CHEMICALS OF LIFE

All cells, tissues and organs are composed of chemicals. Living organisms are made up basically of molecules which constitute the protoplasm of the cells. These are known as **chemicals of life**.
The study of chemicals of life and the reactions they undergo is called **Biochemistry**.
The four most common elements in living organisms are **C, H, O** and **N**; phosphorus and sulphur are found in relatively smaller amount.
The chemicals of life (bio molecules) are broadly grouped into **micro molecules** and **macromolecule**.

Differences between micro molecules and macromolecules

Micro molecules	Macromolecule
Have low molecular mass	Have high molecular mass
Are formed from basic element like C,H,O and N	Are formed by polymerization of a large number of micro molecules
Examples include simple sugars, amino acids, fatty acids, nucleotide, etc	Examples are polysaccharides, lipids, proteins, DNA, RNA, etc

Chemicals of life are grouped into: **Organic** and **Inorganic compounds**. The organic chemicals of life are derived from carbon mainly and include carbohydrates, proteins, lipids, nucleic acids and vitamins. The inorganic chemicals of life include water, minerals, acids and bases.
The dominant compounds of chemicals of life are carbohydrates, lipids, proteins and water.

WATER

Water has many useful properties which arise from its structure.
A water molecule consists of two Hydrogen atoms covalently bonded to an Oxygen atom. Because oxygen is more electronegative than hydrogen, it has a greater pull on the shared electrons. That is, the oxygen atom is slightly negative (δ-) (because of the closer electrons), and hydrogen is slightly positive (δ+). Water is therefore called a ***Polar Molecule.***

PROPERTIES OF WATER

Water is a polar molecule; The slightly negative and slightly positive regions of the water molecule are attracted to charged regions of other polar molecules, forming Hydrogen Bonds (which are weak in comparison with other chemical bonds) with such molecules. This property allows water to take part in some metabolic reactions, *e.g. in Hydrolysis and Condensation reactions.*

Water is an excellent solvent; Ionic substances are soluble (they dissolve) in water because the poles of the polar water molecules interact with the ionic substances and separate them into ions. Substances with polar covalent bonds are similarly soluble because of the interaction of their poles with those of water. Substances that dissolve in water are called hydrophilic ("water loving"). Because they lack charged poles, nonpolar covalent substances do not dissolve in water and are called hydrophobic ("water fearing").

Water has strong cohesion and high surface tension; Cohesion, or the attraction between *like* substances, occurs in water because of the hydrogen bonding between water molecules. The strong cohesion between water molecules produces a high surface tension, creating a water surface that is firm enough to allow many insects to walk upon without sinking.

Water has a high heat capacity; Heat capacity is the degree to which a substance changes temperature in response to a gain or loss of heat. Water forms Hydrogen Bonds within itself. Hydrogen bonds within water give it a high stability, thus water has a high heat capacity, i.e. it changes temperature very slowly with changes in its heat content. Thus, the temperatures of large bodies of water are very stable in response to the temperature changes of the surrounding air. Relatively large amounts of energy is required to warm and boil/evaporate water (latent heat of vaporisation) or remove a relatively large amount of energy to cool and freeze water (latent heat

of fusion). When sweat evaporates from the skin, a large amount of heat is taken with it, hence causes cooling. The high latent heat of fusion allows organisms to live in water since it delays to freeze.

Ice floats on water; Unlike most substances that contract and become denser when they freeze, water *expands* as it freezes, becomes less dense than its liquid form, and, as a result, floats on liquid water. As water decreases in temperature, its molecules are less able to break the Hydrogen bonds, as they have less kinetic energy. This means that a semi-crystalline structure is formed, which holds the water molecules apart, making ice less dense than liquid water, such that it floats. This means that it insulates the water beneath, allowing organisms in the liquid water to survive.

***Water adheres to other molecules*;** Adhesion is the force of attraction between *unlike* substances. When water adheres to the walls of narrow tubing or to absorbent solids like paper, it demonstrates capillary action by rising up the tubing or creeping through the paper. This allows water to be transported in a column along the narrow xylem tubes.

BIOLOGICAL SIGNIFICANCE OF WATER:

- ❖ Provides a liquid environment inside cells & aquatic organisms.
- ❖ High cohesion and surface tension allows aquatic organisms (e.g. insects) to move on water.
- ❖ High density of water allows aquatic organisms to live under ice during the cool season. Since ice is less dense than water, it floats on top allowing organisms to live under it.
- ❖ High latent heat fusion causes water to slowly freeze hence allows organisms to live in water during cool seasons.
- ❖ High specific heat capacity allows organisms to live in water bodies due low chances of it heating up.
- ❖ High latent heat vaporization causes cooling effect.
- ❖ Adhesion allow water to move upward against gravity in a narrow channel (capillary force), hence water moves along the xylem tubes up a tall tree.
- ❖ Low viscosity & high tensile strength also allows water to move freely in small column and reach high up in a big tree.
- ❖ Water is transparent, hence aquatic plants and microorganisms can easily access sunlight to carry out photosynthesis.
- ❖ Water is hardly compressed, hence acting as hydrostatic skeleton in certain organism like worms & ensures turgidity in non woody plants.
- ❖ Water participates in many chemical reactions like hydrolysis due to its polar properties.

MINERAL SALTS

Minerals are the elements which are present in small amounts and vital for normal body functioning. About 4% of human body weight constitutes minerals. They play important role in metabolism of body.

The function of mineral elements and their derivatives in the body are varied but summarised as below:

1. ***Constituents of various chemicals:*** Nitrogen and sulphur are constituents of proteins; Phosphorous is a constituent of ATP; Iodine is found in thyroxin hormone; etc.
2. ***Constituent of structures:*** Calcium and phosphorous are major bone constituents; nitrogen and phosphorous make up nucleic acids; nitrogen and sulphur are components of many connective fibres; calcium is a component of plant cell walls; etc.
3. ***Constituent of enzymes:*** Enzymes are proteins of which all contain nitrogen as a basic constituent. In addition certain enzymes contain metal ions like copper or iron in catalase.
4. ***Constituent of certain pigments***: Iron is a basic component of haemoglobin; copper is a constituent of haemocyanin and haemoerythrin; magnesium and nitrogen are constituents of chlorophyll; iron in cytochromes; etc.

5. ***Metabolic activators:*** Certain ions activate enzymes, e.g. magnesium ions activate enzymes in phosphate metabolism; chloride ions activate amylase enzyme; phosphorous in form of phosphate is required to activate glucose before respiration occurs; copper is an enzyme cofactor in iron synthesis, melanin synthesis, etc.
6. ***Determinants of anion-cation balance:*** Sodium, potassium and chloride ions play a recommendable role in anion-cation balance, especially in nerves, muscles, and sensory cells where they play a role in transmission of impulses. Calcium ions also play an important role in muscle contraction.
7. ***Determinants of osmotic pressure:*** Together with other solutes, mineral ions determine the osmotic pressure of cells and body fluids, which in turn determines water balance in body fluids.

Categories of minerals

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

- **Macro elements:** These are required in large amount (more than 1gm). These include Ca, Mg, K, Na, Cl, S & P.
- **Micro elements:** these are required only in small amounts (less than 1gm). These are also called as trace elements. These includes Cu, Co, Cr, Zn, Se, Fe, Mn, I, F, etc.

MINERALS OF IMPORTANCE IN THE HUMAN BODY

MINERAL	SOURCES	FUNCTIONS	DEFICIENCY	EXCESS
Calcium	Dairy products, and vegetables	-Cell to cell communication. -Builds strong bones and teeth -Nerve transmissions. -Muscle contraction -Hormone secretions. -Blood clotting	Leads to hypocalcaemia	Constipation, increased risks of kidney stones as a result of calcium reacting with oxalic acid.
Potassium	Beef, fish, chicken, potatoes, tomatoes and lima beans	-controls electrical activity of the heart and maintaining a normal heart rhythm. -Build proteins and breaks down carbohydrates. -Maintains the pH balance of blood and supports normal growth.	Symptoms of diarrhoea and vomiting	Cardiac arrhythmias and cardiac arrest may result.
Sodium	Table salt, soy sauce, bacon, fast foods	-stimulates nerve and muscle functioning. -Maintains and corrects balance of fluid in the cells. -Controls the volume of blood which in turn impacts the blood pressure. -Supports the absorption of other nutrients like glucose.	Reduced extra-cellular fluid volume.	-high blood pressure, liver cirrhosis, kidney disease, congestive heart failure.
Magnesium	Beans, nuts, whole grains	-supports biochemical reactions.	Muscle weakness,	

	an green vegetables	-Supports muscle and nerve functioning and keeps the heart beating regularly. -Builds strong bones and builds immunity.	ventricular fibrillation, coma and death.	
Phosphorous	Meat, whole grains and dairy foods.	-plays an important role in building strong teeth and bones, producing proteins the body needs in repairing cells.		
Chloride	Table salt	-Balances the fluids in the body, plays an essential role in production of digestive juices in the stomach.	Muscular cramps	
Iron	Meat, meat products, cereals, vegetables and fruits	-the body uses iron to produce haemoglobin, myoglobin and proteins that carry oxygen in the body.	Results into anaemia.	Liver and pancreatic cancer, symptoms of nausea, vomiting and diarrhoea
Copper	Green vegetables, fish, oysters, liver.	-Responsible for production of metallo enzymes.	Pre-mature birth, poor mental development,	Wilson's disease
Iodine	Milk, sea foods	-Required for the production of thyroid hormones.	Causes goitre	Hyperthyroidism.
Zinc	Yeast, fish, cereal grains bran and germ	-enzyme component of carbonic anhydrase and enzyme activator	Poor growth Depressed appetite Reddening of the skin	
Manganese	Wheat, rice bran, green vegetables	Enzyme activator such as kinases and hydrolases	Retarded growth, skeletal abnormalities, ataxia of the new born and reproductive failure	
Selenium	Wheat, rice, maize	Immune function, component of glutathione peroxidase, production of thyroid hormones	Myopathy Exudative diawthesis	

ORGANIC CHEMICALS OF LIFE

Carbon is an element found in all organic molecules. It has important (unique) properties.

- It is a relatively a small atom with a low mass.
- It forms four strong, stable covalent bonds.

- ❖ Has the ability to form carbon-carbon bonds, thus building up large carbon skeleton with long chain or ring structures.
- ❖ It has the ability to form multiple covalent bonds with itself and other elements.

VITAMINS

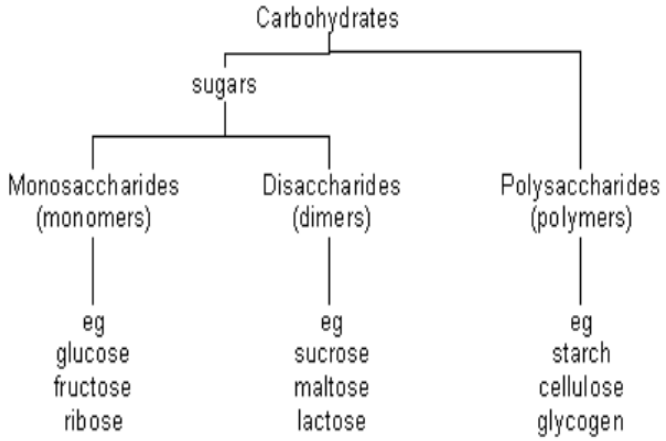
Vitamins are also known as micronutrients. They are organic substances that the body requires in small amounts for metabolism (for normal growth and functioning of the body).
The body is incapable of synthesizing most vitamins or does not synthesize in sufficient amounts for its overall needs. However, plants synthesise vitamins and are supplied for animal diet. They are not related to each other chemically and differ in their physiological actions.
If a diet lacks a particular vitamin, a disorder called deficiency disease results.

TYPES OF VITAMINS

1. **Fat soluble vitamins:** These are vitamins which can dissolve in fats e.g. A, D, E and K. Excess of these vitamins are excreted in urine.
2. **Water soluble vitamins:** These are vitamins which can dissolve in water e.g. C and B. Excess of these vitamins are rarely excreted in urine and are not stored in the body.

CARBOHYRATES

These are organic substances which contain the elements C, H and O in which the ratio of H:O is 2:1 as in water. Carbohydrates have the general formula $C_x(H_2O)_y$; where **x** and **y** may be the same or different.



A Carbohydrate are either **aldehyde** or **ketones** and contains several hydroxyl groups. The chemistry of a carbohydrate are determined by these groups.
Carbohydrates are classified into 3 major classes as: **monosaccharide**, **disaccharides**, and **polysaccharides**.
One major similarities of all carbohydrates is that they are made up of simple sugars or monosaccharide as the basic simple units.
Carbohydrates are stored as starch in seeds of flowering plants, in roots and stem tubers. In mammals, they are stored as glycogen in the liver and muscles.

MONOSACCHARIDES

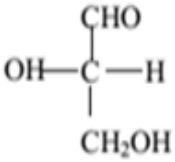
These are single sugar units with the general formula $(CH_2O)n$ or $C_nH_{2n}O_n$; where n signifies the number of **C**, **H**, and **O** atoms.

Characteristics of monosaccharides

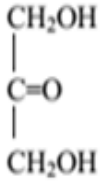
Carbohydrates; **(1)** are sweet; **(2)** cannot be hydrolysed into smaller carbohydrates; **(3)** are soluble in water; **(4)** are crystalline solids; **(5)** are reducing sugars; **(6)** have relatively low molecular masses; **(7)** contain either aldehyde or ketone group; **(8)** diffuse rapidly across a semi-permeable membrane.

A monosaccharide contain either: **(1)** Aldehyde group (CHO) at their terminal endings in which case they are called aldose sugar (aldoses); or **(2)** ketone group (C=O) at the non-terminal carbon in which case they are called ketose sugar (ketoses).

Glyceraldehyde (Aldose sugar)



Dehydroxyacetone (keto sugar)



All the carbon atoms in monosaccharide have OH group attached to them except one. This carbon atom can either make up the aldehyde or the ketone group.
Monosaccharides are named with the suffix ending "ose".
They are composed of 3-7 carbon atoms are classified according to the number of carbon atoms.

Classes of monosaccharides

Class of monosaccharide	**Number of carbon**	**formula**	**Examples**
Trioses (triose sugar)	3	$C_3H_6O_3$	Glyceraldehyde, dihydroxyacetone
Tetroses (Tetrose sugar)	4	$C_4H_8O_4$	Erythrose
Pentoses (Pentose sugar)	5	$C_5H_{10}O_5$	Ribose, Deoxyribose, Ribulose
Hexoses (Hexose sugar)	6	$C_6H_{12}O_6$	Glucose, Fructose, Galactose
Heptoses	7	$C_7H_{14}O_7$	Heptutose

Of these, the Pentoses and hexoses are the most common which exist as chain or ring structure. The ring structures can be 5-sided (furanose rings) or 6-sided (pyranose rings). Pentoses form 5-sided rings while hexoses form 6-sided rings.

Examples of common monosaccharides and their occurrence

Monosaccharide	**Occurrence**
Glucose	Germinating seeds, animals
Fructose	Nectar, honey, fruits
Galactose	Milk

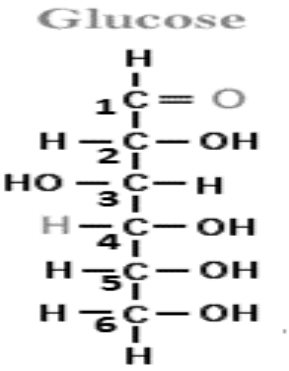
Uses/Importance of monosaccharides

Monosaccharide	**Significance**
Trioses	Intermediates in respiration, photosynthesis and other carbohydrate metabolism
Pentoses	-Synthesis of nucleic acids e.g. ribose is a constituent of RNA, deoxyribose is a constituent of DNA; -Synthesis of coenzymes e.g. ribose is used in the synthesis of NAD and NADP; -Synthesis of ATP requires ribose; -Ribulose biphosphate, a CO_2 acceptor in photosynthesis is made from 5C sugar ribulose.
Hexoses	-Are sources of energy when oxidized in respiration; -Synthesis of disaccharides and polysaccharides

HEXOSES

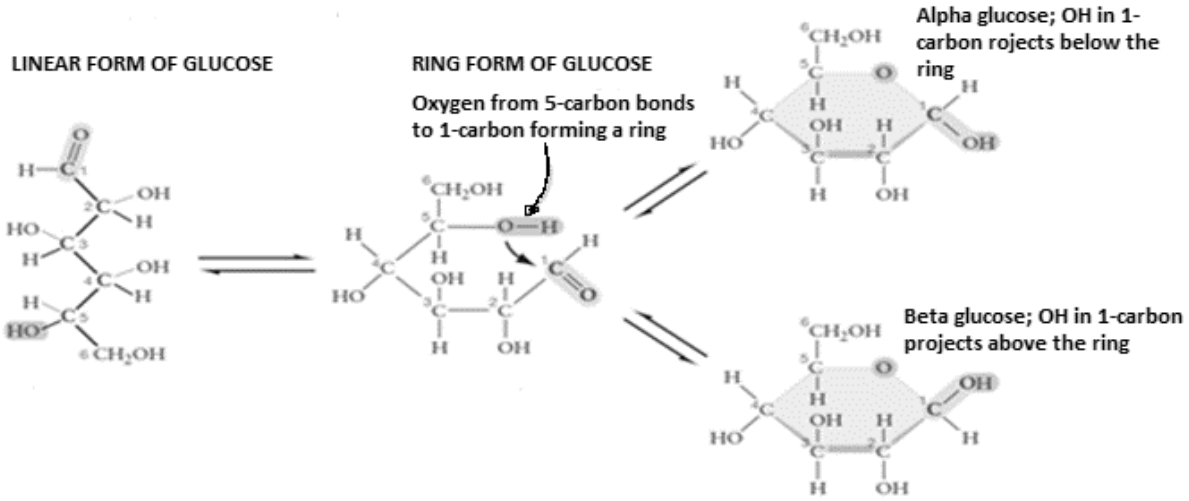
These are 6 carbon sugars e.g. glucose, fructose and galactose. They have the general formula $C_6H_{12}O_6$.

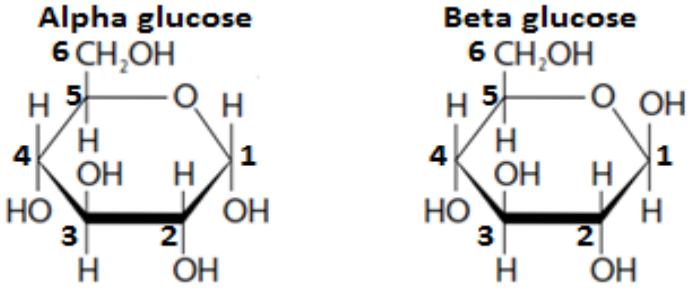
STRUCTURE OF HEXOSES



GLUCOSE

Glucose like exist as straight chain of 6C atoms. It contains aldehyde group. Glucose in common with other hexoses and pentoses also exist as ring structures. At any time, most molecules form ring structures rather than open chain structures. In this case, the oxygen of the aldehyde group combines with carbon atom number 5. This forms a 6 sided structure (pyranose structure)





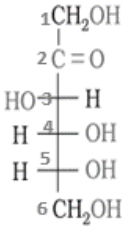
Glucose exists in two possible ring forms:

(1) Alpha (α) ring; where the OH group on carbon 1 projects below the ring; and
(2) Beta (β) glucose; where the OH group on carbon atom 1 project above the ring

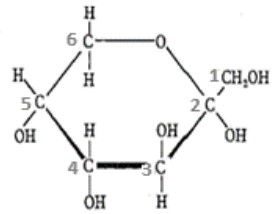
FRUCTOSE

Fructose and glucose exhibit isomerism hence they are isomers.
Glucose contains ***aldehyde*** group while fructose contains ***ketone*** group.
Fructose exists in both open chain and ring structures
The pyranose (6-sided) structure is formed when CH_2OH group at carbon 5 and H at carbon 1 are interchanged and interchanging OH groups at carbon position 1, 2, and 3 in the beta glucose.
Unlike other hexoses, fructose also exists as furanose (5-sided). In this case, carbon 2 in the open chain links with oxygen atom at carbon 5.

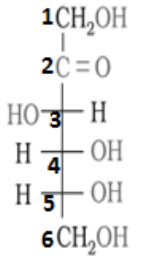
Fructose linear structure



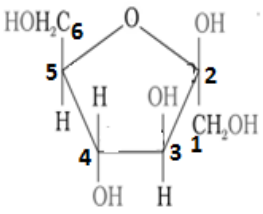
Fructose pyranose structure



Linear fructose structure

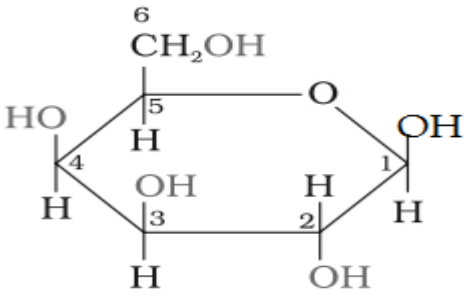


Furanose fructose structure

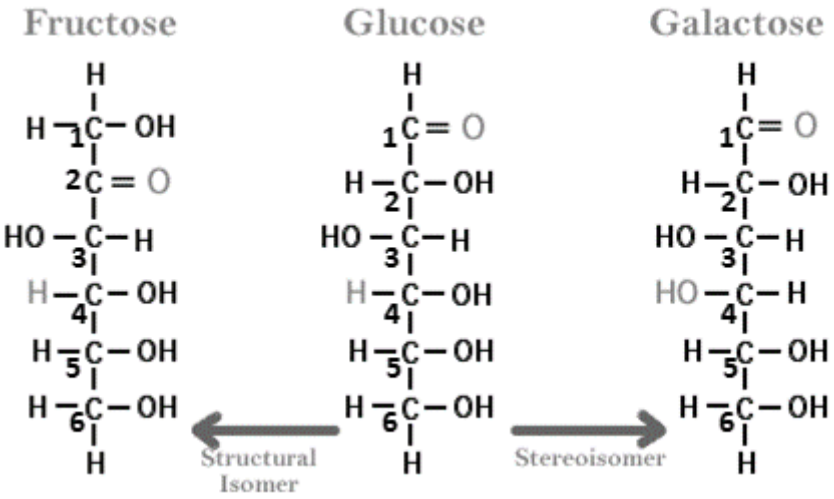


GALACTOSE

Galactose exists as pyranose**.**



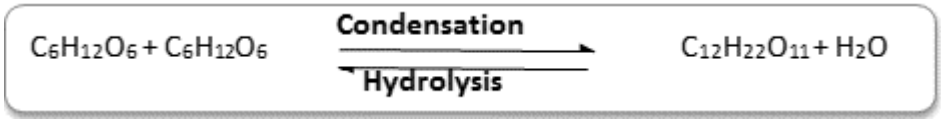
The structure of galactose is obtained by interchanging the OH group at carbon 4 in the beta glucose form with hydrogen atom at carbon 1.



