderm. The connective tissue binds organs and tissues together. It functionary fills space, supports and holds structures in position. From their functions, connective tissues must be strong.

AREOLAR TISSUE

This is one type of connective tissue found all over the body i.e. beneath the skin connecting organs together and filling spaces between adjacent tissues.



Areolar tissue consists of a gelatinous glycoprotein matrix containing four types of cells and two types of protein fibres.

The areolar cells include:

- i) Fibroblasts:** These are long flat cells which synthesize collagen and elastic fibres.

- ii) **Mast cells:** These are amoeboid in shape or oval shaped and contain granular cytoplasm. They secrete fats filled cells and an anticoagulant or ground matrix or substance and macrophages.
- iii) **Fat cells:** These are fats storing cells which accumulate fats in the body structures to form the adipose tissue. They are also responsible for fat metabolism.
- iv) **Macrophage or histocytes:** These are amoeboid cells which are large which ingest a number of foreign particles hence are important in defense against foreign bodies.

The fibres present in areolar tissue give it its strength and toughness. There are two types of fibres in areolar tissue:

- a) The unbranched collagen fibres/white fibres: these appear parallel to each other and are arranged in bundles. They are responsible for strength of tissues since they are flexible and stretchable. They are mainly found in tendons.
- b) Branched elastic fibres/the yellow fibres: these form a dense network of fibres. They cross the matrix. The structures are stretchable and maintain elasticity of the tissue. They are found in ligaments.

Revision question

- a) *What are the main features of the epithelial tissue*
- b) *Draw a well labeled drawing of the areolar tissue and state its function.*

DERIVATIVES OF AREOLAR TISSUE

Three other types of connective tissues are derived from areolar tissue and only differ from each other in the structures present in the matrix. These include;

COLLAGEN TISSUE/ WHITE FIBROUS TISSUE:

This consists of glycoprotein matrix containing densely packed collagen fibres. Collagen fibres consist of three polypeptide chains coiled round each other to form a triple helix. The chains are interlinked by hydrogen bonds and the whole structure is tough and inextensible. Collagen tissue has fibres which are inelastic and have a high tensile strength and contain fibroblasts between rows of fibres. They are found in areas where great strength and less flexibility are required e. g. in the tendons where they attach muscles to bones. They are also found in the Dura matter of the brain and in the cornea of the eye.

ELASTIC TISSUE/ YELLOW FIBROUS TISSUE:

This consists of a glycoprotein matrix containing only elastin fibres running parallel to each other. Elastin consists of interconnected globules within the polypeptide chains arranged randomly. It is strong, elastic, branched and interspread by fibroblasts. Such tissue is found in areas which require strength and elasticity for example in ligaments where it binds bones to other bones. It is also found around the walls of arteries and it is also found as a component of the lungs and associated air passages as well as in the great cords of the neck.

NOTE

Collagen and elastin fibers are non-living derivatives of cells and both are fibrous proteins. Collagen consists of three polypeptide chains coiled round each other to form a triple helix while elastin consists of interconnected globules within the polypeptide chains arranged randomly.

ADIPOSE TISSUE (FATTY TISSUE)

This contains closely packed fat filled cells known as **adipocytes**. Its functions are storage of fats and it is a site for energy production. The fats are deposited in a number of parts of the body e.g. the dermis of the skin where it insulates the body against heat loss. There are two types of adipose tissue;

i) White adipose tissue:

The white adipose tissue is called so because the cells appear white due to accumulation of fats. It is distributed throughout the body particularly the deep layers of the skin.

ii) Brown/ yellow adipose tissue:

This is commonly in young mammals and some hibernating mammals. It is important in temperature regulation. It is supplied with blood capillaries and appears red. It differs from the white because of;

- ❖ It's coloured and has limited location in the body e.g. it is found around the neck.
- ❖ The fats in brown adipose remain as small droplets i.e. do not form big globules.
- ❖ The nucleus of the cell remains centrally placed.

NOTE

The efficiency in binding structures together by connective tissues is achieved by the molecular configuration of the protein molecules. The particular type and abundance of fibre present is related to the stresses and strains to which the tissue is subjected.

BLOOD TISSUE

In blood, the matrix is the watery plasma which carries a variety of different cells. The cells present include:

ERYTHROCYTES (RBC)

These are biconcave in structure. They lack nucleus and are formed in red bone marrow. Their main function is transport of oxygen within the body. They contain red pigment haemoglobin which combines with oxygen to form oxy-haemoglobin; the form in which oxygen is transported in the body.

LEUCOCYTES (WBC)

They are larger and nucleated and most of them are made in the bone marrow while others are made in the lymph nodes and in the thymus gland. Their main role is defense of the body. There are two types of white blood cells, i.e.

a) Granulocytes:

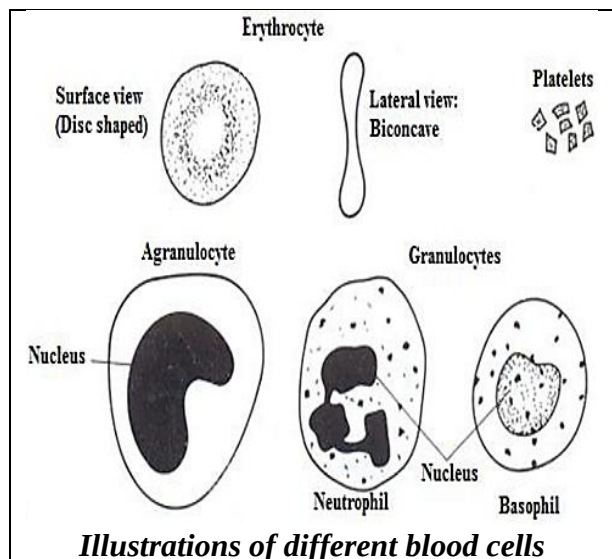
They have granular cytoplasm with a lobbed nucleus and engulf bacteria by phagocytosis.

b) Aggranulocytes:

They have a non-granular cytoplasm with a compact nucleus. Most of them also ingest bacteria. They are produced from the lymph nodes and thymus glands and are known as lymphocytes. Their function is the produce anti bodies.

PLATELETS (THROMBOCYTES)

These are tiny cell fragments important in blood clotting.



FORMATION OF BLOOD CELLS

The process of formation of erythrocytes is known as **haemopoiesis** and the tissue which forms then is known as haemopoetic tissue. In the fetus, erythrocytes are formed in the liver and spleen. In an infant all bones contain haemopoetic tissue. In adults, erythrocytes are formed in the bone marrow of the bones of the pelvis, sternum, vertebrae, clavicle, scapula and skull.

During the process of formation of cells, the bone marrow undergoes two major changes;

- The amount of haemoglobin increases in the cytoplasm.
- There is progressive loss of nuclear material and reduction in the size of the cell. A mature erythrocyte does not contain the nucleus and almost the entire cell is filled with haemoglobin.

NOTE:

- The erythrocytes are nucleated at infant/fetal stage.
- Iron and proteins form the basic raw material for haemoglobin synthesis. Vitamin B₁₂ and folic acid stimulate the maturation of erythrocytes.
- WBC like lymphocytes are formed in the thymus gland and lymph nodes whereas the other types of WBC are formed in long bones e.g. the limb bones which have white bone marrow.

SKELETAL TISSUE

The skeletal tissue is responsible for supporting the body and providing it with a rigid framework. Like connective tissue, it consists of cells embedded in an organic matrix which is comparatively hard. It is made up of cartilage and bone.

CARTILAGE (GRISTLE)

The matrix of cartilage is made up of organic matrix called **chondrin** in which chondrocytes are embedded. Chondrocytes are the cells that secrete the matrix and may occur singly, in pairs or groups of four, eight etc. the matrix is compressible and elastic and is able to absorb mechanical shocks. It is surrounded by a dense layer of cells or tough flexible tissue known as **penchondrium**.

The structure of cartilage is hard but flexible and it is highly adapted to resist any strains that are placed upon it. It is found at the ends of bones, respiratory passages e.g. trachea and parts of the ear. It comprises the

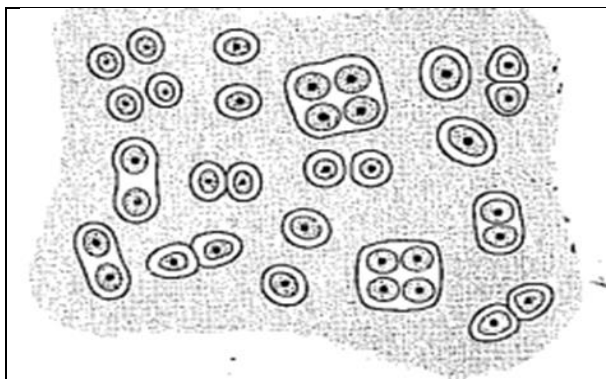
skeleton of cartilaginous fish e.g. sharks, dogfish and rays.

Cartilage can become complex by containing a large number of collagen fibres making it stronger and less flexible; such types of cartilage make up the intervertebral discs while that in the nose and pinna of the ear contains elastin fibres. The collagen fibrils resist any tension which may be imposed on the tissue.

Types of cartilage

i) Hyaline cartilage

Hyaline cartilage is an elastic compressible tissue located at the end of bones, and in the nose, respiratory tract (trachea, bronchi and large bronchioles). It consists of only chondrin and chondroblasts which are embedded in the lacuna. It is glassy in appearance and has very few fibres. It is not supplied with blood vessels and hence depends on diffusion. Hyaline cartilage is also bounded by fibrous layer known as perichondrium in which there are blood vessels. This type of cartilage forms the basis of growth and development in embryos. It reduces friction in areas where it is found.



ii) Fibrous/ tensile cartilage

This has got many fibres not as flexible and elastic as those of hyaline. It is adapted to resist compression due to presence of large bundles of collagen fibres. Its functions are to allow flexibility and reduce friction. It is also found in the intervertebral discs and around the pubic bones of the pelvis. It also provides a cushioning effect around areas it occurs.

iii) Yellow elastic cartilage

This has a network of yellow elastic fibres surrounding the chondroblasts. It is more flexible and elastic than all the other types of cartilage and can recover shape after distortion. It is found in the epiglottis, respiratory tract, the nose and the pinna of the ear supporting the Eustachian tube and the external auditory parts.

Functions of a cartilage

- It is a cushion between bones i.e. acts as shock absorbers e.g. intervertebral discs.
- It is used to reduce friction in joints
- It is the starting material for growth and development of bones.
- It is a supporting tissue in cartilaginous fish.

THE BONE TISSUE

This is a skeletal tissue which is very hard and made up of matrix impregnated with inorganic salts. The cells are embedded in a firm, calcified matrix with about 30% organic material (collagen fibers and glycoproteins) and 70% inorganic salts. These salts confer upon bone its property of extreme hardness.

The structure of the bone is specifically designed to withstand the compression strains falling upon it and to resist tension. Bone reabsorption and reconstruction processes enable a particular bone to adapt its structure to meet any change in the mechanical requirements of the animal during development. Calcium and phosphate may be released into the blood as needed under the control of two hormones namely; Parathormone and calcitonin

Types of bone tissue

The bone tissue is divided into two namely;

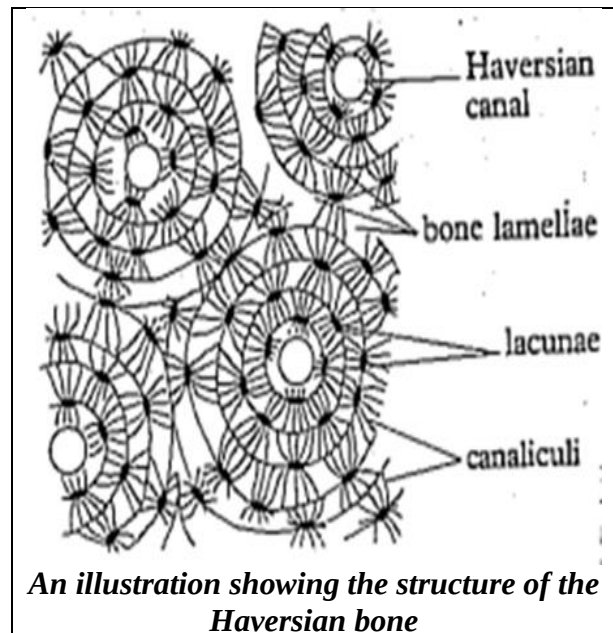
- Compact (Haversian bone)
- Spongy bone

Compact (Haversian) bone

The ostein matrix of bone is made up of collagen together with inorganic substances such as hydroxyapatite together with quantities of calcium, magnesium, sodium, carbonates and nitrates. The combination of organic with inorganic materials produces a structure of great strength. Such components are covered by a tough fibrous membrane called **periosteum**. They are arranged in concentric circles called lamellae which are cylindrical to increase length surround the Haversian canal containing an artery, lymph vessels and nerve fibres. Between the lamellae are numerous lacunae containing living bone cells called **osteoblasts**. They lay down the inorganic components of the bone. As osteoblasts mature, they become less active and contain reduced quantities of cell organelles called **osteocytes**.

Radiating from each lacunae are many fine channels known as **canaliculi** contain

cytoplasmic processes that link the lacunae to another and blood vessels passing through them provide means by which osteoblasts exchange materials. Canaliculi also pass from one lamella to another.



The system of lamellae surrounding the **Haversian canal** is known as the **Haversian system** (osteon). An artery and a vein run through each Haversian canal and capillaries branch from here and pass via the canaliculi to the lacunae of that osteon. They allow the passage of nutrients, respiratory gases and metabolic wastes towards and away from the cells. A Haversian canal also contains a lymph vessel and nerve fibers. Transverse Haversian canals communicate with the marrow cavity in the centre of the whole bone and also interconnect with the longitudinal Haversian canals. These contain large blood vessels and are not encircled by concentric lamellae. Haversian bone is found in the shafts of long bones such as femur and humerus.

Spongy bone

This is less compact and hard as compared to Haversian bone. It possesses a network of interconnected thin bone structures called **trabeculae**. It is less organic and in between the trabeculae is soft marrow tissue. Spongy bone is found in the swollen ends of the long bones in the epiphyses.

Functions of bones

- It is a framework for supporting the body weight
- It provides shape to the body.
- It provides the surface area for attachment of muscles.
- It protects the delicate parts of the body e.g. rib cage
- It acts as reservoirs for minerals such as calcium and phosphorus.
- It is responsible for producing of red blood cells and white blood cells.

Revision question

- a) Draw a well labeled diagram to show the microscopic structure of the compact bone in transverse structure.
- b) State three structural adaptations of compact bone as a suitable skeletal tissue.
- c) Compare the bone and cartilage.

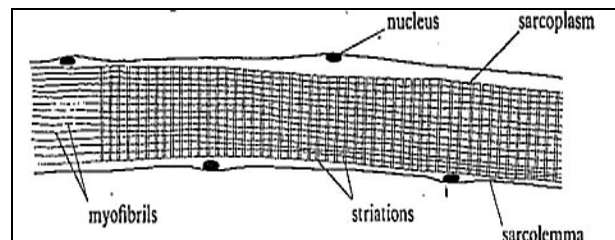
MUSCULAR TISSUE

There are 3 main types of muscular tissue all made up of cells and fibres which are capable of contraction. They are derived from the mesoderm of the embryo. They include:

- 1) Voluntary muscles.
- 2) Involuntary muscles.
- 3) Cardiac muscles.

a) VOLUNTARY MUSCLES

They consist of numerous multi-nucleate cylindrical muscle fibres. The muscle fibres have alternate light and dark band or striations due to the banding pattern and arrangement of thin filaments called myosin filaments which do not extend the whole length of the muscle but consist of functional units called **sarcomeres**. Each multi-nucleate muscle fibre is contained in a plasma membrane called the **sarcolemma** surrounding cytoplasm called **sarcoplasm**. The sarcoplasm contains thousands of myofibrils with characteristic striations, numerous mitochondria and smooth endoplasmic reticulum.



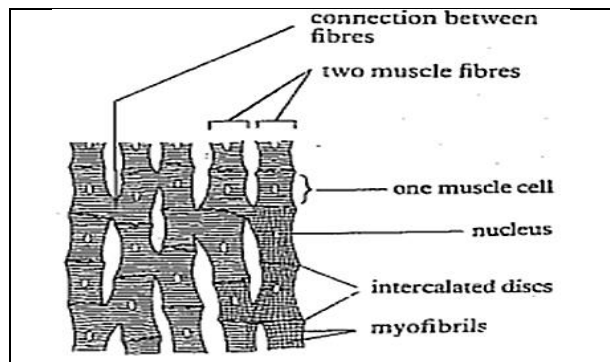
Groups of fibres are bound by a thin film of connective tissue and the whole muscle is bound by a sheath of connective tissue. Blood vessels run longitudinally besides the fibres with many capillary connections and every muscle cell is served by a motor nerve ending in a motor end plate. Its contractions are quick, powerful and voluntary with a short refractory period. They are attached to the skeleton.

b) INVOLUNTARY MUSCLES

It consists of densely packed and elongated fibres running parallel to each other and bound by connective tissue. Each muscle fibre is a single cell containing one nucleus. There are numerous fine contractile fibrils which are made up of thin actin filaments and thick myosin filaments. There is no cross striations in the muscle fibres and each muscle fibre are served by its own nerve cell. These muscles contract rhythmically and do not fatigue easily and their action is controlled by the autonomic nervous system. They are found in places where slow, involuntary movements take place such as the alimentary canal, walls of blood vessels, ducts of glands, and tubes of urino-genital system. It is also found in the dermis of the skin.

c) CARDIAC MUSCLE

It is a specialized muscle found inside the heart. It is capable of rhythmic contraction over a long period of time. Cardiac muscle is **myogenic** and its contraction is stimulated from within the heart itself.



Each muscle cell has one or two nuclei. Their cells have a network arrangement which allows waves of contraction to spread

rapidly over the heart. The **intercalated discs** are reinforced cell membranes and serve as tough junctions between the myofibrils of successful cells.

NERVOUS TISSUE

It is derived from the embryonic ectoderm. It is comprised of closely parked nerve cells called **neurons** with little intercellular space that are specialized for conduction of nerve impulses. Neurons are bound together by connective tissue.

NEURONS

These are the functional units of the nervous system. Neurons are capable of transmitting electrical impulses between receptors and effectors. There are three types of neurons namely; sensory, intermediate and motor neurons.

a) Sensory neuron

These conduct impulses towards the central nervous system (The brain and spinal cord). The nerve endings at the right hand end connect with sensory cells (receptors) and the dendrites in the left hand end connect with nerve cells in the CNS.

b) Intermediate neuron

These are found in the CNS and connect two neurons together (motor and sensory neurons). The dendrites connect up with sensory neurons or neurons in the CNS.

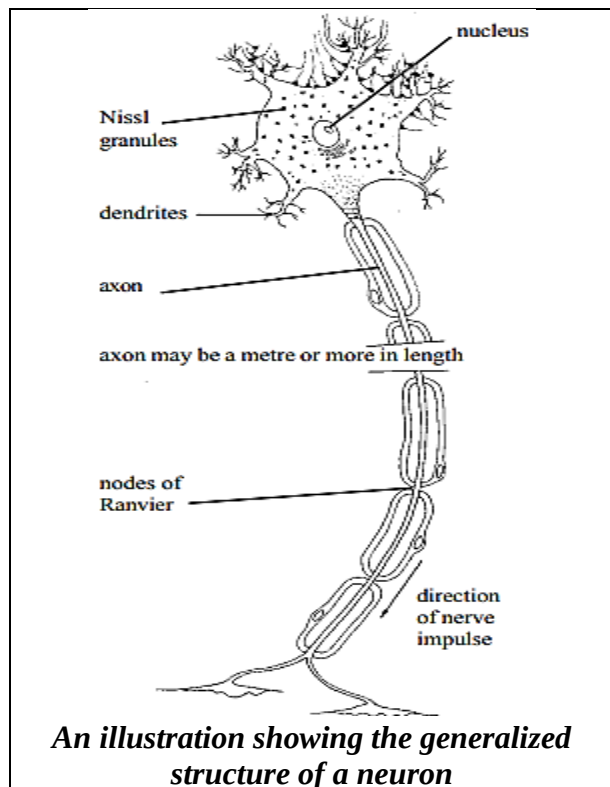
c) Motor neuron

These conduct impulses away from the central nervous system. The dendrites make contact with neighboring neurons in the

CNS. The terminal dendrites at the end of the axon connect up with muscle fibres.

STRUCTURE OF A NEURON

Each neuron possesses a **cell body** which contains a nucleus, Nissl's granules (a group of ribosomes), and RER associated with protein synthesis. Nerve fibres which conduct impulses towards the cell body are called **dendrons**. They are small, relatively wide and break into fine terminal branches called **dendrites**. Nerve fibres that conduct impulses away from the cell body are called **axons**. The end of an axon breaks up into many fine branches with swollen endings called **synaptic knobs**.



Some nerve fibres are completely surrounded and insulated by a fatty **myelin sheath** formed by Schwann cell. The cell

surface of the Schwann cell becomes extended and wraps itself round the nerve fibre. It is mainly a lipid lacking the proteins normally found in membranes. The cytoplasm remains in the region called **neurilemma** around the myelin sheath. Being lipid, the myelin sheath prevents the movement of Na^+ and K^+ in and out of the nerve fibre. This movement is needed to conduct nerve impulses; however it is interrupted at regular intervals by **nodes of Ranvier**. The node occurs between the Schwann cells.

PLANT TISSUES

Plant tissues may be simple or compound.

SIMPLE PLANT TISSUES

These consist of one type of cell in one layer. They include;

a) MERISTEMATIC TISSUE

Structurally the simplest plant tissue is **meristematic tissue**. This occurs at the apical growing points of a plant, for example the tip of the stem and root. Meristematic cells are small, thin walled and lack sap vacuoles and chloroplasts. But they contain undifferentiated plastids whose membranes are the site of intense synthetic activity. Their important feature is their ability to divide and subsequently differentiate into specialized cells.

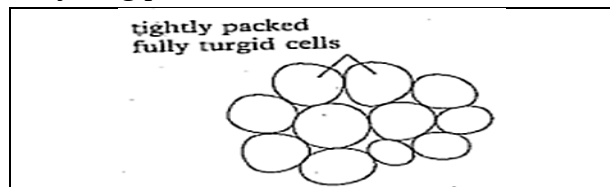
b) EPIDERMAL CELLS

Epithelial cells are located at the surface of a plant. Somewhat flattened and often irregular in shape, epidermal cells form a protective layer covering the more delicate

tissues beneath. They lack chloroplast and outer cellulose walls are frequently thick and impregnated with waxy materials forming a *cuticle* that is impermeable to water and prevents excessive evaporation.

c) PARENCHYMA TISSUE

The parenchyma tissue is a packing tissue consisting of rounded cells tightly together, so as to fill spaces between other tissues. The cells are unspecialized and metabolically active. Its cells are usually spherical though sometimes distorted by pressure from adjacent cells. They are found in the cortex of stems and roots, pith, packing tissue in vascular bundles and bulky in young plants.



Functions of parenchyma tissue

- Parenchyma tissue stores food (storage tissue)
- When tightly packed and turgid, parenchyma tissue provides support in herbaceous plants.
- Some are photosynthetic (parenchyma cells) are known as *chlorenchyma*.
- The epidermis is a specialized parenchyma capable of forming a waxy cuticle of cutin that prevents desiccation.
- Parenchyma also forms guard cells within the lower epidermis.

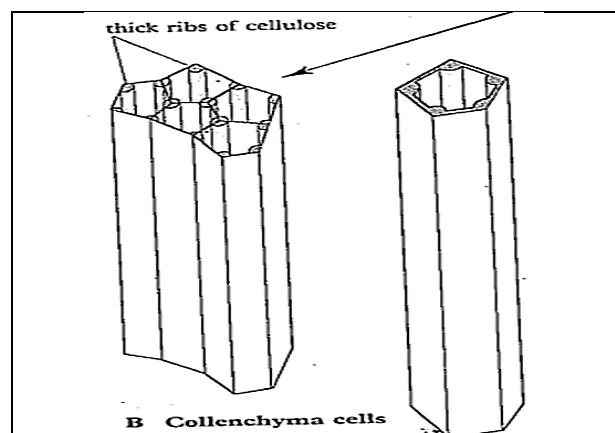
- In roots, cellular hairs near root tips are also made up of parenchyma tissue that assists in water uptake.
- They are used for gaseous exchange because of the presence of intercellular spaces.
- They are important pathways of water and mineral salts.

d) MECHANICAL TISSUES

They are grouped according to the degree of thickening present in the cell wall. Such tissues are found in the midrib and veins of leaves where their function as in stems is to provide strength and support. They are less abundant in roots except in specialized with that involved in providing support. They are mainly of two types i.e. collenchyma and sclerenchyma.

Collenchyma tissue

Collenchyma tissue consists of living cells modified for support and mechanical strength.

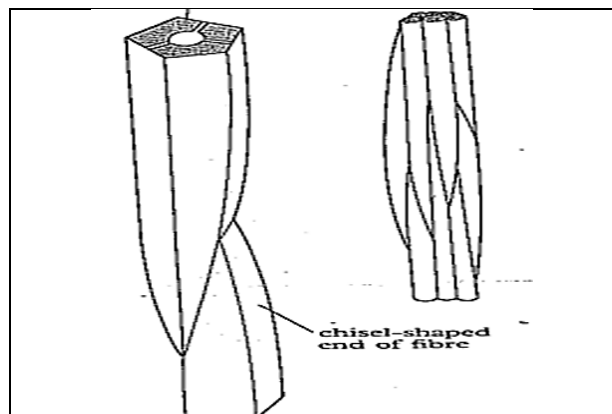


The cells are highly packed together and are made up of cell walls which have additional cellulose deposited in the corners to provide

additional strength. They are elongated and important in growing since they can stretch. They are found in the outer region of the cortex just under the epidermis of the cell.

Sclerenchyma tissues

Mature sclerenchyma cells are dead and therefore not capable of growth. They develop fully when growth of the surrounding tissues is complete. Sclerenchyma cells are strengthened by lignin together with cellulose which is deposited to the primary cell wall where the cell contents are lost after wards. In some places lignin is not deposited due to plasmodesmata. Such regions are called *pits* and they interconnect adjacent cells.



Some sclerenchyma cells are spherical and known as **sclerids** which are found in small groups of seeds and fruits, cortex, pith and phloem. Their function is to toughen these structures. Elongated sclerenchyma cells called **fibres** provide the main supporting tissue of mature stems by forming a cylinder below the epidermis. They are also found in the outer region of the cortex and at peripheral of the xylem and phloem.

Revision question

- a. Describe how each of the following tissues are related to their function.
 - i. Parenchyma tissue
 - ii. Collenchyma tissue
 - iii. Sclerenchyma tissue
- b. Explain the distribution pattern of mechanical tissues in the stem and root of the dicotyledonous plants.

COMPOUND PLANT TISSUES

These are made up of different cells arranged in more than one layer. They include xylem and phloem tissues. Xylem and phloem tissues are collectively known as *vascular bundles*, which are concerned with transport in plants.

XYLEM TISSUE

It consists of parenchyma cells and fibres together with two specialized cells known as vessels and tracheids which are both dead. Vessels and tracheids serve the role of support, water and mineral salt transport from the roots to leaves.

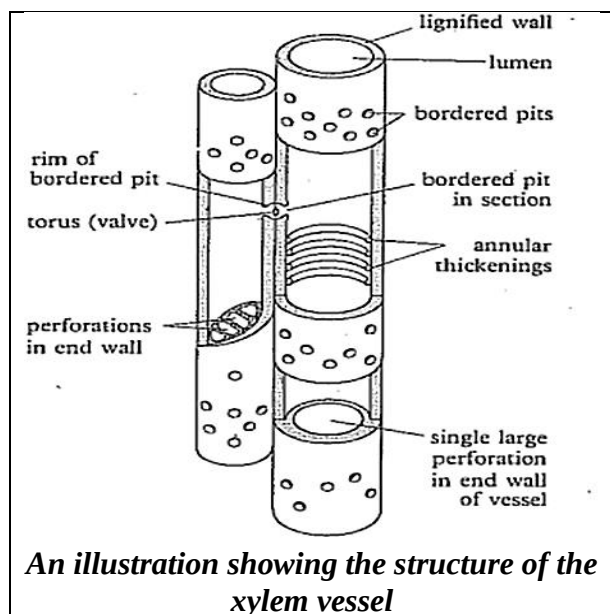
Xylem parenchyma

It has thin cellulose walls and living contents and its functions include food storage, deposition of tannins and crystals, radial transport of food and water, and gaseous exchange through the intercellular spaces.

Vessels

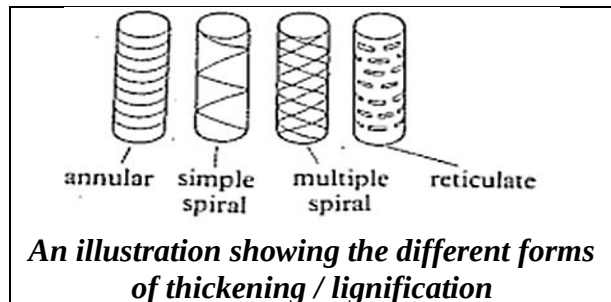
Vessels are the characteristic conducting units of angiosperm xylem. A vessel is formed from a chain of elongated cylindrical cells formed by the fusion of several cells placed end to end in a row. In the course of

development of the xylem vessels, the horizontal end walls of the cells breakdown partially or completely so that the cells are in linkage with each other. At the same time, the cellulose sides' walls become impregnated with lignin which makes them impermeable to water and salts. Lignin is not deposited over the entire cellulose wall but only in rings or in spirals. At impregnation, the protoplasmic contents die leaving a hollow tube known as a *vessel*.



Thickening/ lignification gives the vessels additional strength and prevents the walls from curving in. There are 3 main types of thickening lignification, i.e. annular, spiral and reticulate thickening. **Annular rings** develop when circular deposits of strengthening materials like lignin occur round the interior surface of the xylem. Each ring is separate from each other. **Spiral** is when helical deposits of strengthening materials like lignin occur around the interior surface of the xylem. **Reticulate** is when continuous and interconnected

deposits of strengthening materials like lignin, leaving only dotted but numerous pores through the wall without deposits. Other forms of thickening include; **scalariform** where randomly elongated patches of deposits of strengthening materials occur round the interior surface of the xylem. **Pitted** thickening is when most of the interior of the xylem has deposits of strengthening materials leaving only dotted but numerous pores through the wall without deposits.

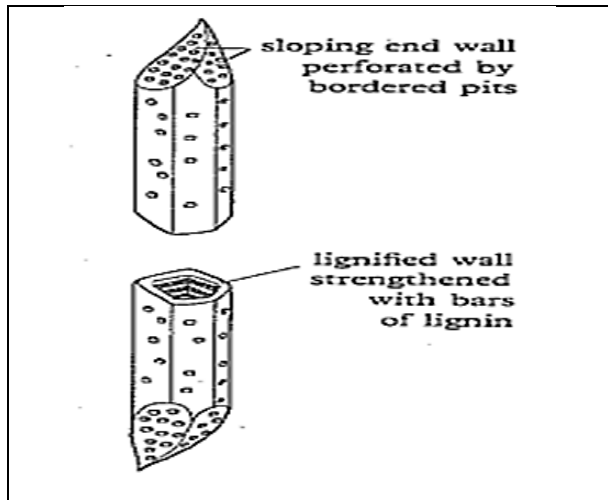


The xylem's lignified walls are perforated with pits where lignin fails to be deposited and only the primary cell wall remains. These pits allow passage of water in and out of the vessel cavity. In some cases, pits are covered by a lignified layer forming a *torus* kind of plug which controls passage of water. The type of vessel found depends on the degree and nature of the cell wall thickened. In proto-xylem, lignin is deposited in rings or spirals such that the cell can still expand

Tracheids

Tracheids are similar to vessels except that they are typically five or six sided, and instead of being open at each end, their tapering end walls are perforated by pits. The tapering end walls overlap with adjacent

tracheids thus have mechanical strength and give support to the plant. They are mainly found in conifers which rely exclusively on them to conduct water from the roots to the aerial parts.



NOTE

- Water travels through the empty lumens and from tracheid to tracheid through the pits via the pit membranes (bordered pits) or through lignified portions of the cell walls.
- Each of the cells forming a xylem vessel is equivalent to a tracheid and is called a vessel element.

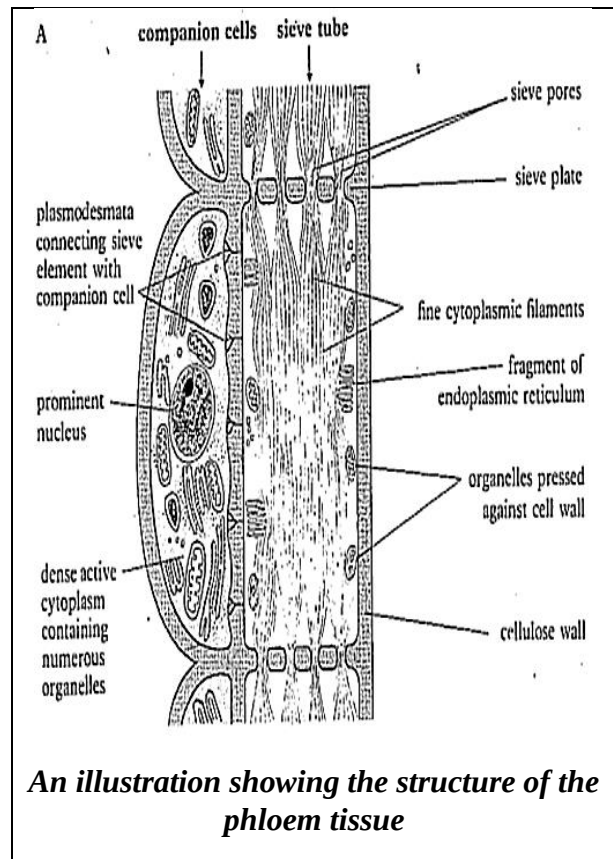
PHLOEM TISSUE

Phloem resembles xylem in possessing tubular structures modified for translocation. However, the tubes are composed of living cells with cytoplasm and have no mechanical function. This tissue comprises of parenchyma, sclereids and fibres with specialized cells for translocation known as

sieve tube elements running parallel to the long axis of the plant and companion cells.

Structure of the phloem tissue

Long sieve tubes are formed by fusion of the sieve tube elements and the partial breakdown of the cross walls between them to form sieve plates and sieve pores. Their cell walls are thickened with cellulose and pectin together with lignin. Phloem cells lack nuclei and the cytoplasm is confined in a companion cell with a nucleus. Sieve elements and companion cells are connected to each other by plasmodesmata.



Each sieve element forms a cell whose nucleus disintegrates during development. Its end walls known as the sieve plates are perforated by numerous pores (sieve pores)

which allow the passage of materials from one sieve element to the next. The inside of the sieve elements contains fine cytoplasmic filaments, mitochondria, plastids and or any other organelles that may persist adjacent to the cell wall. Close to the sieve elements are companion cells which possess a nucleus, endoplasmic reticulum, ribosomes and mitochondria. They are metabolically active and all energy needed for translocation in the sieve elements is derived from here.

Revision questions

- a. *Outline the changes in cell structure which lead to the formation of vascular tissues in higher plants.*
- b. *Give the structural differences between xylem vessels and the phloem sieve tubes.*
- c. *How is the phloem adapted to its functions?*

UNEB trial questions

1.
 - a) How is the chloroplast adapted to its functions
 - b) Describe the modifications of the parenchyma tissue in the different parts of the plant to suit its functions.
 - c) Explain the distribution of mechanical tissues in plants.
2.
 - a) Give an outline of the classification of muscular tissue.
 - b) Describe the structure of the phloem and the cardiac muscle.
 - c) Explain how the structures of the phloem and cardiac muscle are related to its functions.
3. Discuss how structure and function are related to the following tissues
 - a. Voluntary muscle tissue
 - b. Parenchyma tissue.

SUB TOPIC 3: CHROMOSOMES

SUB TOPIC OUTLINE

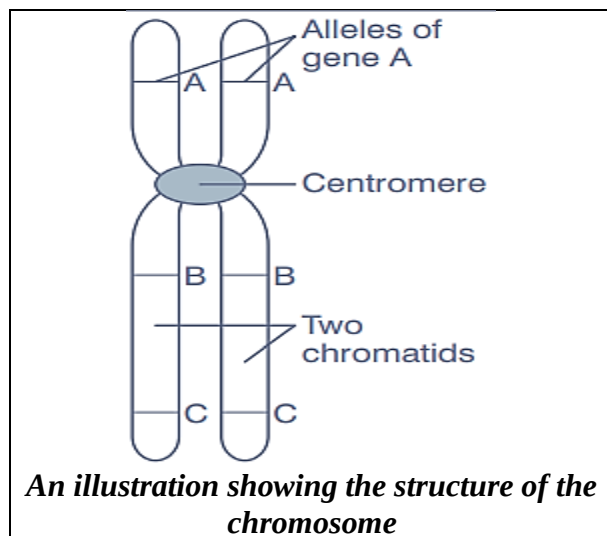
- Composition of chromosomes and structure of nucleotides
- Structure of the nucleic acids: DNA and RNA
- Differences between DNA and RNA
- The Watson - Crick hypothesis of the nature of DNA
- DNA replication
- Nature of genes
- Genetic code

CHROMOSOMES

Chromosomes are the structures that provide continuity between generations of cells. They consist of the genetic material (DNA, 15%), wrapped in proteins (70%) and RNA (10%).

Individual chromosomes are not visible in a non-dividing cell but chromosomal material can be seen if stained. This material is called **chromatin**. It is only at the onset of cell division that individual chromosomes become visible. They appear as long, thin threads about 0.25 μm and 50 μm in length.

Structure of a chromosome



Each chromosome is seen to consist of two threads called **chromatids** joined at a point called **centromere**. The **nucleic acids** in a chromosome are the carriers of the genetic information. Chromosomes vary in shape, and size both within and between species.

Chromosome number

The number of chromosomes varies from one species to another but is always the same for normal individuals in one species. If chromosomes are arranged in matching pairs according to their size and certain features, they form **homologous pairs**. Apart from the sex chromosomes, both chromosomes in a pair normally contain the same genes. However, these may be different forms of the gene.

Although the chromosomal number of a cell varies from two to 300+, the majority of organisms have between 10 and 40 chromosomes in their cells. For example; humans, *Homo sapiens* have 46 chromosomes (23 pairs), chimpanzee have 48 (24 pairs), cat, *Felis cattus* has 38 (19 pairs) and dog, *Canis familiaris* has 78 (39 pairs). One chromosome in each pair comes from the individual's mother and the other from the father.

NOTE

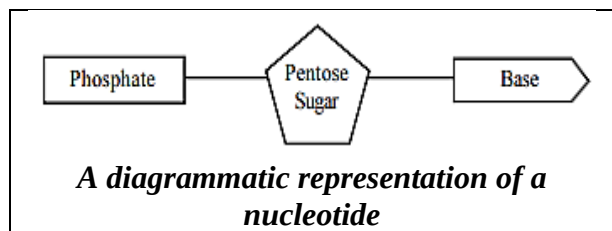
Cells that have the normal set of chromosomes are called **diploid** ($2n$). Cells that give rise to gametes (eggs and sperms) have only one chromosome of each pair, so they have half the normal number of chromosomes. Such cells are called **haploid**. (n)

NUCLEIC ACIDS

These are nitrogen containing organic acids important for making the genetic material and proteins of all organisms. Nucleic acids are made of short chains called **nucleotides**. Like proteins, nucleic acids are long chained molecules but the chains are much longer than those of proteins and the subunits more complex than amino acids. Therefore nucleic acids are called polynucleotides. Nucleic acids include **Deoxyribose Nucleic Acid** (DNA) and **Ribonucleic acid** (RNA). DNA is found mainly in the nucleus of the cell with some small amounts in cytoplasmic organelles such as mitochondria in the cytoplasm particularly in the ribosomes.

THE STRUCTURE OF NUCLEOTIDES

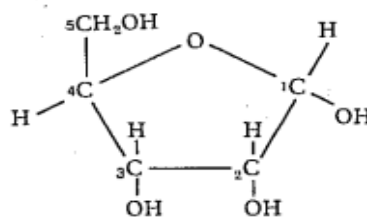
A nucleotide is made up of 3 components namely, pentose sugar, a nitrogenous base and a phosphate derived from phosphoric acid i.e. all nucleotides contain phosphoric acid.



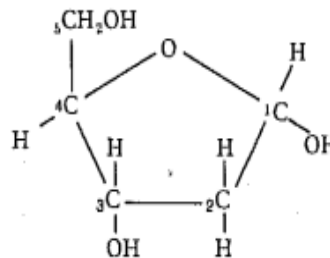
a) Pentose sugar

A pentose sugar consists of a five membered ring of five carbon atoms and one oxygen atom to which various side groups are attached. The pentose sugars in nucleic acids are of 2 types namely; **ribose** sugar in RNA and **deoxyribose** sugar in DNA. The only difference between these two sugars is that deoxyribose lacks an oxygen atom on the second carbon atom in the ring; hence the name *deoxyribose*.

Ribose sugar



Deoxyribose sugar

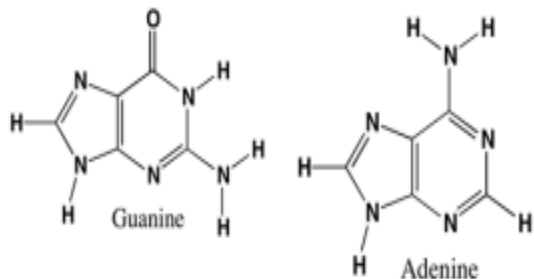


b) Nitrogenous bases

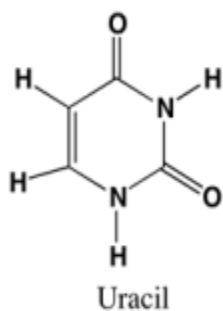
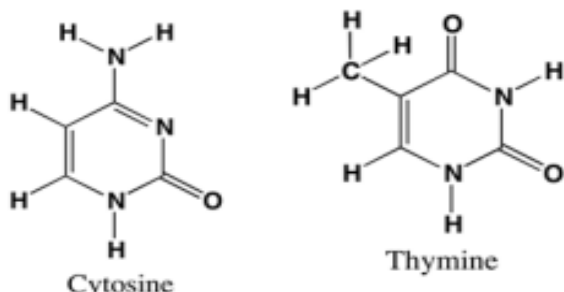
Each nucleic acid contains four different bases of which two are derived from **purines** and another two are derived from **pyrimidines**. The nitrogen in the rings gives the molecules their basic structure. Purines have two rings in their structure while the pyrimidines have one ring in their structure i.e. purines are larger than pyrimidines.

The pyrimidines include; **Cytosine** (C), **Thymine** (T) and **Uracil** (U) while the purines include; **Adenine** (A) and **Guanine** (G). These bases are commonly represented by their initial letters A, G, C, T and U.

These organic bases are structurally simplified by the following structures:



Illustrations showing the structure of the purines

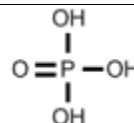


Illustrations showing the structure of different pyrimidines.

The hydrogen atom projecting from the nitrogen plays an important role in the building of the nucleotide.

C) Phosphoric acid

This acid gives the acid character to nucleic acids and its structure is shown below;

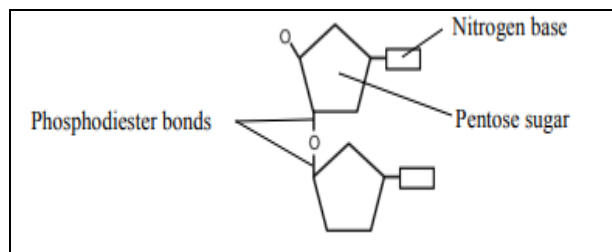


BUILDING OF A NUCLEOTIDE

The three components of nucleotides are combined together by two condensation reactions. A **nucleoside** forms when a pentose sugar joins an organic base by condensation reaction (a water molecule is lost). A **nucleotide** forms when a nucleoside (pentose sugar + organic base) joins a phosphate by loss of second water molecule. A sugar ring attaches itself to a phosphoric acid molecule at position 5, and to one of the five bases at position 1. Two water molecules are lost in the process to give a nucleotide.

By similar condensation reactions between the sugar and a phosphate group of two nucleotides a **di-nucleotide** is formed. Continued condensation reactions lead to formation of a **polynucleotide chain** whose backbone consists of alternating sugar and phosphate groups with the bases projecting outside ways from the sugars. The sugar-phosphate-sugar backbone is formed when the 3' carbon on one sugar joins to the 5' carbon on the next sugar by **phosphodiester bonds** repeatedly to form a polynucleotide (long chain of nucleotides) with organic bases protruding sideways from sugars.

The structure of a polynucleotide is shown below;



The sugars and phosphate groups are identical all the way along the chain with no variation. In RNA all sugars are ribose; in DNA they are deoxyribose. The phosphate groups are identical in both DNA and RNA.

The bases however show no uniformity with the DNA containing A, G, C and T; while in RNA, T is replaced by U. The sequence in which these bases occur along the length of the nucleic acid chain varies from species to species and from individual to individual. It is in this sequence of bases that the nucleic acids carry information controlling the organism's development.

FUNCTIONS OF NUCLEOTIDES

The main function of nucleotides is the formation of nucleic acids, RNA and DNA which play vital roles in **protein synthesis** and **heredity**. In addition, nucleotides form part of other metabolically important molecules; such molecules include Adenosine Tri Phosphate (ATP), Nicotinamide Adenine Dinucleotide (NAD), Flavine Adenine Dinucleotide (FAD), Nicotinamide Adenine Dinucleotide Phosphate (NADP) and co-enzyme A.

RNA (RIBONUCLEIC ACID)

RNA is a single stranded polymer of nucleotides where the pentose sugar is always ribose and the organic bases are

adenine, cytosine, guanine and uracil. There are 3 basic types of RNA molecules known so far all of which are involved in protein synthesis. These RNA molecules are made by the DNA in the nucleus in the process called transcription. These include:

RIBOSOMAL RNA (rRNA)

This is a large complex molecule made up of both double and single helices. Although it is manufactured by the DNA of the nucleus it is mainly found in cytoplasm where it makes up more than half of the mass of the ribosomes. It comprises of more than a half of the mass of the total RNA of the cell and its sequence is similar in all organisms. Ribosomes are the site of protein synthesis, at the ribosomes the mRNA code is translated into a sequence of amino acids in a growing polypeptide chain. This is possible because ribosomes are often found in clusters linked together by strands of mRNA. This cluster of ribosomes is known as **poly-ribosome** or **polysome** and this enables several molecules of the same polypeptide chain to be produced simultaneously.

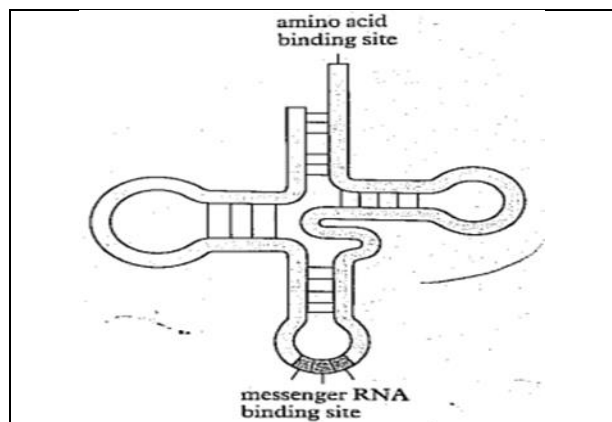
MESSENGER RNA (mRNA)

This is also a single stranded molecule containing triplets of bases known as codons. It is formed from a single strand of DNA during protein synthesis by a process known as **transcription**.

TRANSFER RNA (tRNA)

This is a small molecule with about 80 nucleotides made up of a single strand. It comprises of 10 to 15% of the total RNA within the cell and all types of tRNA are

fundamentally similar. It forms a clover leaf shape with one end of a chain ending in a **cytosine-cytosine-adenine (C-C-A)** base sequence. It is at this base sequence that an amino acid attaches itself. The structure of tRNA is shown below;



There are at least 20 types of tRNA each one carrying a different amino acid. At an intermediate point along the tRNA point is an important sequence of 3 bases called **anticodon**. These bases line up alongside the appropriate **codon** on the mRNA during protein synthesis. This implies that each amino acid has its own tRNA molecule which transfers it from the cytoplasm to the ribosome to join the polypeptide chain being made. Consequently tRNA acts as an intermediate molecule between the codon of mRNA and the amino acid sequence of the polypeptide chain on the ribosomes on the ribosomes.

Adaptations of tRNA:

- Active sites (anticodon and amino acid) are maximally separated to avoid interference
- Small size for mobility readily.

NOTE

A codon is sequence of three organic bases which together form a unit of genetic code in a DNA or RNA molecule to specify an amino acid that joins a polypeptide.

Revision question

- a) State the structural differences between a purine and a pyrimidine base.
- b) Name three pyrimidines and two purines.
- c) Name the RNA which bears the following base triplet.
 - i. Anticodons
 - ii. Codons

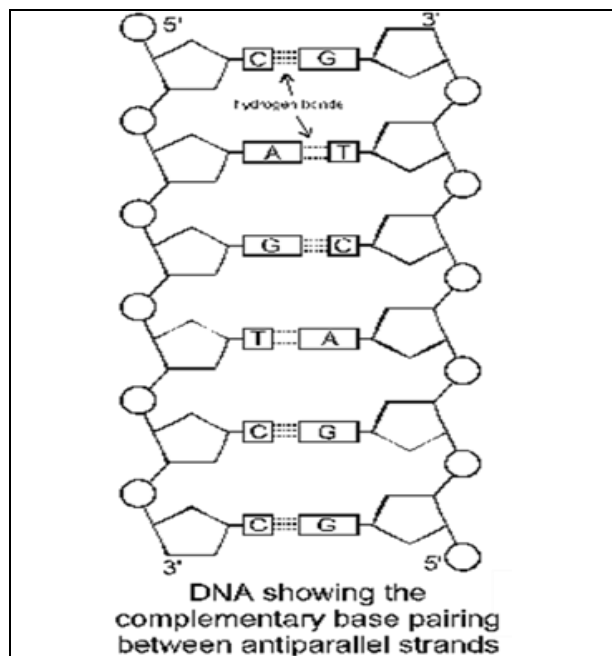
DNA (DEOXYRIBONUCLEIC ACID)

DNA is a very large polymer of nucleotides. It is a double stranded molecule containing a base called thymine in addition to other bases. The polynucleotide strands are antiparallel (face in opposite directions) i.e. one runs from 3' to 5' direction while another runs from 5' to 3' direction. Untwisted DNA is ladder-like, in which the sugar-phosphate backbones represent the handrails while the nitrogen base pairs represent the rungs. Twisted DNA forms a double helix of major and minor grooves. The sugar-phosphate-sugar backbone is held by covalent phosphodiester bonds, while the nitrogen bases from the two strands form weak hydrogen bonds by complimentary base pairing i.e. A with T, C with G.

The Watson - Crick Model of the DNA

According to Watson and Crick, DNA consists of two very long nucleotide chains (DNA double strands) made of repeated

nucleotides. Each nucleotide contains a phosphate, deoxyribose sugar and an organic base.



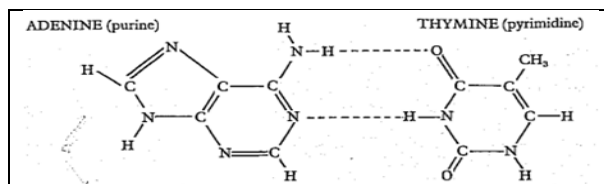
Each chain forms a **right handed helical spiral** and the two chains coil around each other to form a double helix. These chains run in opposite directions and the strands making up these chains are joined together by nitrogenous bases between them held by hydrogen bonds between these bases. During which a pyrimidine base must combine with a purine base. Therefore adenine must combine with thymine and cytosine must combine with guanine. The chains form the sugar phosphate back bone which is made of alternating deoxyribose sugar and phosphates. With this effect, DNA is like a ladder where the alternating deoxyribose and phosphate units form the uprights and the organic base pairing to form the rungs. However, the strands are twisted instead of being like a ladder into a double helix so that each upright winds

around the other. Such a double helix structure is shown below;

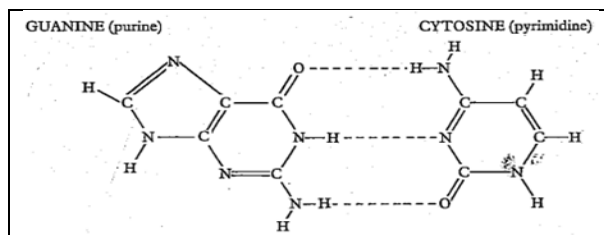
NOTE:

The width between the two strands is constant and equal to the width of the base pair i.e. the width is equal to the purine plus the pyrimidine. Two purines would be too large and two pyrimidines would be too small to span the gap between the two chains of DNA. Therefore, adenine must combine with thymine while guanine must combine with cytosine. The bases are held together by hydrogen bonds and the position of the hydrogen atoms in relation to the shape of the molecule ensures that;

i) *A can only link with T*



ii) *C can only link with G*



The sequence of bases in one chain of DNA determines that in the other and consequently the two DNA chains are said to be complementary. Each of the polynucleotide chains in DNA is extremely long and may contain many million nucleotide units.

The amount of guanine molecules is equal to the amount of cytosine molecules in DNA i.e. $C=G$ or $C/G = 1$ or $C:G = 1:1$. and similarly, the amount of adenine molecules is equal to that of thymine molecules i.e. $A=T$ or $A/T = 1$ or $A:T = 1:1$.

Adaptations of DNA

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

- There are many hydrogen bonds which increase stability of DNA molecule.

Revision questions

- a) *If a DNA molecule contains 40% of its bases as adenine and thymine, how many bases will be guanine in a DNA molecule?*
- b) *Analysis of a sample of DNA showed that 33% of the bases were adenine. What is the percentage of guanine bases in the sample?*
- c) *Compare the RNA and DNA.*

DNA REPLICATION

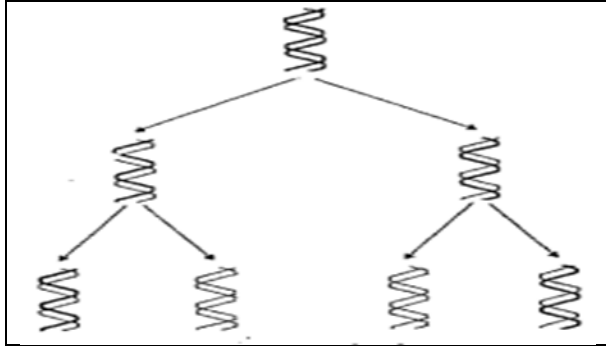
This is the process by which two DNA molecules make exact copies of its self. This enables the transmission of the same genetic information from cell to cell and generation to generation. It involves the breaking down of hydrogen bonds between complimentary bases and breaking the strands at particular points forming a replication strand.

Types of DNA replication

Replication is divided into 3 major types mainly; conservative, semi-conservative, and dispersive replication

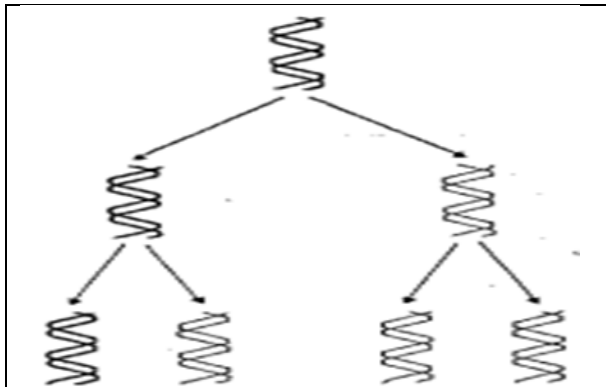
a) Semi-conservative replication

It is the most acceptable hypothesis for DNA replication. In semi-conservative replication the DNA strands unzips (separates) under the influence of helicase and then forms a new DNA strand for each of the old DNA strands using DNA polymerase. The new DNA molecule is composed of one old strand and one new strand. This is shown in the diagram below;



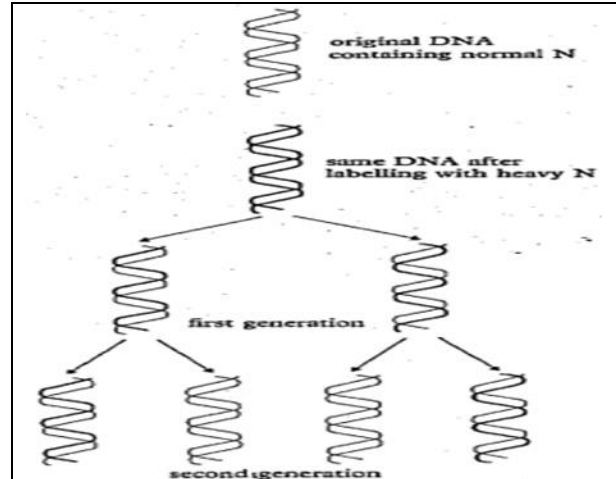
b) Conservative replication

In conservative replication the DNA strand unzips using helicase enzyme and forms two new DNA strands which zip together to become a DNA double helix made of new strands only. The old strands also zip together again after replication so that they form another new DNA molecule made of old strands only. In this hypothesis, the parent DNA provides a skeleton for formation of new DNA strand. This is illustrated in the diagram below;



c) Dispersive replication

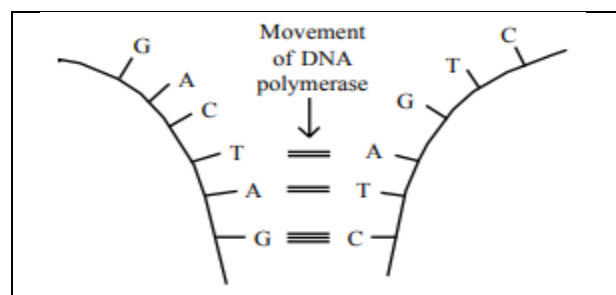
In **dispersive replication**, two new strands are formed each containing alternating old and new bases of nucleotides. This is illustrated in the diagram below;



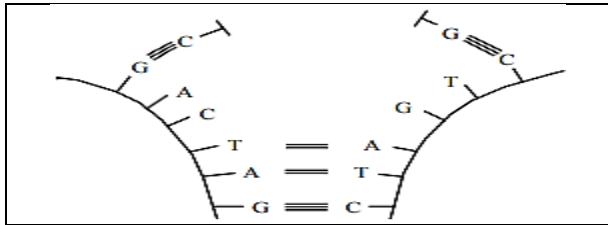
Mechanism of DNA replication

Replication is controlled by an enzyme **DNA polymerase** which links the DNA nucleotides to form long strands of DNA and **helicase enzyme** which causes the unwinding (opening up) of the DNA double strands.

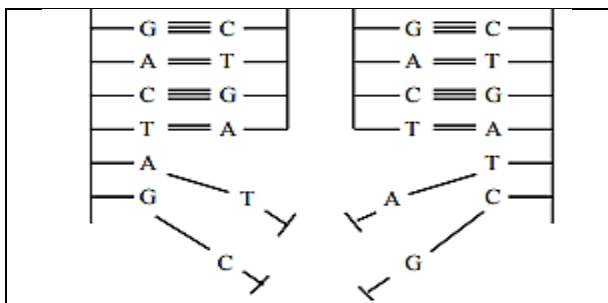
The process is initiated by helicase enzyme which breaks up the hydrogen bonds between the two complementary bases of DNA. The hydrogen bonds linking the base pairs are weak so breakage could easily happen. This leads to uncoiling and unwinding of the DNA strands separating them into single strands. DNA polymerase attaches itself to a single DNA strand. DNA polymerase then starts to move along the strand where it is attached.



Each time this enzyme meets the next base on DNA, a complementary base from the nucleoplasm is inserted to a growing DNA strand e.g. if this enzyme meets T, A is inserted and if it meets C, G is inserted.



This enzyme continues to move in the 5' to 3' direction along one strand meeting one base at a time and instructing a complementary base to be added to the new DNA strand growing as this enzyme moves. This replication is possible because the unwinding enzyme helicase moves along the DNA just in front of DNA polymerase separating and unwinding the two DNA strands by breaking the hydrogen bonds between complementary bases. Several molecules of DNA polymerase act simultaneously at multiple sites, each assembling a separate section of the new strand of DNA.



During replication another enzyme called **DNA ligase** closes up the gaps there by joining the 5' end of one strand to 3' end of the other strand so as to form the new DNA

double helix. Ligase enzyme joins the fragments by forming a “phosphodiester bond”. Normally there are some errors due to the enzyme DNA ligase inserting wrong base. Therefore after replication, repair enzymes move along the new strand removing wrong bases and inserting the correct bases. Any mistake made during DNA replication leads to mutation.

ESSENTIAL ROLE OF DNA

The essential role of DNA lies in heredity and protein synthesis. DNA is material of inheritance and it is through the DNA that hereditary information is passed on from the parents to the off rings

EVIDENCES TO SHOW THAT THE DNA IS A GENETIC MATERIAL

Its ability to replicate

For any genetic material it must have the potential to replicate such that exact copies of the DNA are made. The proteins remain with their DNA and the offsprings get DNA from the parents such that the information can be passed on.

Chromosome analysis

Chromosomes only become visible during cell division suggesting that they carry important information (DNA) which is to be shared by the daughter cells. The chromosomes which play a role in cell division are made of DNA and histone proteins only.

Metabolic stability

Any material responsible for transferring genetic information must be metabolically

stable not break easily when not to alter the information. DNA does not break easily when exposed to chemicals

Location of DNA within the cell

DNA is found in the nucleus where the environment is stable with little metabolic reactions taking place in the cytoplasm there are many biochemical reactions some of which release toxic waste products which may distort the structure of the DNA.

Correlation with mutagens

Mutagens are agents which cause mutations. Some mutation is inheritable and is passed onto the off springs by the DNA and without which it remains very stable so that the code instructions it contains remains unchanged from generation to generation.

Protein synthesis

DNA controls the activities of a cell by directing the synthesis of proteins. This is shown by the various transduction experiments in which the Bacteriophage (virus that attacks bacteria) transfers DNA to a bacterium called *Escherichia coli* (*E. Coli*). The virus DNA instructs *E. coli* to make many new bacteriophage viruses.

Revision question

- Describe the process of DNA replication*
- What are the characteristics of DNA as a good genetic material?*
- Describe how frequent use of antibodies can lead to the evolution of resistant strains of bacteria.*

THE GENETIC CODE

The genetic code is the sequence of bases in DNA which codes for the sequence of amino acids in protein molecules. DNA provides the code (genetic message) for the formation of proteins in an organism which may in turn determine the characteristics of that organism. Every species possesses different DNA and therefore produces different enzymes. The DNA of the different species therefore differs not in the chemicals which it comprises but in the sequence of base pairs along its length. This sequence of triplet base pairs in DNA and mRNA is the code that determines which proteins are manufactured.

Determining the fixing of one amino acid in a polypeptide

There are 20 amino acids which regularly occur in proteins and each of these must have its own code of bases on DNA i.e. the base pairs arrange themselves in form of triplets. This code is triplet because with only four different bases (A, G, C and T) present in the DNA, if each of them was coded for one amino acid, only four different amino acids could be coded for during protein synthesis which would be insufficient for protein formation. Using a pair of bases to specify an amino acid that should be picked by tRNA during protein synthesis gives 16 different codes that are possible for this picking. Therefore, a triplet code of bases has to be used to specify one amino acid that can be picked by tRNA during protein synthesis as this will produce 64 possible codes more than enough to

specify the requirement of the 20 amino acids.

The genetic code is therefore a **triplet code** of word. Each word specifies the position of an amino acid in the corresponding protein chain. The triplet code constitutes the codons of mRNA as these codons are directly made from DNA.

CHARACTERISTICS OF A GENETIC CODE

The genetic code is degenerate

This genetic code is also called a **degenerate code** since there is more than one triplet for most amino acids i.e. it is a degenerate code because a given amino acid may be coded for by more than one code. The degeneracy of the genetic code has two functions namely;

- It permits essentially the same complement of enzymes and other proteins to be specified by microorganisms varying widely in their DNA base composition.
- It provides a mechanism of minimizing mutational lethality. E.g. Substitution of the third base-U in GUU (for valine) with CAG does not change the amino acid coded for.

Nonsense codons

The genetic code also leads to the formation of 3 codons namely, UAA, UAG and UGA which are called **nonsense codons**. These nonsense codons stop the process of protein synthesis by not coding for a specific amino acid at all.

The genetic code is universal

The genetic code is also described as **universal** because the same triplets of bases code for the same amino acid in all organisms. In other words all codons are precisely the same for all organisms. The universality of the code has the following functions;

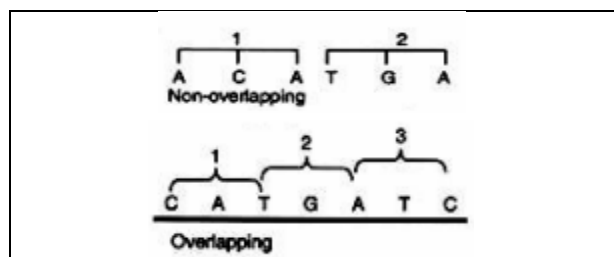
- Genetic material can be transferred between species/ between humans
- One species could use a useful gene from another species
- Bacteria/ yeasts can be genetically engineered to make a useful product

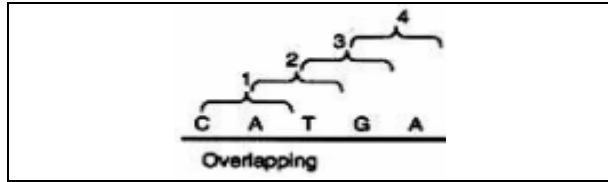
However universality of the genetic code has its disadvantages which include the following;

- Viruses can invade cells and take over their genetic apparatus e.g. HIV
- Viruses cause disease

Non - overlapping

In addition, the genetic code is **non-overlapping** e.g. each triplet of bases is read separately UACACCAUGGGC is read as UAC-ACC-AUG-GGC. The main disadvantage of an overlapping code is that it imposes a constraint on the sequencing of amino acids and this limits its flexibility.





The code is non-ambiguous.

A particular codon will always code for the same amino acid. The same codon shall never code for two different amino acids.

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

A table showing the genetic code with their corresponding amino acids.

SUB TOPIC 4: CELL DIVISION AND CHROMOSOME CONCEPT

SUB TOPIC OUTLINE

- Mitosis and meiosis
- Comparison of meiosis and mitosis
- Significance of the cell division events: formation of spindle fibres, chiasmata, synopsis, bivalents and movements of chromosomes etc.
- Role of meiosis and mitosis in living organisms

Cell division is the splitting of a mature cell to form daughter cells. Cell division is essential to all life. It enables a multicellular organism to grow and to replace worn out or damaged cells and it is a basis of reproduction in every organism.

Important terms used

Interphase:

This is the interval between the end of one mitotic or meiotic division and the beginning of another

Karyokinesis:

This is the actual division of the cell nucleus into two daughter nuclei during mitosis or meiosis.

Cytokinesis:

This is the cleavage of the cytoplasm into daughter cells following nuclear division.

Ploidy:

This is the number of homologous sets of chromosomes in a cell.

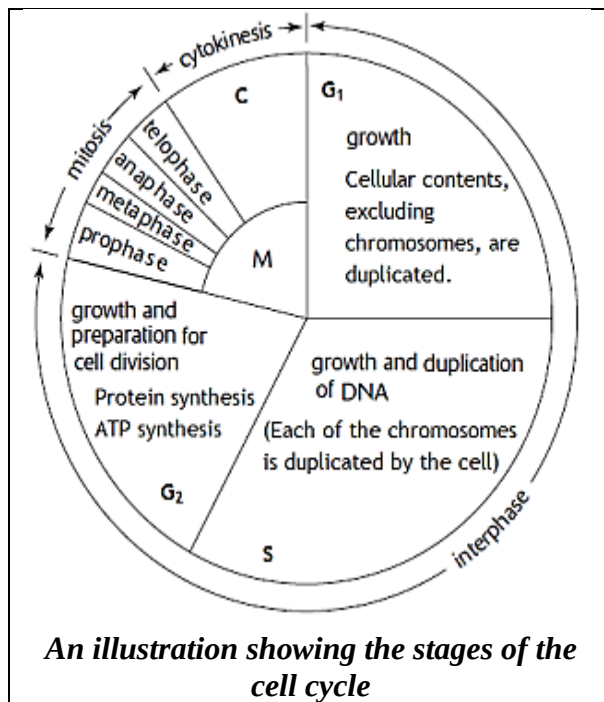
THE CELL CYCLE

From the cell theory, new cells arise from the pre-existing cells by the process of cell division. The cell cycle is a sequence of

events which a cell goes through from the time it is formed until when it is divided again.

STAGES OF THE CELL CYCLE

The cell cycle involves 3 main stages i.e. **interphase**, **nuclear division** and **cytokinesis/cytoplasmic division**.



Interphase

During interphase, the cell grows, carries out its functions and replicates its DNA. After the DNA is replicated, new proteins become attached to it. The chromosomes now

consist of two strands called **chromatids** which contain identical genetic information joined at some point along their length by a **centromere**. The two chromatids possess the same gene at the same position called **loci**. (Singular **locus**)

Interphase has three stages namely; first **growth phase** (G_1), **synthetic phase** (S), and **second growth phase** (G_2).

- During G_1 stage, the cell is very active, growing and carrying out its metabolic functions.
- During S stage, DNA replicates and two sister chromatids form from each chromosome.
- During G_2 stage, the mitochondria divide and the cell continues to grow until mitosis begins. It also involves intensive cellular synthesis including duplication of the centrioles where spindle fibres arise. Centrioles occur at right angles to each other and act as microtubules organising centres (MTOCS). In plants, chloroplasts also divide during G_2 .

Typically interphase lasts about 90 % of the cell cycle.

Nuclear division

Nuclear division takes place during mitosis. The chromatids containing replicated DNA are separated from each other and are redistributed as chromosomes in the nucleus of the two new daughter cells.

Cytokinesis

The cytoplasm divides to form two daughter cells.

NOTE

The duration of the cell cycle varies according to the conditions such as temperature and the type of cell. Some cells such as human nerve cells do not divide at all once they become specialized.

TYPES OF CELL DIVISION

There are two types of cell division i.e

- Mitosis.
- Meiosis.

MITOSIS

This is also known as **replication cell division**. This is the splitting of a mature cell (parental cell) to form two identical daughter cells each containing exactly the same number of chromosomes as the parent cell. Mitosis takes place throughout the growth period of an organism.

Mitosis occurs in four stages i.e

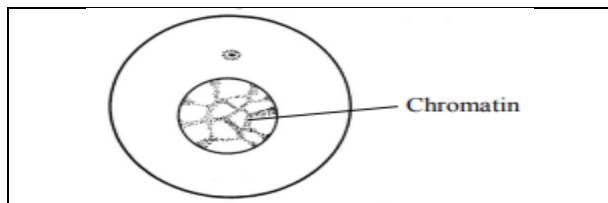
- Prophase.
- Metaphase.
- Anaphase.
- Telophase.

Before the cell undergoes mitosis, it undergoes a preparation stage known as interphase.

Interphase;

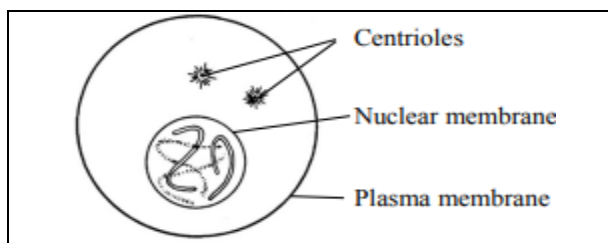
This is called the resting stage but the actual sense the cell is not resting because there are many activities that occur in preparation of the cell for division. These activities include; the production of ATP through cellular respiration to provide sufficient

energy needed for cell division. If a cell is treated with a metabolic poison such as cyanide during interphase, mitosis fails to take place. Synthesis or formation of more organelles such as mitochondria, chloroplasts, Golgi bodies, centrioles, endoplasmic reticulum etc. this ensures equal distribution of cell contents between the daughter cells. Replication of genetic material, DNA replicates, leading to doubling of chromosomal number so that the parental chromosomal number is maintained in the daughter cells. Chromosomes are long thin (thread like) hence not clearly seen and they are highly coiled for easy packing in the nucleus.

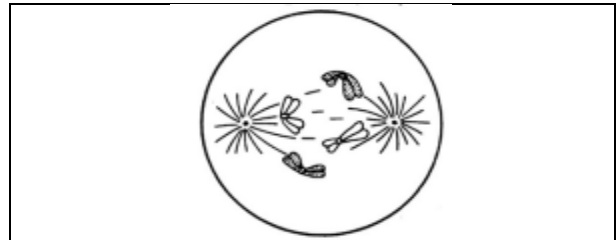


Prophase;

This has two sub stages i.e early prophase and late prophase. During early prophase, in animal cells and some plant cells centrioles migrate to opposite poles of the cell spindle fibres are then synthesized by the centrioles and radiate to the nuclear membrane. Chromosomes shorten and thicken hence easily seen. They uncoil and appear to have centromeres.



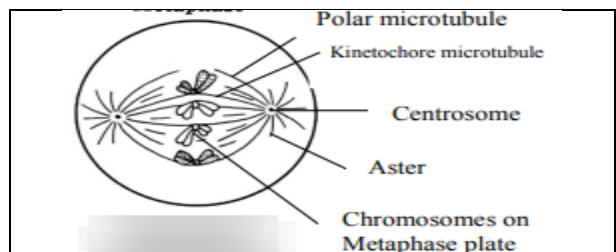
During late prophase, the chromosomes condense further and split vertically to form chromatids which remain attached at the centromere. In this case, the chromosome is said to duplicate. Each chromosome forms the chromatid.



The nucleolus disintegrates i.e breaks down and disappears and the nuclear membrane also degenerates and disappears and thus marks the end of prophase.

Metaphase:

During early metaphase, the spindle fibres completely form. The chromosomes that are made up of chromatids assemble/ align at the equator singly i.e. each chromosome is attached to a single fiber. During the alignment the chromatids face the opposite poles. The chromatids are attached at the equator by the spindle fibres being attached at the centromere.

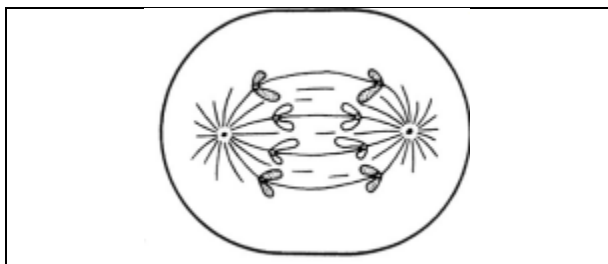


During late metaphase, the chromosomes are pulled along the centromere by the spindles as spindles begin to contract. The

centromere therefore splits in to two to form independent chromatids that are still held close.

Anaphase:

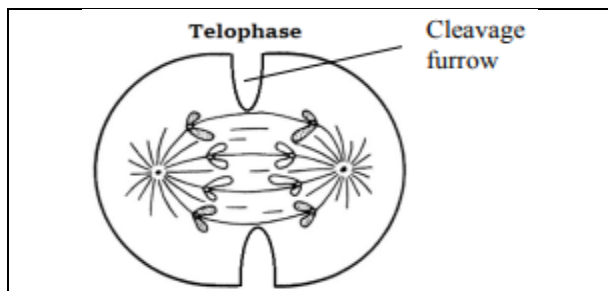
This consists of two sub stages i.e early anaphase and late anaphase. During early anaphase: The spindle fibres contract further using energy provided by ATP generated by mitochondria. The chromatids are separated completely. The independent chromatids migrate to opposite poles, being pulled by spindle fibres as they shorten. During the movements the centromere leads i.e faces the pole.



During late anaphase; Chromatids reach their destination (opposite poles).

Telophase:

When the chromatids arrive at the poles, nuclear membrane reforms: Nucleolus also reforms. Chromatids become long, thin, coiled hence not easily seen. Spindle fibres disintegrate and disappear.



NOTE:

All the above events we have been describing lead to the splitting of the nucleus into two hence nuclear divisions.

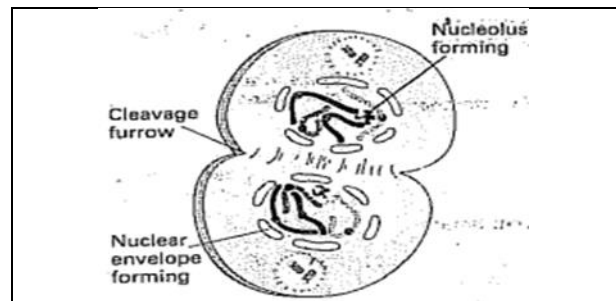
Revision Question:

Describe the events which occur in the nucleus during mitosis.

CYTOKINESIS

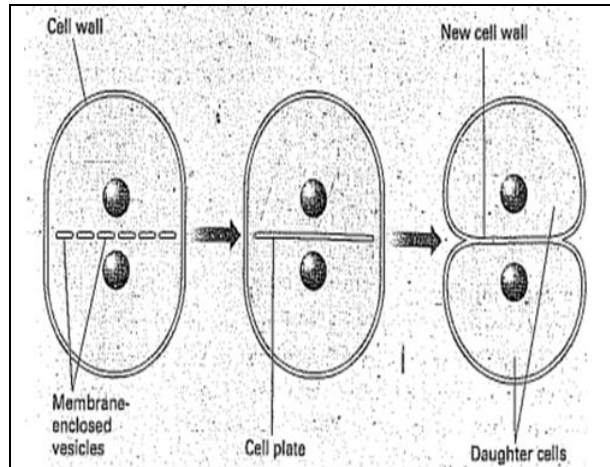
After nuclear division, cytokinesis/cytoplasmic cleavage occur.

In an animal cell cytokinesis occurs when the cell membrane constricts at the centre i.e along the equator forming a cleavage furrow to divide the cytoplasm of the cell into two equal halves each half consisting of a complete nucleus. As a result, two daughter cells are formed and these are identical to the parent cell.



However in a plant cell, cytokinesis occurs by formation of a cell plate along the equator. The cell wall forms during telophase stage of cell division when the cell plate forms between daughter cell nuclei. The cell plate forms from a series of vesicles produced by **dictyosomes**. The 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.



The 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

Revision questions

Compare between mitosis in animals and plants

IMPORTANCE OF MITOSIS

Genetic stability: Mitosis produces two new daughter cells having same number of chromosomes as parental nucleus. Therefore ensuring that genetic information remains constant i.e no variation occurs.