NB: Different 6-carbon monosaccharides can be made by switching positions of atoms on the carbon chains.

DISSACHARIDES

Disaccharides are carbohydrates formed when 2 monosaccharides, usually hexoses combine by condensation reaction.

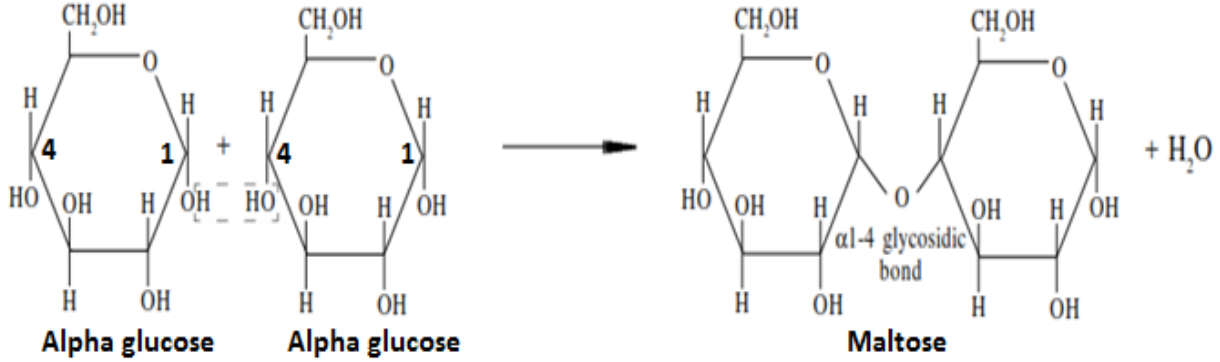


The bond formed between the monosaccharides units as a result of condensation is called **glycosidic bond** and is usually formed between carbon 1 and 4 of the neighbouring units (i.e. 1,4 linkage).

The process may be repeated many times to build up giant molecules of polysaccharide units. The monosaccharide units in the disaccharide/polysaccharide are called **residues**.

The most common disaccharides are maltose, lactose and sucrose.

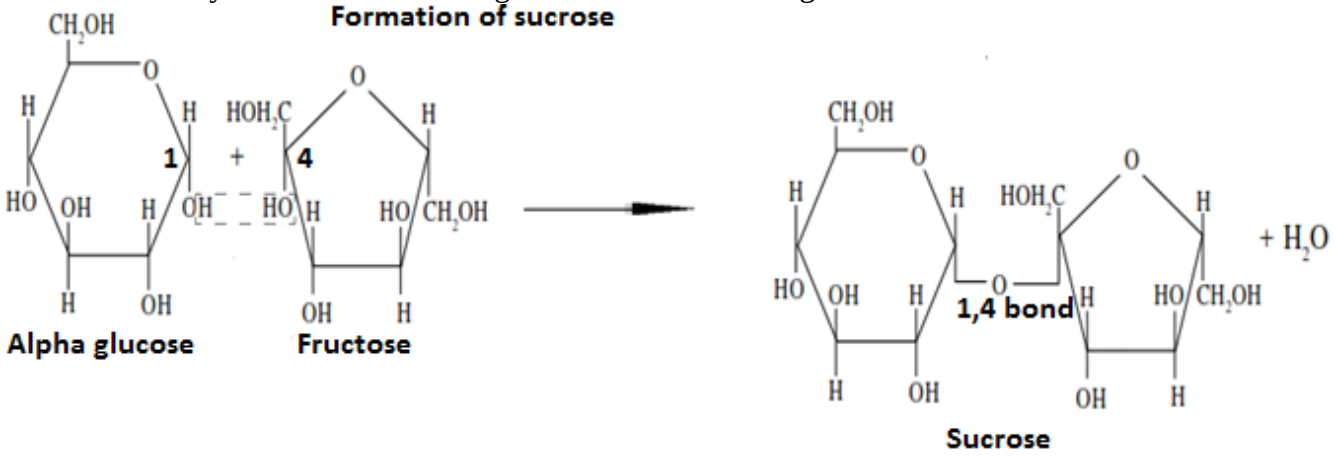
Maltose is also a disaccharide made of two glucose molecules bonded together as shown below.



Maltose mainly occurs as a breakdown product of digestion by enzyme amylase. This occurs in animals and germinating seeds. The latter is used in brewing beer when barley grain or millet is used as source of starch. Germination of barley or millet is stimulated and results in the conversion of starch to maltose, a process called **malting.**
The maltose is the hydrolysed to glucose and the glucose fermented to alcohol.
Lactose (or milk sugar) is exclusively found in milk and is an important source of energy for young mammals. It is formed when an alpha glucose combines with galactose. It can be hydrolysed to its constituents by enzyme lactase

Sucrose is the most abundant disaccharide in nature. It is a non-reducing sugar commonly found in plants, where it is transported in large quantities through phloem tissue. It is formed when an alpha glucose combine with fructose. Sucrose is obtained commercially from the stems of sugar cane and roots of sugar beets.

Formation of sucrose



NB: Sucrose makes a good form of transport of sugar because:
- It is very soluble and therefore can be moved efficiently at high concentration.
- It is relatively unreactive chemically. This means it tends not to enter into general metabolism on its way from one place to another.
- It can easily be stored since it is relatively unreactive chemically.

General properties of disaccharides
- Are sweet
- Soluble in water and can be crystallized
- Readily hydrolyzed by dilute acids to their constituent monomers

REDUCING SUGARS
All monosaccharides and some disaccharides (maltose and lactose) have reducing carbon. In the disaccharide, the reducing carbon of one monosaccharide is linked to another carbon other than the reducing carbon of the other monosaccharide so that one reducing carbon is free to react as a reducing agent.

The sugars are able to reduce Cu^{2+} to Cu^{+} and this forms the basis of Benedict's and Fehling's test.
Cu^{2+} (blue) ⟶ Cu^{+} (Brick-red precipitate)

Sucrose is the only non-reducing disaccharide. Here, the reducing carbon of one monosaccharide is linked to the reducing carbon of the other monosaccharide so that the reducing property is lost.

POLYSACCHARIDES

These are polymers of monosaccharides. They consist of a large number of simple sugars forming a long chain which may be folded, branched or unbranched. The total numbers in them however vary.
The most common polysaccharides are glycogen, starch and cellulose.

Properties of polysaccharides
(i) Have high molecular mass/weight; **(ii)** Insoluble in water; **(iii)** Tasteless; **(iv)** Amorphous(shapeless)

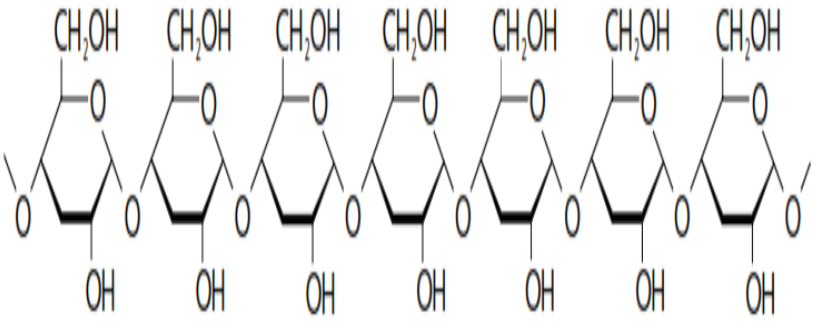
Functions of polysaccharides
- ❖ Source of food and energy stores (e.g. starch and glycogen).
- ❖ Constituents of structural materials e.g. cellulose in plant.

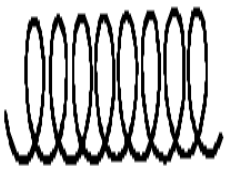
Polysaccharides are convenient storage molecules for 3 reasons:
- ❖ Their sizes are large making them insoluble in water.
- ❖ They fold in compact shape thus occupy small storage space.
- ❖ Are easily hydrolysed to their constituents.

GLYCOGEN
Is an animal store of carbohydrate; equivalent of starch, being composed of alpha glucose residues which are highly branched. The molecules are linked by 1, 4 and 1,6 glycosidic bonds. It is very similar to amylopectin but shows more branching.
Many fungi also store glycogen; in animals, it is stored in the liver and muscles as zymogens (tiny granules)

STARCH
Starch is a storage carbohydrate of plants. It is a polymer of long chain **α-glucose** and is the major fuel store in plants**.**
Starch is composed of **20% amylose, 79% amylopectin** and 1% other substances like phosphate and fatty acids.

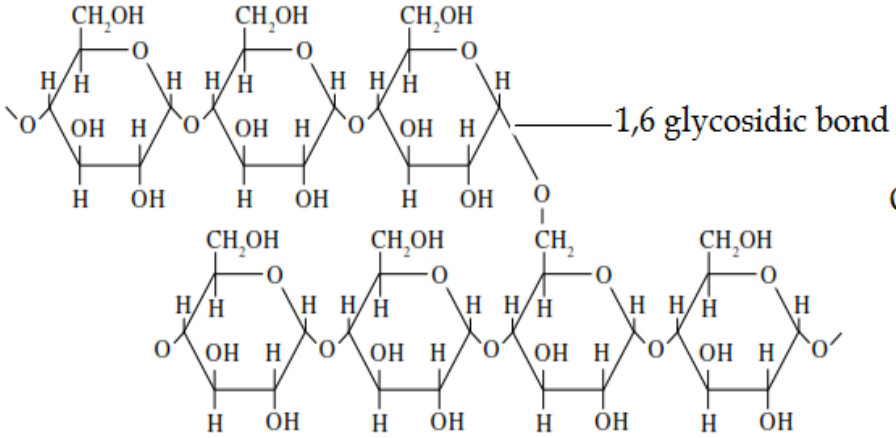
Amylose
Amylose is a straight chain structure consisting of several thousands of alpha glucose residues joined by 1, 4 glycosidic bonds. These bonds cause the chain to coil helically into a





more compact shape.
Amylopectin

Amylopectin is also compact like amylose but is highly branched. It has up to twice as many glucose residues as amylose. The branching is due the formation of 1, 6 glycosidic



bonds.

NB: A suspension of amylose gives a blue-black colour with iodine solution while that of amylopectin gives violet-red colour. This forms the basis of test for starch.

Differences between amylose and amylopectin

Amylose	**Amylopectin**
Stains deep blue or blue-black with iodine	Stains red-violet with iodine
Have low molecular mass	Have high molecular mass
Chain coil helically into a more compact shape	Chain dose not coil helically but highly branch to form a more compact shape
Has 1,4 linkage only	Has 1,4 and 1,6 linkages.
Straight chain	Branched chain

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

 It is a polymer of α-glucose molecules hence a large molecule making it relatively insoluble in water hence an ideal storage molecule.

 The α-glucose molecules are held by glycosidic bonds which can be broken down to free glucose molecules from the stored starch for ATP synthesis during respiration.

 The starch molecule is coiled into a helix with a hydroxide group projecting interiorly making it insoluble in water hence exerts no osmotic effects in cells and is ideal for storage.

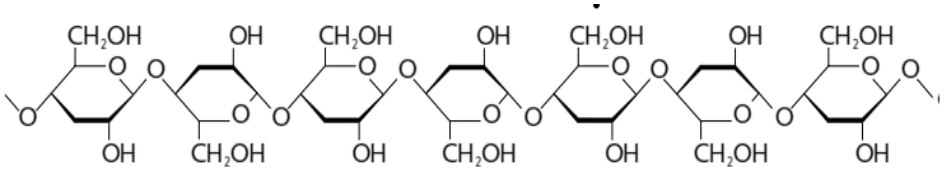
 It is insoluble in water implying that it cannot be lost from the storage cells and tissues in solution form.

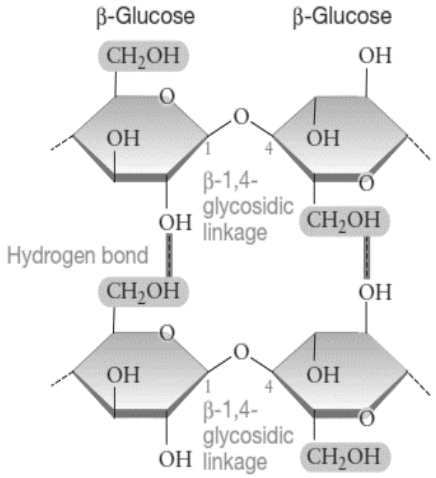
 It is insoluble in water hence it does not affect the osmotic properties of the cells.

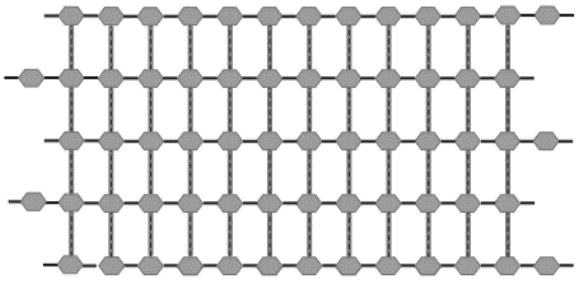
 It is highly coiled into a helix making it compact implying that a lot of it can be stored in a limited space.

CELLULOSE

Is a polysaccharide consisting of long chains of beta glucose molecules linked by glycosidic bonds. Many chains run parallel to each other and have cross linkages between them which makes cellulose its considerable stability, making it valuable as structural material.







Parallel strands joined by hydrogen bonds

Being composed of beta glucose, the chain has adjacent molecules rotated through 180^{o}. This allows hydrogen bonds to be formed between OH groups of adjacent parallel chain which help to give cellulose its structural stability. The rotation of the successive residues is the underlying reason why cellulose has a different structure from starch.

A single cellulose chain may contain as many as 10000 beta glucose residues with a total length of 5 µm. The strength of the glycosidic bonds together with cross linkages between adjacent chains makes it tough like rubber.

The chains of cellulose associate in groups of 60-70 to form micro fibrils, which are arranged in larger bundles to form macro fibrils. These have tremendous tensile strength. In cell walls, the macro fibrils are arranged in several layers in a glue matrix made up of other polysaccharides (i.e. pectins and hemicelluloses).

The macro fibrils of each layer run parallel to each other and at an angle to the macro fabrils of another layer.

Despite the great strength and stability, the plant cell walls are fully permeable to water and dissolved solute. The matrix is riddled with minute water filled channels and the molecules are hydrophilic. These facilitates the exchange of materials.

Functions/uses of cellulose

- ❖ Important food source for some animals e.g. rabbit, snails, and fungi, etc
- ❖ Forms the bulk and roughage in human food and is necessary for proper functioning of digestive system.
- ❖ Prevent the cells from bursting when cells take in water by osmosis and also helps to determine the shape of the cell
- ❖ Cellulose derivatives like cellulose nitrate are used in the manufacture of photographic films and explosives.
- ❖ Provide raw material s for the manufacture of papers and various plastics e.g. cellulose acetate is used in the manufacture of plastics.
- ❖ Cellophane which is used in packaging is got from cellulose.
- ❖ Cotton is made up of 90% cellulose and is used in manufacture of fabrics.

Adaptation of cellulose to its function

- Hydrogen bonds to be formed between OH groups of adjacent parallel chains which gives cellulose its structural stability.
- A single cellulose chain may contain several thousands of beta glucose residues which further enhances its strength.
- Cellulose is composed of glycosidic bonds together with cross linkages between adjacent chains makes it even tougher.
- Cellulose is insoluble in water thus resists dissolution increasing its stability.
- The chains of cellulose associate in groups of 60-70 to form micro fibrils, which are arranged in larger bundles to form macro fibrils to further increase its tensile strength.
- The matrix is riddled with minute water filled channels with hydrophilic molecules thus allows the exchange of materials.

Lignification

Certain plant tissues especially those concerned with providing mechanical strength and conducting water are lignified during their development.

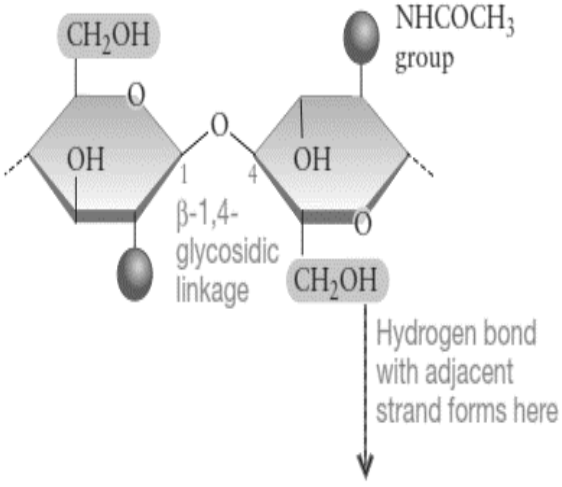
In the process of lignification, lignin (a polymer of various sugars and amino acids) is deposited in the spaces between the cellulose molecules, making the cell wall much more rigid and rendering it impermeable to water and other materials. Once lignification is complete, the protoplasm can no longer exchange material with the outside and it dies.

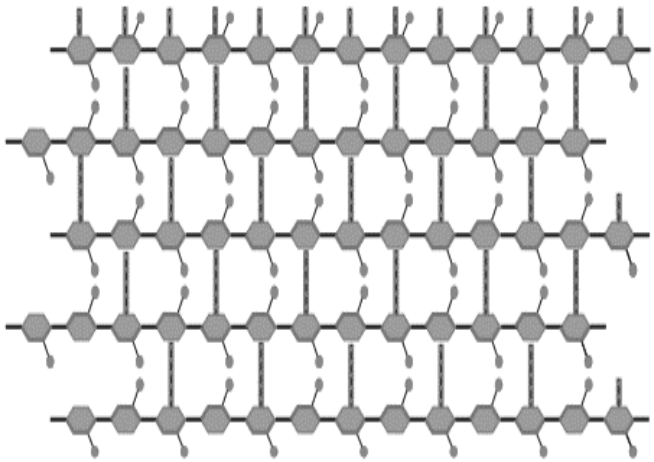
COMPOUNDS RELATED TO CARBOHYDRATES

1. CHITIN

Is closely related to cellulose in structure and function and occurs in exoskeleton of arthropods and in cell wall of some fungi.

Structurally, it is identical to cellulose except that the OH group at carbon 2 is replaced by N-acetyl glucosamine ($NHCOCH_3$).

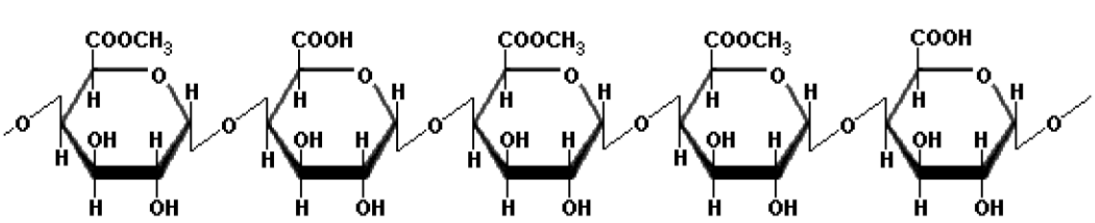




Parallel strands joined by hydrogen bonds

2. PECTIN

Pectin is a polysaccharide of galactose and galacturonic acid units joined with 1,4 alpha linkages. They are components of the middle lamella in plant cell walls as a cementing material and also strengthens tissues in plants. Pectins are found together with calcium ions to form calcium pectate.



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

3. **MUREIN (PEPTIDOGLYCAN);** this is a polymer that consists of sugars and amino acids that form a mesh like structure/layer outside the plasma membrane of most bacteria forming the cell wall. It has a long backbone formed by two forms of amino sugars that alternate with each other linked by beta 1,4 glycosidic bonds. Acts as the strengthening material of bacterial cell wall and it gives it strength and firmness. It is similar in structure to chitin, containing nitrogen like chitin.

4. **INULIN;** this is an unusual polysaccharide whose monomer unit is fructose. It is used as a food store mainly in roots and tubers of Dahlia tubers. This means it's a storage carbohydrate. It is an unbranched chain of 1,2-glycosidic bonds.
5. **CALLOSE;** this is an amorphous polymer of glucose found in a wide variety of location in plants. It is mostly found in response to wounding or stress. It is particularly important in the phloem sieve tubes. It is a 1,3 glycosidic bonds.
6. **LIGNIN;** this chemically resembles mucopolysaccharides. It is formed from sugars and amino acids. It is rigid with condensed molecules and binds cellulose chains to form microfibrils. This impregnates the xylem to form impermeable lining in the process of lignification. It prevents rot, decay and infections.

7. **MUCOPOLYSACCHARIDES;** these are polysaccharides containing amino sugars. An amino sugars is one which contains nitrogen e.g. hyaluronic acids which forms part of the matrix of vertebrate's connective tissue. It is found in cartilage, bones, vitreous humour of the eye and synovial fluid where it functions as a lubricant. The anticoagulant heparin is also a member of this group of polysaccharides.

Explain why carbohydrates form a variety of polysaccharide

1. They form both 1, 4 and 1, 6 glycosidic bonds. This increases the variety of polysaccharides since branching can occur e.g cellulose has only 1, 4 while glycogen and starch have both 1, 4 and 1, 6 glycosidic bonds.
2. They use both pentoses and hexoses to form polysaccharides. In some cases one monosaccharide is used while in other cases, two or more different monosaccharides are used in alternating sequences.
3. The difference in the level of branching shown by carbohydrate polymers, leads to the formation of different polysaccharides e.g glycogen is more branched than starch.
4. The existence of both alpha and beta forms of certain monomers increases the variety of polysaccharides. This causes the difference between starch and cellulose.

5. The high chemical reactivity of monomers makes them combine with other groups to form related monomer units. These combine to form different polysaccharides e.g cellulose differs from chitin.
6. The existence of both ketoses and aldoses which form both five numbered and 6 numbered rings. This causes the difference in certain polysaccharides e.g insulin is different from starch.

Question: Describe the functions of carbohydrates.

LIPIDS

Lipids are esters of fatty acids and glycerol.
Lipids are a large and varied group of organic compound and like carbohydrates, they contain the elements **C, H** and **O** but the proportion of **O** is much smaller in lipids. They need a large amount of oxygen for their oxidation to release energy. Lipid have high proportion of hydrocarbon (CH) in the molecules.
Lipids are insoluble in water but readily dissolve in organic solvents like acetone, alcohol, benzene, etc. The low solubility in water is due to few OH groups in lipids.

PROPERTIES OF LIPIDS

- Are relatively insoluble in water but readily soluble in organic solvents.
- Need a large amount of oxygen for their complete oxidation to release energy
- Are esters of fatty acids and glycerol
- Have very small amount of oxygen compared to carbon and hydrogen.

CLASSIFICATION OF LIPIDS

Lipids are broadly categorized into: **(1)** simple; **(2)** compound; and **(3)** derived lipids.

SIMPLE LIPDIS

Simple lipids include; **(a)** fats; **(b)** oils; and **(c)** waxes

Differences between fats and oils

Oils	**Fats**
Liquids at room temperature	solids at room temperature
Rich in unsaturated fatty acids	Rich in saturated fatty acids
Obtained from plants/animals	Obtained from animals only
Examples: Groundnut oil, shearnut oil, simsim o etc.	Examples: Margarine, butter etc.

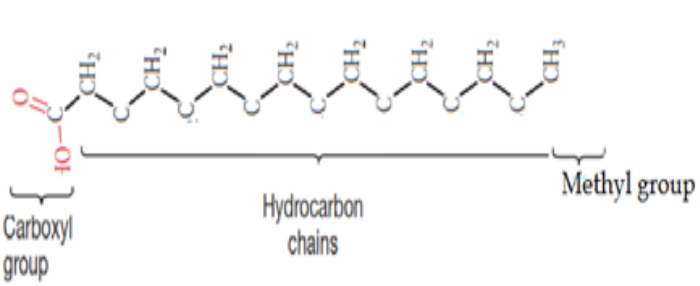
FATTY ACIDS

Fatty acids have the general formula RCOOH or $R(CH_2)_nCOOH$.
A fatty acid is composed of: (a) A methyl group (CH_3)***; (b)*** Hydrocarbon chain (CH)***; (c)*** Carboxylic group (COOH)

The hydrocarbon forms a long hydrophobic tail (*"Hydro*" means water and "*phobos*" means fear/hate). Many of the properties of lipids, especially their solubility in water is determined by the hydrophobic tail.
Most fatty acids have even number of carbon atoms, usually between 14-22 and the common fatty acids have 16 and 18 carbon atoms.

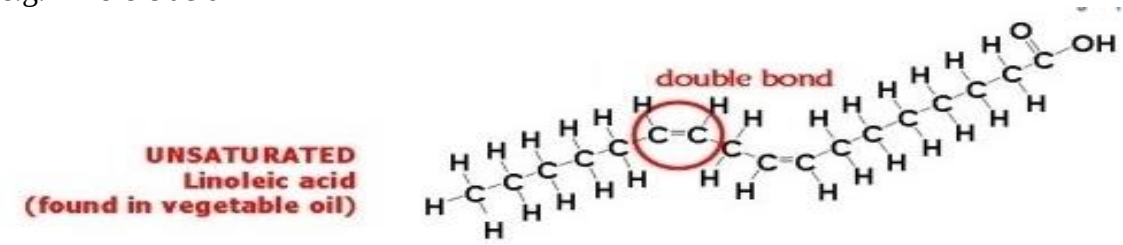
Fatty acids are categorized as ***saturated fatty acids and unsaturated fatty acids***.

Saturated fatty acids lack double bonds e.g. stearic acid ($C_{17}H_{35}COOH$) and palmitic acids ($C_{15}H_{31}COOH$)



Or

Unsaturated fatty acids contain double bonds between carbon atoms in the hydrocarbon tail, e.g. Linoleic acid



- Fatty acids which contain one or more double bonds are said to be unsaturated and those without double bonds are said to be saturated.
- Saturated fatty acids have high melting points and are therefore found in fats while in unsaturated fatty acids, the presence of the double bonds lowers the melting point and are therefore found in oils.

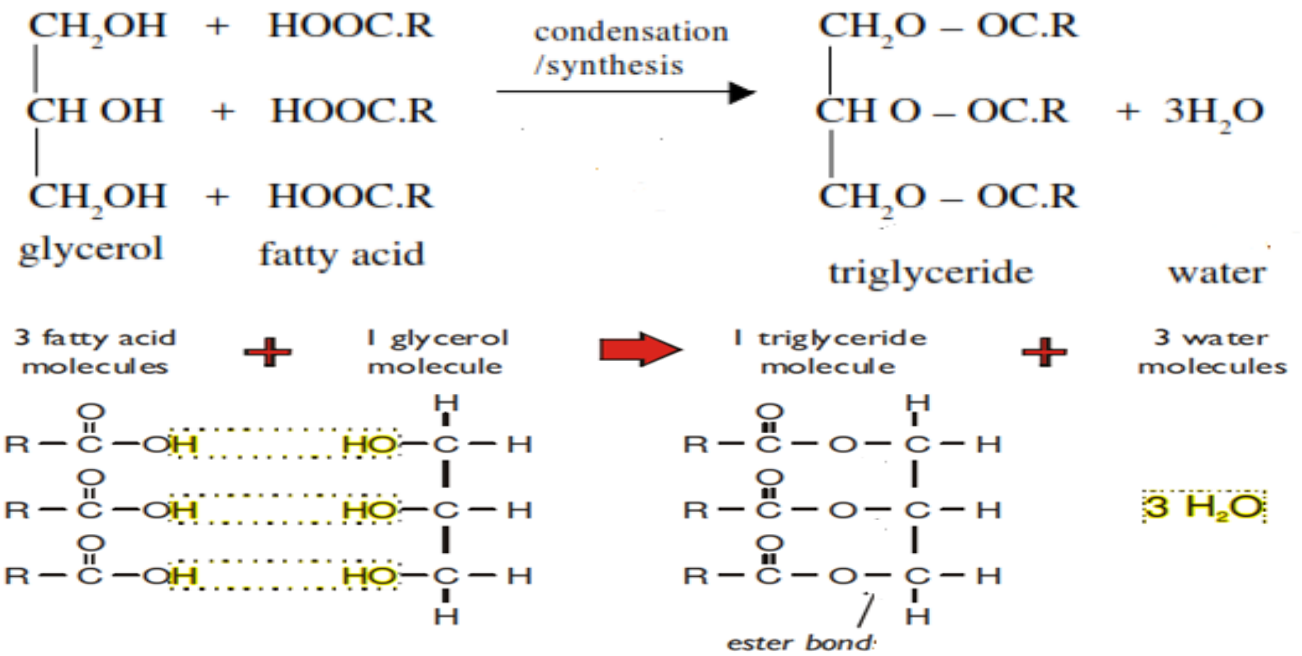
Differences between saturated fatty acids and unsaturated fatty acids

Saturated fatty acids	**Unsaturated fatty acids**
Lacks double bonds between carbon atoms	Have one or more double bonds between carbon atoms e.g. oleic acid has 1 double bond, linoleic acid has 2 double bond while linoleic acids have 3 double bonds between carbon atoms
Melt at higher temperature e.g. stearic acid and palmitic acids melts at 63.1^{o}C and 69.6^{o}C respectively.	Melt at lower temperature e.g. oleic acid, the main constituent of olive oil acid and palmitic acids melts at 13.4^{o}C
Found commonly in fats	Found commonly in oils

FORMATION OF FAT/OIL

Fats/oils are also called **triglycerides.** A triglyceride is formed when each of the OH group of the glycerol combines with a fatty acid. The fatty acids may be the same or different.

During the reaction, the OH groups of the glycerol react with the carboxylic group (COOH) of the fatty acids; 3 molecules of water is lost and ester bonds are formed, hence it's a condensation reaction.



NB:

1. A diglyceride has one molecule of glycerol and 2 molecule of fatty acids while a monoglyceride has one molecule of glycerol and one molecule of fatty acid.
2. The reaction involved in the formation of triglyceride (fat/oil) is a condensation one thus hydrolysis of fat/oil yields fatty acids and glycerol. The hydrolysis takes place in the presence of enzymes lipases.
3. Fats or oils store twice the amount of energy as the equivalent mass of carbohydrate. This is due to high proportion of hydrogen atoms in lipids, which calls for high amount of oxygen to cause complete oxidation. Lipids are therefore important energy reserves in animals and plants.

FATS, OILS AND THE DIET

Fats in the diet are important sources of vitamins e.g. vitamin A, D, E, and K and also forms a convenient long term energy stores in the body.

A balanced diet should contain both fats and oils but because of the link between fats and cardiovascular diseases, it is recommended that people reduce on fatty food intake.

In relation to diet, fatty acids are categorized into **essential fatty acids** and **non-essential fatty acids.**

- **An essential fatty acid** is one which must be included in the diet because it cannot be synthesized by the body. **e.g. Alpha linolenic acid (Omega-3 fatty acid) and linoleic acid (Omega-6 fatty acid).**
- Common sources of essential fatty acids are; fish, seaweed oil, shellfish, vegetables and seed oils.

Functions of essential fatty acids (EFAs)

- ❖ Manufacture of phospholipids which form part of the structure of membranes e.g. cell membrane.
- ❖ Are involved in the break down, transport and excretion of cholesterol.
- ❖ Manufacture of certain other fatty acids which are of physiological importance i.e. prostaglandins which are a group of fatty acids with a wide range of effects on the body e.g. they influence the action of certain hormones, can stimulate inflammatory responses and regulate blood flow to some organs.

- Linoleic acid is needed for the normal functioning and development of the retina of the eye.
- Are rich source of energy when oxidized.
- Stores fat soluble vitamins e.g. A, D, E, and K.
- Are source of metabolic water when oxidized for desert animals such as camels.
- They promote growth and prevent dermatitis in infants (drying and flaking of skin)
- They also regulate cholesterol metabolism
- Also associated with anti-violent behaviour,
- Increased attention span has also been recorded.

NB: *Deficiency of essential fatty acids are rare since large reserves usually exist in the body fat and daily eats is usually adequate.* However, deficiency results in ill health, retarded growth, reproductive challenges and kidney failure.

Non-essential fatty acids are the ones which are synthesized by the body from immediate compounds of proteins and carbohydrate metabolism. The body does not normally suffer from their deficiency except in extreme cases of starvation/malnutrition.

WAXES

These are similar to fats and oils in composition and structure ***except*** that the fatty acids are linked to long chain alcohol other than glycerol.

Functions

- Acts as water proof covering bird's feather, animal fur and skin, arthropod's exoskeleton and leaf and fruits of most terrestrial plants.
- Bee wax form material of honey comb

COMPOUND LIPIDS

This includes phospholipids, lipoproteins and glycolipids.

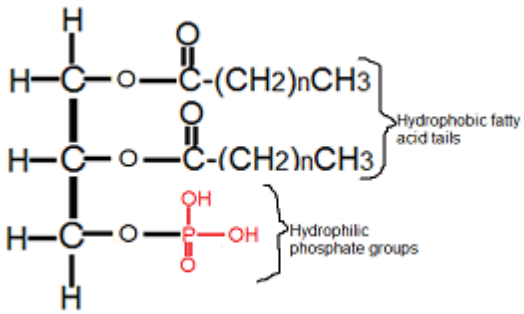
PHOSPHOLIPIDS

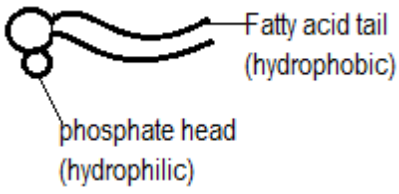
These are lipids which contain a phosphate group.

A phospholipid differs from other lipids by having a phosphate group other than fatty acid attached to one of the OH groups of the glycerol such that it has 2 fatty acids instead of three. Other groups including nitrogen bases may be added to make the structure even more complicated.

Therefore, a phospholipid is formed when one of the OH of glycerol combine with phosphoric acid and the other two OH groups with fatty acids

Because the phosphate head carries electrical charge, it is soluble in water i.e. hydrophilic while the tail is hydrophobic. A phospholipid is therefore soluble in water and organic solvents. Such molecules are said to be **Amphipathic** i.e. have ability to dissolve in water and non-polar solvents which property is important in determining the structure and functioning of the plasma membrane**.** Other examples of amphipathic molecules are intrinsic proteins.





Functions of phospholipids

- The main function of phospholipid is that it forms part of biological membranes, therefore; (1) Gives the membrane flexibility thus allows movement; (2) Affects permeability of the membrane, i.e. allows movement of non-polar substances.
- They may be oxidised to produce energy.
- Cell signalling. Second messengers in signal transduction such as inositol triphosphate are derived from phospholipids.

NB:

The venoms of poisonous snakes contain phospholipases, enzymes that hydrolyses phospholipids to release *lysolecithin,* a strong detergent that dissolves the membranes of red blood cells, causing them to rupture. Venom lipase also easily raptures the Heart tissues.

GLYCOLIPIDS

This is association of lipids with carbohydrates. The carbohydrate forms a polar head and like phospholipids, glycolipids form part of cell membranes and myelin sheath of nerve cells.

Functions of glycolipids

- Cell to cell recognition
- May be oxidised to produce energy
- Act as receptor sites for chemical signals, e.g. neurotransmitters.
- Enhance membrane stability
- Receptor sites for hormones
- Receptor sites for antibodies

LIPOPROTEINS

This is an association of lipids and proteins. Several different classes of lipoproteins, i.e. chylomicrons.

Chylomicrons deliver dietary fats to tissues for a variety of functions like insulation, energy production, protection of internal organs, synthesis of other valuable molecules, storage of fat soluble substances like hormones, etc.

This cholesterol has a strong relationship with cardiovascular diseases (CVDs), such as atherosclerosis.

Atherosclerosis is defined as a narrowing and hardening of arteries that result from chronic lipid deposition, cell proliferation and reactive inflammation in the artery wall.

Atherosclerotic lesions are deleterious because they can intrude into the arterial lumen and impede blood flow. Reduced blood flow compromises the function of downstream tissues because of inadequate oxygenation and metabolite exchange.

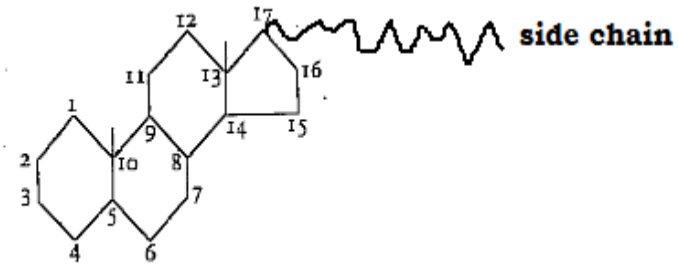
The consequences depend on the nature and location of the affected vessels, i.e.

Atherosclerotic lesions occurring in the; **(1)** coronary arteries lead to coronary heart disease; **(2)** cerebral arteries lead to cerebrovascular disease with stroke being a possible manifestation;

DERIVED LIPIDS

These include steroids and terpenes.

Steroids are composed of 4 fused hydrocarbon rings and long hydrocarbon chain e.g. cholesterol and diosgenin. Three of the rings are 6-sided while one is five sided; all together there are 17 carbon atoms, 6 of which are shared between the rings.



The various steroids differ in the side chain attached to the ring.

CHOLESTEROL

Cholesterol is a lipid containing four rings of carbon and hydrogen atoms with a branched side chain. A single hydroxyl group gives the molecule a small charge as the result of ionisation. Cholesterol is very hydrophobic. Most cholesterol in the body is found in the membranes of cells. In total the body contains a pool of about 120-150g of cholesterol which is maintained by the biosynthesis in the liver and intestine and by ingestion of meat, seafood, eggs and dairy products. Cholesterol is lost from the body mainly as; **(a)** bile salts, but also as **(b)** bile in cells from the lining of the intestine and **(c)** a small percentage as steroid hormones in urine.

Cholesterol is insoluble in water but can be carried in the blood plasma as lipoproteins. Deposits of crystalline cholesterol and droplets of cholesterol esters can cause thickening of the artery walls (atherosclerosis). This can lead to heart attacks (from blockage of coronary artery), stroke (from blockage of brain arteries) or blockage of arteries in the legs.

Summary of functions of some important steroids

Steroid	Functions
Bile acids e.g. Cholic acid	Forms part of bile salts which help in emulsification during fat digestion.
Sex hormones e.g. Oestrogen, progesterone, testosterone	Regulates mating in animals
Corticosteroids e.g. Aldosterone	Regulates the amount of sodium ions in blood.
Calciferol (vitamin D)	Promotes calcium and phosphate absorption; and metabolism.
Ecdysone	Causes moulting in insects
Cholesterol	Component and essential for functioning of cell membrane, e.g. it prevents uncontrolled leakage of small molecules (water and ions) in and out of plasma membrane; constituent of bile salts; constituent of myelin and helps to prevent outward flow of ions which would short circuit the movement of nervous impulse; intermediates for synthesis of steroids in ovaries, testes, and adrenal glands.
Diosgenin	Used in making of anti-fertility pills

FUNCTIONS OF LIPIDS

1. Storage substance in animals and plants

Adaptations:

- High energy yields upon oxidation makes lipids excellent stores of energy. Lipids have a high calorific value than carbohydrates, i.e. a given mass of lipid will yield more energy on oxidation than an equal mass of carbohydrate. This is because lipids have high proportion of hydrogen and an almost insignificant proportion of oxygen compared with carbohydrates.
- Lipids are insoluble in water thus can be stored for long without any loss in solution.
- Lipids are compact thus occupy minimal storage space.
- Lipids are light thus keep the weight to a minimum.
- Have high hydrogen-oxygen content thus yield a lot of metabolic water.

2. Useful source of energy

Upon breakdown, lipids yields $38kjg^{-1}$ of energy. This compares favourably with carbohydrate which yields $17kjg^{-1}$. Thus lipids yield twice the amount of energy produced by carbohydrate for equivalent mass.

3. Insulation

Fats conduct heat slowly and so are useful insulators against heat loss. In endothermic mammals, fat is stored beneath the skin where it minimises heat loss from body surface. In aquatic mammals e.g. whales, seals, large amount of fat is stored in subcutaneous layer (called blubber) which forms an effective insulation.

4. **Protection**
   Fats act as packaging material around delicate organs in mammals, i.e. act as cushions to absorb mechanical impact e.g. fats around kidneys protects them from mechanical damage
5. **Water proofing**
   Waxes are used as water proofing material by plants and animals e.g. it acts as protective substance on cuticle of epidermal layer of plant surfaces. Animals produce oil secretion e.g. from subcutaneous glands which water proof the body. Oils also cover the fur, thus repel water that would otherwise wet it and reduce its effectiveness as an insulator.
6. **Buoyancy**
   Being less dense than water, lipids allow buoyancy of aquatic vertebrates such as sharks, seals, and whales. Oils on bird feathers are especially important in keeping aquatic birds afloat.
7. **Formation of cell membrane**
   Phospholipids and Glycolipids are the major constituents of cell membrane and contribute to vast properties of the cell membrane.
8. **Storage of fat soluble substances**
   Lipids store fat soluble substances, e.g. vitamins, hormones, etc.
9. **Receptor sites**
   Glycolipids act as receptor sites for many molecules, e.g. neurotransmitters, hormones, antibodies, etc.
10. **Cell to cell recognition**
    Glycolipids on the cell membrane are responsible for cell to cell recognition.
11. **Impulse transmission**
    Lipids are component of myelin sheath on the axon membrane, hence increase the speed of impulse transmission through saltatory transmission.
12. **Other functions**
    - **Bee waxes** form material for honey combs.
    - Oils are used as cooking medium.
    - Lipids forms a host of other functions in different organs e.g. plant scent are from fatty acids and their derivatives and play a role in the attraction of insect for pollination.
    - Act as regulators of metabolism, e.g. hormones

NB: Other functions refer to functions of steroids

Summary of lipid functions

Structural functions:

Constitute the chemical messengers for steroid hormones (testosterone, oestrogen, etc).

They are constituents of the cell membrane, i.e. the phospholipid bilayers of the cell membranes.

They form subcutaneous fat in the dermis of the skin which insulates the body against excessive heat loss.

They constitute the waxy cuticle of plants and insects that prevents excessive water loss.

They constitute the myelin sheath of nerve fibres which increase the speed of impulse transmission across the axon.

They constitute the adipose tissue which is important in protecting internal organs from shock.

They are components of hormones and precursors for prostaglandin synthesis.
Components of electron carriers in electron transport system during photosynthesis and respiration.

Physiological functions:
They are good sources of energy in the body.
Solvents for fat soluble nutrients e.g. sterols, vitamins A, D, E, K during their absorption into the body.
Source of metabolic water to desert animals, young birds and reptiles while still in their egg shells.
Storage of fat soluble substances.

PROTEINS

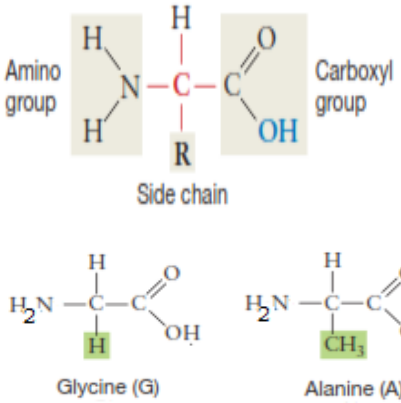
Proteins are polymers of amino acids. Proteins contain the elements C, H, O and N; in some cases P and S are also present. Other elements that may be present are Fe, Zn and Cu.
The variety of proteins in cells is unlimited because the sequence amino acids in each protein is specific and is genetically controlled by DNA of the cell.
Proteins are the most abundant molecules found in cells and form over 50% of total dry mass. Their diversity enables them to display a great range of structural and metabolic activities within an organism.
Proteins are rarely stored in organisms except in eggs and seeds where they are used to form new tissues. Proteins form the basis of structure of living cells.

AMINOACIDS

These are the basic units from which proteins are made. There are over 170 amino acids known to occur in nature; of these only 20 commonly found in proteins. Plants can synthesize all the amino acids they require from simple substances while animals cannot synthesize all they need and thus obtain them from the diet and these are the essential amino acids. Proteins are made up of long chain alpha amino acids.