Growth: the number of cells in organisms increases by mitosis hence increasing the size of the tissue and hence the organism as a whole. This is the basis of growth. Mitosis produces exact copies of the parent cell in multicellular organisms which causes uniform growth of the tissues.

Asexual reproduction: In unicellular organisms such as Amoeba, the parental organisms divide into two. During binary fission in amoeba, the organism divides into two independent organisms. This is a form of mitosis.

Cell replacement; new cells replace the worn out cells a process called cell replacement that occurs during healing. Cell replacement involves mitosis, cells are constantly dying and being replaced, an example is the skin, cavity around the mouth etc

Tissue regeneration; new tissues are formed from pre-existing tissues to give rise to new organs. Some animals are able to regenerate whole part of the body, such as legs and arms in star fish production of the cells involves mitosis.

MEIOSIS

This is a type of cell division which involves splitting of a mature cell into four daughter cells each containing half the number of chromosomes of the parent cell. In this case, the daughter cells are said to be haploid. Meiosis involves two successive divisions (phases) namely;

- Meiosis I (first meiotic division).
- Meiosis II (second meiotic division)

MEIOSIS I

This separates the homologous chromosomes and therefore halves the chromosome number. Before the cell divides meiotically, it undergoes a preparatory stage known as interphase I.

Interphase I

During interphase I, several activities occur to prepare the cell for effective division. Such activities include:

- Replication of genetic material (DNA) making them to double;
- Production/ synthesis of ATP (Adenosine Triphosphate) which is a source of energy required for cell division.
- Formation of more cell organelles such as Golgi body, centrioles, mitochondria etc.
- The cell increases in size.

During interphase the chromosomes are uncondensed i.e coiled, long, thin and not easily seen.

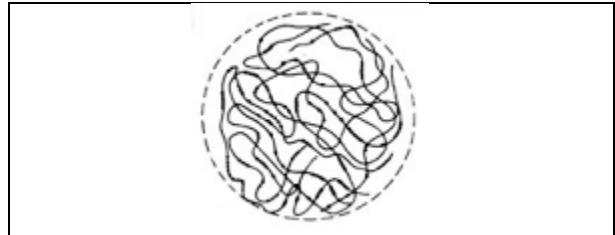
Prophase I

This is the longest phase of meiosis and it is subdivided in to five phases i.e

- Leptotene (single chromosomes).
- Zygotene (synapsis).
- Pachytene (duplication of chromosomes).
- Diplotene (crossing over of chromatids).
- Diakinesis (repulsion of chromosomes to nuclear membrane).

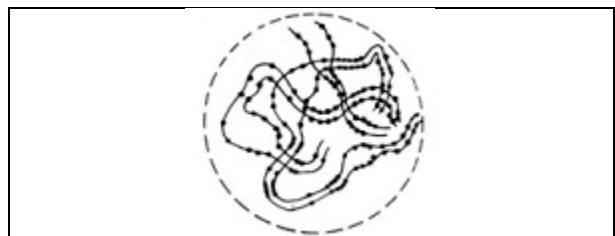
Leptotene:

Chromosomes become visible and appear to be single stranded without centromeres. They are relatively long.



Zygotene:

The chromosomes continue to shorten and thicken hence easily seen. Centrioles move to opposite poles and spindles start forming. The homologous chromosomes pair up to form **bivalents** by the process of synapsis. Homologous chromosomes do not join but lie side by side. Homologous chromosomes appear to have centromeres and have the same length.



Pachytene:

Each of the chromosome splits vertically into two to form two chromatids. This is called chromosomal duplication. The chromatids are still attached to the centromere of chromosomes.

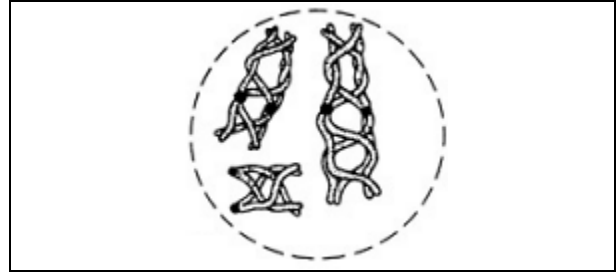


Diplotene:

Chromosomes intimately coil around one another. Homologous chromosomes tend to draw apart there by breaking proportions of non-sister chromatids, the chromatids of the two homologous chromosomes remain in contact at certain points called **chiasmata** (Singular **chiasma**). Chiasmata have two functions namely:

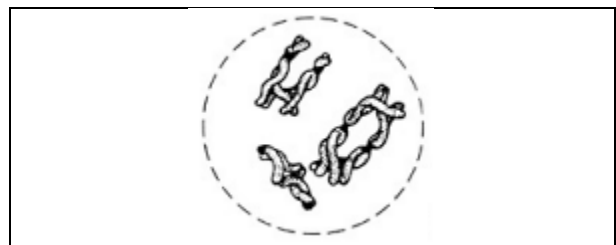
- To hold the two homologous chromosomes together while they maneuver themselves around onto the spindle prior to segregation.
- They represent places where chromatids may break and rejoin a portion of one chromatid change places with the equivalent point of another. This enables exchange of genetic material to occur between homologous chromosomes a condition known as **crossing over**.

Crossing over therefore is the exchange of portions of chromatids of homologous chromosome at points called chiasmata leading to exchange of genetic material between homologous chromosomes or non-sister chromatids. Crossing over results in to formation of new gene combinations which promote genetic variation among organisms of the same parents very important in evolution of species.



Diakinesis

Internal coiling occurs and chromosomes repel each other to far distances between them. The homologous chromosomes push themselves to the periphery of nucleus close to the nuclear membrane. As a result of this opposite movement of chromosomes the number of chiasmata reduces because of breaking up in the process. However, chiasmata formation remains at the tips of the chromosomes.

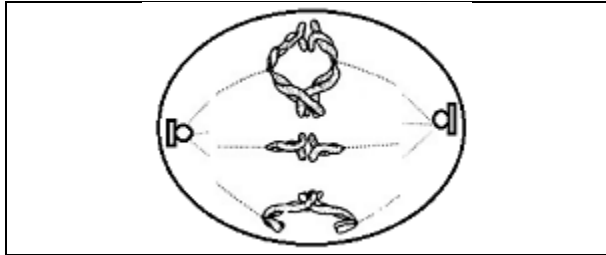


The nucleus disintegrates by shrinking and disappears. The nuclear membrane also disintegrates and disappears; this marks the end of prophase I.

Metaphase I

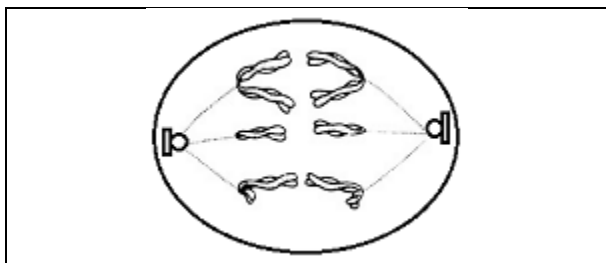
Centrioles reach opposite poles. The spindle fibres form completely. Bivalents arrange themselves at the equator with each of the pair facing opposite poles. The alignment of the bivalents at the equator is completely random in comparison to other bivalents

leading to formation of new gene combinations resulting into genetic variation. The spindles attached to the centromere contract slightly pulling homologous chromosomes slightly apart there by breaking chiasmata if present.



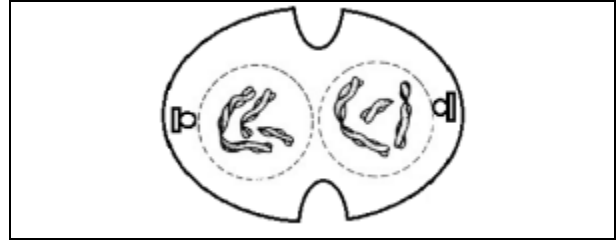
Anaphase I

Spindles continue to contract and shorten. Homologous chromosomes part company and migrate to the opposite poles of the cell. The contraction of spindle fibres and migration of chromosomes require energy provided by the numerous mitochondria in the cell.



Telophase I

Chromosomes reach their respective poles. Chromosomes become long, thin hence not easily seen. Nucleolus reappears and nuclear membrane reappears. Spindle fibres may completely or partially disappear. The centrioles replicate.



In animals Telophase I give rise to two primary spermatocytes in males and in the females, division of cytoplasm gives rise to a primary oocyte and polar body. Finally, cytokinesis occurs to form two daughter cells. In plant cells, meiosis does not include Telophase I and interphase II.

MEIOSIS II

In some cells where after telophase, interphase occurs the nucleolus reappears, nuclear envelope develops again, spindle fibres disintegrate. Following interphase, the cell now undergoes prophase II which is a very short phase compared to prophase I. During when the nucleolus disappears in nuclear envelope break done and where centrioles are present as in animal cell. They divide and move to the opposite poles. The poles of prophase II are at right angles to the plane of the previous cell division and therefore the spindle fibres develop at right angles to the spindle axis of the previous cell division. In those cells which do not undergo interphase, the cell enters the second meiotic division at the stage of prophase II with chromosomes thick and the former spindle still present.

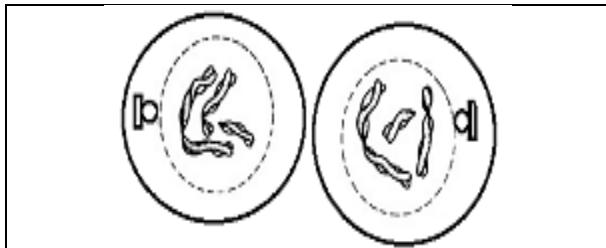
Interphase II

After Telophase I, daughter cells enter interphase II, to prepare for meiosis II. During interphase II there is no DNA

replication. This occurs so as to maintain the haploid state in the gametes therefore maintaining diploid state in the off springs.

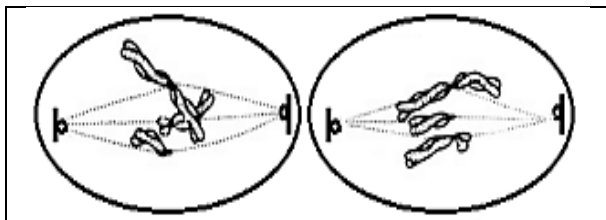
Prophase II

Centrioles migrate to opposite poles. Spindle fibres are then synthesized by centrioles but arranged at right angles to the spindle of meiosis I. Chromosomes shorten and thicken hence easily seen. Chromosomes condense further to split and form chromatids. The chromatids are still attached at the centromeres. Nucleolus degenerates and disappears. Nuclear membrane also degenerates and disappears.



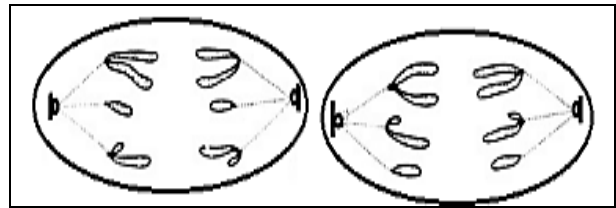
Metaphase II

Spindles form completely. Chromosomes are aligned at the equator singly. During alignment, the chromatids face opposite poles. Chromosomes are held in position by the spindle fibres slightly contract. As a result of centromere splits to form independent chromatids that are still too close to each other.



Anaphase II

Spindles contract further and completely separate the chromatids. Independent chromatids migrate to opposite poles being pulled by spindle fibres. During chromatid movement the centromere face opposite poles. Finally chromatids reach their destination.

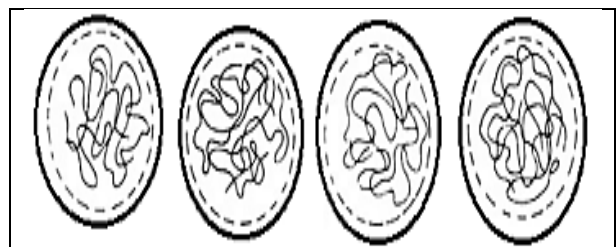


NOTE:

The migration of chromatids requires energy provided by ATP hydrolysis.

Telophase II

When chromatids arrive at the poles, a new nuclear membrane forms around each pole surrounding the chromatids. Nucleolus also forms. Chromatids become long, thin hence not easily seen as chromosomes. Spindle fibres disintegrate and disappear.



Cytokinesis occurs to form four haploid daughter cells collectively called a tetrad. In animals, meiosis occurs in germinal cells or tissue of multicellular organisms leading to production of gametes. In males germinal

cell are found in the testis and when they undergo meiosis, and Telophase II produces secondary spermatocytes which differentiate into spermatozoa (male gametes). In females however, germinal cells are found in ovaries in which Telophase II produces a secondary Oocyte that matures into a functional egg/ovum and a smaller polar body. In flowering plants meiosis occurs in anther heads to produce pollen grains and in females: embryo sac / ovaries to produce eggs / ovules.

NOTE:

As a result of meiosis, four daughter cells are formed from one parent cell. Each daughter cell has half the number of chromosomes of the parent cell. Usually the parent cell is diploid and the daughter cells are haploid. Spermatozoa and ova are haploid cells and pollen grains and ovules may be haploid, diploid, tetraploid or triploid.

SIGNIFICANCE OF MEIOSIS

Genetic variation; meiosis provides opportunity for new combination of genes to occur in gametes and consequently in the off springs. This is possible in two ways.

Crossing over: During crossing over in prophase I segments of chromatids are exchanged leading to formation of new gene combinations which are the basis of variation in the offspring.

Independent assortment of chromosomes; At metaphase I of meiosis, random orientation of bivalents at the equator occurs resulting into formation of new gene combinations passed to gametes and finally to the off springs at fertilization hence genetic variation.

Sexual reproduction: Meiosis leads to the production of gametes in plants and animals. The gametes formed are then used in sexual production. Meiosis ensures that gametes formed are haploid in order to maintain diploid state of organisms after fertilization.

SUB TOPIC 5: PROTEIN SYNTHESIS

SUB TOPIC OUTLINE

- *Formation of RNA (mRNA)*
- *Process of protein synthesis*
- *Role of DNA and RNA in protein synthesis*

Protein synthesis is the process by which the coded information is transferred from the chromosomes in the nucleus to the ribosomes in the cytoplasm to make the proteins.

Proteins are large, organic molecules which play a fundamental role in metabolic activities including nutrition, respiration, transport, sensitivity, co-ordination and reproduction. The characteristics of cells and organisms are determined by the particular

proteins which are present. The synthesis of these proteins involves two types of nucleic acid; DNA and RNA. DNA is contained within the nucleus of a cell and carries the code to determine which particular proteins are made. Various forms of RNA then carry this information to the cytoplasm of the cell and assemble the protein. There are three main stages in the formation of a protein namely; **transcription**, **amino acid activation**, and **translation**.

TRANSCRIPTION

This is the mechanism by which the base sequence of a **cistron** of DNA strand is converted into the complementary base sequence of mRNA.

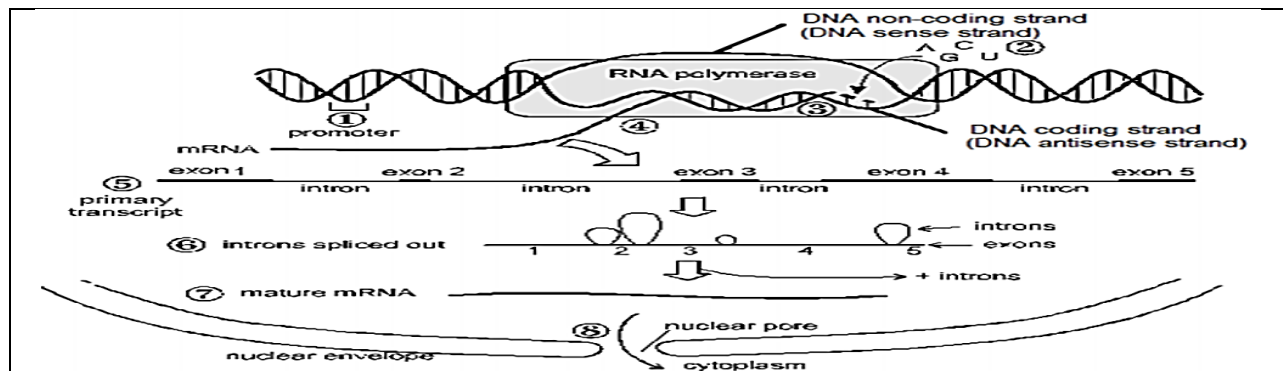
During transcription which occurs after replication of DNA, an enzyme **RNA polymerase** first recognises the **start sequence** in the DNA coding strand and becomes attached to the DNA at this point. This DNA coding strand has a specific region called **cistron** which is used for making mRNA. It is the cistron which is referred to as a **gene**.

The cistron comes into existence during replication when it unwinds. This unzipping is due to the breaking down of hydrogen bonds between the base pairs in the DNA

double helix by **helicase enzyme**. The unzipping exposes the bases along the cistron. RNA polymerase then travels along the DNA cistron and new nucleotides complementary to those in the DNA strand are inserted into the growing mRNA strand. When this enzyme encounters thymine, adenine is inserted into mRNA and when it encounters cytosine, guanine is inserted into mRNA.

Therefore DNA acts as a **template** against which mRNA is constructed. A single molecule of DNA in each chromosome contains numerous shorter sections called genes (cistrons) each of which contains the instructions for making one protein. The coded instructions in each gene must specify the overall length of the protein chain and the exact position of the amino acids within the chain.

At the end of transcription RNA polymerase recognizes the **stop sequence** on the cistron and becomes detached from the cistron at this point. Being too large to diffuse across the nuclear membrane, mRNA instead diffuses through the nuclear pores to the cytoplasm where it attaches itself on the ribosomes. In this way the instructions needed for protein synthesis is transferred into the cytoplasm inform of **mRNA codon**.



AMINO ACID ACTIVATION

Activation is the process by which amino acids combine with tRNA using energy from ATP under the influence of an enzyme ***amino acyl tRNA synthetase***. This produces an amino acid tRNA complex with sufficient energy to form a bond with the neighbouring amino acid. The tRNA molecule with attached amino acid now moves to the ribosomes in order to form the polypeptide chain.

TRANSLATION

This is the mechanism by which the codons of mRNA are converted into a specific sequence of amino acids in a polypeptide chain on the ribosomes. During this process mRNA attaches itself on a group of ribosomes (like beads on a string) to form a structure called ***polysome***. Within the ribosomes there are two tRNA sites where the mRNA codon can become attached by complementary base pairing to a molecule of tRNA bearing the anti-codon.

Therefore the complementary anti-codon of the tRNA-amino acid complex is attracted to the first codon on the mRNA strand enclosed by the ribosomes. The second mRNA codon likewise attracts its complementary anti-codon of the second tRNA amino acid complex. The ribosome acts as a framework which holds the mRNA and the tRNA amino acid complexes together until the two amino acids form a ***peptide bond*** by a ***condensation reaction*** there by forming a ***dipeptide***.

Once the two amino acids have combined into a dipeptide, the first tRNA is

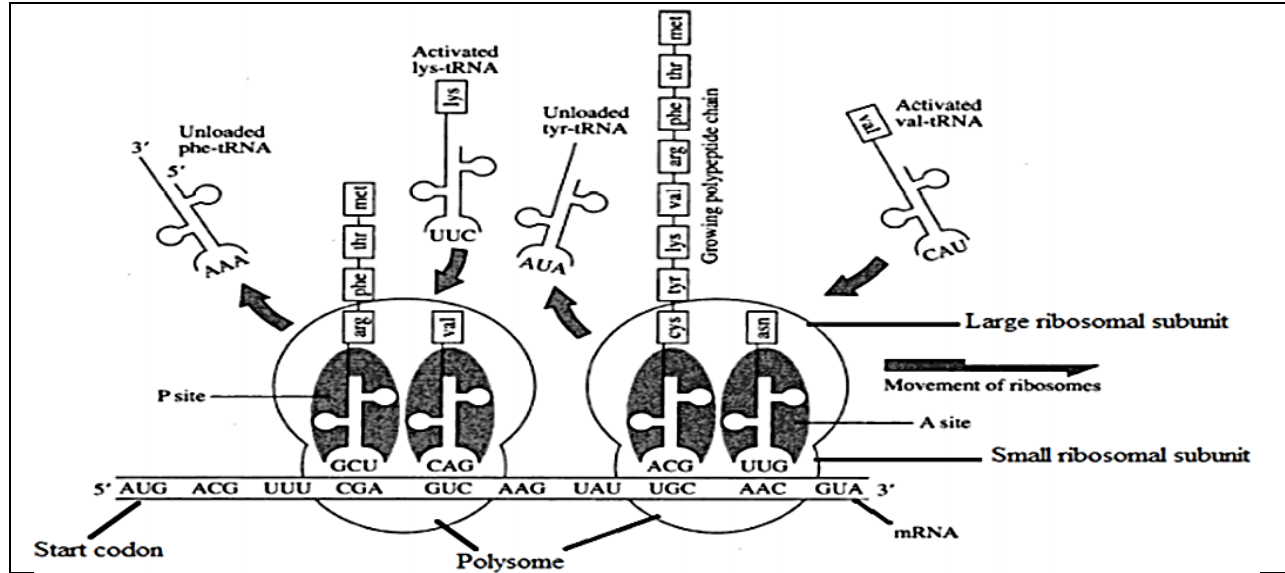
disconnected from its amino acid and therefore leaves the ribosome which moves one step along the mRNA strand so as to hold the next codon-anti codon complex together until the third amino acid is linked with the second by a condensation reaction. In this way, a polypeptide chain is assembled by the addition of one amino acid at a time along the polysome (group of many ribosomes).

Once each amino acid is linked to the growing polypeptide chain, the tRNA which carried it to the mRNA codon is released back into the cytoplasm. This tRNA is again free to combine with its specific amino acid in the cytoplasm. This sequence of the ribosome, steadily reading the mRNA code and translating it, continues until the ribosome comes into contact with one of the nonsense codes (terminating codes) UAA, UAG and UGA at which point the polypeptide is cast off or peeled off from the ribosome and dropped into the cytoplasm.

The polypeptides formed in this way must now be assembled into proteins. Many polypeptides are made in this way because the second and subsequent ribosomes usually pass along the mRNA immediately behind the first ribosome, in this way many identical polypeptides are formed simultaneously.

NOTE:

The function of the ribosome in protein synthesis is to hold in position the mRNA, tRNA-amino acid complex and the asserted enzymes controlling the process until a peptide bond forms between adjacent amino acids



TOPIC 2: CHEMICALS OF LIFE

All living organisms are made up of chemicals which constitute the protoplasm of their cells. These are known as the **chemicals of life** i.e. the chemicals which keep the cells alive. About 99% of the substances in all living organisms are made up of four elements: hydrogen, oxygen, carbon and nitrogen. The chemical composition of plants, fungi, protozoa and prokaryotes is similar to that of other animals.

The study of the chemicals of life and the chemical reactions in which they take place is known as **bio-chemistry**. These chemicals of life are divided into two categories; organic and inorganic chemicals of life. The **organic chemicals of life** are all derived from carbon and include; carbohydrates, proteins, lipids, nucleic acids (DNA and RNA), waxes and steroids as well as vitamins. The **inorganic chemicals of life** include, water, mineral salts, acids and bases. All inorganic and organic chemicals of life must be supplied in appropriate quantities in the diet except nucleic acids and a few vitamins. Therefore there is need for a balanced diet to keep the cells alive.

ATOMS AND ELEMENTS

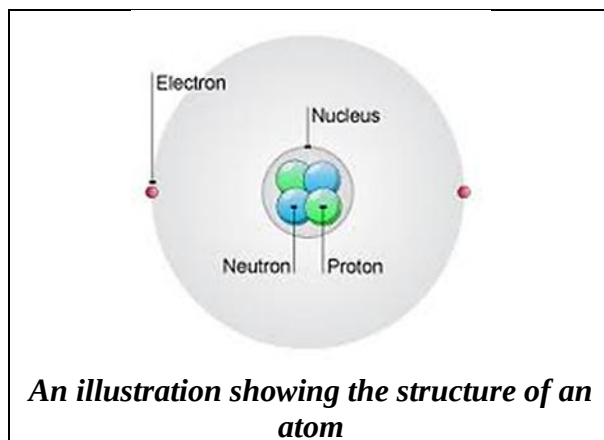
ELEMENTS

An element is a substance that cannot be split into simpler substances by chemical means. Living, dead and non-living things are all made up of elements. The most common elements in organisms are carbon (C), oxygen (O), hydrogen (H), and nitrogen (N). Other elements occur in living organisms in small quantities. These include

phosphorus (P), potassium (K), sodium (Na), sulphur (S), calcium (Ca), magnesium (Mg) and chlorine (Cl).

ATOMS

Each element is made up of atoms. A single atom is the smallest amount of any element that can exist. The structures and functions of whole organisms depend on the structures of the atoms they contain. Atoms can join together with other atoms of the same element or different elements to form **molecules**. Atoms can combine in many different ways to form thousands of different materials. Combinations of different elements are called **compounds**.



The main mass of each atom is in the central **nucleus**. The nucleus is made of even smaller particles of **protons** and **neutrons**. **Electrons** are minute particles that move around the nucleus at very high speeds within **electron shells** or **energy levels**. Their mass is negligible with that of the neutrons and protons.

NOTE

- An atom with equal number of electrons and protons has no overall electrical charge
- The number of protons in the nucleus is different for every element. The number is called the **atomic number**. In a neutral atom, the number of protons equal the number of electrons

ISOTOPES

The atoms of any particular element always have the same number of protons but the number of neutrons can vary. The atoms may therefore have different masses. There are different versions of the same element and are called **isotopes**. The isotopes are identified by the **mass number** of the atoms, which is the number of protons plus the number of neutrons. Different isotopes of the same element have different mass numbers but they all have the same atomic numbers. For example the isomers of carbon atom have mass numbers of 12, 13 and 14 but they have atomic number 6.

A few elements have isotopes that are radioactive which means they are unstable. They change spontaneously to form a different isotope of the same element or a completely different element. Radiation is given out during this change.

Ions

Ions are atoms that have gained an electrical charge. If an atom loses or gains electrons it becomes an **ion**. The addition of electrons produces a negative ion while the loss of electrons gives a positive electron. The loss

of an electron is called **oxidation**, while the gain of an electron is called **reduction**. The atom losing an electron is said to be **oxidised** while that gaining is said to be **reduced**.

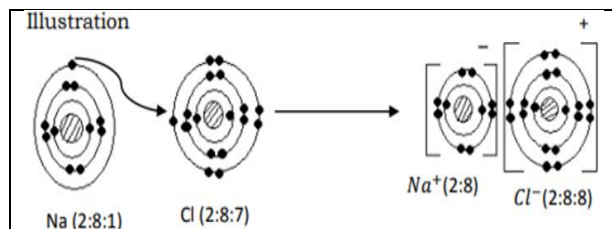
MOLECULES AND COMPOUNDS

Atoms contain electrons which orbit the nucleus in energy levels. Isolated atoms are usually unstable because their outer electron level is not full. They therefore form chemical bonds with other atoms so that their outer shells are filled and obtain a stable outer shell forming **compounds** or **molecules**. Molecules are groups of two or more atoms held together by chemical bonds. Chemical bonds between atoms form because of the interaction of their electrons. The **electronegativity** of an atom, or the ability of an atom to attract electrons, plays a large part in determining the kind of bond that forms. There are three kinds of bonds, as follows:

1. Ionic bonding

Ionic bonds form between two atoms when one or more electrons are transferred from one atom to the other. This bond occurs when the electronegativities of the atoms are very different and one atom has a much stronger pull on the electrons (high electronegativity) than the other atom in the bond. The atom that gains electrons has an overall negative charge, and the atom that loses electrons has an overall positive charge. Because of their positive or negative charges, these atoms are ions. The attraction of the positive ion to the negative ion constitutes the ionic bond. Sodium and chlorine form ions (Na^+ and Cl^-), and the

bond formed in a molecule of sodium chloride (NaCl) is an ionic bond.

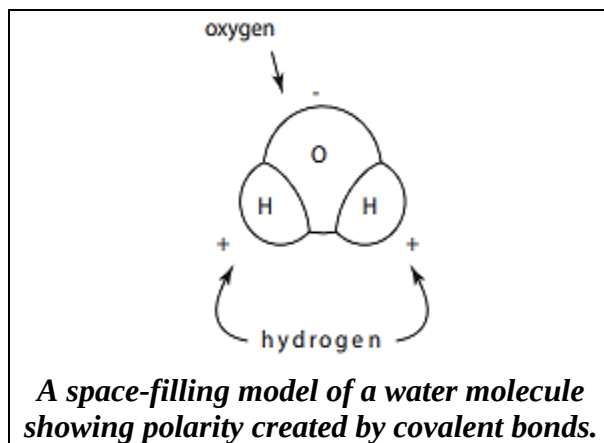


2. Covalent bonding

Covalent bonds form when electrons between atoms are shared, which means that neither atom completely retains possession of the electrons (as happens with atoms that form strong ionic bonds). Covalent bonds occur when the electronegativities of the atoms are similar.

- **Nonpolar covalent bonds** form when electrons are shared equally. When the two atoms sharing electrons are identical, such as in oxygen gas (O_2), the electronegativities are identical, and both atoms pull equally on the electrons.
- **Polar covalent bonds** form when electrons are shared unequally. Atoms in this kind of bond have electronegativities that are different, and an unequal distribution of the electrons results. The electrons forming the bond are closer to the atom with the greater electronegativity and produce a negative charge, or pole, near that atom. The area around the atom with the weaker pull on the electrons produces a positive pole. In a molecule of water (H_2O), for

example, electrons are shared between the oxygen atom and each hydrogen atom. Oxygen, with a greater electronegativity, exerts a stronger pull on the shared electrons than does each hydrogen atom. This unequal distribution of electrons creates a negative pole near the oxygen atom and positive poles near each hydrogen atom.



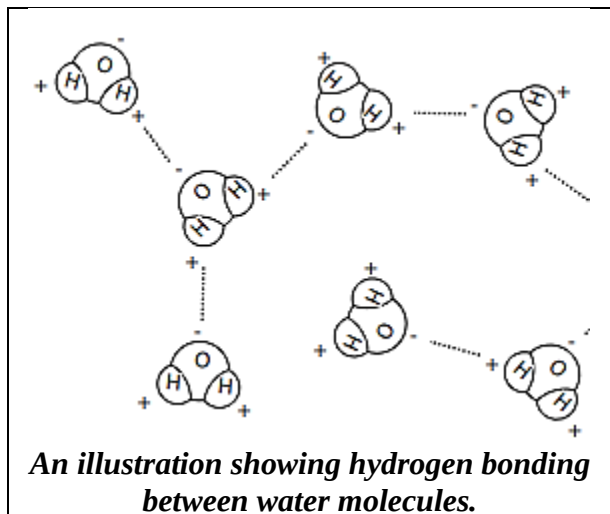
Single covalent, double covalent, and triple covalent bonds form when two, four, and six electrons are shared, respectively.

3. Hydrogen bonding

Hydrogen bonds are weak bonds between molecules. They form when a positively charged hydrogen atom in one covalently bonded molecule is attracted to a negatively charged area of another covalently bonded molecule. In water, the positive pole around a hydrogen atom forms a hydrogen bond to the negative pole around the oxygen atom of another water molecule.

Hydrogen bonds are much weaker than the covalent bonds holding the atoms in the molecules together. These bonds are weak

individually but collectively form important forces which alter the physical properties of molecules. Water forms hydrogen bonds which significantly affects its properties and hence its biological importance



ACIDS, BASES AND SALTS

SOLUTIONS

Almost all the processes that are essential to life take place in solution. A **solution** is a homogeneous mixture of two or more substances in which the particles are completely dispersed. The substance of which there is more, forming the greater part of the solution is called the **solvent**. The substance dissolved in the solvent is called the **solute**

ACIDS

An acid is a compound which when it dissociates in water liberates a hydrogen ion. For example; hydrochloric acid dissociates fully forming hydrogen ions and chloride ions.



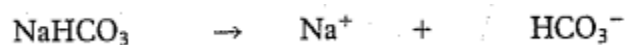
The strength of an acid is determined by the extent to which it dissociates in aqueous solutions. Strong acids dissociate completely while weak acids dissociate partially to form hydrogen ions.

The acidity of the solution is expressed as its **pH**. This is the negative logarithm to the base 10 of the hydrogen ion concentration in moles per liter of solution. pH can also be described as the measure of the hydrogen concentration of the solution. A pH of 7.0 represents neutrality. A solution with a pH less than 7 is **acidic** and a solution with a pH greater than 7 is **basic** or **alkaline**.

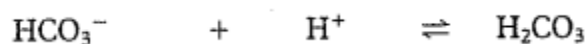
BASES

Bases are substances that react with acids to form salts. Bases that dissolve in water are called **alkalis**.

A base is a proton acceptor which combines with hydrogen atoms liberated by dissociation of an acid in an aqueous solution. For example sodium hydrogencarbonate readily dissociate in solution into sodium and hydrogen carbonate ions



The hydrogencarbonate then accept a free hydrogen ion, if one is available to form carbonic acid



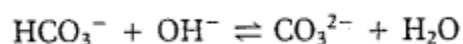
Sodium hydrogencarbonate can remove hydrogen ions from an aqueous solution and

thereby lowering the latter's acidity and increasing its pH. In doing so, it acts as a **buffer**.

BUFFERS

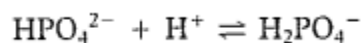
A buffer is a compound which behaves in such a way as to resist changes in pH on dilution or addition of moderate amounts of acid or alkali. However although sodium hydrogencarbonate acts as a buffer on its own, in most cases two or more compounds interact to form a "**buffer system**"

In case of increased acidity, sodium hydrogencarbonate acts as buffer by combining with free hydrogen ions. If the alkalinity is increased, it can react with the free hydroxyl ions to form carbonate ions and water.



Sodium hydrogencarbonate can therefore resist either a decrease or an increase in pH by mopping up the hydrogen or hydroxyl ions as appropriate.

In human body, hydrogencarbonates play a relatively minor role as buffer. More important are phosphate salts like potassium and sodium phosphates which helps to suppress the hydrogen ion concentration in blood. The phosphate combines with free hydrogen ions to form the dihydrogen phosphate



Certain organic compounds for example proteins and haemoglobin can also accept hydrogen ions and are more effective than

phosphates because they occur in much higher concentrations.

Biological importance of buffers

Cells and tissues can only function at or around neutrality; they cannot tolerate fluctuations in pH of more than a unit or two. For this reason, it is essential that the pH of the body fluids should be kept as constant as possible. Any tendency for acidity to increase is counteracted by the buffers which mop up the excess hydrogen ions, thereby helping to maintain constant conditions in the cell.

SALTS

In the body, some of the most common solutes found dissolved in water are **mineral salts**, compounds of a metal with a non-metal or non-metallic radical. Salts are therefore ionic compounds and since they are decomposed by electricity and their free ions enable the passage of electric currents, they are classified as **electrolytes**.

Important cations in the body include: sodium ions, potassium ions, calcium ions, magnesium ion, copper(II) ions, iron(II) and iron(III) ions. Important anions include: chloride, bicarbonate, nitrate, phosphate, sulphate and iodide ions. In addition to these **major mineral elements**, additional ones always present in minute amounts. These **trace elements** include molybdenum and cobalt. Some are required by plants, some by animals and a few by both. Though needed in the smallest quantities, absence of these can cause disease or death

FUNCTIONS OF MINERAL SALTS OR THEIR DERIVATIVES

The functions of mineral salts and their derivatives are varied, but their roles can be summarized as follow:

Constituents of various chemicals

Nitrogen and sulphur obtained by plants as nitrates and sulphates enter into the composition of proteins some of which contain phosphorous and other elements. In addition phosphorous is found in adenosine triphosphate (ATP) and iodine in thyroxine and thyroid gland.

Constituents of structures

Many proteins form structural materials such as connective tissue fibres in which nitrogen and sulphur are important elements. Nitrogen and phosphorous constituents of nucleic acids are found in the chromosomes; phosphorous in the cell membrane; calcium in the plant cell wall; calcium and phosphorous in bones.

Constituents of enzymes

Enzymes are proteins, all of which contain nitrogen. In addition, certain enzymes

contain a metal ion such as copper or iron. For example catalase contains iron which acts as the catalytic centre of the enzyme

Metabolic activators

Certain ions activate enzymes for example magnesium activates enzymes in phosphate mechanisms. Phosphorous as phosphates is required for the activation of sugar before it is broken down in cell respiration.

Constituents of certain pigments

Haemoglobin and chlorophyll contain iron and magnesium respectively. Iron is also found in cytochromes, a group of pigments of great importance in energy release.

Anion-cation balance in cells

Sodium, potassium and chloride ions are particularly important in determination of anion-cation balance in cells especially in nerves, muscles, sensory cells where they are involved in transmission of impulses

Osmotic pressure

Mineral salts together with other solutes determine the osmotic pressure of cells and body fluids.

SUB TOPIC 1: WATER

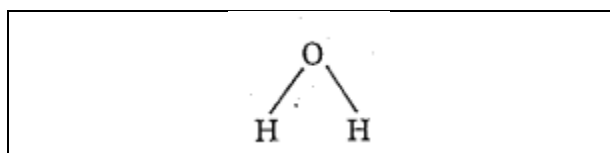
SUB TOPIC OUTLINE

- *Molecular structure of water*
- *Properties of water*
- *Significance of water in the life of organisms in relation to its properties*

Water is formed when two hydrogen atoms combine with an oxygen atom by sharing

electrons. The result is a stable molecule, which is relatively unreactive. The shape of

the water molecule is triangular rather than linear and the angle between the nuclei of the atoms is approximately 105° . Overall the molecule is electrically neutral, but in both of the oxygen-hydrogen bonds, the oxygen draws electrons away from the hydrogen nucleus. Thus there is a net negative charge on the oxygen atom and a net positive charge on the hydrogen atom. A molecule that carries an equal distribution of electrical charge is called a **polar molecule**.



Because of this charge separation, water is an overall neutral molecule. Water molecules form relatively weak bonds called **hydrogen bonds** with other water molecules. Hydrogen bonds are also formed with any charged particles that dissolve in water, and charged surfaces in contact with water. Hydrogen bonds account for the unique properties of water.

BIOLOGICAL IMPORTANCE OF WATER

Water is biologically important as shown by each of its properties.

Solvent properties

The dipolar nature of water makes it an excellent solvent. It is a universal solvent for polar substances e.g. salt and it is also a solvent for non-polar substances e.g. sugar. The polar and ionic substances have an electrostatic charge, so they are attracted to the charges on water molecules. They

dissolve readily in water and are called **hydrophilic**. Non-polar substances such as oil have no charge on their molecules. They do not dissolve readily in water and are called **hydrophobic**. This property enables water to carry out the following functions;

- It is a lubricant e.g. in the joints where it forms the synovial fluid which enables protection against damages.
- It acts as a transport medium as blood, lymph, in the expiratory system as well as in the alimentary canal where it transports materials from one point to another.
- It is an important constituent of the excretory waste products, by which toxic materials are removed from the body.
- It is the largest constituent of the protozoan protoplasm of all cells where it contributes up to 60%.

NOTE

Layers of water molecules form around many non-ionic organic substances, such as sugars because they contain polar side groups

Water has a high heat capacity

Heat capacity refers to the amount of heat required to raise the temperature of 1 kg of water by 1°C . The high heat capacity of water means that the large increase in heat energy around water results into a relatively small rise in the temperature of water because much of the energy supplied to water is used in breaking the hydrogen bonds which restricts the movement of

molecules. The temperature changes within water are therefore minimized as a result of its high heat capacity, this property is significant because;

- It enables life processes such as temperature regulation and gaseous exchange to occur in organisms.
- Such a suitable temperature enables body enzymes to function well without denaturation and/or inactivation.
- It provides a constant internal and external environment for many cells and organisms.

High heat of vaporisation

A relatively large amount of energy is needed to vapourise water due to the hydrogen bonds within water and as a result water has a high boiling point. This is significant because;

- It results into the cooling of the organisms so as to reduce body temperature.
- It is an important heat sink where large bodies of water are responsible for modifying climate by absorbing heat from the sun.

NOTE

The energy transferred to water molecules to allow them vapourise results in loss of energy from their surroundings so that cooling takes place.

High heat of fusion

Latent heat of fusion is the amount of heat energy required to melt a solid such as ice.

With its high heat capacity, water requires relatively large amounts of heat energy to melt ice. Liquid water therefore must lose a relatively large amount of heat energy to freeze. This property is important because it ensures that the cell contents and their environments are unable to freeze.

Density and freezing properties

Water behaves peculiarly when cooled and is most dense at 4°C. In liquid water, hydrogen bonds are constantly forming and reforming. When water freezes, each molecule forms hydrogen bonds with four other molecules. This makes a rigid lattice which holds the water molecules further apart than in liquid water. This is why water expands when it freezes. The density of water decreases below 4°C and ice therefore floats on water. Water below 4 °C tends to rise which maintains the circulation in large water bodies therefore this property is important because;

- It makes water an important factor in the cycling of nutrients needed by living things.
- It makes water a suitable habitat for many aquatic organisms both plants and animals.

High surface tension and cohesion

Water tends to wet most things because its molecules form hydrogen bonding with other substances. Hydrogen bonds give water considerable cohesive forces thus water molecules stick together and also stick to other substances. Cohesion is the force of attraction between molecules of the same kind. This attraction between molecules

enable water to enter narrow spaces, a process called capillarity. At the surface of the liquid a force called **surface tension** exists between the molecules due to the cohesive forces between the molecules. Water molecules have a much stronger attraction to other molecules than to molecules in air. At the air-water surface water molecules on the surface forms hydrogen bonds with other water molecules around and below it, but not with the air molecules above it. This causes the water surface to occupy the least possible surface area. Water has a higher surface tension than any other liquid. This property is important as follows;

- The high cohesion of water molecules enables the movement of water through the xylem to the leaves.
- Surface tension enables small organisms to settle on water or skate over the water surface.
- It enables the water to participate in the absorption of mineral salts from the soil.

Water as a reagent

As a reagent, water is an essential metabolite i.e. it participates in the chemical reactions of metabolism. This property is significant in the following ways;

- Water is a raw material of most bio-chemical reactions taking place such as photosynthesis, respiration, and digestion.

- Water is a medium in which most bio-chemical reactions take place.
- Water is a pre-requisite for fertilization, where fertilization involves mobile gametes e.g. external fertilization in lower plants, fish, amphibians, and internal fertilisation in higher vertebrates and plants.

Incompressibility

This property enables water to carry out the following functions;

- It forms the hydro-static skeleton of animals such as earthworms.
- It provides support to the non woody plants e.g. herbaceous plants by maintaining turgidity of the cells.
- Water provides stomata movement, movement of leaves, opening and closing the flowers e.t.c. to take place through changes in the turgidity of the cells.

High tensile strength

Water can be lifted by forces applied at the top as seen in movement of water to the xylem of tall trees due to strong cohesive forces between water and the walls of the conducting vessels.

Water is transparent

It is important because it enables light to penetrate the water bodies to allow photosynthesis of aquatic plants and also to allow vision to the aquatic animals.

SUB TOPIC 2: VITAMINS

SUB TOPIC OUTLINE

- *Types of vitamins: water soluble and fat soluble, essential and non-essential vitamins*
- *Importance of vitamins in the life of an organism*

Vitamins are organic molecules with diverse functions that are required in very small amounts in the diet for the normal functioning of the body. Plants make their own vitamins but animals obtain many of their vitamins by either feeding on plants or other animals. However under certain conditions, some vitamins are manufactured by the body for example vitamin D can be made in the skin under direct sunlight. For humans, 13 essential vitamins have been identified and are classified as water-soluble or fat-soluble.

Classification of vitamins

They are designated with alphabetical letters and are classified into two:

- i) **Water soluble vitamins;** Water soluble vitamins are those which dissolve in water. They include vitamins B and C.
- ii) **Fat soluble vitamins;** Fat soluble vitamins dissolve in fats but not in water. They include vitamins A, D, E, and K.

Vitamins	Major dietary sources	Major functions in the body	Symptoms of deficiency
			<i>Extreme excess</i>
WATER SOLUBLE VITAMINS			
Vitamin B₁ Thiamine	Pork, legumes, peanuts, whole grains	Coenzymes used in removing carbon dioxide from organic compounds	Beriberi (nerve disorders, emaciation anemia)
Vitamin B₂ Riboflavin	Dairy products, meats, enriched grains, vegetables	Component of coenzymes FAD and FMN	Skin lesions such as cracks at corners of the mouth
Vitamin B₃ Niacin	Nuts, meats, grains	Component of coenzymes NAD ⁺ and NADP ⁺	Skin and gastrointestinal lesions, nervous disorders
			<i>Liver damage</i>

Vitamin B₆ Pyridoxine	Meats, vegetables, whole grains	Coenzyme used in amino acid metabolism	Irritability, convulsions, muscular twitching, anemia
			<i>Unstable gait, numb feet, poor coordination</i>
Vitamin B₅ Pantothenic acid	Most foods: meats, dairy products, whole grains e.t.c.	Component of coenzyme A	Fatigues, numbness, tingling of hands and feet
Vitamin B₉ Folic acid (folanin)	Green vegetables, oranges, nuts, legumes, whole grains	Co enzyme in nucleic acid and amino acid metabolism	Anemia, birth defects
			<i>May mask deficiency of vitamin B₁₂</i>
Vitamin B₁₂	Meats, eggs, dairy products	Co enzyme in nucleic acid metabolism, maturation of red blood cells	Anemia, nervous system disorders
Biotin	Legumes, other vegetables, meats	Coenzyme in synthesis of fat, glycogen, and amino acids	Scaly skin inflammation, neuromuscular disorders
Vitamin C Ascorbic acid	Fruits and vegetables especially citrus fruits, cabbage, tomatoes, green pepper	Used in collagen synthesis (such as for bone, cartilage, gums); antioxidant; aids in detoxification; improves iron absorption	Scurvy (degeneration of skin, teeth, blood vessels), weakness, delayed wound healing, impaired immunity
			<i>Gastrointestinal upset</i>
FAT SOLUBLE VITAMINS			
Vitamin A Retinol	Beta-carotene (pro-vitamin A) in green and orange vegetables, retinal in dairy products	Component of visual pigments, maintenance of epithelial tissues, antioxidant, helps prevent damage to cell membranes	Blindness and increased death rate
			<i>Headache, irritability, vomiting, hair loss, blurred vision, liver and bone damage</i>

Vitamin D	Dairy products, egg yolk; also made in human skin in presence of sunlight	Aids in absorption and use of calcium and phosphorous; promotes bone growth	Rickets (bone deformities) in children, bone softening in adults
			<i>Brain, cardiovascular, and kidney damage</i>
Vitamin E Tocopherol	Vegetable oils, nuts, seeds	Antioxidant; helps prevent damage to cell membrane	Desecration of the nervous system
Vitamin K phylloquinone	Green vegetables, tea; also made by the colon bacteria	Important in blood clotting	Defective blood clotting
			<i>Liver damage and anemia</i>

SUB TOPIC 3: CARBOHYDRATES

SUB TOPIC OUTLINE

- *Structure and components of carbohydrates*
- *Properties of carbohydrates*
- *Condensation and hydrolysis of carbohydrates*
- *Importance of carbohydrates: monosaccharides, disaccharides, polysaccharides*

These are organic compounds made up of carbon, hydrogen and oxygen, in which the ratio of hydrogen to oxygen is 2:1 as in water. They have a general formula of $C_n(H_2O)_m$ where m and n are either the same or different units (n = number of carbon atoms). Most examples of carbohydrates do conform to the general formula e.g. Glucose, $C_6H_{12}O_6$ and Sucrose, $C_{12}H_{22}O_{11}$. Some few carbohydrates do not conform to the general formula e.g. Deoxyribose sugar, $C_5H_{10}O_4$

Carbohydrates are mainly concerned with the **storage and liberation of energy**. A few carbohydrates such as cellulose form important structures of organisms e.g. the plant cell walls.

There are 3 groups of carbohydrates namely;

- Monosaccharides (single sugars).
- Disaccharides (double sugars)
- Poly saccharides (Many sugars or complex sugars)

MONOSACCHARIDES

These are a group of sweet, soluble, crystalline molecules of relatively low molecular mass made of a single sugar. They have between 3 and 10 carbon atoms per molecule.

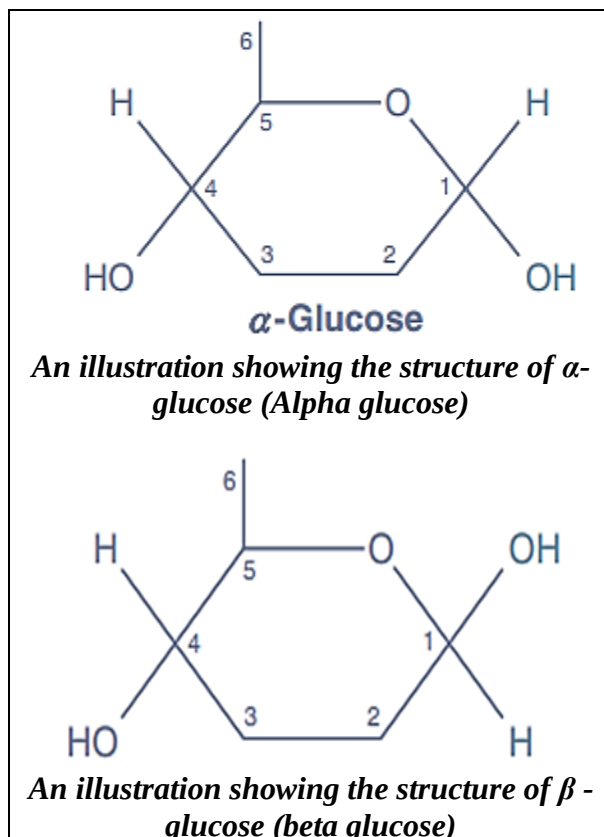
Monosaccharides may contain either an aldehyde group or a ketone within their molecule. If they contain an aldehyde group (-CHO) they are called **aldoses** or **aldo-**

sugars. If they contain a ketone ($C=O$) group in their molecules, they are called **ketoses** or **keto-sugars**. The general formula for Monosaccharides is $(CH_2O)_n$ where n = number of carbon atoms. Where $n = 3$, the sugar is called a **triose sugar**, where $n = 5$, **pentose sugar** and when $n = 6$ **hexose sugar**. Due to the tetrahedron shape of the bonds in the carbon atoms, a hexose sugar (6C) sugar molecule has a ring shape. The side branches project above or below the molecule and their position determines the type of sugar molecule and its properties. Monosaccharides can link together to form larger molecules i.e. they form building units used to form complex sugars.

Monosaccharides have ringed structure and they exhibit **isomerism**. *Isomers* are compounds with the same molecular formulas but different structure formulae. For example, the formula $C_6H_{12}O_6$ can be used for glucose, fructose and galactose. The structures of the various isomers of monosaccharides include the following;

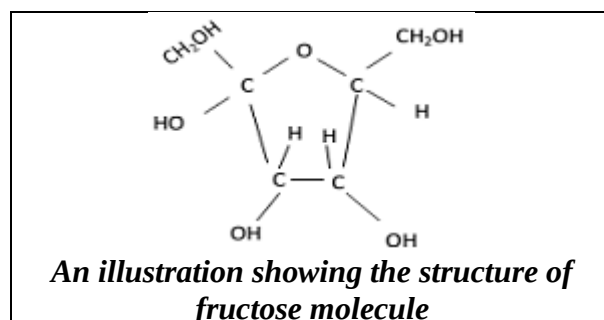
a. GLUCOSE ($C_6H_{12}O_6$)

Glucose can occur in both open (straight) chain and ringed forms. Ring forms of glucose are α -glucose and β - Glucose, which are isomeric forms of glucose which differ in the placement of the hydroxyl group (OH) attached to carbon atom 1. In β - glucose, the -OH group faces upwards towards the oxygen atom in the skeletal ring while α - glucose it faces downwards away from the oxygen atom linking carbon atoms 1 and 5.



b. FRUCTOSE ($C_6H_{12}O_6$)

Fructose is an isomer of alpha glucose when the CH_2OH group interchanges position with the hydrogen (H) atom on carbon atom 1 and when the OH and H atoms on the 2nd and 3rd carbon atoms interchange positions.



c. GALACTOSE

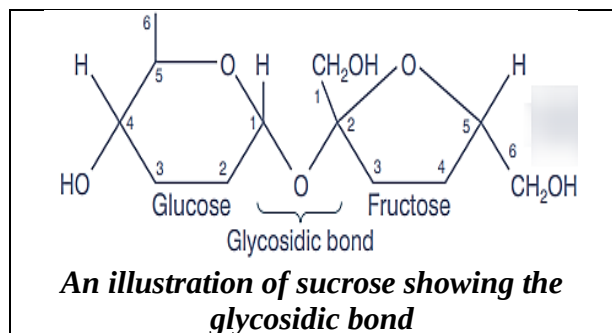
Galactose is an isomer of the alpha glucose when the OH and H on the 4th carbon atom interchange positions.

NOTE:

*Most of the monosaccharides are the **reducing sugars** because they reduce Cu^{2+} in Benedict's solution to Cu^+ ions giving an orange precipitate of copper (I) oxide (Cu_2O). They have an aldehyde group or a free ketone group. Ketoses first isomerise to aldoses before they can act as reducing sugars.*

DISACCHARIDES

A disaccharide is a sugar formed as a result of the combination of two monosaccharides sugars. Because of this reason they are also known as **double sugars**. The general formula $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ and not $\text{C}_{12}\text{H}_{24}\text{O}_{12}$ as expected because these formations involve the loss of one water molecule. Such a reaction which involves the loss of a water molecule during the synthesis of a new compound, is known as a **condensation reaction**. The two monosaccharide units in a disaccharide are held together by a covalent bond known as a **glycosidic bond**.



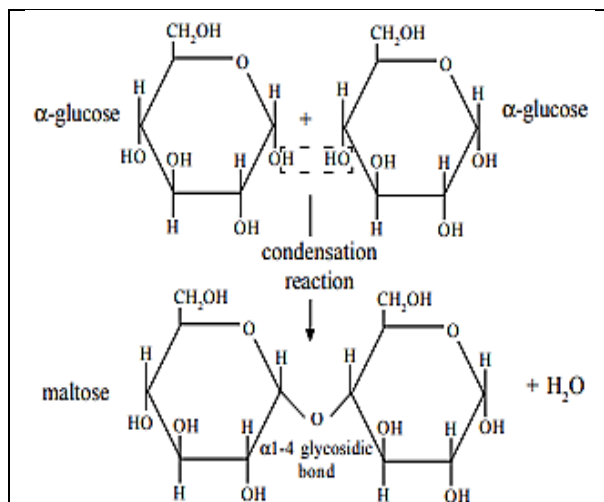
Examples of disaccharides include;

- Maltose = α -glucose + α -glucose
- Sucrose = glucose + fructose
- Lactose = glucose + galactose

Most disaccharides are reducing sugars however there are some few which are non-reducing sugars e.g. sucrose because they lack the reducing group in these molecules. Like monosaccharides, disaccharides are also sweet, soluble in water and crystalline like monosaccharides

Formation of disaccharides

Disaccharides form in a condensation reaction which forms a glycosidic bond. This is illustrated by the following example which illustrates the formation of maltose



POLYSACCHARIDES

These are the sugars formed when many monosaccharides combine as a result of condensation reactions to form chains. Most polysaccharides are formed from hexose sugars and the general formula of $(\text{C}_6\text{H}_{10}\text{O}_5)_n$ where n is a number greater than 40.

Polysaccharides with the number of monosaccharide molecular units ranging from 3 to 10 are called **oligosaccharides** while those whose numbers of monosaccharide molecular units are above 10 are the polysaccharides.

The chains in polysaccharides may be of;

- Variable length although usually very long.
- Branched or unbranched.
- Folded in which case they are suitable for storage e.g. starch
- Straight or coiled: in which case they are ideal for making meshes and for construction e.g. in cellulose used in building cell wall.

Characteristically polysaccharides are un-sweet, insoluble in water and non-crystalline. Due to their insolubility in water, they form good storage compounds in organisms because they cannot diffuse out of the cell and they do not affect the osmotic potential of the cells. The most common polysaccharides are **starch**, **cellulose** and **glycogen**. Upon hydrolysis, polysaccharides can be converted into their constituent monosaccharides such as glucose, ready for use as a respiratory substrate. All polysaccharides are non-reducing sugars.

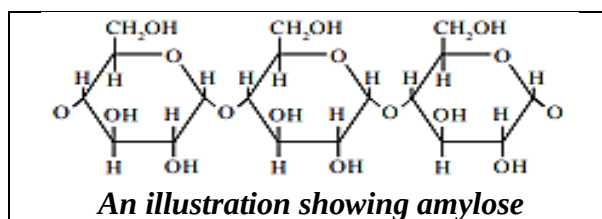
STARCH

This is a polysaccharide made up of many alpha glucose molecules which is found in most parts of the plant. Starch is made from excess glucose produced during photosynthesis and it is the reserve food in plants. It is common in the seeds of most

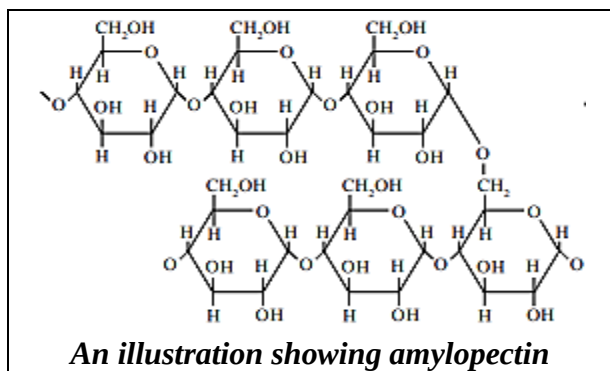
plants such as maize where it forms the food supply for germination.

Starch is made up of two major components namely **amylose** (20% of starch) and **amylopectin** (79% of starch). The 1% of starch is made of other substances such as phosphates.

Amylose consists of unbranched chains of glucose molecules joined by α -1,4-glycosidic bonds which, by hydrogen bonding, form a helix. It is this helix which holds and forms a complex with iodine when we test for starch. The helix also forms a compact shape which allows tight packing and is therefore an excellent storage molecule



Amylopectin consists of glucose molecules joined by α -1,4-glycosidic bonds but after every 25 glucose molecules adjacent chains are connected by α -1,6-glycosidic bonds i.e. amylopectin is branched. These chains are coiled to form a helix in amylopectin where the -OH groups project into the interior and cannot therefore be free to take part in hydrogen bonding. For this reason amylopectin has no cross linkages as amylose whose -OH groups point outwards and can therefore form hydrogen bonds. Therefore starch is not strong enough as a structural polysaccharide like cellulose.



Due to its branching and numerous ends, amylopectin can easily be broken down to maltose by amylase enzyme at a higher rate as compared to amylose

Revision question

Compare and contrast between amylose and amylopectin

GLYCOGEN

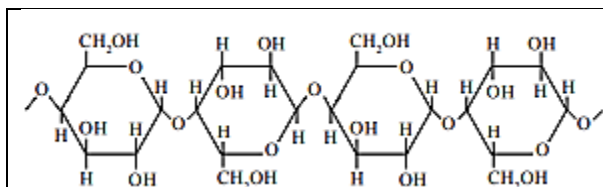
This is the major polysaccharide storage material in animals and fungi. It is stored mainly in the liver and muscles this is mainly because it provides energy more readily than fat within the active tissues of the muscles and the liver. Besides glycogen can be used during anaerobic respiration to provide energy in the muscles e.g. during heavy and physical exercise.

Like starch, glycogen is made up of alpha glucose molecules structure is similar to that of amylopectin except that it has highly branched short tails of alpha glucose molecules as compared to amylopectin. Because it is so highly branched, it can be broken down to glucose very quickly by enzyme glycogen phosphorylase to release energy. It is more soluble in water than starch.

CELLULOSE

This is a polysaccharide made of many beta glucose molecules that form long unbranched parallel chains. It is mainly found in plants because it is the main structure material in plant cell walls and in cotton it makes up to 90%. Many chains run parallel to each other and have cross linkages between them. These cross linkages give cellulose its considerable stability which makes it a valuable structural material. This stability also makes it difficult for animals to digest cellulose and therefore it is not such a valuable food source to the animals.

The difference in the positions of the -OH and the H groups between the alpha glucose and beta glucose on carbon one affects the structural properties of cellulose, in that, the -OH group on carbon 1 in beta glucose faces upwards while it faces downwards in alpha glucose. This makes the -OH groups in cellulose to project outwards from both sides at alternate positions. Cellulose consist of straight chains of molecules where the -OH groups project outwards on both sides of the chain to alternate position which enable cellulose to form cross linkages therefore the free -OH groups are in exposed positions for hydrogen bonding with neighbouring -OH groups of other chains which results in the formation of bundles of cross linked parallel chains.



The above structure shows cross linkages which if combined the strengths of glycosidic bond and covalent bonds make cellulose such a very strong polysaccharide suitable for causing strength in the cell walls of plant cells.

Its chains are linked by hydrogen bonds to make **cellulose microfibrils** which are very strong and rigid and therefore give strength to plant cells and young plants. Hydrogen bonding prevents water entering the molecule. Cellulose is therefore resistant to enzyme hydrolysis which makes it an excellent structural polysaccharide. Cellulose cell walls provide protection to all plant cells. Humans cannot digest cellulose but herbivores have bacteria and protoctists in their digestive system which produce cellulase (β -1,4-glycosidase). The long unbranched fibrous structure provides great mechanical strength.

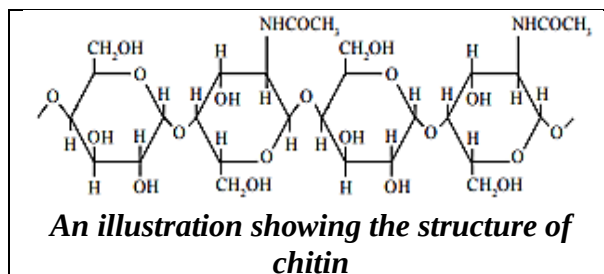
OTHER POLYSACCHARIDES

These include the following;

1. CHITIN

Chemically and structurally chitin resembles cellulose however it differs from cellulose in possessing an acetyl group instead of one of the hydroxide groups in beta glucose. It is made of glucosamine units (glucose + amino acid) and is linked by β -1,4-glycosidic bonds. The presence of the amino group causes even more hydrogen bonding between the chains than in cellulose. Chitin is therefore an extremely resilient and tough polysaccharide. Like cellulose, it has a structural function and it is the major component of the exo-skeleton of insects

and crustaceans. It is also found in fungal cell walls.



2. SUGAR DERIVATIVES

In some compounds containing sugar molecules linked with other non-sugar compounds and such compounds are called sugar derivatives. Some of these are described below form very important compounds.

Mucopolysaccharides

These are formed from amino sugars e.g. glucose amine. An amino sugar is a sugar containing nitrogen. Examples of mucopolysaccharides include the following; **Hyaluronic acid**: this forms part of the vertebrate connective tissues. It is therefore found in cartilage, bones, vitreous humor of the eye and in the synovial fluid. Hyaluronic acid is also found in anti-coagulant called **heparin**. Other mucopolysaccharides are mainly found in the cell walls of prokaryotes such as bacteria.

Nucleotides

A nucleotide is where pentose sugars join with organic bases. Nucleotides are the basic building blocks of nucleic acids such as DNA on which heredity depends and RNA on which protein synthesis depends. Other nucleotides are mainly used in respiration

and these include Adenosine Tri Phosphate (ATP), Nicotinamide Adenine Dinucleotide

(NAD), and Flavine Adenine Dinucleotide (FAD).

SUB TOPIC 4: LIPIDS

SUB TOPIC OUTLINE

- *Structure and components of lipid molecules*
- *Condensation of fatty acids and glycerol to form lipids*
- *Hydrolysis of lipids to fatty acids and glycerol*
- *Properties of lipids*
- *Importance of lipids in organisms*
- *Structure of steroids*
- *Importance of cholesterol*
- *Effects of lipids and steroids to organisms*
- *Comparison between waxes and lipids*

LIPIDS

Lipids are basically natural fats and oils made up of carbon, hydrogen and oxygen but the ratio of hydrogen to oxygen is not 2:1 as in carbohydrates instead the hydrogen atoms are far more than the oxygen atoms. Lipids also include waxes, steroids and phospholipids. Generally all lipids have a high proportion of hydro carbon group (CH_2) in their molecules. They are insoluble in water but can dissolve in organic solvents such as chloroform and benzene.

The low solubility of lipids is due to the low oxygen content and very many CH_2 groups, the numbers of polar $-\text{OH}$ groups that are present in the molecule are very few thus preventing dissolving. It is these polar groups that normally confer solubility in water (H_2O) through ion interaction with water in the case of carbohydrates. Fats are solids at room temperature whereas oils are liquids.

CONSTITUENTS OF LIPIDS

Lipids are made up of **esters** called fatty acids and an alcohol called glycerol. Glycerol has three hydroxyl groups ($-\text{OH}$) and each of these may combine with separate fatty acids forming triglyceride. This combination occurs by **condensation reaction** in which three water molecules are formed and therefore the hydrolysis of the triglyceride will again yield glycerol and 3 fatty acids. Fatty acids have a general formula of $\text{C}_n\text{H}_{2n}\text{O}_2$. Their structural formula can be summarized as below $\text{R}(\text{CH}_2)_n\text{COOH}$. Where n is any even number between 4 and 24. R can be CH_3CH_2 , $\text{CH}_3\text{CH}_2\text{CH}_2$ e.t.c.

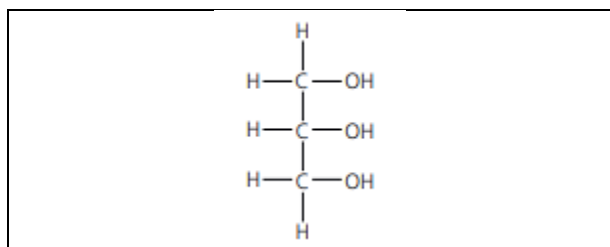
Fatty acids can be classified as **unsaturated** if they contain one or more double bonds e.g. oleic acid. Fatty acids lacking double bonds are said to be **saturated** e.g. stearic acid. Unsaturated fatty acids melt at a much lower temperature than saturated fatty acids. Consequently, saturated fatty acids are

normally found in fats while unsaturated fatty acids are commonly found in oils. Lipids vary due to the presence of many fatty acids. Fats differ from oils in two fundamental ways;

- Fats are made from saturated fatty acids while oils are made from unsaturated fatty acids.
- Fatty acids in oils are smaller than those in fats.

GLYCEROL (Propan-1, 2, 3-triol)

This is an alcohol with the molecular formula of $C_3H_8O_3$. There is only one type of glycerol that exists in both fats and oils whose structure is shown below

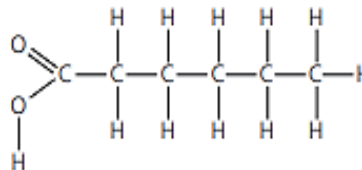


FATTY ACIDS

All occurring lipids have glycerol and therefore it is the nature of the fatty acids which determines the characteristics of any particular lipid. All fatty acids have a carboxyl group ($COOH$), the remainder of the molecule being a hydrocarbon chain of varying length. There are two kinds of fatty acids namely;

Saturated fatty acids

These have only single bonds between the carbon atoms, and each carbon has two hydrogens bonded to it (three hydrogens bonded to the last carbon).

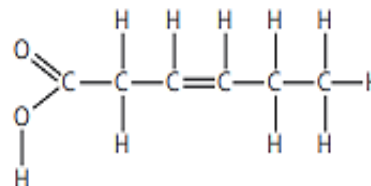


In saturated fatty acids, each of the carbon atoms in this chain, with the exception of the last, has two hydrogen atoms joined to it.

Unsaturated fatty acids

These have at least one double bond between carbon atoms. They are also divided into two main groups namely;

- ❖ A **monounsaturated fatty acid** has one double covalent bond and each of the two carbons in this bond has only one hydrogen atom bonded to it.
- ❖ A **polyunsaturated fatty acid** is like a monounsaturated fatty acid except that there are two or more double covalent bonds.



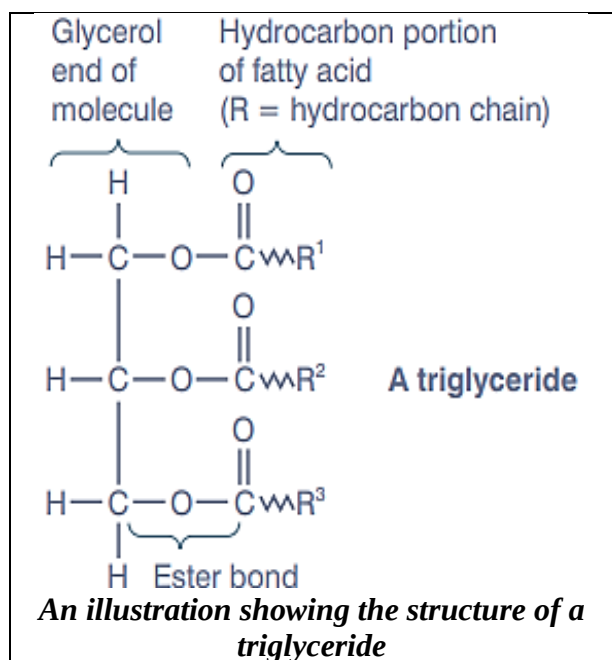
In unsaturated fatty acids, there are one or more double bonds between the carbon atoms in the chain. Because of this, some carbon atoms will be joined only to a single hydrogen atom

In general, saturated fatty acids have higher melting points than unsaturated fatty acids. Fats that are solid at room temperature, such as lard or butter, tend to have more saturated

fatty acids in them, while oils that are liquid at room temperature, such as sunflower or olive oil, have more unsaturated fatty acids.

FORMATION OF A TRIGLYCERIDE

During its formation, a **condensation reaction** occurs in which 3 fatty acids of the same type or different types, combine with one glycerol molecule. During this reaction, the hydroxyl group of glycerol reacts with a carboxyl group (COOH) of the fatty acids to form water and **triglyceride** joined by ester bonds.



NOTE:

A **condensation reaction** is a reaction in which two molecules become covalently bonded to each other through the loss of small molecules usually water, in which case it is called a **dehydration reaction**.

Because fatty acids are synthesized from fragments containing two carbon atoms, the

number of carbon atoms in the lipid chains is always an even number. Lipids require too much oxygen to be oxidized in respiration as compared to glycogen and are therefore used in respiration.

ESSENTIAL AND NON-ESSENTIAL FATTY ACIDS

The essential fatty acids are the ones which cannot be synthesized by the body and must therefore be obtained from the diet e.g. linoleic acid and linolenic acid. A common dietary source for these fatty acids which are essential in our bodies is vegetables and seed oils. Deficiency of essential fatty acids results into retarded growth or deduction in the growth rate, reproductive deficiency and even kidney failure.

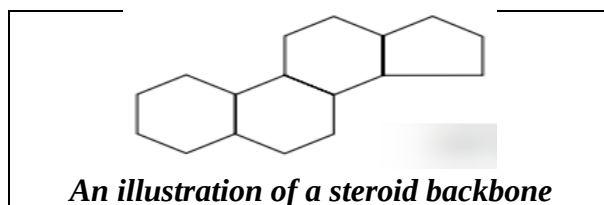
STERIODS AND WAXES

1. Waxes

These are similar to lipids in composition except that the fatty acids are linked to long chained alcohols instead of glycerol. These form a water proof layer on the surfaces of most terrestrial plants and animals.

2. Steroids

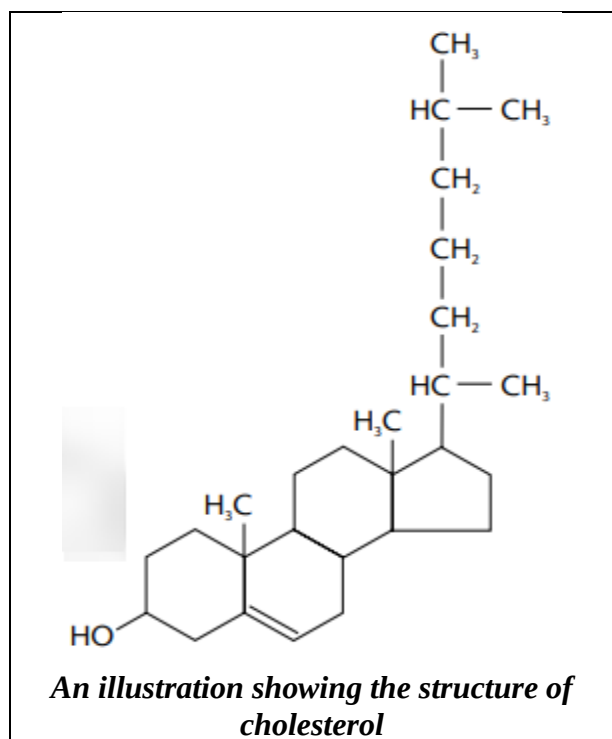
These are lipids whose molecules contain 4 rings of carbon and hydrogen atoms. Steroids are therefore bigger than the common lipids and they are saturated hydrocarbons.



They are biologically important group of compounds which have certain properties in common with lipids, for example their insolubility in water and solubility in organic solvents. The functions of some important steroids are given below;

Cholesterol

Cholesterol is a major component of the cell membrane. It consists of four rings of carbon and hydrogen atoms with a branched side chain. A single hydroxyl group (-OH) gives the molecule a small charge as a result of ionization. Cholesterol is very hydrophobic



Cholesterol readily mixes with lipids conferring on the mixture the ability to absorb water. It has two main important functions in the plasma membrane namely;

- ❖ It limits the uncontrolled leakage of small molecules (water and ions) in and out of the plasma membrane. Cholesterol is also an important constituent of myelin and helps to prevent the outward flow of ions which would 'short circuit' the movement of nerve impulses along the axon.
- ❖ Cholesterol in membranes pull together the acid chains in phospholipids restricting their movement but also not making them solid.

Cholesterol is also a raw material for many other steroids e.g. it is used by the liver in the formation of bile salts and in small quantities used to make steroids in the ovaries, testes and adrenal glands.

Bile acids

These are used in emulsification of fats during digestion.

Sex hormones

Oestrogen and progesterone; these are reproductive hormones in female mammals which regulate the menstrual cycle and controlling pregnancy

Testosterone; this is a reproductive hormone in male mammals controlling sexual behavior and sperm production.

Vitamin D (Calciferol)

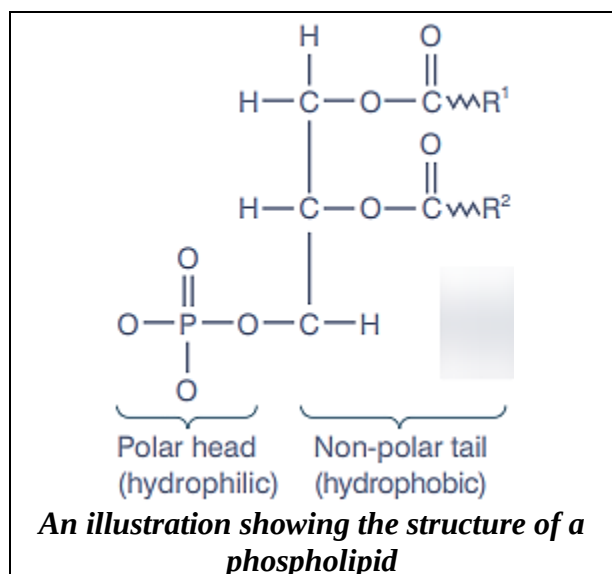
It promotes calcium and phosphate absorption and metabolism. It is also important for the hardening of bones and teeth

Ecdysone (Moulting hormone)

It causes moulting (shedding off the cuticle in arthropods)

PHOSPHOLIPIDS

A phospholipid differs from having a phosphate group (PO_4^{3-}) group attached to one of the hydroxyl groups of glycerol such that they have two fatty acids linked to glycerol by condensation reaction instead of three fatty acids.



Other groups including nitrogenous bases could even be attached to this phosphate group to make the structure even more complex. The phosphate group is electrically charged (PO_4^{3-}) and therefore polar when and so unlike fatty acids dissolve in water. Phospholipids are therefore able to dissolve in both water and organic substances i.e. phospholipids are both hydrophilic and hydrophobic. This property of phospholipids is important in determining the structure and functioning of the cell membrane

FUNCTIONS OF LIPIDS

Lipids store more energy than similar quantities of carbohydrates.

Upon hydrolysis lipids yield more energy than carbohydrates i.e. lipids yield 38KJg^{-1} of energy compared to 17KJg^{-1} for the carbohydrates. This is so because of many covalent bonds of carbon to carbon (C-C) and carbon to hydrogen (C-H) type that is present in lipids due to many hydrogen atoms they contain. These bonds contain large quantities of energy that can be released and used by the cell when required. Therefore carbohydrates yield less energy for the cell but are readily hydrolysed than lipids.

Storage of materials

Lipids are good storage compounds in the body e.g. they store a lot of water and fat soluble vitamins e.g. A, D, E and K. Lipids are good storage compounds because of the following reasons;

- They are insoluble in water and therefore cannot dissolve away and cannot affect the osmotic potential of the cells
- They are much lighter than carbohydrates so as to keep the weight to the minimum
- They have a high calorific value i.e. they have a high energy content
- They are compact and therefore they take up very little space in the cells
- Lipids are poor conductors of heat in the body

Lipids insulate the body against heat loss as they are poor conductors of heat.

This explains why the major fat deposits of the body are found under the skin as subcutaneous fat layer, and around vital organs such as the heart, kidneys, lungs, intestines e.t.c. whose temperatures should not vary much.

- Fats are used as packing material around delicate organs of the body such as kidneys, heart, lungs and intestines so as to protect them from physical damage by acting as shock absorbers.
- Lipids speed up impulse transmission along nerves using the myelin sheath
- Lipids are useful source of metabolic water for desert animals when broken down in respiration

➤ Lipids form very important structures in organisms, the structures include;

- They form the phospholipid layer of the cell membrane by combining with phosphorous to form the phospholipids
- They form the subcutaneous fat layer beneath the dermis of the skin
- They form the waxy cuticle of the insects and plants which prevent excessive water loss
- They form the adipose tissue usually around the delicate organs such as the heart
- They form suberin in plant cell walls especially in endoderm cells

SUB TOPIC 5: PROTEINS

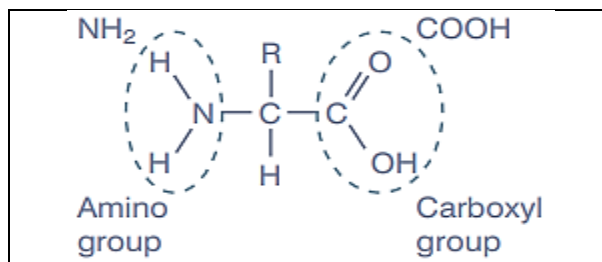
SUB TOPIC OUTLINE

- *Structure and components of proteins*
- *Condensation of amino acids to proteins; hydrolysis of proteins to amino acids*
- *Properties of proteins*
- *Importance of proteins*

Proteins are complex organic compounds with a large molecular mass made of carbon, oxygen, hydrogen, nitrogen and in some cases sulphur. Proteins are the most abundant molecules to be found in the cells and comprise over 50% of their total dry weight. They are therefore an essential component of the diet of animals and may be converted to both fats and carbohydrates by the cells. All proteins are composed of basic structural molecules known as **amino acids**.