STRUCTURE OF AN AMINO ACID

The general structure of amino acid is $RHCNH_2COOH$
An amino acid has 4 different parts; **(1)** The hydrogen (H) group; **(2)** The amino (NH2) group; **(3)** The carboxyl (COOH) group; **(4)** The hydrocarbon (R) group
There is a central carbon atom known as an **alpha carbon** to which the four groups are attached. The R group is the variable part and gives each amino acid its uniqueness e.g. the R group in glycine (the simplest amino acid) is simply H while in alanine the R group **is CH_3**



CHARACTERISTICS OF AMINO ACIDS

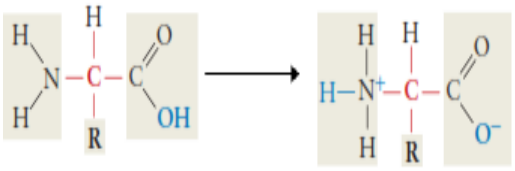
- Are the basic units of proteins
- Have at least one COOH group and one NH_2.
- Are Colourless crystalline solids.
- Generally soluble in water but insoluble in organic solvents.
- Have the general formula $NH_2CRHCOOH$.
- Depending on the alkyl group, they can be put into neutral, acidic and basic amino acids.

CLASSES OF AMINO ACIDS

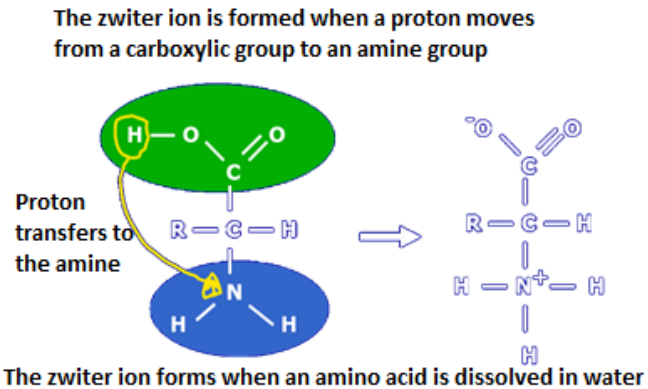
Most amino acids contain one amino group and one carboxylic group and are therefore said to be **neutral amino acids,** e.g. glycine, alanine, phenyl amine etc.
However, some amino acids have more basic (amino) groups than acidic (carboxylic) groups and are referred to as **basic amino acids,** e.g. arginine, histamine, while others have more carboxylic groups than amino groups and are referred to as **acidic amino acids,** e.g. aspartic acid, glutamate, etc.

SOLUBILITY OF AMINO ACIDS

Amino acids are very soluble in water where they form ions. These ions are formed when COOH group loses hydrogen ion making it negatively charged; the H^+ then associate with the NH_2 group making it positively charged. The ion is thus dipolar, i.e. has one end positive and the other negative. Such ions are called **zwitter ions**.



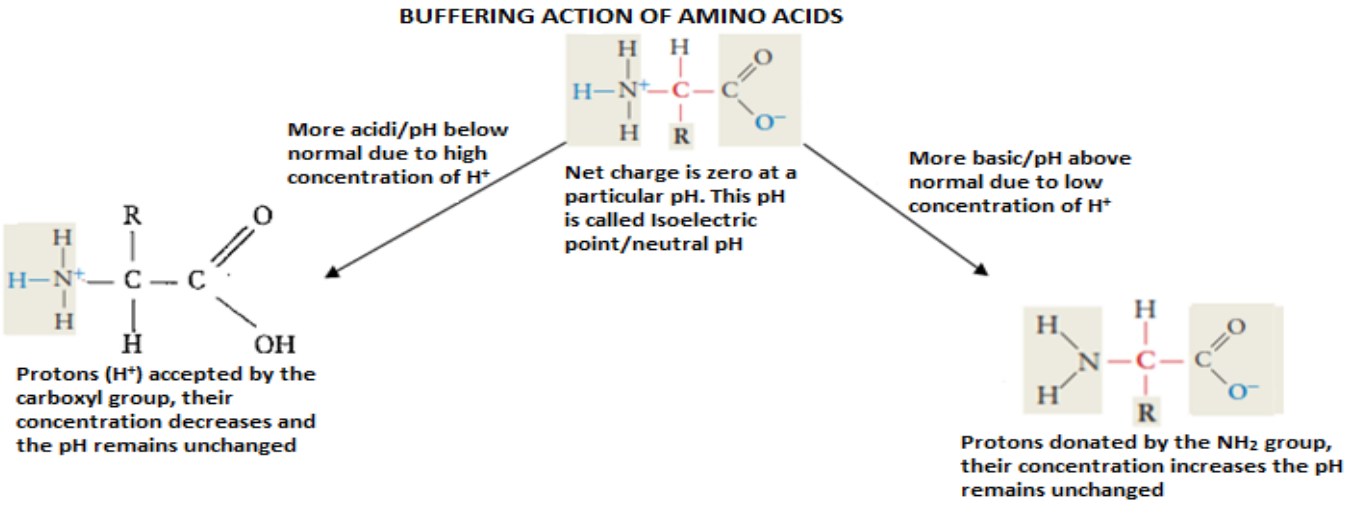
Zwitter ion



AMINO ACIDS AS BUFFERS

Amino acids have both acidic and basic properties (i.e. are amphoteric), therefore can act as buffer solutions. A buffer solution is one that resists the tendency to alter its pH even when small amounts of acid or base are added to it. Such a property is essential in biological systems where any sudden change in pH could adversely affect the functioning of enzymes.

When the pH more acidic, i.e. falls below a required point (isoelectric point of the amino acid), the H^+ (protons) in solution are taken up by carboxylic group thereby decreasing the concentration of protons in solution and the pH remains unchanged.
When the pH is more basic, i.e. rises above the isoelectric point of the amino acid, the H^+ are released from the NH_2 group thereby increasing concentration of H^+ in the solution and the pH remains unchanged.
The effect of all these changes is to keep pH at or near that which is suitable for enzymatic



activities

Alternatively:
When an acid is added, the $-NH_2$ group combines with H^+ ions from the acid to form $-NH_3^+$

$NH_2CHRCOOH\ (aq) + H^+\ (aq) \longrightarrow NH_3^+CHRCOOH\ (aq)$

When an alkali is added, the -COOH group combines with OH^- ions from the alkali by loss of H^+ to form $-COO^-$

$NH_2CHRCOOH\ (aq) + OH^-\ (aq) \longrightarrow NH_2CHRCOO^-\ (aq) + H_2O$

In both cases, the concentration of H^+ ions in solution does not change greatly and so the pH remains almost the same.

AMINO ACIDS AND THE DIET

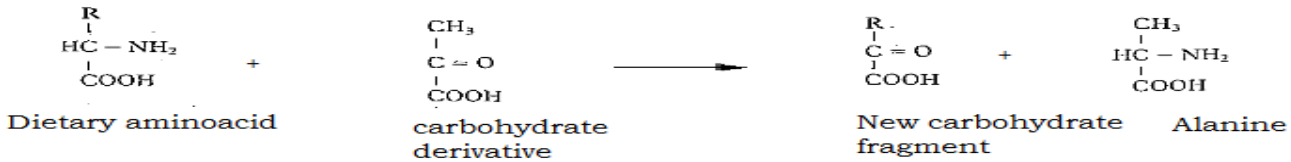
Basing on diet, amino acids can be categorized as essential (EAs) or non-essential (NEAs) depending on whether on whether the amino acid is required in the diet or not.

Essential amino acids

These are amino acids which must be included in the diet because either they cannot be synthesised in the body at all or they are synthesised too slowly to meet the body's need.
Eight of the twenty commonly occurring amino acids are essential for adult humans and 10 for infants. These amino acids are Lysine, leucine, methionine, phenyl amine, histidine, arginine, isoleucine, threonine and saline.
Arginine and histidine are required in children for growth but can be synthesized by adults.
Proteins which are rich in EAs are called ***first class*** or ***high quality proteins***. They are most commonly animal proteins e.g. in milk, eggs, fish, meat, and also in soya beans for vegetarians.
Proteins lacking one or more EAs are known as ***second class*** or ***low quality proteins.***

Non-essential amino acids

These are amino acids which can be made in the body and are also required in the body.
There are 10 NEAs: Alanine, aspartic acid, asparagine, cysteine, glycine, glutamine, glutamic acid, proline, tyrosine and serine.
These non-essential amino acids are synthesized within the body of animals through the process known as ***transamination,*** catalyzed by an enzyme ***transaminase***.
Transamination is the synthesis of an amino acid by the transfer of the amino group from one amino acid to an organic acid. The general principal underlying the reaction is the exchange of chemical group between the amino acid and the organic acid.
The raw material for the process are NEAs provided in the diet and carbohydrate derivatives e.g. pyruvic acid is used in the synthesis of alanine from glycine.

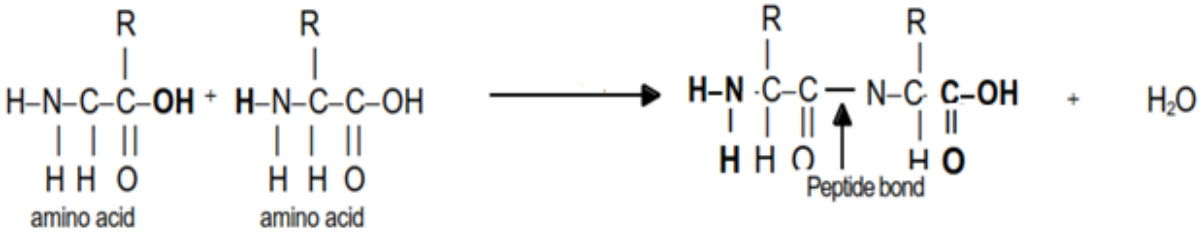


Differences between essential amino acids and non-essential amino acids.

Essential amino acids	Non-essential amino acids
Must be obtained from the diet	Not required in the diet
Cannot be synthesized by the body of animals but plants can synthesize them from simple compound	Can be synthesize by the body

FORMATION OF PROTEINS (POLYPEPTIDES)

When two amino acids are joined together by condensation reaction, a dipeptide is formed. The reaction occurs between amino group of one amino acid and carboxyl group of the other amino acid. The reaction involves loss of a water molecule. The individual amino acids are linked by peptide bond. The dipeptide formed possesses a free carboxyl group at one end and a free amino group at another end that attract further amino acid molecules to the dipeptide thus building a chain of amino acids. Several dipeptides combine in several condensation reactions to form a long chain called a polypeptide or protein.



Proteins are macromolecules consisting of one or more polypeptide chains formed by several dipeptides which combine in several condensation reactions with corresponding loss of water molecules.

For a particular protein, the polypeptides may be twisted and folded in an appropriate way as directed by a particular gene (DNA) which also determines the sequence of amino acids in it.
Because of the property of protein's structure, the 20 commonly occurring amino acids can combine in a great variety of sequence and result in a rich variation in proteins than other chemicals of life.

STRUCTURE OF PROTEINS

Protein possess a characteristic 3-dimensional shape called its configuration or conformation. This shape is important in the functioning of protein molecule e.g. enzymes.
The structure (shape) is describe at four level i.e. primary, secondary, tertiary and quaternary structure.

PRIMARY STRUCTURE

This is the linear sequence of amino acids in a polypeptide chain. It is a chain of amino acids which the polypeptide is composed of. The only form of bonds in the primary structure are the peptide bonds. The sequence of amino acids largely determines the protein's biological function e.g. any particular change in the amino acid sequence in haemoglobin causes sickle cell anaemia which is a serious blood disorder. The sequence of amino acids is specific for each protein and is determined by the DNA of the cell in which the protein is made. Therefore although there are only 20 amino acids commonly found in proteins, they can be arranged in a great number of different ways forming variety of proteins. Examples of protein with primary structure are ***lysozyme*** and ***insulin.*** All other structures of proteins are modification of the primary structure.

The cross linkages in the polypeptide chain (s) in the protein are joined together by four different types of bond. The bonds are formed between the amino acids in the chains due to different properties like acidic, basic, hydrophobic, etc. and they maintain the structure of the protein;

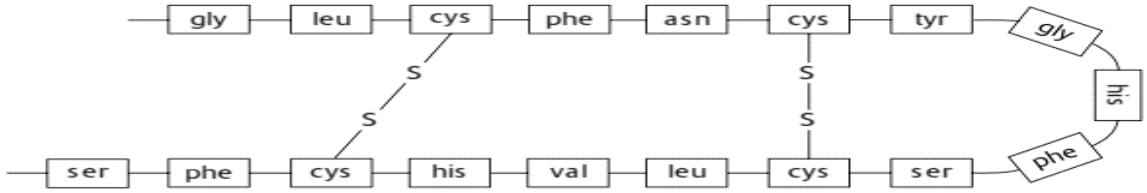
1. Ionic bond. (e.g. between Aspartic acid and Lysine).

Amino acids form zwitter ions which have $H_3N^+$and COO^- group. The formation of peptide bonds during the formation of a polypeptide means that the NH_2 and COOH groups are not available to form ions.

In the case of acidic and basic amino acids, there are additional COOH and NH_2 groups respectively. These groups ionise into COO^- and H_3N^+ ions respectively which occur at the ends of the polypeptide. Any of these available ions may form ionic bonds which to give a polypeptide molecule its particular shape.
However, the ionic bonds are weak and maybe broken by alteration in the pH of the medium around the polypeptide, e.g. adding acid to milk makes it curdle because the ionic bonds in casein (milk protein) are broken and the protein ceases to be soluble.

2. Covalent bonds (Disulphide bonds)

These are in the form of **peptide bonds,** which link one individual amino acid to another in the polypeptide chain. They occur between amino acids that have sulphur. The amino acid cysteine contain sulphurdyl group (SH) in its R group. If two molecules of cysteine line up alongside each other, the neighbouring sulphurdyl groups are oxidised to form a disulphide bond. Disulphide bond may arise between cysteine molecules in the same amino acid chain (intra-chain) or in different amino acid chains (inter-chain), e.g. in insulin, immunoglobulins, etc. In the former, the disulphide bonds make the molecule fold into a particular shape. These bonds are strong and not easily broken e.g. in Fibrous proteins.



3. Hydrogen bond

These are weak bonds formed between hydrogen atom in one amino acid and a highly electronegative element in another amino acid e.g. between hydrogen and oxygen containing lone pair of electrons. When hydrogen is bonded with oxygen (O-H), Nitrogen (N-H) which are highly electronegative, it becomes slightly positively charged. The hydrogen may be attracted towards a neighbouring electronegative oxygen or nitrogen atom such as in C=O or N in NH group. These groups can interact to produce regular shape such as alpha helix and silk. Hydrogen bonds are weak bonds though their occurrence is so frequent which makes the total effect considerable for molecular stability of a protein molecule.

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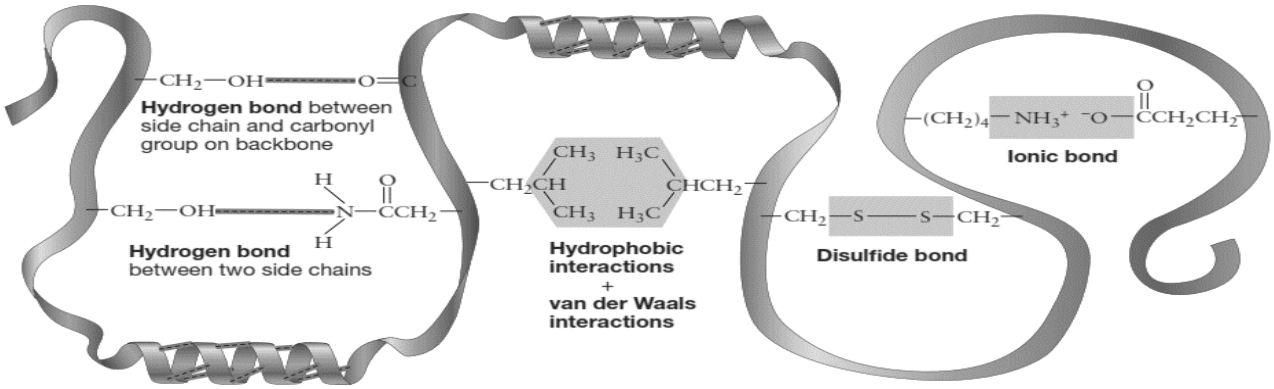
4. Hydrophobic interaction

This is the interaction between non-polar R groups. Some R groups are non-polar and therefore hydrophobic, such as those on amino acids tyrosine and valine. If a polypeptide chain contains many of these groups and is in aqueous environment, the chain will tend to fold so that the maximum number of hydrophobic groups come into close contact and exclude water. This explains how globular proteins fold up. They are weak forces of attraction and hydrophobic groups tend to point inwards towards the centre of roughly spherical molecules while the hydrophilic groups face outwards into the aqueous environment, making the protein molecule soluble.

Summary of types of bonds in primary structure of proteins



SECONDARY STRUCTURE

This is the folding or coiling of the polypeptide chain into a helix. When the amino acids join up in the polypeptide chain, a variety of forces between different parts of the molecule and hydrogen bonding cause the chain or regions of the chain to either coil into an alpha helix or beta pleated sheet. This coiling or folding is the protein's secondary structure. The shape of the helix or sheet is maintained by regularly spaced hydrogen bonds each formed between the NH groups of one amino acid and the C=O group of another amino acid in different parts of a polypeptide chain. A single chain may have some regions coiled into alpha helix and other fold into beta pleated sheet.

Alpha helix:

The most common secondary structure of protein is an extended spiral ring, the alpha helix whose structure is maintained by many hydrogen bonds, formed between neighbouring COOH and NH_2 groups.

The hydrogen atom of NH_2 group of one amino acid is bonded to oxygen atom of COOH group four amino acid away.

An alpha helix is coiled into regular spiral shape.

A protein which is entirely helical and hence fibrous is ***keratin***. Keratin is a fibrous structural protein of hair, wool, nails, claws, feathers, horns, antlers, scales and vertebrate's skin. Its hardness and stretchability vary with the degree of cross linking by disulphide bridges between neighbouring chains.

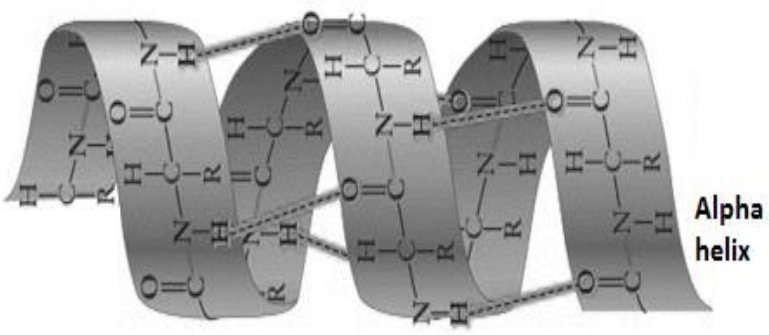
The importance of the alpha helix in protein structure is that it maintains shape of the molecule. This is of great importance in biological functioning of protein molecules particularly enzyme and antibodies whose efficiency depends on their shape.

Apart from keratin, other exampple of such proteins are collagen which is a connective protein which has three polypeptide chains wound around each other forming a tripple helix.

Most proteins are globular molecules in which they are not entirely alpha helix but also contain regons of beta pleated sheet and irregular structure. They are not entirely alpha helical because;

1. Occurance of the disulphide bridges between different parts of the same polypeptide chain.
2. Interference with hydrogen bonding due to certain R groups of amino acids.
3. Inability of the amino acid Proline to form hydrogen bonds.

NB: Keratin and Collagen contain a secondary structure in form of alpha helix.



Beta pleated sheet:
In beta pleated sheet, the 3 polypeptide chains lie parallel with each other and joined by hydrogen bonds.
Examples include, silk (entirely beta pleated), collagen, etc.
The beta pleated sheet in silk is already extended and although it follows folding, it is not elastic and thus silk threads easily break when stretched.
In collagen, three polypeptide chains are wound around each other like strands of a rope to form ***a triple helix.***
There are about 1000 amino acids residues in each chain and the complete triple helix compound is called ***tropocollagen***.
Each chain is itself inform of a loose helix (not an alpha helix). The 3 strands or chains are held together by hydrogen bonds. Many triple helices lie parallel to form fibrils, joined by covalent bonds between neighbouring chains. Fibrils in turn unite to form fibres.

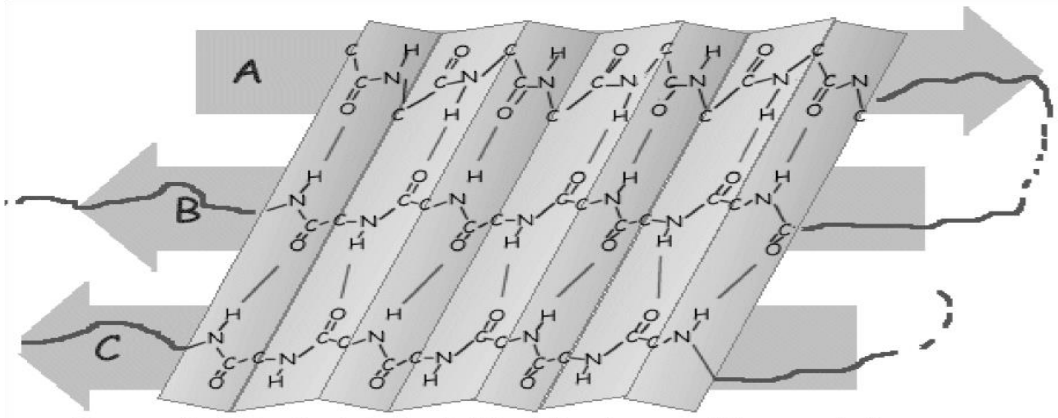


Diagram 1: Beta pleated sheet. The lateral groups (R) are not shown.

NB: Collagen's extremely resistant to stretching is an essential part of its functioning e.g. in tendon, bone, skin, teeth, connective tissue, etc.

Adaptations of collagen to its function:
- ✓ Polypeptide chains form a triple helix to increase their stability.
- ✓ Polypeptide chains are held together by hydrogen bonds to further increase their stability.
- ✓ Collagen is made up of many fibres to increase on its tensile strength.
- ✓ Collagen fibrils that unite to form fibres are held by numerous covalent bonds to increase stability.
- ✓ Collagen is insoluble in water to increase on stability.
- ✓ Collagen fibres are inelastic to reduce on their stretchability.
- ✓ Made up of numerous amino acid residues to further strengthen its structure.