AMINO ACIDS

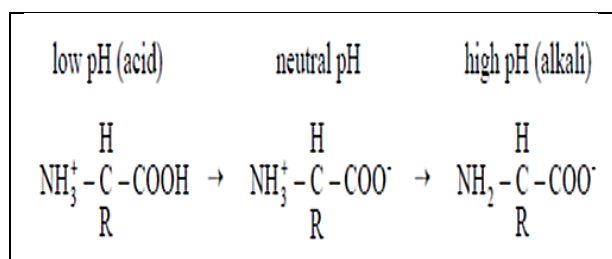
The general formula of amino acids is $RCHNH_2COOH$ whose structure is shown below;



The above structure shows that amino acids are composed of four different parts namely;

- A hydrocarbon group (-CH)
- A carboxyl group (COOH)
- An amino group (NH₂)
- An R group. It is in this R group of the amino acid that lies the difference in the amino acid e.g. in amino acids, glycerine which is the simplest amino acid, R is a hydrogen atom while it's a methyl group (CH₃) in amino acid alanine.

Amino acids are generally soluble in water but insoluble in organic solvents. At neutral pH (found in most living organisms), the amino acid exists as a dipolar ion (**zwitterion**). The charge on the ion changes with pH. In an acid solution, the amino acid picks up hydrogen ions and becomes positively charged. In alkaline solution, the amino acid donates hydrogen ions to the medium and becomes negatively charged. The pH at which the amino acid is electrically neutral is called the **isoelectric point**. The charge on the amino acid changes with pH as shown below;



The presence of an amino group which is **basic** and a carboxyl group which is **acidic** in all amino acids accounts for the name amino acids and also confer on the amino acids on **amphoteric** nature i.e. amino acids

have both acidic and basic properties. This implies that amino acids can donate hydrogen ion (protons) as acids do and also can accept hydrogen ions (protons) as bases do. In amino acids, these abilities to donate or receive protons are conferred by a carboxyl and amino groups respectively.

Their amphoteric nature is useful biologically as it means that they can act as **buffers** in solutions thereby resisting changes in the pH of the solution. A buffer solution is the one which is able to resist changes in the pH of the solution. Amino acids therefore can donate hydrogen ions as the pH increases so as to lower the pH and also accept hydrogen ions from the solution as the pH decreases so as to raise the pH. Amino acids therefore play an important role as buffer in the tissue fluid and in the cytoplasm of most cells thereby maintaining the pH within the narrow limits needed for normal metabolism and efficient enzyme functioning. This is because changes in pH denature enzyme which can be fatal to the living organism. It is these changes with pH, that explain the effect of pH on enzymes. A solid, crystallised amino acid has the uncharged structure, but this form never exists in solution, and therefore doesn't exist in living things.

AMINO ACIDS AND DIET

There are 20 common naturally occurring amino acids whose different combinations result in a great variety of the proteins since each amino acid has its own set of properties. Amino acids are classified into two groups namely; essential and non-essential amino acids.

Essential amino acids;

These are the amino acids which cannot be synthesized by the body and therefore must be obtained from the diet. These amino acids include the following; Isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, arginine, and histidine

Foods containing all the essential amino acids are known as **first class protein food** and such foods include all animal proteins and some few plant proteins e.g. the soya bean. Food lacking one or more essential amino acids is known as **second class protein food** and this includes most plant proteins and a few animal proteins.

Non-essential amino acids

These are amino acids which the body can synthesise in such sufficient quantities for them not to be required in the diet. The absence of one or more of these amino acids results in retarded growth and particular symptoms, characteristics of the particular amino acid lacking. Non-essential acids include the following; Alanine, Aspartic acid, Glutamic acid, Glycine, Proline, Serine, Tyrosine, Cysteine, Asparagine, and Glutamine

Non-essential amino acids are synthesised in the body through a process known as **transamination** which involves the use of enzymes known as **transaminases**, the raw materials for this process are the essential amino acids provided in the diet and carbon dioxide derivatives e.g. pyruvic acid which is obtained from the breakdown of sugar during respiration.

FORMATION OF A POLYPEPTIDE

Initially two amino acids are united in a condensation reaction to form a **dipeptide** with the loss of a water molecule. The bond that is formed is called a **peptide bond**. Later several dipeptides combine in several condensation reactions to form **polypeptides** which consist of up to 500 amino acids or more. The individual amino acids within the polypeptide chain are linked by peptide bonds to form a protein. These polypeptides made are then folded and twisted in an appropriate way as directed by a particular gene (DNA) which also determines the sequence of amino acids in the chain.

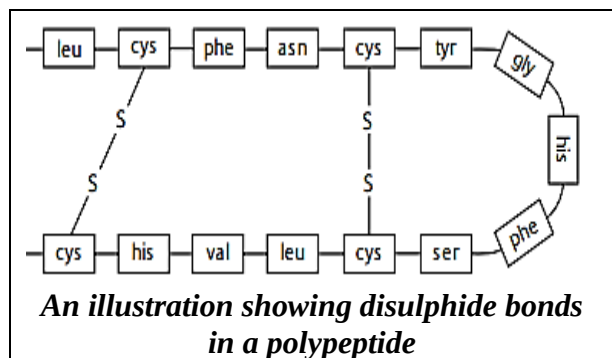
Amino acids are able to form other bonds with reactive groups apart from the peptide bond such bonds include the following;

1. the ionic bond

At a suitable pH an interaction may occur between ionised amino groups and a carboxyl and this results in the formation of an ionic bond between the two amino acids. This bond can be easily broken in an aqueous medium by changing the pH of the medium.

2. the disulphide bond

This bond arises between sulphur containing groups of any two oxidised cysteine molecules of amino acids. Disulphide bonds may be formed between different parts of the same chain (hence folding the chain into a particular structure) or different chains of amino acids. They are strong and not easily broken.



3. the hydrogen bond

This occurs between certain hydrogen atoms and certain oxygen atoms that contain ion pairs of electrons. The hydrogen bond is weak, but as its occurrence is more frequent, the total effect makes a considerable contribution towards molecular stability, as in the structure of the α -helix.

CLASSIFICATION OF PROTEINS

Proteins are classified according to their orders of organization, particularly of the amino acids within the peptide chains. The proteins are also classified as primary structure proteins, secondary, tertiary and quaternary structure proteins.

PRIMARY STRUCTURE

This refers to the sequence of amino acids found in the polypeptide chains of the proteins. This sequence determines the properties and shape of the proteins. The primary structure is specific for each protein and is determined by the DNA of the cell from which it is made.

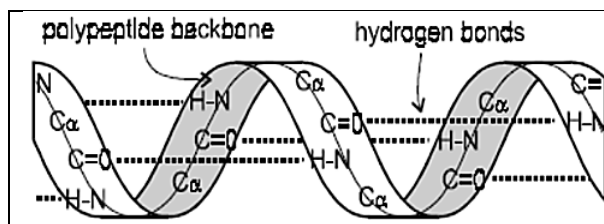
A primary structure is held together by the covalent bonds called peptide bonds between adjacent amino acids. All other protein structures are modifications of these

primary structures. One major importance of the primary structure of the protein in relation to function is found in enzymes, in which the structural configuration of the active site of the enzymes determines whether a particular substrate will fit in the active site of that enzyme. The primary structure is clearly shown by insulin hormone.

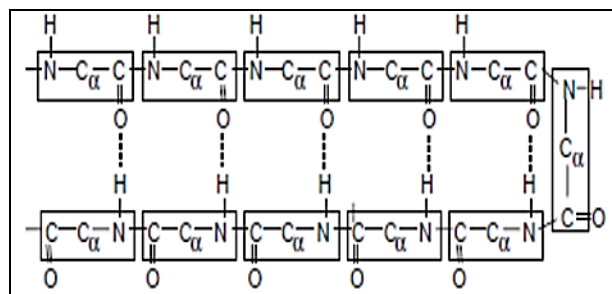
SECONDARY STRUCTURE

This refers to the regular arrangement of the polypeptide chains of the proteins as a result of hydrogen bonding which can be either **alpha-helix** or **beta-pleated sheets**. This is because after their formation, the chain of amino acids in the polypeptide folds spontaneously to make complex configurations categorised into alpha-helices or beta-pleated sheets held together by hydrogen bonds.

An alpha-helix is the one in which the polypeptide chain is loosely coiled into a regular spiral shape joined by numerous hydrogen bonds. It is regular in that the repeating constituents of the polypeptide backbone in the spirals are at a specific distances.



The β -pleated sheets are chains of polypeptides arranged in a zigzag format with antiparallel strands held together by hydrogen bonds.



The hydrogen bonds stabilise the helix by joining together the amino group of one turn and a carboxyl group of another turn. Therefore, the importance of the secondary structure is that it maintains a particular shape of a protein keeping it stable by twisting it.

This secondary structure is of greater importance in the biological function of proteins particularly enzymes and antibodies whose efficiency depends on maintaining a particular shape. It is also important in the formation of fibrous proteins which are insoluble in water and are resistant to changes in temperature and pH. It is also used in the formation of **structural proteins** such as keratin, silk and collagen. Keratin is a **fibrous protein** found in the hair, nails, horns, feathers and wool. Collagen is also a **fibrous protein** found in mammalian connective tissue such as bones, cartilage, tendons and the skin. Both keratin and collagen contain a secondary structure in the form of an alpha-helix.

TERTIARY STRUCTURE

This is a structure resulting from other uniform coiling and folding of the polypeptide helix in to a very compact structure. For this to happen all the three types of bonds namely, ionic, hydrogen and

disulphide bonds must be present in the protein so as to contribute to the maintenance of the structure.

It is the structure which explains the complex molecular shape of some proteins especially **globular proteins**, especially enzymes, myoglobin and insulin. This structure contains many cross linkages formed by many bonds within the polypeptide chains which make the proteins strong molecules. These are soluble in water because they consist of polar groups and amino acids which congregate outside and interact with water. There hydrophobic chains contain non polar amino acids and are usually pushed inwards into the centre of the molecules.

QUATERNARY STRUCTURE

This is the structure which arises from the combination of a number of different polypeptide chains and associated non protein groups into a large protein molecule. Such a structure is shown by haemoglobin.

Structurally haemoglobin consists of 2 α -polypeptide chains and 2 β -polypeptide chains arranged around a complex ion containing prosthetic groups called haem groups. Such polypeptide chains are normally fitted together in such a way that they form larger and more complex protein structure. The 4 polypeptide chains in haemoglobin are called globin. Each chain in haemoglobin carries a haem group to which one molecule of oxygen binds.

NOTE

A **prosthetic group** is an organic or inorganic compound fixed on the proteins. If

*the prosthetic group in a protein is organic in nature then such a group is called a **co-enzyme**. If the prosthetic group is inorganic in nature then such a group is called a **co-factor***

DENATURATION OF PROTEINS

The three dimensional (3-D) structure of a protein is in part at least, due to fairly weak hydrogen and ionic bonds. Any agent which breaks these bonds will cause the 3-D shape to be changed. In many cases, the globular proteins revert to a more fibrous form. This process is called **denaturation**. The actual sequence of amino acids is unaltered, only the overall shape is changed. This is still sufficient to prevent the molecule from carrying out its usual functions in an organism.

FACTORS THAT CAUSE PROTEIN DENATURATION

Denaturation of a protein maybe permanent or temporary depending on the following factors:

Heat

Heat increases the kinetic energy causing the atoms of the protein to vibrate more thus breaking hydrogen and ionic bonds

pH

Additional H^+ in acids combine with COO^- groups on amino acids and form $COOH$ hence breaking the ionic bonds. However, reduced number of H^+ causes NH_3^+ groups to lose H^+ and form NH_2 hence breaking the ionic bonds.

Inorganic compounds

The ions of heavy metals such as mercury and silver are highly electropositive. They combine with COO^- group and disrupt ionic bonds. Similar highly electronegative ions such as cyanide combine with NH_3^+ group and disrupt ionic bonds.

Organic compounds

Organic solvents alter the hydrogen bonding in the protein. For example alcohol denatures certain bacteria proteins hence used in sterilization.

Mechanical force

Physical movement may break the weak hydrogen bonds in the protein. For example stretching a hair breaks the hydrogen bonds in the keratin helix making it straight. If released the hair returns to its original length.

SUB TOPIC 6: ENZYMES

SUB TOPIC OUTLINE

- *Criteria for naming enzymes: type of substrate, type of reaction*
- *The enzyme action: lock and key, induced fit*
- *Properties of enzymes relating to factors affecting enzyme activities*
- *Role of enzymes in living organisms*
- *Inhibition: competitive/non-competitive, reversible/non reversible*

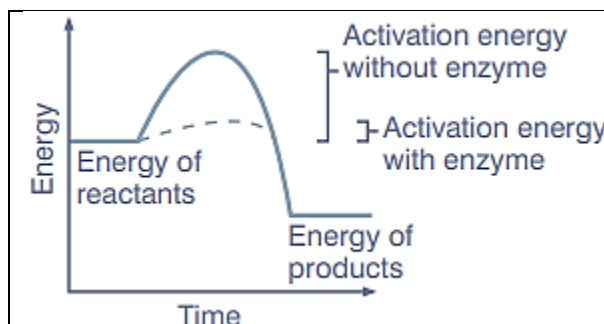
In order for a chemical reaction to take place, the reacting molecules (or atoms) must first collide and then have sufficient energy (activation energy) to trigger the formation of new bonds. Although many reactions can occur spontaneously, the presence of a catalyst accelerates the rate of the reaction because it lowers the activation energy required for the reaction to take place. A **catalyst** is any substance that accelerates a reaction but does not undergo a chemical change itself. Since the catalyst is not changed by the reaction, it can be used over and over again. Most biological catalysts are globular proteins known as **enzymes**.

ENZYMES

An enzyme is an organic catalyst protein in nature which speeds up the rate of metabolic reactions in an organism without itself undergoing a permanent change.

Without enzymes the reactions that occur in living organisms would proceed so slowly, if at all, to cope up with the rates required for maintenance in life. Also increasing the rate of a body reaction would be by increasing the temperature of the body. This would denature proteins, disrupt membranes and be very expensive in terms of energy expenditure. Enzymes are **biological catalysts** and therefore enable metabolic reactions to proceed rapidly and at low temperatures. Enzymes are able to speed up chemical reactions by lowering the **activation energy** needed. Activation energy is the energy needed to make particles react when they collide. A fixed amount of energy in the environment can

activate a certain number of reacting particles per second. If the activation energy is reduced to one-tenth, the same energy will activate 10 times as many particles: the reaction will be 10 times faster.



Enzyme reactions may be described as either **catabolic**, if they are involved in the breakdown of compounds or **anabolic**, if they are involved in the synthesis of compounds. The total of all catabolic and anabolic reactions in a living cell or organism is what is called **metabolism** of the cell or organism.

NOTE

*Other substances also carry out catalytic functions in living organisms. **Abzymes** are antibodies with catalytic functions and **ribozymes** are molecules of RNA which act catalytically on themselves.*

THE CONTROL OF METABOLIC PATHWAYS

Commonly a number of enzymes are used in sequence to convert one substance into one or several products via a series of intermediate compounds. The chain of reactions involved in converting the substrates to their products through a series of intermediate compounds i.e. known as the

metabolic pathway. Many such pathways can proceed simultaneously in a single cell. The reactions proceed in an integrated and controlled way and this can be attributed to the specific nature of enzymes.

A single enzyme will catalyse only a single reaction, therefore enzymes serve to control the chemical reactions that occur within the cells and ensure that these reactions proceed at an efficient rate. The cells also make use of the properties of enzymes to exercise control over metabolic pathways as illustrated in the example above. The high concentration of the end product of the pathway may inhibit the enzyme at the start of the pathway this is called **end product inhibition**. In most cases of end product inhibition, the enzyme catalyzing the first step in the reaction sequence is inhibited by the end product and this mechanism is termed as **negative feedback** because the information from the end of the pathway which is fed back to the start of the pathway has a negative effect.

Control of the metabolic pathways has the following advantages;

- It allows energy to be derived in usable form from many small catabolic reactions than it would be in a single large reaction.
- It allows substrates to be partially broken down so as to provide raw materials for other reactions in the cell. Some of the intermediate compounds formed in the pathway have increased functions to perform within the cell.

- It allows the synthesis of complex organic compounds from simple raw materials using the genetic conditions prevailing in the cells which would not be synthesized in one step pathway.
- It increases the ability of the cell to control the products made in anabolic pathways when the reactions in them proceed in small steps.

THE STRUCTURE AND MECHANISM OF ACTION OF ENZYMES

ENZYME STRUCTURE

Structurally an enzyme is a complex three dimensional **globular protein** some of which have other associated molecules (conjugated proteins): the protein part of this enzyme is called **apoenzyme**. If the non-protein portion of the enzyme is readily detached and actually participates in reactions with two or more different enzymes, it is known as **coenzyme** e.g NAD^+ and NADP^+ . If the non-protein molecule remains more or less permanently attached to one particular enzyme, it is called a **prosthetic group** for example haem, chlorophyll etc. sometimes a metal ion is required for the functioning of an enzyme e.g thrombokinase enzyme requires Ca^{2+}

Even though the enzyme molecule is normally larger than the substrate molecule it acts upon, only a small part of the enzyme molecule actually comes into contact with the substrate. This region of the enzyme molecule which comes into contact with the substrate is called the **active site**.

Only a few of the amino acids of the enzyme molecule actually make up the specific sequence of amino acids that make up the active site. The rest of the amino acids in the enzyme molecule are used to maintain the globular structure of the enzymes. The specific sequence of amino acids in the active site gives the active site of a **specific configuration**. It is the active site configuration which controls enzyme functioning and properties. It is at the active site that bonding of substrates occurs.

THE MECHANISM OF ENZYME ACTION

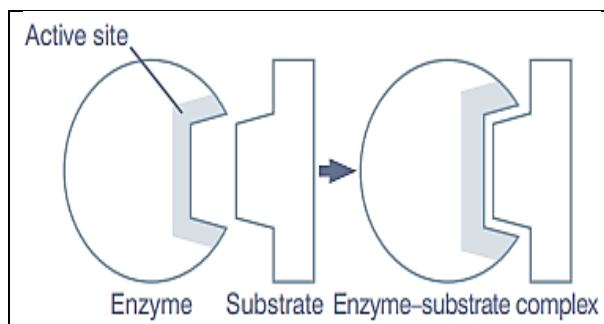
Enzymes generally work by lowering the activation energy. Enzymes therefore make it easier for a reaction to take place than it would without them. How an enzyme lowers activation energy of the reaction is explained by a number of mechanisms described below;

THE LOCK AND KEY HYPOTHESIS

According to this hypothesis, enzymes have active sites into which specific substrate molecules fit exactly. The **substrate molecule** is the key whose shape is complementary to that of the enzyme active site. The enzyme is the **lock** where the substrate fits therefore both the enzyme and the substrate have complementary structures.

The substrate molecules combine with an enzyme molecule to form a compound called enzyme substrate complex. When the substrate binds with the enzyme molecule, the substrate molecules become slightly distorted putting a strain on the bonds of the

substrate molecules which results into breaking of these bonds and rejoining them using less energy. The enzyme-substrate molecule forms an enzyme-end product complex which splits into the enzyme and the end products. The enzyme remains unchanged while the products are released from the active sites since they have a different shape from the substrate.



The lock and key hypothesis is important in that it explains the various properties of enzymes in the following ways;

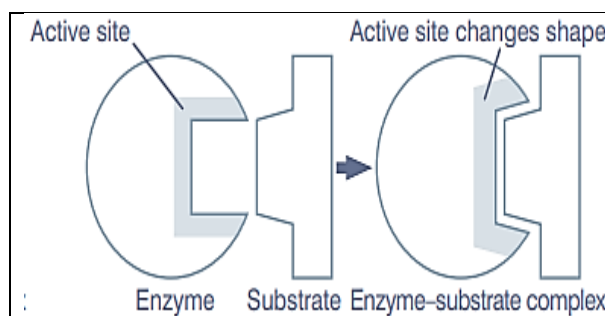
- It explains the specificity of enzymes because it shows that only substrates with complementary shapes to the active sites can actually fit into the active sites to form products.
- It explains how enzymes can be used over and over again. In other words, it shows that once the active site is set free at the end of the reaction, another substrate can combine with it to form an enzyme substrate complex.
- It explains why to some extent the rate, of an enzyme controlled reaction is limited by increasing the substrate concentration. This is so because the reaction is inhibited

when all the active sites of an enzyme have been bonded to.

- It explains why and how enzymes can be inhibited this is because inhibitors having a similar shape to that of the active site of the enzyme may occupy the active site before the substrate and prevent the substrate from occupying the active site hence inhibiting the reaction.
- It further explains how heating lowers the rate of a controlled reaction. This is because heating denatures the enzyme thereby changing its shape which prevents the substrate from fitting into the active site.
- Also changes in PH break the bonds which maintain the three dimensional shape of the enzyme and as a result change the active site configuration. This makes the substrate fail to fit through the active site.
- It explains why enzymes are protein in nature because the structure of proteins is based on a sequence of amino acids in their primary structures which sequence also exists in the active sites of enzymes thereby determining the properties of enzymes.
- It explains how enzymes reduce the activation energy of a chemical reaction by showing that when a substrate binds to the enzyme, substrate molecule becomes slightly distorted which strains the bonds in it and as a result less energy is needed to break the bond.

THE INDUCED FIT HYPOTHESIS

This alternative hypothesis is proposed in line with more recent evidence that the lock and key are not actually static but are able to change their shapes during combination so that the two fit each other properly. In the presence of the substrate, the active site of an enzyme may change in order to suit the shape of the substrate.



The enzyme in this hypothesis has a binding site configuration which attracts the substrate. On binding to the enzyme the substrate disturbs the shape of the active site and causes it to assume a new configuration. It is this new configuration which allows the substrate to suit properly in the active site and this enables the formation of an enzyme substrate complex in which the substrate molecules become slightly distorted. This strains the bonds in a substrate and as a result less energy is needed to break these bonds to form an enzyme product complex.

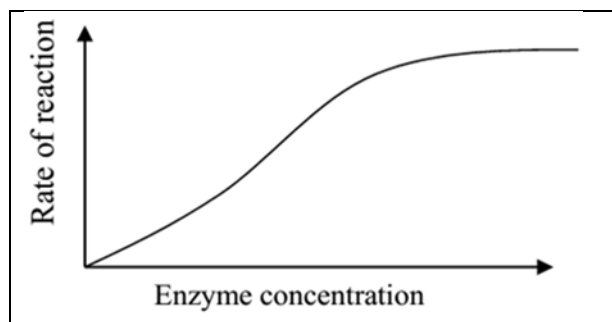
THE RATE OF ENZYME CONTROLLED REACTIONS

The rate of an enzyme controlled reaction is measured by the amount of substrate changed into products per unit time. Any factor that influences an enzyme will alter the rate of the reaction that is being

catalyzed. The factors affecting the rate of reactions include the following;

ENZYME CONCENTRATION

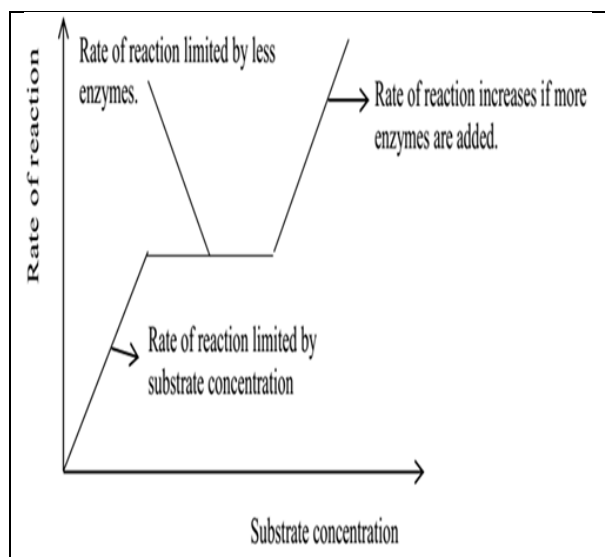
Provided that the substrate concentration is maintained at a high level and other conditions such as pH and temperature are maintained constant, the rate of a reaction increases with increase in enzyme concentration until when the rate remains constant. Usually the enzyme concentration is much lower than the substrate concentration. Therefore as the enzyme concentration increases, the rate of substrate is either being exhausted in the reaction or greatly reduced thereby limiting the reaction.



SUBSTRATE CONCENTRATION

The rate of enzyme controlled reaction increases with increase in the substrate concentration for a given quantity of an enzyme until such a concentration when all the active sites of an enzyme are saturated. At such concentration the rate of reaction becomes constant or levels. After leveling of the rate of the reaction, the rate can only be increased by increasing enzyme concentration which would provide new active sites for the substrate. The increase in substrate concentration increases the

interaction between the enzyme molecules and the substrate molecules which increases the rate of collision between the enzyme and the substrate so as to form the products.



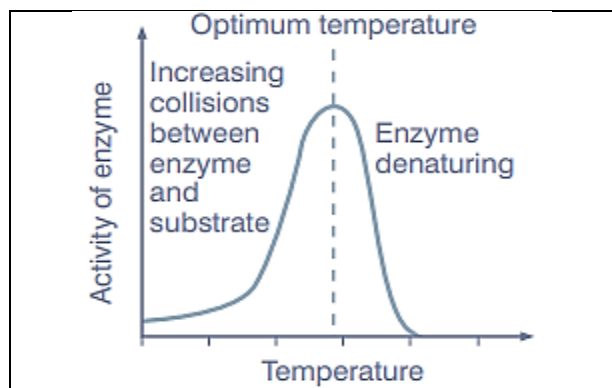
TEMPERATURE

An increase in temperature affects the rate of an enzyme controlled reaction in two ways;

- As the temperature increases the kinetic energy of the substrate and enzyme molecules also increases and so they move fast. The faster these molecules move, the more they collide with one another and therefore the greater the rate of reaction.
- Secondly as temperature increases above the optimum, more atoms which make up the enzyme molecules vibrate. These vibrations break the hydrogen bonds and other forces which hold the molecules in their precise shape hence changing enzyme active sites. The three

dimensional shape of the enzyme molecules is therefore changed by these vibrations as the bonds, hydrogen bonds and hydrophobic interactions, which were holding it get broken to such an extent that the active site no longer allows the substrate to fit. Under these conditions the enzyme is said to be **denatured** by the increasing temperature and therefore loses its catalytic x-tics.

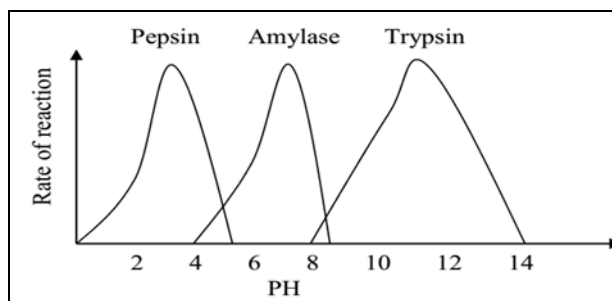
Therefore increasing the temperature beyond the optimum temperature rapidly denatures enzymes and very low temperatures **inactivate** enzymes. At the optimum temperature enzymes attain their maximum activity thereby providing the maximum rate of the reaction. Inactivated enzymes are not denatured and therefore they can regain their catalytic properties when higher temperatures are provided.



PH

The hydrogen bonds which make up the three dimensional molecular shape of the enzyme may be broken by the concentration of hydrogen ions present. PH is the measure

of the hydrogen ion concentration. By breaking the hydrogen bonds which give enzyme molecules their shape, any change in the pH can effectively denature enzymes. Each enzyme works best at a particular pH and deviations from this optimum pH may result into denaturing of these enzymes.



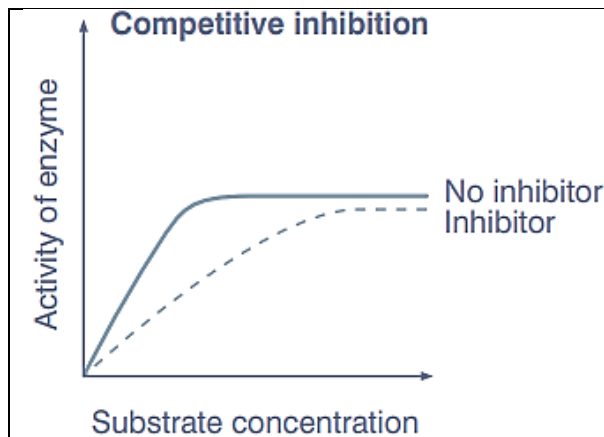
INHIBITION

The rate of enzyme controlled reaction may be decreased by the presence of inhibitors. There are two types of inhibition namely;

- Competitive inhibition.
- Non- competitive inhibition.

Competitive inhibition

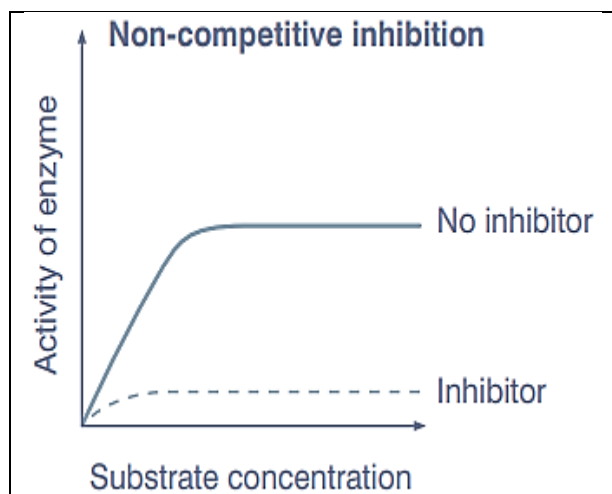
This is where inhibitors are structurally similar to the substrate molecules and as a result compete with the substrate for the active site on the enzyme molecule.



The degree of inhibition depends on the relative concentration of a substrate and inhibitor. This inhibition is therefore always reversible i.e. the inhibition effect can be removed by increasing the concentration of the substrate. This inhibition occurs when the inhibitor is of a higher concentration than the substrate. This inhibition is therefore temporary and therefore does not cause permanent change to the enzyme. Once the inhibitor combines with the enzyme active site it prevents the substrate molecules from occupying the active site and so reduces the rate of the reaction. Melanic acid is an example of a competitive inhibitor.

Non- competitive inhibition

This is where inhibitors are structurally different from the substrate and as a result do not compete with the substrate for active site on the enzyme molecules but its attachment elsewhere on the enzyme changes the structure of the active site so that the substrate cannot fit. These inhibitors show no structural resemblance to the substrate.



These inhibitors attach themselves on the surface of the enzyme other than the active site thereby changing the shape of the active site which is at another location of the enzyme molecule. This change of the active site is achieved by an **allosteric** change and these inhibitors prevent the enzyme from carrying out its activities.

The degree of inhibition depends on the concentration of the inhibitor alone and cannot be varied by changing the amount of the substrate. This inhibition may be reversible to some extent or irreversible in most cases it is irreversible, this is because it depends mainly on the concentration of the inhibitor alone because the substrate does not compete with the inhibitor. In this inhibition the enzyme active site is changed in such a way that it can no longer accommodate the substrate.

Irreversible non-competitive inhibitors bind tightly to enzymes and leave them permanently damaged and so unable to carry out its catalytic function. These drastic effects occur at very low concentrations of inhibitor. Example of irreversible inhibitors include potassium cyanide which attaches its self to the copper prosthetic groups of an enzyme called cytochrome oxidase thereby inhibiting respiration hence causing death. Others include heavy metal ions such as mercury ions Hg, Pb and Ag which cause disulphide bonds in proteins to break whereby denaturing all the proteins. Disulphide bonds maintain the shape of the enzyme molecule and once broken the structure of the enzyme molecules becomes irreversibly altered with a permanent loss of its catalytic property

Importances of enzyme inhibitors

- They provide important information about the shapes and properties of the active site of an enzyme.
- They can be used to block particular reactions thereby enabling bio-chemists to re-construct metabolic pathways
- They can be used in medicine and agriculture e.g. as drugs and pesticides respectively.
- Enzyme inhibition is also used to control the metabolic pathways by regulating the steps in them. This usually occurs during end product inhibition.

NOTE:

*Allosteric enzymes are the ones which can change the shape of the active site due to the presence of a non-competitive inhibitor at a second site where the inhibitor binds known as **allosteric sites**.*

*An **allosteric effect** is the one where a chemical reaction involving one region of a protein molecule changes the shape and property of the second region of the protein molecule known as an active site.*

ENZYME CO-FACTORS

A co-factor is a non-protein substance which is essential for some enzymes to function efficiently. There are three types of co-factors i.e. activators, co-enzymes and prosthetic groups.

Activators

These are inorganic substances, usually metal ions, which are necessary for the functioning of certain enzymes. The enzyme thrombokinase which converts prothrombin protein in blood plasma to thrombin during clotting is activated by calcium ions (Ca^{2+}).

Co-enzymes

These are non-protein organic substances which are essential for the efficient functioning of some enzymes but are not themselves bound to the enzyme i.e. acetyl co-enzyme A.

Prosthetic group

This is a non-protein organic or inorganic substance which is essential for the efficient functioning of some enzymes and it bound to the enzyme.

INDUSTRIAL APPLICATIONS OF ENZYMES

Enzymes are increasingly being used in biotechnological processes because:

- they catalyse reactions at moderate temperatures, saving heating costs;
- each is specific and catalyses only one reaction, so there are few by-products;
- they have a high turnover rate (catalyse thousands of reactions per second), so little is needed;
- they are often cheaper than conventional inorganic catalysts.

Biotechnologists often prefer to use isolated enzymes rather than whole micro-organisms because:

- some of the resources needed for the process are used by micro-organisms to produce their own biomass;
- micro-organisms produce many by-products, so purification is more costly;
- it is easier to optimise conditions for a single enzyme-controlled reaction than for all the reactions involved with a micro-organism.

The following are some of the uses of enzymes on industrial scale;

- They are used in making biological detergents which are usually made using proteases produced in an extra-cellular form from bacteria
- They are used in baking industry in which fungal α -amylase enzymes which catalyses the breakdown of starch in the flour to be used.
- They are used in making baby foods which contain trypsin used to pre-digest the baby foods.
- They are used in the brewing industry which uses enzymes produced from cereals during beer production to produce simple sugars from starch which is used by the yeasts during fermentation to enhance alcohol production.
- They are used in the dairy industry where an enzyme rennin derived from the stomach of young ruminant animals is used to manufacture cheese. In addition lactose breaks down lactose glucose and galactose.
- The rubber industry uses catalase enzyme to generate oxygen from peroxides so as to convert latex to form rubber.
- They are used in the paper industry which uses amylase to degrade starch to a lower viscosity product needed for sizing and coating paper.
- They are used in the photographic industry which uses protease to dissolve gelatin away from the films thereby allowing the recovery of the silver present.

TOPIC 3: CELL PHYSIOLOGY

Topic content

- Process of diffusion: definition, factors affecting the process of diffusion
- Process of osmosis: water potential, osmotic potential, wall pressure, turgidity, plasmolysis, haemolysis
- Significance of process of diffusion and osmosis in organisms
- Exchange of solvents and solutes in plant and animal tissues or cells in relation to its structure
- Process of active transport
- Cytosis: phagocytosis/ pinocytosis, exocytosis/endocytosis
- Ways by which unicellular organisms obtain water and fluids

MOVEMENT OF MATERIALS IN AND OUTSIDE THE CELL

There is need for exchange of materials between the cells and the surroundings as various organelles and structures within a cell require a variety of substances in order to carry out their functions. The materials might be required by cells as essential materials e.g water, glucose, amino acids, irons etc. some may be excretory materials which to be passed out of the cells e.g carbondioxide. Some materials are synthesized with in the cells but are utilized outside the cell e.g extracellular digestive enzyme. In this case, the materials are secreted by the cells. All above movement occur across the cell membrane which acts as a selective but between the cell and the environment.

The internal volume of the cell is huge compared with the size of the molecules within the cell. Some of these molecules need to be distributed fairly evenly throughout the cytoplasm, for example, amino acids (so that they stand a better chance of meeting and combining with transfer-RNA molecules for use in

polypeptide synthesis). Other molecules need to be transported to and from specific locations in the cell. For example, polypeptides must be transported from the rough endoplasmic reticulum to the Golgi body (so that they can combine to make proteins, or combine with other substances to make, for example, nucleoproteins) Intracellular transport thus requires transport of solutes to, away from, and across membranes. Membranes are selective and control the movement of substances between the organelles and the cytosol. In effect, the partially permeable membranes of the organelles contain specialised micro environments within the cell.

The mechanism of process of movement across the membrane can be categorized as passive mechanism, this doesn't require energy or active, and require energy.

Passive mechanism

(a) Diffusion.

- Simple diffusion.
- Facilitated diffusion.

(b) Osmosis.

Active mechanism

- (a) Active transport.
- (b) Endocytosis.
 - Phagocytosis.
 - Pinocytosis.
- (c) Exocytosis/ secretion.

DIFFUSION

Diffusion is the movement of particles or molecules from a region of high concentration to the region of low concentration.

Diffusion occurs along a concentration gradient in fully permeable membrane and continues until an even distribution of molecules is achieved. The net diffusion of different types of particle can take place in opposing directions. Diffusion of particles in one direction does not hinder the movements of other particles in opposite direction.

NOTE

Concentration gradient refers to the difference in concentration between two points of a diffusing particle. Diffusion can occur across membranes so long as the membrane is fully permeable to the diffusing molecules. It also occurs due to the continuous, random movements of particles in liquids and gas.

(a) Simple diffusion.

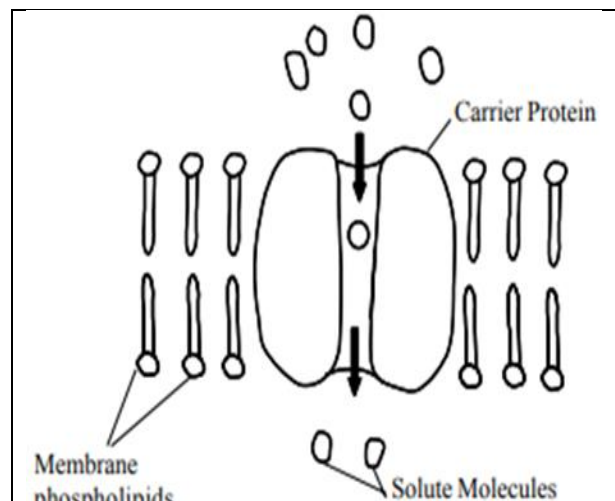
In simple diffusion, non-polar (uncharged) molecules and fat soluble molecules pass through the cell membrane easily and unaided. This is due to the lipid bilayers

with in the cell membrane. In simple diffusion, the rate of diffusion increases as the concentration gradient increases. If the concentration of molecules outside the cell is very high relative to the internal cell concentration, the rate of diffusion will also be high.

(b) Facilitated diffusion.

This is the process by which the ions and polar molecules are passed across the cell membrane by acting as a specific molecule. The specific molecule will be in form of **protein channels**.

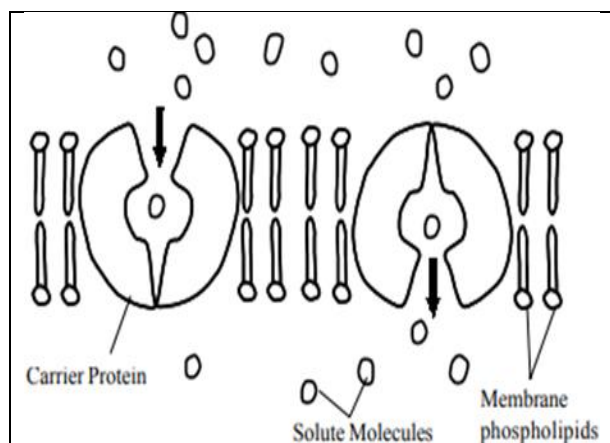
Channel proteins are fixed shape molecules, and the site for the diffusion of many charged ions. These channels are selective about which ions can pass through. For example, there are different channels for potassium ions and for sodium ions in nerve cells. Many channel proteins are 'gated', in that they allow the passage of ions only under particular conditions. In nerve cells, the signal for an ion channel to 'open' may be particular change in potential across the membrane.



Sometimes there is a **carrier protein** combines with a molecule at one side of the membrane and releases it on the other side e.g movement of red blood cell, movement of ADP in to mitochondria and ATP out of the mitochondrion. The carrier proteins may:

- ❖ contain special hydrophilic (water-liking) channels through which solutes can pass, or move in the
- ❖ membrane forming openings (gates), ferrying the solutes across.

In facilitated diffusion the carrier protein can transport the solute either way depending on the concentration gradient. Carrier proteins are specific to particular solute molecules. The carrier protein for the facilitated transport of glucose is called a **permease**. The glucose is bound to the permease on one side of the membrane and is released from the permease on the other side of the membrane. In a plant cell, glucose may be released through chloroplast membranes and absorbed into plastids (amyloplasts) to be stored as starch. Like enzymes, permeases can be inhibited by substances that resemble the normal substrate.



At low concentrations of the solute, the rate of diffusion is almost linear, like in simple diffusion but steeper. Facilitated diffusion can increase the rate of diffusion of particular molecules at low concentrations. However, the rate of facilitated diffusion levels off with increasing solute concentrations and additional increases in solute concentration cannot increase the rate of diffusion once carrier proteins are saturated.

Examples of diffusion in living organisms

- Gaseous exchange over respiratory surfaces in animals and via stomata in plants.
- Absorption or production or digestion like glucose and amino acids across epithelial lining of the ileum.
- Exchange of waste materials and between tissue fluids and cells in tissues.
- Exchange of materials i.e gases, nutrients and wastes in the organism and the environment in single called organisms like amoeba.

RATE OF DIFFUSION

The rate of diffusion in a given direction across the exchange surface:

- Is directly proportional to the area of the surface
- Is directly proportional to the concentration gradient
- Is inversely proportional to the distance.

These factors are summarized in the following equation known as Fick's law

$\text{Rate of diffusion} \propto \frac{\text{difference in concentration} \times \text{surface area of boundary}}{\text{thickness of boundary}}$

Increasing the factors on the upper side of line of the equation will make diffusion faster while increasing that on the bottom will slow it down. This applies to situations where there no barrier to the movement of the substance.

Diffusion through a cell membrane is affected by the nature of membrane i.e. its permeability and the size and type of molecule or ion diffusing through it.

FACTORS AFFECTING THE RATE OF DIFFUSION

Concentration gradient

The greater the concentration gradient, the higher the rate of diffusion. Organisms must therefore maintain a fresh supply of a substance to be absorbed by creating a stream over the diffusion surface. Equally the substance once absorbed must be rapidly transported away.

Diffusion distance/ thickness of the membrane

This refers to the distance over which diffusion occurs. The shorter the diffusion distance, the higher the rate of diffusion. The rate of diffusion is inversely proportional to the diffusion distance.

$d \propto \frac{1}{L}$	d – rate of diffusion. L – diffusion distance.

In living organisms, any structure across which diffusion regularly take place must therefore be thin.

Temperature

Increase in temperature increases the rate of diffusion since temperature increases the kinetic energy of the molecules hence more collisions and vice versa.

Size of diffusing molecules or particles

The larger the particles, the lower the rate of diffusion and the smaller the molecules, the higher the rate of diffusion. Fat soluble molecules diffuse more rapidly through cell membranes than water soluble molecules.

Nature of the membrane

The more permeable the membrane, the higher the rate of diffusion. Diffusion frequently takes place across epithelial layers or cell membranes. Variations in the structure may affect diffusion e.g the greater the number and size of pores in the cell membrane, the greater the rate of diffusion.

Surface area across which diffusion occurs

The higher the surface area, the higher the rate of diffusion. Diffusion surfaces frequently have structures for increasing their surface area and hence the rate at which they exchange materials.

Density of the medium

The higher the density of the medium, the lower the rate of diffusion.

OSMOSIS

Osmosis is the process by which solvent molecules move from a region of their high concentration to the region of their low concentration across a semi permeable membrane. It is the movement of solvent molecules from a dilute solute to a concentrated solution across a semi permeable membrane.

Osmosis is a special form of diffusion, involving water and a partially permeable membrane. If the solution is separated from its pure solvent e.g. water, different forces act on these solution causing water molecules to move in a particular direction.

TERMS USED IN OSMOSIS

Water potential

This is the capacity of the solution to give out water in a system and the free energy of pure water at atmospheric pressure and a defined temperature. It is also defined as the tendency for water molecules to enter or leave that solution by osmosis.

Pure water has the highest water potential of zero at atmospheric pressure. Water moves from a region of high water potential to a region of lower water potential. A crucial point to learn is that the highest water potential is 0. All other water potential values are negative numbers and water moves towards the region with the more negative water potential. Solutions have negative water potentials and the more concentrated a solution is, the lower (or more negative) is the water potential.

Solute potential

This is the measure of water potential of a solution due to the presence of solute molecules. The more solute molecules present in a solution, the lower (negative) is the solute potential. The solute potential is the negative component of water due to the presence of solute molecules.

For a solution at atmospheric pressure, the water potential is equal to the solute potential i.e $\psi = \psi_s$.

Osmotic pressure

This is the hydrostatic pressure required to resist the osmotic flow of water into a solution, separated from pure water by a partially permeable membrane. The more concentrated the solution, the higher is the osmotic pressure. Osmotic pressure can also be defined as a tendency of a soil to take in water when separated from pure water by a selectively partially permeable membrane.

Pressure potential

This is the pressure exerted by the protoplast against the cell wall as the cell takes in water. It is also known as **turgor pressure**. It has a positive value. It can also be negative in the xylem of transpiring plant where the column of water is under tension.

Water potential, solute potential and pressure potential all act on a cell at the same time. The relationship between water potential, solute potential and pressure potential is as follows

$$\psi = \psi_s + \psi_p.$$

Revision question

Explain why water potential of sucrose solution has a negative value.

Hypotonic solution

This is a solution of higher water potential or solute potential than the cell sap of the cell it surrounds. A cell placed in such a solution will take in water by osmosis.

Hypertonic solution

This is a solution of lower water potential than the cell sap of the cell surrounding it. A cell placed in such a solution will lose water to the solution by osmosis.

Isotonic solution

This is a solution with the same water potential / solute potential as the cell sap of the cell surrounds. A cell placed in such a solution will experience no net osmosis.

OSMOTIC RELATIONSHIPS IN CELLS

Cells owe most of their properties due to the permeability of their cell membrane. In case a cell is surrounded by pure water or a solution whose solute concentration is lower than that of the cells contents, water flows into the cell by osmosis and this brings about the swelling of the cell. In this case, the solution is said to be hypotonic since the osmotic pressure of the external solution is lower than that of the cell hence there is net water movement into the cells.

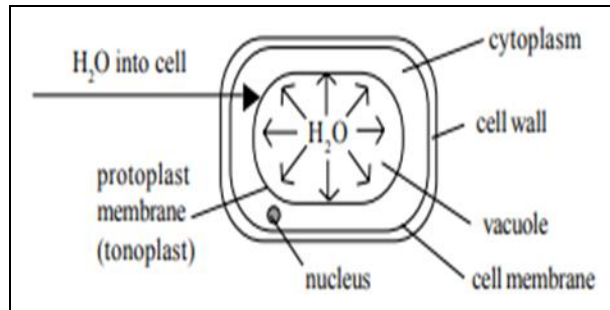
And if the cell is surrounded by a solution whose solute concentration and osmotic pressure exceeds that of the cell, water flows

out of the cell hence it shrinks. In this case the external solution is said to be hypertonic hence there is net water movement out of the cells to the surrounding solution. If the solute concentration of the cell and its surrounding medium are the same, there is no net flow in either direction and the external solution is said to be isotonic with the cell. The osmotic flow of water into a cell is called **endosmosis** while the osmotic flow out of the cell is called **exo-osmosis**.

OSMOSIS IN PLANT CELL

The cell has got cell sap or vacuolar sap which contains solute. The solute makes it an osmotically active aqueous solution bound by a membrane called tonoplast. The cell surface membrane, cytoplasm and tonoplast act together as one partially permeable membrane. On the outside of the plant cell is the cell wall which is freely permeable to aqueous solution i.e it is porous.

When a plant cell placed in a hypotonic solution or pure water, the cell will take in the water by osmosis. The protoplast will extend and begins to press against the cell wall exerting a pressure called pressure potential (also turgor pressure). The cell wall exerts an equal but opposite pressure called wall pressure against the protoplast. As the cell continues to take in water, the pressure potential increases. Water potential also increases and solute potential also increases and the cell wall said to be turgid. If the cell is in pure water, pressure potential will increase to the maximum. The cell at this point is said to be **fully turgid**.

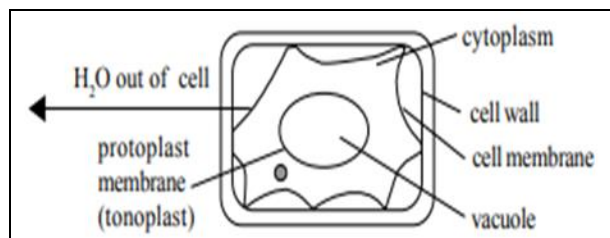


The pressure potential/ turgor pressure will be equal to the osmotic pressure. Pressure potential or turgor pressure will be maximum when the amount of water leaving the cell equals that entering. There is no net uptake of water. The cell wall is equilibrium with the surrounding solution i.e.

$$\Psi_s = \Psi_{\text{cell}}$$

Turgidity plays a very important part in supporting plants and maintaining their shape and form. The stems of herbaceous plants are held erect by being filled with fully turgid cells ached together. Turgor is also responsible for holding leaves in a flat horizontal position.

When a plant cell placed in a hypertonic solution, the cell will lose water by osmosis. The protoplast will shrink, the cell wall will become **plasmolysed**. The point when the protoplast has just stopped exerting a pressure on the cell wall is called **incipient plasmolysis**.



The cell is **flaccid** as the cell continues to lose water; its volume begins to decrease. Its water potential decreases, solute potential decreases. A point is reached when the protoplast crowns off and becomes completely detached from the cell wall. The cell is said to be **fully plasmolysed**. The space between the cell wall and protoplast will be occupied by the bathing/ surrounding solution.

NOTE

During dry, hot days, in some plant leaves and stems turgor is reduced and the plant visibly droops. Wilting is the phenomenon where the stems and leaves of a plant lose more water by evaporation than they can absorb. In wilting, the whole cell including the wall shrinks and no gap develops between the lams membrane and the cell wall.

Plant water relations

In plant water relations, we need to consider three factors namely;

- Water potential of the whole cell
- Osmotic potential of the sap
- Pressure potential

In case a plant cell is plasmolysed and then placed in pure water, water immediately enters the sap vacuole by osmosis and the protoplast begins to expand. As the influx of water continues, the protoplast goes on expanding until it comes into contact with the cellulose wall.

When this point is reached, the influx of water starts being opposed by the inward pressure of the cell wall i.e. pressure

potential. The water potential of the cell now becomes less negative than the osmotic potential of the sap by the amount of the pressure potential. As this continues, full turgor is reached where the cell can expand no more, water potential of the cell reaches zero and osmotic potential of the sap is exactly counter balanced by the pressure potential. In a cell which is plasmolysed to the extent that the protoplast loses contact with the cell wall: pressure potential is equal to zero, and the water potential is equal to the solute potential, pressure potential is equal and opposite to solute potential hence water potential is equal to zero.

OSMOSIS IN AN ANIMAL CELL

Animal cells are partially surrounded by a partially permeable cell membrane. Most of the solutes in the cell are located in the cytoplasm. The animal cells like the plant cells will take in or lose water across cell membrane depending on the solute concentration of the cell and that it's surrounding medium. The only difference is that animals can't withstand gaining or losing too much water to become fully turgid or flaccid respectively due to lack of a cell wall.

Osmosis in red blood cell

When a red blood cell placed in pure water (solution of higher water potential). The cell

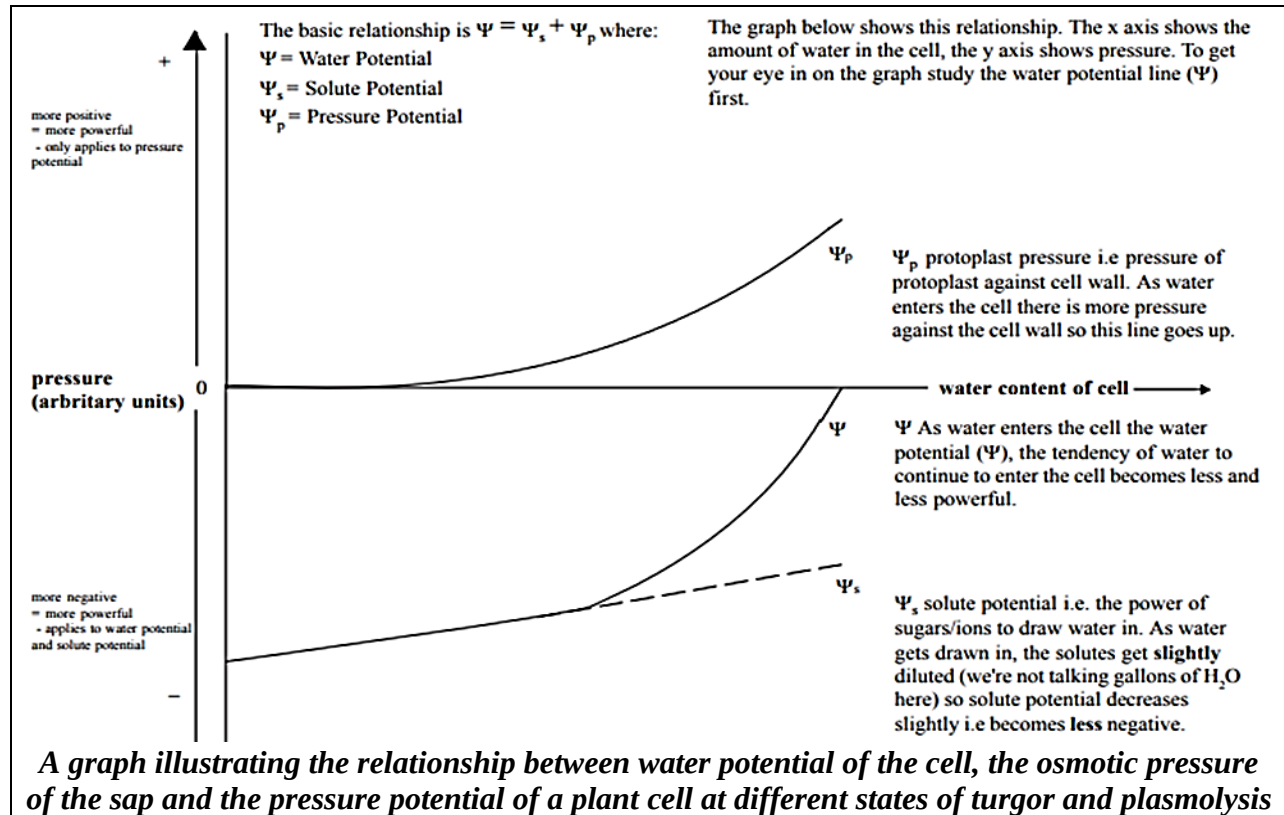
takes in water by osmosis, swells and bursts due to capturing of its cell membrane. This is termed as a **haemolysis**.

When a red blood cell placed in solution of lower water potential. The cell loses water by osmosis and shreds. The cell membrane shrinks, this is termed as **crenation/ lacking**. To prevent the two above situations from happening animal cells exist in isotonic nature in the tissue fluid and plasma. This is achieved through osmoregulation.

Osmosis in amoeba

Amoeba along with many other protozoans, normally has a water potential more negative than the pond water in which it lives (it has a higher osmotic potential than the pond water) the difference in water potential leads to a net inflowing of water into the cytoplasm of the amoeba, which uses its contractile vacuole to pump out the excess water that accumulates inside its single cell.

Amoeba may also adjust the quantity of dissolved substances in the cytoplasm in the cytoplasm (for example by active pumping of ions) so that the water entering by osmosis is reduced to a volume that the contractile vacuole can pump out efficiently.



Importance of osmosis

- It aid in the uptake of water from the soil by root hairs of plat roots.
- It aids in the movement of water from cells in plants.
- It aids the re absorption of water from the kidney tubules.
- It is used in the uptake of water from surrounding mediums by microorganisms.
- It is responsible for turgidity which provides support in herbaceous plants and young plants.
- It enables absorption of water from the alimentary canal.
- It helps in bringing about opening and closing of stomata.

ACTIVE TRANSPORT

This is the active movement of ions across a membrane against the concentration gradient using energy.

A.T.P is required for this movement. The movement is against the concentration gradient as well as the electrostatic attractions. Therefore active transport involves the movement of ions / molecules against their electrochemical gradient. Active transport takes place by means of carriers in the cell membrane. The carrier molecule is a membrane which spans the entire membrane. Transportation is ought to occur as follows;

- The substances to be transported are attached to the carrier on one side of the membrane.

- The configuration of a carrier molecule changes in such a way that the substance is moved through it from the other side of the membrane hence energy comes from the hydrolysis of A.T.P.

Active transport only takes place in a living system that is actively producing energy by respiration. Temperature and oxygen concentration which affect the rate of transpiration also affect active transport.

Active transport involves carrier proteins in the membrane referred to as a “pump”. The carriers are specific to the substances they transport and act as one way valves. The carriers may move:

- A single substance in a single direction (**uniport carriers**) For example, some calcium pumps.
- Two substances in the same direction (**symport carriers**) For example, glucose-sodium pumps.
- Two substances in opposite directions (**antiport carriers**). For example sodium-potassium pumps.

MECHANISM OF ACTIVE TRANSPORT

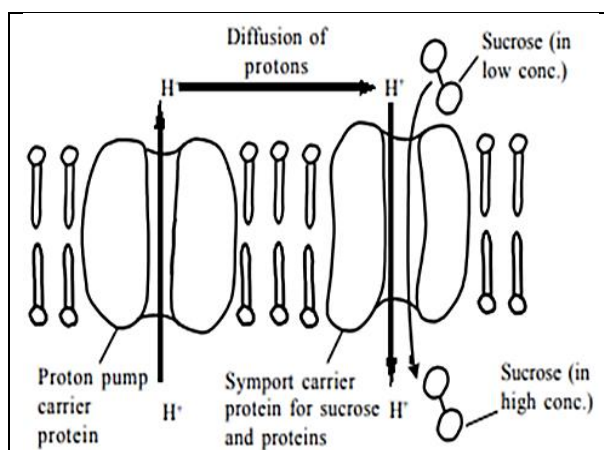
The precise mechanism of active transport is unclear. There are two hypothesis which explain active transport namely

One hypothesis is called **co transport** where the pumping of one substance indirectly drives the transport of one or more other substances against a concentration gradient. For example *proton pumps*. These are active transport mechanisms use to transport hydrogen ions (protons) across membranes.

Proton pumps are present in the vacuolar membranes (tonoplasts) of plant cells, yeasts and fungi, in the endoplasmic and lysosomal membranes of animal cells, in the inner mitochondrial membrane and in chloroplast thylakoid membranes.

In many cases proton pumps enable other molecules to be transported with the protons. For example:

- ❖ sucrose is transferred across membranes (for example, chloroplast membranes, cell surface membrane) in conjunction with protons,
- ❖ ATP in the mitochondria is released by a proton pump mechanism during aerobic respiration,
- ❖ ATP in the chloroplasts is released by a proton pump mechanism during the light-dependent stage of photosynthesis



The proton pump actively drives protons across the membrane (using energy from ATP). This forms a high concentration of protons which then diffuse back across the membrane via the symport carrier protein. This, by an unknown mechanism, enables

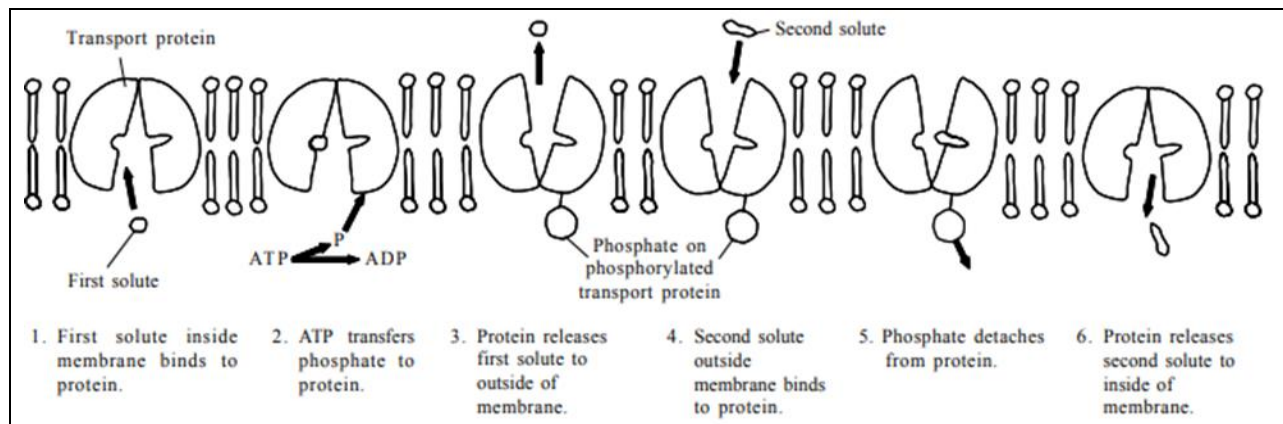
sucrose to be actively transported across the membrane via the symport carrier, against the sucrose concentration gradient.

A similar process is used to transport glucose and amino acids into the cells lining the digestive tract in mammals. In this case, absorption of nutrients is dependent on the sodium pump.

Another hypothesis suggests the use of **primary pumps**, protein molecules which change shape to transport solutes from one side of the membrane to another. To do this ATP is hydrolysed to ADP. The terminal phosphate group attaches directly onto the

protein causing it to change shape in such a way that a substance is moved through it to the other side of the membrane. This hypothesis is consistent with the current view of how proteins are arranged in the plasma membrane.

One example is the sodium potassium pump which pumps sodium ions out of the cell and potassium ions inside the cell. An ion pump is of great importance in animal cells, since these are not protected by a rigid cell wall. If such a cell contains an excessive quantity of ions, there is a danger that it may take up so much water by osmosis that it swells and bursts.



SODIUM -POTASSIUM PUMP

This is an example of active transport where sodium ions are actively pumped outside the cell while potassium ions are actively pumped in. A.T.P is required for the process. This type of pump is almost universal in animal cell membranes, and is common in plant cell membranes also.

A protein in the cell membrane becomes the pump; it is thought to work as follows;

- The protein accepts sodium ions and A.T.P. The A.T.P is hydrolyzed and the protein acts as a phosphorylated protein.
- The protein configuration changes leading to release of sodium ions to the outside. Outside the cell the protein accepts the potassium ions.
- Potassium causes the release of phosphate from protein (dephosphorylating of proteins). The protein configuration changes

leading to release of potassium ion to the inside.

Importance of sodium potassium pump

- It maintains the electrical activity in active cells, i.e creating resting potential for nerve transmission.
- It's also responsible for maintaining electrical coordination of cells.
- Controls osmoregulation in cells, when sodium ions are pumped out, water molecules follow by osmosis.
- Absorption of glucose along the intestinal lining. As sodium ions are pumped out by the sodium potassium pump, the sodium ions try to diffuse back into cell in contact with glucose aided by the carrier protein in the membrane. Any co-Acid absorption occurs similarly.
- Selective reabsorption of glucose and sodium from primal convulvent tubule and active sap secretion of potassium ions in the glomerular filtrate in the distal convoluted tubule.

IMPORTANCE OF ACTIVE TRANSPORT

- It aids in the uptake of mineral salts by root hairs.
- Secretion and uptake of ions in chloride secretory cells in gills of fish.
- Loading of sucrose into sieve tubes across the plasma membrane of transfer cells.

EVIDENCE IN ACTIVE TRANSPORT

- Many essential substances occur at much higher concentration inside

cells from outside. This type of movement only occurs in living systems that are actively producing energy.

- The rate of movement of substances is affected by temperature and oxygen concentration. Both are factors known in affect the rate of transportation.
- It is inhibited by metabolic poisons like cyanide an indication that it depends on metabolic energy.
- The cells involved in active transport have very high concentration of mitochondria.

CYTOSIS

Most cells carryout cytosis, active transport which involves infoldings or outfoldings of the sections of the cell surface membrane. This involves the contractile proteins in cellular microfilaments and microtubules. Cytosis may result in the bulk transport of materials into the cell or out of the cell. This is possible due to the dynamic, mobile structure of the cell membrane, and involves the formation of tiny vacuoles of substances to be moved.

ENDOCYTOSIS

This is the bulk movement of materials into the cell. It occurs by invagination of the plasma membrane which thus forms small vesicles or food vacuoles that become detached and enter the cytosol. It involves;

Phagocytosis (cell eating)

This is the mechanism were the cell takes in solid particles leading to the formation of small vesicles called phagocytic vesicles or

food vacuoles. The vesicles move to the centre of the cytoplasm where lysosomes fuse with them. The solid food particles are then digested by enzymes in the lysosomes. The vesicles migrate to the cell membrane fusing with releasing the undigested materials to the outside.

Example of phagocytosis;

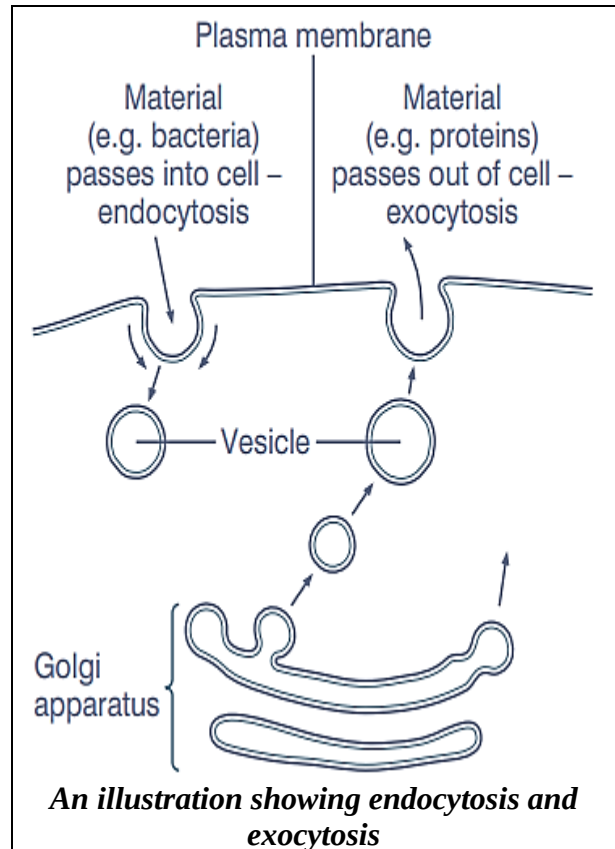
- White blood cells engulfing and digesting bacteria.
- Amoeba feeding on solid food material

Pinocytosis (cell drinking)

This is the mechanism where a cell in liquid material leading to the formation of small vesicles called micro pinocytic vesicles. Tiny pinocytic channels are continually formed at the cell surface by invagination of the plasma membrane. Pinocytic channels provide a means by which liquids can be brought into contact of the cell, and their breaking up into numerous vacuoles aids distribution and increases the surface area where absorption can take place. The rest is similar to phagocytosis.

Examples of Pinocytosis

- Amoeba taking in liquid material.
- White blood cells.
- Taking up of fat droplets by micro villi.



EXOCYTOSIS

This is the bulk movement of materials out of a cell. The materials to be taken out are packed in vesicles which are fused with the cell membrane. Exocytosis is therefore the opposite of endocytosis. Examples include; Removal of undigested material by amoeba or white blood cells.

TOPIC 4: LEVELS OF ORGANISATION AND DIVERSITY OF LIFE

SUB TOPIC 1: DIVERSITY OF LIVING ORGANISMS

SUB TOPIC CONTENT

- *Principles of taxonomy: identification, classification and nomenclature*
- *Principles of classification: artificial and natural classification*
- *Importance of studying classification*
- *Criteria for classifying organisms: morphology, anatomy, physiology*
- *Hierarchy of classification according to Carl Linnaeus*
- *Scientific/binomial nomenclature and local names*

CLASSIFICATION

Classification is the science of placing or organisms and then assigning their names. This is important because there is diversity of life hence classification imposes order and a general plan upon the diversity of living things. The aim of classification in biology is that it reflects the evolutionary relationships (phylogeny) between organisms.

The study of biological classification is called **taxonomy**. Any useful scheme of classification must be flexible allowing new organisms to be added into the scheme as they are identified and named. Similarly it must be possible to add extinct organisms, discovered as fossils, once it becomes clear how they relate to living forms. A functional scheme of classification must also allow biologists to search for related and similar organisms without having to refer to the entire collection of organisms. Carl Linnaeus proposed a scheme of classification which has become widely accepted. In this scheme, organisms are grouped together according to their basic

similarities. Relationships are based on homologous rather than analogous characteristics. **Homologous** characters are those that have a fundamental similarity of origin, structure and position regardless of their function in the adult. **Analogous** characters are those that have a similar function in the adult but do not have the same origin.

TAXONOMY

Taxonomy is the study of classification of living organisms, including its principles, practice and rules.

TYPES OF TAXONOMY

Orthodox taxonomy

In orthodox classification, organisms are put into groups according to the presence or absence of certain fundamental characteristics. The aim of this type of classification is to show the degree to which different groups are connected in evolution, in other words to reflect on their phylogenetic relationships. Such classification is also called **evolutionary classification**.

Numerical classification

In this classification, organisms are classified using numerous characteristics. The closeness between different groups is determined by the total number of individual characteristics which they have in common. Usually between 10 and 100 characters are selected and they all carry equal weight; the greater the number of characteristics, the more valid the classification is presumed to be. Any observable characteristics may be chosen: morphological, physiological, biochemical or behavioural. The characters are not selected because they are thought to be important phylogenetically. This means that the classification is not based on any preconceived ideas regarding possible evolutionary relationships. Such a classification is called a **phenetic classification** and it can be applied to any taxa from species to phyla.

TAXONOMICAL HIERARCHY

Linnaeus arranged the organisms in a hierarchy with the largest group, the **kingdom**, at the top of the hierarchy. The groups are still used today and, in descending order of size are:

- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

This hierarchy is constructed for our convenience, and it is frequently changed or modified.

NOTE

A group of related species forms a genus and related genera form a family. Several related families group to form orders, orders into classes, classes into phyla (singular phylum) and phyla into kingdoms.

Species

The term species can be defined as a *group of closely related organisms which are capable of interbreeding to produce fertile offsprings*. Occasionally two organisms which are genetically closely related can interbreed to produce *infertile* offsprings.

Each species possesses its own distinct structural, behavioural and ecological characteristics. As the hierarchy progresses up, the number of similarities between the members of each group decreases. For example, members of the same genus have more characteristics have more characteristics in common than members of the same family and order.

PRINCIPLES OF TAXONOMY

Taxonomy has three main principles i.e. **identification**, **nomenclature** and **systematics**.

SYSTEMATICS

Systematics is the grouping of organisms into different groups depending on levels of organisms. The taxonomical groups from the largest to the smallest are Kingdom, Phylum, Class, Order, family, Genus, and Species. Each taxonomic group is called a **taxon** or **taxa** (plural). Each taxon possess a diagnostic feature i.e. features which are

unique (peculiar) to that group. Each higher category includes a wider range of organisms and with each higher category, the relationship between organisms become less and less obvious.

The smallest natural showing group is the species. Species is a group of organisms with a lot of characteristics in common capable of interbreeding to produce fertile off-springs. Gradation from one species to a closely related one does not occur. There are no intermediate forms, but sharp and distinct differences between each species and any other. Members of a species can interbreed freely with one another, but not usually with members of another species; if they do, the hybrid offsprings are infertile. Sometimes, species are split into **subspecies** or **varieties**. These are capable of interbreeding but can be distinguished by slight structural differences.

NOMENCLATURE

A classification system imposes an agreed name to each organism. This is essential for effective communication and it imposes a general plan upon the diversity of living organisms.

Nomenclature is the assigning of names to organisms. The modern nomenclature is the one that was proposed by Carl Linnaeus in his system called **binomial nomenclature**. Binomial nomenclature is a system in which an organism is given two names, namely generic name and specific name. The generic name describes the genus to which the organism belongs. The names given to living organisms are called **scientific names** e.g. *Homo sapiens* is a scientific name of man

Rules used in assigning names to living organisms

Each organism is given a name that has two parts i.e. generic and specific part. The 1st part indicates genus. The 2nd part indicates the species.

The generic name begins with a capital letter while a specific name begins with a small letter and the two names are underlined separately e.g. *Homo Sapiens*. Both names are written in italics or underlined separately when unwritten. The name of the genus is used in the same species but not in the same genus. The specific name can be shared by a number of organisms in the same species but not in the same genus.

All names are written according to Roman alphabet as used in English. The genus name can be used alone to represent all species in genus but the specific name is not used alone.

The names of organisms are derived from Latin and if not they are Latinised; the importance of this is to avoid confusion of using local names and ensure effective communication for all biologists which over.

IDENTIFICATION OF ORGANISMS

This is a process of sorting out of organisms basing on their basic characteristics from a bigger group called **taxon** (taxa). A taxon is a group of organisms with similar characteristics.

Identification of organisms can be done using biological keys. A key is a convenient method of enabling a biologist to identify an organism. It involves listing the observable

characteristics of an organism and matching them with those features which are diagnostic of a particular group.

Dichotomous keys

A dichotomous key is a key which consist of pairs of contrasting statements that are numbered leading to isolation of individual organisms from bigger groups. Each statement has a feature of difference in relation to the specific characteristics of organs in the group. For identification of specimens using a dichotomous key a table of characteristics is constructed then a flow chat is also drawn to show the difference and the total number of contrasting pairs of statements. The number of contrasting pairs of statements is given by the formula $(n-1)$ where n is the number of specimens provided. If n is equal to five then the number of contrasting statements is four.

An example of a dichotomous key for identifying arthropods is shown below,

- 1 a) Has 8 legs.....W
b) Has 6 legs.....2
- 2 a) Has long antennae.....X
b) Has short antennae.....3
- 3 a) Has proboscis.....Y
b) Has mandibles.....Z

NOTE

In classifying organisms simple observable structural characteristics are used such as presence or absence of hairs, number of appendages, shape of the structure etc. characteristics like size and colour are not

used since size changes with age and colour changes with environment.

CHARACTERISTICS USED IN IDENTIFICATION

Morphology

External features permit quick identification. Such features are often used at the level of families or genera but when distinguishing between species much smaller features may be used.

Anatomy

With advent of electronic microscope, cell structure has been used to make a fundamental split in the classification of living organisms namely between prokaryotes and eukaryotes. This characteristic can also be used at other levels of taxonomy for example the number and structure of chromosomes can enable entomologists to distinguish between different kinds of locusts.

Biochemical composition

Sometimes it is impossible to distinguish between similar organisms using structural criteria hence the need to use the chemical substances which they contain. This is particularly useful when identifying bacteria. Using techniques like chromatography and electrophoresis it is possible to compare the amino acids in the proteins of different organisms.

NOTE

Other characteristics used in classification include immunological reactions, the types of symbiots with which the organisms

associate and their behaviour such as their responses to stimuli.

PRINCIPLES OF CLASSIFICATION

Classification is the process of sorting a variety of items into manageable groups. There are mainly two main types of biological classification, one artificial and one natural.

Artificial classification: this is based on one or a few easily observable characteristics for simplicity and convenience. For example organisms can be placed in groups according to where they live, how they move or their size.

Natural classification: this considers natural relationships between organisms e.g. internal and external features. A natural classification system uses similarities between organisms. These similarities can be of two types, homologous and analogous characteristics:

- **Homologous** characteristics have an underlying similarity of origin, structure and position irrespective of function. For example, the flipper of a dolphin, arm of a human, wing of a pigeon and wing of a bat are homologous because they are all modifications of the same structure, the vertebrate pentadactyl (5 fingered) limb.
- **Analogous** characteristics have similarity of function but they are not homologous. For example, the wings of insects and birds have the same function, flight, but their structures are very different. The wing of an

insect is not developed from the basic pentadactyl limb.

A modern system of natural classification of organisms uses morphological, anatomical, biochemical, behavioural, chromosomal and genetic fingerprinting characteristics in an attempt to classify organisms according to their evolutionary (phylogenetic) relationships. Species are placed in the same group only on the basis of shared homologous features and shared evolutionary history.

IMPORTANCE OF CLASSIFICATION

- It helps us to understand a variety of life to which different organisms belong.
- It helps the biologists to communicate effectively about the nature of organisms.
- It enables us to classify new species when they are discovered basing on their characteristics.
- It helps us to solve other biological problems e.g the origin and spread of disease causing germs.
- It also allows us to generalize the groups about the organisms in the same group.

CHALLENGE OF CLASSIFICATION

Although classification is a way of ensuring order on the diversity of life placing every organism in a specific category it belongs, it has often proved that organisms cannot be placed in the same group and hence placed in different groups and this has led in to splitting of some groups into particular groups.

TWO KINGDOM CLASSIFICATION SYSTEM

Originally two kingdoms are plants and animal kingdoms were the first to be recognized. The animal kingdom contained mainly motile organisms which fed heterotrophically and the plant kingdom contained many static organisms which fed autotrophically by photosynthesis. Unicellular heterotrophs (protozoa) were put in the animal kingdom and unicellular autotrophs (protophyta) were put in the plant kingdom with algae. Fungi were considered to be plants which had lost their chlorophyll and taken up a heterotrophic mode of nutrition. Bacteria were put in the plant kingdom mainly on the grounds that they possessed a cell wall.

Using two kingdom systems plants and animal kingdom left out many organisms that could not be placed anywhere accurately and had three main problems:

- Unicellular flagellates such as *Euglena* and its relatives were put with the protozoa in the animal kingdom but they contain chlorophyll and feed autotrophically by photosynthesis. Moreover some flagellates can feed autotrophically or heterotrophically depending on conditions
- Although fungal hyphae bear a superficial resemblance to the filaments of simple multicellular algae like *spirogyra*, fungi are very different from green plants because they lack chlorophyll and feed heterotrophically. Their cell structure

also differs from that of plants greatly.

- Electron microscope has shown bacteria to have a simple prokaryotic cell structure and the feature is also found in blue-green algae. So the bacteria and blue-green algae appear to be similar to each other and markedly different from all other organisms which are eukaryotic

FIVE KINGDOM CLASSIFICATION SYSTEM

Today the most widely accepted system is the five kingdom system which was proposed by R. H. Whittaker in 1969. It classifies organisms into five kingdoms namely;

- Animalia which is reserved for multicellular motile organisms which feed heterotrophically
- Plantae which is reserved for multicellular organisms which feed by photosynthesis
- Protista which consists of protozoa and unicellular algae
- Monera which consists of bacteria
- Fungi which consists of fungi

Organisms when placed in these kingdoms basing on the following features;

- ❖ Type of the cell i.e prokaryotic cell or Eukaryotic cell.
- ❖ Levels of organization are either unicellular or multi cellular.
- ❖ Type of nutrition some organisms feed autotrophically by photosynthesis, some saprophitically

and other as heterotrophically i.e

they feed on other organisms.

SUB TOPIC 2: VIRUSES

SUB TOPIC OUTLINE

- *Structure of viruses*
- *Classification of viruses*
- *Economic importance of viruses*
- *Methods of preventing the spread of other viral diseases*

A virus is a tiny pathogen composed of a core having nucleic acid enclosed by a **capsid** which can be a protein or a lipoprotein. This is in turn covered by a protein coat. Viruses are characterized by total dependence on the living host cell and are obligatory parasites. They are at the borderline between living and non-living things. The virus DNA or RNA takes over the protein synthesising machinery of the host cell, which then helps to make new virus particles.

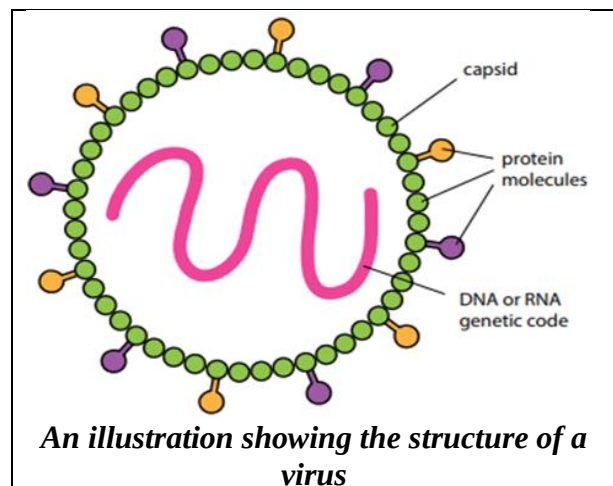
Viruses are the smallest living organisms, ranging in size from about 20-300 nm; on average are about 50 times smaller than bacteria. They cannot be seen with a light microscope and they pass through filters which retain bacteria.

CLASSIFICATION OF VIRUSES

Viruses are classified by their structure and nucleic acid types. They are made up of a nucleic acid core surrounded by a coat of protein: outside cell their inert particles are known as **virions**. Most viruses found in animal cells and those attacking bacteria (bacteriophages) have nucleic acid DNA. Other animal viruses and plant viruses contain RNA. Electron microscopy and X-

ray defraction have shown viruses to be of a variety of shapes such as spherical e.g. poliomyelitis, straight rod e.g. tobacco mosaic or flexible rods e.g. potato virus X.

Structure of viruses



Core

This is the inner region in which the genetic material (DNA or RNA) is found. The DNA or RNA may be single stranded or double stranded

Capsid

This is the protective coat of protein surrounding the core. The Capsid is made up of subunits called *capsomeres*.

Envelope

This is found only in some large viruses

CHARACTERISTICS OF VIRUSES

- They are smallest living organism without cellular structures.
- They reproduce only inside the host cells.
- They can only survive inside the host cell therefore they are obligate parasites.
- They are highly specific to their host i.e. each virus will recognise a specific host.

Viruses are sometimes classified as living because;

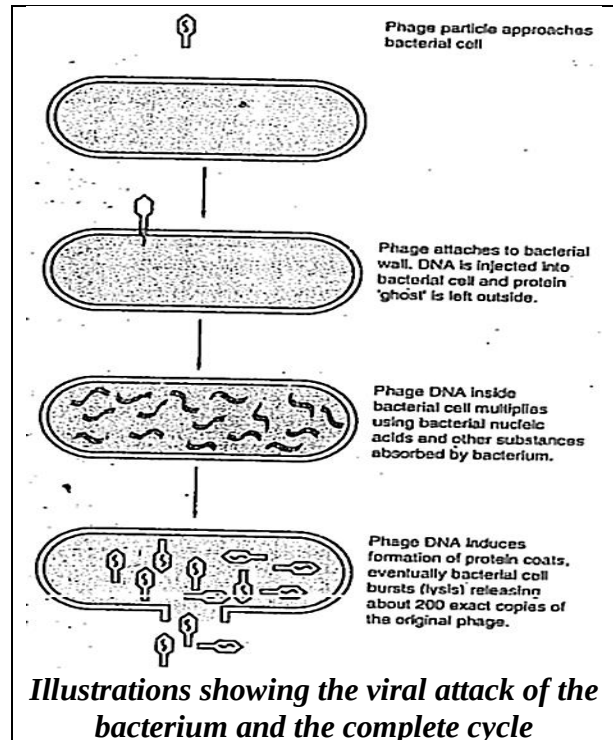
- ❖ They possess a nucleic acid RNA or DNA possessed by other living.
- ❖ They carry out respiration, a characteristic of living organisms.
- ❖ They reproduce like all living organisms.
- ❖ They die when subjected to unfavourable conditions
- ❖ They are known to respond to stimulus.

Sometimes viruses are classified as non-living because;

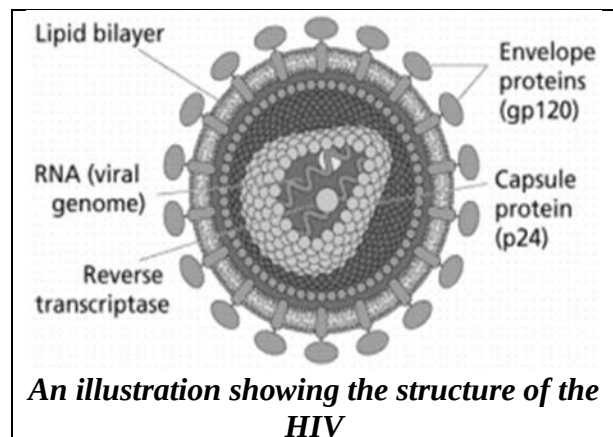
- ❖ They do not possess reproduce independently i.e. they only reproduce inside the host cell.
- ❖ They possess RNA or DNA but not both.
- ❖ They appear crystalline under very unfavourable conditions.
- ❖ They are tiny to be living.

THE BACTERIOPHAGE

The bacteriophage feeds on bacteria. It gets attached onto surface of the bacterial cell. The viral DNA enters the bacterial cell and suppresses the activities of the bacteria but instead it instructs the host cell DNA to make viral DNA.



HUMAN IMMUNO DEFICIENCY VIRUS (HIV)



The HIV virus is spherical and about 1000nm in diameter. The core region contains 2 molecules of single stranded RNA and reverse transcriptase enzyme surrounded by a cone shaped protein capsid. The capsid is enclosed by an envelope composed of a lipid and glycoprotein.

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

The envelope contains glycoproteins which bind specifically to helper T-cell receptors,

enabling the virus to enter the helper T-lymphocytes

ECONOMIC IMPORTANCE OF VIRUSES

Viruses can cause diseases to humans, livestock and crops. Viral diseases in animals include influenza flue measles, swivel fever, chickenpox, and foot and mouth disease of the cattle. The common plant viral diseases include tobacco mosaic, cassava mosaic etc. that can be prevented by burning the crop remains. They can be used in biological control of pests e.g. the Myxomatosis was used to control rabbits in Australia. Rabbits were formerly not in Australia but when introduced they found the environment favourable and increased in number becoming a menace to the people.

SUB TOPIC 3: KINGDOM MONERA

SUB TOPIC OUTLINE

- *Structure of a bacterial cell*
- *Characteristics of bacteria: shape, cell, reproduction, movement*
- *Economic importance of bacteria in the environment*

The kingdom is made up of the bacteria and archaea, the most ancient of living organisms. Prokaryotes are organisms whose genetic material is not bound by a nuclear membrane. All members are unicellular and they belong to two main groups;

Archaea: This group contains organisms that grow under extreme conditions e.g. halophiles which grow under extremely high salt concentration.

Hyperthermophiles: This group contains organisms that grow under very high temperatures.

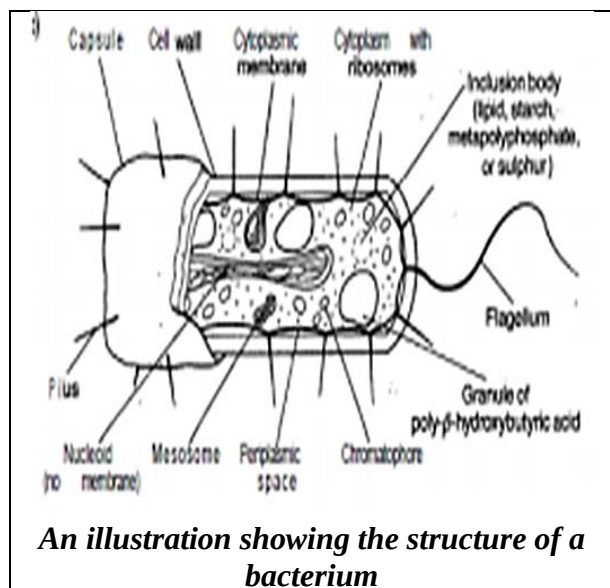
CHARACTERISTICS OF MONERA KINGDOM

- They are all prokaryotes i.e they lack nucleus.
- They are microscopic single called organism with a variety of size and shape.

- They contain circular DNA attached to the cell wall.
- They have a few membrane bound organelles.
- Their cells are made up of a cell wall.
- They reproduce both a sexually and sexually depending on whether the conditions are favourable or not. Asexual reproduction is by binary fission while sexual is by transduction.
- Some bacteria live a parasitic mode of life throughout.

BACTERIA

Bacteria form a diverse group with members that range widely in size and shape. Most occur as single cell, but some stick together to form chains or clusters. They are the smallest unicellular organisms and they are the most abundant.



They occupy many areas such as dust, water, air in and out the animal in hot

springs as well as in areas of freezing temperatures. Some bacteria live a parasitic mode of life throughout obligate parasites while others live a parasitic life today and a free life tomorrow (facultative parasites and others are free living bacteria.)

FUNCTIONS OF THE PARTS

Photosynthetic membrane; it contains chlorophyll for trapping solar energy required for photosynthesis.

Mesosome; it is important in respiration.

Circular DNA; it is important in cell division and controls activities of the cell.

Mucilage; it is associated with protection and enabling the bacteria to stick together and onto surfaces.

Cell wall; it is important in protection and is a polysaccharide (murein) as the strengthening material plant cells are made up of the polysaccharide cellulose as the strengthening.

CLASSIFICATION OF BACTERIA

This is based on structural and metabolic features. The following features have been traditionally used to categorize bacteria.

- Many bacteria are categorized by their mode of nutrition, or how they metabolize resources.
- Some bacteria are distinguished by their ability to produce endospores, resistant bodies that contain the genetic material and a small amount of cytoplasm surrounded by a durable wall.

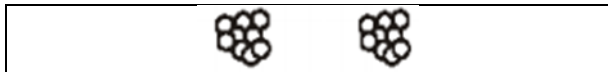
- Bacteria are distinguished by their means of motility, whether by flagella, corkscrew motion, or gliding through slimy material that they secrete. When flagella are present, they can be apical or posterior, or they can completely cover the cell.
- Bacteria are classified into one of three shapes: cocci (spherical), bacilli (rod shaped), and spirilla (spirals).
- The cell wall distinguishes two broad groups of bacteria.

CLASSIFICATION BY SHAPE

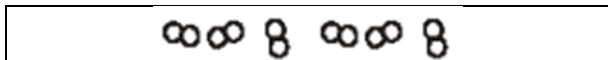
There are four main shapes of bacteria and they are as follows;

a. **Spherical shape** (cocci, singular = coccus)

They may be clusters e.g. *Staphylococcus aureus* which causes boils and food poisoning.



They may occur in pairs enclosed by a capsule, diplococci e.g. *Diplococcus pneumoniae*. They live in the nasal passage where they cause diseases like pneumonia.



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

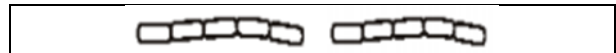


b. **Rod shaped** (bacilli, singular = bacillus)

They may occur as single rods e.g. *Escherichia coli* which lives in the guts of humans and is a friendly bacterium which synthesizes Vitamin B and K and *Bacillus anthrax* which causes anthrax

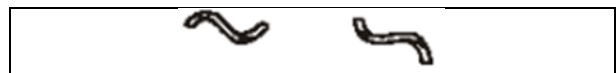


They may occur in chains e.g. *Azotobacter* which fixes nitrogen in the soil.

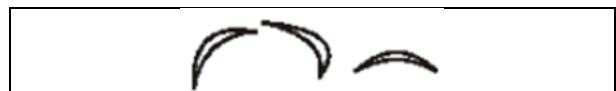


c. **Curved or spiral shaped**

Spiral shaped bacteria include *Spirillum* species



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



d. **Filamentous bacteria**

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

CLASSIFICATION BY METHOD OF RESPIRATION

a. Aerobic bacteria

These bacteria require oxygen for respiration. Obligate aerobes cannot survive without oxygen but facultative aerobic bacteria can survive in the absence of oxygen.

b. Anaerobic bacteria

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

CLASSIFICATION BY METHODS OF NUTRITION

a. Autotrophic bacteria

These bacteria manufacture their own organic food from carbon dioxide.

Photoautotrophic (photosynthetic) bacteria use energy of sun light to convert carbon dioxide into carbohydrates. Examples include; the blue-green bacteria, sulphur bacteria and cyanobacteria. Cyanobacteria are photosynthetic, using chlorophyll a to capture light energy, splitting H_2O , and releasing O_2 as do plants. They also contain accessory pigments called **phycobilins**. Some have specialized cells called **heterocysts** that produce nitrogen-fixing enzymes. When nitrogen is fixed, inorganic, unreactive nitrogen gas is converted into ammonia (NH_3), which can then be used for making nitrogen-containing amino acids and nucleotides.

Chemoautotrophic (chemosynthetic) bacteria use energy from chemical reactions to convert carbon dioxide into carbohydrates. Inorganic substances such as ammonia, methane and hydrogen sulphide are oxidized to release energy. Some of these are called nitrifying bacteria because they convert nitrite (NO_2^-) to nitrate (NO_3^-).

b. Heterotrophic bacteria

This feeds on already made organic food but in different ways. Chemo-heterotrophic bacteria obtain energy from chemicals in food.

Saprotrophic bacteria obtain their food from dead and decayed organic matter. Such bacteria secrete enzymes into the food, and absorb the soluble products of extra cellular digestion with the saprotrophic body for assimilation.

Parasitic bacteria live on other organisms (hosts) from which they obtain food as the host suffers harms.

Mutualistic bacteria live in close associations with legumes in the root nodules. Nitrogen-fixing bacteria are heterotrophs that fix nitrogen. Many of these bacteria have mutualistic relationships with plants; that is, both the bacteria and the host plant benefit from an interdependent relationship. The bacteria live in nodules, specialized structures in plant roots.

NOTE:

Escherichia coli contribute vitamins B and K groups. *Rhizobium* fixes nitrogen into the plants as it is provided with a shelter.

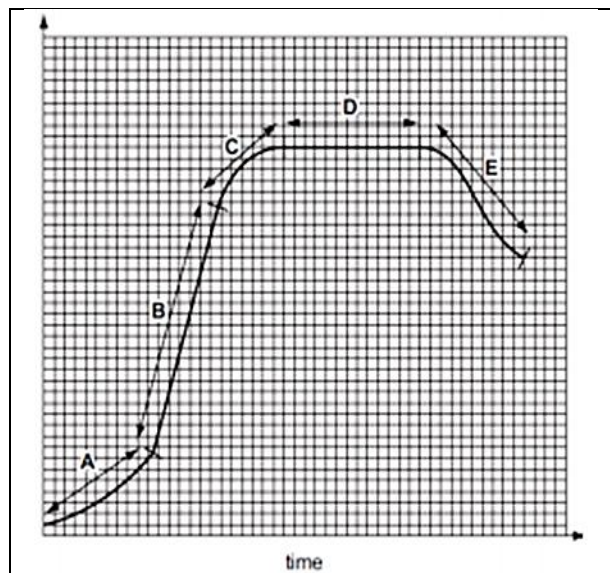
CLASSIFICATION BY STAINING REACTION

Gram positive bacteria; they stain purple with a gram stain. The cell wall lacks an extra outer membrane. They are susceptible to both antibiotics and lysosome activity.

Gram negative bacteria; they stain pink with a gram stain. Their cell wall possesses an extra outer membrane which is made out of lipids and polysaccharides which is thought to interfere with phagocytosis by white blood cells. This outer membrane gives them protection against penicillin and lysozymes.

POPULATION GROWTH IN BACTERIA

On reaching a certain point / stage which cannot be controlled by the nucleus, the bacteria reproduce asexual by binary fission.



The above curve is called a normal sigmoid growth curve with five regions.

Lag phase (A); phase at which growth is proceeding at its minimum there is a gradual increase in population size this is because bacteria are getting used to their new environment and growth has not yet achieved its maximum growth way few bacteria have attained the required size to divide by binary fission. The bacteria are still synthesizing new enzymes to digest the wide spectrum of nutrients available in the medium.

Log phase (B); this is the phase at which at which growth is proceeding at its maximum. The bacteria have got under the new environment they have already made the enzymes required to digest the food nutrients and many have attained the required size to divide. There is almost no death causing a rapid increase in the population.

Self – retarding phase (C); there is a decrease in the overall rate of population growth i.e. the number of new cells produces per unit time decreases causing a retardation growth. There are so many bacteria cells competing for essential nutrients to set in for aerobic bacteria cells oxygen is no longer enough and space is becoming limited causing death of some bacteria cells. Their own toxic wastes begin to accumulate causing a decrease in the rate of population growth.

Stationary phase (D); at this point growth rate is zero rate of production of new cells is counteracted by death of some number of the cells so no net increase as a result of many factors including;

- Exhaustion of essential minerals
- Accumulation of own toxic wastes.
- Stiff competition for space.
- Oxygen for aerobic bacteria.

Decline phase (E); Death rate increases exceeding birth rate due to total exhaustion of nutrients and oxygen for aerobic bacteria. There are too many wastes and there is lack of space.

Factors which affect bacterial growth

- Nutrient availability
- Oxygen availability
- Temperature. High temperature speeds up bacterial population growth up to 40°C after which it declines. Very low temperatures slow down bacterial growth because the enzymes become inactivated.
- Availability of moisture
- Accumulation of toxic waste products (carbon dioxide). Low pH results from the reaction between carbon dioxide, from respiration with water to form the weak carbonic acid. Low pH inhibits bacterial population growth while high pH favours bacterial population growth.

ECONOMIC IMPORTANCE OF BACTERIA

Uses of bacteria

- They fix nitrogen in the soil e.g *Azobacter*, *Nitrosomonas*.

- They decompose organic matter to release nutrients in the soil and hence improve on soil fertility and properties such as soil aerobic soil structure, soil water, holding capacity e.t.c.
- In milk industry they are used in the production of Ghee, cheese, yoghurt etc.
- In leather industry they are used in leather turning.
- The bacteria *E. coli* found in the gut makes vitamin B and K.
- Bacteria are also important in digestion of cellulose in some organisms.
- Bacteria are used in production of antibiotics and vaccines.
- Bacteria are used in treatment of sewage in the process called biodegradation in the study of genetics.
- They are also good producers in aquatic ecosystem.

Harmful effects of bacteria

- They spoil food e.g milk can change to sour milk as a result of bacteria.
- Bacteria also damage underground pipes made up of metals.
- They cause disease to plant and animals e.g pneumonia, syphilis, gonorrhea, typhoid, cholera, yellow swine fever in pigs.

SUB TOPIC 4: KINGDOM PROTOCTISTA

SUB TOPIC OUTLINE

- *Characteristics of protoctista*
- *Structure of protozoa and algae*
- *Economic importance of protozoa and algae*
- *Common diseases caused by protozoa*

Protists are eukaryotes and they may be unicellular or multicellular. Organisms in this kingdom may be algae like, animal like, or fungus like. In many cases, the evolutionary relationships among the various groups are either very weak, poorly understood, or both. Thus, this kingdom is artificial and is used more for convenience than to present actual evolutionary relationships. Features shared by two or more groups may represent **convergent evolution**; that is, the features arose among the groups independently.

GENERAL CHARACTERISTICS

- They are single called eukaryotic organisms or organisms which are assemblages of similar cells. Some contain chlorophyll and make their own food others feed heterotrophically.
- A few individuals are multicellular and colonial in organization. In other protists, certain cells and regions have become specialised and independent.
- Some have flagella, others cilia for locomotion.

SUB KINGDOM PROTOZOA

The protozoa include a great diversity of minute, eukaryotic organisms. Most are single celled animal like organisms. Nutrition is mostly heterotrophic, but the mode of nutrition may change according to the food available.

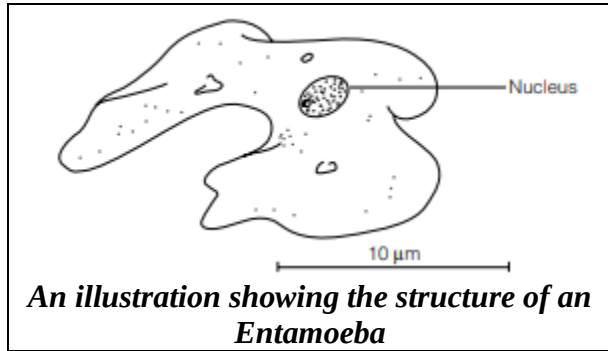
Characteristics of protozoa

- They are single called organisms.
- Some move by pseudopodia, some by cilia and others by flagella.
- They don't make their own food and feed heterotrophically.
- Some are parasites and live on or in the bodies of organisms.
- Some have single nucleus, others have two nuclei i.e. micro and macro nuclei.
- They store food in form of glycogen

They are placed under several phyla but those of much importance at this level include the following.

PHYLUM RHIZOPODA

Examples include; *Amoeba proteus* which lives in fresh water and *Entamoeba histolytica* which causes amoebic dysentery

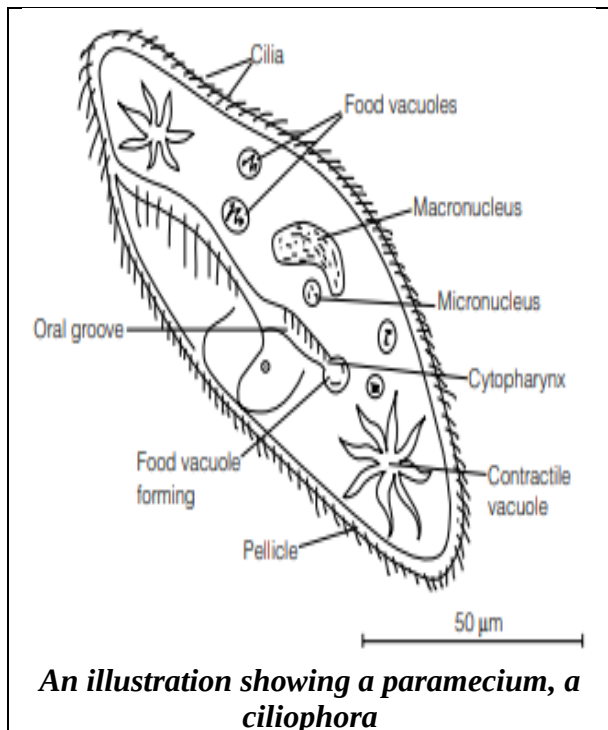


Characteristics

- ❖ They are unicellular and bear pseudopodia (false feet) which enables movement and phagocytosis
- ❖ They reproduce asexually
- ❖ They feed heterotrophically

PHYLUM CILIOPHORA

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

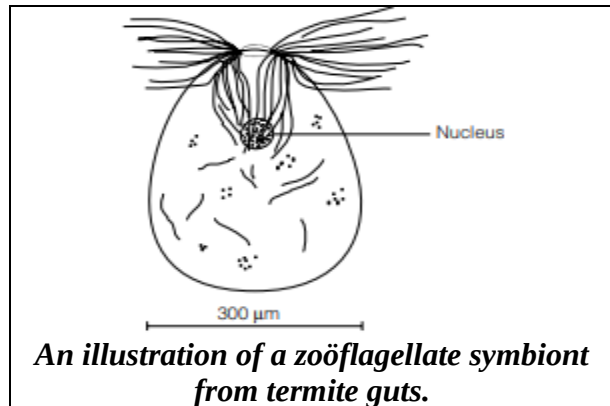


Characteristics

- ❖ They are unicellular
- ❖ They feed heterotrophically
- ❖ Their cilia has a 9+2 tubule arrangement
- ❖ The cilia collects food and enable locomotion in water
- ❖ Their habitat is fresh water and marine water
- ❖ They have two types of nuclei, the larger macro nucleus which controls all cell metabolic activities and the micro nucleus which controls sexual reproduction called conjugation.
- ❖ The macro nucleus is polyploid i.e. it has more than two sets of chromosomes and the micro nucleus is diploid i.e. it has two sets of chromosomes.

PHYLUM ZOOMASTIGINA

Examples include *trypanosoma* and *trichomonas*. The former are common parasites of mammals, particularly in tropical countries. They live in the blood and other tissues. The intracellular stage of the life cycle lacks a flagellum, but the extracellular stage has a flagellum extending laterally along the body and anteriorly. The parasites are transmitted by blood-sucking insects. *Trypanosoma brucei* is a cause of ***African sleeping sickness*** and is transmitted by the tsetse fly. Zoöflagellate hindgut symbionts of termites are among the most complex of protozoans: their cellulases digest wood eaten by their hosts, producing glucose which the termite can then assimilate.

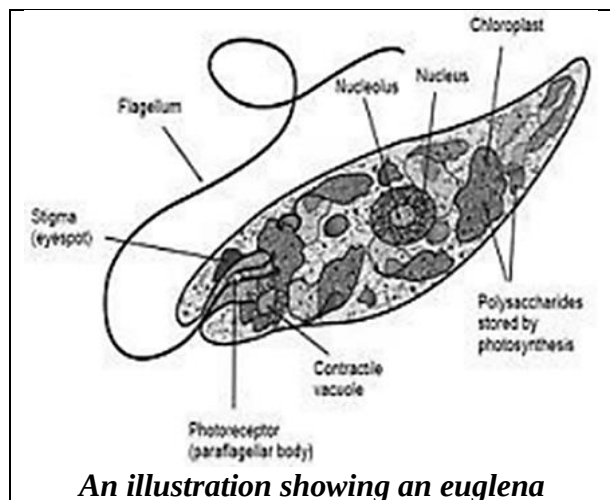


Characteristics

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

PHYLUM EUGLENOPHYTA

It consists of a group of organisms seen as intermediate between the protozoa and algae, some are photosynthetic and some non-photosynthetic. The only member is euglena which lives in an aquatic environment.



Characteristics

- ❖ They are mostly unicellular
- ❖ They reproduce asexually
- ❖ They move by flagella
- ❖ Some are photosynthetic while others are heterotrophic in absence of light.
- ❖ Food is stored as a carbohydrate called **paramylon**.
- ❖ Some have an eye spot that permits photo taxis, the ability to move in response to light.
- ❖ They lack a cell wall. The body is covered by a tough protein layer called **pellicle**.

PHYLUM APICOMPLEXA

Members include *plasmodium* which causes malaria in humans

Characteristics

- ❖ they are unicellular
- ❖ they are heterotrophic
- ❖ they lack locomotory structures
- ❖ they are spore producing parasites of animals
- ❖ they reproduce sexually and asexually
- ❖ their lifecycles are complex involving several animal hosts

Life cycle of plasmodium

An infected anopheles mosquito bites a person, injecting plasmodium sporozoites in its saliva. The sporozoites enter the person's liver cells. After several days, the sporozoites undergo multiple divisions and become merozoites, which use the apical complex to penetrate red blood cells. The

merozoites divide asexually inside the red blood cells. At intervals of 48 or 72 hours (depending on the species), large numbers of merozoites break out of the blood cells, causing periodic chills and fever. Some of the merozoites infect other red blood cells.

Some merozoites form gametophytes. Another anopheles mosquito bites the infected person and picks up plasmodium gametophytes along with blood. Gametes form from the gametophytes; each male gametophyte produces several slender male gametes. Fertilisation occurs in the mosquito's digestive tract, and a zygote forms. An oocyst develops from the zygote in the wall of the mosquito's gut. The oocyst releases thousands of sporozoites, which migrate to the mosquito's salivary glands.

PHYLUM OOMYCOTA

These are either parasites or saprobes. They are much like fungi in that they form filaments (hyphae) which secrete enzymes that digest the surrounding substances. The breakdown products of digestion are then absorbed. The filaments of the oomycota lack septa which in many of the true fungi partition the filaments into compartments. Because they lack septa, they are **coenocytic** containing many nuclei within a single cell.

Its cell wall is made of cellulose rather than chitin found in true fungi. They are characterized by production of spores that bear flagella. Such spores are produced both sexually and asexually. They include *peronospora* which grows on grapes and *pythium* which causes late potato blight and tomato rot.

Sub kingdom Algae

Photosynthetic eukaryotic organisms with a cell wall structure similar to that of green plants. Algae show great diversity in structure, ranging from unicellular and simple filamentous forms to huge sea weeds. Algae occur in water or on very damp surfaces.

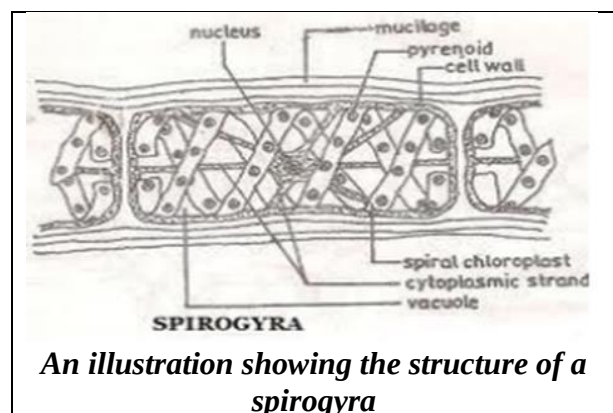
PHYLUM CHLOROPHYTA

The members include volvox, chlorella and spirogyra. *Chlorella* which is a unicellular non filamentous alga that lives in fresh water ponds *Chlamydomonas* which is a motile unicellular algae

Characteristics

- ❖ They contain chlorophyll and therefore they are photosynthetic
- ❖ Their cell walls contain cellulose
- ❖ They store starch
- ❖ They reproduce sexually and asexually

Spirogyra



Spirogyra is a filamentous algae that lives in fresh water ponds. It is multi cellular but cells are not specialised, within each cell

these are extensive structures including a central nucleus with a nuclear membrane, cytoplasmic strands and a spiral chloroplast with food reserves in form of starch in the pyrenoids

Adaptation of spirogyra to its habitat

- It has chloroplasts with chlorophyll, trapping solar energy for photosynthesis.
- Has mucilage making it slimy not to be eaten by animals.
- The filament is very long increasing surface area to trap solar energy for photosynthesis.

Life cycle of a spirogyra

Spirogyra reproduces both asexually and sexually. Asexual reproduction is by fragmentation during when the filament breaks into pieces called fragments when conditions are favourable.

During unfavourable conditions, the algae reproduce sexually by conjugation. Two adjacent filaments develop conjugation tube through which the nucleus from the donor filament passes and fuses with the nucleus of the receiver nucleus forming a diploid zygote. Under unfavourable conditions the zygote develops a thick wall forming a resistant zygospore which remains dormant until the conditions become favourable. The diploid zygospore undergoes meiosis which develops into new algae.

PHYLUM PHAEOPHYTA

This division consists of organisms which contain a brown pigment called *xanthophyll* together with chlorophyll A and C e.g. *fucus*,

ascophylum, *laminaria* etc. they are mainly multicellular. Their cell wall has got alginic acid.

Characteristics

- ❖ They possess chlorophyll and therefore carry out photosynthesis
- ❖ They are multicellular
- ❖ They are marine and are therefore called the sea weed
- ❖ They contain a brown pigment called fucoxanthin which gives them a brown colour

PHYLUM RHODOPHYTA

This is a form of algae which has a red photosynthetic pigment. They are mainly multicellular and also make their own food. The members include chlorella.

Characteristics

- ❖ It is marine
- ❖ It contains chlorophyll hence it carries out photosynthesis
- ❖ It contains a red pigment called phycoerythrin and a blue pigment called phycocyanin
- ❖ It produces agar which is extracted from them for laboratory purposes

Economic importance of algae

Uses of algae

- They act as fertilizers hence supply nutrients to the gardens.
- They are producers in aquatic ecosystem and therefore provide food to other organisms, make oxygen available for other organisms

and reduce carbon dioxide which would cause acidity in water.

- They are used in production of drugs.
- They are also used in industries for manufacture of perfumes, shoe polish, tooth paste etc.
- Some algae are edible to man and can be eaten.
- They are also used in purification sugar and petrol.

- Chlorella can be cultivated to provide Single Cell Protein (SCP) for humans and animal consumption

Harmful effects of algae

- They pollute water environment i.e algae blooms.
- They can cause corrosion of concretes and metal walls.
- They damage tea leaves i.e the parasitic form of algae.

SUB TOPIC 5: KINGDOM FUNGI

SUB TOPIC OUTLINE

- *Characteristics of fungi: feeding, reproduction*
- *Characteristics of Rhizopus or mucor and the mushroom*
- *Economic importance of fungi*
- *Common fungal diseases*

The fungi range in size from microscopic to the very large fungi such as toad stools, mushrooms, and puffballs which can be easily seen by the naked eye. Fungi are eukaryotic organisms made up of thread like structures known as **hyphae** forming a branching network. The hyphae may be septate or aseptate. Septate hyphae have cross walls called **septa** which divide the cytoplasm into cells containing one nucleus. Septa are absent from aseptate hyphae and the cytoplasm contains very many nuclei, they are multinucleate, or **coenocytic**. The cell walls of fungi consist of **chitin**, a nitrogen-containing polysaccharide.

Fungi are dominantly haploid, but most form temporary diploid structures for sexual reproduction. The following stages occur during sexual reproduction.

- **Plasmogamy** is the fusing of cells from two different fungal strains to produce a single cell with nuclei from both strains. A pair of haploid nuclei, one from each strain, is called a **dikaryon**. A hypha containing a dikaryon is called a **dikaryotic hypha**.
- **Karyogamy** is the fusing of the two haploid nuclei of a dikaryon to form a single diploid nucleus.
- **Meiosis** of the diploid nucleus restores the haploid condition. Daughter cells develop into haploid spores, which germinate and form haploid hyphae.

Fungi reproduce asexually by various means, including fragmentation (the breaking up of hyphae), budding (the

pinching off of a small hyphal outgrowth), and asexual spores. Two kinds of asexual spores are described below:

- **Sporangiospores** are produced in saclike capsules called sporangia (singular, sporangium) that are each borne on a stalk called a sporangiophore.
- **Conidia** (singular, *conidium*) are formed at the tips of specialized hyphae, not enclosed inside sacs. Hyphae bearing conidia are called conidiophores.

GENERAL CHARACTERISTICS OF FUNGI

- They are heterotrophic i.e they do not contain chlorophyll and therefore feed saprophitically or parasitically. Many parasitic fungi have hyphae called **haustoria** that penetrate their host.
- Their body is thaloid or flattened i.e not differentiated into leaves, stem or roots.
- They reproduce by spore formation or sporulation or budding or fragmentation.
- They do not have cilia or flagella at any stage of their life cycle.
- They live in moist soil, on bodies of other organisms

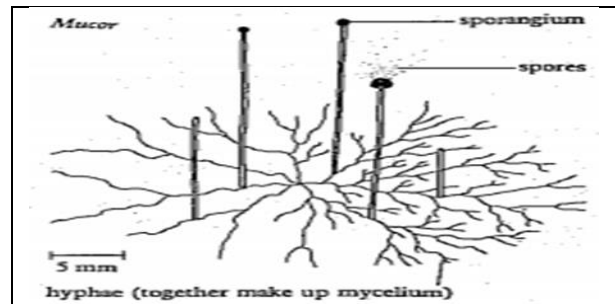
CLASSIFICATION OF THE KINGDOM

Depending upon the classification scheme, the groups are considered either divisions (and bear the “-mycota” suffix) or classes (“-mycete” suffix). As a result, division and class names are often used interchangeably

(Zygomycota and zygomycetes, for example). The most important phyla are:-

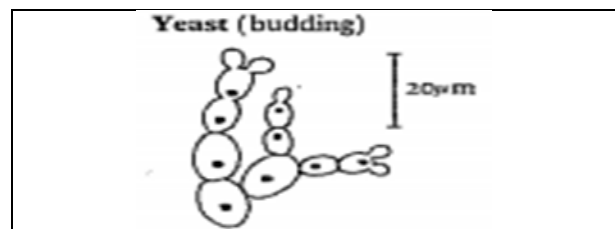
PHYLUM ZYGOMYCOTA

These reproduce by their sporangium produce spores using conidia for example bread moulds (*Rhizopus*) made up of numerous hyphae which are aseptate, except when filaments border reproductive filaments. Zygomycetes reproduce sexually by fusion of hyphae from different strains, followed by plasmogamy, karyogamy, and meiosis. Haploid zygospores are produced, which germinate into new hyphae.



PHYLUM ASCOMYCOTA

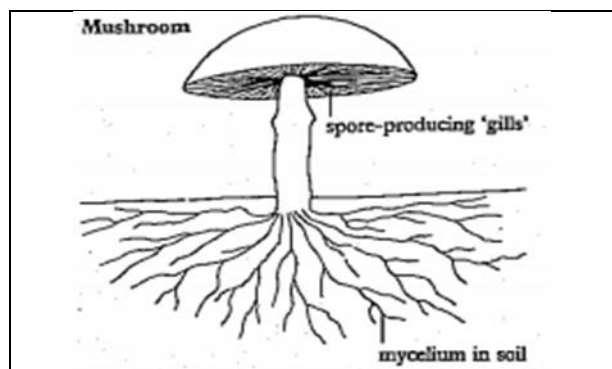
These reproduce by a sexual means by producing spores in a conidia e.g *saccharomyces* (yeast), *aspergillus* and *penicillium*. Mycelium of hyphae partially divided into multinucleated compartments of septa. The septum has a central pore, and cytoplasm is continuous throughout the mycelium.



Ascomycota reproduce sexually by producing haploid **ascospores**. After plasmogamy of hyphae from unlike strains, a dikaryotic hypha produces more filaments by mitosis. Karyogamy and meiosis subsequently occur in terminal hyphal cells producing four haploid cells. These four cells divide by mitosis to produce eight haploid ascospores in a sac called an **ascus** (plural, **asci**). In many ascomycetes, the asci are grouped together into a specialized fruiting body, the ascocarp.

PHYLUM BASIDIOMYCOTA

Sexual reproduction is by formation of basidia. They include mushrooms, toadstools, puff balls, bracket fungi very large fungi and reproduce by forming large spores.



Sexual reproduction e.g. in bread mould

Two hyphae that are participating in sexual reproduction come together and develop extensions where they exchange their nuclei.

The two hyphae are denoted as negative and positive. The positive being the donors and the negative being the receivers. When nuclei join, they form a developed zygote which develops a thick layer a zygospore. The zygospore undergoes meiosis to restore the normal chromosome number. When conditions become favorable, the zygospore germinates into new hyphae.

Economic importance of fungi

- Some fungi are parasites and cause diseases to both plants and animals for example in human, Ringworms and Athlete foot are fungal infection, in plants, potato blight caused by *Phytophthora infestans*.
- Saprophytic fungi such as bracket fungi attack timber of wood causing dry rot. This may make the roof collapse.
- Fungi such as penicillium and Erythromycile are important in the synthesis of antibiotics e.g. penicilline and Erythromycine respectively.
- The fungus yeast (*saccharomyces*) is useful in baking and fermentation.
- Some fungi are used in cheese manufacture. The fungus ferments the milk sugar lactose forming lactic acid which converts soluble milk protein caseinogen to the insoluble curd casein which forms the cheese.

SUB TOPIC 6: KINGDOM PLANTAE:

SUB TOPIC OUTLINE

- *Structural features of lower plants and higher plants*
- *Characteristics of lower plants: bryophyta, pteridophyta/filicinophyta*
- *Characteristics of higher plants: coniferophyta, spermatophyta; gymnosperms and angiosperms to class level*
- *Economic importance of plants in the environment*

This is a very diverse kingdom ranging from very primitive plants the mosses to very huge trees which are high adapted to life on land. In order to survive the transition from water to land, it was necessary for plants to make adaptations for obtaining water and to prevent its loss by **desiccation** (drying out). Water was also required to provide a medium for the fertilization of eggs by flagellated sperm. In addition, once plants emerged from the protective cover of water, genetic material was more susceptible to damage by ultraviolet radiation. The following list summarizes the major plant adaptations for survival on land.

- Except for the primitive bryophytes (mosses, liverworts, and hornworts), the dominant generation of all plants is the diploid sporophyte generation. A diploid structure is more apt to survive genetic damage because two copies of each chromosome allow recessive mutations to be masked.
- All plants possess a cuticle, a waxy covering on aerial parts that reduces desiccation.
- The development of a vascular system in plants further reduced their dependency on water. Without a vascular system, all cells must be reasonably close to water. A vascular

system reduced this dependency by providing a system for water to be distributed throughout the plant. Once cells were relieved of their dependency upon water, tissues specialized for specific tasks evolved. True leaves developed as centers for photosynthesis, true stems developed to provide a framework to support leaves, and true roots developed to obtain water and anchor the plant. Two groups of vascular tissues evolved, xylem and phloem. Xylem is specialized for water transport, and phloem is specialized for sugar transport.

- In the more primitive plant divisions, flagellated sperm require water to swim to the eggs. In the more advanced divisions (Coniferophyta and Anthophyta), the sperm, packaged as pollen, are adapted for delivery by wind or animals.
- In the most advanced division, the Anthophyta, the gametophytes are enclosed (and thus protected) inside an ovary.
- Plants of the Coniferophyta and Anthophyta have developed adaptations to seasonal variations in the availability of water and light. For example, some trees are

deciduous; that is, they shed their leaves to minimize water loss during slow-growing (or dormant) seasons. In contrast, desert annuals will germinate, grow, flower, and produce seeds within brief growing periods in response to a spring rain.

CHARACTERISTICS OF KINGDOM PLANTAE

- They are autotrophs i.e they make their own food.
- Their cell wall is made up of cellulose.
- They lack contractile fibre and cannot locomote.
- They have a life cycle showing alternation of generation.

CLASSIFICATION OF PLANTS

There are 4 important divisions including

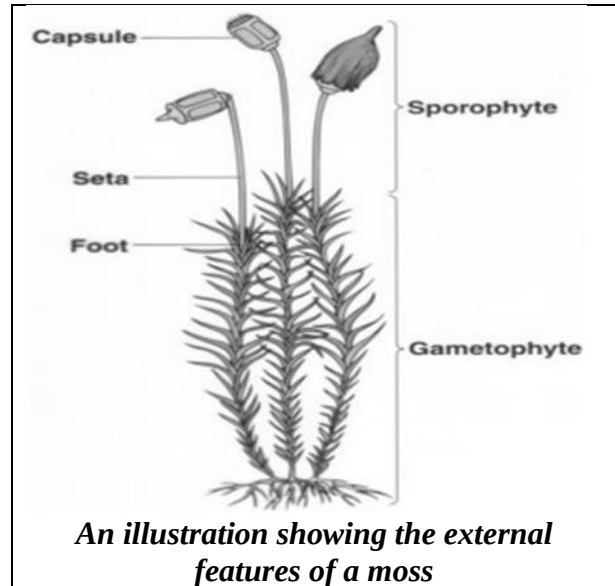
DIVISION BRYOPHYTA

The bryophytes are considered to be the first plants to colonise land and are still poorly adopted to land conditions in that they are confined to moist shade places. They include the mosses and liver worts.

Characteristics of bryophytes

- Their body is thallus made up of mainly parenchyma cells i.e it is only differentiated into simple leaves and stem but they lack roots through they have root like structures called rhizoids.
- They have very small conducting tissues.

- They live mainly in moist places e.g damp soil.
- They show alternating of generation in their life cycle. The gametophyte is the most dominant generation.
- Their body is divided into two main parts i.e gametophyte and sporophyte
- Their anthozoids are biflagellate



Alternation of generation

It is the change in the form/stage of a plant in its life cycle. Bryophytes show alternation of generation between their gametophyte stage and sporophyte stage. During alternation of generation, the gametophyte is the gamete producing stage since it contains the male and female parts within the leaves. The female rosette contains a structure called **archegonium** that produces the female gamete ovum and the male reproductive part called **antheridium** that produces the male gamete called **antheroids**. The male gamete has a flagella and swims in a film of water into the female organ

archegonium. It then fuses in the ovum to form a zygote.

During saprophyte generation, a saprophyte that produces spores is involved. The diploid zygote formed during gametophyte generation develops into a saprophyte to obtain nutrients from it. The mature sporophyte then develops a capsule in which spores are produced by meiosis and when the capsule matures, it splits to release the spores. Spores are small structures or bodies which when landed on suitable environment germinate and develop into a microscopic structure called **protonema** which later develops into a gametophyte and the gametophyte generation alternates to the sporophyte.

Differences between sporophyte and gametophyte

Gametophyte phase.	Sporophyte
• Haploid state • Gametes are produced by mitosis. • Gametophyte self-supporting pond • Gametophyte takes the largest phase of the life cycle. • Made up of leaf like structures	• Diploid state. • Gametes are produced by meiosis • Depends on gametophyte for support and nutrition • Takes the shortest phase of the cycle. • Made up of a capsule and its stalk.

Why bryophytes are poorly adapted on land?

- They like in only moist habitats and due to this they are described as “amphibians” of the plant kingdom.
- They lack the conducting tissues such as the xylem and phloem and the movement of materials in them is by diffusion.
- They depend on water for their sexual reproduction especially during the movement of the sperm from the male reproductive organ to effect fertilization.
- They lack true roots and support in them is mainly by simple rhizoids.

DIVISION PTERIDOPHYTA

Ferns are basically terrestrial that grow well in moist places. The plant body is sporophyte which has true roots, stem, leaves and vascular tissues (xylem and phloem). The plant body is rhizome with an underground stem and fibrous / adventurous roots. Ferns range from simple plants to tree ferns with compound pinnate or bipinnate leaves depending on the species. The vascular leaves have only xylem tracheids without vessel. The gametophyte is a very small structure reproduced to a simple prothalus

General characteristics of pteridophytes

- They are non-flowering plants.
- They are terrestrial plants which grow in moist places.
- Their sporophyte has true leaves, roots and stem. It also has muscular tissues, the xylem and phloem.

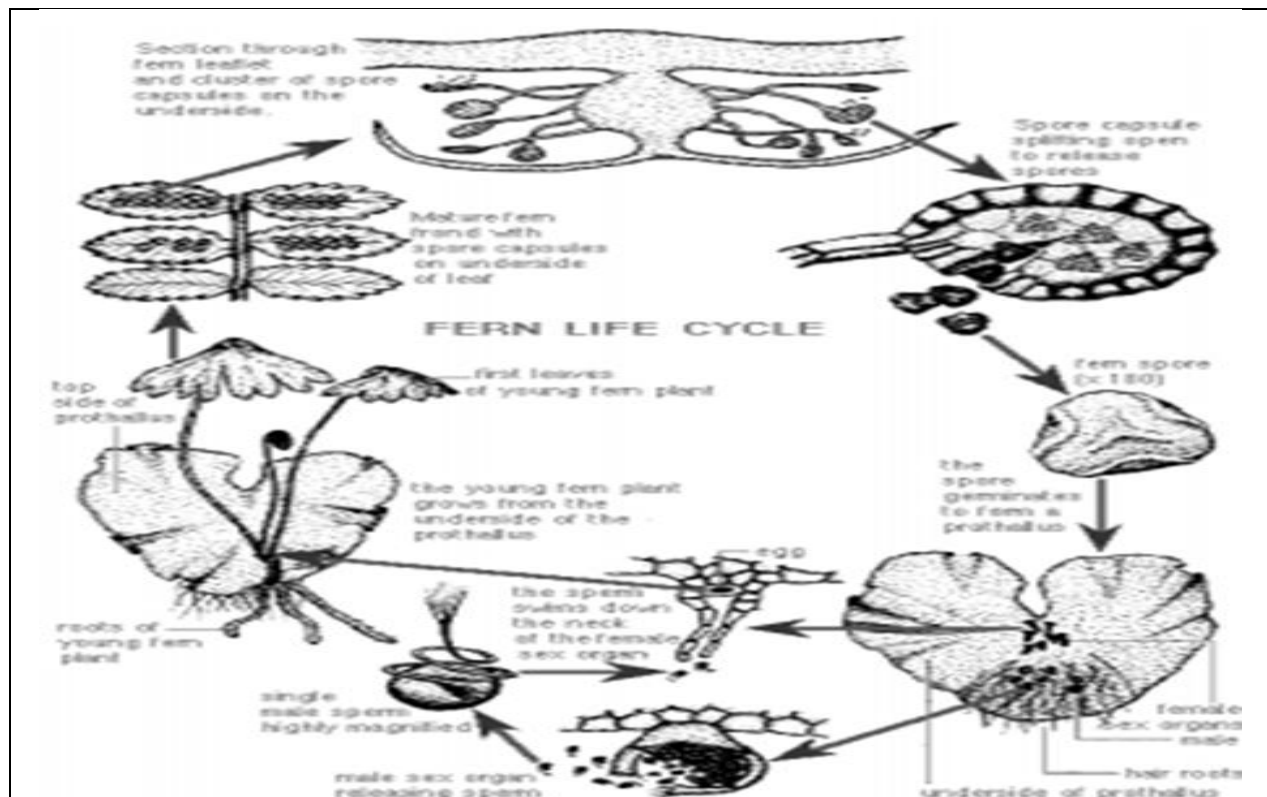
- Their gametophyte is a very small structure reduced to a simple prothallus.
- They produce antherozoids which have a single flagellum.
- They also show alternation of generation in which sporophyte is the most dominant generation i.e the gametophyte depends on the sporophyte.

Life cycle of pteridophytes

Ferns also show alternation of generation i.e sporophyte generation being dominant. The fern plant is the diploid sporophyte and its life cycle alternates between sporophyte and gametophyte. The sporophyte produces spores by meiosis in the sporangium. Many sporangia clusters underneath the leaf forming sori. A sporangium is protected by a

covering called **inducium** where mature the sporangium splits or ruptures and releases haploid spores which follow on moist soil and germinate into **prothallus** which is the gametophyte. It is a very small structure and does not contain any tissue. It later develops rhizoids on its underside to gain support in the soil.

The gametophyte contains both male and female sex organs called antheridium and archegonium respectively. The antheridium produces haploid sperm (spermatozoids) by mitosis while the archegonium produces a haploid ovum also by mitosis. The sperm cell has flagella and moves in water into the archegonium. It then fuses with the ovum in the archegonia to form a diploid zygote. The diploid zygote then develops into a diploid sporophyte as a fern plant that can survive independently.



Significance of alternation of generation

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

DIFFERENCES IN THE ALTERNATION OF GENERATION OF BRYOPHYTES AND PTERIDOPHYTES

Bryophytes	Pteridophytes.
• The gametophyte is the dominant generation and supports its self • They lack true roots • They lack vascular tissues e.g xylem and phloem. • The gametophyte is made up of simple leaf like structures. • The sporophyte consists of a capsule on a stalk. • The gametophyte develops into a protonema.	• The sporophyte is the dominant generation. • Have true roots. • They have vascular tissues both xylem and phloem. • The gametophyte has a simple heart shaped structure. • The sporophyte is a complete plant with roots, stems and leaves. • The gametophyte develops into a prothallus

Adaptations of pteridophytes to life on land:

- They have vascular tissues which conduct water, mineral salts and organic products of photosynthesis.
 - They have true roots for firm support in the soil and for water/mineral salt absorption.
 - The gametophyte is highly reduced to a heart – shaped structure.
 - The surface of the leaves is covered with a waxy cuticle which is water repellent minimizing water loss.
 - In tree ferns, there is secondary growth forming wood (secondary xylem for support against wind.
- However ferns are still poorly adapted on land because it:
- They still depend on water for fertilization.
 - Moist ferns live in moist environment and may not survive dry environment.
 - They lack xylem vessels and have only tracheids. Tracheids are inefficient in transporting water for long distances.

Revision question

- i Explain what is meant by alternation of generations.
- ii Compare the life cycle of a moss and a fern
- iii What is importance of alternation of generations to the life of a moss and a fern?
- iv How are the ferns better adapted to terrestrial life than mosses?

DIVISION CORNIFEROPHYTA

This is a division of cone bearing plants. They are the non-flowering plants. They are perennial plants which form large trees and can grow for year's examples include conifers and the pine tree, fir, cypresses, cycads, and yews.

General characteristics of corniferophyta

- They have vascular tissues but xylem has only tracheids and their phloem lacks companion cells.
- They have long narrow niddle
- The reproductive parts are born in cones.
- They are monoecius with both reproductive organs are located on the same plant but different parts.
- They undergo single fertilization.
- They produce resein to protect them.
- They produce necked seeds i.e their seeds are not enclosed in the ovary.
- They do not have a fruit since they don't have ovaries.
- They bear seeds.
- They also show alternation of generation.

DIVISION SPERMATOPHYTA:

These are the seed bearing plants. They have a gametophyte much reduce and it produces the pollen grains and the egg cell by the process of meiosis. The main plant body is the sporophyte and the gametophyte depends on the sporophyte.

Angiospermatophyta

This division is divided into two classes namely monocotyledonae and dicotyledonae. They are the flowering plants and they have the following characteristics:

- Their seeds are enclosed in the ovary and are not naked.
- They produce flowers which act as gametophytes producing both male and female gametes.
- After fertilization, the ovary develops into a fruit.
- Their conducting elements are fully developed with the xylem having both tracheids and vessels while the phloem tissue having companion cells. Therefore the companion cells and the vessels are distinguishing characteristic of angiosperms.
- Some form wood as a result of secondary growth while others are simple herbs and shrubs.
- They show double fertilization with one of the male nucleus fusing with the polar nuclei forming a triploid endosperm tissues and the other fusing with the egg cell forming a diploid zygote

Life cycle of angiosperm

Flowering plants show alternation of generations between the sporophyte and the gametophyte. The sporophyte is the dominant phase while the gametophyte is much reduced and the gamete producing parts are found within. The female gametes are produced from the embryo sac. Both are produced by meiosis. The male gametes called the pollen grains contain two male nuclei and the female gametes are the egg cells. Male gametes are motile but the female are immotile. During fertilization, one male nucleus fuses with the polar nuclei forming a triploid endosperm. The zygote formed after fertilization develops into an embryo which is surrounded by the endosperm.

Adaptations of angiosperms to life on land:

- The gametophyte is much reduced and is protected by the sporophyte.
- They have xylem vessels increasing efficiency in transportation of water and mineral salts.
- They produce seeds which can undergo dormancy when conditions are unfavourable and germinate when conditions become favourable.
- They have companion cells with numerous mitochondria for active transport of sugars.
- Fertilization is independent of water but dependent on agents like wind and insects.
- The aerial epidermis of the leaves is perforated forming stomata for gaseous exchange.
- They undergo secondary growth forming wood for support.
- Their roots are modified variously for support, absorption of water, reproduction and food storage.
- Their leaves are modified to survive in dry environments such as being spiny, succulent, rolled, hairy e.t.c.
- The cells of their cells are highly lignified for extra support.

SUB TOPIC 7: KINGDOM ANIMALIA.

SUB TOPIC OUTLINE

- *Characteristics of vertebrates and invertebrates*
- *Distinguishing structural features of various animal phyla: Porifera, cnidarian, Platyhelminthes, nematoda, annelida, mollusca, Echinodermata, arthropoda and chordate*
- *Economic importance of animal groups*

The animal is made up of multicellular organism which are heterotrophic some are motile since they have locomotory organs while others are immotile since they lack locomotory organs such as the sponges which are firmly attached on the substratum

like the rock. All animals have the following characteristics.

- They are all multicellular and eukaryotic.

- They are all heterotrophic i.e. feed on ready-made food.
- They have nervous system or a co-ordination system and respond to changes in the environment except the sponges which lack nervous system.
- They show division of labour i.e. particular cells performing particular functions.
- The cells in multicellular organs are organised into cells, tissues, organ, systems and the organisms.

CRITERIA FOR CLASSIFYING ANIMALS

When grouping the animals, we base on the features they have in common to put them in the same group. There are many features used in classifying animals. These include:

BODY SYMMETRY

Some animals are symmetrical i.e. they cannot be divided into two equal halves in any plane e.g the sponges are mirror images of each other. Some animals have a radial symmetry both internally and externally and their bodies can be divide into two equal halves in any plane e.g. in the hydra. In the star fish, the symmetry is penta-radial i.e. the body can be divided into two equal halves in 5 planes. In higher animals the symmetry is bilateral externally i.e. the body can be divided into two equal parts right and left which are mirror images of each other externally. This is not true for the internal organs since some are not poured in bilateral symmetry

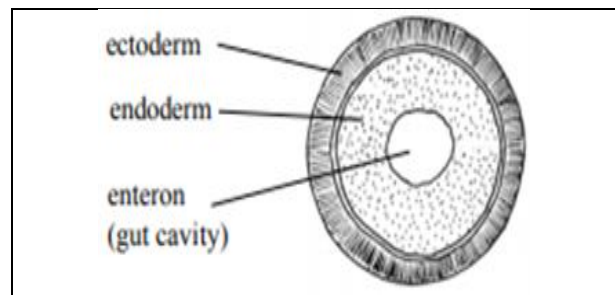
The animals show various sides or surfaces including the anterior (front end), posterior (hind end), dorsal surface (upper surface), ventral surface (lower surface) and the lateral surface (side surface).

BODY LAYERS

Some organisms have two main layers and they are called diploblastic. Others have three main body layers and they are called triploblastic.

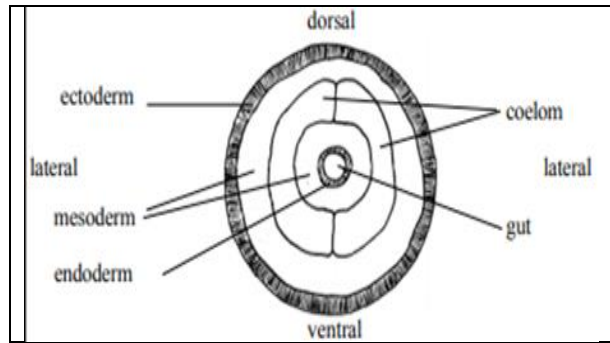
Diploblastic animals

This refers to an animal that has two basic germ layers in its body, the ectoderm and the endoderm. Germ layers consist of cells that can differentiate into particular tissues. For instance, ectoderm cells can differentiate into nervous tissue, endoderm cells differentiate into the lining cells of the digestive tract.



Triploblastic animals

This refers to an animal that has three basic germ layers in the body, the ectoderm, mesoderm and endoderm. The mesoderm can differentiate into blood, muscle tissues and skeletal tissues



BODY CAVITIES

Some animals contain a fluid filled cavity called a **coelom** others do not have cavities. The coelom is the space or body cavity present between the body wall and the digestive system. The body wall is made up of 3 layers; ectoderm, mesoderm and endoderm. Some animals may not have a true coelom and are called acoelomates e.g the sponges and the flat worms. Others have a true coelom and they are called coeloms such as the higher animals while others have a pseudo coelom called a haemocoel e.g in arthropods.

Significance or importance of possessing a mesoderm in the body

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

the use of flagella or cilia inappropriate.

Functions of the coelom

- It enables the activities of the body wall to operate independent of each other.
- In lower organisms, the coelom is fluid and the fluid acts on a circulating media for exchange of materials.
- It provides space for enlargement of internal organs.
- It acts as a shock absorber preventing mechanical damage to internal organs.

Problems caused by the coelom

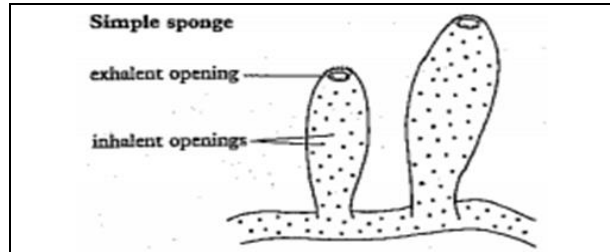
- It separates the body wall from the gut, causing difficulty in transporting digested food and respiratory gases resulting into the development of transport system
- Increased size and complexity requires a more complex coordination system, therefore a more elaborate nervous system

PHYLUM PORIFERA

This includes the sponges. Their body is covered with cavities connected to the outside environment by pores hence the name porifera. Although classified as animals, they have no tissues, organs, no mouth and no digestive system. Their entire body structure is built around a unique water canal system which is used for filter feeding.

They are non-motile and firmly attached onto the sub-stratum in water unlike other

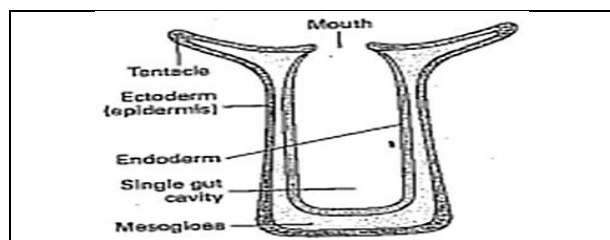
animals, sponges lack a nervous system. They reproduce by budding. Their body shape varies with the direction and force of water currents.



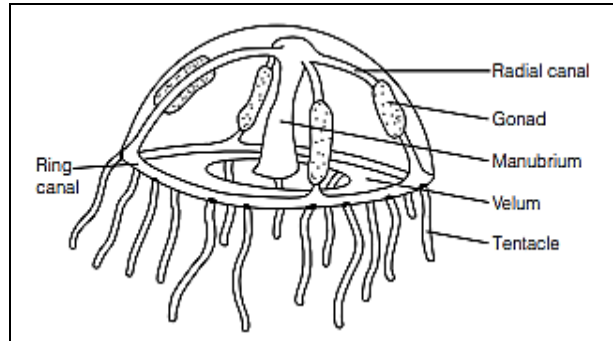
PHYLUM COELENTERATA

Cnidarians include the hydra, jelly fish, sea anemone. The body has 2 layers and is described as diploblastic i.e. the endoderm and ectoderm with a radial symmetry. The two layers are separated by a small cavity called mesogloea.

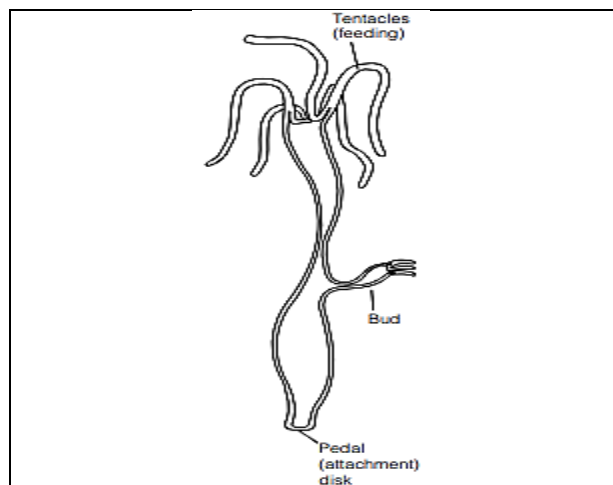
They are soft bodied animals that can exist in two forms; as a polyp or as a medusa. Typically the polyp spends most of its time attached to a substrate such as a rock. It has a tubular body usually with a mouth and a ring of tentacles on top for example sea anemone.



A medusa is a free flowing bell shaped individual with a tube hanging down in the centre. The tube ends in a mouth and tentacles usually line the edge of the bell for example jelly fish



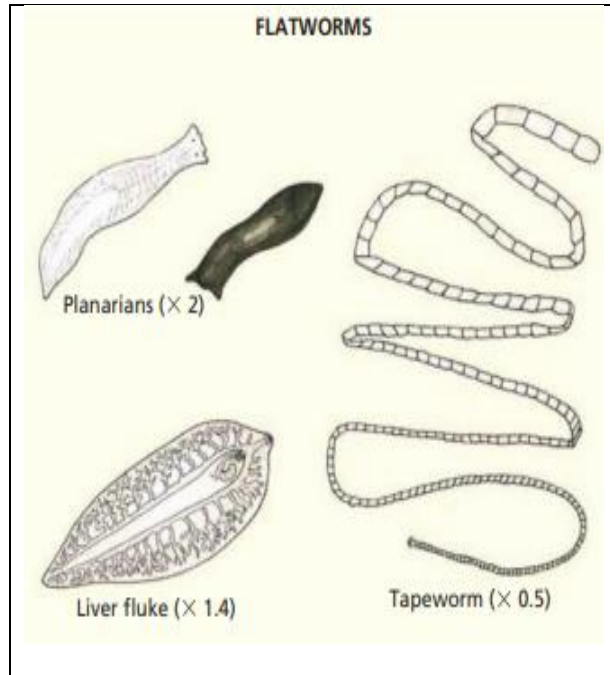
In hydra there are two forms, the polyp and medusa so it shows **polymorphism**. Polymorphism is the existence of the cell organisms in a number of morphologically distinct forms. The hydra shows a tissue level of organisation. A tissue is a group of inter-connected cells performing specific functions. They have nematoblasts (stinging cells) which when touched (stimulated) release a chemical which can be used to capture prey or used to defend against predators.



PHYLUM PLATYHELMINTHES:

These are the flat worms and most of them are parasitic. They have a bilateral symmetry and lack a true coelom e.g. Taenia

soleum (pork) tape worm, planaria (free living flat worm), lanes sarginata (beef tape worm).



Characteristics

- ❖ They are triploblastic i.e. the body is composed of three layers, the outer ectoderm and the inner endoderm and between these two is the mesoderm
- ❖ They have bilateral symmetry i.e. the body can only give two equal and opposite halves if cut along one plane.
- ❖ They have an un-segmented body
- ❖ Their bodies are dorsal ventrally flattened
- ❖ They have flame cells for excretion and osmoregulation
- ❖ They are hermaphrodites, often with elaborate precautions to minimise self-fertilization

Adaptations of platyhelminthes to a parasitic mode of life

- ❖ They have a special way of gaining entry into the body of the host but locomotory structures are generally reduced or absent.
- ❖ They have structures which anchor them onto their host. Liver flukes have suckers; tapeworms have both hooks and suckers.
- ❖ They protect themselves against the internal environment. Flatworms produce inhibitory substances to prevent their being digested by host enzymes.
- ❖ They have complex lifecycles. Fasciola and Taenia have a secondary host which transfers one parasite from the primary host to another.
- ❖ They have a very high reproductive output. Adults devote much of their energy and body space to sexual reproduction.

PHYLUM NEMATODA

These are the round worms with a bilateral symmetry and they have pseudo coelom. Most of them are parasites e.g. *Ascaris lumbricoides* (intestinal worms), *Enterobius Vermicularis* (pinworms), *Ancylostoma duodenale* (hook worm), filarial worms (cause elephantiasis)

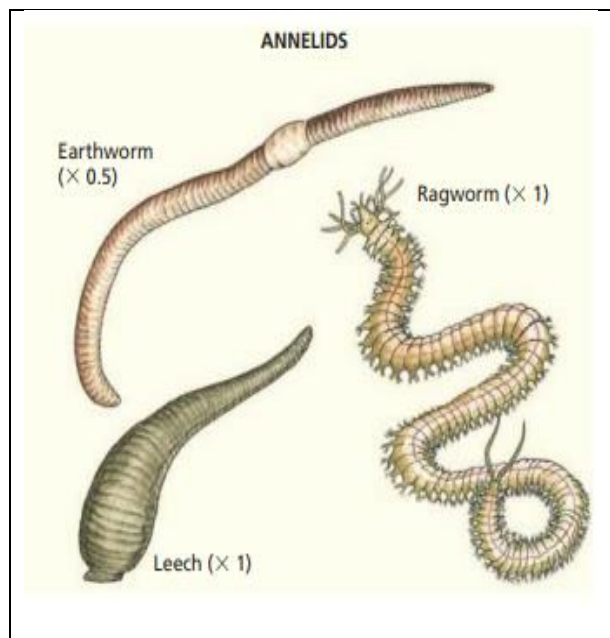
Characteristic features

- ❖ They are triploblastic
- ❖ They have bilateral symmetry
- ❖ They have an un-segmented cylindrical body

- ❖ Their alimentary canal is straight from the mouth to the anus.
- ❖ Their sexes are separate
- ❖ They lack cilia
- ❖ A cuticle of protein is present
- ❖ Some are free living plant and animal parasites
- ❖ They are elongated and round in cross-section with pointed ends

PHYLUM ANNELIDA

These are the segmented worms. The body is elongated with a well-developed coelom. Examples include; the earthworms, leech worm, hug worms. They have a hydrostatic skeleton.



General characteristics

- ❖ They are coelomate and triploblastic
- ❖ They have no chitinous cuticle
- ❖ They possess chitinous bristles called chaetae
- ❖ They have bilateral symmetry

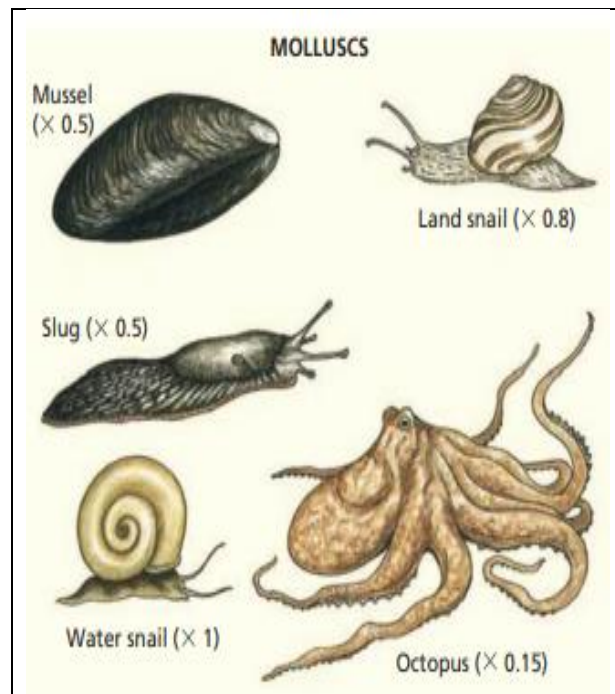
- ❖ They exhibit metameric segmentation i.e. their segments are repeated and are of the same age and size

Biological importance of earthworms

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

PHYLUM MOLLUSCA

These include the molluscs e.g squids, snails, octopus, e.t.c. The body is unsegmented, soft and a coelom is present some like the land snails have a shell made up of chitin used for protection.



Characteristics

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

PHYLUM ARTHROPODA

This includes the arthropods and they are the largest group of animals. They have the following characteristics

- They have a segmented body.
- They have jointed legs.
- They have an exo-cuticle made up of a polysaccharide chitin.
- Body coelom is a haemoceal.
- They have a dorsal heart with an open circulatory system.
- They excrete uric acid through malpighian tubules.

Reasons for the success of arthropods:

- Possession of an exo-cuticle which protects the animal from mechanical damage prevents excessive water loss and makes up the wings which are used for light.
- Excretion of uric acid which requires little or no water for its elimination.
- Some arthropods have large compound eyes for proper vision.

Disadvantages associated with the presence of an exoskeleton

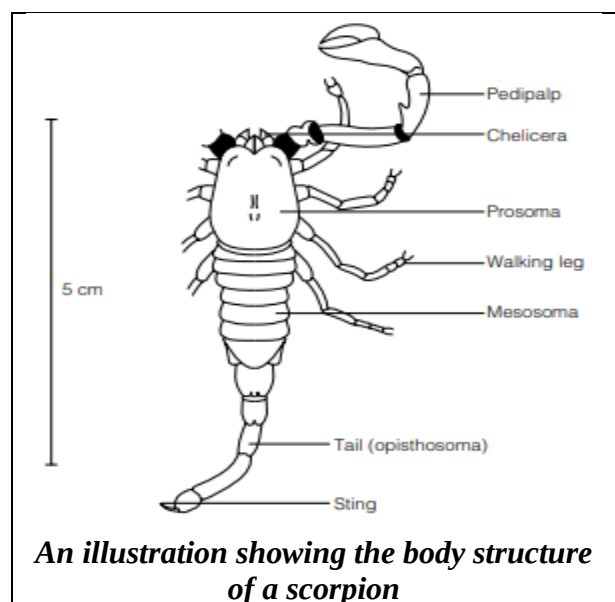
- It's weight to strength ratio decreases with the size of the animal making it less efficient as the animals becomes larger
- It resists growth and therefore periodical moulting (ecdysis) is required if the animal is to grow
- During moulting, the body of the arthropod is soft and very vulnerable to attack by predators and pathogens

CLASSIFICATION OF ARTHROPODS

The phylum arthropoda is made up of many classes

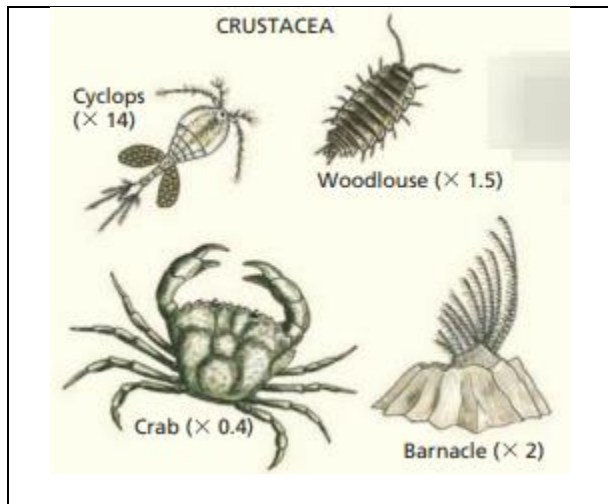
CLASS ARACHNIDA e.g spiders, ticks, and scorpions

The body is divided into cephalo thorax and abdomen. They have 4 pairs of jointed legs. They have simple eyes. They breathe through the tracheal system. They lack antennae but use pedipalp for sensitivity.

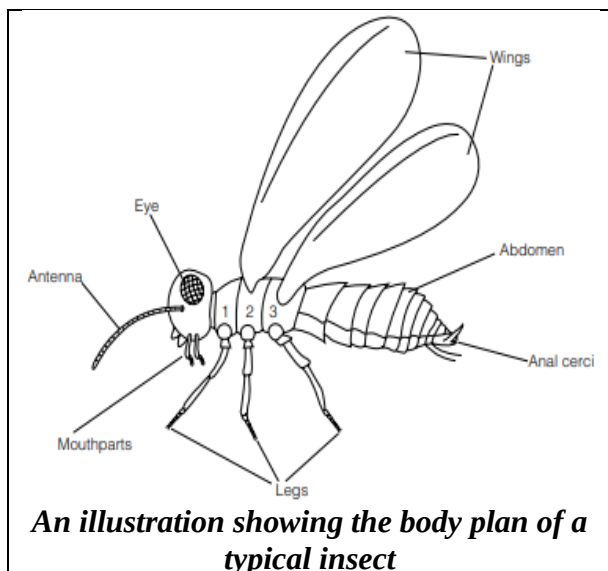


CLASS CRUSTACEAN

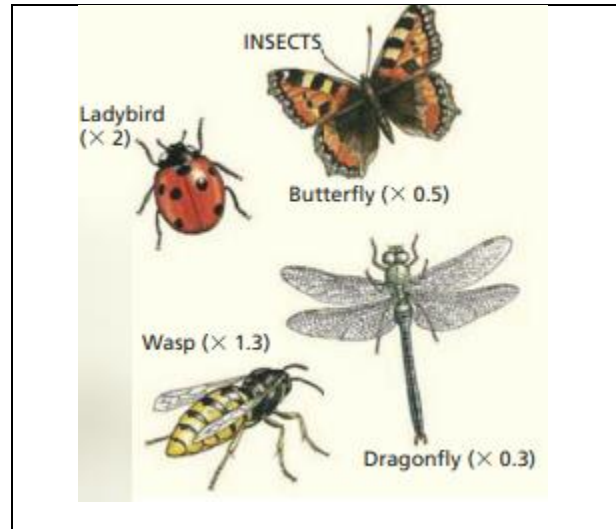
These include the crabs, lobster, cray fish, water flea e.tc. The body is divided into cephalo thorax and abdomen. They have 5 pairs of jointed legs or both the cephalo thorax and abdomen. Majority is aquatic and breathes through gills. They have 2 pairs of antennae. They have a pair of compound eyes.



CLASS INSECTA



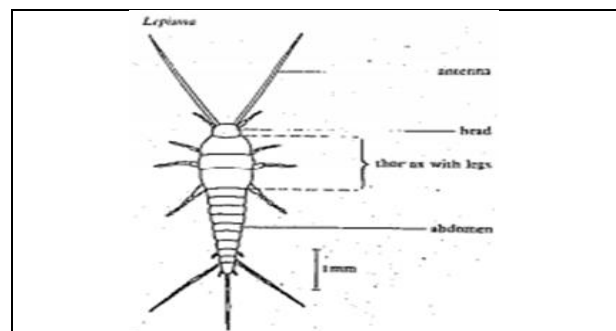
The body is divided into head, thorax and abdomen. They have 3 pairs of jointed legs. They have a pair of segmented antennae. The thorax is divided into 3 segmented. These are prothorax, mesothorax and metathorax; each with a pair of jointed legs. They have a pair of large compound eyes. They respire through the tracheal system.



CLASSIFICATION OF INSECTS

The class is divided into

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



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

a. Exopterygota

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

b. Endopterygota

The wings develop internally. They undergo complete metamorphosis i.e. holometabolus. The larval stage is specialised for eating and growing. They are known by such names as caterpillars and grub. The adult is specialised for dispersal and reproduction. Examples include; Pieris (butterfly), Apis (honey bee), and Musca (housefly)

SOME ORDERS OF CLASS INSECTA

Order Orthoptera

Examples include crickets, grasshoppers and walking sticks. They have the following characteristics

- Chewing mouth parts
- Straight wings
- Complete metamorphosis
- Two pairs of wings with the front wings being narrow and leathery. The hind wings are broad, membranous and folded when at rest

Order Dictyoptera

Examples include cockroaches and mantids and their characteristics include;

- They are dorso ventrally flattened
- They undergo incomplete metamorphosis
- Two pairs of wings with the front wings being narrow and leathery. The hind wings are broad, membranous and folded when at rest.