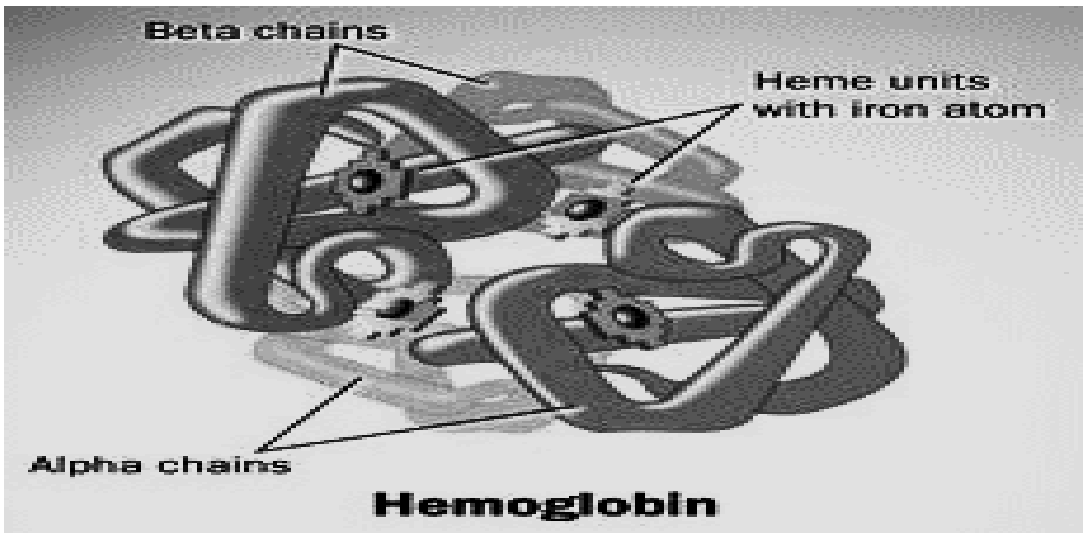
TERTIARY STRUCTURE
This describes the way the polypeptides fold into a compact globular shape. The way it folds is determined by interaction between amino acids. The shape is maintained by hydrophobic

interactions, ionic, hydrogen, and disulphide bonds. The hydrophobic interactions are quantitatively the most important and occur when the protein folds so as to shield the hydrophobic side groups from the aqueous surroundings, at the same time exposing hydrophilic side chains.
Tertiary structure explains the complex molecular shape of some proteins especially globular proteins e.g. myoglobin. Proteins with globular shape generally have specific metabolic activities

QUARTENARY STRUCTURE

Many highly complex proteins consist of more than one polypeptide chain and sometimes with a prosthetic group. The separate polypeptide chains are held together by hydrophobic interactions, hydrogen and ionic bonds. Their precise arrangement is called ***quaternary structure.***
Therefore, the quaternary structure describes the way two or more polypeptide chains are held together by ionic, hydrogen and hydrophobic interactions and sometimes with an inorganic component, to form a protein, e.g. in haemoglobin.
Haemoglobin consists of 4 polypeptide chains of two types, i.e. two alpha chains and two beta chains. Each of the polypeptide combines with an iron containing haem group.

Haemoglobin just like other typical globular proteins consists of a hydrophobic side pointing inwards to the centre of the molecule, and a hydrophilic side pointing outwards, making it water soluble. This explains why a mutation that causes one of its hydrophilic amino acids to be replaced by a hydrophobic amino acid occurs, its solubility is reduced resulting into sickle cell anaemia.



Adaptations of haemoglobin to its function:
- ✓ Highly folded to occupy small space in RBC.
- ✓ Highly soluble to be easily transported in blood.
- ✓ Reversible affinity for oxygen allows loading and unloading of oxygen molecule.
- ✓ Presence of haem group that loads oxygen.

Differences between polypeptide chain and polysaccharide

Polypeptide chain	Polysaccharide
Nitrogen atom is present	Does not have nitrogen atom in its structure
Built up from numerous monomers	May have only one or maximum of 2 monomers

Monomers are amino acids	Monomers are monosaccharides
Monomers bonded via peptide bonds	Monomers bonded via glycosidic bonds
May involve many types of bonds	Only glycosidic bonds present

CLASSIFICATION OF PROTEINS

Because of the complexity of protein molecules and their diversity, it is difficult to classify them in a single well defined fashion.

Proteins are thus classified according to;

(1) structure; **(2)** composition; and **(3)** function

CLASSIFICATION OF PROTEINS ACCORDING TO STRUCTURE

The two basic forms of proteins based on structure are ***globular and fibrous proteins***

GLOBULAR PROTEINS

These consist of highly irregular sequence of amino acids in their polypeptide chains. Their polypeptide chains are highly tightly folded to form spherical shapes. They are far compact and far less stable and have metabolic roles within organisms.

Nature/ characteristics of globular proteins

(a) Tertiary structure is the most important; **(b)** Polypeptides fold to form spherical shape; **(c)** readily soluble in water; **(d)** Heat coagulable i.e. easily go into colloidal state

Examples of globulins are; all enzymes, some hormones e.g. insulin, microfilaments, microtubules, myoglobin, haemoglobin and other respiratory pigments, antibodies, etc.

Occurrence of globular proteins

- In cells of plants and animals.
- In antibodies
- In plant seeds
- In blood plasma
- In cells where they are important in maintenance of composition of protoplasm
- The cytoskeleton e.g. in the composition of microfilament and microtubules
- In plasma membrane where they also act as carrier proteins and passage proteins

Functions of globular proteins

- As buffers. This is because of amphoteric nature of proteins.
- As structural components especially in the formation of plasma membrane and cell structures e.g. microfilaments and microtubules are components of cytoskeleton.
- As regulators of metabolic pathways, e.g. hormones, enzymes, antibodies, etc.

FIBROUS PROTEINS

These have their primary structure with regular repetitive sequences. They form long chains which may run parallel to one another being linked by cross linkages. Their branches are unbranched. Three of such chains are wound into a helix and cross linked to each other that provides additional structural support. They are stable molecules and so they have a structural role. They are insoluble in water.

Nature/ characteristics of fibrous proteins

(a) Secondary structure is the most important; **(b)** Insoluble in water; **(c)** physically tough; **(d)** have long parallel polypeptide chains crossed-linked at intervals forming fibres or sheets.

NB: Intermediate proteins; are fibrous proteins but are soluble in water e.g. fibrinogen, caseinogen.

Occurrence of fibrous proteins

In body structures like hooves, nails, hairs, horns, feathers, skin, connective tissues, scales, etc.

Functions of fibrous proteins

Perform structural roles in cells e.g. collagen found in tendon, bones, connective tissue, myosin found in muscle, silk found in spider's web, keratin found in hairs, horns, nails, feathers, etc.

Differences between globular proteins and fibrous proteins

Fibrous proteins	Globular proteins
Insoluble in water	Soluble in water
Stable structure	Relatively unstable structure
Repetitive regular arrangement/sequence of amino acids	Irregular arrangement/sequence of amino acids
Actual sequence of amino acids may slightly vary between two examples of the same protein	Actual sequence of amino acids highly specific and never varies between two examples of the same protein
Polypeptide chains in them form long parallel strands	Polypeptide chains are folded and coiled into spherical shape
Mainly support and structural in function	Mainly metabolic functions
Examples include keratin and collagen	Examples include hormones, antibodies, enzymes, etc.
Length of the chain may vary in two examples of the same protein	Length of the chain normally identical in two examples of the same protein
They are secondary proteins	They are tertiary proteins
Not easily denatured by high temperatures	Easily denatured by high temperatures

CLASSIFICATION OF PROTEINS ACCORDING TO COMPOSITION

Proteins are classified as ***(1) simple; (2) derived*** and ***(3) conjugated proteins.***

1. **Simple proteins;** made up of only amino acids. They do not contain non- protein group in them. Examples of simple proteins are histones, albumin, and globulins, enzymes
2. **Derived proteins** results from proteins which have been denatured or broken down products of original proteins. This could be peptones.
3. **Conjugated proteins;** are complex compounds consisting of globular proteins tightly bound to non-protein material. The non-protein material is called **prosthetic group**, which may be organic or inorganic in nature.
   If the prosthetic group is organic in nature, then it is called **coenzymes** but if it is inorganic in nature, then it is called **activator.** Coenzymes, activators and prosthetic groups are all ***enzyme cofactors.***

Examples of conjugated proteins with their functions are as below

Name of the protein	Prosthetic group	Location/function
Phosphoproteins	Phosphoric acid	Casein in milk, vitelline in egg yolk
Glycoprotein	carbohydrate	Cell membrane, mucous, mucin (component of saliva)
Nucleoprotein	Nucleic acid	Components of viruses, chromosomes and ribosomes.
Chromoproteins	Coloured	Haemoglobin, phytochrome, chlorophyll and other

	pigment	respiratory pigments/cytochromes
Lipoproteins	Lipid	Cell membrane; distribute cholesterol in the body
Flavoprotein	FAD	Electron transfer during respiration
Metal protein	Metal	Nitrate reductase i.e. enzyme which catalyses conversion of nitrate to nitrite.

Other conjugated proteins include; some enzymes (zymoproteins); some hormones e.g. insulin, secretin, prolactin; ferrodoxin; rhodopsin; acetyl co enzyme A, etc.

CLASSIFICATION OF PROTEINS ACCORDING TO FUNCTION

Type of protein	Example	Location/function
Structural	Keratin	Skin, feathers, nails, scales, etc.
	Collagen	Component of connective tissue(ligament), tendon, cartilage
	Elastin	Elastic connective tissue
	Viral coat protein	Rapture nucleic acids of viruses
Hormones	Insulin and glucagon	Regulation of glucose metabolism
	ACTH	Stimulate growth and activities of adrenal cortex
Enzymes	Trypsin	Catalyses hydrolysis of protein
	RuBP carboxylase	Catalyses carboxylation in photosynthesis
	Glutamine synthase	Catalyses synthesis of glutamine from glutamic acid and ammonia
Respiratory pigments	Haemoglobin	Transport of oxygen and some carbon dioxide in mammal
	Myoglobin	Storage of oxygen in muscle
Transport proteins	Serum, albumin	Transport of fatty acids and lipids in blood
Protective	Antibodies	Defend the body against pathogens
	Fibrinogen	Form fibrins during blood clotting
	Prothrombin	Forms thrombin involved in blood clotting
Contractile	Myosin	Moving filaments in myofibrils of muscle
	Actin	Stationary filaments in myofibrils of muscle
Storage	Albumin	Egg white protein
	Casein	Milk protein
Toxin	Venom	Toxin made by snake
	Diphtheria	Toxin made by bacteria

PROPERTIES OF PROTEINS

- Have amphoteric properties
- Made up of large sized molecules
- Shows specificity e.g. enzymes
- Undergo irreversible denaturation by heating, chemical treatment, radiation
- Are colloidal in nature
- On hydrolysis, yields a mixture of amino acids and sometimes ammonia
- Are insoluble in fat solvents

COLLOIDS

A colloid is a particle which remains dispersed in solution than settling out or floating.
Colloids are too small to settle out under gravity but also too large to dissolve
The biological importance of colloids is that they have a strong capacity to absorb water and other substances because of having a large surface area.

SUMMARY OF THE FUNCTION OF PROTEINS

1. **Energy**
   Proteins are good sources of energy especially during starvation. Proteins are deaminated and the organic acids produced enter the Krebs cycle at different stages for metabolism to produce energy.
2. **Structural and support**
   Keratin, a fibrous protein found in skin, scales, claws, nails, feathers, hooves, etc. offers protection. Lipoprotein makes the structural component of all cell membrane. Collagen, a fibrous protein which resist stretching gives strength and flexibility in tendons, cartilage and bonds. Elastin offers strength and elasticity to ligaments. Sclerotin provides strength in insect's exoskeleton. Ossein gives structural support in bones.
3. **Movement**
   Actin and myosin are fibrous filaments needed for muscular contraction i.e. Sarcomere contraction.
4. **Enzymes**
   Many protein enzymes are involved in digestion, e.g. Amylase, a globular protein catalyses hydrolysis of starch. Trypsin, hydrolysis of protein. Besides digestion, enzymes also control many important metabolic pathways including respiration.
5. **Hormones**
   Proteins act as regulators of body metabolism**.** Insulin and glucagon regulate glucose metabolism. ACTH stimulate growth and activities of adrenal cortex.
6. **Transport**
   Serum and albumin transport of fatty acids and lipids in blood. Haemoglobin, a chromoprotein transports oxygen in vertebrate's blood.
7. **Respiration**
   Myoglobin stores oxygen in muscles, which oxygen is used in aerobic respiration to produce sufficient energy for muscle contraction. Mucin keeps respiratory surface moist to dissolve respiratory gases.
8. **Storage**
   Albumin stores protein (white egg)**.** Casein stores protein in milk and is responsible for the white colour of milk. . Ferritin combines with iron for storage in the liver.
9. **Nutrition**
   Mucin traps food in filter feeders. Mucin prevents autolysis and lubricates the guts wall. Fibrous proteins in granal lamellae of chloroplast arrange chlorophyll molecules in position to receive maximum sunlight during photosynthesis. Several protein enzymes are involved in food digestion.
10. **Defence**
    Antibodies are globulins used for defence against infection. Fibrinogen and thrombin are involved in blood clotting.
11. **Toxins** e.g. Snake venoms, diphtheria in bacteria.
12. **Sensitivity and coordination**
    Rhodopsin and opsin are visual pigments in the retina and are very sensitive to light. Phytochromes are plant pigments important in controlling flowering and germination.

13. Reproduction

Hormones e.g. Prolactin induces milk production in mammals. Chromatin gives structural support to chromosomes. Keratin form hair, for horns, and antlers which may be used sexual display. Gluten stores protein in seeds and nourishes the embryo.

14. Regulation

Proteins regulate the internal environment and acts as buffers. Transduction of energy e.g. FAD is important in electron transfer chain in respiration.

QTN: ***How does the molecular structure of proteins relate to their functions?***

They are large molecules, they don't dissolve but form colloidal suspensions which have a large surface area and so important in connecting molecules together within the cell and maintaining the molecular organisation within the body.

Proteins have both acidic and basic properties (amphoteric) due to the presence of the carboxyl and amino groups in their chains. This enables the proteins combine with both acids and bases and therefore act as buffers.

Proteins can combine with other substances in organisms. Many structures found in organisms are conjugated proteins. The non-protein component is called **Prosthetic Group** e.g. in yolk the prosthetic group is phosphoric acid, in mucus it is a carbohydrate, in hemoglobin it is iron continuing pigment called haem.

QUESTION: ***HOW ARE DIFFERENT PROTEINS RELATED TO THEIR ROLES?***

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

ii) Some proteins function as enzymes. These have a globular structure and are soluble in water e.g. digestive enzymes like pepsin, respiratory and photosynthetic enzymes.

iii) Some proteins function as hormones regulating metabolic processes. These are globular and soluble in water e.g. insulin which regulates metabolic activity.

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

v) Some proteins are involved in transport and are globular with primary or tertiary structures e.g. serum albumen that transports fatty acids and lipids in blood.

vi) Some proteins are involved in immunological responses hence protecting the body. These are globular e.g. antibodies, fibrinogen and thrombin.

vii) Some proteins are contractile e.g. they are fibrous with a secondary structure e.g. myosin and actin filaments in muscles.

viii) Storage proteins are toxins and soluble and water with a globular structure e.g. snake venom, bacteria toxins, etc.

ix) Some proteins are insoluble in water e.g. ovalbumin that occurs in egg white, casein in milk, etc.

x) Globular proteins form colloidal suspensions that hold molecules in position within cells e.g. proteins in the cytoplasm of most cells where they are soluble in water and have a large surface area.

xi) Globular proteins in blood are buffers since they are soluble in water.

Checkup:

By now you should be able to: (i) **Describe:** structure and components of proteins,

Properties of proteins, Condensation of amino acids to form proteins, Hydrolysis of proteins to amino acids. (ii) **Explain**: Importance of proteins, functions of proteins in living organisms, effect of heat and temperature changes on proteins. (iii) **Relate**: the molecular structure of proteins to their roles.

PROTEIN DENATURATION

This is the loss of the protein's specific 3 dimension conformation (tertiary structure). The dimensional structure of a protein is due to weak ionic and hydrogen bonds. Any agent that breaks these bonds cause the three dimensional structure to be changed and become more fibrous. The loss may be temporary or permanent but the primary structure remains unaffected.

It involves breakage of hydrogen and ionic bonds. The relatively stronger covalent bond i.e. peptide and sulphur bridges remains intact.

Due to the fact that the biological function of a protein depends on its shape, a denatured protein cannot carry out its functions effectively.

Renaturation is the spontaneous folding back of the protein that has been denatured to a small extend such the molecule gains back its original structure in presence of favourable conditions. If the degree of denaturation is great, Renaturation cannot take place even when the ideal conditions are provided.

Factors that cause protein denaturation

1. **Heat/ high temperature;** causes atom in a protein to vibrate more due the increased kinetic energy which causes hydrogen and ionic bonds to break thus distorting the 3 dimensional structure. This leads to coagulation of the protein e.g. boiling an egg makes the egg albumen more fibrous and less soluble.
2. **Organic chemicals and detergents;** these disrupt the hydrophobic interactions and form bonds with hydrophobic non polar groups. This disrupts the hydrogen bonding. Organic solvents include benzene, chloroform, ethers etc. For example, alcohol denatures bacterial proteins, thus making it useful for sterilization (disinfectant).

3. **Inorganic chemicals;** Ions of heavy metals like Ag^+ and Hg^{2+} are highly electropositive and form bonds with carboxylate group in the polypeptide chain and results in disruption of ionic bonds. They also reduce the proteins electrical polarity thus increasing the protein insolubility. This makes the protein to precipitate out of the solution. Similarly, highly electronegative ions, e.g. cyanide combine with the NH_2 group and disrupt ionic bonds. This explains why respiratory pigment cytochrome oxidase is inhibited by cyanide, thus cyanide is called a respiratory poison.

4. **Radiations;** like x-rays, γ-rays, etc. may alter protein's structure and sometimes permanently. They beak hydrogen and ionic bonds in it. This is the basis of mutations caused by radiations.

5. **Alkalis**; these reduce the number of H^+ ions in the medium. As a result, the NH_3^+ ions group in the amino acids loose H^+ to form NH_2 thus resulting in the breakages of ionic bonds. Examples include souring of milk by alkalis.

6. **Acids;** these increase H^+ in the medium. These combine with COO^- group at the end of the polypeptide chain forming COOH which leads to breakage of ionic bond. Examples include souring of milk by acid and lowering of pH of casein making it insoluble.

7. **Mechanical force;** Physical movement of protein may break the hydrogen bonds e.g. stretching the hair breaks the hydrogen bonds in the alpha helix of keratin making the helix to extend and the hair stretches; and if released the hair returns to its normal length. However, if hair is wetted and then dried under pressure, it keeps its new length and shape. This forms a basis for hair styling.

QTN: Discuss the functions of proteins under the following titles; Nutrition, Respiration, Transport, Growth, Excretion, Support and Movement, Sensitivity and coordination and reproduction. (50 marks)
Reference book: Understanding Biology by Suzan Toole Page 32.

ENZYMES

Enzymes are biological (organic) catalyst which speed up a chemical reaction but remains unchanged itself at the end of the reaction. They are biological catalyst because they are complex globular protein molecule produced by living organism (cells)
They catalyse a vast range of chemical reaction at a temperature for living organism .i.e. ranging from 5^{o}c to 40^{o}c.
Enzymes are important because in their absence, reactions in the cell would be too slow to sustain life.

METABOLISM

This is the total sum of all the biochemical reactions going on in the cells of an organism.
There are two types of metabolism: **(1)** Anabolism; and **(2)** catabolism. These reactions occur in different parts of the cell.
Anabolism involves the synthesis of molecules and usually require energy and are catalysed by enzymes. An example of an enzyme involved in anabolism is glutamine synthase which catalyse the synthesis of amino acid glutamine from glutamic acid and ammonia.

Glutamic acid + ammonia + ATP $\xrightarrow{\text{Glutamine synthase}}$ Glutamine + water + ADP + Pi

Catabolism involves the breakdown of molecules and usually release energy. They usually involve oxidation and hydrolysis and are catalyzed by enzymes. An example of an enzyme involved in catabolism is amylase.

Starch + water $\xrightarrow{\text{Amylase}}$ maltose

Metabolic pathways

A number of enzymes are used in a sequence to convert one substance into another or several products via a series of intermediate compounds. The chain of reactions is referred to as ***a metabolic pathway***.
Many such pathways occurs in the cell. The reaction proceeds in a controlled manner due to specific nature of enzymes. A single enzyme will generally catalyse a single reaction.

Enzymes ensure that metabolism proceeds by small gentle steps in an orderly fashion to prevent chaos from different reaction taking place in the cell.
The advantage of this is:

- Large catabolic reaction would create unfavorable conditions e.g. very high temperature since a lot of heat would be released than it would be in a single reaction.
- Allows energy to be derived in a useable form from small catabolic reaction than it would be in a single large catabolic reaction.

- Allows substrate to be partially broken down so as to provide raw material for other reaction. Some of these intermediates have their own function to perform in the cell.
- Allows the synthesis of complex organic compounds from simple raw materials and in gentle conditions prevailing condition in the cell which would not synthesized in one step.
- Increases the ability of the cell to control the product made in anabolic pathways when reactions proceed in small steps. This is so because some products are harmful to the cells, and thus have to be removed.

Comparison of inorganic catalyst and enzymes

Similarities

- Both remain chemically unchanged after the reaction, hence can be reused.
- Both are required in small quantity compared to the substrate.
- Both do not initiate the reaction but only lowers the activation energy for the reaction.
- Both do not alter the position of equilibrium of a reversible reaction, but facilitate the attainment equilibrium.
- Both form short-lived complexes with the reactants, which are then broken to give the product and free catalyst.

Differences

Enzyme	Inorganic catalyst
Can catalyse only a specific reaction i.e. specific to substrate	Can catalyse a large number of reactions.
Are protein in nature and have 3-D structure	Are small molecules or simple mineral ions.
Can be regulated by specific substance hence their activity and conformation can be changed	Cannot be regulated by any substance
Are extremely sensitive to changes in pH and temperature.	Are less sensitive to changes in pH and temperature.

Properties of enzymes

- Enzymes are protein in nature and are coded for by the DNA of the cell in which it's made.
- Are highly specific i.e. generally catalyse only one reaction. This is because their activity is determined by the configuration which only fit the configuration of certain type of substrate
- They catalyse reaction in either direction according to the prevailing condition e.g. in respiring tissue, concentration of carbon dioxide is high and carbonic anhydrase catalyses conversion of carbon dioxide to carbonic acid

  Carbon dioxide + water $\xrightarrow{\textit{carbonic anhydrase}}$ Carbonic acid

  While in the lungs, Carbon dioxide concentration is low and carbonic anhydrase catalyses conversion of carbonic acid to Carbon dioxide and water vapour

  Carbonic acid $\xrightarrow{\textit{carbonic anhydrase}}$ Carbon dioxide + water vapour

- Small amount of enzyme catalyses a large quantity of substrate.
- Their presence do not alter the nature/properties of the end product.
- Their activities are altered by substrate concentration, pH, temperature and inhibitors

NOMENCLATURE AND CLASSIFICATION OF ENZYMES

Nomenclature

Enzymes are named in two ways:

The short trivial names i.e. the names commonly used e.g. pepsin, rennin, trypsin, etc. These are their original names they acquired before the detail systematic names based on internationally accepted system of classification.

Most trivial names ends with the suffix "ase" which is either added to the name of the substrate e.g. lactase from lactose, cellulase from cellulose, etc. or added to the name of the reaction they catalyse e.g. dehydrogenase from dehydrogenation, carboxylase from carboxylation, etc.

Classification

Enzymes are classified based on:

- ❖ Type of reaction they catalyse
- ❖ Areas of operation

Classification based on the type of reaction

According to the International Union of Biochemistry (IUB), enzymes are classified and named according to these six groups of enzymes;

1. **Hydrolases;** this catalyse reactions in which a substrate is hydrolysed (broken) into simpler products.

$$\underset{\text{substrate}}{AB} + \underset{\text{water}}{H.OH} \rightleftharpoons \underset{\text{products}}{AH + B.OH}$$

   E.g. enzymes that break materials in the lysosomes and all digestive enzymes.
2. **Oxido-Reductase;** These catalyse the oxidation of substrates. They can be ***Oxidases*** that catalyse the transfer of hydrogen to molecules of oxygen .e.g. cytochrome oxidase or can be ***dehydrogenases*** that catalyse the transfer of hydrogen to coenzymes like NAD e.g. alcohol dehydrogenase that catalyses the rate of converting ethanal to ethanol.
3. **Transferases;** These catalyse the transfer of functional groups from one substrate to another .e.g. Phosphotransferases, Aminotransferases, etc.
4. **Isomerases;** These control the conversion of one isomer of a compound to another isomer of the same compound .e.g. Hexosephosphate isomerase.
5. **Ligases;** this group catalyse reactions in which new chemical bonds are formed using energy from ATP. E.g. DNA and RNA Ligase that control the synthesis of macromolecules like nucleic acids.
6. **Lyases;** these catalyse the breakdown of complex substrate into simpler products but unlike in the case of hydrolytic reactions, water is not used e.g. Decarboxylases, Deaminases.

Classification basing on areas of operation

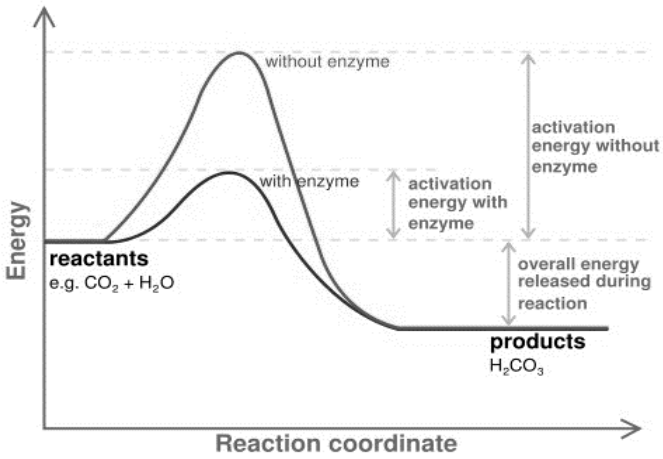
According to areas of operation, enzymes are classified as ***intercellular enzymes and extracellular enzymes.***

Intracellular enzymes operate within the cells where they are produced e.g. all respiratory enzymes. Extracellular enzymes operate outside the cell where they are produced e.g. all digestive enzymes.

ENZYME STRUCTURE AND FUNCTION

Enzyme is normally larger than the substrate molecule it acts on; only a small part of the enzyme actually comes into contact with the substrate. This region is called the ***active site.*** Only a few of the amino acids of an enzyme make up the active site. These amino acids are called ***catalytic amino acids*** and are often located some distance apart in the polypeptide chain but are brought into close proximity by the folding of the chain. The catalytic amino acids are between 3-12 amino acids. The remaining amino acids forms the bulk of the enzyme and helps to maintain the correct shape of the enzyme.

ENZYME ACTION



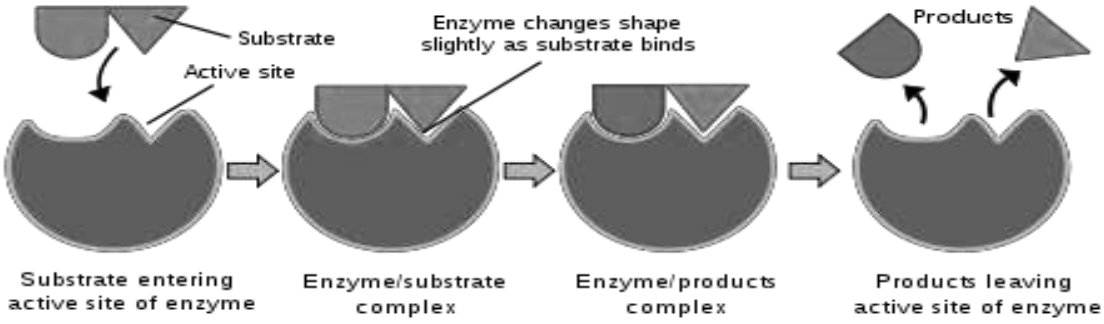
Most reactions in a cell require very high temperatures to get going, which would destroy the cell. Enzymes work by lowering the Activation Energy of a reaction.
The Activation Energy of a reaction is lowered by putting stress on the bonds within a molecule, or by holding molecules close together. This increases the likelihood of a reaction, and so lowers the energy required to begin it.

MECHANISMS OF ENZYME ACTION

How enzymes do their work can be explained by two mechanism i.e. **(1)** lock and key hypotheses; and **(2)** induced fit hypotheses.

LOCK AND KEY HYPOTHESIS

This theory is based on the fact that all enzymes have a complex globular shape with specific configuration of the active site to which substrate with similar configuration fits just like a key fits its lock.
The two molecules (i.e. enzyme and substrate) are held together by ionic or hydrogen bonds that form temporary complexes called ***enzyme-substrate complex*** and later ***enzyme-product complex.***
The complex in which the substrate binds more tightly to the enzyme corresponds to the transition state which is more stable (Lower energy) than the transition state in uncatalysed reaction.
The product normally has different shape from that of the substrate, so once formed, it escape from the active site; leaving the enzyme free to become attached to another substrate with a similar configuration.



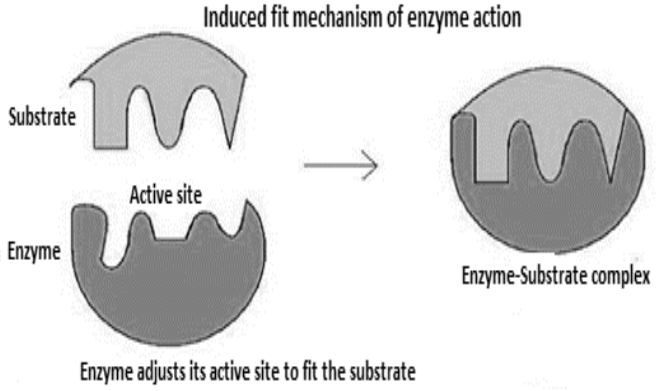
Advantages of the lock and key hypotheses

- Explains the specificity of enzymes i.e. only substrate with conformation similar to the active of the enzyme forms E-S complex hence a reaction is catalysed.
  NB: Enzyme ***specificity*** is a phenomenon where by most enzymes work with only one or with limited range of substrates.
- Explains why enzymes can be used over and over again. Once the active site is set free, another substrate can combine with it.
- Explains why to some extent, the rate of an enzyme-controlled reaction is limited by substrate concentration, i.e. the reaction is inhibited when all the active sites have been occupied.
- Explains why and how enzymes are inhibited.
- Explains why enzymes are inactivated by high and pH changes.
- Explains how the enzymes reduce the activation energy of a chemical reaction by showing that when a substrate attaches to an enzyme, it is slightly distorted which strains the bonds in it and as a result less energy is used/needed to break the chain.

INDUCED FIT HYPOTHESIS

This is a modification of the lock and key hypothesis. It states that the shape of active sites are not exactly complementary, but change shape in the presence of a specific substrate to become complementary.

The bond between the amino acids of the active site of the enzyme is relatively flexible. When a substrate combines with an enzyme, the active site may mould into a shape that fits the substrate. The enzyme initially has a binding configuration which attracts a substrate. On binding to the enzyme, the substrate disturbs the shape of the enzyme and causes its active site to assume a new conformation. It is this new configuration which is catalytically active and forms Enzyme-Substrate complex and later Enzyme-Product complex. Later, the product is released leaving the enzyme ready to bind another substrate.



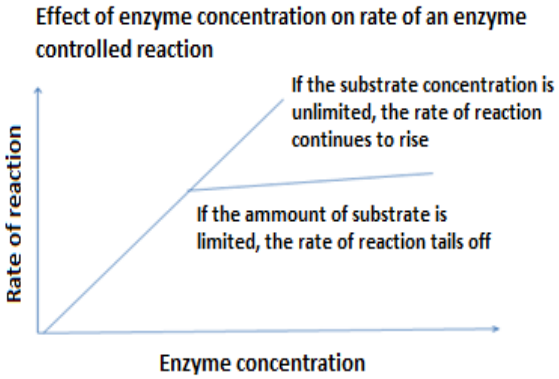
FACTORS WHICH AFFECTS ENZYME ACTIVITY

Concentration of enzymes, Concentration of substrate, temperature of the medium, pH of the medium, presence of inhibitor, and presence of coenzymes are factor which affect enzyme activity.

1. ENZYME CONCENTRATION

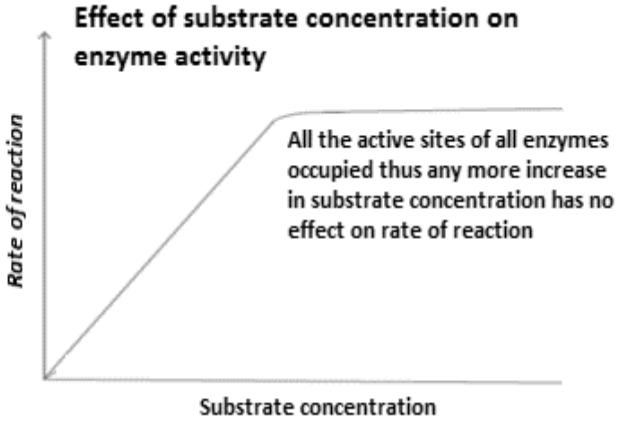
The active site of an enzyme may be used again and again. This explains why enzymes work efficiently even at very low concentration. The number of substrate molecule which an enzyme can act upon in a given time is called its ***turnover number***. This varies from millions of substrate

molecules per minute in the case of fast acting enzymes to few hundred per minute for slow acting enzymes provided suitable conditions exist.
The rate of a reaction is directly proportional to the concentration of the enzyme. If the amount of substrate is restricted, it may limit the rate of the reaction. Thus addition of more enzymes cannot increase the rate and it tails off.



2. SUBSTRATE CONCENTRATION

For a given amount of enzyme, the rate of an enzyme-controlled reaction increases with increase in substrate concentration up to a certain point where any further increase in substrate concentration has no effect on rate of reaction. This is called saturation point.



At low substrate concentration, the active sites of the enzyme molecules are not all used i.e. there is simply not enough substrate molecules to occupy them all.
As the substrate concentration increases, more and more active sites come into use. A point is reached however where all the active sites are being used. At this point increasing substrate concentration can't influence the rate of the reaction as the amount of the enzyme is the limiting factor. The graph thus tails off at a certain substrate concentration so that the only way to increase the rate of the reaction is to increase amount of enzyme.

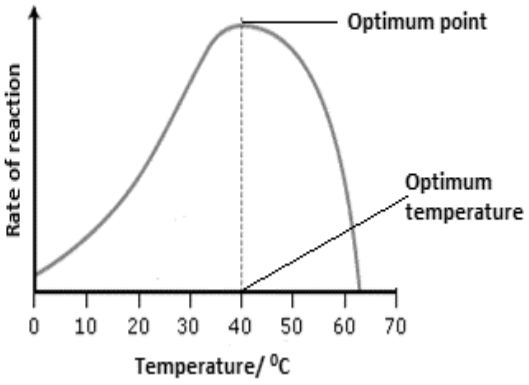
3. TEMPERATURE

At low temperature, the enzymes are inactive and thus their activities is low hence low rate of reaction.

An increase in temperature affects the rate of enzyme controlled reaction in two ways:
As the temperature increases, the kinetic energies of the substrate and enzyme molecules increase and so they move faster. The faster these molecules move, the more often they collide with one another and the greater is the rate of the reaction.

Further temperature increase makes more atoms which make up the enzyme to vibrate faster. This leads to

Effect of temperature on an enzyme controlled reaction



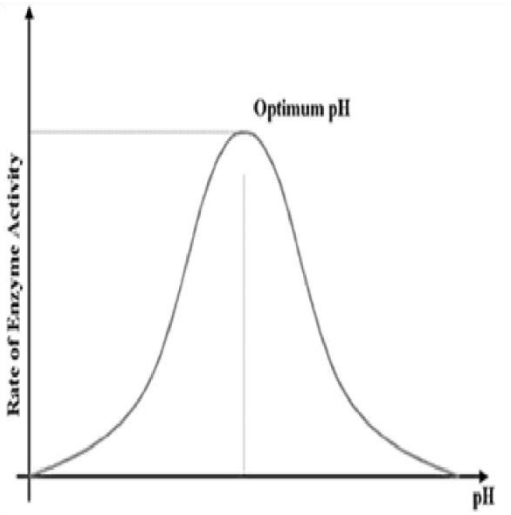
breakage of hydrogen and ionic bonds which hold the molecule in the precise shape. The 3-dimensional shape of the enzyme molecule is altered to such an extent that their active site no longer fits the substrate. The enzyme is thus said to be **denatured.**

NB: As temperature increases, the rate of enzyme activity increases and almost doubles for every 10^oC rise up to about 40^oC, when it is maximum. Therefore, 40^oC is called an optimum temperature. Above this temperature, the rate of enzyme activity begins to fall and about 60^oC, the enzyme activity stops due to enzyme denaturation.

Optimum temperature for enzymes varies considerably e.g. many arctic and alpine plants have enzymes which functions efficiently at around 10^oC while in algae inhabiting hot springs, enzymes continues to function at about 80^oC. For many enzymes, the optimum temperature lies at around 40^oC and denaturation occurs at about 60^oC.

4. pH

This measures the acidity and basicity of a solution. It is a measure of the hydrogen ion (H^+) concentration, and therefore a good indicator of the hydroxide ion (OH^-) concentration. It ranges from pH1 to pH14.
The precise 3-dimensional molecular shape vital for the functioning of enzymes is partly the result of hydrogen bonding and ionic bonds. These bonds may break due to alteration in hydrogen ion concentration. By breaking these bonds, the shape of enzyme molecule, and importantly, its active site, is altered thus lowering its activity and finally it becomes denatured.



Every enzyme has its own range for its efficient functioning. Most intracellular enzymes function at around neutral pH and excessive acidity or alkalinity renders them inactive, e.g. ptyalin works best around pH 7 (neutral);

Some digestive enzymes prefer purely acidic or alkaline environment, e.g. pepsin functions in acidic medium (a pH of 2-5), while trypsin only functions in alkaline medium in the duodenum at a pH of around 8-9.

NB: Small changes in pH above or below the Optimum do not cause a permanent change to the enzyme, since the bonds can be reformed, and this explains why some enzymes have a range of pH in which they are effective. However, larger/extreme changes in pH can cause enzymes to denature and permanently lose their function.

5. ENZYME COFACTORS
Cofactors are non-protein components required by enzymes for their efficient functioning. An enzyme cofactor complex is called ***holoenzyme.***
An enzyme portion without the cofactor is called ***Apoenzyme***
Cofactors vary from simple inorganic ions to complex organic molecules and they include the following: **(1)** inorganic ions/activators; **(2)** coenzymes; and **(3)** prosthetic groups.

ACTIVATORS (Inorganic ions)
These are inorganic ions which may temporarily bind to the active site of the enzyme increasing their efficiency.
They are thought to either mould the enzyme or the substrate into a shape which allows enzyme-substrate complex formation therefore increasing the rate of a particular enzyme-catalysed reaction e.g. the activity of salivary amylase is increased by the presence of chloride ion; zinc ions for dehydrogenase, Fe^{2+}/Fe^{3+} for cytochrome, Mg^{2+} for phosphotransferase, thrombokinase/thromboplastin is activated by Ca^{2+} ions, etc.

COENZYMES
These are complex non-protein organic compounds/molecules loosely attached to an enzyme, which are essential for efficient functioning of an enzyme, e.g. NAD, NADP, ATP, coenzyme A.
All coenzymes are derived from vitamins. They usually do not bind with the enzyme but function as carrier by transferring chemical groups or atoms from the active site of one enzyme to the active site of another enzyme.
NAD works in conjunction with dehydrogenase enzymes by acting as a hydrogen acceptor.

PRSOTHETIC GROUP
These are non-protein organic molecules firmly attached to an enzyme. They function by transfer of chemical group or atoms from the active site of an enzyme to some other substances. They assist in catalytic function of the enzyme. Examples include FAD, haem, etc.
Haem is a ring shaped organic compound with iron at its centre. Haem plays a role as an oxygen carrier in haemoglobin, as well as a prosthetic group of electron carrier cytochrome oxidase and enzyme catalase.

6. ENZYME INHIBITORS

Enzyme inhibitors are substances which slow down or stop enzyme-controlled reaction. They do so by altering the shape of the active site either directly or indirectly.
Enzymes inhibitors are broadly classified basing on their effect on the enzyme, i.e. they can be **(1)** Reversible (temporary) or **(2)** Non reversible/Irreversible (permanent).

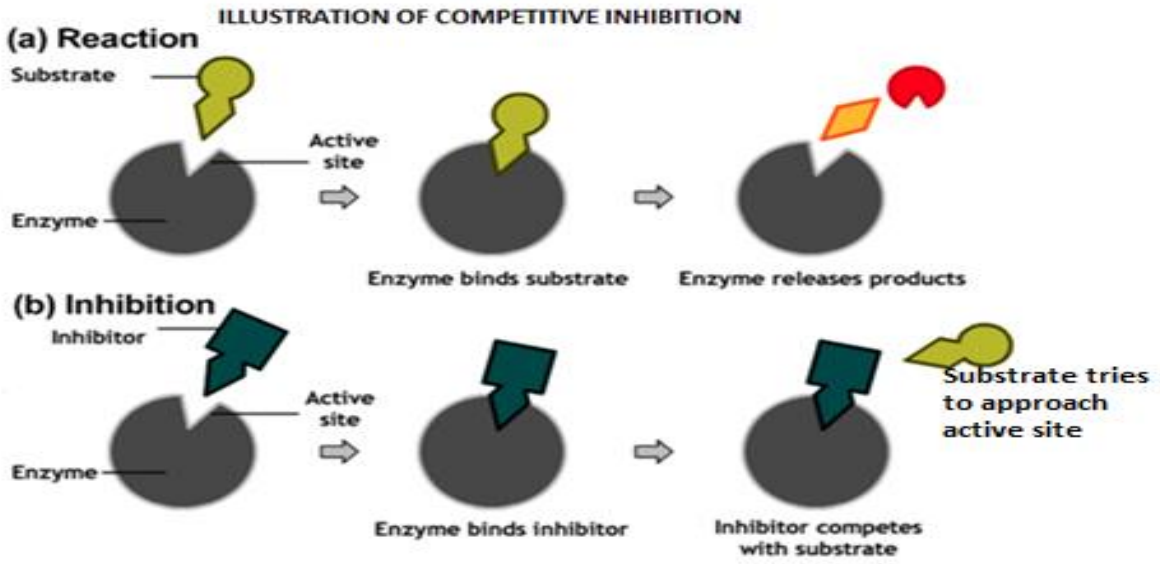
REVERSIBLE INHIBITORS.
A reversible inhibitor has a temporary effect and binds temporarily on the enzyme thus causes no permanent damage to the enzyme. This is because it binds to the enzyme with weak bonds such as hydrogen bonds which can easily be broken. Removal of the inhibitor restores the normal activity of the enzyme. All competitive inhibitors are reversible.

Reversible inhibitors may be further classified as **(1)** ***Competitive*** and **(2)** ***Non Competitive***

COMPETITIVE INHIBITIORS
Competitive inhibitors compete with the substrate for active site of the enzyme molecule. Competitive inhibitors are structurally similar with same configuration like the substrate of the enzyme and bind to the active site. This means that when a competitive inhibitor binds to the active site of an enzyme, it prevents the real substrate from binding to the active site so reduce the rate of reaction. The same quantity of products is formed because substrates continue to use enzyme molecules which are unaffected by the inhibitors. However, it takes a longer time to make the product.

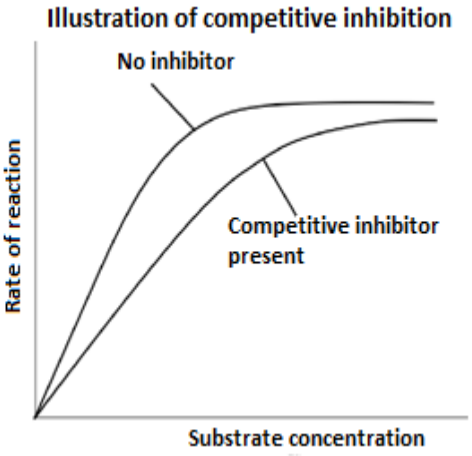
Only once the inhibitor has been released from the active site can the substrate bind, therefore competitive inhibition is always reversible.