Order Isoptera

Members include termites and their characteristics include;

- Chewing mouth parts
- Workers and soldiers are wingless
- They undergo incomplete metamorphosis
- Reproductive termites possess two pairs of similar membranous wings which are held out flat when at rest and the wings are shed off after the mating

Order Hemiptera

It includes all the bugs, and their characteristics include;

- Piercing and sucking mouthparts
- Two pairs of membranous wings

Order Homoptera

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

- They have piercing and sucking mouth parts
- Incomplete or complete metamorphosis
- Some species can reproduce without mating

- Some are wingless, others possess one or two pairs of membranous wings

Order Hymenoptera

Members include ants, wasps, bees and sawflies. Their characteristics include;

- Chewing and lapping mouth parts
- Worker ants and few others are wingless
- Two pairs of small stiff and membranous wings that interlock during flight
- The front wings are larger than the hind wings
- They undergo complete metamorphosis

Order Lepidoptera

Members include butterflies and moth. Their characteristics include

- Long antennae
- Complete metamorphosis
- Sucking mouth parts shaped like a coiled tube when at rest
- The front wings are usually larger than the hind wings
- Possess to pairs of usually broad wings which possess scales

Order Diptera

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

- Two large compound eyes
- Piercing mouth parts
- Complete metamorphosis

- The two front wings are transparent and the two hind wings are reduced to halteres which serve as balancing organs during flight

Order Siphonoptera

This order includes the fleas and their characteristics include;

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

Order Odonata

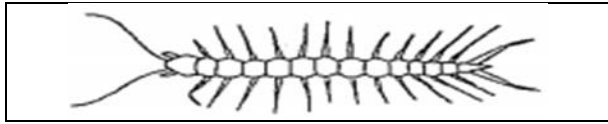
Members include dragon flies and damsel flies. Their adult characteristics include;

- Chewing mouthparts
- Two pairs of equal sized transparent membranous wings that cannot be folded.
- They have huge eyes
- They possess very small antennae
- Legs cannot walk but are used to capture prey in air
- They mate in flight
- They exhibit incomplete metamorphosis

CLASS CHILOPODA:

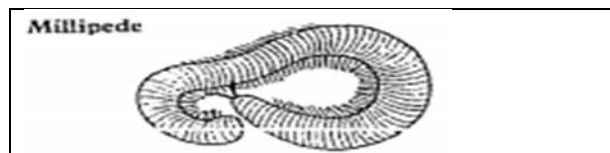
This includes the centipedes. They have one pair of legs on each segment and usually they have 10 – 30 pairs of legs. They are carnivorous with poisonous claws. They respire through the tracheal system. They have a pair of antennae on the head. Compound eyes absent, they have only

simple eyes and the body is divided into the head and many segments



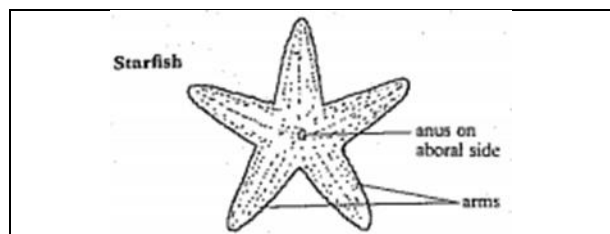
CLASS DIPLOPODA:

This includes the millipedes with the following characteristics; They have 70 – 100 segments. They are herbivorous and feed on rotting leaves. Respiration is through the tracheal system. They have a pair of antennae on the head. They have simple eyes and compound eyes are absent. Body is divided into the head and many segments.



PHYLUM ECHINODERMATA

Echinoderms are marine animals and they have a spiny skin. They include star fish, sea urchin and sea cucumber.



Characteristics

- ❖ Their skin bears spines hence the name of the phylum

- ❖ Adults show penta-radial symmetry (5-way symmetry) but their larval forms show bilateral symmetry
- ❖ The mouth generally occurs on the lower side (oral side) while the anus occurs on the upper side (lateral side)
- ❖ They lack a proper circulatory system
- ❖ They are exclusively marine inhabitants
- ❖ They have a calcareous skeleton
- ❖ They move slowly by the concerted action of numerous suckorial tube feet

PHYLUM CHORDATA

The phylum contains the highly developed animals. During their lifetime, all chordates possess the following structures;

Notochord

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

Hollow dorsal nerve cord (central nervous system)

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

Pharyngeal gill slits (visceral clefts)

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

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

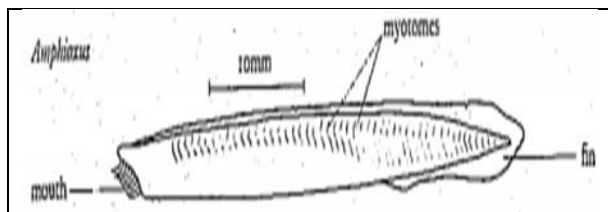
Other features possessed by my most but not all chordates include;

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

Classification of the phylum chordate:

Sub phylum acraniata:

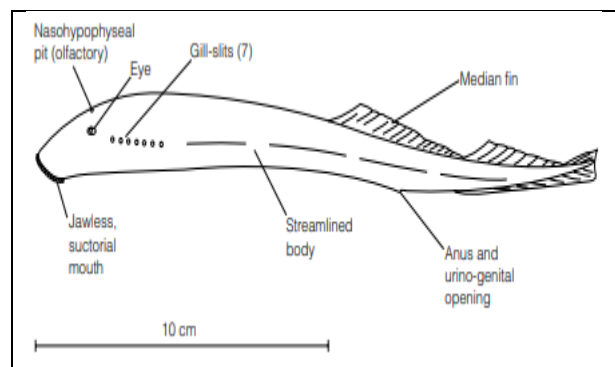
These lack the cranium and their brain is naked. Their notochord is persistent even in the adult stage e.g the extinct *Amphioxus* and sea squirt.



Subphylum craniata;

This includes all those chordates with a brain case or cranium and their notochord disappear in the adult stage leaving the dorsal nerve chord. The sub-phylum craniata is divided into two super classes;

(a) Super class Agnatha; which are the jawless fishes but with a round, sectorial mouth and rasping tongue. Examples include lamprey



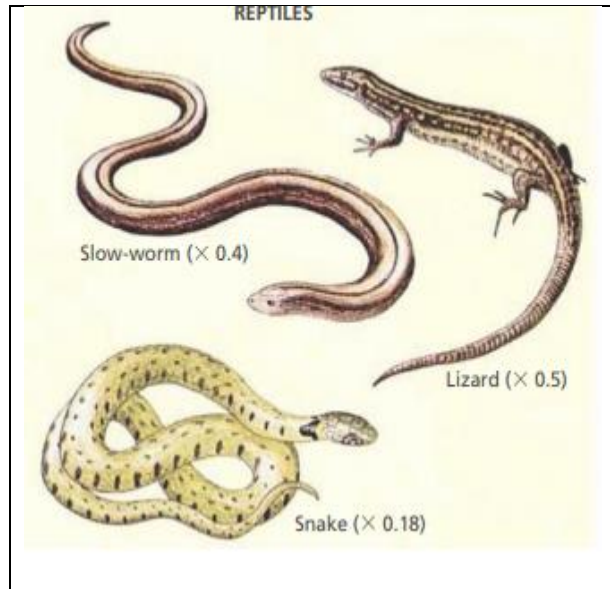
(b) Super – class Grathastomata: these are chordates with well-developed jaws. This is divided into several classes including:

Class Reptilia:

These are the reptile's e.g lizards, snakes, crocodiles, turtles, alligators, tortoises e.t.c. They have the following characteristics

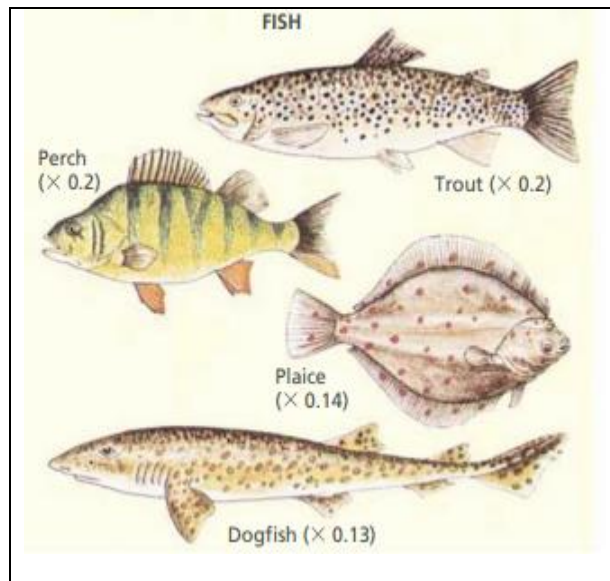
- They have scales covering their bodies. Scales are important in minimising water loss.
- They carry out internal fertilization and lay shelled eggs. Such an egg can overcome the dry land environment.
- They use lungs for gaseous exchange.

- They excrete uric acid which is less toxic and requires little or no water for its elimination.
- They are ectothermic i.e. their body temperature changes with environment temperature.

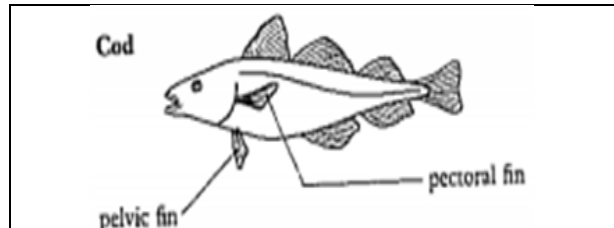


Class Pisces:

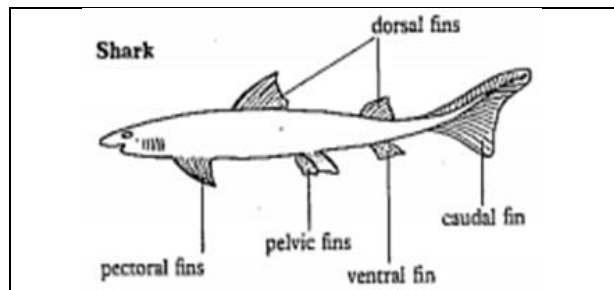
This includes the fishes.



It is divided into two sub classes i.e. sub-class Osteichthyes which includes the bony fish.



Sub class chondrichthyes which includes the cartilaginous fish.



Fishes have the following general characteristics:

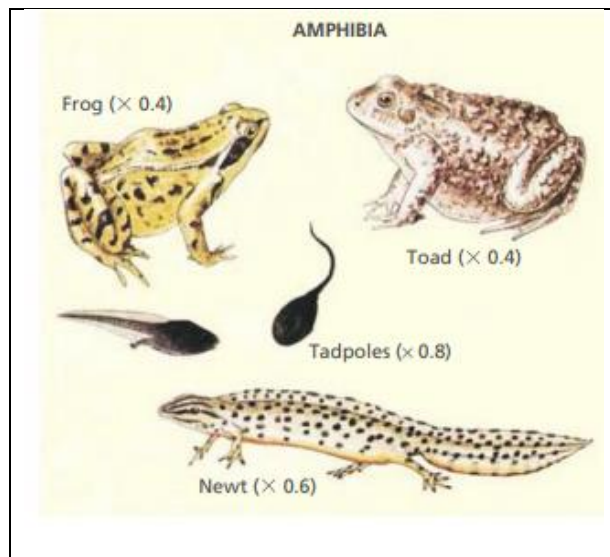
- They excrete ammonia which is highly toxic and requires a lot of water for its elimination.
- Gaseous exchange i.e. through gills.
- They have a two chambered heart.
- Locomotion is by use of fins.
- They are exothermic.

Class Amphibia

Amphibians include toads, newts, and salamanders. They have the following general characteristics:

- They have a moist skin which they use for gaseous exchange.
- They have a 3 chambered heart.

- They use 3 types of gaseous exchange i.e. the skin, the mouth and the lungs.
- Fertilization is external.
- They are exothermic.
- Newts and salamanders possess tails in adults and in the larva stage but frogs and toads possess the tail in the larva form only
- Visceral clefts (gills) are present in aquatic larvae and gills are present in adults

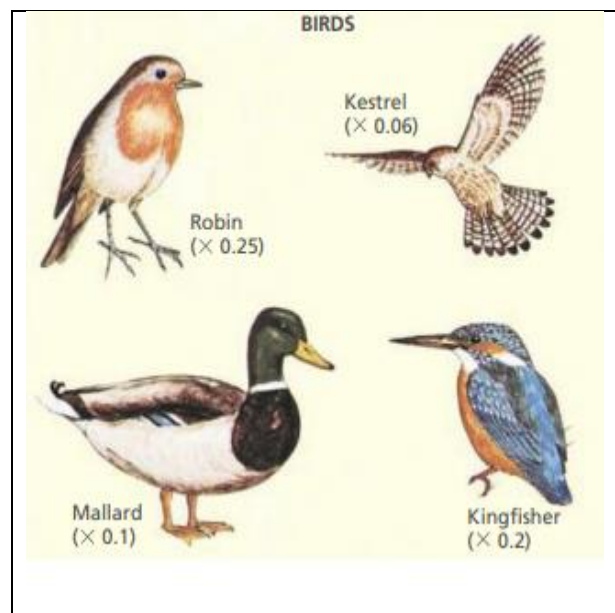


Class Aves:

This includes the bird; they have the following characteristics

- Body is covered with feathers for insulation.
- Fore limbs are modified to form wings for flight.
- They have a 4 chambered heart so they can maintain a high blood pressure.

- They lay a shelled egg which can survive in the environment.
- Gaseous exchange is through lungs.
- They excrete uric acid which is less toxic and requires little or no water for its elimination.
- They are endothermic so they can maintain a high and constant body temperature.
- They show a high degree of parental care and demonstrate cart ship prior to mating which involves nest building.



Class Mammalia;

This includes the mammals and they are the most highly developed chordates. They share the following characteristics.

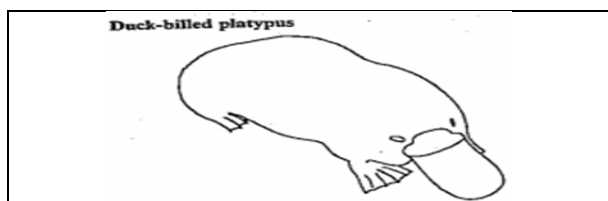
- They produce their young ones at an advanced stage of growth
- They nourish their young ones on milk rich in nutrients essentials.

- They show a high degree of parental care and they train their young ones how to avoid predation and how to hunt for food.
- They show extensive courtship prior to mating. This prevents wastage of gametes since species identification is possible. Fertilization is internal reducing until a stage when it is produced at an advanced stage when it is produced at an advanced stage of growth and development.
- Body is covered with fur for insulation. They have external earlobes or pinnae.
- They have different types of teeth (heterodont) due to difference type of diet. They have two sets of teeth the milk and permanent set (diphodont).
- They have a 4 chambered heart and therefore they can maintain a high blood pressure.
- They are endothermic therefore can maintain a high and constant body temperature.

The class is divided into two sub classes namely

Subclass prototheria

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

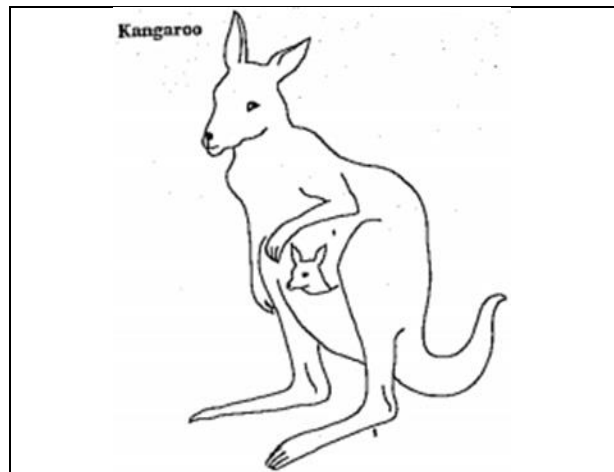


Subclass theria

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

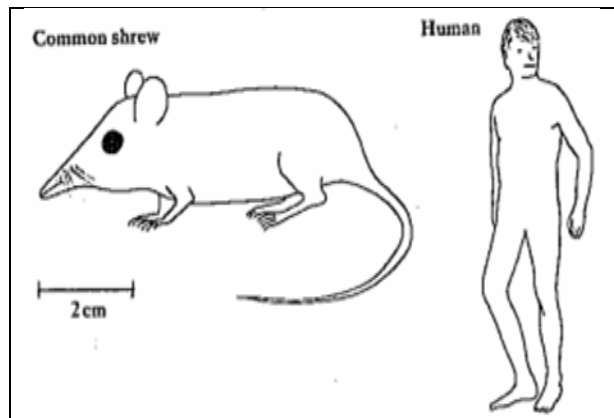
Meta-theria/marsupial mammals

These are mammals which have pouches in which the young ones are located and suckle for most of their development, having been born in a very immature state e.g. kangaroo



Eutheria/placental mammals

These are mammals whose young ones develop to mature ones while in the womb or placenta before they are born. Examples include humans and rats



ADAPTATIONS OF ANIMALS TO LIVE ON LAND

Oxygen being less soluble and more plentiful in air than in water has led to the animals developing moist gaseous exchange surface coupled with breathing mechanisms e.g. lungs in invertebrates

To avoid desiccation, various animals have developed different mechanisms e.g. amphibians are restricted to damp habitats. Reptiles, birds, mammals and insects have a water tight surface layer which enables them to inhabit dry areas. Reptiles and birds produce a semi-solid nitrogenous waste containing uric acid which requires less water.

Internal fertilisation and production of shelled eggs in reptiles and internal development in mammals enables them to conserve water and become fully terrestrial. Amphibians have failed to overcome the problem of reproducing on land as they keep reverting to water for egg laying to prevent them from drying.

Air provides very little supply to terrestrial animals because of its low density as compared with water which has a high density. These animals have developed skeletons for support in air and muscular mechanisms for locomotion. Amphibians, reptiles, birds and mammals have strong muscles and they are tetrapods (four limbed animals) with limbs built on the pentadactyl. This enables the body to be lifted off the ground and propel the animal forward.

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

TOPIC 5: ECOLOGY

Ecology is the scientific study of the interactions between living organisms and with their environment that determine their distribution and abundance within a particular environment.

SOME OF THE IMPORTANT TERMS ENCOUNTERED IN ECOLOGICAL STUDIES

a) **Ecosystem**

A natural unit composed of living (biotic) and non-living (abiotic) components whose interactions lead to a self-sustaining system e.g. ponds, lakes, forest, desert, stream. The two major factors within an ecosystem include:

- ✓ The flow of energy through an ecosystem.
- ✓ Cycling of matter within an ecosystem.

b) **Synecology**

This is study of many species within an ecosystem

c) **Autecology**

This is study of single organisms or populations of single species and their relationship to their environment e.g. considering a lion in the bush, what does it feed on?, how does it reproduce?, what are its competitors?, what are its predators?, etc.

d) **Species**

A species is a group of organisms showing resemblance among themselves in appearance, behavior, chemistry and genetic makeup. Organisms that reproduce sexually

are classified as members of the same species if, under natural conditions, they can;

- i) actually or potentially breed with one another
- ii) produce fertile offspring.

e) **Population**

This is the total number of members of a species occupying a specific area at the same time. E.g. tilapia fish in a pond, mahogany trees in a forest, people in a country

f) **Community**

All the organisms of different species that interact in a given, well defined area e.g. all organisms within a pond

g) **Habitat**

Specific locality where an organism normally lives within the environment e.g. the underside of a log for earthworms, intestines of man for tapeworms, ponds for frogs, kitchen for cockroaches, e.t.c.

h) **Microhabitat**

Small locality within the habitat with particular conditions (microclimate) that support specific organisms e.g. mosses can grow at the upper side of a fallen log, while the underside supports earthworms.

i) **Niche /Ecological niche**

The role an organism plays in the habitat, and its interactions with other organisms i.e. the sum of all environmental factors that influence the growth, survival and

reproduction of a species. A niche is like the “profession” of an organism.

i. Fundamental niche

The physical conditions under which a species might live, in the absence of interactions with other species.

ii. Realized niche

The role an organism plays in the habitat, and its interactions with other organisms in the presence of competition and other constraining factors i.e. is the set of conditions under which an organism exists in nature.

j) Native species

Species that normally and thrive in a particular ecosystem

k) Non-native/alien/exotic species

Species that migrate into the ecosystem or are deliberately or accidentally introduced into an ecosystem by humans e.g. crops and game species

l) Indicator species

Species that serve as early warnings of damage to a community or an ecosystem

m) Keystone species

Species that play more important roles than others in maintaining the structure and

function of ecosystems of which they are a part i.e. it is a dominant species that dictates community structure by affecting abundances of other species.

Examples:

- Top predator keystone species like lions, crocodiles and great white sharks exert a stabilising effect on their ecosystems by feeding on and helping regulate the populations of certain species.
- Bats and birds regenerate deforested areas by depositing plant seeds in their droppings.
- Elephants uproot and break trees, creating forest openings in the savanna grasslands and woodlands, which promotes growth of grasses for grazers and also accelerates nutrient recycling.
- Dung beetles remove, bury and recycle animal wastes (dung)

NOTE:

All species play some role in their ecosystems and thus are important, therefore the assertion that some species are more important than others remains controversial

SUB TOPIC 1: COMPONENTS OF THE ECOSYSTEM

SUB TOPIC OUTLINE

- *Definition of ecosystem*
- *Abiotic and biotic components: air, water, soil, living organisms*
- *Abiotic factors: light, temperature, humidity, atmospheric pressure, rainfall, edaphic factors*
- *Biotic factors: competition, predation, biological associations*
- *Influence of abiotic and biotic components and factors on the environment on distribution and abundance of organisms*

An ecosystem describes the interrelationships between the organisms in a community and their physical environment. It is a natural unit composed of living and non-living components whose interactions result in a stable self-perpetuating system. An ecosystem is stable in such a way it can adjust to changes within itself; self-perpetuating in that it can continue on its own without the necessity for human or other interference. It is made up of a community of organisms which interact with one another and with non-living components of the environment.

THE MAJOR PARTS OF THE EARTH'S LIFE SUPPORT SYSTEM

a) Atmosphere

It is a thin envelope or membrane of air around the planet.

b) Biosphere

This is the part of the earth in which living organisms exist and interact with one another and with their non-living environment. It reaches from the deepest ocean floor, 20 kilometers (12 miles) below sea level, to the top of the highest mountains. The biosphere can be divided

into a series of biogeographical regions each inhabited by distinctive species of animals and plants. These organisms are able to move freely from place to place within each region, but not from region to another, this being prevented by various natural barriers. Such biogeographical regions include: Eurasia, Americas, Africa and Australia. Although they possess a different fauna and flora, two such geographical regions maybe virtually identical in their climatic conditions and this is reflected in similar adaptations shown by their respective inhabitants.

c) Troposphere

This is the inner layer of the earth extending about 17 kilometers (11 miles) above sea level, but containing most of the planet's air, mostly nitrogen (78%) and oxygen (21%).

d) Stratosphere

This is the layer stretching 17–48 kilometers (11–30 miles) above the earth's surface. Its lower portion contains ozone (O₃) to filter out most of the sun's harmful ultraviolet radiation.

e) **Hydrosphere**

It consists of the earth's liquid water (both surface and underground), ice (polar ice, icebergs, and ice in frozen soil layers) and water vapour in the atmosphere.

f) **Lithosphere**

This is the earth's crust and upper mantle. The crust contains nonrenewable fossil fuels and minerals as well as renewable soil nutrients needed for plant life.

BIOMES

These are large regions of the biosphere characterized by a distinct climate and specific life-forms (especially vegetation) adapted to it. It is largely climatic conditions that determine the dominant plant type of a region and hence the biome. Examples of the major terrestrial biomes of the world:

- a) **Tropical forests:** occur at low latitudes where the rain falls abundantly all year long and temperature is warm and characterized by dense, lush vegetation and intense variety of species.
- b) **Savannah:** warm and dry grasslands with few trees, typically supporting grazing of animals, and trees may lose their leaves during the dry season.
- c) **Deserts:** areas of very little rainfall, ranging from entire barrenness to seasonal rainfall that supports growth of some vegetation. Deserts are a result of a lack of usable water either because rainfalls too rarely and soon evaporates in heat (dry deserts) or

because the water is permanently frozen (cold deserts)

- d) **Chaparral** (temperate shrub land): grow where summers are hot and dry, and the winters are cool and wet. Vegetation is composed of mainly dense spiny shrubs with tough evergreen leaves.
- e) **Temperate grassland:** are similar to savannas but occur in cooler climates e.g. Canadian prairies and pampas of Argentina.
- f) **Temperate forests:** include deciduous and evergreen forests but contain far fewer species than a tropical rainforest. They occur where the rain is intermittent, the winters are cold and summers warm.
- g) **Taiga** (coniferous forest/boreal forest): conifer forests in cold subarctic or subalpine conditions
- h) **Tundra:** treeless plains in the arctic; cold for most of the year. It is characterised by grasses, lichens, sedges, and mosses as the predominant species.

ECOLOGICAL IMPORTANCE OF FORESTS

- Through photosynthesis forests convert inorganic carbondioxide to organic compounds some of which are food, to man and other animals.
- Photosynthesis by forests releases oxygen the animals use
- Carbondioxide extraction from air during photosynthesis reduces the effects of global warming.
- Evapo-transpiration sometimes results into rain formation.

- Modification of microclimate by providing cool and humid conditions.
- Are habitats for terrestrial species.
- Source of scientific information.
- Provides genetic resources and biodiversity

HARMFUL EFFECTS OF DEFORESTATION

- Reduced absorption of carbon dioxide increases effects of global warming.
- Habitats of organisms get destroyed.
- Biodiversity reduces due to migration and death.
- Preys get exposed to their predators.
- Species extinction may occur.
- Results in increased soil erosion
- Microclimate of the area gets altered.
- Reduction in the food available to herbivores
- Reduction in rain formation in the area.

EXAMPLES OF AQUATIC BIOMES

- a) Fresh water life zones: such as lakes and streams
- b) Ocean / marine life zones: such as estuaries, coastlines, coral reefs, and the deep ocean.

NOTE

*An **ecotone** is a region located between two adjacent ecosystems, containing a mixture of species from either of the ecosystems, and often species not found in either of the bordering ecosystems. Examples include;*

- (i) *wetland or marsh found between dry land and the open water of a lake*
- (ii) *zone of grasses, small shrubs and scattered small trees found between grassland and a forest.*

THE MAJOR COMPONENTS OF AN ECOSYSTEM

An organism's environment i.e. the conditions in which it lives may be subdivided into physical (**abiotic**) and **biotic** conditions. Both profoundly affect the distribution and abundance of organisms in different habitats.

a) Abiotic / nonliving components:

These are physical and chemical factors that influence living organisms in land (terrestrial) ecosystems and aquatic life zones.

An outline of the major abiotic (physical and chemical) factors affecting terrestrial ecosystems and aquatic life zones include;

- Sunlight (intensity, quality and duration)
- Temperature
- Water / rainfall
- Humidity
- Wind (air current)
- Latitude (distance from equator)
- Altitude (distance above sea level)
- Fire
- Soil (edaphic) factors
- Light penetration
- Water currents
- Dissolved nutrient concentrations
- Suspended solids
- Salinity

Abiotic conditions are not directly associated with presence of other organisms. Some physical factors are directly climatic. Others are not necessarily associated with climate, though they may be the indirect result of it. Those exclusively connected with soil are known as **edaphic**. The ability of organisms to tolerate fluctuations in the physical factors may limit their geographical or local distribution.

b) **Biotic / living components:**

These are the plants, animals and microorganisms. An organism's biotic environment is made up of other organisms with which it comes into regular contact. With certain of these organisms it has a special relationship which may profoundly influence the distribution and abundance.

EFFECTS OF ABIOTIC (PHYSICAL AND CHEMICAL) FACTORS ON THE ECOSYSTEM

1. Temperature

- Alternate heating and cooling of rocks causes them to shatter into smaller pieces that finally form soil.
- Changes in environmental temperature may result in migration of organisms e.g. birds to avoid overheating or freezing.
- Low temperature inactivates enzymes while excessive heat denatures enzymes, which is fatal.
- High temperature results in increased transpiration in plants and sweating in mammals.
- Since a 10°C rise in temperature causes enzyme reaction to double up

to 40°C , increased temperature results in increased photosynthesis in plants.

- Low temperature stimulates flowering in some plants e.g. cabbages (**vernalisation**)
- Exposure to low temperature (**stratification**) stimulates germination in some seeds after water imbibition.
- Low temperature breaks dormancy of buds in some plants (bud-break).
- When environmental temperature is low, small sized animals **hibernate** e.g. bats, dormice, hamsters, hedgehogs, and rodents like mice. Hibernation is seasonal response by animals to cold temperature during which they become dormant, body temperature and metabolic rate fall to the minimum required for maintaining the vital activities of the body. The animals, said to be in 'deep sleep' ably reduce energy needs to survive the winter when food is scarce. When environmental temperature is high, some animals **aestivate**. Aestivation is seasonal response by animals to drought or excessive heat during which they become dormant, and the metabolic rate followed by body temperature fall to the minimum required for maintaining the vital activities of the body e.g. *African lungfish* burrows into mud till the dry season ends, earthworms and garden snails also aestivate

2. Light (Intensity, Quality and Duration)

- It is a source of energy for photolysis of water during photosynthesis.
- Induces flowering in long-day plants e.g. barley, but inhibits flowering in short-day plants e.g. tobacco.
- It is necessary for the germination of certain seeds e.g. lettuce.
- Excessive light bleaches chlorophyll in plants.
- Stimulates mating of certain organisms e.g. fireflies.
- Absence of light causes **etiolation** in plants i.e. elongation of shoot internodes.
- It induces onion bulb formation but inhibits tuber formation in potatoes.
- It inhibits leaf fall from deciduous trees and formation of winter buds in temperate trees.
- Light breaks dormancy of buds.
- Sun light stimulates the manufacture of vitamin D in the skin. The dermis contains lipids called sterols, which are converted by ultraviolet light into vitamin D.
- Ultraviolet light causes skin cancer in humans
- Light enables the mechanism of photoreception in eyes.
- Increased illumination causes stomatal opening, which results in increased transpiration, or stomatal closure, which reduces transpiration.
- Photoperiod affects migratory and reproductive behaviour in various animals e.g. sunlight polarised by water acts as a compass for migration of salmon fish.

- Absence of light results in failure of chlorophyll formation in plants i.e. plant remains yellow, and leaves fail to expand.

3. Wind

- Wind increases transpiration by blowing away water vapour around stomata hence increasing evaporation but still air results in decreased transpiration because it allows buildup of water vapour around stomata.
- Wind increase causes reduction in sweating because it allows evaporation from the skin.
- Wind influences the dispersal or migration of flying animals.
- Dispersal of seeds and spores aided by wind increases the spread of non-motile organisms like plants, fungi and some bacteria.
- Wind causes stunted and distorted growth of trees on windward slopes of highlands.
- Wind aids pollination in certain plants e.g. most grasses, hence their distribution may be dependent on wind patterns
- Wind takes part in rainfall formation.
- Wind circulates atmospheric gases e.g. carbondioxide, oxygen and water vapour.
- Wind is important in current and wave formation in seas, lakes that enables the generation and distribution of mineral salts
- Wind causes physical damage to vegetation, animals and buildings.

4. Humidity

- Low humidity results in increased evaporation from leaves while increased humidity causes low rate of evaporation, and much heat retention in the body.

5. Topography (altitude, slope steepness-gradient and aspect of a place)

- Higher altitudes are associated with lower average temperatures, higher precipitation, increased wind speed, more intense radiation, lower atmospheric pressures, low partial pressures of oxygen, all of which influence plant and animal lives. Mountains also act as barriers to dispersal and migration, and act as isolating mechanism to cause speciation.
- Slope reduces water logging in soil, but encourages soil erosion, which prevents proper plant establishment, especially at steep slopes.
- In the northern hemisphere, south facing slopes receive more light and heat energy than north facing slopes and valley bottoms (reverse is true in southern hemisphere). This encourages plant growth in more illuminated areas than elsewhere.

6. Fire

This is a major disturbance to the savanna communities. Fire originates from carelessness, lightning strikes and volcanoes, and accordingly many plants show adaptations related to fire occurrence:

- Grasses grow in tussocks to protect the young growing buds.
- Some tree stems are succulent i.e. store water in parenchyma cells to reduce on the effects of fire heat.
- Many plants are annuals to avoid fire severity in form of seeds, which may be underground.
- Some trees have heat resistant tissues.

Effects of fire on the ecosystem

- By removing old leaves, it stimulates trees and grasses to produce new buds.
- It breaks seed dormancy in some plants.
- It causes the release of mineral nutrients from stems in the form of ash
- It results in steady growth of vegetation.
- Since leaf litter and ground cover plants are burnt, soil erosion increases severely.
- There is reduction in population density of plants and animals. The later run away from the area burning or get preyed upon; those that burrow suffocate by smoke.
- It destroys predatory animals that would pose a problem to other animals and plants e.g. aphids, scales.
- The new palatable vegetation that grows acts as food for herbivores.
- It stimulates flowering in some plants e.g. spear grass.

NOTE:

- ❖ *Fire favours grasses at the expense of trees because;*
 - *Grass meristems are at the leaf bases/soil level. The leaf bases and soil protect the grass meristems from fire*
 - *Trees grow from cambium and buds which are exposed to fire during burning hence more liable to death*
- ❖ *Light shower of rain is worse than no rain at all because; there's inducement of stomata opening yet heat is still high, resulting in rapid water evaporation yet there's little water in soil to counter the loss.*

7. SOIL (EDAPHIC) FACTORS:

Soils are derived from rocks by physical and chemical weathering processes coupled with decay of plant and animal bodies.

Components of soil

a) Inorganic particles

These enable soil to be categorized as silt, loam, clay, and sand, depending on particle sizes

b) Soil air

It fills the pores in soil and is usually saturated with water vapour, more carbondioxide and less oxygen, and sometimes ammonia and methane may be present.

c) Dissolved minerals in soil (inorganic salts)

These are derived from either bacterial action or rock breakdown by chemical weathering.

d) Soil PH

Water logged soils are usually nitrogen and phosphorus deficient; hence plants growing in such areas tend to be carnivorous/ insectivorous to satisfy their needs.

e) Soil water:

Water is essential for growth of plants and animals, holds dissolved minerals in solution and contributes to weathering of rocks.

- i) **Capillary water:** it is the most important source of water to plants, bound around soil particles by surface tension.
- ii) **Hygroscopic water:** forms a thin layer tightly bound by surface tension on soil particles and is unavailable to plants
- iii) **Osmotic water:** forms a thin layer around hygroscopic water and is utilized by roots of a few plants.
- iv) **Gravitational water:** water that drains through soil to the bottom layers after rain, under the influence of gravity.
- v) **Field capacity:** the total amount of water that a soil can hold against the force of gravity.

f) **Organic matter in soil**

This comprises two main constituents, Dead Organic Material (**DOM**) and living organisms, which when dead are decomposed by bacteria and fungi to humus. The decomposition (biodegradation) of DOM (detritus) releases inorganic nutrients into soil for plants to absorb. Soil living organisms include termites, rodents, snakes, but of all earthworms are particularly important.

Biological importance of earthworms

- They feed on DOM and also ingest mineral particles, and as a result their activity tends to mix plant material intimately with soil.
- The faecal pellets, which they drop, contain mucus and bacterial polysaccharides that hold together the fine particles so as to produce faecal crumbs that improve soil structure.
- Their burrows also improve aeration in soil.

THE MAJOR BIOTIC / LIVING COMPONENTS OF ECOSYSTEMS

They are classified as either producers or consumers based on how they get food.

1. Producers / autotrophs:

These are the green plants, algae and phytoplanktons which capture sunlight to make carbohydrates like glucose by photosynthesis releasing oxygen gas in the process, or some chemosynthetic bacteria which convert simple compounds like hydrogen sulphide (H₂S) and CO₂ into

organic nutrient molecules using sources of energy other than light e.g. geothermal energy.

2. Consumers / Heterotrophs:

These are the animals that get energy and nutrients by feeding on other organisms or their remains. Consumers are classified as:

- a. **Herbivores**/primary consumers – if they feed directly on producers
- b. **Carnivores** - if they feed on other consumers
 - Secondary consumers feed only on primary consumers
 - Tertiary and quaternary (higher level) consumers feed on other carnivores
- c. **Omnivores** – eat plants and animals e.g. cockroaches, humans, pigs, rats, bears, foxes etc.

3. Scavengers

These feed on dead organisms e.g. vultures, flies, hyenas, and some species of sharks and ants

4. Detritivores (detritus feeders and decomposers)

These feed on detritus or parts of dead organisms and cast off fragments and wastes of living organisms

- i) **Detritus feeders** extract nutrients from partly decomposed organic matter in leaf litter, plant debris and animal dung e.g. crabs termites, earthworms, woodlice, sea cucumbers e.t.c. Unlike decomposers, detritivores are larger

and digest food internally rather than externally. Detritus refers to fragments of organic remains.

ii) **Decomposers / Saprobionts / Lysotrophs** – mostly certain types of bacteria and fungi, which recycle organic matter in ecosystems by:

- Biodegrading (breaking down) dead organic material (detritus) to get nutrients.

This enables the disposal of plant litter, dead animal bodies, animal wastes and garbage, which would accumulate everywhere.

- Releasing the resulting simpler inorganic compounds into the soil and water, where they can be taken up as nutrients by producers.

SUB TOPIC 2: CONCEPT OF THE ECOSYSTEM

SUB TOPIC OUTLINE

- *Aquatic and terrestrial ecosystems: and properties of an ecosystem feeding relations, cycling of materials, succession, climax and balance of nature*
- *Ecological factors influencing the life of organisms in an ecosystem: abiotic, biotic, edaphic*
- *Changes in an ecosystems: ecosystem productivity, succession and climax*
- *Feeding relations: food chains, food webs, ecological pyramids*
- *Recycling of nutrients and energy flow in ecosystems*
- *Biogeochemical cycles: nitrogen, carbon and water*

Ecosystems are often thought as closed systems, but they are not really closed. No ecosystem is completely self-contained; they all need an outside source of energy, usually the sun as life cannot exist without it.

What sustains life on earth?

There are three interconnected factors that sustain life on earth namely:

a) The one-way flow of high quality energy from the sun:

- Through materials and living organisms in their interactions
- Into the environment as low quality energy – mostly heat dispersed into

the air or water molecules at low temperature.

- Eventually back into space as heat.

b) The cycling of matter through parts of the biosphere

c) Gravity, which:

- Allows the planet to hold on to its atmosphere.
- Causes the downward movement of chemicals in the matter cycles.

How does the sun sustain life on earth?

Energy from the sun sustains most terrestrial and aquatic ecosystems. The energy;

- Lights and warms the planet.
- Supports photosynthesis in plants and some bacteria
- Powers the cycling of matter.
- Drives the climate and weather systems that distribute heat and fresh water over the earth's surface.

THE FATE OF SOLAR ENERGY REACHING THE EARTH

Because of the small size, the earth receives only about one-billionth of the sun's output of energy, much of the energy being either reflected away or absorbed by chemicals in the atmosphere. Most of the energy that reaches the atmosphere is:

- (i) visible light
- (ii) infrared radiation-heat
- (iii) Ultra-violet radiation that is not absorbed by the ozone layer.

The incoming energy warms the troposphere and land, evaporates water and cycles it through the biosphere and generates winds. This energy is also captured by green plants, algae and bacteria to fuel photosynthesis and make the organic compounds that most forms of life need to survive.

ENERGY FLOW THROUGH AN ECOSYSTEM

The energy flows in one direction through the ecosystem: green plants and other autotrophs harness light energy from the sun for photosynthesis and animals and other consumers eat the autotrophs and each other. This one-way flow of energy is a consequence of the laws of thermodynamics: energy can neither be created nor destroyed and when energy is

transformed from one type to another, some is converted to heat. The transfer of food energy in an ecosystem in an ecosystem can be shown in a number of ways namely food chains, food webs, pyramids of numbers, biomass and energy.

Techniques used in constructing food chains and webs

The techniques used in constructing food webs and food chains include

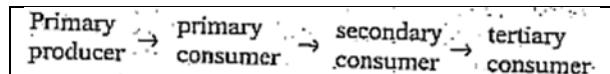
- Direct observation of organisms as it feeds so as to establish the organisms prey. Examination of stomach content through dissecting the animals' stomach
- Faecal method; observation of faecal materials egested by an animal.
- Use of radioactive tracers to label the environment from which organisms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

FOOD CHAIN

A food chain is a simplified sequence illustrating the flow of energy from one organism to another in a community. It shows a sequence of organisms usually starting with a producer and ending with a top consumer, in which each organism is the food of the next one in the chain. The arrows show the direction of flow of energy, with the arrow head always pointing away from the organism being eaten. Each organism within the chain represents a **trophic level**.

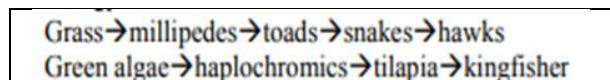
Most food chains start with autotrophs (**primary producers**). These include some bacteria as well as green plants. Organisms that are unable to utilize light energy for

synthesis of food must obtain it by consuming other organisms. These are heterotrophs and include all animals as well as fungi and some bacteria. If they feed on primary producers, they are called **primary consumers**. They are typically herbivores but also include plant parasites. Some heterotrophs, the carnivores feed on other heterotrophs. These are called **secondary consumers** if they feed on a herbivore and **tertiary consumers** if they feed on other carnivores.



Types of food chains

Grazing food chains start with green plants convert carbon dioxide & water into chemical compounds. These are grazed upon by herbivores. Energy is further transferred to carnivores. It can be in grass land or water body (aquatic).



Detritus food chain is the one where the consumers obtain energy from fragments of dead decaying organic matter. It exists in both aquatic and terrestrial habitats and the 1st trophic level is occupied by a decomposing organic e.g. in temperate forests.

NOTE

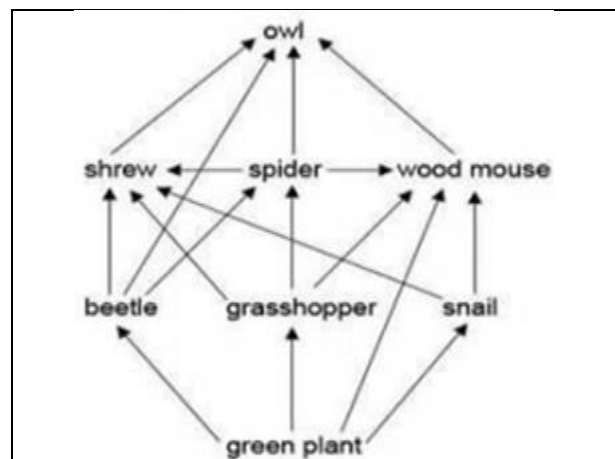
The number of links in a food chain is usually limited to four or five. This is because at each trophic level, a high

percentage of the useful energy consumed as food is converted to heat, and lost from the food chain.

FOOD WEB

Food chains help to show how substances such as insecticides are transferred in an ecosystem. However, they do not reflect the complex feeding relationship that exist in most ecosystems and give a false impression that each organism feeds on only one other type of organism. Most organisms in fact have a wide range of food items and belong to more than one trophic level. The food chains in an ecosystem are usually interconnected and form a food web.

A **food web** is a complex nutritional relationship showing alternative sources of food for each organism in a food chain i.e. a complex network of food chains linked to one another.



NOTE

Changes in the population of one organism can influence those of another even if they are not directly linked in a food chain.

Limitations of the food web

In large ecosystems, the relationships are often so complex that related species with similar diets are grouped together on the food web. Only a part of the ecosystem is usually shown on a food web as decomposers are usually omitted. A food web showing all the feeding relations of every species would have so many lines that it would be almost incomprehensible. Food webs also give no information of how much energy flow from one part of the ecosystem to another.

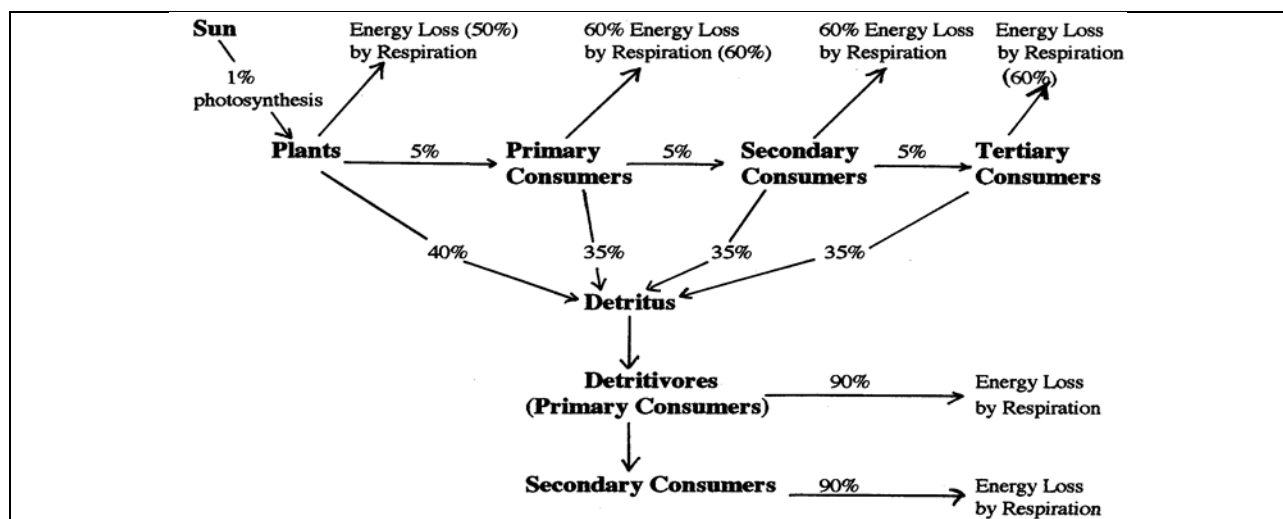
ENERGY FLOW THROUGH THE ECOSYSTEM

The primary source of energy is the sun. Of the energy received by the earth, less than 0.1% is fixed by green plants as chemical energy in biomass in organic substances during photosynthesis (Gross Primary Production); the rest is reflected by the atmosphere, heats the earth's surface or causes evaporation of water.

Part of gross primary production is used by green plants for aerobic respiration while

what remains (Net Primary Production) is used as food by primary consumers, during which only about 5 – 10% of the energy is transferred from producer to primary consumer (a loss of 90 – 95% occurs) because much of plant biomass is indigestible to herbivores. The energy obtained by herbivores through feeding on producers is less than what producers get from the sun because some is lost in egestion, excretion, and not all parts are eaten.

When carnivores eat herbivores still the energy they obtain is less than what herbivores obtain from feeding on producers, and the trend is maintained even as top carnivores feed on secondary consumers. Therefore, with each energy transfer some usable energy is degraded and lost to the environment as low quality heat, thus the energy available to each successive trophic level declines, and the more trophic levels in a food chain or web, the greater the cumulative loss of energy during its flow through the various feeding levels. This limits the number of feeding levels to 3 or 4, or very rarely 5 or 6.



ENERGY BUDGETS

An energy budget shows the percentage allocation of energy consumed by an individual organism to the various processes in the body such as respiration, growth and reproduction

Terms used with energy budgets

1. Gross primary productivity (GPP)

It is the rate at which producers convert solar energy into chemical energy stored in organic substances. It is also the total amount of energy fixed by producers per unit area of photosynthetic surface per unit time.

Productivity may be expressed as units of energy (e.g. $\text{kJm}^{-2}\text{yr}^{-1}$ or $\text{kCal m}^{-2}\text{yr}^{-1}$), or units of mass (e.g. $\text{kg m}^{-2}\text{yr}^{-1}$)

GPP is greatest: (i) in shallow waters near continents (ii) along coral reefs where abundant light, heat and nutrients stimulate the growth of algae. (iii) Where upwelling currents bring nitrogen and phosphorus from the ocean bottom to the surface.

GPP is lowest in: (i) deserts due to low precipitation (rainfall, hail, snow, sleet) and intense heat (ii) the open ocean due to lack of nutrients and sunlight except near the surface.

2. Net primary productivity (NPP)

NPP is the rate at which energy for use by heterotrophs or consumers is stored in new organic substances. It is the energy that remains to be used by consumers after producers have used part of GPP for their own respiration.

$$\text{NPP} = \text{GPP} - (\text{respiration} + \text{metabolism})$$

NPP most productive ecosystems include estuaries, swamps and marshes and tropical rainforests while NPP least productive ecosystems are open ocean, tundra – arctic and alpine grasslands and desert. Despite its low net productivity, the open ocean produces more of the earth's NPP per year than any other ecosystem because of its large size

3. Secondary production

It is the rate which energy is used to make new biomass in consumer. This the energy remaining in heterotrophs available for production (growth, repair and reproduction) after losses through egestion, excretion and respiration

4. Biomass

It is the dry weight of all organic matter contained in organisms per unit area of ground or water. Biomass is expressed as g/m^2

Standing biomass (Standing crop biomass)

is the dry weight of all organic matter contained in organisms per unit area of ground or water at a given moment in time

5. Trophic efficiency (Ecological efficiency)

It is the percentage of energy at one trophic level that is converted into organic substances at the next trophic level. Trophic efficiencies range from less than 1% (e.g. herbivores eating plant material) to over 40% (e.g. zooplanktons feeding on phytoplanktons)

NOTE:

- ❖ Of the energy received by the earth, averagely less than 3% is fixed by green plants.
- ❖ Energy transfer from producer to primary consumer is typically in the order of 5 – 10% of NPP (a loss of 90 – 95% occurs) because:
 - i) Much of plant biomass (NPP) is indigestible to herbivores e.g. no animal enzymes can digest lignin and cellulose
 - ii) An individual herbivore may not eat much of the plant biomass e.g. roots may be inaccessible.
- ❖ Energy transfer from primary consumers (herbivore) to secondary consumers (carnivores) is typically 10 – 20% of herbivore mass (a loss of 80 – 90% occurs). This more efficient because:
 - i) Animal tissue is more digestible than plant tissue
 - ii) Animal tissue has a higher energy value
 - iii) Carnivores may be extremely specialized for prey consumption.

But still less than 100% because:

- i) Some animal tissue e.g. bones, hooves, hides is not readily digestible
- ii) Feeding is not 100% efficient – much digestible material e.g. blood and food fragments may be lost to the environment.

The number of trophic levels (feeding levels) rarely exceeds five because the more trophic levels in a food chain or web, the greater the cumulative loss of usable energy as it flows through the various trophic levels, leaving very little energy to support organisms feeding at the high trophic levels. This explains why:

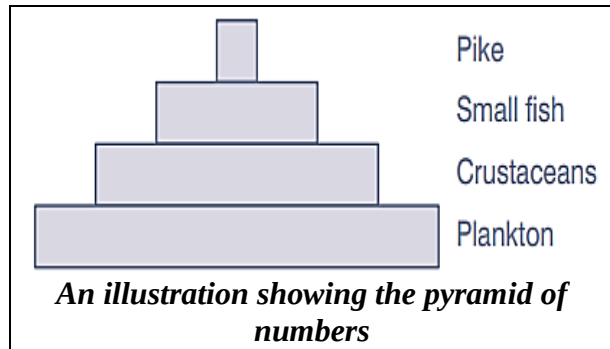
- i) *There are so few top carnivores e.g. eagles, hawks, tigers, white sharks*
- ii) *Such species are first to suffer when the systems that support them are disrupted*
- iii) *These species are so vulnerable to extinction.*
- iv) *The longest food chains can only be supported by an enormous producer biomass e.g. in oceans.*

ECOLOGICAL PYRAMIDS

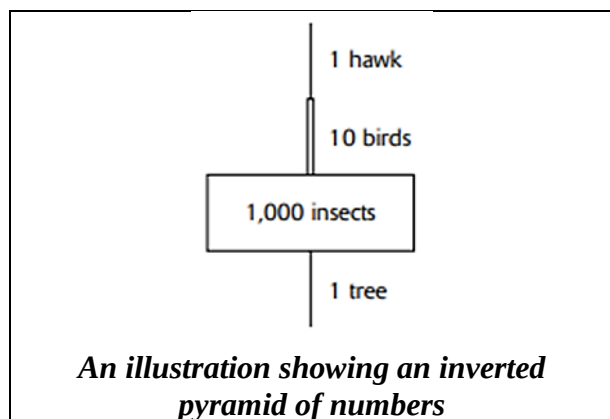
These are histograms that provide information about feeding (trophic) levels in ecosystems. They exist in three types i.e pyramid of numbers, biomass and energy.

PYRAMID OF NUMBERS

It is a graphical method that shows the quantitative relationships between organisms at each trophic level. Each trophic level is represented by a rectangle, the length of which is proportional to the number of organisms at that level. The overall shape is roughly that of a pyramid with primary consumers outnumbering the primary consumers which in turn outnumber secondary consumers. Starting with the rectangle for the first trophic level, the number of organisms decreases as the number of trophic levels increase.



However pyramids of numbers do not always have this shape. A single large tree for example can form an ecosystem that supports many thousands of insects and when parasites are included in a pyramid of numbers, the upper level can be much larger than the one below it. These are called **inverted pyramids**.



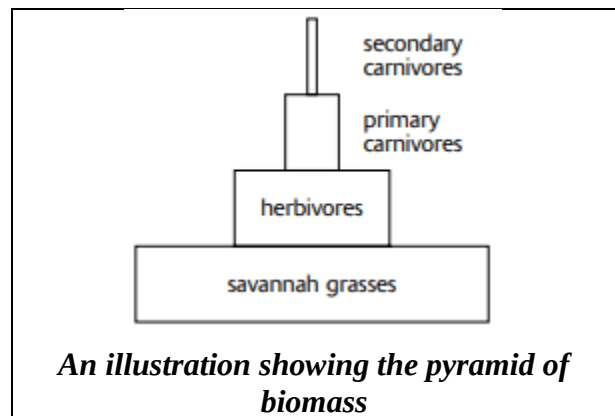
The pyramid of numbers has a number of disadvantages which include:

- All organisms are equated regardless of their size
- No account is made for juveniles and other immature forms of a species whose diet and energy requirements may differ from those of an adult.
- The numbers of some individuals are so great that is impossible to

represent them accurately on the same scale as other species in the food chains.

PYRAMID OF BIOMASS

It is a histogrammatic representation of the biomass (number of individuals x mass of each individual) at each trophic level in an ecosystem at any one time. Biomass is expressed as g/m^2 . The pyramid of biomass takes into account the difference in size of organisms. In such pyramids, the horizontal axis is the total dry mass of an organism at a particular trophic level not their numbers.



Advantage:

It eliminates scale problems encountered when constructing a pyramid of numbers.

Disadvantages:

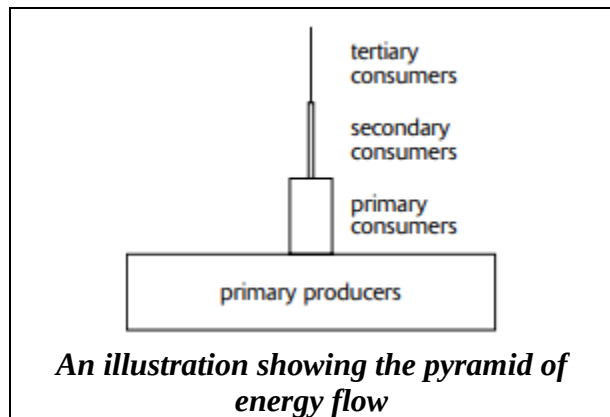
- An inverted pyramid of biomass can occur if the producer level includes organisms with a high turnover rate (rapid reproduction) so that they have a high productivity over a period of time e.g. in open water of oceans, the zooplankton biomass can exceed that of phytoplankton

because the former eat the latter almost as fast as they are produced, so the producer population is never very large.

- The sampling situation at any one time deals with standing crop biomass (amount of material present at a particular instant) rather than with productivity (the capacity of any trophic level to produce biomass over a period of time) e.g. zooplankton in a marine ecosystem.

PYRAMID OF ENERGY FLOW

It is a histogrammatic representation of the flow of energy through each level of an ecosystem during a fixed time period (usually one year, to account for seasonal effects). Energy values may be expressed variously e.g. $\text{kJ m}^{-2}\text{yr}^{-1}$ or $\text{kCal m}^{-2}\text{yr}^{-1}$



Advantages

- It compares productivity because a time factor is incorporated.
- Biomass may not be equivalent to energy value, e.g. 1g of fat has many more kJ than 1g of cellulose or lignin.

- No inverted pyramids are obtained because of the automatic degradation of energy quality.
- The solar input of energy may be included as an extra rectangle at the base.

Disadvantage:

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

NOTE:

- ❖ *Because such pyramids represent energy flows, not energy storage, they should not be called pyramids of energy (a common error in some books)*
- ❖ *Energy flow pyramids explain why the earth can support more people if they eat at lower trophic levels by consuming grains, vegetables and fruits directly rather than passing such crops through another trophic level and eating grain eaters.*

AQUATIC ECOSYSTEMS

Limnology is the study of waters contained within continental boundaries. **Oceanography** is the study of open oceans. Limnology covers lakes, rivers, ponds, streams, wetlands, estuaries, and reservoirs while oceanography covers the open sea.

TYPES OF AQUATIC LIFE ZONES

- a) Marine / saltwater (coastlines, coral reefs, coastal marshes, mangrove swamps and oceans)

- b) Fresh water (lakes, rivers, ponds, streams, and inland wetlands)
- c) Brackish water (estuarine)

ORGANISMS IN AQUATIC LIFE ZONES

Most organisms are classified on the basis of their most common habitat.

- **Neustons** are those which live at or close to the fresh water surface and include duckweeds, bladderworts, pond-skaters, diving beetles, springtails, water boatmen
- **Planktons** mainly depend on water currents for locomotion and they include phytoplanktons like the algae and free-floating microscopic cyanobacteria, Zooplanktons like non-photosynthetic consumers e.g. single celled protozoa and jellyfish
- **Nekton** are the strongly swimming consumers e.g. fish, turtles, whales inhabiting the pelagic zone
- **Benthos** are the bottom dwellers e.g. oysters, barnacles, crabs lobsters
- **Decomposers**, mostly bacteria and fungi, and viruses are usually associated with suspended particles.

A. FRESH WATER LIFE ZONES

Fresh water is the water with a dissolved salt concentration of less than 1% by volume. Fresh water may be **lentic** (standing) e.g. lakes, ponds, inland wetlands or **lotic** (flowing) e.g. rivers and streams

The major ecological and economic roles of fresh water systems

Ecological roles

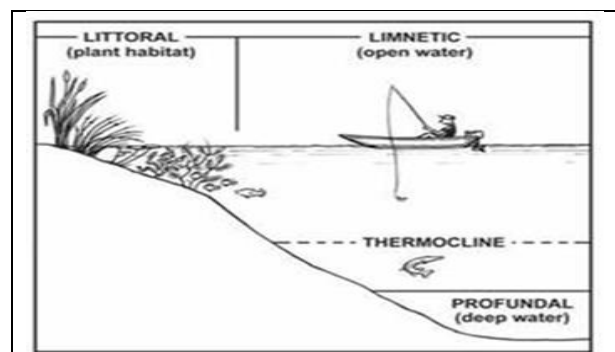
- Moderation of climate.
- Taking part in nutrient cycling.
- Dilution of wastes and enabling of waste treatment.
- Are habitats for aquatic and terrestrial species.
- Source of scientific information.
- Provides genetic resources and biodiversity.
- Recharging of ground water

Economic roles

- Source of food.
- Provision of drinking water.
- Provision of irrigation water.
- Generation of hydroelectric power.
- Provide transportation routes.
- Provision of recreation.
- Source of employment

THE STRUCTURE OF LAKE ECOSYSTEM

Because ponds are shallow, sunlight often penetrates to the bottom so ponds usually have one zone. In contrast, lakes normally consist of four distinct zones that are defined by their depth and distance from the shore.



a) **Littoral zone:**

This is characterised by closeness to the shore, much illumination, strong wave action, abundant populations of animals e.g. snails, frogs, turtles and plants, firm attachment of organisms to rocks or plants, rocky or mobile sand substrate, shallowness, high rate of decomposition that releases nutrients into water, much photosynthesis coupled with oxygen production.

b) **Pelagic (limnetic) zone:**

This is characterised by an absence of contact with either lake bottom or shore, inhabitants are good at swimming e.g. fish like perch and pike, and whales, to avoid sinking to the bottom, much illumination, much photosynthesis from planktons coupled with oxygen production.

c) **Profundal zone:**

This is the deep, open, cooler water where it is too dark for photosynthesis, hence very low oxygen level. Some fish are found in this zone.

d) **Benthic zone:**

It is at the bottom of the lake inhabited mostly by organisms like bloodworms, oysters, barnacles, crabs and lobsters that tolerate cool temperature and low oxygen levels

LIMITING FACTORS IN AQUATIC ECOSYSTEMS

The important environmental factors determining the types and numbers of organisms found at different depths in aquatic life zones include;

- Temperature
- Access to light for photosynthesis
- Dissolved oxygen content. The amount of oxygen gas dissolved in a given volume of water at a particular temperature and pressure
- Availability of nutrients such as carbon (as dissolved CO_2 gas), nitrogen (as NO_3^-), phosphorus (mostly as PO_4^{3-}) for producers
- Salinity. Amounts of various inorganic minerals or salts dissolved in a given volume of water.

Light penetration in a lake

Based on light penetration, different zones can be established within a lake.

- **Euphotic (photic) zone:** this is a sunlit zone extending to a depth where light dims to about 1% of that at the surface, characterised by net oxygen production during day which reduces at night. All the littoral zone and upper parts of limnetic zone form the photic zone.
- **Aphotic:** there is low illumination for photosynthesis but respiration occurs at all depths. The photic zone's lower boundary varies daily and seasonally with changing solar intensity and water transparency, which greatly depends on algal blooms or suspended sediment.
- **Sublittoral zone:** this is a transition between littoral and profundal zones, characterised by low illumination of less than 1% of that at the surface to favour some plant growth at great depth.

Temperature (thermal properties of lakes)

Heat transmitted with light in aquatic ecosystems performs two major functions:

- regulation of rates of chemical reactions and biological processes
- establishment of **thermal stratification**. Thermal stratification is the formation of different temperature layers in deep water

HOW THERMAL STRATIFICATION OCCURS IN LAKES

In warm weather the surface of a lake is heated by the sun. The warmed surface becomes less dense, and so remains at the surface, floating on the colder water beneath. The surface continues to gain heat from the sun, while the bottom water remains cold. If this surface heating continues for some days, without storm winds to stir the lake, a marked temperature difference can develop between the top and bottom water and the following compartments are recognised:

- a) **Epilimnion**: upper warmer water, usually well oxygenated
- b) **Metolimnion** (thermocline): middle portion between Epilimnion and Hypolimnion where the rate of temperature change with depth is rapid.
- c) **Hypolimnion**: the deepest portion, with denser and cooler water, usually with low oxygen concentration

OLIGOTROPHY, EUTROPHY AND DYSTROPHY

Oligotrophic lake is one which is infertile (contains few nutrients), **Eutrophic lake** is one whose nutrient concentration is high, **Dystrophic lake** is one which contains a very high concentration of humic acids leached from decaying aquatic vegetation in the watershed, causing water to be brown coloured. Dystrophic lakes are usually acidic, shallow and unproductive because brown colour reduces light penetration. The fertility of water depends on the concentration of dissolved nutrients, which depends on seasons.

Nutrients enter lake water

- in runoff water
- inlet streams carrying components of sewage and leached ions from land
- from air
- from decomposition of organic matter

They are lost through

- outlet streams
- absorption by autotrophs
- incorporation into mud.

The most abundant cations of lake water are sodium, potassium, magnesium, and calcium while the most abundant anions are carbonate, sulphate and chloride. Other essential nutrients that are scarce in lake waters are phosphorus and iron

Explanation for the scarcity of phosphorous and iron in fresh water

The fate of phosphorus and iron that enter lake water and reach the mud depends on whether the mud is oxidised or reduced.

- a) Dissolved Iron (II) when deposited at the bottom of an oligotrophic lake gets oxidised by oxygen in the hypolimnion to insoluble iron (III), which remains fixed and insoluble in the mud. But iron falling through the anoxic hypolimnion of a Eutrophic lake lies on the reduced mud as iron (II) and is easily re-dissolved into the bottom waters hence available to autotrophs.
- b) When a lake has anoxic bottom water, as when a lake stratifies in summer, the top mud is chemically reduced, a condition that allows the mud to release phosphorus back to the water. The bottom water thus becomes phosphorus-rich. Stirring of the lake by winter storms brings the phosphorus-rich water to the surface, completing an annual cycle and fertilizing the lakes for a spring plant bloom.

OXYGEN AND CARBONDIOXIDE AVAILABILITY IN WATER

Oxygen enters an aquatic system from the atmosphere and through photosynthesis by aquatic producers, and is removed by aerobic respiration of plants, animals and decomposers. Carbondioxide enters an aquatic system from the atmosphere and through aerobic respiration by plants, animals and decomposers, and is removed by photosynthesising plants. Some dissolved CO_2 forms carbonate ions (CO_3^{2-}),

which are stored as calcium carbonate for long periods in sediments, minerals and shells and skeletons of aquatic animals.

STRATIFICATION IN TROPICAL LAKES

In tropical lakes, the range of temperature from top to bottom of the columns of water is not great because the density of water changes more rapidly at higher temperatures. The hypolimnion in a lowland tropical lake is nearly always without oxygen due to;

- high productivity caused by high temperature
- biological decomposition of the large inputs of organic matter from productive tropical ecosystems on the banks.

The typical jungle lake therefore, is turbid, murky and opaque with biological activity.

BIOGEOCHEMICAL CYCLING

This is the process by which chemical compounds of a particular element that constitutes living matter are transferred between living organisms (biotic phase) and non-living environment (abiotic phase). These cycles driven directly or indirectly by incoming solar energy and gravity include the carbon, nitrogen, phosphorus, oxygen, sulphur and hydrological (water) cycles, but a few have been considered below.

1. WATER CYCLE

The water cycle is powered by energy from the sun and by gravity, and it involves the following main processes:

- a) Evaporation (conversion of water into water vapour)
- b) Transpiration (evaporation from leaves of the water extracted from soil by roots and transported throughout the plant)
- c) Condensation (conversion of water vapour into droplets of liquid water)
- d) Precipitation (rain, hail, snow and sleet)
- e) Infiltration (movement of water into soil)
- f) Percolation (downward flow of water through soil and permeable rocks to ground storage areas called aquifers)
- g) Runoff (downslope surface movement back to the sea to resume the cycle)

2. CARBON CYCLE

The carbon cycle is based on carbon dioxide gas, which makes up 0.036% of the volume of the troposphere and is also dissolved in water.

- Carbon fixation involves the reduction of carbon dioxide to large organic molecules during photosynthesis and chemosynthesis.
- During aerobic respiration, the carbon in glucose and other complex organic compounds is converted to carbon dioxide into the atmosphere or dissolves in water.
- Over millions of years, buried deposits of dead plant debris and bacteria are compressed between layers of sediment to form the carbon-containing fossil fuels e.g. coal, oil and natural gas, which when burnt release carbon dioxide into air.
- In aquatic ecosystems, carbon dioxide may

- i) remain dissolved
- ii) be utilized in photosynthesis
- iii) react with water to form carbonate ions (CO_3^{2-}) and bicarbonate ions (HCO_3^-).

- As water warms, more dissolved carbon dioxide returns to the atmosphere.
- In marine ecosystems, some organisms take up dissolved carbon dioxide molecules, carbonate ions (CO_3^{2-}) and bicarbonate ions (HCO_3^-) and these ions react with calcium ions (Ca^{2+}) to form calcium carbonate (CaCO_3) to build their shells and skeletons.
- When the animals with calcium in shells and skeletons die and drift into deep bottom sediments of oceans, immense pressure causes limestone and chalk to form after a very long period of time.
- Weathering processes release a small percentage of carbon dioxide from limestone into the atmosphere

How human activities affect the carbon cycle

- Clearing of trees and other plants that absorb CO_2 through photosynthesis results in its increased concentration.
- Burning of fossil fuels and wood adds large amounts of CO_2 into the troposphere.

3. NITROGEN CYCLE

Nitrogen is the atmosphere's most abundant element, with chemically unreactive nitrogen gas making up 78% of the volume

of the troposphere. However, N_2 cannot be absorbed and metabolized directly by multicellular plants and animals.

- Atmospheric electrical discharges in the form of lightning causes nitrogen and oxygen in the atmosphere to react and produce oxides of nitrogen, which dissolve in rainwater and fall to the ground as weak acidic solutions e.g. nitric acid.
- Nitrogen fixation occurs when the nitrogen in soil is reduced to ammonium ions, catalysed by nitrogen-fixing bacteria which may be free-living e.g. *Azobacter*, symbiotic in root nodules e.g. *Rhizobium* or cyanobacteria e.g. *Nostoc*.
- Nitrification occurs when ammonium compounds in soil are converted first to nitrite ions by *Nitrosomonas* bacteria and later to nitrate ions by *Nitrobacter* bacteria.
- Ammonification (putrefaction) occurs when decomposers e.g. some bacteria and fungi convert nitrogen-rich organic compounds, wastes like urea and dead bodies of organisms into ammonia and ammonium ion-containing salts.
- Assimilation occurs when inorganic ammonia, ammonium and nitrate ions are absorbed by plant roots to make DNA, amino acids and protein.
- Denitrification occurs when mostly anaerobic bacteria e.g. *Pseudomonas denitrificans* and *Thiobacillus denitrificans* in water logged soil and deep in ocean, lake and swamp

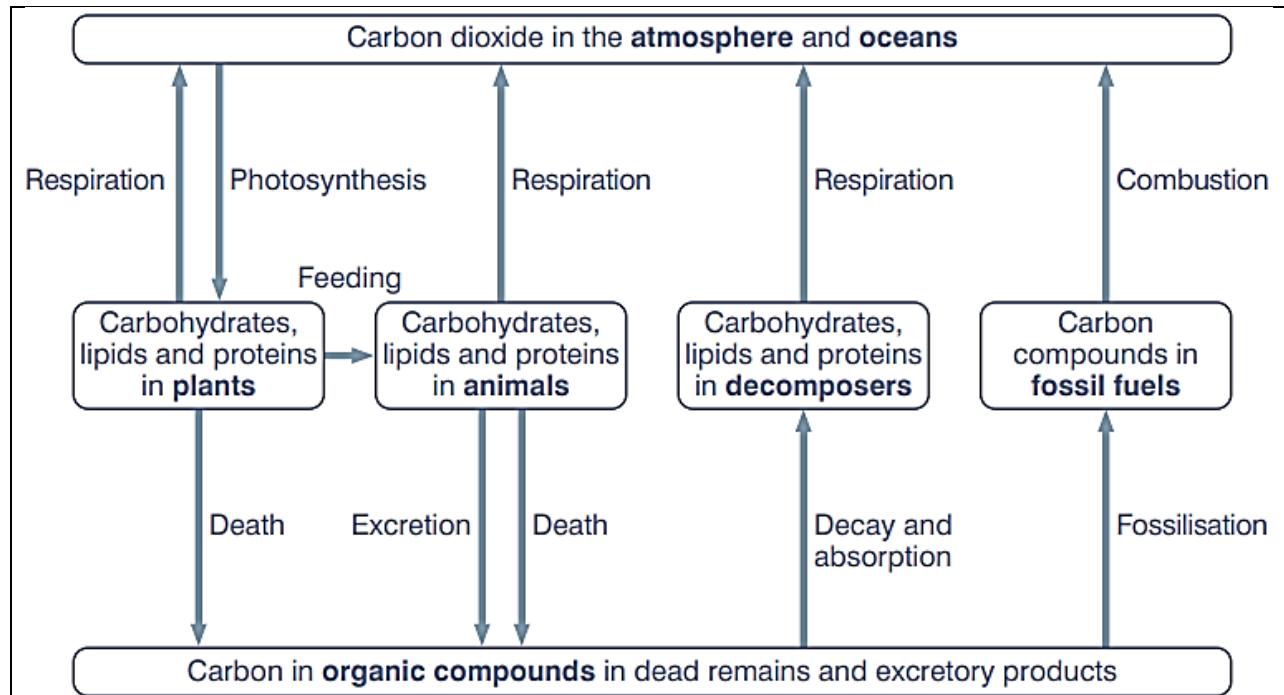
bottoms convert ammonia and ammonium ions back into nitrite and nitrate ions, and then into nitrogen gas and oxygen. Nitrogen gas is released into the atmosphere while oxygen is used for the respiration of these bacteria.

How human activities affect the nitrogen cycle

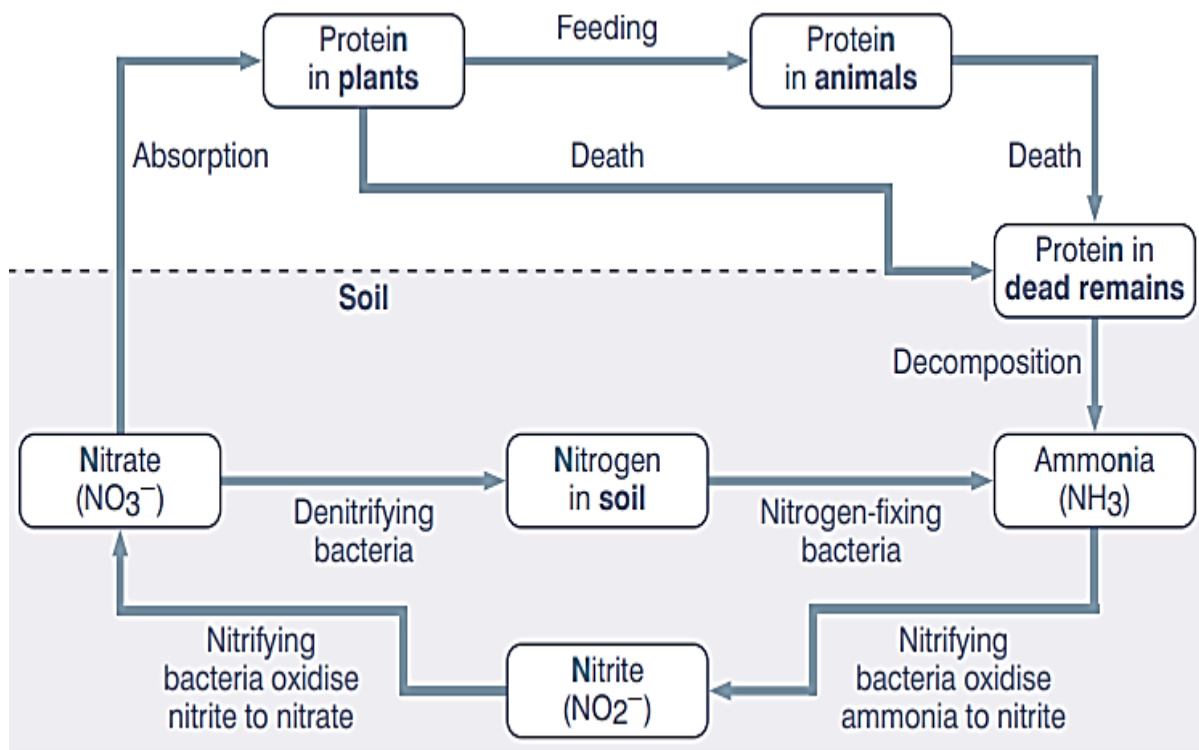
- Burning of fuels forms nitric oxide, which reacts with atmospheric oxygen to form nitrogen dioxide gas that reacts with water vapour to form acid rain containing nitric acid. Nitric acid together with other air pollutants; damages trees, corrodes metals and upsets aquatic ecosystems.
- The inorganic fertilizers applied to soil are acted upon by anaerobic bacteria to release nitrous oxide into the stratosphere, where it; contributes to ozone depletion and greenhouse effect.
- Nitrogen is removed from top soil when we; harvest nitrogen-rich crops, irrigate crops and burn or clear grasslands and forests before planting crops
- Adding nitrogen compounds to aquatic ecosystems e.g. sewage algal blooming, which upon death, their decomposition causes oxygen shortage resulting into death of aerobic organisms e.g. some fish.
- The accelerated deposition of acidic nitrogen containing compounds e.g. NO_2 and HNO_3 onto terrestrial ecosystems stimulates growth of

weeds, which out compete other plants that cannot take up nitrogen as

efficiently.



An illustration showing the processes in the carbon cycle



An illustration showing the nitrogen cycle

SUB TOPIC 3: INTERDEPENDENCE OF ORGANISMS

SUB TOPIC OUTLINE

- *Interaction among organisms and their effect: interspecific and intraspecific relationships between organisms, competition, parasitism, predation, saprophytism, mutualism, commensalism*
- *Significance of organism interaction in nature*

HOW BIOTIC FACTORS AFFECT THE DISTRIBUTION AND ABUNDANCY OF ORGANISMS

Of all living organisms, humans exert most influence on the distribution and survival of other species through a multitude of activities like pollution, deforestation, farming, construction, e.t.c. Other factors which affect the distribution and abundance of organisms include:

Predation

Predation is another form of community interaction. In a general sense, a predator is any animal that totally or partly consumes a plant or another animal. In predation, members of one species (the predator) feed on all or part of a living organism of another species (the prey). Therefore, predators are only found where there is prey e.g. herbivores are found where there is suitable plant material.

Competition

Intraspecific competition is the competition between members of the same species for the same resources, while interspecific competition is the competition between members of two or more different species for food, space, good hiding place, water, sunlight, nesting sites or any other limited resource. Competition is very intense when

there is significant *overlap of niches*, and in this case, one of the competing species must

- migrate to another area if possible
- shift its feeding habits or behaviour through natural selection and evolution
- suffer a sharp population decline
- become extinct in that area, otherwise two species can never occupy exactly the same ecological niche.

Parasitism

In instances where one organism uses another as host, their distribution is related e.g. in **parasitism** one species (parasite) lives on or in another organism (host), in mutualism two species interact in ways that benefit both e.g. nitrogen fixing bacteria and legumes, in commensalism one species neither harms nor helps the other species much it interacts with e.g. There is no harm caused to large trees when epiphytic plants like orchids attach on the branches to get support and be elevated to access sunlight and water vapour in air.