NB: Competitive enzyme inhibitors work by preventing the formation of enzyme-substrate.



An e.g. of competitive inhibitor is malonate/malonic acid.
Malonic acid competes with succinate/ succinic acid (substrate) for the active site of enzyme succinate dehydrogenase of the Krebs cycle. The enzyme catalyses oxidation of succinate to fumerate with release of energy but this reaction is competitively inhibited by malonate and the release of energy is reduced.

If the concentration of the substrate is increased, less inhibition occurs. This is because the substrate and the inhibitor are in direct competition and the greater the proportion of the substrate molecules, the greater their chances of finding the active sites of enzymes molecules , leaving fewer to be occupied by the inhibitor. Competitive inhibition is therefore reversed by increasing the concentration of the substrate.
If the concentration of the inhibitor is high, the rate of reaction is reduced.

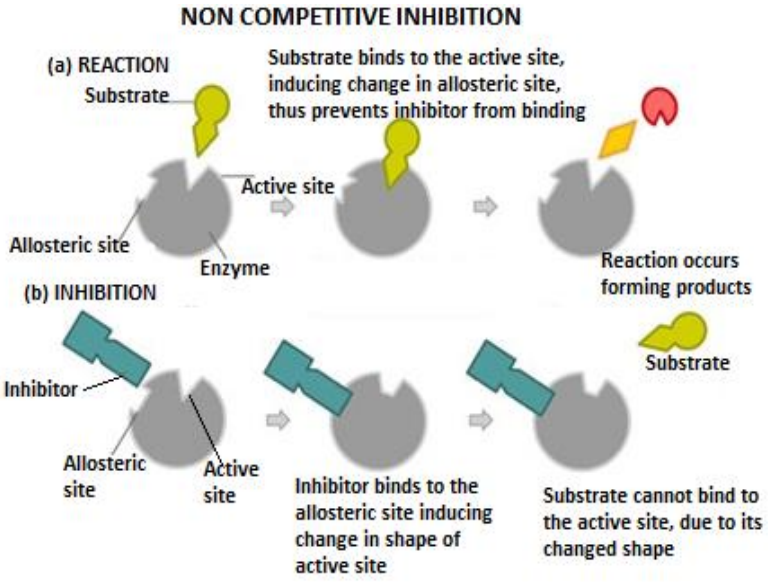


NB: The knowledge of competitive inhibition helps us to understand the effect of a group of antibiotics known as sulphonamides. Antibiotics (e.g. penicillin) destroy infectious microorganism without damaging the tissues of the host. Sulphonamides were the first antibiotics to be used to prevent the spread of microbial infections in wounds during the 2nd world war. They inhibit an enzyme needed for the synthesis of folic acid from PAB (Para AminoBenzoate), a substance essential for the growth of many pathogenic bacteria.

NON-COMPETITIVE INHIBITION

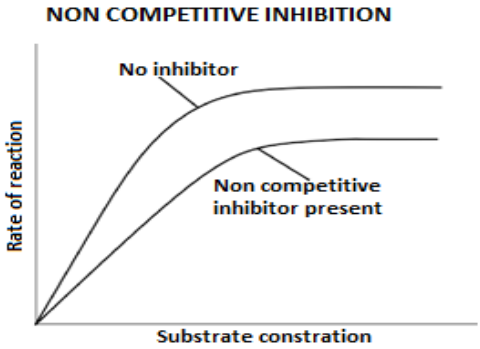
Non-competitive inhibitor has no structural similarity to the real substrate and does not attach itself to the active site of the enzyme molecule but elsewhere on the enzyme molecule.

The attachment however causes a change in the shape of the active site such that substrate can no longer properly occupy the active site hence preventing catalysis.



Non-competitive enzyme inhibitors work not only by preventing the formation of enzyme-substrate complexes, but also by preventing the formation of enzyme-product complexes, so they prevent the substrate from reacting to form product.

The rate of reaction decreases with increasing concentration of the inhibitor. When the inhibitor saturation point is reached, the rate of reaction will almost be zero.



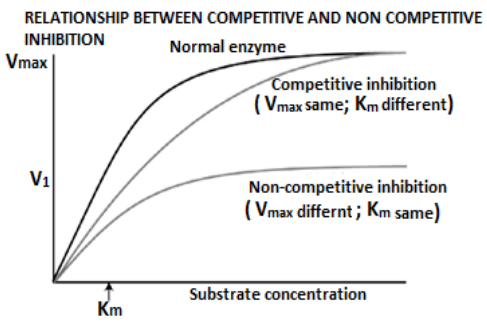
In the presence of a non-competitive inhibitor, increasing the substrate concentration cannot prevent the inhibitor from binding to the enzyme as the two bind to different sites. Therefore, no matter how high the concentration of substrate is, some of the enzymes will still be inhibited, therefore, the maximum rate of reaction will always be lower.

Non-competitive inhibition can be reversible/temporary or irreversible/permanent.

Many non-competitive inhibitors are irreversible and permanent, and effectively denature the enzymes which they inhibit.

Some chemicals cause non-competitive irreversible inhibition of enzyme, e.g. very small concentration of heavy metal ions like Ag^{+}, Hg^{2+}, As^{+} or certain iodine containing compounds completely inhibit some enzymes. These combine with the sulphuryl group (SH) and completely inhibit enzymes by permanently destroying their structures.

Another common example of a non-competitive irreversible inhibitor is nerve gas DFP (diisopropylfluorophosphates), designed for use in the warfare. It binds with amino acid serine at the active site of the enzyme acetyl cholinesterase which breaks down neurotransmitter acetylcholine after the impulse has been transmitted. Acetylcholine is required to continue the passage of impulses from one nerve cell to another across the cleft, if acetylcholine accumulates, nerve impulses cannot be stopped, causing prolonged muscle contraction which in turn result to paralysis and death.



A common example of non- competitive reversible inhibitor is cyanide. It attaches itself to copper, the prosthetic group of

cytochrome oxidase responsible for the transfer of hydrogen during cellular respiration, thereby inhibiting the production of energy in cells. For this reason, cyanides are known as ***respiratory poisons.***

DIFFERENCES BETWEEN COMPETITIVE AND NON-COMPETITIVE INHIBITION

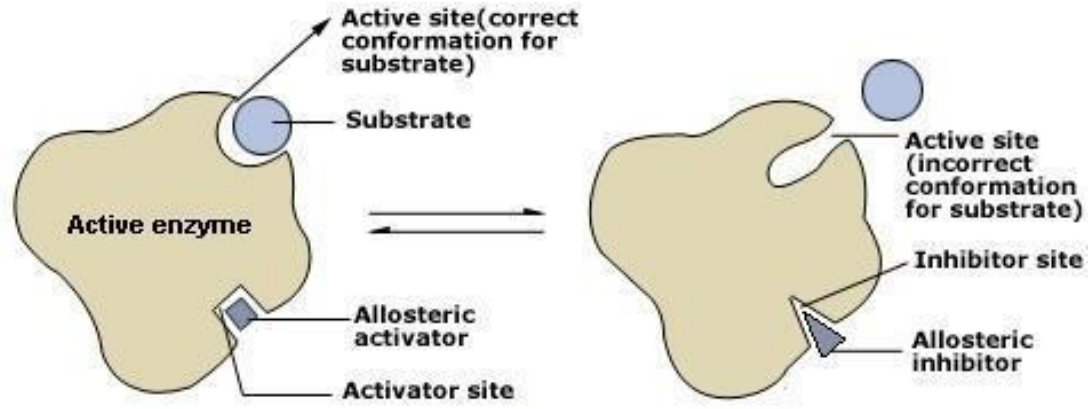
Competitive inhibition	Non-competitive inhibition
Inhibitor is similar to substrate in structure	Inhibitor is entirely different from substrate in structure
Inhibitor attaches itself to the active site of the enzyme molecule	Inhibitor forms a complex at a point other than the active site of the enzyme molecule
Substrate and inhibitor compete for the active site of the enzyme molecule	Substrate and inhibitor do not compete for the active site of the enzyme molecule.
Inhibitor does not alter the structure of enzyme molecule	Inhibitor alters the shape of the active site of the enzyme
Inhibition can be reduced by increasing substrate concentration	Inhibition continues until saturation point is reached.

ALLOSTERIC ENZYMES

Compounds called allosteric effectors bind to the enzyme at sites away from the active site. They may speed up or slow down the rate of enzyme controlled reactions.

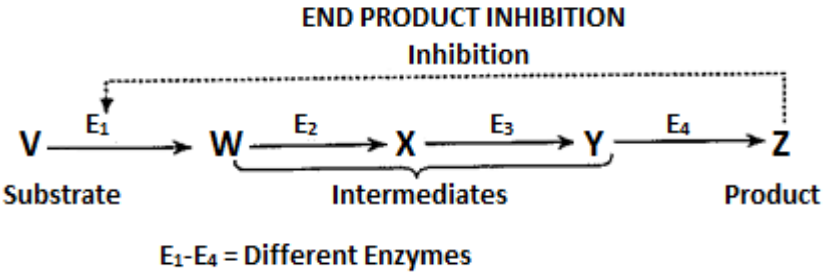
Non-competitive inhibition occurs when a compound or molecule is bound to a region of the enzyme other than the active site. This region is known as allosteric site. It does not prevent the binding of the substrate to the active site but it alters the shape of the enzyme and the alignment of the catalytic site of the enzyme. The change in the conformation of the enzyme is called ***allosteric effect*** and the enzyme whose shape is changed is called ***allosteric enzyme.***

Allosteric effectors are also called ***allosteric inhibitors*** e.g. in glycolysis, when ATP is at its high concentration, it inhibits one of the enzymes allosterically. However, when cell metabolism increases and ATP is used up the overall ATP concentration decreases and the pathway once again comes into operation because the inhibitor i.e. ATP has been removed. This is called ***end product inhibition.***



END PRODUCT INHIBITION (NEGATIVE FEEDBACK INHIBITION)

When the end product of a metabolic pathway begins to accumulate, it may acts as an allosteric inhibitor of the enzyme controlling the first step of the pathway. Thus the end product



switch off its own production as it begins to builds up. The process is self-regulatory. As the product is used up, its production is turned on. This is called ***end product inhibition*** and is an example of a ***negative feedback mechanism.***
An example of this controlled mechanism in biological process is given by the enzyme trypsin secreted by pancreas in form of trypsinogen. The active site of this enzyme is covered by a polypeptide chain which is stiff and gets off only when the enzyme reaches the intestine. The removal of this polypeptide chain is catalysed by an enzyme enterokinase present in the small intestine.

IMPORTANCE OF ENZYME INHIBITORS
- ❖ Provide important information about the shape and properties of the active site of an enzyme.
- ❖ Can be used to block particular reactions thereby enabling biochemist to reconstruct metabolic pathways.
- ❖ Can be used in medicine and agriculture e.g. manufacture of drugs and pesticides.
- ❖ Applied in control metabolic pathways by regulating the stages in them e.g. by end-product inhibition and allosteric inhibition.

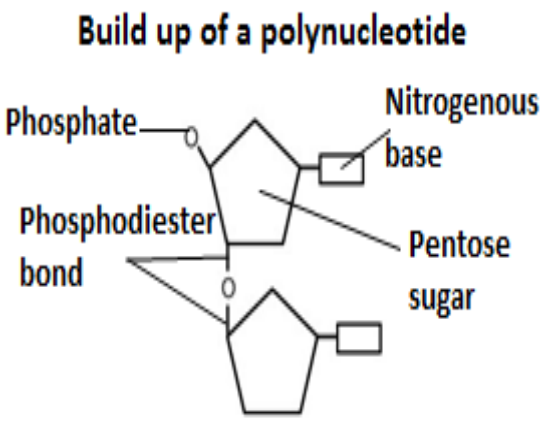
NUCLEIC ACIDS

The term nucleic acids comes from the fact they are mainly found in the nucleus.. They constitute the genetic material of all living things. Within the structure of nucleic acids is coded information (instructions) that govern all cellular activities. This control is largely achieved by enzymes, which determine the kind and extent of chemical reactions, and the enzymes synthesis is controlled by nucleic acids.

Types of nucleic acids:
Two types of nucleic acids exist; **(1)** Deoxyribonucleic acid (**DNA**); and **(2)** Ribonucleic acid (**RNA**)

GENERAL STRUCTURE OF NUCLEIC ACIDS
(Describe the structure of nucleic acids /a nucleic acid)
Nucleic acids are **polymers** made of subunits called **nucleotides.**
A **nucleotide** is made up of three molecules:

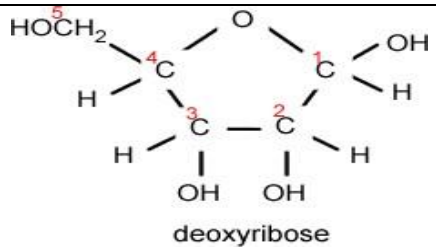
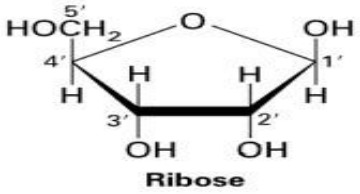
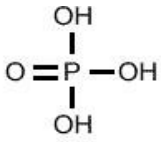
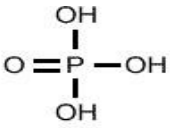
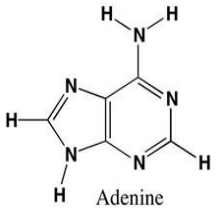
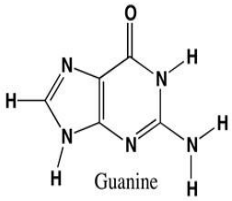
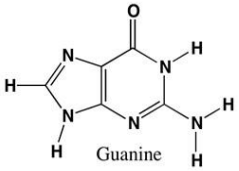
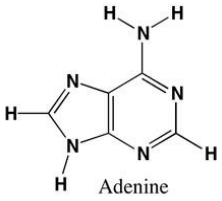
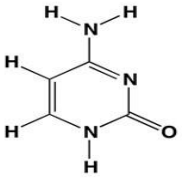
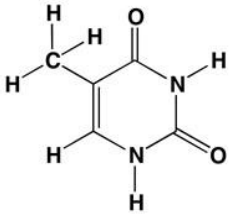
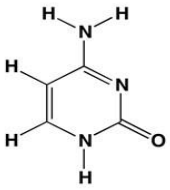
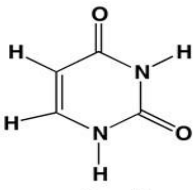
1. **Phosphate group;** this has the same structure in all nucleotides in both RNA and DNA and give the nucleic acids their acidic character.
2. **Pentose sugar** – either Deoxyribose (in DNA) or Ribose (in RNA)
3. **Nitrogen base** – any purine (Adenine, Guanine) or pyrimidine (Cytosine and either Thymine in DNA or Uracil in RNA)



Nucleoside forms when a pentose sugar joins an organic base by **condensation reaction** (a **water molecule** is lost**)** forming a ***Glycosidic*** bond.
Nucleotide forms when a **nucleoside** (pentose sugar + organic base) joins a phosphate by loss of **second water molecule.** 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 sugar-phosphate backbone of DNA is the same in all organisms from the bacteria to higher organisms but the base sequence is extremely variable.
The sequence of bases along the polynucleotide chain forms the genetic code which determines the characteristics of an organism that are inherited from the parents.

COMPONENTS OF NUCLEOTIDES

MOLECULE	DNA	RNA
Pentose sugar	 deoxyribose	 Ribose
Phosphoric acid	 Phosphoric acid	 Phosphoric acid
Purines (Double ringed organic bases)	 Adenine  Guanine	 Guanine  Adenine
Pyrimidines (Single ringed organic bases)	 Cytosine  Thymine	 Cytosine  Uracil

DNA MOLECULE

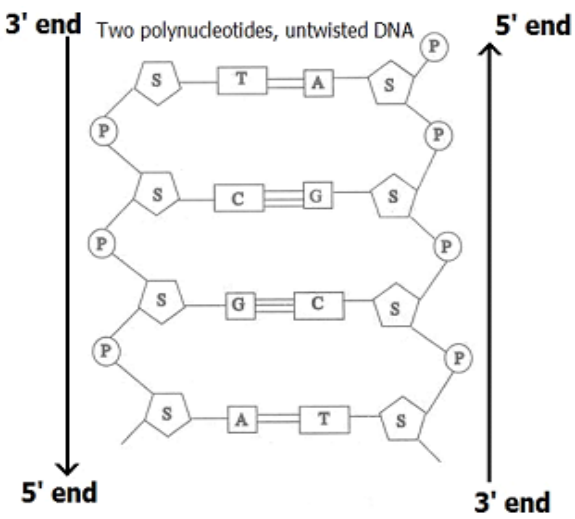
DNA STRUCTURE ACCORDING TO WATSON AND CRICK

DNA is a very large polymer of **nucleotides**. A DNA **nucleotide** is made up of three molecules:

(i) Phosphate group

(ii) Deoxyribose sugar

(iii) Nitrogen base - either adenine **(A)**, guanine **(G)**, thymine **(T)** or cytosine **(C)**.

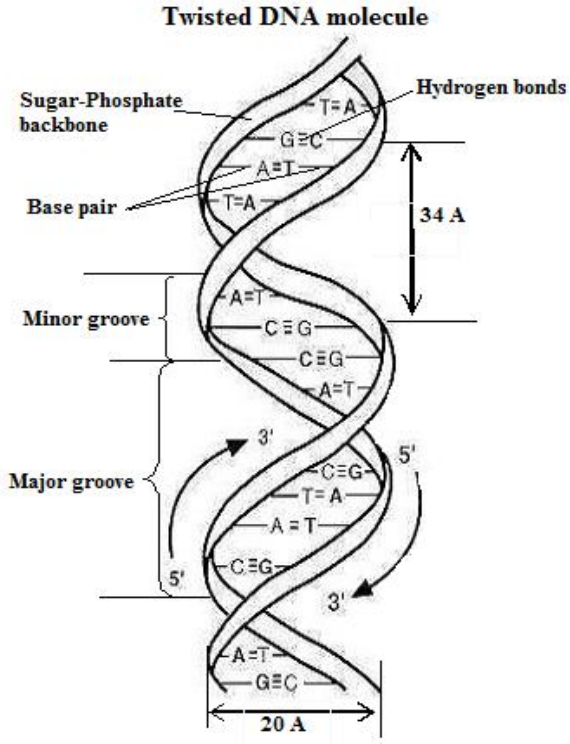


DNA is made of two polynucleotide strands thus double stranded. The strands are antiparallel (run in opposite directions) i.e. one runs from 3^I to 5^I direction while another runs from 5^I to 3^I direction.

Untwisted DNA is ladder-like, in which the sugar-phosphate backbones represent the handrails while the nitrogen base pairs represent the rungs.

The two strands form a right handed helical spiral and the two chains coil around each other to forms a double helix.

Each chain has sugar-phosphate-sugar backbone held by covalent **phosphodiester bonds,** with nitrogen bases projecting at right angles from the two strands joined by **weak hydrogen bonds** between the hydrogen atom of a base in one chain and nitrogen and oxygen atoms of a base in another chain by complimentary base pairing i.e. A with T, C with G. Adenine bonds with Thymine with a double bond while Guanine bonds with Cytosine with triple bonds. The width between the two backbones is constant and equals to the width of the base pairs i.e. the width of a purine plus a pyrimidine.



ADAPTATIONS OF DNA

(i) Sugar-phosphate backbone is held together by strong covalent phosphodiester bonds to provide stability.

(ii) The two sugar-phosphate backbones are antiparallel which enables purine and pyrimidine nitrogen bases to project towards each other for complimentary pairing.

(iii) Sugar-phosphate backbones are two (i.e. it is double stranded) to provide stability.

(iv) The two sugar-phosphate backbones form a double helix to protect bases/hydrogen bonds.

(v) Long polynucleotide chains for storage of much information.

(vi) Double helical structure makes the molecule compact to fit in the nucleus.

(vii) Base sequence allows information to be stored.

(viii) Double stranded for replication to occur semi-conservatively/ strands can act as templates.

(ix) Complementary base pairing for accurate replication/identical copies can be made.

(x) Weak hydrogen bonds enable unzipping (separation of strands) to occur readily.

(xi) There are many hydrogen bonds which increase stability of DNA molecule.

(xii) Nucleotides can link in many forms to form chains of infinite forms that enable it to store the genetic information for all organic.

Characteristics of DNA as a genetic material

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

Characteristics of a hereditary material

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

THEORIES OF DNA REPLICATION

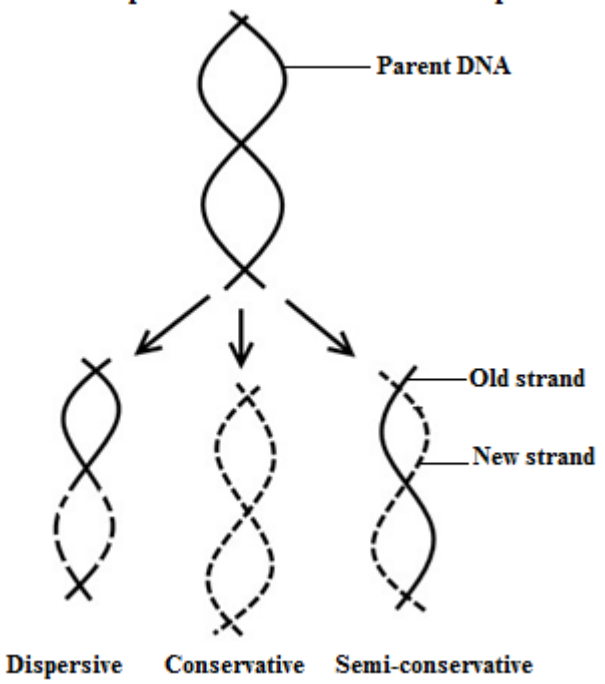
DNA replication is the process by which the parent DNA molecule makes another copy of itself.