Pollination and dispersal

The **pollination and dispersal** relationship between flowering plants and animals such as insects, birds and bats may be highly elaborate and species-specific. This Co-

evolution ensures that the distribution of the plants and their pollinators or agents of dispersal is related e.g. arum lily flower is pollinated by dung flies.

NOTE

What is **Co-evolution**?

This is the long term evolutionary adjustment of two or more groups or organisms that facilitate those organisms living with one another. Examples include:

- ❖ *Many features of flowering plants have evolved in relation to the dispersal of the plant's gametes by animals, especially insects. The animals have in turn evolved a number of special traits that enable them to obtain nectar.*
- ❖ *Grasses have evolved the ability to deposit silica in their leaves and stems to reduce their risks of being grazed. In turn, large herbivores have evolved complex molars with enamel ridges for grinding up grass.*

Mimicry

Some species gain protection to avoid predation by **mimicking** (looking and acting like) other species that are distasteful to the predator. This ensures that the distribution of the mimic and mimicked species is related e.g. the non-poisonous viceroy butterfly mimics the poisonous monarch butterfly. In the course of evolution preyed upon species have evolved **deceptive looks** to avoid predation e.g. span worms have shapes that look like twigs, some insect pupae may look like tree thorns. Therefore

such animals are distributed where there are plants that ensure their survival.

Antibiosis

This is the secretion of chemicals by organisms, that may be repellant to members of the same species or different species e.g. penicillium (a fungus) secretes antibiotics that inhibit bacterial growth, ants release pheromones to warn off other members of a species in case of danger.

Mutualism

Mutualism is a relationship in which both species benefit. Examples of mutualism include:

- Certain acacia trees provide food and housing for ants. In exchange, the resident ants kill any insects or fungi found on the tree. In addition, the ants crop any neighboring vegetation that makes contact with the tree, thereby providing growing space and sunlight for the acacia.
- Lichens, symbiotic associations of fungi and algae, are often cited as examples of mutualism. The algae supply sugars produced from photosynthesis, and the fungi provide minerals, water, a place to attach, and protection from herbivores and ultraviolet radiation. In some cases, however, fungal hyphae invade and kill some of their symbiotic algae cells. For this and other reasons, some researchers consider the lichen symbiosis closer to parasitism.

Commensalism

In commensalism, one species benefits, while the second species is neither helped nor harmed. Examples of commensalism include;

- Many birds build their nests in trees. Generally, the tree is neither helped nor harmed by the presence of the nests.
- Egrets gather around cattle. The birds benefit because they eat the insects aroused by the grazing cattle. The cattle, however, are neither helped nor harmed.

PREDATOR-PREY INTERACTIONS IN ECOSYSTEMS

In predation, an organism may feed on, or be fed on by other organisms. In such cases the distribution of feeder and fed are related. Predators can be categorized as follows:

- A **true predator** kills and eats another animal.
- A **parasite** spends most (or all) of its life living on another organism (the host), obtaining nourishment from the host by feeding on its tissues. Although the host may be weakened by the parasite, the host does not usually die until the parasite has completed at least one life cycle, though usually many more.
- A **parasitoid** is an insect that lays its eggs on a host (usually an insect or spider). After the eggs hatch, the larvae obtain nourishment by consuming the tissues of the host. The host eventually dies, but not

until the larvae complete their development and begin pupation.

- A **herbivore** is an animal that eats plants. Some herbivores, especially seed eaters (granivores), act like predators in that they totally consume the organism. Others animals, such as those that eat grasses (grazers) or leaves of other plants (browsers), may eat only part of the plant but may weaken it in the process.

Evolutionary importance of predation

Predation usually eliminates the unfit prey (the sick, weak and aged). This gives the remaining prey access to the available food supply and also improves their genetic stock, which enhances the chances of reproductive success and long-term survival.

How predators are suited for capturing prey

- Herbivores simply walk, swim, or fly up to the plants they feed on.
- Some carnivore like cheetah and lions have muscular limbs for running very fast to catch prey.
- Other carnivores like bald eagles, hawks, lions e.t.c. have keen eyesight for locating prey.
- Carnivores like wolves and African lions cooperate in capturing prey by hunting in packs.
- Other predators have characteristics that enable them to hide and ambush their prey e.g. praying mantises sit in flowers of similar colour and ambush insects, alligators lie at stream bottom and dangle worm-like tongue

to entice fish into its powerful jaws, a chameleon has a cryptic colouration that enables walk to prey unnoticed

- Some predators have a highly developed sense of smell for locating prey e.g. meerkat locates insects by smelling.
- Some nocturnal predators like bats and owls have a highly developed sense of detecting sound made by prey.
- Electric fishes such as *Malapterurus* (cat fish) and electric rays produce high voltage discharge of up to 350v that stun their prey while the electric fish *Gymnarchus* produces a low electric potential of less than 0.1v to detect prey.
- Web-spinning spiders use their silky webs to catch small sized ground walking or flying insects.
- Ant-lions (lacewing fly larvae) lay traps by making pits in the ground where preys fall.
- Some snakes e.g. puff adder, cobra, Naja and mamba, *Dendroaspis* have glands that secrete poison (venom), which the fangs inject into the prey to immobilise it.

How prey are suited for avoiding predation

- Ability to run, swim or fly fast.
- Possession of highly developed sense of sight or smell for alerting the presence of predators.
- Possession of protective shells e.g. turtles and snails for rolling into armour-plated ball

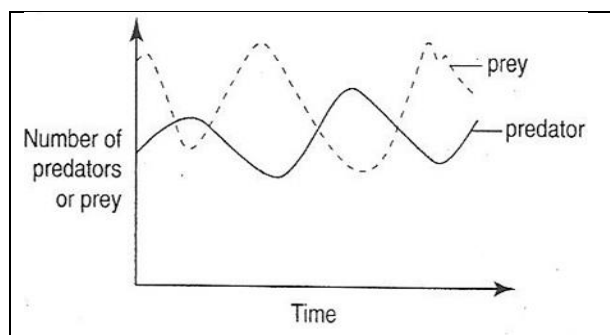
- Possession of spines (porcupines) or thorns (cacti and rose-bushes) for pricking predators.
- In some lizards tails break off when attacked, giving the animal enough time to escape.
- Some prey camouflage by changing colour e.g. chameleon and cuttlefish, or having deceptive colours that blend with the background e.g. arctic hare in its winter fur blends into snow.
- Some prey species discourage predators with chemicals that are poisonous (e.g. oleander plants), irritating (e.g. bombardier beetles), foul smelling (e.g. stinkbugs and skunk cabbages) or bad tasting (e.g. monarch butterflies and buttercups)
- Some prey species have evolved warning colouration – contrasting pattern of advertising colours that enable predators to recognise and avoid such prey e.g. the poisonous frogs, some snakes, monarch butterflies and some grasshoppers.
- Some species gain protection to avoid predation by mimicking (looking and acting like) other species that are distasteful to the predator e.g. the non-poisonous viceroy butterfly mimics the poisonous monarch butterfly. **Batesian mimicry** occurs when the palatable species mimics other distasteful species viceroy butterfly mimics the poisonous monarch butterfly, the harmless hoverfly mimics the painful stinging wasp while **Mullerian mimicry** occurs

when both the mimic and mimicked are unpalatable or dangerous e.g. the five spot Burnet and related moths.

- Other preys gain some protection by living in large groups e.g. schools of fish, herd of antelope, flocks of birds.
- Some prey scare predators by puffing up e.g. blowfish, or spreading wings e.g. peacock.
- The flesh of some slow-moving fish is poisonous e.g. porcupine fish.
- Some preys secrete poisonous or repellant substances e.g. scorpions, caterpillars, some grasshoppers, culex mosquito eggs.
- The electric fish *Malapterurus* (cat fish) produces high voltage discharge of up to 350v that shocks any predator that makes contact with it.
- Other preys employ alarm signals and call e.g. ants, various fish, small birds and mammals.

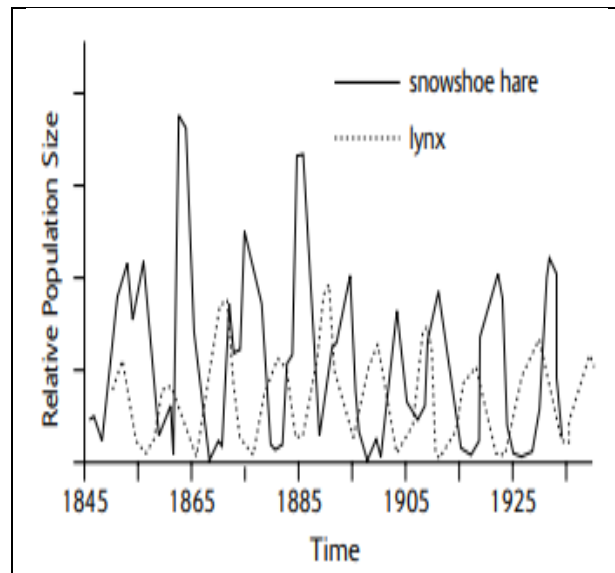
PREDATOR-PREY INTERACTIONS

The first ecologists to model predator-prey interactions mathematically were Alfred Lotka (1925) and Vito Volterra (1926) after observations of interactions among natural populations. They proposed what is called “*The Lotka-Volterra predator-prey model*”



THE LYNX – HARE CYCLE

One of the best-studied cases of animal population cycle is that of the snowshoe hare, *Lepus americanus*, and the Canadian lynx, *Lynx Canadensis*, one of the snowshoe hare's chief predators, with observation spanning for about 200 years in the boreal forests of North America.



For many years, predation has been the explanation for the oscillations in the population of the hare and lynx. According to this predation (**top-down control**) hypothesis:

- When the lynx population is low, few hares are eaten and so the number of hares increases greatly.
- The large number of hares allows lots of lynx to survive and reproduce, leading to a great increase in the number of lynx.
- With the increased lynx population, most of the hares are eaten and their population crashes.

- The shortage of hares results in starvation of lynx and being unable to reproduce, leading to a crash in the number of lynx.
- Finally, the very low number of lynx allows the hare population to recover, causing the cycle to start again.

Research has cast doubt on the above appealing hypothesis because snowshoe hare populations have been found to have similar boom- and-bust cycles on islands where the lynx are absent. Researchers now hypothesise that the periodic crashes in the hare population is influenced by both predation and food (quantity and quality).

According to the **food availability hypothesis**, as the hare population increases:

- ❖ Their food, plants are consumed faster than they can be replenished, especially during winter, causing starvation and weight loss, which result in accelerated high rate of mortality due to predation.
- ❖ The new shoots formed by food plants after substantial browsing contain high levels of toxins that persist for up to two years. The unpalatable food repels the hungry hares, causing them to starve, resulting in death.
- ❖ As the hare population density is reduced, predator populations decline in turn, plant populations recover, and hares take advantage to increase in number. Thus the cycle repeats itself.

If this bottom-up control hypothesis is correct, instead of lynx controlling hare populations, then it is the changing hare population size that may be causing fluctuations in the lynx population.

NOTE:

- ❖ *The food availability and predation hypotheses are not mutually exclusive alternatives but rather are complimentary.*

**INTERACTIONS INVOLVING
COMPETITION**

Organisms frequently compete with one another for such resources such as food, light, water, shelter, mate or nesting site. It may be interspecific or intraspecific. Species compete with other species by:

- a. **Interference competition**, in which one species may limit another's access to some resource, regardless of its abundance, using the same types of methods found in intraspecific competition e.g. a hummingbird species may chase away other hummingbirds from its territory; many desert plants secrete substances into soil, which inhibit the growth of competing species or germination of seeds.
- b. **Exploitation competition**, in which competing species have roughly equal access to a specific resource but differ in how fast or efficiently they exploit it. The most competitive species gets more of the resource and inhibits the growth, reproduction or survival of the other species.

The closer the ecological niches of the competing organisms, the fiercer the competition. Coexistence is impossible between two species which compete with each other in every way. Sooner or later one will oust the other. In other words two different species can never occupy exactly the same ecological niche. This is known as **competitive exclusion principle**.

THE COMPETITIVE EXCLUSION PRINCIPLE

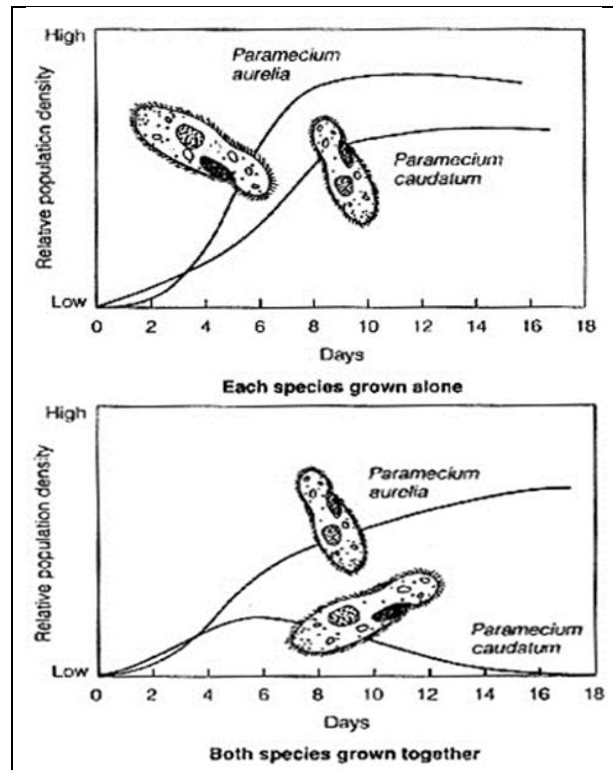
When two species compete for exactly the same resources (or occupy the same niche), one is likely to be more successful. As a result, one species outcompetes the other, and eventually, the second species is eliminated. The competitive exclusion principle, formulated by G. F. Gause, states that “no two species can sustain coexistence if they occupy the same niche.”

Experiments with Paramecia

Gause mixed two species of *Paramecium* that competed for the same food. Two closely related species of single-celled, *bacteria eating Paramecia* were grown, first separately and then together in culture tubes. The research revealed the following:

- i. When grown together, *Paramecium aurelia* survived, while the population of *Paramecium caudatum* quickly declined
- ii. At a full-strength food concentration, the decline in the *Paramecium caudatum* population was approaching exclusion by 16 days but exclusion was not complete.

- iii. At half-strength food concentration, *Paramecium caudatum* had been entirely eliminated by day 16.



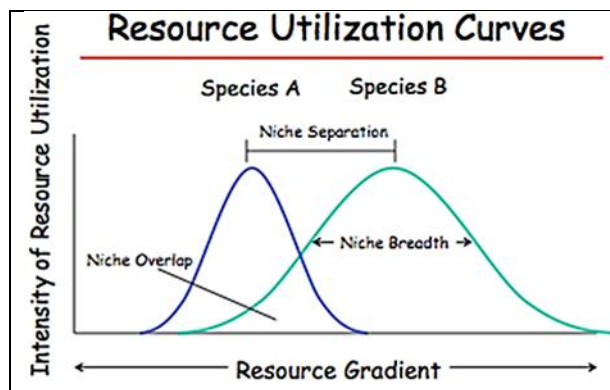
Explanations

There is rapid growth of population densities of both organisms because of: abundance of food and absence of interspecific competition for food. Stable populations are established afterwards for both organisms because of intraspecific competition for food. The population density of *P. aurelia* grew faster than that of *P. caudatum* because the former used the available food supply more efficiently than the latter. The population density of *P. caudatum* decreased to extinction because of being out-multiplied and outcompeted for food by *P. aurelia*. This is attributed to the smaller size of *P. aurelia*.

RESOURCE PARTITIONING

Some species coexist in spite of apparent competition for the same resources. Close study, however, reveals that they occupy slightly different niches. By pursuing slightly different resources or securing their resources in slightly different ways, individuals minimize competition and maximize success. Dividing up the resources in this manner is called **resource partitioning**.

Resource partitioning is the dividing up of scarce resources so that species with similar needs use them at different times, in different ways and different places. Over a time scale long enough for evolution to occur, some species that are in competition for the same resources evolve adaptations that reduce or avoid competition or an overlap of their fundamental niches. Resource partitioning decreases competition between two species leading to increased niche specialization.



Realized niche

The niche that an organism occupies in the absence of competing species is its **fundamental niche**. When competitors are

present, however, one or both species may be able to coexist by occupying their **realized niches**, that part of their existence where niche overlap is absent, that is, where they do not compete for the same resources. For example; under experimental conditions, one species of barnacle can live on rocks that are exposed to the full range of tides. The full range, from the lowest to the highest tide levels, is its fundamental niche. In the natural environment, however, a second species of barnacle outcompetes the first species, but only at the lower tide levels where desiccation is minimal. The first species, then, survives only in its realized niche, the higher tide levels.

Examples of resource partitioning

- When living in the same area, lions prey mostly on larger animals while leopards on smaller ones.
- Hawks and owls feed on similar prey, but hawks hunt during the day and owls hunt at night.
- Each of the five species of common warblers minimizes competition with the others by;
 - (i) spending at least half its feeding time in a different part of spruce tree branches e.g. some hunt at the extreme top, others at the lower portion, some mid-way e.t.c
 - (ii) Consuming somewhat different insect species.
- Different species of eagles in a forest feed at different times of the day e.g. bald headed eagles are most active early mornings and evenings while

the white-breasted eagles feed vigorously towards noon.

- *Paramecium aurelia* and *paramecium bursaria* can coexist in a tube containing yeast because the former feeds on yeast suspension in the upper layers of the fluid whereas the latter feeds on the bottom layers.
- Various bird species in a coastal wetland feed in different ways e.g. flamingos feed on tiny mud organisms, brown pelicans form air dives for fish, herons wade into water to seize small fish, herring gulls are tireless scavengers, and piping plovers feed on insects and tiny crustaceans on sandy beaches.
- In an abandoned field, drought tolerant grasses with shallow, fibrous root system grow near the soil surface to absorb moisture; plants with a taproot system grow in deeper soil while those with a taproot system that even branches to the topsoil and below the roots of other species grow where soil is continuously moist.

NOTE:

- ❖ *The more two species in the same habitat differ in their use of resources, the more likely they can*

coexist. Two competing species also may coexist by sharing the same resource in different ways or at different times

- ❖ *A specie with a narrow niche breathe is called a **specialist** while the one with a wide niche breadth is called a **generalist**.*
- ❖ *The tendency for characteristics to be more divergent when populations belong to the same community than when they are isolated is termed **character displacement**.*

Character displacement (niche shift)

As a result of resource partitioning, certain characteristics may enable individuals to obtain resources in their partitions more successfully. Selection for these characteristics reduces competition with individuals in other partitions and leads to a divergence of features, or character displacement. For example two species of finches that live on two different Galapagos Islands have similar beaks, both suited for using the same food supply (seeds). On a third island, they coexist, but due to evolution, the beak of each bird species is different. This minimizes competition by enabling each finch to feed on seeds of a different size.

SUB TOPIC 4: POPULATION AND NATURAL RESOURCES

SUB TOPIC OUTLINE

- *Population characteristics: density, age structure, sex, growth pattern, birth rate and death rate*
- *Population density dependent factors and density independent factors*
- *Methods of measuring and estimating population density*
- *Population growth patterns*
- *Natural resources types; renewable/nonrenewable, importance and conservation*
- *Environmental resistance: density dependent factors affecting “balance of nature”*
- *Importance of natural resources*
- *Methods of conservation of resources*

POPULATION AND COMMUNITIES

A population is a group of individual organisms usually belonging to the same species within a community. Populations are dynamic, constantly changing components of ecosystems. Population ecology is the study of the growth, abundance, and distribution of populations.

Community structure

It is the spatial distribution of individuals and populations within the community. Community structure is characterised by different species each with different number, sizes, stratification and distribution of individuals, different ecological niches, which may resemble or differ from each other and interactions between species.

BIODIVERSITY

Biodiversity is the different life forms and life-sustaining processes that can best survive the variety of conditions currently on earth. Examples of biodiversity include:

- a) **Genetic diversity** – variety in the genetic makeup among individuals within a species.

- b) **Species diversity** (species richness) – number of species present in a habitat.
- c) **Ecological diversity** – the different biological communities e.g. forests, deserts, lakes etc.
- d) **Functional diversity** – biological and chemical processes or functions such as energy flow and matter cycling needed for the survival of species and biological communities.

Specie abundance

Species abundance refers to the number of individuals of each species

Species diversity (richness) and stability

Specie richness is the number and range of different species found in an ecosystem. A measure of species diversity is helpful when considering the interaction of edaphic, climatic and biotic factors which influence an ecosystem. In general, a stable ecosystem has a wide range of different species, each with a smaller population size. Such populations are dominated by biotic factors. A less stable ecosystem is one which is under stress due to pollution or extreme climatic conditions, has just a few species

with very large populations and is dominated by abiotic factors.

Species stability however has several meanings which include:

- ❖ **Resistance**; the ability of an ecosystem to resist a change following disturbance
- ❖ **Resilience**; the ability of an ecosystem to return to its original state after being changed
- ❖ **Local stability**; the tendency of a community to return to its original state after being changed
- ❖ **Global stability**; the tendency of a community to return to its original state after a large disturbance.

Each of these types of stability is sometimes, not always related to species diversity. Complex ecosystems with high species diversity are assumed to be more stable because they have a large number of alternative links between different species. A change in population density of one species would therefore be less likely to affect the density of others. Several species may be able to carry out the same function such as pollination, decomposition or photosynthesis and if something happened to one species, another could take over. Low species diversity leads to instability. However, the relationship between species diversity and ecosystem stability probably varies with the environment.

Measurement of species diversity

One method of measuring species diversity is the Simpson index used to identify plant diversity. It involves counting the numbers

of each type found in a given area. The diversity is then calculated using the formula

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

where D = diversity index
 N = total number of plants
 n = total number of species
 Σ = sum of.

The index can be related to the abiotic harshness of an environment or the level of pollution in an ecosystem. It is sometimes used as an indicator of ecological stability. The assumption being the greater the species, the greater the stability. However, one weakness of the index is that it makes no allowance for differences in size of the individual. It is also difficult to calculate the index for plants because it is not always easy to calculate what constitutes an individual plant.

FACTORS THAT AFFECT SPECIES DIVERSITY ON LAND AND IN WATER

Latitude in terrestrial communities;

Species diversity decrease steadily with distance from the equator toward either pole, resulting in the highest species diversity in tropical areas e.g. tropical rain forests and lowest in polar areas such as arctic tundra. The main effect of latitude is on temperature, which later affects life.

Depth in aquatic systems;

In marine communities, species diversity increases from the surface to a depth of 2,000 metres and then begins to decline with depth until the deep-sea bottom is reached.

This change is attributed to light penetration which affects photosynthesis, availability of oxygen and availability of dead organisms at the sea bottom.

Pollution in aquatic systems;

Increased pollution kills off or impairs the reproductivity of various aquatic species hence reducing species diversity and abundance.

Other factors that affect population abundance and diversity are:

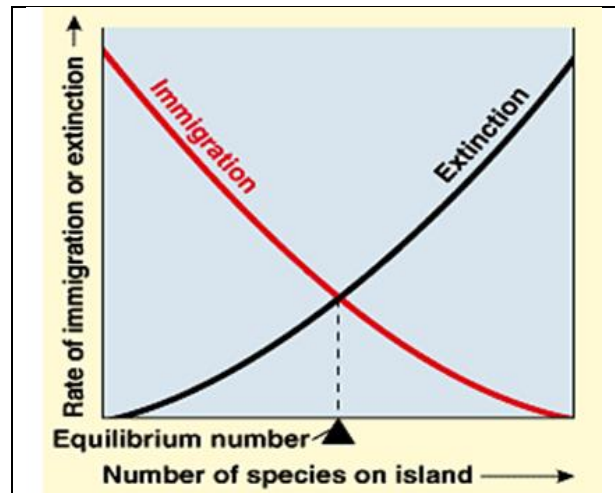
- **Increased solar radiation** increases species diversity in terrestrial communities.
- **Increased precipitation** in terrestrial communities increases species diversity.
- **Increased elevation** decreases species diversity.
- **Pronounced seasonal changes** increase species diversity.

FACTORS THAT AFFECT SPECIES DIVERSITY IN AN ISLAND ECOSYSTEM

Robert MacArthur and Edward O Wilson (1960s) studied communities on islands after which they proposed the species equilibrium model or the theory of **island biogeography**.

- According to this model, the number of species found on an island is determined by a balance between two factors:
 - (i) *The rate at which new species immigrate to the island and*

- (ii) *The rate at which species become extinct on the island.*



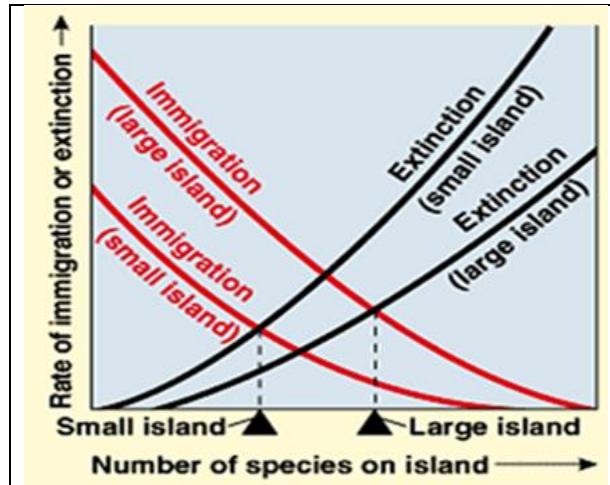
- The model predicts that at some point the rates of immigration and extinction will reach an equilibrium point that determines the island's average number of different species (species diversity)
- The model also predicts that immigration and extinction rates (and thus species diversity) are affected by two important features of the island;
 - (i) *Size of the island.*
 - (ii) *Distance of the island from the nearest main land.*

Size of the island

Larger islands tend to have higher species diversity than small islands because of two reasons:

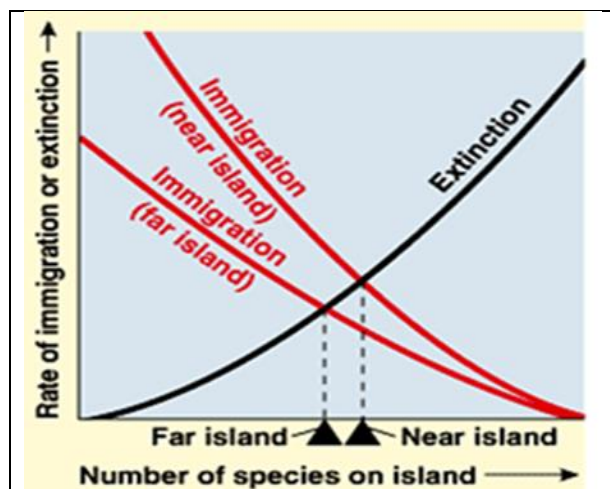
- i. Small islands generally have lower immigration rates since they are a smaller target for potential colonizers

- ii. Smaller islands should have a higher extinction rate because they generally have fewer resources and less diverse habitats for colonizing species.



Distance of the island from the nearest main land:

For two islands of about equal size and other factors, the island closest to the main land source of immigration species will have the higher immigration rate and thus a higher species diversity (assuming that extinction rates on both islands are about the same).



EXPLANATIONS FROM THE OBSERVATIONS MADE FROM THE GRAPHS

a) Immigration and extinction rates

- The rate of immigration decreases with increase in species number, while the extinction rate increases with increase in species number on the island.
- The equilibrium number of species on the island is reached when immigration rate and extinction rate equal.
- Extinction rate increases with increasing species number because of interspecific and intraspecific competition.

b) Effect of island size on immigration and extinction rates

- The rate of extinction increases with increase in species number on the island on both small and large islands, but it is higher on small islands than on large islands. The higher extinction rate on small islands is because of the fewer resources and less diverse habitats for colonizing species.
- The rate of immigration decreases with increase in species number on both small and large islands, but with a large island having a higher immigration rate than a small island. Small islands have lower immigration rates because they are a smaller target for potential colonizers.

c) Effect of distance from mainland on immigration and extinction rates

- For both near and far islands, immigration rate decreases with increase in species number, but immigration rate is higher on near island than on the distant island. The higher immigration rate on near island is because of the easy reach by organisms enabled by its proximity to the main land.
- Since extinction rate increases with increasing species number that exert interspecific and intraspecific competition, extinction rate is far higher on small islands due to the fierce competition caused by the higher immigration rate because of easy reach by organisms enabled by its proximity to the main land.

ECOLOGICAL SUCCESSION

Ecosystems are dynamic. They are constantly changing, not only in response to physical factors such as climate but also in response to biological factors resulting from the activities of organisms within the community. Communities gradually change from one type to another. The sequence of change from the initial colonization of a new area to establishing a relatively stable community is called **ecological succession**. Ecological succession is a long-term directional change in the composition of a community brought about by the actions of the organisms themselves. It can also be defined as is the change in the composition of species over time.

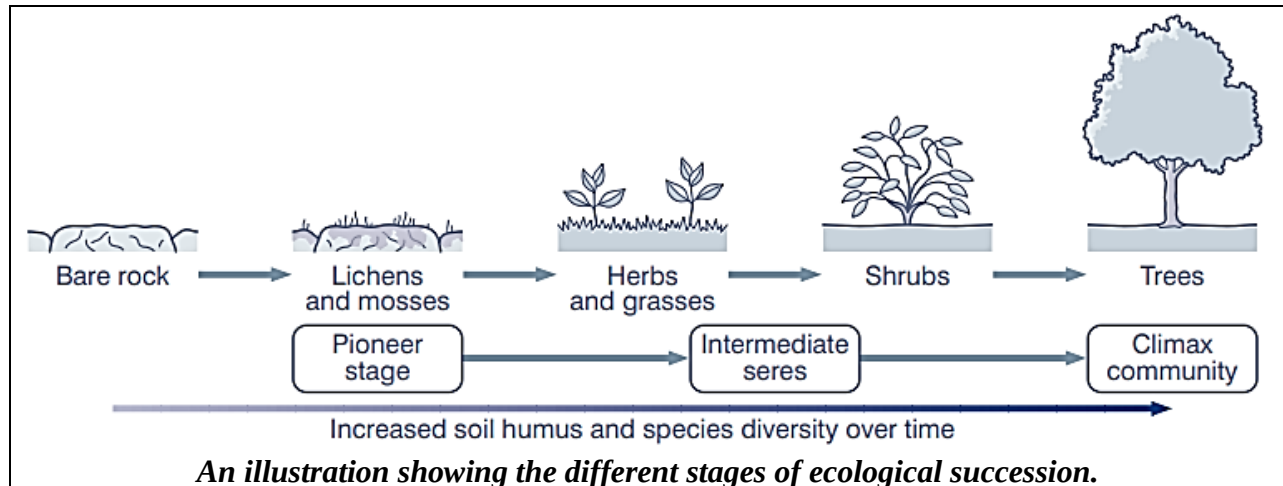
STAGES OF SUCCESSION

Succession proceeds via several stages called *seral stages* to a **climax community**, and the complete succession is called a **sere**. Each stage has its own community of organisms and can usually be identified by the plants it contains. A climax community is the final community at the end of succession, which a particular environment can sustain. The climax community is characterised by;

- ❖ diverse species
- ❖ complex feeding relationships and
- ❖ progressive increases in biomass.

The traditional view of succession describes how one community with certain species is gradually and predictably replaced by another community consisting of different species. As succession progresses, the species diversity and total biomass increase. Eventually, a final successional stage of constant species composition, called the climax community, is attained. The climax community persists relatively unchanged until destroyed by some catastrophic event, such as a fire.

Succession, however, is not as predictable as once thought. Successional stages may not always occur in the expected order, and the establishment of some species is apparently random, influenced by season, by climatic conditions, or by which species happens to arrive first. Furthermore, in some cases, a stable climax community is never attained because fires or other disturbances occur so frequently.



Succession occurs in some regions when climates change over thousands of years. Over shorter periods of time, succession occurs because species that make up communities alter the habitat by their presence. In both cases, the physical and biological conditions which made the habitat initially attractive to the resident species may no longer exist, and the habitat may be more favorable to new species. Some of the changes induced by resident species are listed below:

- ❖ Substrate texture may change from solid rock, to sand, to fertile soil, as rock erodes and the decomposition of plants and animals occurs.
- ❖ Soil pH may decrease due to the decomposition of certain organic matter, such as acidic leaves.
- ❖ Soil water potential, or the ability of the soil to retain water, changes as the soil texture changes.
- ❖ Light availability may change from full sunlight to partly shady, to near darkness as trees become established.

- ❖ Crowding, which increases with population growth, may be unsuitable to certain species.

NOTE

During succession

- *Each species facilitates the emergence of other species by modifying the environment, making it more suitable for new species with different niche requirements.*
- *Early species inhibit / hinder the establishment and growth of other species by releasing toxic chemicals that reduce competition from other plants.*
- *Late successional plants are largely unaffected by plants at earlier stages of succession, explaining why late successional plants can thrive in mature communities without eliminating some early successional and mid successional plants.*
- *Plagioclimax community is one that is gradually established after human interference, and it appears very*

*different from the original climax.
This is termed deflected succession.*

TYPES OF SUCCESSION

a) Primary succession

This is the gradual change in species composition of an area that has never had any vegetation growing on it. It occurs on bare rocks exposed by erosion, newly cooled lava, abandoned highway or parking yard, newly created shallow pond, sand dunes.

Before a community of producers, consumers and decomposers can become established on land, soil forms first. Soil formation begins when **pioneer species** (lichens and mosses) attach to bare rocks. The pioneer species *form soil by trapping wind-blown soil particles*, producing tiny bits of organic matter and secreting mild acids that slowly break down the rock. Alternate heating and cooling also causes break down of rocks.

As patches of soil build up and spread, eventually the pioneer species are replaced by the early successional plant species like small grasses and ferns, whose seeds and spores respectively germinate after arriving by wind or in droppings of birds. Some of their roots penetrate and break rocks into soil particles, and the decay of their wastes and dead bodies increases nutrients in soil.

After a long period of time, the soil becomes deep, moist and fertile enough to support the growth of mid successional plant species like herbs, grasses, low shrubs and small trees that need a lot of sunlight. Late successional plant species (mostly trees that tolerate shade) later replace the mid-

successional plant species. Unless natural or human processes disturb the area, a complex forest community remains.

b) Secondary succession

This is the gradual change in species composition of an area where the natural community of organisms has been disturbed, removed or destroyed but some soil or bottom sediment remains. Because some soil or sediment is present, new vegetation usually can begin to germinate within a few weeks. Seeds, spores can be present in soil or they can be carried from nearby plants by wind, birds or animals. The ground may even contain resistant plants that survived the changes. It occurs on abandoned farmlands, burnt or cut forests, heavily polluted streams, flooded land.

NOTE

The changes are not restricted to the plants. As more and varied plant species enter, they create more niches for animals. Both change the physical environment. Many factors can determine the climax, such as rainfall, temperature and grazing. As the community becomes more complex, the species diversity increases.

ADAPTATIONS OF PLANTS TO CLIMAX COMMUNITIES

Plants have adapted differently so as to survive in the different climax communities or the different stages of the two types of succession. They can be divided into four depending on where they are living;

- Xerophytes
- Hydrophytes

- Halophytes
- Mesophytes

XEROPHYTES

These grow in arid or semi-arid habitats. They have adaptations to absorb and retain water as well as reducing the rate of transpiration. Their characteristics include the following;

a. Modified leaves.

- Some have very small leaves to reduce on the surface area over which water is lost
- Some shed their small leaves in the dry season to further reduce on the rate of transpiration
- The leaves of some are reduced to hard spines thus reducing the surface area over which water can be lost
- The leaves may be small, rolled-up or needle-like to reduce on the number of stomata exposed to air
- There's a waxy cuticle on the surface of the leaves to reduce on the evaporation rate

b. Distribution of stomata

- They generally have few stomata, and these are mainly located on the lower leaf surface
- The stomata in cacti are located in grooves or sunken pits in which moist air is trapped
- In cacti stomata open at night when the temperatures are low to reduce on the rate of transpiration

Other modifications include;

- c. Water storage in plant tissues. some plants store water in leaves e.g. Bryophyllum and stems e.g. banana
- d. Extensive rooting system. They have deep and extensive rooting systems to absorb as much water as possible
- e. Some have hairy leaves to trap moist air around the stomata
- f. Some plants are very short-lived i.e. they grow, blossom and produce seeds in a short wet season.
- g. Some have tissues resistant to water loss
- h. Milky latex. Some plants have a white latex in their stems which reduces on their rate of transpiration and also makes them distasteful to herbivores

HYDROPHYTES

These grow in fresh water habitats. They are subdivided into the submerged aquatic plants e.g. elodea, floating aquatic plants e.g. water lettuce and water hyacinth. Partially submerged plants are those in which the roots are submerged but the leaves and stems are above or on the water surface e.g. water lily and papyrus. They need to get rid of excess water, absorb maximum sunlight, remain buoyant and absorb respiratory gases. Their characteristics include;

Submerged plants

- ❖ The lamina is thin to allow water and dissolved oxygen to enter the leaves by osmosis through the epidermis
- ❖ Elongated petioles
- ❖ Aerial flowers

- ❖ They have numerous chloroplasts to trap as much light as possible for photosynthesis
- ❖ They are broad to increase on the surface area for trapping sunlight and diffusion of respiratory gases.

Partially submerged plants

- ❖ The leaves have a thick waxy cuticle on the upper layer to minimise water loss
- ❖ Stomata are located only on the upper surface to permit exchange of gases with the atmosphere

Floating plants

- ❖ Some species bear numerous hairs on the upper surface to trap air and so make the plant buoyant e.g. the water fern
- ❖ Water hyacinth has air filled tissues in the swollen base of the leaf petioles which makes the plant float
- ❖ The air filled tissues of the hyacinth also store oxygen
- ❖ Their roots are freely suspended in water from which they derive their mineral nutrients
- ❖ Their leaves have a large surface area (broad) to trap as much light as possible for photosynthesis

HALOPHYTES

These grow on salty habitats such as sea and ocean shores. They have a problem of absorbing water from their highly saline surrounding and getting rid of excess salts.

Their characteristics include;

- They have special salt-secreting glands located on the upper epidermis. These extract and remove excess salts absorbed into the tissues from the saline water.
- They produce aerial stilt or prop roots which grow down into the soft mud and give the plant firm anchorage and support.
- They have special aerial roots called pneumatophores which project upwards from the soil so as to take up oxygen through the numerous lenticels on their surface
- They are viviparous i.e. the seeds germinate while the fruit is still on the parent plant.
- The seedlings are long and pointed to enable them penetrate the mud when they drop off from the parent plant.

MESOPHYTES

These grow under average conditions. They have the following characteristics;

- The leaf surface of some plants is hairy thus trapping air which forms a humid insulating layer that lowers the rate of transpiration
- They have more stomata on the lower surface than on the upper surface to reduce on water loss through the stomata
- Some plants have a milky latex which, being viscous, reduces transpiration.
- A thick waxy transparent cuticle on the upper surface which minimises water loss through the upper

epidermis yet it still permits light penetration into the leaf.

POPULATION DYNAMICS

These are changes in populations in response to environmental stress or environmental conditions. To study the dynamics of a population, it is necessary to estimate its size.

TERMS ENCOUNTERED IN POPULATION STUDIES

Population size

This is the number of individuals in a population

Population density

This is the total number of organisms of a species per unit area (land) or per unit volume (water)

Population growth

This is a change in the number of individuals (increase-positive or decrease-negative)

Population growth rate

This is a change in the number of individuals per unit time.

Dispersion

This is the distribution of organisms in a habitat.

Age distribution

This is the proportion of individuals of each age in a population.

Birth rate (natality)

This is the number of offspring produced in a given time, usually expressed as a percentage.

Death rate (mortality)

This is the number of individuals dying per unit of time per unit of population

Biotic potential

This is the capacity of growth of a population.

Intrinsic rate of increase

This is the rate at which a population would grow if it had unlimited resources.

Environmental resistance

These are all the environmental factors acting jointly to limit the growth of a population.

Carrying capacity

This is the maximum number of individuals of a given species that can be sustained indefinitely in a given area of land or volume of water.

Sex ratio

This is the ratio of males to females in a population (Humans: it is calculated basing on 100 females e.g. 89 males to 100 females)

Fertility rate

This is the number of new individuals produced by one organism per unit time.

MAJOR CHARACTERISTICS OF POPULATIONS

Populations change in size, density, dispersion and age structure.

Main types of population dispersion:

- i) **Uniform distribution:** organisms are equidistantly placed due to severe struggle for resources in the environment.
- ii) **Random distribution:** organisms are dispersed by chance, with neither forces of attraction nor repulsion, and the environment provides uniform factors.
- iii) **Clumped distribution:** organisms aggregate into groups to gain better protection, feeding, reproduction etc. Clumped dispersion is the most common pattern of population distribution.

Age structure

- The young – age group before reproduction.
- Middle age – reproductive age.
- Old age – age after reproductive stage.

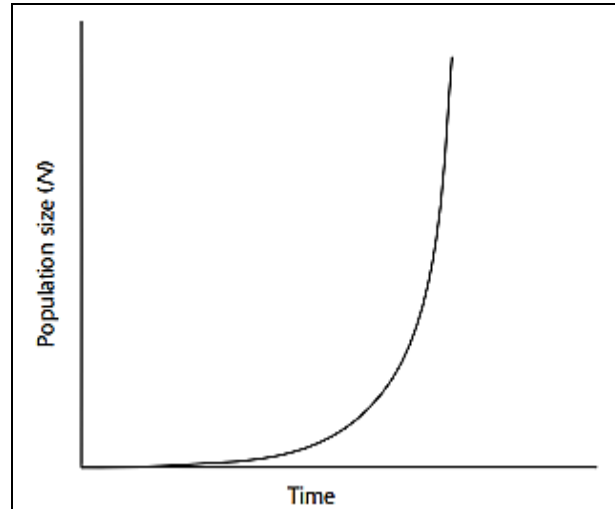
$\text{Population change} = (\text{birth} + \text{immigration}) - (\text{deaths} + \text{emigration})$

$\text{Population growth rate} = (\text{final population} - \text{initial population})$

POPULATION GROWTH PATTERNS

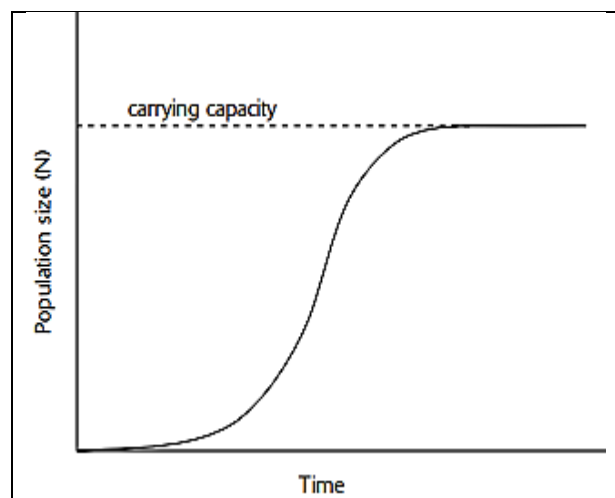
Exponential population growth (J-shaped curve)

It is a theoretical population growth curve in which the population growth rate increases with time indefinitely.



Population growth starts out very gradually and then proceeds rapidly as the population increases. It occurs when resources are unlimited and the population can grow at its intrinsic rate of growth. However this is rare in nature because of limiting factors (**environmental resistance**).

Logistic population growth (sigmoid or S-shaped curve)

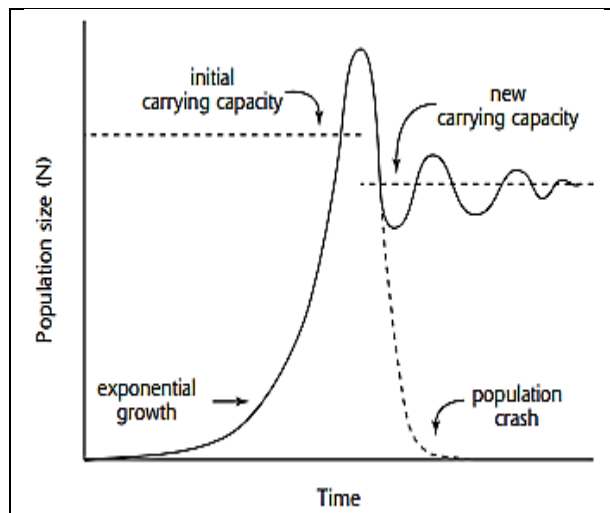


Population growth starts out slowly and then proceeds faster to a maximum (carrying capacity) and then levels off. Population

then fluctuates slightly above and below the carrying capacity with time. The population stabilises at or near the carrying capacity (K) of its environment due to environmental resistance e.g. the growth of sheep population on the island of Tasmania, south of Australia in the early 19th century.

What happens when population size exceeds the carrying capacity?

The population suffers a dieback or crash, unless the excess individuals switch to new resources or move to an area with more favourable conditions



FACTORS THAT TEND TO INCREASE OR DECREASE POPULATION THE SIZE OF A POPULATION

Biotic potential

The biotic potential is the maximum growth rate of a population under ideal conditions, with unlimited resources and without any growth restrictions. For example, some bacteria can divide every twenty minutes. At that rate, one bacterium could give rise to

over a trillion bacteria in ten hours. In contrast, elephants require nearly two years for gestation of a single infant. Even at this rate, however, after two thousand years, the weight of the descendants from two mating elephants would exceed that of the earth. The following factors contribute to the biotic potential of a species:

- Favourable light – mostly for plants.
- Favourable temperature.
- Favourable chemical environment (optimal level of critical nutrients and toxic wastes).
- High reproductive rate.
- Adequate food supply
- Ability to compete for resources.
- Ability to hide from or defend against predators.
- Ability to resist disease and parasites.
- Ability to adapt to environmental changes.
- Ability to migrate and live in other habitats.
- Suitable habitat.
- Generalised niche

Environmental resistance

These are external factors that affect population growth. The form that environmental resistance takes depends on the species in question. In general the following factors all limit population growth;

- Too much or too little light, mostly for plants.
- Too much or too little temperature.

- Unfavourable chemical environment (too much or too little of critical nutrients and high waste accumulation).
- Low reproductive rate.
- Inadequate food supply
- Too many competitors for resources.
- Insufficient ability to hide from or defend against predators.
- Inability to resist disease and parasites.
- Inability to adapt to environmental changes.
- Inability to migrate and live in other habitats.
- Unsuitable or destroyed habitat.
- Specialised niche

HOW POPULATION DENSITY AFFECTS POPULATION GROWTH

Density-dependent population control

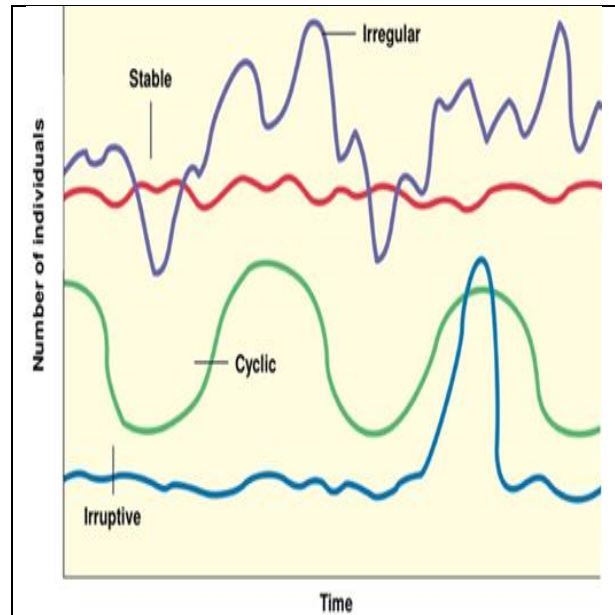
This involves factors whose effectiveness depends on the number of individuals present in a unit of space i.e. the more individuals there are in the population, the greater the percentage of the population that dies or fails to reproduce. Examples: Competition for resources like food, disease, predation, parasitism (biotic factors mainly)

Density-independent population control

This involves factors whose effectiveness is not related to the density of the population. Any change in the factor affects the same proportion of the population regardless of population density. Examples: temperature, rainfall, light, floods, soil nutrients, pollution, fires, drought, hurricanes, habitat destruction e.g. clearing a forest or filling in

a wetland, pesticide spraying etc. (mainly abiotic factors)

KINDS OF POPULATION CHANGE CURVES IN NATURE



a) Stable population growth curve:

Trees in a tropical rain forest where there is little variation in temperature and rain fall from year to year.

b) Irruptive population growth curve:

Some algal populations in freshwater habitats, raccoon and feral house mouse. This is caused by some factor that temporarily increases the carrying capacity e.g. more food, favourable weather, or fewer predators.

c) Irregular population growth curve

This is partly attributed to chaos in such systems but causes and interactions are not clearly understood.

d) cyclic population growth curve

Lemmings (small rodents whose populations rise and fall every 3-4 years), grouse, lynx and snowshoe hare (whose populations generally rise and fall on a 10-year cycle). The actual causes are poorly understood, although predators sometimes are blamed

SURVIVORSHIP

This is the percentage of an original population that survives to a given age. Survivorship curve is a graph which shows the number (or percentage) of surviving individuals of each age group of a population for a particular species. **Survivorship curves** describe how mortality of individuals in a species varies during their lifetimes

Importance of plotting survivorship curves

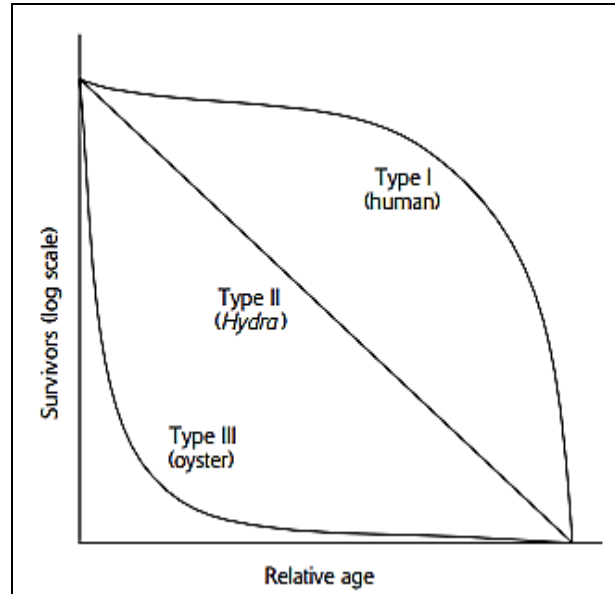
- Enables determination of mortality rates of individuals of different ages and hence to determine at which age they are most vulnerable.
- Enables identification of factors causing death at different ages so as to plan regulation of population size

Survivorship curve & typical examples of organisms

Late loss curves (Type I) Humans, elephants, rhinoceroses, mountain sheep

- These are organisms with stable populations close to carrying capacity of the environment (**K**).
- They produce few young ones which are cared for until reproductive age,

thus reducing juvenile mortality and therefore enabling high survivorship to a certain age, then high mortality at later age in life.



Constant loss (Type II) Many song birds, lizards, small mammals and hydra

- This is characteristic of species with intermediate reproductive patterns with a fairly constant rate of mortality in all age classes and thus a steadily declining survivorship curve.
- There is an equal chance of dying at all ages.
- These organisms face a fairly constant threat from starvation, predation and disease throughout their lives.

Early loss curves (Type III) Most annual plants, most invertebrates and most bony fish species. Type III curves describe species in which most individuals die young,

with only a relative few surviving to reproductive age and beyond.

- These are organisms with a high intrinsic rate of increase.
- They produce many offspring which are poorly cared for resulting into high juvenile mortality. Only those few larvae that survive being eaten become adults.
- There is high survivorship once the surviving young reach a certain age and size.

DETERMINATION OF POPULATION SIZE OF ORGANISMS

It is rarely possible to count all the individuals present of a certain population hence it is necessary to estimate the size of any population. Sampling methods take many different forms and the one chosen depends on various factors including the species studies and also its habitat.

Importance of estimating population size

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

pests enables control measures to be prepared.

Factors to consider before counting organisms

- The area of land or volume of water or air under study must be determined.
- The nature of vegetation cover of the habitat.
- Size of the organisms under study
- Facilitation in terms of equipment to be used.
- Behaviour of the organisms e.g. their hostility and level of excitement when disturbed
- Topography of the area.
- Whether the habitat is terrestrial or aquatic.
- Risks expected to be faced during the exercise.
- The duration the exercise is expected to last.

METHODS OF DETERMINING POPULATION SIZE OF ORGANISMS

1. TOTAL COUNT

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

- a. census of people after every ten years
- b. aerial counting from a low flying aircraft of large, sessile, slow moving animals and mobile but large animals e.g. giraffes, elephants, lions, e.t.c.

Aerial counting

Advantages

- Population size is quickly estimated.
- Hostile animals are less likely to harm the researcher
- It provides a lot of other information on the species.

Disadvantages

- It may cause discomfort to animals resulting in hiding.
- Can only be used in clear weather conditions.
- Aircrafts are expensive to buy or hire and operate.
- Can only be used on large animals.
- The calculations involved may cause inaccuracy

2. COUNTING BY SAMPLING

This is when the number of organisms is determined in several sample plots that represent a known fraction of the total area under investigation from which estimation of the total population size of the whole area is made by simple calculations. Sample counting is applied when the number of the organisms is large, covers a large area or where the behaviour of organisms does not allow easy contact.

a) Quadrating

Quadrat sampling is suitable for slow moving animals and plants. A metallic, plastic or wooden frame of known area e.g. 1m^2 or 0.25m^2 is randomly thrown several times in the area under investigation and all individuals within the quadrat are counted

each time. Population density is expressed as an average figure per metre squared. Total population is got by multiplying the average with the total area under investigation.

Example:

Three counts of 103, 46 and 20 of a plant species, were made using a quadrant of 25cm^2 . The population density of the plant per m^2 is?

$$\text{Population density} = \frac{103 + 46 + 20}{3} = 56.3$$

25cm^2 contain 56.3.

1cm^2 contains $\frac{56.3}{25}$ plants

$$\begin{aligned} 100\text{cm}^2 \text{ contain } \frac{56.3}{25} \times 100 \\ = 225 \text{ plants} \end{aligned}$$

Advantages:

- The method is relatively accurate
- It enables comparison of species density in different areas
- It provides an absolute measure of abundance.

Disadvantages:

- time consuming
- not suitable for fast moving animals
- not suitable for large sized animals.
- Grass in tussocks appear indistinguishable and may disturb.

b) Capture-recapture (Lincoln index) method

This method is used on highly mobile animals like fish, small mammals e.g. rats,

birds, and arthropods e.g. insects like butterflies, grasshoppers, cockroaches. It involves capturing and counting the organisms (N_1), marking them in a way that causes no harm, and returning them to the natural environment. After allowing sufficient time for the population to mix thoroughly, a second catch (N_2) is made and the number of marked individuals recaptured is recorded as N_3

$$\text{Estimated total population (P)} = \frac{N_1 \times N_2}{N_3}$$

Example:

In estimating the number of fish in a small lake, 625 fish were caught, marked and released. After one week, 920 fish were caught and of these, 150 bore marks. What was the estimated size of fish population?

$$\begin{aligned} P &= \frac{N_1 \times N_2}{N_3} \\ P &= \frac{625 \times 920}{150} \\ &= \underline{3833 \text{ fish}} \end{aligned}$$

Assumptions which the method bases on:

- That organisms mix randomly within the population
- That the time allowed for random mixing is enough.
- That changes in population size due to immigration, emigration, death and birth are negligible.
- That the movement of organisms is restricted geographically.

- That there is even dispersing of organisms within the study area.
- That the mark does not hinder the movement of the organisms or make them conspicuous to predators.

Disadvantages / Limitations:

- It is only reliable when the organisms' range of movement is relatively restricted and defined
- Animals often move in groups whose members recognise one another and avoid mixing with those of other groups
- Many animals have particular localities (home ranges) where they confine, so the marked animals may not spread widely
- Loss of marked individuals reduces those recaptured and this causes inaccuracy.

Other sampling methods include

Aerial photography

Using a light aircraft aerial photographs of large animals in herds e.g. elephants, are taken after which numbers of animals are counted on the photographs.

Transect sampling

It is used to investigate the transition of one community to another, particularly when the communities occur in a linear sequence e.g. up a rocky seashore.

i) **Line transect** involves laying down a calibrated tape or string along the ground in a straight line between two poles across the area of study and then all individual

organisms touching the line are recorded. A profile of the area is made on reduced scale noting the position of individuals, their height, branching and horizontal spread. On completion a vertical and horizontal distribution of a community is made.

ii) Belt transect involves setting up two line transects at fixed width, say 0.5m or 1m apart between which all individuals are recorded, after which the findings are presented just like it is with line transect.

iii) Continuous transect is a line or belt transect in which the whole belt or line is sampled.

iv) Interrupted transect involves taking samples at regularly spaced vertical or horizontal intervals.

Removal method

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

After sweeping with a heavy net, counting and recording of the animals captured is done. The procedure is repeated several

times and the gradually decreasing numbers of organisms is noted.

A graph of number of animals captured per sample against the previous cumulative number of animals captured is plotted and extrapolation of the line of the graph is made to the point at which no further animals would not be captured, from which the population is estimated. Thus for example the number collected in the 1st sweep is plotted against zero as no previous animals had been collected, the number collected in the 2nd sweep against that collected in the 1st, the number in the 3rd sweep against the sum of the 1st and 2nd and so on.

Revision Question

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

a) Fish in a pond

b) Terrestrial plants

c) Large mammals

SUB TOPIC 5: EFFECT OF HUMAN ACTIVITIES ON ECOSYSTEM

SUB TOPIC OUTLINE

- *Effects of human activities on an ecosystem components and factors in a habitat*
- *Natural resources, utilization and sustainable development*

Human activity damages the biosphere. The effect of human activities on the environment is proportional to the size of the human population. Exponential population growth, destruction of habitats

for agriculture and mining, pollution from industry and transportation, and many other activities all contribute to the damage of the environment.

POLLUTION

Pollution is the release of substances or energy into the external environment in such quantities and for such duration that they cause harm to living organisms or their environment. Air pollution, water pollution, and land pollution contaminate the materials essential to life. Many pollutants do not readily degrade and remain in the environment for decades.

Pollutants include noise, heat and radiation as different forms of energy, many chemical compounds and elements and excretory products. The parts of the external environment affected include air, water and land. Many pollutants such as sewage, smog and oil are complex mixtures of various compounds. Pollutants are categorized basing on their persistence in the environment namely;

a) Degradable pollutants:

These are pollutants that are broken down completely or reduced to acceptable levels by natural physical, chemical and biological processes and hence effectively, at least in the long run from the ecosystem. **Biodegradation** is the breakdown of complex chemical pollutants into simpler chemicals by living organisms (usually specialised bacteria).

b) Slowly degradable

These take a longer time to degrade e.g. DDT - an insecticide, and plastics.

c) Non-degradable pollutants:

These cannot be broken down by natural processes e.g. the toxic elements lead, mercury, arsenic, selenium etc.

AIR POLLUTION

Pollutant and its sources	Effects on living organisms	Control measures
Carbon monoxide [CO] • Motor vehicle exhausts • Incomplete combustion of fossil fuels • tobacco smocking	✓ Prevents oxygen usage by blood by forming carboxy-haemoglobin, which may cause death. ✓ Small concentrations cause dizziness and headache	✓ Efficient combustion of fuels in industry and homes ✓ Avoid smocking. ✓ Vehicle exhausts gas control e.g. in USA.
Sulphur dioxide [SO₂] Combustion of Sulphur containing fuels, oil, coal gas	✓ Causes lung diseases, irritation of eye surface, and asthma resulting into death if in high concentrations. ✓ Forms acid rain which increases soil PH. ✓ Reduces growth of plants and	✓ Use of Sulphur free fuel e.g. natural gas. ✓ Installation of SO₂ extraction units in industrial flues and chimneys.

	kills lichens. Lichens are indicator species for SO₂ pollution. The presence of many lichen species indicates low level of SO₂ pollution in that area.	
Ozone, O₃ • Motor vehicle exhausts • combustion of fossil fuels to form nitrogen dioxide which decomposes to form oxygen atoms that combine with oxygen molecules to form ozone	<u>Low level</u> (tropospheric) ozone causes ✓ Internal damage to leaves hence reducing photosynthesis. ✓ Eye, throat and lung irritation which may result into death. ✓ Greenhouse effect by absorbing and radiating heat which raises the temperature at the earth's surface. <u>High level</u> (stratospheric) ozone offers protection against excessive solar heat by absorbing solar ultraviolet radiation which would reach the earth's surface	Vehicle exhausts gas control e.g. in USA.
Smoke House coal, smoke, soot, motor vehicle exhausts, tobacco smoking and incomplete combustion of refuse in incinerators and bonfires	✓ Causes lung diseases when inhaled ✓ Sunlight barrier, hence reducing photosynthesis. ✓ Stunted growth of plants ✓ Stomatal blockage hence reducing photosynthesis.	✓ Usage of smokeless fuels ✓ Efficient combustion ✓ No smoking ✓ Vehicle exhausts gas control
Dust Solid fuel ash, soil, quarrying, mining, e.t.c.	✓ Lung diseases ✓ stomatal blockage ✓ Stunted growth of plants. ✓ Smog – forms when temperature inversion occurs (layer of warm air traps cool air containing dust and smoke close to the earth's surface)	✓ Installation of dust precipitators in industrial chimneys. ✓ Efficient combustion. ✓ Wearing of face masks by factory workers.
Carbondioxide [CO₂] • Motor vehicle exhausts	✓ Causes Greenhouse effect; warming up of the earth's atmosphere as a result of the blanket of some atmospheric	Planting more green plants, reduction in combustion of fossil fuels by relying on alternative sources of energy

combustion of fossil fuels	gases e.g. CO₂ preventing escape of solar radiation higher into space. ✓ Increased atmospheric CO₂ levels results in global	e.g. solar energy
Nitrogen oxides Car exhaust emissions and industrial flue gases	Acid rain formation, contribute to greenhouse effect.	Car exhaust control
Chlorofluorocarbons [CFCs] Aerosol propellants, refrigerator and air conditioner coolants, expanded plastics. E.g. bubbles in plastic foam used for insulation and packaging	Enters stratosphere, the chlorine reacts with ozone hence reducing the ozone layer and permitting greater penetration of UV light to cause global warming.	Ban on the use of CFCs
Noise Discos, road traffic, engines, machines, aeroplanes, firearms	Hearing impairment, total deafness, and nervous disorders.	Effect laws against excessive noise, put on ear muffs and plugs while in industry.
Radioactive fallout from explosion, nuclear weapons and nuclear power fuels	Ionizing radiation causes cancer	Nuclear power controls

GREEN HOUSE EFFECT AND GLOBAL WARMING

Evidence suggests that the Earth's temperature has been rising for some time. This could be due to deforestation and increased combustion of fossil fuels enhancing the greenhouse effect.

Greenhouse effect

This is a description of the condition which results when greenhouse gases i.e. gases in the troposphere (atmosphere's inner most layer extending about 17km above sea level) like carbondioxide, water vapour, methane and nitrous oxide allow mostly visible light,

some infrared radiation and ultraviolet radiation from the sun to pass through the troposphere to the earth, which transforms this solar energy to longer-wavelengths - infrared radiation (heat), which then rises into the troposphere. Molecules of greenhouse gases absorb and emit this heat into the troposphere as even longer-wave length infrared radiation, which causes a warming effect of the earth's surface and air. The tropospheric gases act like a glass of large green house surrounding the earth.

Global warming

This is the observed average global temperature rise of 0.8°C since 1900 as a result of the enhanced natural greenhouse effect.

The origins of greenhouse gases are:

- combustion of fossil fuels by motor engines and industries releases carbondioxide and methane into the troposphere
- deforestation and clearing of grasslands reduces the uptake of carbondioxide in photosynthesis
- ruminant fermentation produces methane, which is released into the troposphere
- use of aerosol propellants, which contain CFCs that are 105 times worse than carbondioxide as greenhouse gases
- cultivation of rice in swamps and paddy fields causes anaerobic fermentation, which produces methane
- use of inorganic fertilisers causes the release of nitrous oxide

Effects of global warming

- Rise in sea level due to melting of polar ice and thermal expansion of seas.
- Altered temperature gradients cause cyclones and heavy rains as water evaporates quicker.
- Species migrations which are likely to cause pests/diseases to extend their ranges.
- Reduced crop yields due to drier weather.
- Increased crop yields because of more rainfall and longer growing seasons in some regions.
- Flooding low-lying islands and coastal cities.
- Extinction of some animal and plant species.
- Increased death of the human population.
- Greatly increased wild fires in areas where the climate becomes drier.

ACID RAIN

Formation

Combustion of fossil fuels releases Sulphurdioxide and nitrogen oxides into the atmosphere. Catalysed by ammonia and unburnt hydrocarbons, these oxides react with water in the clouds to form solutions of sulphuric acid and nitric acid, which make up acid rain.

Effects

- Hydrogen ions bound to soil particles are displaced into runoff water by the SO_4^{2-} ions from sulphuric acid, causing formation of

soft exoskeletons, which results into death of invertebrates

- Aluminium ions are displaced from soil by SO_4^{2-} ions into water where it interferes with gill functioning in fish causing their death.
- Aluminium ions displaced from soil by SO_4^{2-} ions into water are toxic when absorbed by plants
- The leaching action of acid rain removes calcium and magnesium ions from soil causing poor formation of middle lamella and chlorophyll in leaves.
- Contributes to human respiratory diseases such as bronchitis and asthma.
- Can leach toxic metals such as lead and copper from water pipes into drinking water.
- Damages statues and buildings
- Decreases atmospheric visibility, mostly because of sulphate particles
- Promotes the growth of acid-loving mosses that can kill trees.
- Loss of fish populations when the PH lowers below 4.5

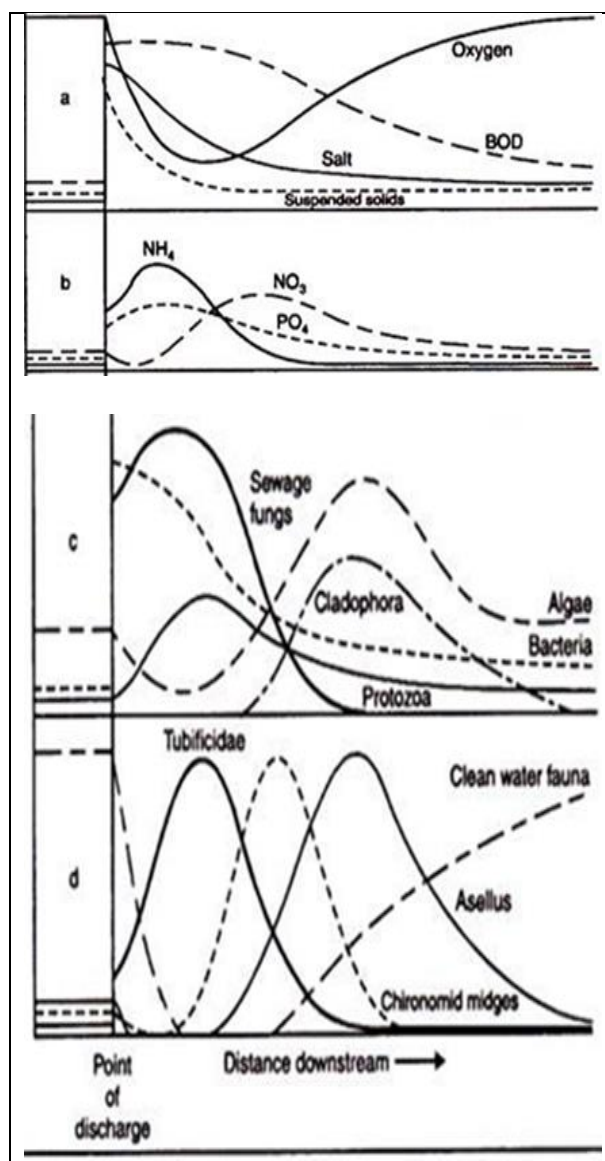
Prevention

- Installation of SO_2 extraction units (wet scrubbers) in chimneys of industries.
- Cleaning up exhaust emissions by encouraging several pollutants to react with one another to give less harmful products in catalytic converters.
- Reduce coal use.
- Increase use of renewable resources.

MAJOR CATEGORIES OF WATER POLLUTION

A) SEWAGE DISCHARGE INTO RIVERS

Sewage is liquid waste (composed of faeces, urine, water, detergents and other substances) from industries and or homes carried through pipes called sewers. Effects of sewage discharge into rivers - changes in abiotic (a and b) and biotic (c and d)



Dissolved oxygen and B.O.D (Biological or biochemical oxygen demand)

Dissolved oxygen level is high in unpolluted water but decreases rapidly at sewage outfall (discharge) to the minimum and then increases gradually downstream, returning to a normal level further downstream.

Explanation

B.O.D is very low in unpolluted water, increases rapidly at outfall then decreases gradually downstream. Decomposition of organic components of sewage by aerobic bacteria coupled with reduced photosynthesis because of low illumination caused by suspended solids in sewage rapidly reduce oxygen (cause oxygen sag) and create a high BOD at outfall. The gradual increase of oxygen downstream is because of increased photosynthesis and dissolution from atmosphere. The death of aerobic bacteria due to reduction in organic substances decreases BOD down stream

Suspended solids

Suspended solids are very few before outfall, increase rapidly at the sewage discharge but progressively decrease downstream. This is because sewage discharge adds decomposable organic matter into the water at the point of discharge, the progressive decrease downstream is due to bacterial consumption and dilution by water.

NH_4^+ , NO_3^- and PO_4^{3-} (Ammonium, nitrate and phosphate ions)

- NH_4^+ , NO_3^- and PO_4^{3-} ion concentration is very low before outfall

- NH_4^+ ions increase rapidly at discharge, then very rapidly to a maximum just after outfall, then decreases first rapidly and later gradually to a very low level downstream.
- NO_3^- ions first decrease gradually to a minimum concentration after outfall, gradually increase to a maximum a short distance downstream, then decreases gradually further downstream.
- PO_4^{3-} ion concentration increases (1) rapidly at discharge, (2) gradually just after outfall to a maximum, then decreases gradually to a very low level downstream.

Explanation

Sewage contains NH_4^+ ions. Putrefying (ammonifying) bacteria convert organic nitrogen-containing compounds in sewage to NH_4^+ just after outfall. Downstream, NH_4^+ ions are converted to NO_3^- by nitrifying bacteria and further downstream there is dilution by water. NO_3^- ions first decrease due to consumption by sewage fungus abundant at outfall, then gradually increase because NH_4^+ ions are converted to NO_3^- by nitrifying bacteria, then decrease gradually due to consumption by plants and algae. Sewage contains PO_4^{3-} ions from (1) detergents and (2) decomposition of organic matter, yet the consumption by autotrophs is very low at outfall, accounting for the high PO_4^{3-} ion concentration. PO_4^{3-} ion gradual decline downstream is caused by (1) absorption by the progressively increasing populations of autotrophs (2) storage in sediments.

Aerobic bacteria, sewage fungus, algae and higher plants

Aerobic bacteria are very few before, but very many at outfall, then their population decreases rapidly immediately and gradually after out fall downstream. Sewage fungus is contained in sewage population, increases to a maximum immediately after outfall, but decreases rapidly downstream to very low level. Algae and higher plant populations decrease rapidly to a minimum at outfall but increase rapidly a short distance downstream and return to normal further downstream.

Explanation

Sewage contains aerobic bacteria that feed on organic substances, but population falls as availability of oxygen and nutrients diminishes. Population increases at outfall because the sewage fungus thrives in anaerobic conditions and is very tolerant of high ammonia concentrations. The rapid decrease in populations results from reduced photosynthesis because of the turbidity caused by suspended solids, the rapid increase is because of the high concentrations of NO_3^- (nitrate) ions and increased illumination because suspended solids reduce and water becomes clearer.

B.O.D (Biological oxygen demand)

Mass of oxygen consumed by microorganisms in a sample of water in a given time - usually measured as the mass (in mg) of oxygen used by 1dm^3 of water stored in darkness at 20°C for 5 days. B.O.D indicates the oxygen not available to more advanced organisms. Therefore a high

B.O.D indicates anaerobic conditions (low oxygen availability).

NOTE:

Flowing rivers naturally undergo self-purification to recover from pollution through a combination of dilution and biodegradation, but the recovery time and distance depend on;

- *volume of incoming degradable wastes in sewage*
- *flow rate of the river*
- *temperature of the water*
- *PH level of the water*

B) HEAT (THERMAL) POLLUTION:

Main human sources are: water cooling of electric power plants and some types of industrial plants.

Harmful effects

- Lowers dissolved oxygen levels since solubility of most gases reduces with temperature.
- Makes aquatic organisms more vulnerable to disease, parasites, and toxic chemicals
- When a power plant shuts down for repair or opens, fish and other aquatic organisms adapted to a particular temperature range can be killed by the abrupt change in water temperature. This is known as ***thermal shock***.
- Some aquatic animals may migrate to waters with favourable temperature.

C) ADDITION OF INORGANIC CHEMICALS, PLANT NUTRIENTS AND SEDIMENTS INTO LAKES

Pollutant	Examples	Main human sources	Harmful effects
Plant nutrients	Nitrate (NO_3^-), phosphate (PO_4^{3-}) and ammonium (NH_4^+) ions. The nutrient enrichment of water bodies is termed eutrophication	Raw sewage discharge, detergents and other chemical release from industries, leaching of inorganic fertilizers e.g. NPK from farmland.	• Rapid growth of algae and green protists (algal blooming) reduces light penetration in water leading to death and decay of algae, which depletes water of dissolved oxygen, killing fish and other aerobic animals. • Excessive levels of NO_3^- if drunk in water lowers the oxygen carrying capacity of blood and kills unborn children and infants ("blue baby syndrome")
Sediment	(1) Soil (2) Silt	Land erosion	It cause turbidity / cloudiness in water and reduce photosynthesis, settle and destroy feeding and spawning grounds of fish, clog and fill water bodies, shortening their lifespan, disrupt aquatic ecosystems and carry pesticides, bacteria and other harmful substances into water.
Inorganic chemicals	Acids, compounds of toxic metals like lead (Pb), mercury (Hg), arsenic (As) and selenium (Se) and (3) salts e.g. NaCl in ocean water	Surface runoff, industrial effluents and household cleaners.	• Drinking water becomes unusable for drinking and irrigation • Lead and Arsenic damage the nervous system, liver and kidneys, they harm fish and other aquatic life, they lower crop yields and they accelerate corrosion of metals exposed to such water.

CHEMICAL PEST CONTROL

Properties of an **ideal pesticide**, should be;

- biodegradable / non-persistent so that toxic products are not left in or on crop plants
- specific so that only pest species is killed.
- not accumulate either in specific parts of an organism or as it passes along food chains.
- effectively control the pest under field growing conditions.
- easy to apply at the correct dosage.

Problems of using insecticides

- Accidental misuse of toxic chemicals results in death of humans and domestic animal.
- Many are **non-specific**, killing non-target species, particularly natural predators of the pest species
- **Pest resistance** occurs i.e. genetic variation enables a few individuals in the pest population to survive and may quickly reproduce.
- There is **pest replacement** i.e. since most crop are susceptible to attack by more than one pest species, and the pesticide may be more deadly to one species than another, elimination of one species may simply allow another species to assume major pest proportions
- **Pest resurgence** may occur i.e. non-specific pesticides may kill natural predators as well as pests, and so a small residual pest

population may multiply quickly without being checked.

- **Bioaccumulation** (some molecules of the pesticide may be stored in specific organs or tissues at levels higher than would be expected) and biological magnification (the pesticide may get more concentrated as it passes along the food chains and webs) may occur.

NOTE

*A chemical that has an LD50 (median lethal dose) of 50 milligrams or less per kilogram of body weight is a **poison**. **LD50 (median lethal dose)** is the amount of a chemical received in one dose that kills exactly 50% of the animals in a test population, within a 14-day period.*

BIOLOGICAL PEST CONTROL

Control of a pest population using its natural predator, parasite or pathogens. Steps involved in biological control:

- ✓ Identifying the pest and tracing its origins, i.e. where it came from.
- ✓ Investigating the original site of the pest and identifying natural predators, parasites or pathogens of the pest.
- ✓ Testing the potential control agent under careful quarantine to ensure its specificity.
- ✓ Mass culturing of the control agent.
- ✓ Development of the most effective distribution / release method for the control agent

TOPIC 6: INHERITANCE AND EVOLUTION

SUB TOPIC 1: GENETICS

Genetics: This is the study of the mechanism by which characteristics (traits) are transmitted from parents to the offsprings. This transmission occurs via gametes during fertilization in sexually reproducing organisms.

Therefore genetics can also be referred to as the study of inheritance characteristics of the parents by the offsprings. The characteristics of organisms are controlled by internal factors called **genes** located on chromosomes. A gene is a section of DNA that determines a particular characteristic in an organization or a section of DNA that controls the production of a polypeptide chain in an organism.

Heredity is the transmission of characteristics from parents to offsprings (**progeny**). Such characters are also called **traits**. In humans, characters like hair texture, height; skin colour, body build and hair colour are inheritable characters.

THE IMPORTANCE OF GENETICS

Genetics is important in the following ways:

- It is used in genetic engineering where better breeds and varieties of plants and animals are produced. This is intended to increase production and improve resistance of diseases and pests. This can be done locally through cross breeding.
- It is used in the legal profession to determine the paternity of the child
- i.e. genetics is used to settle paternal disputes by confirming who the father of the child is. This can be proved through use of blood groups as these groups are genetically inherited and can therefore be used to prove the rightful father of the child. If the blood groups fail to prove then DNA analysis can be used.
- They are used in blood transfusion. Genetic principals are used during blood transfusion so that blood being transfused is compatible to avoid blood clotting (Agglutination) in the recipient.
- It is used in the control of the transmission of genetic diseases. These diseases are genetically engineered e.g. hemophilia, color blindness, acandroplasia e.t.c. can be eliminated from the human population by following the principles of genetics as these diseases are genetically inherited.
- It can be used in crime investigation i.e. use of the DNA finger prints to identify criminals
- It is used in molecular biology to manufacture artificial enzymes, hormones and vaccines.
- It enables humans to choose the right partners during marriage by choosing those with characteristics for reproduction.

TERMINOLOGIES INVOLVED IN GENETICS

Alleles

These are alternative forms in which the gene can exist but control contrasting features of characteristics. Alleles exist in pairs e.g. consider a gene for height. This gene can be expressed in form of allele as T (for tallness) and t (for shortness). Therefore these two alleles can exist as TT and tt.

Locus (plural loci).

This is the position on the chromosome where the genes are located.

Homozygous condition

This is a condition where an individual possess identical alleles for a particular gene e.g. TT, tt, AA.

Heterozygous condition

This is a condition where an individual possess non-identical alleles for a particular gene e.g. Tt, Bb. Heterozygous individuals are genetically called carriers of the recessive characteristic. Recessive characteristics can only be expressed when two carriers make an organism which is phenotypically recessive appears e.g. the sickle cell anemia individuals, albinos, hemophiliac e.t.c.

Pure breeding (breeding true)

This is where the individuals crossed are homozygous and therefore produce consistently the same characteristic, generation after generation. A pure breed should therefore be a homozygous

individual when considered for a particular characteristic.

Hybrid

This is heterozygous individual obtained from crossing two parents with contrasting characteristics but when these parents are pure breeding e.g. **tt X TT**

Dominant allele

A dominant allele is the one that can express its self phenotypically in both homozygous and heterozygous forms.

Recessive allele

This is an allele that can only express itself phenotypically in the homozygous form as it is suppressed by the dominant allele in the heterozygous form.

NOTE:

Recessive alleles are presented by small letters (lower case) while dominant alleles are represented by capital letters (upper case)

Phenotype

This is the physical or outward appearance of an organism.

Crossing (X)

This refers to the mating of the male and female organisms under a consideration.

First filial generation (F₁)

This refers to the set of offsprings obtained from crossing two pure breeding parents with contrasting characteristics. These

individuals are therefore heterozygous or hybrids.

Second filial generation (F₂)

This refers to the set of offsprings that are obtained from crossing mature hybrid of parents of the first filial generation.

Selfing

This refers to the crossing of offsprings of the same parents.

Test cross

This is the mating of a phenotypically dominant individual with a recessive individual so as to determine the genotype of the phenotypically dominant individual. This is due to the fact that a phenotypically dominant individual can either be heterozygous or homozygous. If the homozygous offsprings resemble the dominant parent then the dominant parent is said to be homozygous and if the offsprings formed from the test cross shows a phenotypic ratio of 1:1, then the parent with an unknown genotype is heterozygous.

Back cross

This is the mating of an offspring with one of its parent so as to prove the genotype of the parents.

Reciprocal cross

This is a cross in which the phenotypes of the same characteristics are interchanged among the parents during a genetic experiment.

MENDEL'S GENETIC EXPERIMENTS AND MONOHYBRID INHERITANCE

This is the inheritance of a single pair of characteristics from the parent to offsprings. Examples include, height, blood groups, albinism, sickle cell anemia, and sex linked characteristics e.t.c.

This mechanism of inheritance was discovered by a scientist called **Gregory Mendel** who carried out a number of genetic experiments using the garden pea plants. He also observed many sexually reproducing organisms and found out that they had variations among themselves despite being of the same species.

In these experiments, Mendel carried out cross pollination between tall pea plants and short pea plants he had grown in his garden. In order to carry out a proper cross, Mendel covered the stigma of all flowers of one group of pea plants in order to have male pea plants. He also removed all the anthers from the flowers of another group of pea plants in order to have female pea plants. Using a brush he transferred pollen to tall pea plants from short pea plants. He observed the F₁ offsprings were all tall. He then selfed the F₁ pea plants to get F₂ which was found to be a mixture of tall pea plants and short pea plants.

In order to perform good genetic experiments, Mendel used a garden pea plant because such plants have good characteristics for genetic experimentation which included the following;

- They have many contrasting characteristics without any intermediates such as tall and short stems, smooth and wrinkled seeds, yellow and white flowers i.e. a good genetic organism must show many discontinuous variation characteristics
- They produce large numbers of offsprings which provide a large sample for experimentation so as to get reliable results.
- It is possible for them to undergo controlled pollination.
- They are so small that they can be conveniently handled.
- They have a short life span and they can be reproduced very quickly before the end of the life span.

Mendel was successful in his genetic experiment because;

- He had a systematic approach to his work. This is because he dealt with a single characteristic (monohybrid inheritance) and then later long he considered two characteristics simultaneously (di-hybrid inheritance).
- He was very patient during his experiments so that he was able to reproduce the garden peas for several generations.
- He used a very a good experimental organism, the garden peas.

Limitations of Mendel's experiments

- Mendel had no knowledge about genes, chromosomes and how they behave during meiosis

- Mendel's laws apply to diploid organisms only and not all organisms are diploid.
- According to Mendel, some alleles are dominant while others are recessive, yet some alleles may be co-dominant, whereby neither of the alleles of gene pair dominates the other, but contribute equally towards the expression of the phenotype
- It's not true that all genes assort independently; some genes do not assort independently like in linkage
- Mutation usually changes the expressions of characteristics away from what Mendel observed.

Conclusions from Mendel's experiments

About the actual mechanism of inheritance

- ❖ The phenotypic characteristics are under the control of internal factors (these factors were later named genes).
- ❖ It is these factor that are transmitted from the parents to the offsprings i.e. (from one generation to the next).
- ❖ For each character, an organism inherits from the parents two alleles (internal factors), one from each parent and it is these factors which account for variations in inherited characters.
- ❖ The factor which phenotypically appears in F1 generation is dominant to the one which fails to phenotypically in F1 but instead appears in the F2 generation.
- ❖ During sexual reproduction the egg cell and the sperm makes equal

contribution to each of the characteristics of the offspring such that the offspring has both male and female parental characteristics. This is because the two alleles for a heritable character separate or segregate during formation of

gametes in meiosis and end up in different gametes.

- ❖ Always in F₂ generation, the dominant and recessive offsprings appear in a phenotypic ratio of 3:1. The results, using proportions only, are summarised in the table below;

Character	Type of cross	F ₁ generation	F ₂ generation	Ratio
Stem length	Tall X Short	All tall	787 tall, 277 short	2.84:1
Seed colour	Green X Yellow	All yellow	6022 yellow, 2001 green	3.01:1
Seed shape	Round X Wrinkled	All round	5474 round, 1850 wrinkled	2.96:1
Seed coat	Coloured X White	All coloured	705 coloured, 224 white	3.15:1
Pod colour	Green X Yellow	All green	428 green, 152 yellow	2.82:1
Pod shape	Inflated X Constricted	All inflated	882 inflated, 299 constricted	3:1
Flower colour	Purple X white	All purple	705 purple, 224 white	3:1

MENDEL'S FIRST LAW OF INHERITANCE

From this experiment about monohybrid inheritance he suggests the law of genetics which is known as the **law of segregation**.

This law states *that in diploid organisms each characteristic is controlled by a pair of alleles but during gamete formation the alleles separate so that each gamete possesses a single allele.*

Explanation of Mendel's first law of inheritance

This law is explained by meiosis which halves the chromosome number in that each characteristic of an organism is determined by a pair of alleles located on the pair of homologous chromosomes in the nucleus of the cell of an organism. Each allele of the pair for a characteristic is therefore carried

by a single chromosome of the homologous pair when homologous chromosomes segregate and move towards opposite pole of the cell during anaphase I of meiosis. This results into each gamete carrying one allele of the gene pair due to the separation of a pair of chromatids during anaphase I.

WORKED EXAMPLES

1. In a garden pea plant there are two forms of heights i.e. tall and short. When a pure breeding tall pea plant was crossed with a short pea plant all the offsprings obtained were tall when the offsprings were selfed a phenotype ration was obtained in F₂.

a. Using suitable genetic symbols, workout the genotypes and phenotypes of the F₂ generation

b. What are the phenotypic and genotypic ratios of the F₂ generation?

c. Explain how you would determine the genotype of F₁ tall pea plants formed

d. Suppose 300 pea plants were produced in the F₂ generation

i. How many were tall?

ii. How many were short?

Solution

(a)

Let **T** represent the allele for tallness
Let **t** represent the allele for shortness

Parental phenotype (2n): tall pea plant X short pea plant

Parental genotype: $TT \quad X \quad tt$

Meiosis

Gametes (n): All **T** All **t**

Fertilization:

F₁ genotypes (2n): All **Tt**

F₁ genotypes (2n) are all tall pea plants.

Selfed:

Parental phenotypes (2n): tall pea plant X tall pea plant

Parental genotype: $Tt \quad X \quad Tt$

Meiosis

Gametes (n): **T** **t** **T** **t**

Fertilization

F₂ genotype (2n): $TT \quad Tt \quad Tt \quad tt$

F₂ phenotype: Tall pea plants Short pea plant

F₂ genotypic ratio 1 **TT**: 2 **Tt**: 1 **tt**

F₂ phenotypic ratio: 3 tall: 1 short

(c) determine the genotype of F₁ pea plants, carry out a test cross, by crossing the F₁ tall pea plants with short pea plants.

Parental phenotype: tall pea plant X short pea plant

Parental genotype (2n): $Tt \quad X \quad tt$

Meiosis

Gametes (n): **T** **t** All **t**

Fertilization

Test cross offspring genotype: $Tt \quad tt$

Test cross phenotypic ratio 1 tall: 1 short

This shows that F₁ tall pea plants were heterozygous

(d)

i. $\frac{\text{homozygous tall}}{\text{total}} \times 700 = \frac{1}{4} \times 700 = 175 \text{ plants}$

ii. $\frac{\text{homozygous short}}{\text{total}} \times 700 = \frac{1}{4} \times 700 = 175 \text{ plants}$

iii. $\frac{\text{heterozygous}}{\text{total}} \times 700 = \frac{2}{4} \times 700 = 350 \text{ plants}$

Homozygous tall

Homozygous

Heterozygous =

2. Suppose a man who is a tongue roller marries a woman who is a non-tongue roller and all the children obtained in F1 are tongue rollers.

(a) Work out the phenotypic and genotypic ratio as obtained in F2 generation.

(b) What is the probability that the 4th born is a non-tongue roller?

3. A man with normal skin marries a carrier for albino skin. What is the probability that some of their children will be albinos?

NOTE:

Albinism is a monohybrid condition due to lack of melanin pigment in the skin. It arises due to a mutation which alters the gene responsible for the synthesis of melanin. This makes an albino to have white hair, very light coloured skin and pink eyes.

FACTORS WHICH MODIFY OR AFFECT MENDEL'S MONOHYBRID 3:1 AND 1:2:1 RATIOS

1. LETHAL GENES:

These are genes that lead to the death of the bearer. Lethal genes are divided into 3 major categories;

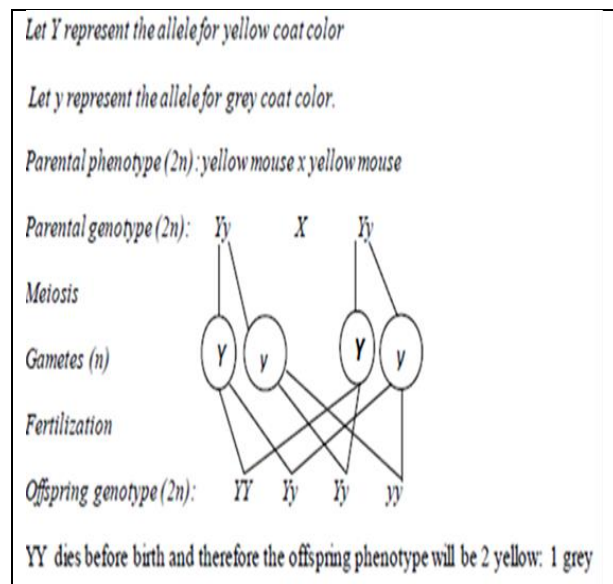
- a. **Gametic lethal genes.** These are genes which kill the gametes and therefore prevent fertilization.
- b. **Zygotic lethal genes.** These are genes which kill the zygotes and embryos before birth e.g. the gene that determine coat color in mice.

- c. **Infantic lethal genes.** These are genes which kill individuals between birth and reproductive stages e.g. the gene that determines chlorophyll formation in maize, sickle cell anemia in man e.t.c.

Lethal genes in mice

The gene that determines coat color in mice is a zygotic lethal gene. In mice, there are two colours determined by these genes i.e. yellow and grey (agouti). If two yellow mice are crossed they produce both yellow and grey offspring however these offspring appear in a phenotypic ratio of two yellow; 1 grey instead of 3:1.

This is because the homozygous dominant yellow mice die in the uterus which reduces the phenotypic ratio. The yellow mice produced are always heterozygous and this changes the monohybrid genotypic ratio from 1:2:1 to 2:1



NOTE:

a) Dominant lethal genes are very rare in a population because they are usually manifested easily in growth and development of the offspring at an early age and hence easily eliminated.

b) A **pleiotropic gene** is the one which controls more than one aspect or characteristic in the metabolism of an organism e.g. the **Y** gene in mice is controlling both viability and coat colour, for viability the **Y** gene acts as a recessive gene since homozygous **YY** mice dies in the uterus and since **Yy** mice are yellow this phenomenon is called **pleiotrophy**.

2. CO-DOMINANCE

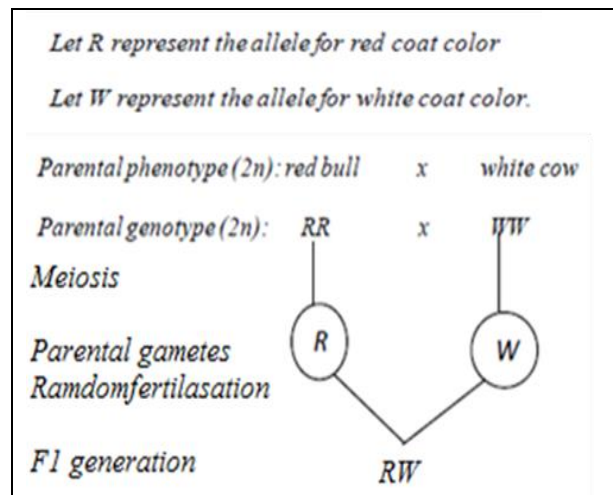
This is a phenomenon whereby the alleles controlling a particular characteristic have equal powers of expressing themselves in the phenotype in the heterozygote. Therefore the offsprings produced will have a mixture of the two parental characteristics in the phenotype. **Co-dominance** is taken to be a form of incomplete dominance since no allele suppresses the phenotypic expression of another. In co-dominance which use capital letter to represent all the two alleles each letter corresponding to each of the two characteristics.

Examples of co-dominance include the following;

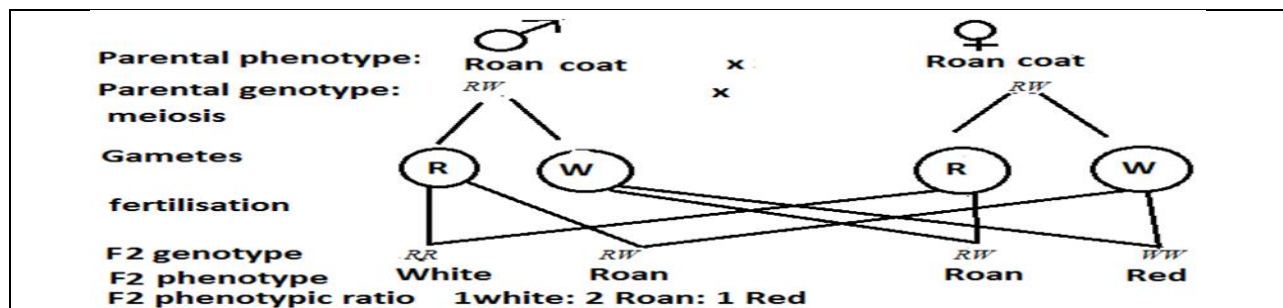
- The gene that determines coat color in cattle
- Inheritance of blood group AB in man
- Inheritance of sickle cell trait

Inheritance of coat colour in cattle

Consider a cross between a red bull and a white cow whose **F₁** offsprings are selfed. Work out the genotypes and phenotypes in **F₁** and **F₂** generation stating in each case the ratios



When the **F₁** roan offspring are selfed, the **F₂** offspring will be red, roan and white in the ratio 1 red: 2 roan: 1 white as shown below



INHERITANCE OF SICKLE CELL ANAEMIA

This is an abnormal condition in which the red blood cells collapse into a sickle shape under low oxygen concentration due to the presence of abnormal haemoglobin (Hbs) in the red blood cells. The normal haemoglobin is found in red blood cells with a bi concave disc shape

Sickle cell anaemia is caused by a substitution mutation, in which an amino acid known as **glutamic acid**, responsible for the formation of normal haemoglobin is replaced by another amino acid called **valine** which leads to the formation of **HbS** in the red blood cells.

Haemoglobin is made of four polypeptide chains, two α -chains which are 141 amino acids long and two β -chains which 146 amino acids long. The substitution mutation occurs at the sixth amino acid in the β -chain, this results in wrong amino acid, valine, being incorporated into two of the β -polypeptide chains. **Valine** is non-polar and hydrophobic which makes its presence in the haemoglobin (**HbS**) less soluble when deoxygenated. Therefore when HbS loses its oxygen, the molecules come out of solution and crystallise (solidify) into rigid rod-like fibres. These change the shape of the red blood into a sickle shape.

Effects of sickling red blood cells

a. Anaemia this is occurs because the sickle cells are destroyed which lowers the amount of oxygen to be carried leading to acute anemia. This leads to;

- ❖ Fatigue (weakness)

- ❖ Poor physical development
- ❖ Dilation of the heart which may lead to heart failure
- ❖ Infections which lead to frequent illness

b. Interference with circulation of blood because the cells get jammed in capillaries and small arteries. This leads to;

- ❖ Heart damage which leads to heart failure
- ❖ Lung damage which leads to pneumonia
- ❖ Muscle and joint damage which leads to rheumatism and pain
- ❖ Gut damage which leads to abdominal pain
- ❖ Kidney damage which leads to kidney failure
- ❖ Liver damage

c. Enlargement of the spleen because the sickle cells collect in the spleen for destruction

The effects above make the homozygous sufferers to often die before reproductive age.

NOTE:

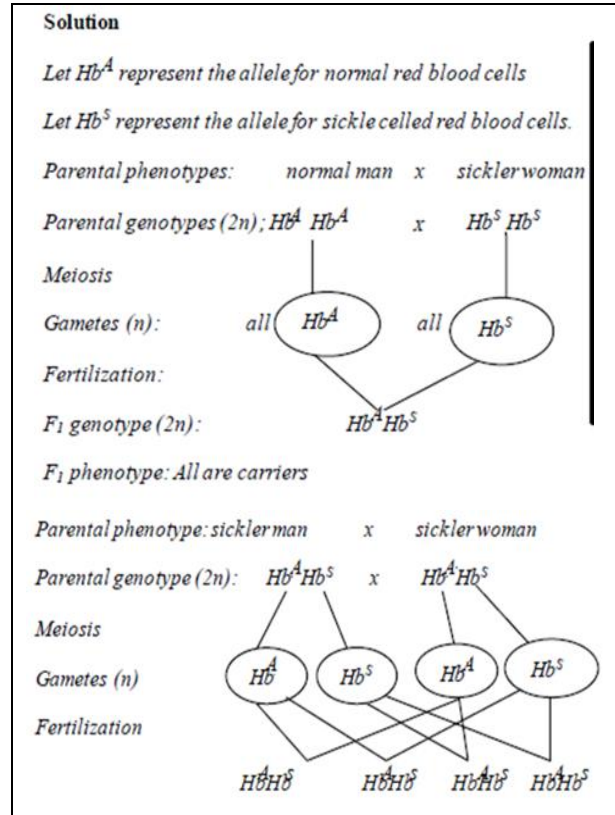
The allele that causes erythrocytes to have a distorted form in sickle-cell anaemia also causes these blood cells to rupture easily, thereby inducing anaemia. This gene can also be described as pleiotropic since it has more than one effect in an organism.

In heterozygous individuals, half the molecules made are HbS and HbA i.e. the alleles HbA and HbS are co-dominant and the faulty gene is not recessive.

Heterozygous people are not affected except at unusually low oxygen concentrations, such as when flying in an unpressurised aircraft or climbing at high altitude. Then some of the cells sickle. The **heterozygous** condition is known as **sickle cell trait**.

These individuals have a **selective advantage** over non carriers because they are far less susceptible to malaria (the malaria parasite multiplies inside normal red blood cells) so are more likely to survive in malaria infested areas, and pass on their genes to the next generation. A single copy of the sickle-cell allele increases resistance to malaria. The final frequency of the gene in the population varies according to the amount of malaria. Carriers (heterozygotes) of sickle cell anaemia show the sickle cell trait, a co-dominant condition, in which most of the red blood cells have normal haemoglobin and only about 40% of the red blood cells have abnormal haemoglobin S. This produces mild anaemia and prevents carriers of the sickle cell trait from contracting malaria. This is because when the plasmodium that causes malaria enters a red blood cell with haemoglobin S, it causes extremely low oxygen tension in the cell which leads to the cell sickling in heterozygotes. These sickled cells are quickly filtered out of the blood stream by the spleen, thus eliminating the parasites.

Consider a normal man marrying a sickle cell anaemia woman. Consider another man who is a carrier of sickle cell anaemia of the same disease. Work out the phenotypic and genotypic ratios arising from these two marriages.



F_2 genotypic ratio: 1 $Hb^A Hb^S$: 2 $Hb^A Hb^S$: 1 $Hb^S Hb^S$

F_2 phenotypic ratio: 1 normal: 2 carrier for the sickle cell trait: 1 sickle cell anaemia

Therefore a normal man mating with a woman with sickle cell anaemia obtains F_1 offsprings which are phenotypically normal but carriers, if the two carriers mate to form F_2 , the phenotypic ratio will **be 1:2:1**

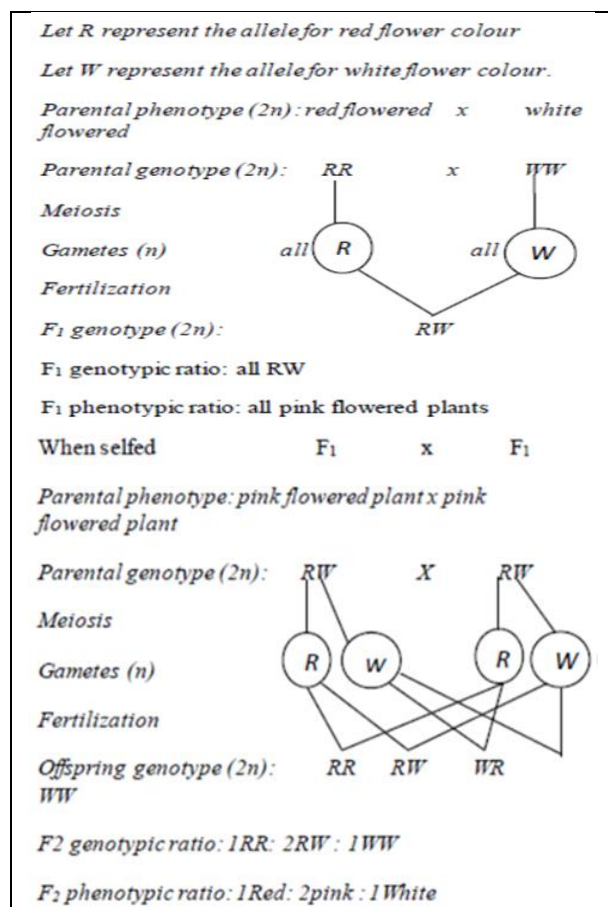
3. INCOMPLETE DOMINANCE

This is a condition whereby the characteristics of the alleles blend together to form an F_1 Offspring phenotype which is intermediate between the two parental phenotypes. Therefore the F_1 individuals do not resemble any of the parents.

It can also be defined as a situation with by the heterozygote shows a phenotype intermediate between the parental phenotypes. In incomplete dominance no gene dominates the other in the phenotype but instead forms intermediate phenotypes and are therefore represented using capital letters.

Example

In a snap dragon plant, when a red flowered is crossed with a white flowered plant, all the F₁ plants obtained are pink flowered. When the F₁ are selfed, the F₂ phenotypic ratio is 1:2:1 instead of 3:1. Using suitable genetic diagrams, explain the above results.



DIHYBRID INHERITANCE

This is the type of inheritance whereby two characteristics are transmitted from the parents to the offsprings at the same time.

When Mendel considered the inheritance of two characteristics simultaneously, he concluded that these characteristics are inherited independently and each pair of alleles separates during meiosis and during fertilization each of the alleles combines randomly with either alleles of another pair. From this conclusion Mendel made his second law of inheritance which states that; *“each characteristic in diploid organisms is controlled by a pair of alleles which separate so that each allele randomly combines with any other allele of another pair.”* Mendel also described it as the **law of independent assortment**.

This law is explained by meiosis as follows.

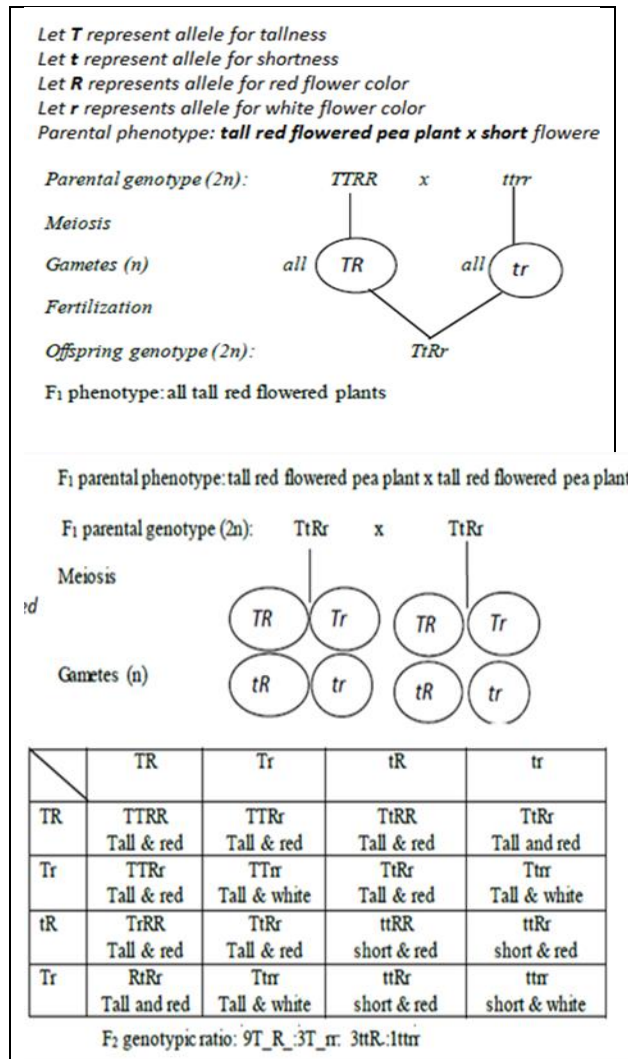
During gamete formation, during meiosis, the distribution of each allele from a pair of homologous chromosome is entirely independent of the distribution of alleles of other pairs. During metaphase I of meiosis homologous chromosomes lineup on the equator of the spindle and subsequently separate (segregate) independently during metaphase I and move to opposite poles independently during anaphase I which leads to a variety of allele recombination in the gametes formed, as long as each gamete has one allele for each gene.

Example

In the garden pea plant, the gene controlling flower color is located on the same chromosome with that controlling height.

Suppose a pure bleeding tall red flowered plant is crossed with a white short flowered plant, the F₁ offsprings obtained are tall red flowered plants. If the F₁ offsprings are selfed,

- What would be the phenotypic ratio in the F₂ generation
- If 700 pea plants are formed in F₂ generation, what would be number of pea plants in each phenotypic class?
- How would you experimentally determine the genotypes of the F₁ plants?



F₂ phenotypic ratio: 9 tall red flowered: 3 tall white flowered: 3 short red flowered: 1 short white flowered

By carrying out a test cross between F₁ tall red flowered pea plant with short flowered pea plants

Test cross phenotypic ratio: **1 tall red flowered: 1 tall white flowered: 1 short red flowered: 1 short white flowered**. This ratio proves that the F₁ plants were heterozygous (TtRr).

NOTE:

In dihybrid inheritance, some of the offsprings formed in the F₂ have a mixture of the two parental phenotypes that gave rise to F₁ and such offsprings are known as **recombinants** while other offsprings in F₂ resemble one of the two parental phenotypes that gave rise to F₁ and such offsprings are known as **parentals**.

Recombinants arise when **crossing over** takes place during the formation of gametes in meiosis which leads to the mixing of the two parental characteristics. The number of recombinants in F₂ is usually smaller than that of the offsprings which resembles the parental phenotypes (parental offsprings). This is because crossing over occurs by chance which reduces the number of recombinants formed.

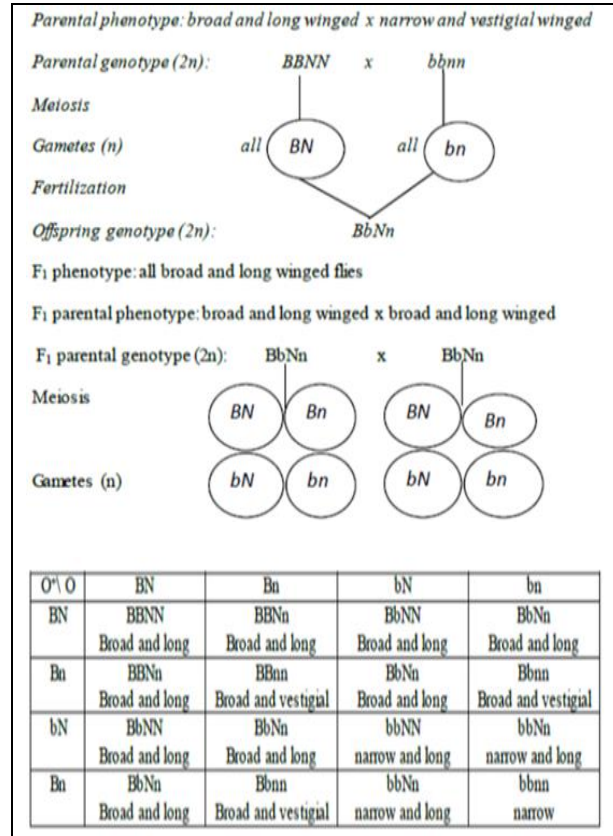
Example 2

In drosophila melanogaster flies, the gene determining the size of the abdomen occurs on the same chromosome with that determining the length of the wings. When a pure breeding broad and long winged female

fly was crossed with a narrow and vestigial winged male fly all the F₁ offsprings obtained head broad abdomen and long wings. If the F₁ offsprings were selfed to obtain F₂.

- Using suitable genetic symbols work out the phenotypes and genotypes that were obtained in F₂ generation.
- Suppose 480 flies were obtained in F₂ work out the numbers of the flies for each phenotype class.
- How many of these flies were recombinants.

*Let B represent allele for broadness
Let b represent allele for narrow
Let N represent allele for long
Let n represent allele for vestigial winged*



SUB TOPIC 2: CHROMOSOMES AND GENES

INHERITANCE OF COMPLEMENTARY GENES

These are two or more genes which interact together in order to control a single characteristic in an organism. Inheritance of these genes therefore does not agree with Mendel's laws of inheritance. Although these genes control a single characteristic, they show independence assortment. Therefore these genes are passed on from the parents to the offspring in a normal Mendelian fashion. The best example of complementary genes is genes which control the shape of combs in chicken.

In chicken there are four types of combs namely;

- walnut comb
- single comb
- pea comb
- rose comb

These four types of combs are controlled by the two genes located at two loci situated on different chromosomes and which interact together to give rise to the four comb types. The shape of the combs is controlled by two genes which are represented by two alleles shown below;

Let **P** represent the allele for **pea comb**

Let **R** represent the allele for **rose comb**

The pea comb develops in the presence of the **P**-allele and in the absence of the **R**-

allele while the rose comb develops phenotypically in presence of **R**-allele and in the absence of the **P**-allele. When both alleles, P and R, are present together a walnut comb develops. A single comb appears only in the homozygous double recessive condition

Consider a cross between a pea comb shaped cock with a rose combed hen whose F1 offspring are then selfed. What is the phenotypic ratio obtained in F2?

Parental phenotype: pea combed cock x rose combed hen

Parental genotype (2n): PPrR x ppRR

Meiosis

Gametes (n) all Pr all pR

Fertilization

Offspring genotype (2n): PpRr

F1 phenotype: all walnut combed chicken

F1 parental phenotype: walnut combed chicken x walnut combed chicken

F1 parental genotype (2n): PpRr x PpRr

Meiosis

Gametes (n)

O\O	PR	Pr	pR	pr
PR	PPRR Walnut comb	PPRr Walnut comb	PpRR Walnut comb	PpRr Walnut comb
Pr	PPRr Walnut comb	PPrr Pea comb	PpRr Walnut comb	Pprr Pea comb
pR	PpRR Walnut comb	PpRr Walnut comb	ppRR rose comb	ppRr rose comb
pr	PpRr Walnut comb	Pprr Pea comb	ppRr rose comb	pprr single comb

F2 genotypic ratio: 9PpRr:3PPrr:3ppRR:1pprr

F2 phenotypic ratio: 9 walnut combed: 3 pea combed: 3 rose combed: 1 single combed

In this inheritance, the genes are usually situated at different loci at different chromosomes from where they interact together and give rise to four distinct phenotypes for a single characteristic. The walnut comb results from a modified form of co-dominance in which atleast one dominant allele of either pea comb or rose comb is present.

This is an incidence where by a 9:3:3:1 phenotypic ratio is obtained for a single characteristic. Although this ratio is this pattern of inheritance differs from the hybrid inheritance because;

- The F1 progeny (offspring) resembles neither parents i.e. they are all walnut comb shaped unlike their parents.
- The F2 progeny also contains two new phenotypes which do not exist in the F1 parents namely walnut and a single comb shaped and these appear in a higher ratio as compared to the rose and the pea comb

MODIFICATION OF 9:3:3:1 PHENOTYPIC RATIO

This ratio is mainly modified by the inheritance of lethal genes, linkage of genes and epistasis.

1. EPISTASIS:

This is a form of gene interaction in which one gene suppresses the effect of another gene that is situated at a different locus on chromosomes. It also refers to a condition in which non-allelic genes interact during which the epistatic allele of the epistatic gene on one locus suppress the phenotypic

expression of the hypostatic allele of the hypostatic gene on another locus.

An **epistatic allele** is the one which suppresses the action of another allele in the phenotype though they are not located on the same locus and the suppressed gene or allele at another locus is the **hypostatic one**.

They are 3 types of epistasis which include the following;

Dominant epistasis. This is the type of epistasis where the epistatic allele is dominant such that its presence suppresses the phenotypic expression of the recessive allele on another locus. This type of epistasis changes the phenotypic ratio from 9:3:3:1 to 12:3:1.

Recessive epistasis. This is the type of epistasis where the epistatic allele is recessive, such that its presence in homozygous condition, suppresses the phenotypic expression of the dominant allele located on another locus. This type of epistasis changes the dihybrid phenotypic ratio from 9:3:3:1 to 9:3:4.

Isoepistasis. This is the type of epistasis in which both alleles and the non-allelic genes have equal powers of suppressing each other in the phenotype. This modifies the dihybrid phenotypic ratio to 15:1.

Examples

In oats the inheritance of color is controlled by the epistatic gene which has two alleles, one allele being dominant for color appearance while the other allele is for no color formation (white or albino) i.e. the hypostatic gene is responsible for color

deposition or type of color. Where by black is dominant over white

Consider a cross between homozygous black oat plant with a homozygous white oat plant and then the F1 plants are selfed to get F2.

a. Work out the phenotypic ratio of the F2 generation

b. How many individuals are found in each of the phenotypic classes obtained in F2 if 130 individuals were found in F2?

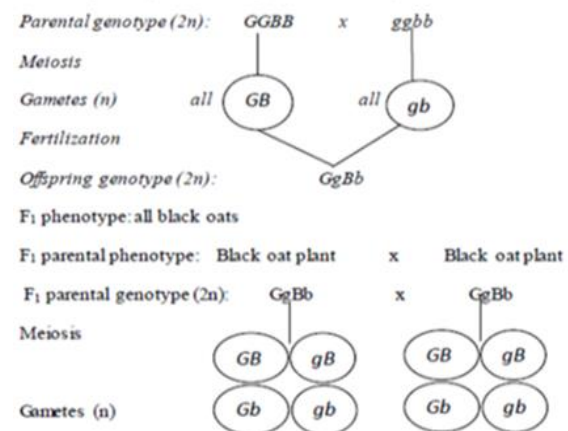
Let **G** represent the allele for color formation (epistatic)

Let **g** represent the allele for no color formation (albino\ white)

Let **B** represent the allele for black

Let **b** represent the allele for grey

Parental phenotype: black oat plant x white oat plant



F2 phenotypic ratio: 9 black oats : 3 grey oats : 4 white oats.

$$i. \frac{\text{black oats}}{\text{total}} \times 480 = \frac{9}{16} \times 130 = 73.125 \text{ plants}$$

$$ii. \frac{\text{grey oats}}{\text{total}} \times 480 = \frac{3}{16} \times 130 = 24.375 \text{ plants}$$

$$iii. \frac{\text{white oats}}{\text{total}} \times 480 = \frac{4}{16} \times 130 = 32.5 \text{ plants}$$

Revision Question

In white leg horn fowl, plumage colour is controlled by two sets of genes, including the following;

W (white) dominant over w (colour)

B (black) Dominant over b (brown)

*The heterozygous F1 Genotype **WwBb** is white. Account for this type of gene interaction and show the phenotypic ratio of the F2 generation*

LINKAGE OF GENES

Linked genes are more than two genes located on the same chromosome but controlling different characteristics and are inherited together as a single block.

Linkage is the occurrence of more than one gene on the same chromosome which are inherited together along with the chromosome as a single block. It is also defined as the existence of genes determining different characteristics on the same chromosomes such that the two are inherited together.

TYPES OF LINKAGE

1. Complete linkage

This is a condition where two or more genes are located so close to each other on a chromosome that they are inherited together since they pass to the same gamete. No genetic recombination occurs between them. (No crossing over)

2. Incomplete linkage

This is a condition where two or more genes are located relatively further apart on the same chromosome that during crossing over, new genetic recombination occur between

them. These genes may not be inherited together.

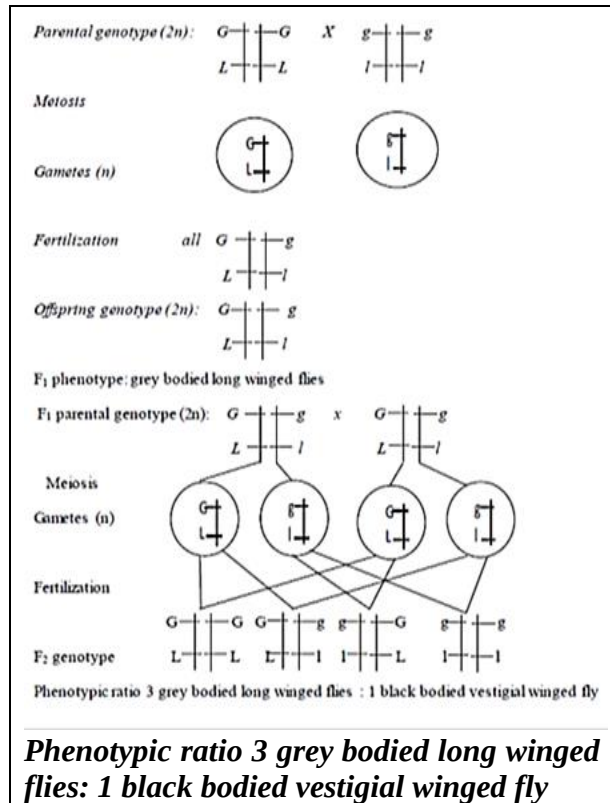
Linked characteristics are the ones controlled by genes located on the same chromosome and so are transmitted together with the chromosome from generation to generation.

Although these genes occur on the same chromosome, each one controls the specific characteristic irrespective of the other. However, linked genes do not show independent assortment during gamete formation and therefore the phenotypic ratio obtained in **F2 is 3:1 instead of the expected 9:3:3:1** for the two linked characteristics. Sometimes crossing over occurs, thereby separating the linked genes on the chromosomes leading to the formation of recombinant gametes during meiosis and this gives an F2 phenotypic ratio of 9:3:3:1 for the linked characteristics.

Example

In drosophila flies the genes controlling body color and the length of wings occur on the same chromosomes and are linked together. Consider a cross between a pure breeding grey bodied long winged fly with a black bodied vestigial winged fly whereby the grey bodied is female while the black bodied is male. If all the F1 flies obtained here grey bodied and long winged, what are the phenotypic and genotypic ratios of the F2 flies?

*Let **G** represent the allele for grey body
Let **g** represent the allele for black body
Let **L** represent the allele for long wings
Let **l** represent the allele for vestigial wings*



The above results are correct if no crossing over during gamete formation. In case the genes are not completely linked together in the chromosome crossing over can occur between the non - sister chromatids so as to produce recombinant gametes and this gives a phenotypic ratio in F₂ of the 9:3:3:1 as shown below.

	GL	Gl	gL	gl
GL	GGLL Grey body long wings	GGLl Grey body long wings	GgLL Grey body long wings	GglL Grey body long wings
Gl	GGLl Grey body long wings	Ggll Grey body vestigial wings	GglL Grey body long wings	Ggll Grey body vestigial wings
gL	GgLL Grey body long wings	GglL Grey body long wings	ggLL Black body long wings	ggLl Black body long wings
	long wings	body wings	winged	winged
Gl	GglL Grey body long wings	Ggll Grey body vestigial wings	ggLl Black body long winged	ggll Black body vestigial winged

F₂ phenotypic ratio: 9 grey body long winged flies: 3 grey body vestigial winged flies: 3 black body long winged flies: 1 black body vestigial winged flies

CROSSOVER VALUE AND CHROMOSOME MAPS

The recombinant gametes are formed by crossing over between non-sister chromatids in meiosis I. Such recombinant gametes lead to recombinant offsprings in the phenotypes. Recombinant gametes and recombinant offsprings occur in lower numbers compared to the parental gametes and parental offsprings because crossing over occurs by chance. The percentage of recombinant offsprings in the progeny (total number of offsprings) gives a cross over value which indicates the relative distance between the genes on the chromosomes and the likelihood of undergoing crossing over.

Cross over value (C.O.V) =

number of recombinants x 100%

Total number of offsprings

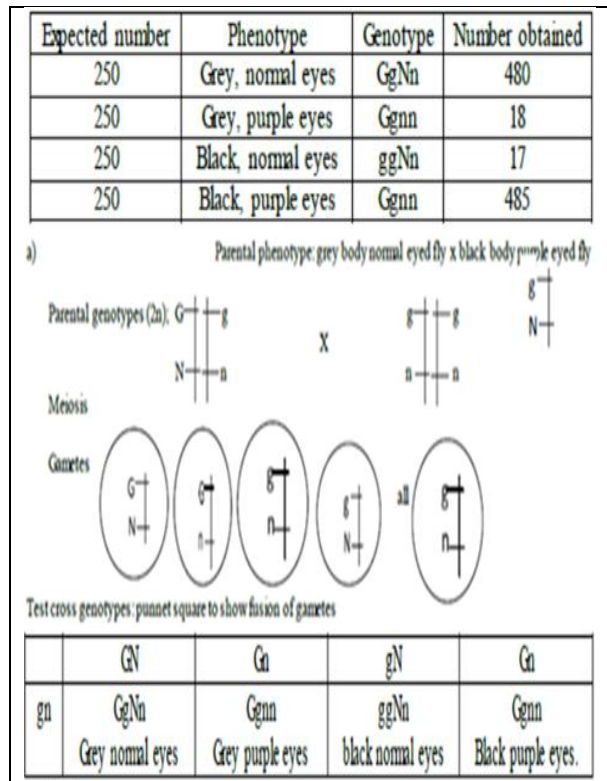
The distance between genes on the chromosome is measured in arbitrary units known as **map units**. 1 map unit = 1 cross over value (C.O.V)

The larger the C.O.V, the more separated the two genes are on the chromosomes and the higher the chances of crossing over taking place. The illustration of the distance between the genes on the chromosome gives the chromosome map i.e. a figure that shows a relative distance between the genes on the same chromosomes. The illustration of

distance between the genes on the chromosome is the **chromosome map**.

Example 1

In drosophila flies the genes controlling body color and eye color occur on the same chromosome and are linked together. In an experiment, a heterozygous female fly for grey body and normal eyes was crossed with a black body and purple eyed fly. In these flies, grey body is dominant over black while normal eyes are dominant over purple flies. If 1000 offsprings were obtained from this cross as shown in the table below;

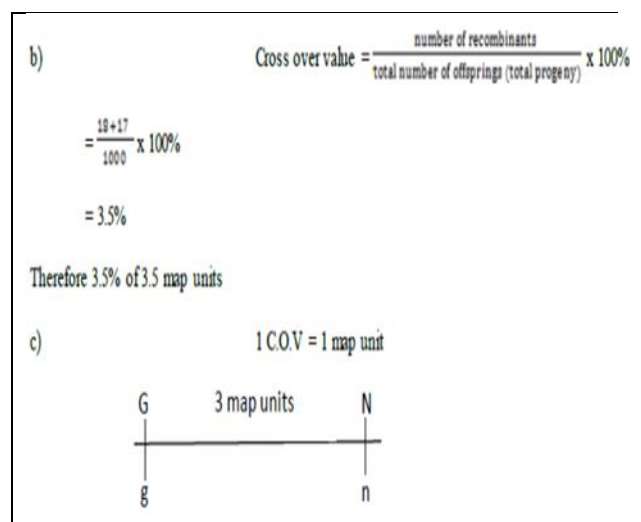


Test cross phenotypic ratio

1 grey normal eyed fly: 1 grey purple eyed:
1 black normal eyed: 1 black purple eyed.

The obtained results in the test cross differ from the expected ones because the genes are linked together on the chromosomes and were separated by crossing over which occurs by chance hence resulting into formation of fewer recombinants compared to the parents.

Expected number	Phenotype	Genotype	Number obtained
250	Grey, normal eyes	GgNn	480
250	Grey, purple eyes	Ggnn	18
250	Black, normal eyes	ggNn	17
250	Black, purple eyes	Ggnn	485



Example 2

Further experiment on these flies indicated that the genes for body color, length of wings and eye color are on the same chromosomes. Using the information in the table below calculate the cross over value and illustrate the distance between the genes.

<i>Expected</i>	<i>Phenotype</i>	<i>Genotype</i>	<i>Obtained</i>
250	Grey, long	Gg Ll	400
250	Grey, vestigial	Gg ll	95
250	Black, long	gg Ll	105
250	Black, vestigial	gg ll	400

$$\text{Cross over value} = \frac{\text{number of recombinants}}{\text{total number of offsprings (total progeny)}} \times 100\%$$

$$= \frac{95 + 105}{1000} \times 100\%$$

$$= 20\%$$

Therefore 3.5% of 3.5 map units

NOTE:

*Drawing the chromosome map is also called **gene mapping** where the position of genes*

are shown on the chromosomes as well as the distance separating with them. Sometimes it is possible to indicate many genes on chromosome and their distances of separation.

Consider the cross over values involving for different genes P, Q, R and S.

The distance separating these four genes is shown below;

$$P-Q = 24\%$$

$$R-P = 14\%$$

$$R-S = 8\%$$

$$S-P = 6\%$$

Draw the chromosome map to show the position of these chromosomes.

Answer.

Draw the chromosome map for these genes

a. Insert the positions of the genes with the smallest cross over value in the middle of the chromosome map.

b. Examine the next largest cross over value and insert both possible positions of its genes on the chromosomes relative to either S or P.

c. Repeat the procedure for all the remaining cross over values until you reach the largest cross over values.

Importance of cross over values

- Used to show the relative positions of linked genes of a chromosome.
- Used to construct a gene/chromosome map

- Used to show the possibility of crossing over occurring between linked genes
- Used to show the distance between linked genes. I.e. a cross over value of 1 % is equivalent to the distance of 1 unit.

FACTORS THAT AFFECT CROSSING OVER

1) The relative distance between the genes on the chromosome. When the genes are far apart from each other on the chromosome, they have high chances of forming chiasmata in between thereby leading to genetic exchange on the other hand when genes are very close to each other on the chromosome, their chances of forming chiasmata is limited.

2) The position of the centromere on the chromosome. If the genes are very close the centromere there chances of undergoing genetic exchange are limited. However, if the genes are far away from the centromere, there are high chances that they can be exchanged by crossing over.

3) Temperature. Crossing over decreases with increase in temperature because the process of meiosis requires suitable temperature that can promote efficient crossing over.

4) Age of the organism. Increase in age lowers the chances of crossing over. Meiosis is more efficient in grown up adults before menopause stage in females and before senescence in male.

5) Mutagens. These can decrease or increase the rate of crossing over. The

chances of crossing over are greatly reduced by presence of chemical substances that inhibit chiasmata formation thereby preventing cross over e.g. in drosophila flies.

INHERITANCE OF SEX

The sex of an organism is determined by two factors namely; environmental conditions and genetic factors.

Environmental determination of sex

In lower animals, sex can be determined by environmental factors such as temperature, salinity, type of food e.t.c. for example in tadpoles the eggs laid in cool places develop into males while those laid in warm places develop into females.

Genetic sex determination

The sex organs development can be determined by the sex genes or the chromosomes. Under chromosomal sex determination, sex can be determined by;

a. The number of chromosomes. E.g. in bees the females are diploid and have 32 chromosomes while the males are haploid and have 16 chromosome. In grasshoppers the females have 24 chromosomes while the males have only 23 chromosomes.

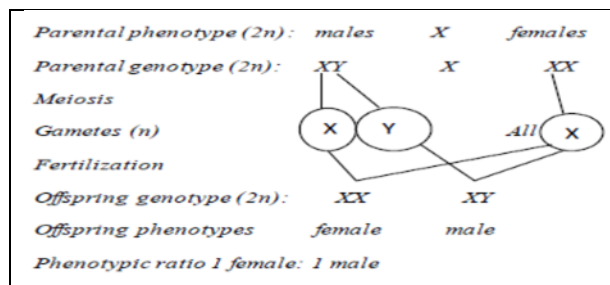
b. The sex chromosomes. In heterogametic organisms there are two sex chromosomes that determine the sex of an individual namely the X and Y chromosomes e.g.

The females are **XX** and are described as **homogametic** while the males are XY and are described as **heterogametic**. Therefore in these organisms it is the presence of the Y

chromosome that makes one a male and its absence makes one a female. This implies that it is the type of sperm (whether X or Y) that fertilizes the egg which determines the sex of the offspring.

In birds sex is determined by the X and Y chromosomes except that the females are XY while males are XX.

In grasshoppers sex is only determined by X chromosomes where by the males are XO i.e. they lack only one X chromosome while the females are XX.



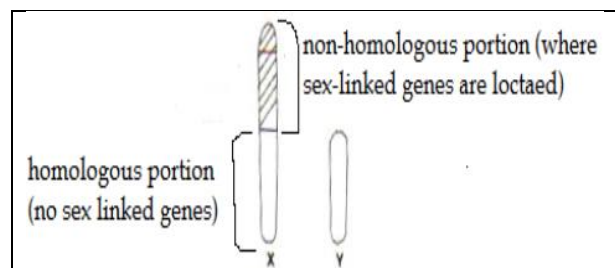
SEX LINKED CHARACTERISTICS

This is the transmission of characteristics (from parents to offsprings) whose genes are located on the sex chromosomes i.e. the genes controlling such a character are transmitted along with those that determine sex on the same chromosome.

Most sex linked characters are controlled by genes located on the X chromosome and very few are controlled by genes located on Y chromosome. Examples of sex-linked characteristics include; haemophilia, red green colourblindness, brown teeth, Duchenne muscular dystrophy e.t.c. Sex linked characteristics can therefore be defined as those whose genes controlling

them occur on the sex chromosome and yet they do not determine sex.

Sex linked characters are often expressed more in males than females. This is because the males being heterogametic have a non-homologous portion of the X chromosome while the sex linked allele is located and therefore such an allele cannot be suppressed in the phenotype by any other dominant allele.



This implies that the genes of the sex linked characters of the males are located in the non-homologous portion and therefore whenever a recessive allele of these characters appears, it has to be expressed in the phenotype since it does not have a counterpart allele that can suppress its phenotypic expression.

In the case of females, the X chromosomes are completely homologous to each other and this gives chances of development of carrier females (heterozygous females) for sex linked characters who may never express the characteristic in the phenotype as the recessive sex linked allele would be suppressed by the dominant allele on the counterpart X chromosome.

Sex linked characters are determined by recessive alleles. However sex linked characteristics undergo a characteristic **cross**

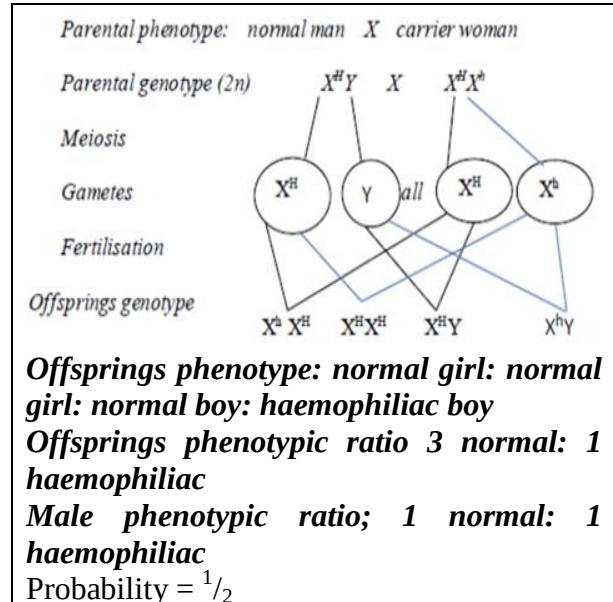
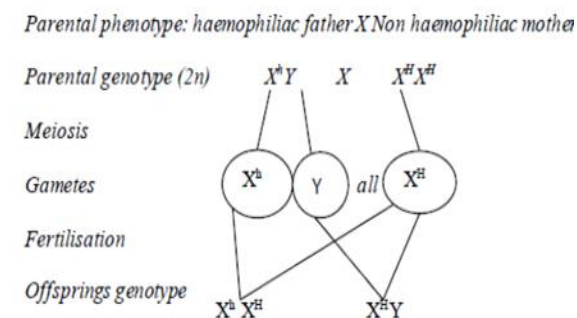
pattern of inheritance i.e. the fathers transmit their sex linked characters to their grandsons through their daughters who are carriers. This implies that the father will not transmit the sex linked character to his sons but instead to his daughters. This is because the son only inherits the father's Y chromosome and not the X chromosome that controls the sex-linked characteristics.

Although sex linked characters are mostly carried on the X chromosome there are a few of them which are carried on the Y sex chromosome and these are called **holandric characters** i.e. development of many hairs in the nostrils and ears.

Worked examples

Consider a normal man who marries a female whose father was having haemophilia and the mother was homozygous normal. Using suitable genetic symbols, work out the phenotypes and genotypes of their offsprings. What is the probability that this couple will produce a haemophilic boy?

Let H represent allele for non hemophilic
Let h represent allele for hemophilic



NOTE:

Haemophilia is a condition whereby blood takes too long to clot after an injury leading to excessive bleeding of the victim. This makes hemophilic individuals rare in population as most of them die before reproductive age.

Color blindness is a condition whereby an individual fails to see the colors or fails to distinguish between particular colors e.g. red, green color blindness where the red and green cone cells of the eye retina are defective due to some sex linked gene in an individual which does not allow such an individual to distinguish between red and green. Colour blind individuals are more common in the population than haemophiliacs because haemophiliacs have higher chances of dying before reaching reproductive age to pass on their genes to the next generations whereas color blind individuals survive and reach reproductive age in most cases which enables them to

reproduce and pass on their gene of colour blindness to the next generation which increases their number in the population. Besides, haemophiliac people may not choose to marry due the lethal gene they have, thereby becoming unable to pass on their genes to the next generation.

Example 2

Green color blindness is sex linked in man. A normal man married a color blind woman. Using suitable genetic symbols workout the genotypes and phenotypes of their children.

SEX LIMITED AND SEX INFLUENCED CHARACTERISTICS

Sex limited characteristics are the ones which occur particularly in one sex. These characteristics occur at a later stage in the life of an organism e.g. in human beings they normally occur at puberty.

In human beings the males have the following sex limited characteristics beard, deep voice, hairs in the ears and nostrils, porcupine characteristics e.t.c. In human females these characteristics include development of breasts, widening of the hip girdles e.t.c.

Sex influenced characteristics are those whose dominancy is determined by the sex of the bearer e.g. baldness of the head occurs in males and not in females because the genes determining it are dominant in males and recessive in females.

MULTIPLE ALLELES

This is another form of co-dominance. Multiple alleles refer to more than two

possible alleles of which any two can occur at a single locus at any one time.

Examples of characteristics controlled by multiple alleles include;

- Blood groups in humans
- Coat color in rabbits
- Eye color in rabbits and mice

Inheritance of ABO blood system

The ABO blood group system is controlled by three alleles of a gene **I** (isohaemagglutinin) occur at a single locus any time. These alleles are A or I^A , B or I^B and O or I^O . These alleles I^A and I^B are equally dominant while the allele. I^O is recessive to both.

The transmission of these alleles occurs in a normal Mendelian fashion. The table below summarizes the possible phenotype and blood group.

GENOTYPE	PHENOTYPE
$I^A I^A$ (AA)	Blood group A (homozygous)
$I^A I^O$ (AO)	Blood group A(heterozygous)
$I^B I^B$ (BB)	Blood group B
$I^B I^O$ (BO)	Blood group B
$I^A I^B$ (AB)	Blood group AB (co-dominant)
$I^O I^O$ (OO)	Blood group O

Physiology of the blood groups in humans

Human blood contains blood group antigens and blood group antibodies. Some of these specifically determine blood groups e.g. allele **A** determines the production of antigen **A**, allele **B** determines the production of antigen **B** and allele **O** does not code for the production of any antigens. Antigens **A and B** occur on the plasma

membranes of red blood cells. These antigens have corresponding protein molecules known as blood group antibodies (agglutinins) in blood plasma. These antibodies can react with the antigens under the lock and key hypothesis should they be similar to the antigens brought into the recipient's blood, leading to the formation of a precipitate or an agglutinate in blood.

Therefore an individual should not have blood group antibodies corresponding or similar to his blood group antigens in order to avoid agglutination. Consequently, individuals should have the following antibodies not corresponding to their antigen to avoid blood clotting.

Example

1. A man having blood A marries a woman having blood group AB. What are the possible genotypes and phenotypes of their offsprings if the man is heterozygous for blood group A?

Let I^A represent the allele for formation of antigen A

Let I^B represent the allele for formation of antigen B

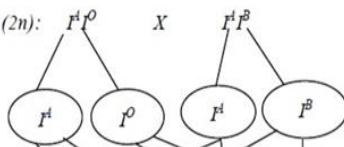
Let I^O represent the allele for no formation of antigen A or B

Parental phenotype: blood group A x blood group AB

Parental genotype (2n): $I^A I^O$ X $I^A I^B$

Meiosis

Gametes (n)



Offspring genotype (2n): $I^A I^A$ $I^A I^B$ $I^A I^O$ $I^O I^B$

F₂ genotypic ratio: 1 $I^A I^A$: 1 $I^A I^B$: 1 $I^A I^O$: 1 $I^O I^B$

F₂ phenotypic ratio: 2 blood group A: 1 blood group AB: 1 blood group B

Revision Question

A boy has blood group A and his sister has blood group O. which combination of genotypes and phenotypes do you think their parents have. Show your working.

The importance of blood groups

1. They are important during blood transfusion where they are used to prevent agglutination (precipitation) of blood of the recipient. To avoid agglutination, the donors blood group should be compatible (matching with) to that of the recipient by having the donors blood group antigen that is different from the blood group antibody of the recipient.

When the recipient's gets antibodies from the donor, such antibodies become diluted in the recipient's blood and so cause either minor clotting of blood or no blood clotting at all and so cannot lead to death of the recipient. However, in case the donor introduces an antigen that is similar to the antibody of the recipient, it stimulates the recipient's blood to produce more antibodies which attack and react with the donor's antigen to cause severe blood clotting. Therefore an individual with a specific antigen on the red blood cell membrane does not possess its corresponding antibody in the blood plasma to avoid agglutination.

Blood plasma permanently contains two blood group antibodies a and b which do not correspond with a specific antigen in blood to avoid agglutination e.g. a person with blood group A has antigen A and antibody

to avoid agglutination. A person with blood group B cannot donate blood to a person of blood O because antigen B in the donor's blood will be attacked by antibody b in the recipient's blood leading to agglutination. The same applies to blood group A and blood group AB donors to blood group O recipients.

It is possible for blood group A to donate blood to blood AB, because the donors blood, blood group A, has antigen A which cannot stimulate the recipient's blood group AB to attack antigen A since blood group AB individuals lack antibodies that can attack antigen A to cause an agglutination.

A person of blood group AB cannot donate blood to a person of blood group O. This is because the donor's blood has antigen A and antigen B, which stimulate the recipient's blood to produce corresponding antibodies a and b, which then attack and react with antigen A and B in the recipient's blood.

Blood group AB individuals can receive blood from all other individuals having other blood groups. Therefore individuals with blood group AB are called universal recipients. This is because such individuals have no antibodies in their blood plasma that can react with antigens A and B in the donor's blood.

Individuals with blood group O can donate blood to all other blood groups and are therefore called universal donors. This is because blood group O individuals do not have any antigens in their red blood cells that can react with antibodies in the blood plasma of the recipient to cause agglutination.

The table below summarises the possible and impossible blood transfusions.

Recipient		Donor's blood group			
Blood group	Antibody in plasma	A	B	AB	O
A	B	✓	X	X	✓
B	A	X	✓	X	✓
AB	None	✓	✓	✓	✓
O	a and b	X	X	X	✓

✓ = compatible with recipients blood

X = Incompatible with recipient i.e. agglutination occurs

- They are used in **settling court cases** about who the father of the child is (i.e. paternity suits). Although blood groups cannot prove beyond reasonable doubt who the father of the child is it is possible to use their inheritance to show that an individual could possibly be the father of the child.

Consider a mother who is of blood group O having child of blood group O and the child produced also with blood group O. she claims that the father is a man whose blood group is AB. Since the child is blood group O its only possible genotype is IOIO and it must therefore have inherited one IO allele from each parents. Since the man is of blood group AB he cannot donate the IO to the child and therefore he cannot be the father of the child. Even if the father was found to be of another blood group such as blood group A still the evidence will be insufficient because any other man can possess such a blood group and donate the IO allele to the child. Therefore a DNA test should be carried out to confirm who the father of the child is.

3. Blood groups can also be used as an **evidence of evolution**. This is because organisms of different species having similar blood group systems such as the ABO system are believed to have originated from the same ancestor in the course of evolution for example humans, chimpanzees, gorillas, Baboons e.t.c.

THE RHESUS BLOOD GROUP SYSTEM

The rhesus blood group system is also inherited in a similar way to the ABO blood group system. Individuals with red blood cells with the D-antigens (Rhesus factor) are said to be rhesus positive (**Rh+**) however **Rh+** allele is taken to be dominant over the rhesus negative (Rh-) allele. The Rhesus factor is controlled by three alleles C, D and E which determine the production of D-antigens on the surface of the red blood cells. Allele mainly determines the production of D-antigens and it is this antigen which is the fundamental determinant of blood grouping under the rhesus blood group system.

Marriage complications of the Rhesus system

If an Rh+ man marries an Rh- woman, most of their children are likely to die immediately after birth or before birth. The first child usually survives because the time is too short for the mother to produce enough antibodies known as anti D agglutinins which can pass to the foetus to cause death. If a mother becomes pregnant after the first child, the Rh+ foetus formed can die due to antibodies of the mother

entering the foetal circulation. This is because during the first pregnancy, especially the time of giving birth, the blood of the child which is Rh+ may mix with that of the mother which is Rh-, thereby introducing D-antigens in the mother's blood. Also, some of foetal erythrocytes of the first child with D-antigens in them may cross the placenta and enter the body of the Rh- mother towards the end of the gestation period. D-antigens will then stimulate the mother's blood to produce many antibodies called anti D-agglutinins which attack and react with the D-antigens introduced in the mother's blood if the mother becomes pregnant again and the child is Rh+. These antibodies in the mother's blood will pass via the placenta and enter the foetal blood circulation, where they will attack and react with D-antigens in the child's blood causing the red blood cells of the child to clump together, this disease is known as **haemolytic disease of the new born** (erythroblastosis foetalis). This results into acute anaemia of the foetus which can lead to death of the foetus.

The problem may be solved in two major ways;

- The mother may be injected with anti-D-agglutinins in the first 72 hours after her first born so as to make her immune system insensitive towards D-antigens.
- By carrying out proper intermarriages where by Rh+ man marries Rh+ woman and Rh- woman gets married to Rh- woman.

Another blood group system in humans called the MN blood group system is controlled by 2 alleles **M** and **N** which are co-dominant. M and N alleles also

determine the production of antigens respectively. Individuals therefore have the following genotypes if this blood group system **MM**, **NN**, **MN**.

SUB-TOPIC 3: VARIATION

VARIATION

This is the description of the differences in phenotypic and sometime genotypic characteristics shown by organisms belonging to the same species or natural population due to interaction between the genes and the environment. Variations can be clearly seen among sexually reproducing organisms due to some differences in genetic constitution that occur during meiosis.

Variations are important because they make organisms better adapted to their environment. This is because some variations within the population are favorable (beneficial) to the organisms possessing them making such organisms better adapted or fit to survive in their environment and this gives a selective advantage to those organisms possessing them. Other variations are unfavorable because they are disadvantaged in the environment and organisms possessing such. The first organisms therefore survive, grow and reproduce and pass on their favorable characteristics to the next generation. If this continues for a long time it leads to the emergence of new species in the population having good characteristics and therefore better adapted to the environmental change. Variation is therefore a raw material for

evolution during which new species are formed.

TYPES OF VARIATION

There are two types of variation namely;

- Continuous variation
- Discontinuous variation

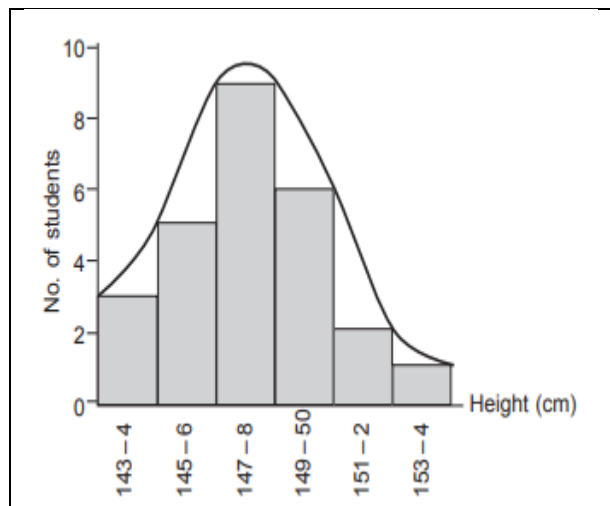
Continuous variation

This is the type of variation whereby characteristics in a given population show a smooth gradation between two offsprings with the intermediate phenotype being the majority in the population and few individuals being at the extremes of the characteristics. This implies that organisms do not show any clear cut differences among themselves. It is brought about by the influence of many genes but can also be influenced by environmental factors. Continuous variation characteristics are therefore influenced by both environmental conditions and genetic factors.

Examples of continuous variation characteristics include skin color, height, weight, intelligence e.t.c. These characteristics are quantitative i.e. they can be measured and are controlled by many genes. These characteristics are therefore described as **polygenic characteristics** i.e. characteristics which are controlled by a

number of genes during their transmission i.e. many genes control a single characteristic. These genes are sometimes referred to as **multiple genes**. Although these genes may determine a single characteristic each of them has its own alleles which occur on different loci.

The transmission of x-tics that are controlled by many genes from one generation to another is **called polygenic inheritance** and such characteristics are known as polygenic characteristics. The statistical analysis of these characteristics gives a normal distribution curve shown below;



The above graph shows that continuous variation characteristics appear in the graded pattern and therefore show a smooth graduation. It also shows that most of the individuals in the population lie along the normal.

Discontinuous variation

This is the type of variation where individuals show clear cut differences among themselves in the population with no

intermediate phenotypes between them but instead they are grouped into distinct categories. These characteristics are therefore qualitative and cannot be measured. Such characteristics include sex, blood groups in man, tongue rolling, e.t.c. This variation is controlled by a **single gene** and cannot be influenced by environmental conditions i.e. they are purely genetically controlled.

CAUSES OF GENETIC VARIATION

This is caused by the **gene reshuffling** and **mutations**.

Reshuffling of genes refers to the random orientation of chromosomes at the equator of the spindle during meiosis which changes the positions of the genes on the chromosomes. Reshuffling of genes include the following;

Crossing over:

This is the exchange of genetic material between the non-sister chromatids of homologous chromosomes during pachytene stage of prophase I of meiosis. This produces new linkage groups and so provides a major source of genetic recombination of alleles on chromosomes which results into formation of recombinant gametes and leads to variation in the offsprings formed. When the gametes undergo random fertilisation, offsprings with different genetic constitution are produced.

Independent assortment

During independent assortment in during metaphase 1, chromosomes are distributed

randomly at the equator and segregate (separate). It is by pure chance as to which chromosome from each homologous pair ends up in a daughter cell at the end of meiosis and therefore all sorts of allele combinations are possible in the gametes. This reshuffles the existing alleles thereby producing new genetic recombination's in of the gametes and the offsprings formed from these gametes when they fuse randomly during fertilisation.

Independent assortment can therefore be defined as the random orientation of the chromatids of homologous chromosomes (bivalents) on the equator of the spindle during metaphase 1 of meiosis which determines the direction in which the pairs of chromatids move during anaphase 1. This is so because after random arrangement on the equator of the spindle the chromosomes subsequently segregate (separate) independently thereby leading to the mixing of genes in addition during metaphase II the orientation of the pairs of chromatids is again random at the equator of the spindle and determines which chromosomes migrate to the opposite poles of the cell during anaphase II.

Fertilization

Fertilization occurs randomly between the male and female leading to mixing of genes in different combinations.

Mutation

Mutations change the genotype of an organism with respect to a specific characteristic as it produces new alleles in the population hence making it to vary due

to the combination of mutant and non-mutant gametes during random fertilisation.

Genetic drift

This refers to a loss of genes from a small population or the change of genes of a small population by chance alone and not natural selection which results into the change of the gene frequency of the small population. This changes the phenotypic appearance of the organisms thereby making them to vary.

Cross breeding

This mixes genes from different individuals resulting into the formation of hybrids (heterozygotes) with improved qualities compared to the parents. Cross breeding can be defined as mating of organisms that are pure breeding in which one has better x-tics than another which results into the formation of the hybrid offspring.

MUTATION

This refers to the sudden or spontaneous genetic changes which occur in the genetic constitution of an organism. These changes are brought about by mutagens. Mutations change the genotype of an organism with respect to a given characteristic as it produces new alleles in the population. Mutations cause permanent genetic variations unlike reshuffling of genes whose genetic variations are temporary as they can be undone (removed) in subsequent generations due to chromosomes rearranging themselves alongside with their genes.

During mutation, some genetic material may be lost, doubled, inverted, translocated (moved), and mixed, resulting into mutants

having different genetic constitution from the non-mutants. The mutants formed transmit these mutated genes to their offsprings through random fertilisation which makes the offsprings become different from the non-mutants.

Individuals or cells resulting from mutations are known as mutants. The sudden changes in the genetic constitution of an organism are brought about by substances called **mutagens**. The common mutagenic agents include the following;

- Gamma rays
- Alpha and beta particles
- X-rays
- Cosmic rays
- Ultra violet rays
- Excessive heat
- Chemicals such as caffeine and heroin, opium, cocaine
- DDT and other insecticides
- Colchicine
- Marijuana
- Formaldehyde
- Some food preservatives, color and sweeteners
- Accidents.

NOTE:

*Mutations usually occur in germ cells during gamete production and so lead to the formation of mutant gametes. When these gametes fuse randomly with mutant or non-mutant gametes of another parent, a mutant offsprings is formed which must have unique characteristics compared to the parents. Such mutations are known as **gametic mutations**. Some mutations may occur in*

*somatic cells and are therefore known **somatic mutations** e.g. cancer.*

TYPES OF MUTATIONS

There are two types of mutations (germ mutations) namely;

- Chromosomal mutations
- Gene mutations (or point mutations)

Somatic mutations cannot be inherited while gametic mutations can be transmitted from parents to the offsprings indeed most of the gene and chromosomal mutations are gametic and can therefore be inherited or they are usually recessive.

CHROMOSOMAL MUTATIONS

This refers to the changes that occur in the chromosome number or chromosome structure but can be transmitted from the parents to the offspring.

Chromosome mutations usually occur during prophase I of meiosis where a number of mistakes are made on the chromosome structure i.e. chromosomes break and join wrongly. It can also arise during anaphase I and II where by some chromosomes may fail to separate and move to opposite poles which brings about an increase in the number of chromosomes or polyploidy i.e. an increase in the number of chromosomes beyond the normal diploid number. The process by which chromosomes fail to separate during anaphase I of meiosis is known as non-disjunction.

Chromosomal mutations are divided into the following categories namely;

a. Mutations that change the chromosome structure

Such mutations include the following;

i. Deletion

This is a form of mutation where part of a chromosome breaks and gets lost leading to the formation of a number of chromosomes that is shorter than the original chromosome. This is the most dangerous form of mutation because it leads to loss of genes from the chromosome. In human beings deletion leads to cat cry syndrome where the voice box fails to develop properly.

ii. Inversion

This is the form of mutation where part of a chromosome breaks, rotates through 180 degrees and rejoins in the reverse way, this in turn changes the sequence of genes on the chromosomes as well as the sequence of bases on the DNA strand which makes the offspring vary.

iii. Duplication

This is a form of mutation whereby a portion of chromosomes bearing certain gene is doubled. This form of mutation causes over amplification of certain phenotypes whose genes have been duplicated. This form of mutation is of importance in crop and animal husbandry since it increases yields and improves other characteristics.

iv. Translocation

This is a form of mutation whereby a portion of a chromosome breaks and is moved to join another chromosome which maybe homologous or non-homologous.

b. Mutations that change the chromosome number

These are mutations that affect the whole chromosome and change the chromosome number in the cell. This normally occurs during meiosis at anaphase I and II where two of the same type of chromosomes or chromatids fail to separate and are transmitted together into a single gamete leaving the other gamete empty a concept known as **non-disjunction**. The other chromosomes not affected by non-disjunction are usually distributed normally by meiosis into gametes formed.

Non-disjunction results into formation the formation of gametes either with an extra number of chromosomes ($n+1$) ($n+2$) ($n+3$) e.t.c. or a less number of chromosomes ($n-1$). Therefore, this condition where by half of gametes contain extra number of chromosomes while the other half of gametes formed during meiosis contain a chromosome missing is known as **aneuploidy**.

If a chromosome is present in triplicate in the fertilised egg (so that the cell has a total of $2n+1$ chromosomes), the aneuploidy cell formed is said to be **trisomic** and if a chromosome is missing, so that the zygote cell formed has $2n-1$ chromosomes, the aneuploid cell is said to be **monosomic**. Mitosis will subsequently transmit this variation to all embryonic cells (somatic cells) leading to the formation of an organism with variation in the form of a set of symptoms caused by the abnormal dose of genes associated with extra or chromosomes missing.

Some organisms have more than two complete sets of chromosome missing in each of their cells and such organisms are called **polyploids**.

NOTE:

The zygote produced with odd number of chromosomes in the above cross containing less than the diploid number of chromosomes usually fails to develop. But those with extra sets of chromosomes though odd numbered or even numbered usually develop and in most cases this produces severe abnormalities. In humans, non-disjunction causes the following abnormalities.

1. DOWN'S SYNDROME (mongolism)

This disease is also referred to as mongolism and it is caused by an extra autosomal chromosome in position number 21 of the homologous chromosome pairs.

Mongolism occurs as result of non-disjunction in chromosome number or during anaphase I of meiosis in gametes formation leading to formation of abnormal gametes with 24 chromosomes. In such a case if a normal gamete fertilizes an abnormal gamete, the zygote formed will have 47 chromosomes instead of the normal 46. This form of syndrome occurs in both males and females. It can take place during sperm production but it's more common during oogenesis.

Mongolism is due to a type of mutation known as **translocation** in which chromosome 21 is translated or moved to chromosome 14 in most cases or chromosome 22 in some cases. Most non

disjunction occurs in meiosis I where it causes failure of the whole chromosome 21 to separate if it occurs in meiosis II the chromatids fail to separate leading to Down's syndrome.

Mongolism causes miscarriage in mothers and the chances of it to occur increases with age of the females. This form of syndrome results in individuals having the following characteristics;

- They are mentally retarded
- They have a low resistance to infections and therefore have a short life span
- They have frequent saliva flow from the mouth
- They have slit eyed appearance.

2. HETEROSOME NON-DISFUNCTION

This is non-disjunction of sex chromosomes which produces a variety of aneuploid conditions which include the following;

Klinefelter's syndrome (XXY)

This results from non-disjunction of the sex chromosomes pair in either males or females resulting into a male with 47 chromosomes and genotype XXY. It may occur if a normal Y sperm fertilizes an abnormal egg. It may also occur if an abnormal sperm (XY) fertilizes a normal egg (X).

Individuals suffering from Klinefelter's syndrome have the following characteristics;

- They are infertile (sterile) and therefore they don't produce sperms

although erection and ejaculation occurs.

- Their testes are usually very small compared to the normal males i.e. the testes fail to grow to the expected size.
- They have very subnormal intelligence
- They tend to be taller than the average height
- They have little facial hair
- They possess some female secondary sexual characteristics e.g. developed breasts and wide hips.
- Their trunk may show signs of obesity

Turner's syndrome (XO)

This monosomy condition occurs in females resulting into a female with 45 chromosomes and genotype XO. It occurs as a result of non-dysfunction which results into an abnormal egg or an abnormal sperm. If an abnormal sperm fertilizes a normal egg this condition occurs and if an abnormal egg that is empty is fertilized by a normal sperm containing X chromosomes this condition again occurs. Individuals with Turner's syndrome vary from others by having the following characteristics;

- They do not show female secondary characteristics such as developed breasts, menstruation, widening of hips e.t.c.
- They are infertile with no ovaries but with a small uterus.
- They have a short height than the women average height.
- They have a webbed neck.

- They are usually of normal intelligence

Triple X syndrome (XXX)

This also occurs in females due to non-disjunction which results into formation of an abnormal egg containing XX chromosomes and if such an egg is fertilized with a normal X sperm the triple X female occurs with 47 chromosomes and these individuals have the following characteristics;

- They are fertile females
- They are mentally normal
- They are physically normal
- They have a very high sex libido

XYY syndrome

This condition occurs in males with genotype XYY. It occurs in case the Y chromosome undergoes duplication and fails to separate at anaphase I. This may result into production of abnormal sperms containing YY which if they fertilize a normal X egg and XYY syndrome occurs. Individuals with this syndrome vary from other males by having the following characteristics;

- They are usually very aggressive and therefore common in prisons and security forces.
- They are fertile males.
- They are giants.
- They are mentally and physically normal

POLYPOIDY (EUPLOIDY)

This is a condition whereby cells of organism possess extra sets of chromosomes beyond the normal diploid number. Polyploidy therefore makes the genetic constitution of an organism multiplied to become $3n$, $4n$, $5n$, $6n$ e.t.c.

Polyploidy is a useful phenomenon in plant breeding where the chromosome number is increased so as to improve on the vigor (characteristic) of the plant i.e. plants acquire better characteristics such as high yields, high resistance to diseases, quick maturity, high resistance to pests e.t.c. It is more common in plants than animals because the increased number of chromosomes in animal polyploidy causes errors in gamete formation unlike in plants which usually reproduce vegetatively without such errors.

Polyploidy brings about genetic variation within a population as it results into the formation of new and different genetic combinations within some individuals of the population. This makes some polyploids within the population better adapted than their original parents and so are favoured by a selection pressure of nature to survive, reproduce and transmit their adaptive variations to their offsprings. However, better adapted polyploids may fail to interbreed with diploid organisms, thereby forming a new species due to possession of extra sets of chromosomes beyond the diploid number.

Polyploidy also results into formation of new species via **interspecific hybridisation**, a process in which the F1 hybrids formed

are sterile because their chromosomes cannot form homologous pairs being that they arise from organisms of different species, but when a diploid number of chromosomes of F1 hybrids is doubled due to non-disjunction, tetraploids ($4n$) can be formed as F2 hybrids which can interbreed among themselves to produce fertile offsprings. The F2 tetraploids formed by interspecific hybridisation can interbreed among themselves to form fertile offsprings but cannot interbreed with any of the original parents because of having extra sets of chromosomes thereby becoming a new species.

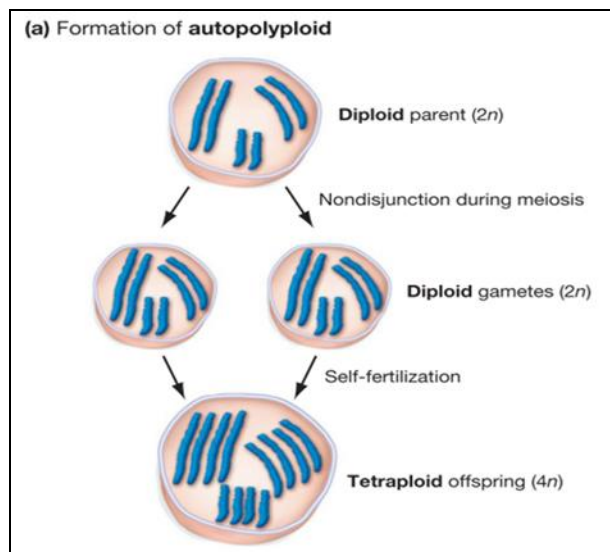
The F2 offsprings formed are described as allopolyploids because they are formed by a type of polyploidy known as halopolyploidy. Halopolyploidy is the one which occurs when two different species interbreed and produce a sterile F1 hybrid whose chromosome number gets doubled by non-disjunction thereby changing the sterile F1 hybrids into fertile F2 hybrids. The halopolyploids formed are fertile with each other but cannot interbreed with a diploid parental species. The F1 hybrids are sterile because the set of chromosomes from one species cannot pair during meiosis with another set of chromosomes from another species.

The tetraploids formed are fertile because homologous pairing of chromosomes can occur in meiosis, as the two sets of parental chromosomes present in diploid gametes are produced which contain nine chromosomes from the parental cabbage and 9 chromosomes of the parental radish. There

are two forms of polyploidy namely; autopolyploidy and allopolyploidy

1. Autopolyploidy

This is where the chromosome number of some individuals in a given species is increased either naturally or artificially by preventing cytokinesis or preventing the formation of spindle fibres during cell division. This can be done artificially using colchicines which prevents formation of spindle fibers thereby increasing the chromosome number. This mutation prevents the tetraploids from successfully interbreeding with the diploid plants of the original population leading to the reproductive isolation. However, the tetraploids can still produce fertile offsprings by self-pollination or by mating with other tetraploids



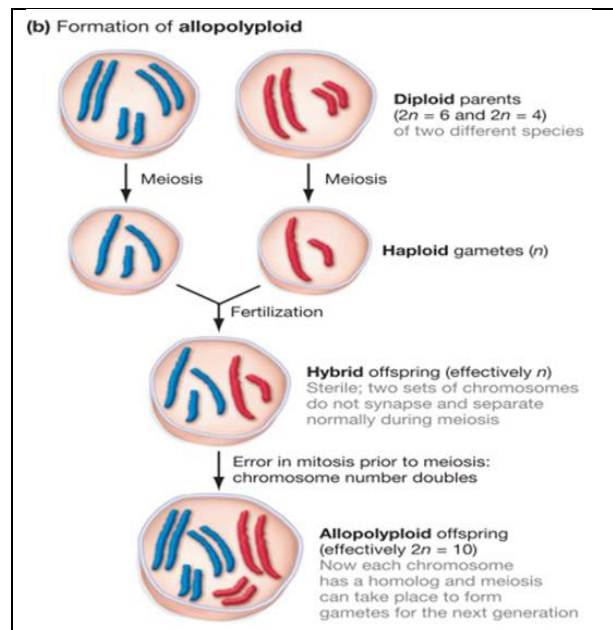
Autopolyploid can be as fertile as diploids if they have an even number of chromosomes and they can be infertile if they have odd number of chromosomes because they cannot form homologous pairs. Colchicines

and other related drugs have been used in breeding in certain varieties of tobacco and tomatoes whose cells have a large nucleus.

2. Allopolyploidy

This is a condition which arises when the chromosome number in the sterile hybrids gets doubled and produces fertile hybrids. Sometimes the F1 offsprings formed may be sterile but if these individuals are crossed with another related

During meiosis in F1 hybrids chromosomes from each parent cannot pair together to form homologous chromosomes hence the F1 hybrids produces gametes with a diploid set of chromosomes. This brings about allopolyploid as illustrated below;



The allopolyploid is fertile because homologous pairing of chromosomes can occur in meiosis as the two sets of parental chromosomes are present. Allopolyploid is an example of interspecific hybridization i.e.

form of sympatric speciation which occurs when a new species is produced by the crossing of individuals from two unrelated species.

Gene mutations (point mutation)

This is a sudden change in the sequence of nuclear nucleotides or bases of DNA. These mutations are of the following types;

1. **Substitution.** This type of mutation whereby or more bases of nucleotides may be replaced with wrong nucleotides or bases. Sickle cell anemia in man is an example of a substitution gene mutation where an individual gets abnormal hemoglobin S in the red blood cells. Such individuals have a wrong better polypeptide chain in their hemoglobin due to the substitution where by glutamic acid that causes the formation of normal hemoglobin

is replaced by another amino acid called **hyaline** which caused formation of hemoglobin S in sickle cell anemia in individuals.

2. **Deletion.** This is a form of gene mutation where a section of DNA is lost. This results into wrong transcription and wrong translation processes in protein synthesis. This mutation is dangerous because it leads to absence of certain structures or wrong physiological processes taking place in an organism.

3. **Inversion.** This is where a group of nucleotides in DNA becomes reversed after rotating through 180 degrees.

4. **Insertion.** This is where one or more nucleotides may be fixed in a particular DNA strand.

SUB TOPIC 4: POPULATION GENETICS

Population genetics is the branch of biology that deals & provides the mathematical structure for the study of micro evolutionary process.

Microevolution refers to the change in one gene pool or the allele frequencies that occur within a population over time. Mainly due to mutations, genetic drift, gene flow, selection (natural and artificial), gene flow for example industrial melanism, microevolution of resistance to antibiotics, pesticides etc.

Macroevolution refers to speciation or evolutionary changes at a level higher than the species level, resulting into formation of

a higher taxonomic group such as class or genus. Some biologists believe that macroevolution results from a build-up of small changes due to microevolution. One common misconception about evolution is that individual organisms evolve. It is true that natural selection acts on phenotypic x-tics of individuals to determine the fate of genotype. Each organism's combination of traits affects its survival and reproductive success compared to other individuals; it's only those individuals that can reproduce successfully before death that contribute to the future species. But the evolutionary impact of natural selection is only apparent in the changes in a population of organisms over time, for this reason; though individual

organisms are acted upon by natural selection, its populations that evolve but not individuals. The population is the smallest unit of evolution.

TERMS USED:

A **population** is a group of organisms of the same species living together in a given habitat at a given time.

A **gene** is the basic unit of inheritance of a particular characteristic. The process of natural selection determines which gene passes on to the gene pool of the next generation.

Alleles are the alternative forms of the same gene, determining contrasting characteristics.

The genetic composition of an organism with respect to particular alleles is called the **genotype**. The observable characteristic of an organism due to its genotype and sometimes environmental influence is its **phenotype**.

Evolution is the process of change in the frequency of genes and alleles in a gene pool or population, by a mechanism of natural selection of the fittest genes and alleles.

NOTE

Fitness is the ability of an individual to produce surviving, fertile offspring relative to that ability in other individuals in the population.

Evolution comprises of change in the frequency of alleles in a gene pool from generation to generation. A population whose gene pool changes consistently from

*generation to generation is undergoing evolution and is said to be a **dynamic gene pool**. A population whose gene pool does not change from generation to generation does not undergo evolution and is said to be **static**. A static gene pool represents a species population whose genetic variation is inadequate to cause evolutionary change.*

A **species** refers to a group of organisms with similar features which can interbreed successfully to produce fertile offsprings.

Gene pool; Refers to the total variety of genes and alleles present in a sexually reproducing population. A population whose gene pool shows consistent change from generation to generation is said to be undergoing evolutionary change.

NB:

A static gene pool is one where genetic variation is inadequate to bring about evolutionary change.

Whereas natural selection happens on individual organisms of a species, its only populations which can evolve.

Allele frequency refers to the total number of copies of a given allele expressed as a percentage of the total number of alleles for that gene in a population. For example in human beings, production of body pigments is determined by a dominant allele while the recessive allele results into no pigment production (albinism). The frequencies of the dominant and recessive alleles are 99% and 01% respectively. Since the total percentage is 100%; $99 + 01 = 100$. However, frequencies in population genetics are usually represented as decimals rather

than percentages or fractions, $\rightarrow 0.99 + 0.01 = 1.00$.

Mathematically; if we let p and q to represent the dominant and recessive allele frequencies respectively,

Then $p + q = 1$ (i)

From equation (i) above; if the allele frequency of either allele is known, the allele frequency of the other can be determined. E.g. If the allele frequency of the recessive allele is 25%,

Then $q = 0.25$. Using $p + q = 1$, $p = 0.75$.

Genotype frequency refers to the total number of individuals carrying a particular genotype expressed as a percentage of the total population.

In most populations, it's only possible to estimate the frequency of two alleles in a homozygous recessive state as this is the only genotype which can be directly observed phenotypically. E.g. 1 person in 10000 is albino. Albinism is known to be a recessive character, for the person to be an albino, they must be possessing two copies of the defective allele (homozygous recessive).

The mathematical relationship between the frequencies of alleles and genotypes in populations was developed by Hardy and Weinberg. The relationship is therefore known as the '**Hardy-Weinberg principle**'.

Hardy-Weinberg's principle

It states that "*The allele and genotype frequency of a large sexually reproducing population remains constant from*

generation to generation provided that disruptive factors like mutation and selection do not act"

The gene pool of such a population remains static and the population is said to be in Hardy-Weinberg equilibrium, it cannot undergo evolutionary change. For this principle to hold, the following factors must be fulfilled:

- Provided the population is sufficiently large that no genetic drift occurs. The smaller the population, the more likely it is that allele frequencies will fluctuate by chance from one generation to the next.
- Mating should be random such that no sex selection occurs. If individuals mate preferentially within a subset of the population, such as their close relatives (inbreeding), random mixing of gametes does not occur, and genotype frequencies change.
- All genotypes should be equally fertile such that there is no selection or genetic load.
- No mutations should occur as these tend to increase genetic diversity. The gene pool is modified if mutations alter alleles or if entire genes are deleted or duplicated.
- Provided generations do not overlap.
- There should be no emigration or immigration i.e. there is no gene flow between populations.
- Natural selection should not act, as this would favour some genotypes over others. Differences in the survival and reproductive success of

individuals carrying different genotypes can alter allele frequencies. All gene types are equally fertile, so that no selection occurs

NB:

In prevalence of the above factors, the frequencies of all alleles and genotypes will remain constant over generations. In case all or at least one of the above factors is reversed, the frequencies are prone to change and the stability of the population is upset. This initiates evolutionary change.

Hardy-Weinberg equation is a mathematical relationship between the frequencies of alleles and genotypes in a population. This can be used to calculate genetic changes in populations.

Considering a population with a certain gene occurring in two allelic forms, one homozygous for a dominant allele **A** and the other for a recessive allele **a**; all the F1 off springs will be heterozygous (**Aa**). If the frequency (probability) of **A** = **p** while that of **a** = **q**. The results from a cross between two F1 organisms would be as follows:

F1 phenotypes	Heterozygous	X	Heterozygous
F1 genotypes	Aa		Aa
Gametes	A a		A a
Random fertilization	AA (p ²)	2Aa (2qp)	aa (q ²)

Therefore:

p² = homozygous dominant

2pq = heterozygous

q² = homozygous recessive

Genotype frequency (sum of the 3 genotypes) = 1

$$p^2 + 2pq + q^2 = 1$$

In mathematical terms p + q = 1 is the mathematical equation for probability and p² + 2pq + q² = 1 is the binomial expansion of that equation i.e. (p + q)². That is allele frequency is p + q = 1 and genotype frequency is p² + 2pq + q² = 1

Examples

1. One person in 10000 is albino, i.e. the albino genotype frequency is 1 in 10000. Since albino is recessive;

$$q^2 = 1/10,000 = 0.0001$$

$$q = \sqrt{0.0001} = 0.01$$

Therefore the frequency of the albino allele is 0.01 or 1%

Since p + q = 1

$$p = 1 - q$$

$$p = 1 - 0.01 = 0.99$$

Therefore the frequency of the dominant allele in the population is 0.99 or 99%

Since p = 0.99

$$p^2 = 0.99^2 = 0.9801$$

Therefore the frequency of the homozygous dominant genotype is 0.9801 or 98%

$$2pq = 2 \times 0.99 \times 0.01 = 0.0198$$

The frequency of heterozygous genotype is 0.0198 or 2%

2. In a population where 14% of babies are born with sickle cell anaemia, what is the percentage of the babies born with sickle cell trait?

Let $Hb^A Hb^A$ = normal blood (homozygous)

$Hb^A Hb^S$ = sickle cell trait (heterozygous)

$Hb^S Hb^S$ = sickle cell anemia (homozygous)

Since $Hb^S Hb^S = 14\%$, then $q^2 = 0.14$

And $q = \sqrt{0.14} = 0.374$

Since $p + q = 1$, then $p + 0.374 = 1$

$p = 1 - 0.374 = 0.626$

$p^2 = (0.626)^2 = 0.392$

Then $2pq = 2 \times 0.626 \times 0.374$

$= 0.468$

Hence 46.8% of the babies born have sickle cell trait.

3. In a population of 200 plants 128 are homozygous tall, 64 are heterozygous tall and 8 are dwarf.

i) Using suitable symbols, state the genotype of all the plants

ii) Calculate the allele frequency of t and T

iii) Calculate the genotype frequency

4. In a Caucasian population, the frequency of individuals affected by cystic fibrosis is approximately 1 in 2500. This is a recessive disorder and affected individuals are homozygotes. If q represents allele

frequency of the disease, find the frequency of the carrier genotype.

5. In a human population the gene responsible for tongue rolling is dominant over the gene for non-tongue rollers. The population of tongue roller is 84% and non-tongue roller is 16%. Find the percentage of individuals, who are,

i) Homozygous for tongue rolling

ii) Heterozygous for tongue rolling

The implications of the Hardy- Weinberg principle

1. Sexual reproduction with its reshuffling of genes is not by its self-enough to cause evolution, since it does not alter the allele frequency but only alters the genotype frequencies. Reshuffling of genes only changes the genetic combination by forming recombinants (a process called **genetic/sexual recombination**) through: -

- crossing over during meiosis
- Independent assortment and segregation during meiosis.
- Random fusion of gametes

2. Since it states the conditions under which evolution will not occur, the Hardy – Weinberg law indicates that if those conditions do not exist, evolutionally change is likely to occur. Thus, change in allele frequency causing evolution is likely to occur if:

- There is no random breeding.
- The population is small and leads to **genetic drift**.

- Genotypes are not equally fertile, so there is **genetic load**.
- Populations are close, causing **gene flow** between population
- Mutation occurs
- Natural Selection occurs
- Generations overlap causing gene flow.

3. Measurements of allele frequency provide a means of measuring the rate of evolution change.

Factors responsible for changes in allele frequencies of the population

The 4 major sources of genetic variation within a gene pool are;

- Crossing over during meiosis
- Independent segregation during meiosis
- Random fertilization
- Mutation

Others are explained below:

Natural selection:

This tends to favour alleles and genotypes that produce environmentally adapted phenotypes, leading to increase in their frequencies while those that are less adapted to the environment are eliminated hence their frequencies decline.

Gene flow:

It refers to the movement/continual interchange of alleles from one population to another as a result of interbreeding among the members of the two populations. This results into introduction of new alleles hence

from other populations leading to change in the allele frequencies of the population.

However, gene flow is said to be conservative to evolutionary change in the long run. It tends to ensure uniform distribution of alleles in all populations which reduces genetic variation and increases uniformity among organisms as all populations share a common gene pool, this limits the action of n/s. For this reason, interrupting gene flow is a prerequisite to evolutionary change and speciation.

Mutations:

Mutations are random occurrences which change the genetic constitution of organisms. They greatly increase genetic diversity, where advantageous mutations are favoured by natural selection and disadvantageous ones are phased out.

Non-Random Mating:

This occurs when there is sexual selection (a mechanism on non-random mating). It occurs when the presence of one or more inherited characteristics increases the likelihood of successful fertilization. In such cases, only organisms having certain characteristics will have high chances of reproducing hence passing on their traits to next generations, while those without such features will have reduced reproductive potentials. Only some alleles will be passed to next generation leading to change in their frequencies.

Sexual selection occurs when the presence of one or more inherited characteristics increases the chances of successful fertilisation of gametes. Many structural and

behavioural mechanisms in both plants and animals prevent mating from being random e.g.

- a) Flowers possessing larger and more bright coloured petals and greater amounts of nectar are likely to attract more pollinating insects
- b) Colour pattern in insects, birds, fish, mammals; and behavioural pattern involving nest building, territoriality and courtship makes animal mating selective.

Sexual selection thus ensures that organisms with more favourable characteristics have an increased reproductive potential so their alleles are passed on to the subsequent generations with increasing frequency. This change in allele frequency causes evolution. Other examples include eye colour in drosophila (females prefer red-eyed males), colour patterns in insects and birds, petal size and colour in flowers etc.

Genetic drift:

This refers to the change in the gene frequencies within a population as a result of chance rather than by n/s. Although chance events occur in populations of all sizes, they alter allele frequencies substantially only in small populations.

A phenomenon associated with genetic drift is the founder effect. A small population may become isolated from a large population and it may not be truly representative of the original population in terms of allele and genotype frequencies. Some alleles may be absent while others may be disproportionally represented.

Continuous breeding within the pioneer population will produce a gene pool with allele frequencies different from that of the original parent population; this is known as the founder effect (as it occurs in the founder population).

In the same way, a sudden change in the environment, (such as a fire or flood) may drastically reduce the size of a population, just by chance, certain alleles may be overrepresented among the survivors, others may be underrepresented, and some may be absent altogether. Ongoing genetic drift is likely to bring about changes in the allele frequencies of the population and may result into a gene pool that is different from the original population. This is referred to as the bottleneck effect, (named so because the population passed through a restricted path)

Random genetic drift may lead to the following;

- Total loss of some alleles from the population, due to death of the few individuals carrying such alleles
- Total extinction of the population
- The population becoming much better adapted to the environment
- Wide divergence of the population from the parent population, and all these occur just by chance rather than n/s.

Another effect of genetic drift is **gene fixation**. Gene fixation is the establishment of only one allele of a gene in a population as a result of eliminating its alternative alleles. The locus of the gene thus becomes homozygous in all individuals after fixation. Gene fixation may result from the founder

effects by genetic drift, or by natural selection against the eliminated alleles.

NOTE:

Whereas genetic drift may lead to a reduction in variation within a population it can increase variation within the species as a whole. Small isolated populations may develop characteristics unusual of the main population which may have a selective advantage if the environment changes. In this way genetic drift can contribute to the process of speciation.

Genetic load:

This is the existence within the population of disadvantageous alleles in heterozygous genotypes. Very many disadvantageous alleles are able to exist in populations in heterozygous forms as in this form they are rarely expressed phenotypically for possible elimination by environmental selection, for example albinism, colour blindness, sickle-cell anemia, etc. The maintenance of fairly high frequencies of a recessive allele which may be potentially hazardous in a homozygous recessive state is referred to as the **heterozygous advantage**. Thus, **heterozygote advantage** is a situation in which the heterozygote is **fitter** than either of the homozygotes. It maintains and increases the frequency of recessive alleles in the population. The most obvious example is illustrated by the sickle-cell trait.

Revision question

What is meant by genetic drift?

How can the genetic equilibrium of a population be upset?

SICKLE CELL TRAIT

Sickle-cell trait is a condition when an individual has one copy of the normal allele for hemoglobin production and a recessive allele for abnormal hemoglobin. Such heterozygotes/carriers have both normal and sickle-shaped red blood cells and this is referred to as sickle-cell trait.

Symptoms of sickle cell anaemia

The Red blood cell becomes **sickle-shaped** at low oxygen concentration. The abnormal haemoglobin molecules tend to crystallize, deforming some of the cells into a sickle shape. Sickle cells are useless to the body and so they are broken down causing anaemia. Anaemia results into oxygen deficit, leading to frequent illness, weakness and fatigue, poor physical development and dilation of the heart (large heart).

The sickle cells get clogged (jammed) in the capillaries and small blood vessels and prevent normal blood flow. This may cause heart damage causing rheumatism, gut damage causing abdominal pain, kidney damage leading to kidney failure and liver damage. A combination of heart damage and dilation of the heart may cause heart failure. The sickle cells collect in the spleen for destruction causing enlargement of the spleen.

Causes of sickle cell anaemia

Sickle cell anaemia results from a gene mutation in the gene producing haemoglobin as follows:

- Haemoglobin is made of four polypeptide chain, two chains which are 141 amino acids long and two β - chains which are 145 long.
- The DNA which codes for the sixth amino acids in the β - chain in haemoglobin has a mutant where by the base adenine replace thymine. This is a substitution mutation.
- The mRNA produced has the triplet code GUA (for the amino acid Valine) rather than GAA (for the amino acid glutamic acid).
- The β - chain produced has one glutamic acid molecule replaced by a valine molecule. Glutamic acid carries a negative charge and its polar, whereas valine is non- polar and hydrophobic.
- The presence of valine makes deoxygenated abnormal haemoglobin called (**haemoglobin s or HbS**) less soluble.

Thus. the low oxygen concentration when HbS losses it's oxygen, the molecules come out of the solution and crystallize into rigid rod – like fibres.

- These HbS fibres change the shape of the RBC which is normally a flat circular biconcave disc to become crescent (sickle) shaped. These sickle cells are less efficient in carrying oxygen hence cause anaemia and may block small vessels causing permanent organ damage and the possibility of death.

The distribution of the sickle cell allele is evidence of evolution in action.

The distribution of the sickle allele coincides with that of malaria. Malaria is a major

source of illness and death in many parts of Africa. Malaria is caused by the blood parasite, plasmodium.

Homozygous recessive individuals usually die before reaching adulthood thereby, eliminating two recessive alleles from the populations. Sickle-cell carriers have consistently shown a high resistance to malaria much more than both the normal and the sick. This therefore confers a selective advantage to the heterozygotes leading to consistently high frequencies of the sickle cell allele especially in such areas as the tropics where malaria is prevalent.

Explanation

The carriers have both normal and sickle-shaped red blood cells, the former contain very low levels of oxygen due to abnormal hemoglobin while the latter contain high oxygen levels. This makes it difficult for the plasmodia parasites to survive in the low oxygen environments in sickle cells and to adapt to constantly changing oxygen contents. Some of them die while others are effectively eliminated by the body defense system before establishment of the disease leading to resistance.

Revision question

Mutations are normally harmful when they are in homozygous recessive condition and yet they sometimes do not disappear from a population in a few generations. Why is this so? Illustrate your answer using a gene for sickle cell.

What factors are likely to bring about a change in the frequency of a particular gene in a population?

Explain the meaning of the following:

- Genetic variation
- Reproductive isolation

Explain how the gene frequency of a population may be altered.

SUB TOPIC 5: ORIGIN OF LIFE

EVOLUTION

Evolution is the gradual development of more complex organisms from the pre-existing less complex organisms over the course of time. It is the process by which new species are formed from pre-existing ones over a period of time. It is also a gradual process by which the present diversity of plant and animal life arose from the earliest and most primitive organisms.

THE ORIGIN OF LIFE

There are 5 major theories accounting for the origin of life on earth.

1. The theory of special creation

The theory of special creation asserts that life was created by a supernatural being at a particular time. This theory was up held by most of the world's major religions and institutions. The supernatural being is called God, and each religion and civilization has a specific name it gives its God, e.g. Allah by Muslims, Jehovah by Christians. It states that living organisms are created from no definable precursor. This occurred at successive intervals, each species being created separately.

It holds that; all species are independent, in the sense of being unrelated to each other; life on earth is young—perhaps just 6000 years old; and species are immutable, or

incapable of change. These beliefs were explained by the instantaneous and independent creation of living organisms by a supernatural being.

2. The theory of spontaneous Generation.

The theory of spontaneous generation asserts that life arose from non-living matter on numerous occasions by a process of spontaneous generation. This theory was held by Ancient Chinese, Babylonian and Egyptian civilizations.

The theory of spontaneous generation is also called the theory of **abiogenesis** since it asserts that life arose from non-living matter. For example, Egyptians thought that snakes arose from mud while Greeks believed that rats arose from garbage. There was also an outstanding belief that bacteria suddenly arose from spoilt milk. The theory of abiogenesis was disapproved in a series of experiments by Louis Pasteur in 1860.

He carried out an experiment on the broth of milk where by initially he left the milk to stand uncovered. He found out that it had gone bad. When he boiled the broth of milk, micro-organisms failed to develop and it did not go bad. He eventually concluded that the micro-organisms do not come from milk but are found in the atmosphere and when in contact with milk, they make it go bad.

3. The steady state theory

The steady state theory asserts that the earth had no origin, has always been able to support life, has changed remarkably little if at all and that the species had no origin. This theory proposes that earth has always existed and the species have always existed on the unchanging earth. Evidence of this theory is based upon;

- The increasing age of the earth with each improvement in scientific dating techniques.
- The presence of fossils, for example the coelacanth, latimeria off the coast of Madagascar.

4. The Cosmozoan Theory.

The Cosmozoan theory asserts that the life on earth came from elsewhere in outer space (the cosmos). The theory states that life had an extra-terrestrial origin. Evidence of this theory is based upon

- Repeated sightings of UFO's
- Cave drawings of rocket like objects and space men
- Reports of encounters with aliens
- The presence of organic molecules in meteoritic commentary material.

5. The theory of biochemical evolution.

The theory of biochemical evolution asserts that life rose according to chemical and physical laws. The theory suggests that the earth is about 4.5 -5.0 billion years old, the hostile conditions of the primitive earth lead to the formation of oceans of a **primordial soup** containing organic compounds from which life arose.

These organic molecules arose from gas mixtures using lightening, ultra-violet radiations or gamma radiations as energy sources. Water vapour arose from volcanic eruptions but during that era, the atmosphere lacked oxygen because it was too hot (about 4000°C – 8000°C). However, Oxygen occurred as Silicon dioxide and Iron Oxide.

Life is thought to have arisen from these organic molecules (amino acids). This theory was experimentally proved by a scientist, Stanley Miller in 1953. He exposed a variety of gas mixtures to an electric spark which represented lightening as a source of energy. By this means, Miller synthesised 15 amino acids, adenine and simple sugars like ribose.

From the same raw materials, Melvin Calvin using gamma radiations produced a mixture of amino acids, six carbon sugars, purines and pyrimidines. Synthesis of organic molecules is thought to have taken place in the atmosphere and the products were subsequently brought down to the earth's surface in heavy rains and accumulated in lakes and oceans.

Life is believed to have started in water and its more likely that the first organisms were heterotrophs feeding on the organic soup (sugars in the water) they respired anaerobically and reproduced asexually. Later on, some were able to utilise sunlight (solar) energy to synthesise new cellular materials.

Later on, Oxygen was evolved from photosynthetic organisms and this resulted into building up of Oxygen in the atmosphere. Once the first reproducing

organisms had originated, rapid evolution is thought to have occurred to produce more

complex and better adapted forms of organisms.

SUB TOPIC 6: MECHANISM OF EVOLUTION

There are three main theories of evolution Lamarckism, Darwinism and Neo – Darwinism

LAMARCKISM

Lamarckism is a theory of evolution that was proposed in 1809 by Jean Baptiste Lamarck (1744 -1829) to account for the mechanism of evolution based on two conditions (principles): the use and disuse of parts and the inheritance of acquired characteristics.

a) *The principle of use and disuse of parts.*

Changes in the environment may lead to changed patterns of behaviour which can necessitate new and increased use or disuse of certain organs or structures. Increased (repeated) use would lead to increased size, efficiency and effectiveness of the structures. While increased disuse would lead to decrease in size (atrophy) and decreased efficiency (degeneration) of the structure.

b) *The principle of inheritance of the acquired characteristics.*

Lamarck believed that the characteristics an individual acquired during its lifetime were inheritable and thus transmitted to the offspring.

Examples of Lamarckism

- Lamarck believed that the long necks and legs of the modern day giraffes

were a result of generations of short necked and short legged ancestors stretching their necks and legs to reach leaves at progressively high levels of trees. Each generation passed on their slightly longer necks and legs to their offspring until the size of the present day giraffe was reached.

- The shape of the flat fish is a result of the fish constantly lying on their sides in shallower water.

The significances of Lamarckism

Lamarck's emphasis on the role of the environment in producing phenotypic changes in the individual was correct. For example body building exercises will increase the size and efficiency of body muscles. However these acquired characteristics (phenotypic changes) are not heritable thus cannot be passed on to the offspring e.g. a body builder does not necessarily produce children with large muscles. This is because somatic changes do not affect the gene type and gametes, and are therefore not passed on to the offspring.

DARWINIAN EVOLUTION THEORY

Darwinism is a theory of evolution that was proposed by Charles Darwin (1809 – 1882) and Alfred Russell Wallace (1823 – 1913) in 1858 which asserts that natural selection is the mechanism by which new species arose from pre-existing species.

THE THEORY OF NATURAL SELECTION

The theory of natural selection is based on three observations and two deductions;

Observation 1:

Individuals within a population produce an average more offspring than are needed to replace themselves. This over production of offspring means that if they all survived, there would be an exponential increase in the size of any population

Observation 2:

The numbers of individuals in a population remain approximately constant. Thus despite the tendency to exponentially increase numbers by over production of offspring, most population actually maintain relatively constant numbers

Deduction 1:

Many individuals fail to survive or reproduce. Thus the members of the population constantly compete with each other in an effort to survive, meaning that there is a 'struggle for existence' within the populations.

Observation 3:

Variation exists within all populations. The offspring of many species show individual variations best adapted to their environment which let them survive and reproduce more offspring than the less adapted individuals. Thus the 'struggle for existence' or 'survival of the fittest'.

Deduction 2:

In the struggle for existence, those individuals showing variations best adapted to their environment have a reproductive advantage and produce more offspring than the less adapted ones.

This deduction is the hypothesis of natural selection. Where the better adapted variations have a selective advantage over the less adapted ones which are said to be at a selective disadvantage. As such, 'the fittest' individuals are selected for, while the unfit are selected against. The better adapted variations then increase in frequency while the less adapted variations die out.

Examples of Darwinism

The ancestors of the modern-day giraffe had necks and legs of varied length. These variations were genetic and therefore heritable. Intraspecific and interspecific competition for tree leaves favoured longer necked and longer legged variations over the shorter ones. The longer necked and longer legged forms would use their competitive advantage to feed on leaves at higher levels of trees, while the shorter ones would fail to reach these leaves and hence died of starvation. The longer-necked forms thus survived the competition and reproduced and thus perpetuated their favourable traits to subsequent generations. Over the course of time, selection for the longer forms led to development of the present day long-necked and long legged giraffes.

Therefore, in the process of natural selection, nature selects those individuals which are best fit and lets them survive and

reproduce, while the unfit fail to survive or reproduce and hence die out.

The significance of Darwinism

The theory highlights the role of variation in the process of evolution. Darwinism clearly illustrates the significance of the environment in creating the natural selection pressure on the population and the role of natural selection in producing evolutionary change in populations.

NEO – DARWINISM EVOLUTION THEORY

Neo-Darwin is a theory of organic evolution by the natural selection of inherited characteristics. It is a modern theory of evolution which is a modification of Darwinism based on evidence from genetics, molecular biology, palaeontology, ecology and ethology.

It states that organisms produce more offspring than can possibly survive resulting in a struggle for existence. Organisms differ in ways which affect their survival, that is, act as a selective advantage in the struggle for existence. Such variations are controlled by genes and are therefore inherited. Natural selection keeps species best adapted to a particular environment. For natural selection to bring about formation of new species, there has to be isolation. Isolating barriers which prevent them from interbreeding. The separated populations adapt to their own particular environment and may diverge eventually forming new species.

The significance of Neo – Darwinism

Neo - Darwinism attempts to prove the reality of evolution by:

- Establishing the fact that organism changed in the past, which is *past evolution*.
- Demonstrating a mechanism which results in organic changes which is *natural selection of genes or inherited characteristics*.
- Highlighting organic changes happening today which is *evolution in action*.

NATURAL SELECTION AT GENE LEVEL

Differential mortality is important because it occurs before the individual has had a chance to reproduce. It eliminates unfavourable alleles from the population. Any other process that also encourages the transmission of any favourable alleles and blocks transmission of unfavourable ones can be said to contribute towards evolutionary process e.g. in terms of breeding, this can either be by;

Natural infertility

It is also the failure to compete for a mate or differential mortality where, individuals die before they engage in reproduction. For such an organism, genes will be prevented from passing on to the next generation leading to elimination of such genes, a phenomenon known as **genetic drift**.

Such disadvantageous alleles however cannot be wiped out of a population by natural selection since they confer advantageous characters in heterozygous state for example the allele for sickle cell trait. People having the sickle cell trait are highly resistant to malaria and so they can reach reproductive age hence maintaining such an allele. This selection in favour of heterozygous individuals is called **heterozygous advantage**.

Heterozygous advantage is the maintenance of a recessive allele which may be

potentially harmful in a homozygous form or genotype in a population. Due to heterozygous advantage, individual organisms and populations always harbour a number of deleterious alleles (alleles which confer disadvantages) and this is called genetic load. Natural selection is responsible for maintaining the constancy of species in a generation if the environment remains stable and for changing them if the environment changes

SUB TOPIC 7: EVIDENCE FOR EVOLUTION

PALAEONTOLOGY

Palaeontology is the study of fossils. Fossils are any form of preserved remains from once living organisms. Fossils may be; entire organisms (e.g. frozen ice), hard skeletal materials (trapped by sedimentary rock), muscles and casts, petrifications, impressions, imprints or coprolites (faecal pellets, in sedimentary rock, which contain evidence of what the organism fed on). This could be due to lack of bacterial or fungal activity which prevents decomposition.

It is observed that older fossils appear less complex compared to more recent fossils and present day living organism. The fossil materials show how over time, organisms in the past continued to resemble present day forms.

This observation suggests that over the course of time, organisms have changed from the less complex to the more complex forms, hence providing evidence of

evolution. By accurately estimating the age of the rock using carbon dating techniques, the age of the fossil found in that particular rock can also be obtained. The sequence of existence of the fossils can be determined by determining the sequence of the ages of the different layers of rocks.

Criticism of fossil evidence

The major criticism of fossil evidence is lack of continuous fossil record. These gaps in the fossil record are called **missing links**; are used as strong evidence against evolution. However, the presence of missing links in fossil history can be explained due to the fact that:

- Dead organisms decompose rapidly.
- Dead organisms are eaten by scavengers
- Soft bodied organisms do not fossilize easily.
- Only a small fraction of living organisms would have died in

conditions favourable for fossilization

- Only fractions of fossils have been discovered.

Support for evolution, thus increases as more missing links are discovered, either as fossil, such as seymourie (amphibian / reptile), archaeopteryx (reptile / birds) and cynognathus (reptile /mammal) or as living organisms such as peripatus and Latimeria.

Alternatively, the missing links may be explained as a result of **punctuated equilibria**; The theory of 'punctuated equilibrium' attempts to explain the presence of gaps in fossil records called "missing links" The theory proposes that species remain unchanged for long periods of time before giving rise to new species in a comparatively short period of time. Thus new species appear suddenly that intermediate links in the lineage do not exist i.e. that periods of no change in evolution are interrupted by periods of relatively sudden and rapid speciation.

Species therefore remain unchanged when the environment is unchanged. The species then change suddenly when there are sudden and important changes in environmental conditions. Therefore, the apparent "jumps" or 'missing links' in the fossil history may be due to the process of punctuated equilibrium / '**saltatory evolution**'

N.B

*The alternative theory to punctuated equilibrium is **gradualism**, which is a model for evolutionary change that evolution occurred slowly by accumulating small*

changes over a long period of time. Charles Darwin's view of evolution was based on gradual changes in the features of specific species.

COMPARATIVE EMBRYOLOGY

Embryology is the study of embryonic development. A study of the embryonic development of the vertebrate classes by Van Baer (1792 – 1867) showed structural similarities in the five groups especially during cleavage, gastrulation and early differentiation.

At comparable stages, vertebrate embryos possess:

- visceral clefts in the pharyngeal region
- segmented myotomes (muscle blocks)
- internal paired gill pouches,
- a post – anal tail and
- a single blood circulation with a two-chambered heart.

Those similarities suggest that all the vertebrates (Pisces, amphibian, reptile, Aves and Mammalia) share a common evolutionary ancestor. As development proceeds, changes occur which produce the different characteristics of each class depending on the embryo's parentage. These differences arise by adaptive radiation as each vertebrate class adapts to a different environment. This causes the divergent evolution of the vertebrate classes.

Haeckel formulated the principle that '**ontogeny recapitulates phylogeny**', meaning that the stages of embryonic development (ontogeny) through which an

organism passes repeat its evolutionary history (phylogeny)

CONTINENTAL DRIFT

The complementary shapes of the continents suggest that one can pull the continents together and they fit into each other easily like Jigsaw puzzles. This observation suggests that the continents were once one large land mass (the Pangaea), which broke up into different continents which shifted apart into their present-day positions. This is the hypothesis of **continental drift**.

Continental drifting is based on **plate tectonics**. The concept of plate tectonics suggests that the land mass of the earth floats on the dense molten core of the earth. The continents shifted apart as a result of convection currents with in the earth spreading upwards and outwards dragging the plates on which the continents float.

Continental drifting explains the mechanism of allopatric speciation since the drifting continents and their separating waters create geographical barriers that prevented gene flow between the separated members of the same ancestral population. This geographical isolation led to a build-up of **reproductive isolation** among separated populations. As a result of adaptive radiation, each group adapted to different environmental conditions, resulting in the formation of new species (speciation), as in the case of camels and llamas. Speciation is the most profound effect of evolution.

BIOGEOGRAPHY

Biogeography is the study of the range and distribution of organisms in different places

throughout the world. Such distributions are consistent with the hypothesis that, when forms are related, they evolved in one locale and then spread to accessible regions. It is observed that all species are highly adapted to their environment to varying degrees.

This observation supports the view that only those organisms that are structurally, morphologically, physiologically and behaviourally adapted to an environment will be able to survive and reproduce in that particular environment, while the less adapted organisms die out. This therefore acts as evidence for natural selection.

The same observation suggests that the environmental changes produce appropriate changes in the forms of organisms able to survive and reproduce in the new changed environment, there by resulting in evolution. Therefore, species' environmental specificity is clear evidence of mechanism of natural selection and the resulting process of evolution,

COMPARATIVE ANATOMY

Anatomy is the study of the structure of organisms. Comparative study of anatomy of groups of organisms reveals basic structural similarities e.g.

- The basic structure of all flowers consists of sepals, petals, androecium and gynoecium.
- The limb–bone pattern of all four-legged animals from Amphibia to Mammalia has the same five-digit structural plan called the **pentadactyl/ limb plan**.

These structural similarities suggest that these groups of organisms have descended from a common evolutionary ancestor which had these basic structures.

Organs from different species having a similar basic form, structure, body position & embryonic development are called **homologous structures**. The homologous structures showing adaptations to different environmental conditions, modes of life and hence performing different functions are examples of adaptive radiation which results in divergent evolution. For example:

The pentadactyl fore limb has been modified into flippers for swimming in whales, wings for flying in bats, hand for manipulation in man, pads for digging in moles and legs for running in horses.

The fruit pericarp has been modified; it is fleshy and succulent in tomatoes for animal dispersal, dehiscent in beans for mechanical dispersal, hard and water proof in the coconut for water dispersal, and wing –like in the sycamore for wind dispersal.

The primitive biting and chewing mandibulate mouth parts of insects have been modified into sucking mouth parts in butterflies, piercing and sucking mouth parts in aphids.

Vestigial organs are a special type of homologous structures which in some species have greatly degenerated, atrophied and thus serve no apparent function. For example, the human appendix is homologous to the functional appendix of herbivorous mammals and the vertebrae of the human coccyx are homologous to the

functional tail of vertebrae of other animals e.g. monkeys.

The existence of homology within a group of organisms is evidence of descent from a common ancestor and indicates close phylogenetic relationships. The similarity of the basic form indicates a similar ancestry, while the differences are adaptations to perform different functions in different environments hence adaptive radiation resulting into divergent evolution. Vestigial organs also lost function as a result of gradual evolutionary modification.

COMPARATIVE MOLECULAR BIOLOGY

Molecular biology is the study of chemicals of life. Comparative study of chemicals found in living organisms reveals many similar molecules in different organisms e.g. nucleic acids, ATP, cytochromes, and amino acids are found in almost all living organisms. The occurrence of similar biochemicals in a wide range of organisms supports the view that all organisms descend from a common evolutionary ancestor and supports the existence of biochemical homology.

However, many chemicals are confined to specific taxa, e.g. plants contain cellulose, starch and chlorophyll while they are absent in animals. These biochemical differences suggest a process of **adaptive radiation** as different organisms and taxa adapted to particular environmental conditions resulting in the development of different bio-chemicals or even differences in the specific structures of similar chemicals.

This explains why analysis of bio-chemicals such as phosphagens (high energy phosphate storage compounds), blood pigments, serum, protein and DNA, leads to the construction of evolutionary relationships basing on similarities and differences in specific structures.

COMPARATIVE CELL BIOLOGY

Cell biology is the study of the structure and functioning of a cell. Comparative study of organelles and physiological processes occurring in a cell reveals striking similarities in all organisms for example the process of tissue respiration follows very similar metabolic pathways in all organisms.

These similarities are evidence that all organisms have evolved from a common ancestor and any difference in cell biology are indicative of the divergent evolution of species due to the adaptive radiation as species adapted to different environmental conditions. Adaptive radiation is the evolution of an ancestral species into different species to fill different ecological niches.

This detailed comparison of metabolic paths and organelles can be used to establish evolutionary relationships of organisms. Eg. ribosomes inside mitochondria and chloroplasts are similar to those of bacteria, suggesting that the organelles might have evolved from bacteria. This is the basis of the *endosymbiotic theory*.

CLASSIFICATION

Classification is the science of grouping organisms into groups (taxa) basing on similarities and differences in their

characteristics. The more similar organisms are, the more closely related; suggesting closeness in evolutionary history (phylogeny). Thus, classification of organisms basing on structural similarities which is the basis of the natural phylogenetic classification suggests the existence of a process of descent by gradual modification which is evolution.

The differences between taxa & organisms arose by progressive adaptations of organisms within a particular taxon to particular environmental conditions over the course of time. This adaptive radiation resulted in divergent evolution.

ADAPTIVE RADIATION

When the same ancestral stock of organisms move to different environments, they face different environmental selection pressures due to the different environmental conditions and thus develop different structures with the same basic plan in order to adapt to their different environmental conditions. This is the principle of adaptive radiation.

a) Homologous structures and divergent evolution.

When a group of organisms have a homologous structure, which is adapted to perform a variety of different specialised functions, it illustrates the principle of adaptive radiation. Examples of homologous structures performing different functions:

- The pentadactyl limb (the wing of a bat, the human hand, the flipper of a seal, the paw of a rabbit, the leg of a horse).

- The mouth parts of insects (biting and chewing in locusts, sucking in butterflies, piercing and sucking in mosquitoes, licking and biting in honey bees)

The presence of a similar structure in an ancestral form which has become greatly modified and specialised to perform a variety of functions, is an indicator of the process of descent by gradual modification which is termed as evolution. Such adaptive radiation suggests the existence of divergent evolution.

b) Analogous structure and convergent evolution.

This is a structure that has a similar function in separate lineages but differs in anatomy and ancestry. They are structures, bearing no close phylogenetic links but showing adaptations to perform the same functions. Thus, analogous structures have different basic forms, structure, and embryonic development, with different evolutionary ancestries, but performing a similar function. Examples of analogous structures;

- The wings of insects (evolved from the arthropod exoskeleton) and the wings of birds
- The jointed legs of insects evolved from the arthropod exoskeleton and the jointed legs of vertebrates (evolve from the vertebrate endoskeleton)
- The hair on plant leaves and stems and the fur on mammalian bodies.
- birds (use feathers and bats' (use a stretched membrane) wings
- The eyes of vertebrates and eyes of invertebrate cephalopod molluscs (squids and octopi)
- Among prokaryotes, bacterial and archaeal flagella are similar in size and rotation mechanism, but they are composed of different proteins

The existence of analogous structures suggests the occurrences of convergent evolution. When different ancestral stocks of organisms move to the same environment and face the same environmental selection pressures, they develop similar applications of basically different structures in order to adapt to the same environmental conditions and modes of life.

Convergent evolution results in the possession of structures which are similar in function, but different anatomically and phylogenetically which are called ***analogous structures*** Parallel evolution as a result of convergent evolution and divergent evolution.

The significance of divergent evolution as an evolutionary mechanism is highlighted by the parallel evolution of marsupial and placental mammals. Both groups (the Australian marsupials and placental organisms are thought to have undergone divergent evolution by adaptive radiation in identical ecological niches but in different parts of the world. This occupation of identical niches in different zoogeographical regions resulting in convergent evolution caused parallel evolution of the two groups.

Revision questions

Explain what is meant by each of the following concepts;

- a) Continental drift*
- b) Divergent evolution*
- c) Industrial melanism*
- d) Vestigial organs*

EVIDENCES OF PRESENT DAY EVOLUTION

EFFECT OF DRUGS / CHEMICAL RESISTANCE

Malaria resistance to chloroquine

The long-term use of chloroquine in treating malaria has led to development of resistance to the drug by most plasmodium species. This observation states that over the course of time plasmodium species have evolved from a non-resistant to a resistant form by gradual modification. Continued and frequent exposure of plasmodia to chloroquine where malaria is endemic constituted an intense selection pressure. These varieties of plasmodia which were, either naturally or as a result of mutation, resistant to chloroquine survived exposure to the drug and multiplied in numbers; while the non-resistant varieties died.

This process of natural selection gradually and progressively reduced non-resistant varieties; while increasing the proportion of resistant forms eventually resulting in the evolution of plasmodium varieties resistant to the drug. Thus, malaria resistance to chloroquine is strong evidence of the mechanism of natural selection and the

process of descent by gradual modification which is evolution.

Resistance of plasmodium to chloroquine may arise by;

- Failure of plasmodium to absorb the drug.
- The development of alternative metabolic pathways that bypass biochemical reactions targeted by the drug.
- The formation of resistant forms inaccessible by the drug.
- The development of enzymes which detoxify the drug.
- General tolerance to the effects of the drug molecules.

Pest resistance to pesticides

When a population of pests is exposed to a particular pesticide for the first time, much of the pests population is killed. However, with successive exposure, the proportion of the pest population killed progressively reduces, until the pesticide is no longer effective in controlling the pest. Therefore, the pest population evolves from non-resistant to a resistant form due to natural selection.

This occurs due to selection for the resistant varieties which survive exposure to the pesticide and reproduce thereby perpetuating their resistant characteristics or genes to successive generation; as the non-resistant varieties die out with each successive pesticide application. This natural selection is the cause of the evolution of the resistant forms, for example mosquitoes of the genus

Aedes, which carry yellow fever, are now resistant to DDT.

Anti-biotic resistance by bacteria

Antibiotics are drugs used to treat bacterial infections and diseases. A number of diseases caused by bacteria have developed resistance against certain antibiotics e.g. some strains of *Staphylococcus aureus* are resistant to penicillin and methicillin (multi-drug resistance).

Antibiotic resistant bacteria form when **a chance mutation** produces an individual bacterium with an allele that makes it resistant, by allowing the bacterium to produce an enzyme (penicillinase) which destroys penicillin. When the population to which the resistant mutant belongs is exposed to the antibiotic, the mutant will survive and reproduce while those without the mutant allele will be killed which leads to the evolution of a large population of antibiotic resistant bacteria.

Resistance to a wide variety of insecticides, fungicides, antibiotics, antiviral drugs, and herbicides has evolved in hundreds of insects, fungi, bacteria, viruses, and plants. In every case, evolution has occurred because individuals with the heritable ability to resist some chemical compound were present in the original population. As the susceptible individuals die from the pesticide, herbicide, or drug, the alleles that confer resistance increase in frequency.

Heavy metal tolerance in plants

Soil heaps, which contain waste materials from mining activities contain high

concentrations of certain heavy metals, e.g. Tin, Lead, Copper, Nickel and Zinc

In high concentrations, these heavy metals are toxic to most plants and heaps of soil are largely devoid of vegetation. However certain varieties of grasses e.g. *festuca*, *ovina* and *agrostic tenuis* and hoetails have become genetically adapted to survive such in such an environment. Random mutation of unpolluted areas led to the development of individuals with greater tolerance to heavy metals than others. Tolerant plants may;

- Trap the heavy metals in organic molecules in their cellulose cell walls.
- Confine the metals to the vacuoles.
- Excrete the metals back into the environment.

Restoration ecologists introduce such species (plants, lichens) to sites polluted by mining and other human activities and then harvest these organisms to remove the metals from the ecosystem a process called Bioremediation. (This is cheaper than soil remediation, the detoxification of contaminated soils, focused on non-biological technologies, such as removing and storing contaminated soil in landfills)

Tolerant plants are less competitive (have a selective disadvantage) in unpolluted areas where the concentration of the heavy metals is low and so do not survive there. However, these tolerant individuals flourish in polluted areas where the heavy metals kill off their competitors and they pass on tolerance to their offspring.

ARTIFICIAL SELECTION

Early human civilization was characterised by the cultivation of plants and domestication of animals derived from wild ancestral stock. But many of these wild stocks of plants and animals were of 'poor quality'. By realising that the 'like produce the like' humans developed the idea of **selective breeding**. By selecting those members of the species with favourable characteristics such as tender meat, improved flavour, increased size, pleasant colour, and better taste; and artificially breeding them by selective mating, selective vegetative propagation and selective pollination. The desired characteristics were perpetuated.

The continued selective breeding by humans has produced a variety of plants and animals of agricultural value. Selective breeding is a form of artificial selection by humans based on naturally existing inherited characteristics

or inheritable characteristics developed by mutation.

The argument for evolution is that since humans can select those organisms with desirable characteristics and perpetuate them through artificial selection, while eliminating those with undesirable characteristics through **extermination, sterilization and segregation**, then nature can equally select those varieties better adopted to the environment and let them live and reproduce, thus natural selection, while the less adopted variations fail to survive or to reproduce and die out. This natural selection based on inherited characteristics causes evolution.

Revision questions

- i State five evidences of evolution
- ii To what extent do the evidences you have stated above, support the theory of evolution.

SUB-TOPIC 8: SELECTION AND SPECIATION

NATURAL SELECTION

Natural selection is the process by which those organisms that are morphologically, physiologically, structurally and behaviourally better adapted to the environment, survive and reproduce and pass on their advantageous genes to the next generation, while those that are less well adapted either fail to survive or to reproduce and hence die out. Failure to reproduce constitutes **genetic death** as it eliminates the organism's gene from the population.

The well adapted organisms pass on their successful characteristics (genes and alleles) into the next generation while the poorly adapted do not. This increases the frequency of the successful genes and alleles in the population.

How does natural selection occur?

When a population increases in size, some environmental resources and conditions become limiting, for instance food availability decreases and the availability of light in plants decreases.

This increases interspecific competition for the limited resources within members of the population.

During the competition, some organisms exhibit phenotypic characteristics which give them a competitive advantage over the others and so they obtain the resources survive and reproduce. Those organisms lacking those characteristics are at a competitive disadvantage and may die before reproducing; and are thus eliminated from the population. Thus, both the environment and the population size act together to produce a selection pressure with varying intensity and direction.

The well adapted phenotypes thus turn their competitive advantage into a selective advantage that confers upon them a reproductive advantage. And so, natural selection determines which alleles are passed on to the next generation by virtue of the relative selective advantage they confer upon their phenotypes

The selection pressure offers a means of increasing or decreasing the spread of an allele within the gene pool and these changes in allele frequency lead to evolutionary change. Natural selection therefore acts at the level of the gene or allele and is based upon the existence of genetic variation within the population.

Evidence for natural selection

Industrial melanism

Moths collections of the 19th century showed the peppered moth as a white moth while occasional specimens showed a dark moth form. However, by the end of the

19th century, near the industrial city of Manchester, the dark form had become more common (about 98% of the population). This change in the frequencies of the two forms of peppered moth is an example of evolution taking place. This change resulted from natural selection in industrial areas. A phenomenon called **Industrial melanism**.

In the 19th century before industrial revolution, trees were covered with whitish lichens and walls painted white. This allowed the light form to camouflage against the white background and thus hide from the predatory birds. The dark form could be highlighted on this white background and thus faced high levels of predation.

By the end of the 19th century, with industrialisation, air pollutants including gasses, smoke and soot killed off the lichens, and darkened the barks of trees and walls of building. This change in the environment allowed the dark form to camouflage facing less predation hence increasing in frequency. The light form would be highlighted on the dark background and face more predation thus reducing in frequency.

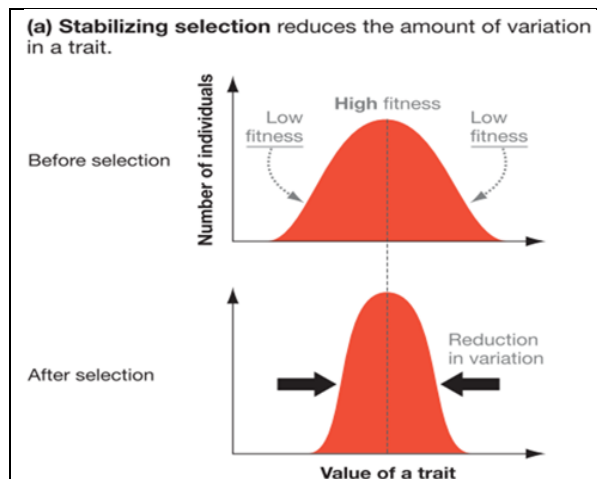
Industrial melanism provides evidence for natural selection, where changes in the environment due to industrialisation caused a change in the selection pressure (predation of the non-camouflaged form). This natural selection was based on differences in melanin concentration of the two forms guided by industrialization hence the term industrial melanism.

TYPES OF SELECTION

Stabilizing selection

This is selection which favours average phenotypes over either extreme. It selects for average phenotype and against both the lower extreme and upper extreme. E.g. the optimum birth weight in humans is 3.6 kgs, and babies lighter or heavier than this optimum are at a selective disadvantage and have a slightly increased mortality rate.

Also, average weight and average height humans have a selective and reproductive advantage over the extremely small or shorter and the extremely fat or tall, hence both extremes tend to be unhealthy. Stabilizing selection pressure do not promote evolutionary change but tend to maintain phenotypic stability with in the population from generation to generation.

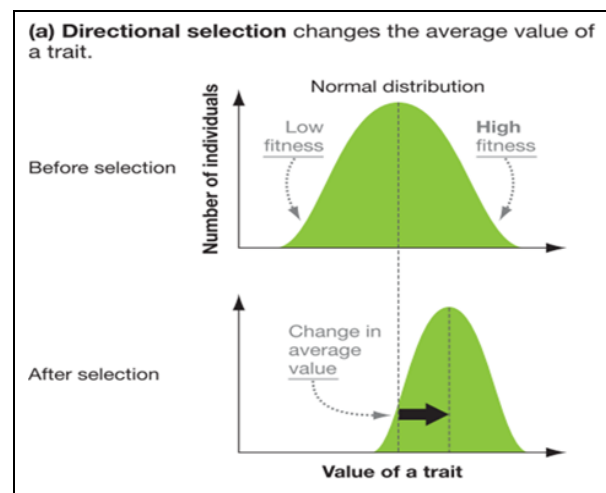


Directional selection

This is the selection which favours the phenotypes at one extreme over the other. It selects for one extreme and against the other. E.g.

- If birds prefer eating big seeds to small ones, there will be selection for small seeds and against big seeds.
- Strong lions are selected for, while weak ones are selected against.

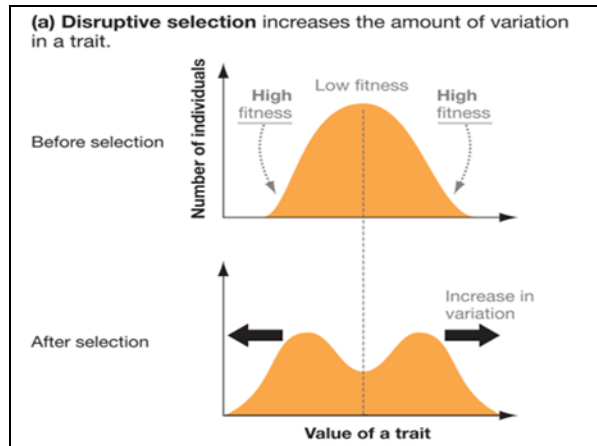
Directional selection operates in response to gradual changes in environmental conditions and brings about evolutionary change.



Disruptive selection

This is selection which favours both extremes and selects against the average intermediates. e.g. if birds prefer to eat intermediate (average-sized) seeds and ignore the very small and very large seeds. Disruptive selection can be very important in bringing about evolutionary change.

Micro evolution due to disruptive selection may give rise to subpopulations, polymorphs, ecotypes, races, and demes. And if gene flow is prevented between the subpopulations, each subpopulation may give rise to a new species (speciation.)



The biological significance of natural selection

- It offers a mechanism by which species adapt to change in environmental conditions, by allowing the continued survival and perpetuation of only those alleles that better suit the phenotype to the environment.
- It allows species to extend their geographical range to new different environment by adaptive radiation, thereby reducing risks of species extinction.
- It leads to change in the frequency of alleles in gene pools of populations thereby causing evolution, which may ultimately lead to the formation of new better adapted species. (Speculation)

SPECIATION

Speciation is the process by which one or more species arise from pre-existing species. This mainly occurs by a reproductive isolation of a species to form two new species.

The concept of species

A species is a group of closely related organisms capable of interbreeding freely to produce fertile offspring and which are reproductively isolated from other species. Members of the same species share a unique set of structural and functional characteristics, occupy the same ecological niche, and show close similarity in genetic karyotype.

The process of formation of new species

A single species may give rise to new species, a process called **intraspecific speciation**, or two different species may give rise to a new species by **interspecific hybridisation**.

If **intraspecific speciation** occurs while the population is separated geographically, it's termed as **allopatric speciation**. If the process occurs when the populations are occupying the same geographical area it is termed as **sympatric speciation**.

Intraspecific speciation

Speciation occurs as a result of the formation of barriers which lead to **reproductive isolation** between members of the population. The means of producing and maintaining reproductive isolation within a population are called **isolating mechanisms**. Isolating mechanisms which act before fertilisation are called **pre-zygotic mechanisms**, while mechanisms acting after fertilisation are called **post-zygotic mechanisms**.

The pre-zygotic isolating mechanisms are barriers to the formation of hybrids, which include:

Ecological isolation;

This is where two species occupy the same geographical region but have differences in habitat preferences. These never encounter one another and so their gametes cannot fuse.

Seasonal isolation

This is where two species occupy the same habitat but mate or flower at different times of the year. The reproductive organs mature at different times of the year, preventing fusion of gametes.

Behavioral isolation

This is where animals of different species exhibit specific courtship patterns and mating only results when the courtship display by one sex leads to acceptance by the other sex. Mismatching of courtship displays leads to failure of mating and fusion of gametes is therefore prevented as in certain fish, insects, birds, reptiles and mammals.

Mechanical isolation

This occurs in animals where differences in genitalia prevent successful copulation, for example insect's genitalia work as a lock and key system. In plants, it occurs where related species of flowers have different pollinating animals.

The post-zygotic isolating mechanisms are barriers affecting hybrids; a hybrid is the offspring of a cross between different

species or breeding lines. Post-zygotic mechanisms include:

Hybrid viability

This is where hybrids are formed but fail to develop to reproductive maturity. This occurs because genetic incompatibility prevents normal mitosis after formation of the zygote.

Hybrid sterility

This is where hybrids form and develop to reproductive maturity, but fail to produce functional gametes. Here, mitosis occurs in the hybrid and the individual develops to reproductive maturity, but meiosis being more sensitive to chromosomal imbalance fails as a result of segregation, resulting in abnormal gametes or complete failure of meiosis, for example the mule ($2n = 63$) is a sterile hybrid of a horse (*Equus equus*, $2n = 64$) and a donkey (*Equus hemionus*, $2n = 66$).

Hybrids break down

This is where the F_1 hybrids are fertile, but the F_2 generation and back crosses between F_1 hybrids and formed between different species of cotton (genus *Gossypium*) suffer hybrid breakdown.

THE PROCESSES OF SPECIATION

Allopatric speciation (peripatric)

Allopatric speciation occurs as a result of spatial / geographical isolation of a population by a physical barrier splitting it into two or more isolated populations. Geographical barriers such as mountain ranges, seas or rivers, deserts may produce

barriers to gene flow due to spatial separation. Such barriers may arise due to processes such as glaciation, volcanic activity, flooding, earthquakes, landslides and continental drift. This inability of organisms or the gametes to meet leads to reproductive isolation.

The geographically distinct regions, differ in environmental resources and conditions such as flood availability and climatic factors. The separated populations are thus subjected to different selection pressures. Each isolated population adapts to its own environment through natural selection leading to changes in allele frequencies of the separated gene pools as a result of adaptive radiation.

The changes may also occur as a result of random genetic drift when a few colonizing individuals become founders of a new species population in a previously unoccupied area such as a newly emerged island, as a result of the founder effect. The founder effect is the loss of genetic variation that occurs when a new population is established by a very small number of individuals from a larger population

Prolonged separation of the population leads to genetic isolation even when brought together. In this way, new species arise since the separated population can no longer interbreed.

Sympatric speciation

Sympatric speciation involves the development of some form of reproductive isolation mechanism without spatial

separation of the population by geographical barriers. Such reproductive isolation usually results from mutation leading to the following isolating mechanisms;

- i **Mechanical isolation** whereby copulation cannot occur due to incompatible genitalia.
- ii **Seasonal (temporal) isolation** where by the reproductive organs mature at different time of the year and so the organisms mate or flower at different times of the year. This prevents fusion of their gametes.
- iii **Behavioural isolation** where by differences in courtship pattern prevent mating and hence fusion of gametes.
- iv **Ecological isolation** where by differences in habitat preference prevent fusion of gamete even when in the same geographical region.
- v **Gametic isolation**; Failure for the gametes to meet for example sperms may not survive in the female's reproductive tract, or the pollen tube may fail to grow. Failure of the gametes to fuse as a result of difference in genetic makeup of gametes making the gametes incompatible.
- vi **Hybrid unviability** where by the hybrids produced fail to develop to maturity and so they die off
- vii **Hybrid sterility** where by the hybrids produced are viable but sterile.

Sympatric speciation also occurs by polyploidy. Polyploidy is a chromosomal

mutation resulting in gametes and somatic cells having additional haploid sets of chromosomes. There are two forms of polyploidy: autopolyploidy and allopolyploidy.

Autopolyploid involve gamete and somatic cells containing extra sets of the haploid numbers of chromosomes from only one species. During mitosis for example, the chromosomes undergo replication (interphase) and the chromatids separate normally (in anaphase) but the cytoplasm may fail to clear during cytokinesis, resulting in the formation of a tetraploid cell ($4n$) with a larger nucleus. The tetraploid cell will undergo normal mitosis to produce tetraploid daughter cell with large sizes due to increase in volume of the cytoplasm.

When a tetraploid cell under goes normal meiosis, it produces diploid gamete cells ($2n$). A normal haploid gamete (n) can fuse with a mutant diploid gamete ($2n$) to produce a triploid, a diploid gamete can fuse with another diploid to form a tetraploid species ($4n$) and so on

The chemical colchicine can induce polyploidy by inhibiting spindle formation by disrupting microtubules so that the chromatid fail to separate during anaphase; autopolyploid are fertile when they have an even number of chromosomes to give even homologous pairs during meiosis.

A modified form of polyploidy occurs in animals through chromosome replication without cell division, a process called endomitosis, to give polyploidy cells and tissues, for example in the salivary glands

of *Drosophila* and tetraploid cells in the human liver.

Polyploidy is much more common in plants than in animals this is because.

- Most plants are capable of self-pollination and can undergo vegetative propagation.
- Mutant polyploid animals usually fail to locate a genetically compatible mate or may be sexually selected against due to their abnormalities

But animal species that are permanently parthenogenetic are certainly polyploidy as in some insects and primitive fish. Autopolyploidy is a case of intraspecific speciation. Interspecific hybridisation involves amphiploidy followed by allopolyploidy. When two individuals of two different but closely related species are accidentally hybridized, the F_1 offspring are amphiploid with a diploid set of chromosomes from two different species. These amphiploid F_1 hybrids are sterile as they possess non-homologous chromosomes which cannot pair during meiosis, resulting in failure to produce functional gametes. This is hybrid infertility.

However, all the non-homologous chromosomes of the F_1 hybrid can undergo non-disjunction during meiosis. The foundation gametes of the F_1 can also occur by autopolyploidy occurring in the sterile amphiploids where the chromosomes replicate but the cytoplasm fails to clear, causing a doubling of the hybrid

chromosome number such that F₂ offspring are called allopolyploids.

Allopolyploids have double the number of chromosomes of a sterile amphiploid hybrid; and are thus fertile with themselves but infertile with both the F₁ amphiploid and the original non-mutant parental species, due to the extra set of chromosomes.

In plants, polyploidy has the following effects: shorter stem length, speciation, increased chance of evolution increased genetic variations, intensity to day length, increased size, increased hardness, increased resistance to drought, increased crop yield, increased nutrient content in edible parts, earlier maturation, increased number of flowers, fruits, leaves and storage organs, increased responsiveness to water and fertilizers. Such advantageous features usually rise due to heterozygosity of allopolyploids causing hybrid vigour. In animals, polyploids, usually have severe genetic disorders, shorter live spans or both

SPECIES EXTINCTION

The IUCN publishes detailed lists of species at risk of extinction in **red data book**, which identify 4 categories of risk.

Rare:

Species with small populations and either restricted geographically with localized habitats or with widely scattered individuals. These are at risk of becoming rarer, but they are not in immediate danger of extinction

Vulnerable

These are species under threat of or actually declining in number, or species which have been seriously depleted in the past and have not yet recovered.

Endangered

These are species with low population numbers that are in considerable danger of becoming extinct.

Extinct

These are species which cannot be found in areas they recently inhabited nor in other likely habits.

THE CAUSES OF SPECIES EXTINCTIONS

Natural selection

Species that are better adapted to the environment out compete and replaces the less well adopted species which die out.

Habitat destruction

Caused by human activity, like timber cutting, industrial and agricultural expansion and urbanization has driven many species to extinction.

Competition from humans and their animals

Species restricted to small areas are often unable to compete with influx of humans and their animals for example the giant tortoises in the Galapagos Islands.

Overhunting, overfishing and collecting

Humans hunt tigers for sport, crocodiles for their skins, fish are fished transport. Parrots and tamarins are collected for pet trade, and some species are overhunted for food. This

greatly reduces the population sizes leading to extinction.

Destroyed by humans as a health risk

Many species are persecuted because they carry diseases of humans and domesticated species, for example badgers (tuberculosis of cattle) and eland (spiral-horned African antelope.)

Pollution

Oil pollution endangers some rare marine bird species. Bioaccumulation of persistent pesticides along food chains endangers predatory birds such as peregrines, falcons and golden eagles.

Very little or few variations

Species with very little genetic variation have reduced adaptability (evolutionary plasticity) making them prone to extinction when important environment changes occur.

Small population sizes

When the number of individuals belonging to a particular species are too few, the species may be easily wiped out by natural selection/environmental changes, human activity or natural calamities.

Restricted geographical range

If the members of a species, however large, are restricted to a small geographical area, the species is much more likely to face extinction if this area is altered, such as by catastrophes, human activity.

Natural calamities

Catastrophes such as volcanicity, earthquakes, glaciations, landslides, floods, fire, meteor showers, cause death and sudden

environmental changes, and are therefore very likely to cause mass extinction.

Sudden environmental changes

When the environment undergoes rapid and sudden changes, such as due to global warming and glacial activity, species may lack ample time for adapting to such changes, and thus face extinction.

THE METHODS OF PREVENTING SPECIES EXTINCTION

- Establishing game parks, national parks, nature reserves and similar protected areas.
- Planned land use.
- Protecting and restoring species habitats.
- Legal protection of endangered species, for example it is illegal to collect, trade in or kill Koalas in Australia.
- Providing refuge and assisted breeding programmes for endangered species, such as zoos and botanical gardens.
- Removal of endangered plants and animals from areas affected by natural disasters and human activity.
- Controlling and reducing the impact of modern intensive agriculture.
- Control of introduced species to protect indigenous ones
- Ecological study of threatened habitats.
- Establishing sperm banks and seed stores to maintain the full range of genetic diversity of species.

- Controlling pollution such as smoke emissions, oil spillages, over- use of pesticides, fertilizers.
- Recycling materials.
- Education and sensitization to create awareness of importance of biodiversity, prevention of habitat destruction and encouraging of species conservation.
- Restricting urban and industrial development.
- Reclaiming derelict sites, such as mining, water tips
- Prohibiting release of non-native species into an area.
- Limiting the exploitation of renewable resources to sustainable yields.

APPENDIX

You should consider this book, however, as a supplement to your textbook, your laboratory exercises, and your teacher's notes. Much of the excitement and adventure of biology can be obtained only through hands-on activities and discussions with teachers. In addition, textbooks provide background information, extensive examples, and thought-provoking questions that add depth to your study of biology. Each time you study a topic in class, after listening to the lessons and reading the textbook, use this book to review. Underline or highlight material to help you remember it. Write in the margins any additional material that you heard in lectures or read in your textbook that you or your teacher thinks is important. Then answer the questions and read the answers at the end of each section. This will reinforce your learning.

At the end of your biology course, this book will be a single, condensed source of material to review before the UACE exam. Begin your final preparation several weeks before the UACE exam by reviewing the material in each section.

Hints for Taking the Multiple-Choice Section

In the UACE paper 1, questions for the multiple-choice section are provided in the question paper. While reading the questions in the booklet, feel free to cross out answers you know are wrong or underline important words. After you've selected the answer from the various choices, you carefully fill the boxes, with labels A, B, C, or D. Some specific strategies for answering the multiple-choice questions follow.

- Don't let easy questions mislead you. The multiple-choice questions range from easy to difficult. On one exam, 92 percent of the candidates got the easiest question right, but only 23 percent got the hardest question right. Don't let the easy questions mislead you. If you come across what you think is an easy question, it probably is. Don't suspect that it's a trick question.
- Budget your time by skipping hard questions. If you come across a hard question that you can't answer quickly, skip it, and mark the question to remind you to return to it if time permits. If you can eliminate some of the answer choices, mark those also so that you can save time when you return. It's important to skip a difficult question, even if you think you can eventually figure it out, because for each difficult question you spend three minutes on, you could have answered three easy questions. If you have time at the end of the test, you can always go back. If you don't have time, at least you will have had the opportunity to try all the questions.
- Make only educated guesses. If you're not sure of the answer to a question, don't guess unless you can make an educated guess. You make an educated guess when you can reduce the answer to two or three choices. If you get an answer right, you receive one point. If you leave it blank, you receive no points.

- Carefully answer reverse multiple-choice questions. In a typical multiple-choice question, you need to select the choice that is true. In the exam, you will find many reverse multiple-choice questions where you need to select the false choice. These questions usually use the word “EXCEPT” in sentences such as “All of the following are true EXCEPT . . .” or “All of the following occur EXCEPT. . . .” A reverse multiple-choice question is more difficult to answer than regular multiple-choice questions because it requires you to know four true pieces of information about a topic before you can eliminate the false choice. It is equivalent to correctly answering five true-false questions correctly to get one point; if you get one of the five wrong, you get them all wrong. Reverse multiple-choice questions are also difficult because halfway through the question, you can forget that you’re looking for the false choice. To avoid confusion, do the following: After reading the opening part of the question, read each choice and mark a T or an F next to each one to identify whether it is true or false. If you’re able to mark a T or an F for each one, then the correct answer is the choice marked with an F. Sometimes you won’t be sure about one or more choices, or sometimes you’ll have two choices marked F. In these cases, you can concentrate on the uncertain choices until you can make a decision.

Hints for Taking the Essay Section

The essay questions are provided in UACE paper 2. During the 10-minute reading period, read the questions thoroughly, circling key words. Next, write a brief outline using key words to organize your thoughts. When the writing period begins, begin writing your answer on the answer sheets that are provided separately. If for some reason you don’t write an outline, go back and reread the question halfway through writing your answer. Make sure that you’re still answering the question. It’s easy to get carried away, and by the end of your response, you might be answering a different question. Strategies for answering the essay questions follow.

- Don’t approach the essay section with apprehension. Most students approach the essay section of the exam with more anxiety than they have when approaching the multiple-choice section. However, in terms of the amount of detail in the knowledge required, the essay section is easier. On essay questions, you get to choose what to write. You can get an excellent score without writing every relevant piece of information. Besides, you don’t have time to write an entire book on the subject. A general answer that addresses the question with a limited number of specifics will get a good score. Additional details may (or may not) improve your score, but the basic principles are the most important elements for a good score. In contrast, a multiple-choice question focuses on a very narrow and specific body of knowledge, which you’ll either know or you won’t. The question doesn’t let you select from a range of correct information. This isn’t true for the essay questions.
- Give specific information in your answer. You need to give specific information for each essay question. Don’t be so general that you don’t really say anything. Give more than

just terminology with definitions. You need to use the terminology to explain biological processes. The combination of using the proper terminology and explaining processes will convince an AP exam reader that you understand the answer. Give some detail when you know it—names of processes, names of structures, names of molecules—and then tell how they're related. The reader is looking for specific information.

- Answer each part of an essay question separately. Many of the essay questions ask several related questions. A single question, for example, might have two or three parts, each requesting specific information. You should answer each part of the question in a separate paragraph, which helps the reader recognize each part of your answer. Some questions are formally divided into parts, such as a, b, c, and d. Again, answer these questions separately, in paragraphs labeled a, b, c, and d.
- Answer all parts of an essay question. When you answer the essay questions, it is extremely important that you give a response for each part of the question. Don't overload the detail on one part at the expense of saying nothing in another part because you ran out of time. Each part of the question is apportioned a specific number of points. If you give abundant information on one part, and nothing on the remaining parts, you receive only the maximum number of points allotted to the part you completed.
- Budget your time. Just as it's most important to answer all parts of a question, it's best to respond to all the essay questions rather than to answer two or even three of them extremely well, with no response on the last one or two. You'll probably know something about every question, so be sure you get that information written for each question. If you reach the last question with five minutes remaining, for example, use that time to write as much information as possible. One or two points is a lot better than zero.
- Don't worry if you make a factual error. What if you write something that is incorrect? The exam readers and markers look for correct information. They search for key words and phrases and award points when they find them. If you use the wrong word to describe a process, or identify a structure with the wrong name, no formal penalty is assessed. If you're going to get any points, however, you need to write correct information.
- Don't be overly concerned about grammar, spelling, punctuation, or penmanship. The exam markers don't penalize for incorrect grammar, spelling, or punctuation or for poor penmanship. They are interested in content. However, if your grammar, spelling, or penmanship impairs your ability to communicate, then the readers cannot recognize the content, and your score will suffer.
- Don't write a standard essay. Don't spend your time writing a standard essay with introduction, support paragraphs, and conclusion. Just dive right into your outline and answer the question directly. On the other hand, your essay response cannot be an outline; it must have complete sentences written in paragraph form.
- Drawings and illustrations can improve your score. Drawings and diagrams may sometimes add as much as 1 point to your essay score. But the drawings must be

explained in your essay, and the drawings must be labeled with supporting information. If not, the exam marker will consider them doodles, and you will get no additional points.

- Pay attention to direction words. A direction word is the first word in an essay question that tells you how to answer the question. The direction word tells you what you need to say about the subject matter that follows. Here are the most common direction words found on the exam:

- ❖ Discuss means to consider or examine various aspects of a subject or problem.
- ❖ Describe means to characterize or give an account in words or diagrams where appropriate. It requires you to impart knowledge of facts or process. The answer should be concise and presented logically
- ❖ Define means to give a precise meaning for a word or phrase.
- ❖ Explain means to clarify or make understandable. It means to state with reference to theory and reason, the cause, effect and the implications of the factor affecting the subject. Clarity and relevance are important.
- ❖ Compare means to discuss two or more items with an emphasis on their similarities.
- ❖ Contrast means to discuss two or more items with an emphasis on their differences.
- ❖ Calculate means to show all the stages involved in deriving the answer to a numerical problem. It is always a good idea to begin with a formula or an explanation of the terms used in the calculation.
- ❖ Outline implies brevity but only absolutely essential information should be stated
- ❖ What is meant by..... Normally implies that a definition is required supported by relevant comment on the significance or context of the term(s) used. The amount of additional information given in your answer should be indicated by the value mark indicated.

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