1. ***Fragmentation hypothesis (Dispersive hypothesis)***
   The parent DNA molecule breaks into segments and new nucleotides fill in the gaps precisely.
2. ***Conservative hypothesis***
   The complete parent DNA molecule acts as a template for the new daughter molecule, which is assembled from new nucleotides. The parent molecule is unchanged.
3. ***Semi-conservative hypothesis***
   The parent DNA molecule separates into its two component strands, each of which acts as a template for the formation of a new complementary strand. The two daughter molecules therefore contain half the parent DNA and half new DNA.

NB: The semi conservative hypothesis was shown to be the true mechanism by the work of Meselsohn and Stahl (1958) in their experiment on bacterium *E. coli* using radioactive ^{15}N.
E. coli was grown for many generation in a medium in which normal ^{14}N was replaced by heavy isotope ^{15}N. Heavy isotope was integrated into all the bacterial DNA (Grew *E. coli in ^{15}N for several generations so that all the DNA was labelled).* They shifted cells to ^{14}N media and allowed them to replicate their DNA 1 time. Sample of DNA was taken.

Cells were allowed to replicate their DNA again (total of 2 times) and the sample of DNA was taken.
They used a special centrifugation of DNA samples to determine the isotope composition and pattern of labelling in the DNA, a found pattern matched semi-conservative.

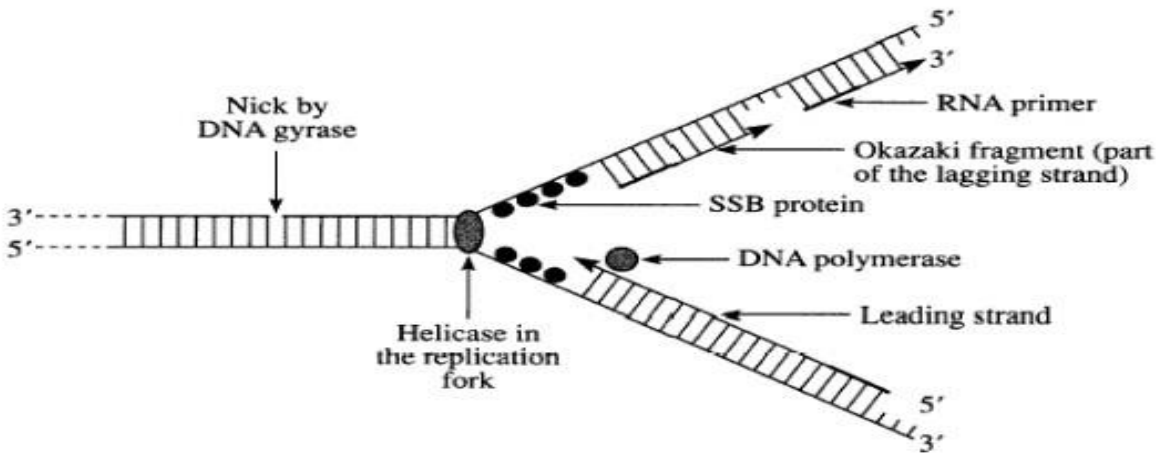
Illustration of three possible theories of DNA replication



DESCRIPTION OF DNA REPLICATION
DNA replication is the process by which parent DNA molecule makes another copy of itself, **semi conservatively** (1 new, 1 old strand together).
It occurs during the **synthesis** phase of interphase.
DNA Helicase enzyme binds onto the DNA molecule and unwinds/unzips DNA at replication origins by breaking the hydrogen bonds between base pairs to expose the bases using energy form hydrolysis of ATP; creating the Y-shaped **replication fork** (the two opened strands of DNA behind it).
Note: DNA is replicated a bit at a time and the whole molecule is never completely uncoiled.
DNA polymerase then moves in 5^1 to 3^1 direction along the exposed base sequences on the leading strand, attaching free DNA nucleotides of complementary bases to Old strand creating a new DNA strand as it goes. Nucleotides used naturally in the cells have two extra phosphate groups attached. This activates the nucleotides. As each nucleotide links to the growing chain, the two extra phosphate groups are broken off. This releases energy that enables the remaining phosphate groups of the nucleotide to form a bond with sugar molecule of the neighbouring nucleotides.
DNA ligase joins adjacent Okazaki fragments on the lagging New strand (new strand laid down in the opposite direction of the replication fork) and any sections of new DNA on the leading strand (new strand laid down in the direction of the replication fork) that need to be joined.
DNA polymerase reads the exposed code from **3^I to 5^I** end and therefore assembles the new strand from **5^I to 3^I end**.
Several molecules of **DNA polymerase** act simultaneously at multiple sites, each assembling a separate section of the new strand of DNA.

These new DNA segments are then joined together by the enzyme **DNA ligase**.
The two new daughter molecules then coil up again to reform the double helix structure.

Illustration of DNA replication



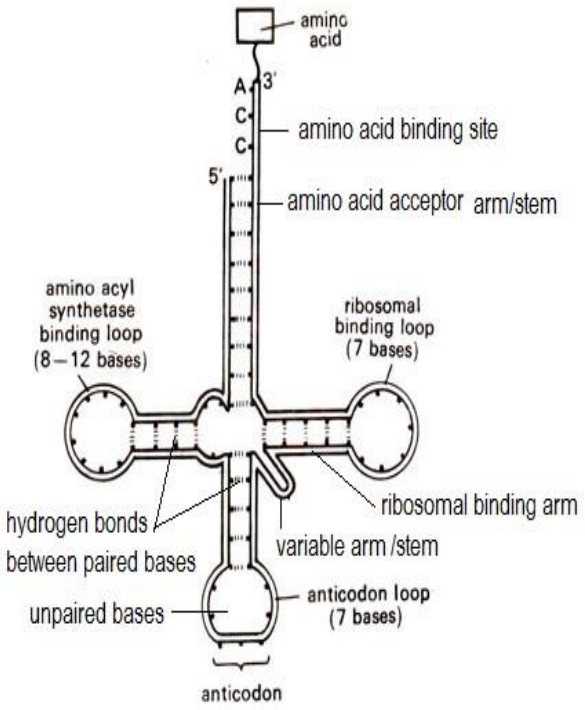
RNA MOLECULE

GENERAL STRUCTURE OF RNA

RNA molecules are small/short, single stranded (rRNA and mRNA) or a complex structure (tRNA) polymer of **nucleotides**.
RNA **nucleotide** is made up of three molecules: **(i)** Phosphate group **(ii)** Ribose sugar **(iii)** Nitrogen base - either adenine **(A)**, guanine **(G)**, cytosine **(C)** or uracil **(U)**.
The sugar-phosphate-sugar backbone is held by covalent **phosphodiester bonds.**
RNA occurs in three types whose sizes, shapes, amounts/abundance and roles vary:

1. Ribosomal RNA (rRNA) Forms 80% of the total RNA in a cell. rRNA in different species vary in size but with organic base sequence which is very similar in organisms within the same kingdom. It is manufactured by the DNA specifically by the nucleolus but found in the cytoplasm. Permanently associated with protein to form component of ribosomes. rRNA is a site of protein synthesis in cells.	**2. Messenger RNA** (mRNA) Forms 3-5% of the total RNA in a cell. Single stranded polynucleotide chains with 5' to 3' polarity containing triplet bases called codons. Manufactured in the nucleus by the process of transcription. mRNA carries coded information from DNA to ribosomes in the cytoplasm during protein synthesis.

3. Transfer RNA (tRNA)
Forms about 15% of the total cell RNA.
Primary structure in all tRNAs has sequences of 73 to 93 nucleotides. 3' end *always terminates* with the sequence CCA, where amino acid attaches while the 5' end terminates in base G.
Secondary structure forms a clover leaf shape with hydrogen bonded base-paired *stems.*
Cloverleaf contains three non-base-paired *loops*:
(i) Aminoacyl synthetase binding loop
(ii) Anticodon
(iii) Ribosomal binding loop.
Anticodon is a single stranded loop at the bottom.
tRNA carries amino acids in the cytoplasm to ribosomes.
Adaptations of tRNA: (1) Active sites (*anticodon* and *amino acid*) are maximally separated to avoid interference; **(2)** Small size for mobility readily.



COMPARISON OF DNA AND RNA
Similarities
Both: **(1)** are polymers of nucleotides **(2)** carry genetic information **(3)** have same purine bases adenine and guanine plus pyrimidine bases cytosine **(4)** originate from the nucleus **(5)** occur in the cytoplasm
Differences

Aspect	Deoxyribonucleic Acid (DNA)	Ribonucleic Acid (RNA)
Function	✓ It's the blueprint of biological guidelines in organisms ✓ Stores genetic information for a long time and transmits it.	✓ Carries out DNA's blueprint guidelines. ✓ Transfers genetic information needed for the creation of proteins from the nucleus to the ribosome.
Structure	✓ Double-stranded. ✓ Hydrogen bonds occur between complementary nitrogen bases of opposite strands (A-T, C-G) ✓ Spirally twisted to produce a regular helix ✓ Occurs in form of chromatin or chromosomes	✓ Single-stranded. ✓ Base pairing through hydrogen bonds occurs in the coiled parts. ✓ The strand may fold at places to form a secondary helix. ✓ Occurs in ribosomes or forms association with ribosomes
Base Pairing	✓ Adenine links to thymine (A-T) ✓ Purine and pyrimidine bases are in equal number	✓ Adenine links to uracil (A-U) ✓ No proportionality between numbers of purine and pyrimidine bases.
Location	✓ Much of DNA is in the nucleus of a cell, little in mitochondria and chloroplasts.	✓ Much of RNA is in the cytoplasm, little in the nucleus.

Stability	✓ Deoxyribose sugar in DNA is less reactive because of C-H bonds. ✓ Stable in alkaline conditions. ✓ Long lived	✓ Ribose sugar is more reactive because of COH (hydroxyl) bonds. ✓ Not stable in alkaline conditions. ✓ Some RNA are very short lived while others have somewhat longer life.
Propagation	✓ DNA is self-replicating.	✓ RNA is synthesized from DNA when needed.
Unique Features	✓ DNA is protected in the nucleus, as it is tightly packed.	✓ RNA strands are continually made, broken down and reused.
Size	✓ Very large/long (has over a million nucleotides) ✓ Quantity is fixed in a cell	✓ Much shorter (Depending on the type, RNA contains 70 – 12,000 nucleotides). ✓ Quantity is variable
Types	✓ Only two types: intra nuclear and extra nuclear DNA	✓ Three different types: mRNA, tRNA and rRNA

THE CENTRAL DOGMA OF MOLECULAR BIOLOGY
It states that **DNA makes RNA, RNA makes proteins**

PROTEIN SYNTHESIS

This is the process by which the coded information is transferred from the chromosome in nucleus to the ribosomes in the cytoplasm to make the proteins.
The instructions for the manufacture of these proteins are located in DNA which is located the nucleus but the central protein synthesis occurs in the cytoplasm and involves ribosomes.
Although the DNA controls all the activities of the cell, it can directly only synthesize proteins mostly enzymes that are responsible for controlling cell metabolism. It is the particular range of enzymes in the cells which determines what type of cell it becomes and that's how the DNA controls all the activities of the cell.
It involves steps; amino acid synthesis, transcription, amino acid activation and translation.

1. Amino acid synthesis

In plants, amino acids are formed in the mitochondria and chloroplasts in the series of stages.
It starts with plants absorbing nitrates from the soil, the nitrates are reduced to amino groups, and amino groups are then combined with a carbohydrate skeleton .e.g. alpha keto-glutarate from the Krebs cycle. Amino groups are transferred from one carbohydrate skeleton to another by the process of transamination.
Animals obtain their amino acids from the food ingested although they have some capacity of synthesizing their own non-essential amino acids by deamination and transamination processes in the liver.

2. Transcription

This is the mechanism by which the base sequence of a section of DNA representing a gene is converted into complementary base sequence of mRNA.
A specific region of DNA molecule called a ***cistro***n unwinds the double helix; weak hydrogen bonds between base pairs in the DNA double helix are broken; under the control of enzyme ***Helicase***. This exposes the bases along each single strand; and only one of these strands is used as a template for formation of a complementary mRNA. Each base on the template strand attracts

free complementary RNA nucleotides from the nucleoplasm; free Guanine base on the template attracts an RNA nucleotide with cytosine base while the free Adenine attracts Uracil.

A large enzyme RNA polymerase attaches to the strand at a particular base sequence called promoter site that initiates transcription. It moves along the strand in the 5' to 3' direction adding one complementary RNA nucleotide at a time to the newly unwound portion of DNA and the DNA double helix reforms behind the RNA polymerase. On reaching a special stop sequence called ***terminator,*** the enzyme detaches and mRNA peels away from the DNA.

A number of mRNA molecules may be formed before RNA polymerase leaves the DNA which closes up reforming a double helix. The formed mRNA molecule is too large to diffuse through the nuclear membrane but leaves the nucleus through the nuclear pores into the cytoplasm. In the cytoplasm, it is attracted to the ribosomes.

Importance of transcription

(i) DNA is too large to fit through the nuclear pores, yet mRNA being small can readily exit the nucleus.

(ii) DNA contains many codes that aren't always needed at a given time, so m-RNA only carries that code needed to make specific proteins out of the nucleus to the ribosome.

3. Amino acid activation

This the process by which amino acids combines with tRNA using energy from hydrolysis of ATP.

The amino acids present in cells must first be activated before they can be assembled into the polypeptide chain.

Each type of tRNA binds with a specific amino acid under the control of enzyme ***Aminoacyl-tRNA synthetase*** forming ***Aminoacyl-tRNA complex*** with sufficient energy in the bond between the final A nucleotide of CCA and the amino acid to later form a peptide bond with an adjacent amino acid, thus there must be at least 20 types of tRNA.

Each tRNA differs in the composition of its triplet bases called anticodons. The triplet base sequence at the anticodon is directly related to the amino acid carried by the tRNA.

All tRNA have a free end which terminates in the triplet CCA at the 3' end onto which the amino acid becomes attached.

The tRNA molecule with amino acid attached now moves to the ribosomes.

4. TRANSLATION

This is the means by which the sequence of bases in the mRNA molecule is converted into a sequence of amino acids in a polypeptide chains.

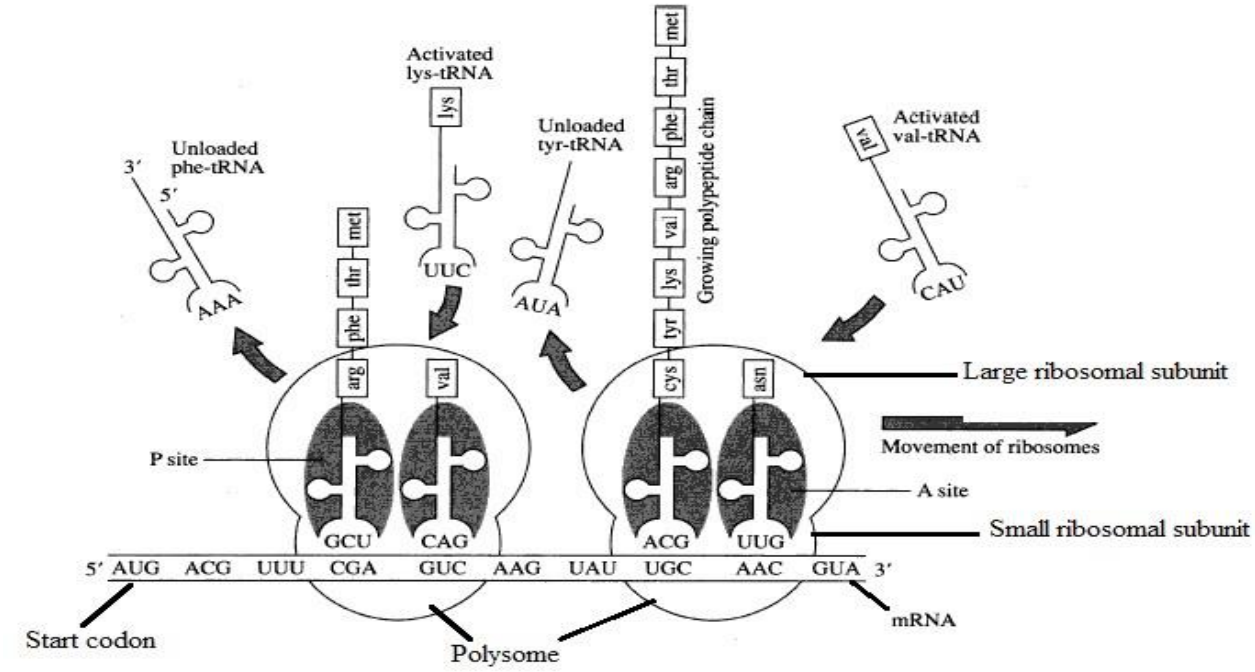
It involves chain initiation, chain elongation and chain termination.

A group of ribosomes can get attached onto the mRNA forming a polyribosome (polysome), this enables synthesis of many polypeptide chains of the same kind at the same time. First two mRNA codons enter into the ribosome and tRNA-amino acid complex carrying the first amino acid methionine with anticodons complementary to the start codon AUG on the mRNA is attracted. The second codon on the mRNA also attracts a tRNA-amino acid complex with anticodons complementary to it. The ribosome is the framework that holds the mRNA, the tRNA-amino acid complex and associated enzymes together until the two amino acids form a peptide bond under the control of enzyme ***peptidyl transferase.*** Once the amino acid has been added to the growing polypeptide chain, the ribosome moves one codon along the mRNA to hold the next codon-anticodon complex together until the third amino acid is linked and in this way, a polypeptide chain is assembled by addition of one amino acid at a time.

Second and subsequent ribosomes pass along the mRNA immediately behind the first one; this produces many identical polypeptide chains simultaneously.

The tRNA molecule that previously attached the polypeptide leaves the ribosome and passes back into the cytoplasm to be reconverted into new Aminoacyl-tRNA complex.
The ribosome continues to move along mRNA until it reaches the nonsense (stop) codon that signals STOP that don't code for any amino acid. The terminating codons are UAA, UAG and UGA. At this point, the polypeptide chain is cast off and leaves the ribosome and the process of translation is complete.

The polypeptide chain formed is then assembled into proteins. This may involve folding of the polypeptide chain into a secondary structure; this can also fold into a tertiary structure and its combination with other polypeptide chains and prosthetic groups to give a quaternary and conjugated proteins.
Newly synthesised proteins can be packaged and sent to Golgi complex for modification/processing. This is called p**ost translation processing of the protein.**



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

Compare the processes of DNA replication and transcription

Similarities

Both: **(1)** involve unwinding the helix **(2)** involve separating the two strands **(3)** involve breaking hydrogen bonds between bases **(4)** involve complementary base pairing **(5)** involve C pairing with G **(6)** work in a 5` to 3` direction **(7)** involve linking/ polymerization of nucleotides **(8)** DNA or RNA polymerase require a start signal

Differences

DNA replication	**Transcription**
Involves DNA nucleotides, where the pentose sugar is Deoxyribose, and the base adenine	Involves RNA nucleotides where the pentose sugar is ribose, and the base adenine pairs

pairs with thymine	with uracil
Both strands are copied	Only one strand copied
Ligase enzyme / no Okazaki fragments are involved	No ligase enzyme / no Okazaki fragments
Has multiple starting points	Has only one starting point
replication gives two DNA molecules	transcription gives one mRNA

Compare DNA transcription with translation

Both: **(1)** Occur in 5' to 3' direction **(2)** Require ATP

Differences

(i) DNA is transcribed while mRNA is translated
(ii) Transcription produces RNA while translation produces polypeptides/ protein
(iii) RNA polymerase for transcription while ribosomes for translation/ ribosomes in translation only
(iv) Transcription occurs in the nucleus (of eukaryotes) while translation occurs in the cytoplasm/ at ER
(v) tRNA is needed for translation but not transcription

Explain briefly the advantages and disadvantages of the universality of the genetic code to humans.

(i) Genetic material can be transferred between species/ between humans
(ii) One species could use a useful gene from another species

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NATURE OF GENES

Mendel proposed that all characteristics of organisms were determined by heredity units which he called elements and later were called genes which were located on the chromosome. He thus defined a gene as a unit of inheritance. This definition doesn't talk of anything about the physical nature of the gene.

A gene then can also be defined as a specific region of the chromosome determining a distinct characteristic in the organism.

Since genes are known to determine the structural, physiological and biochemical characteristics of organisms, it can be defined in terms of its function. Initially it was known to be the shortest segment of a chromosome responsible for the production of a specific product (protein) thus, a gene can be defined as a piece of DNA which code for a protein. This can precisely be stated as 'a gene is a DNA code for a polypeptide.

THE GENETIC CODE

This is a sequence of bases on the DNA which codes for the sequence of amino acids in a protein molecule.

DNA provides the code (genetic message) for formation of proteins in an organism which in turn determine the characteristics of that organism.

Every species possess different DNA thus produce different enzymes. The difference lies in the sequence of bases and not in the chemical composition.

This sequence of the triplet base pairs in DNA and messenger RNA is the code that determines the protein to be manufactured.

There are 20 common amino acids used to make proteins which the bases in the DNA must code for. There are 64 different codes that code for the 20 amino acids and three of these don't code for any amino acid and thus called the stop or nonsense codons that stop the translation process. The remaining 63 codons code for particular amino acids.

Breaking the code is finding out the particular triplet code that codes for a particular amino acid.

FEATURES OF A GENETIC CODE

1. **The code is a triplet code**

This means that three bases in DNA code for one amino acid in a protein.
The DNA code for a protein is first copied into mRNA thus mRNA is complementary to the DNA. The complementary triplets in mRNA are referred to as codons and each is three bases long and is the code for one amino acid.

2. **The code is degenerate**

This means that more than one codon can code for the same amino acid. A degenerate code is that where the number of amino acids is less than the number of codons that cod for it.
The only exceptions are methionine and Tryptophan which are only coded for by only one codon while many others are coded for by several codons.

3. **The code is punctuated**

The genetic code has initiation or start codons. The codon AUG is the start codon and codes for amino acid methionine. This means all polypeptide chains start with amino acid methionine. It also has the stop codons (full stops) or nonsense codons that determine the end of the code message. They don't code for any amino acid and so mark the end point of a gene. They act as the stop signals for the termination of the polypeptide chains during translation. The stop codons are; UAA, UAG, UGA.

4. **The code is universal**

The same triplet codon codes for the same amino acid in all living things. All organisms contain the same 20 amino acids and the same nitrogenous bases.

5. **The code is non-overlapping**

From the start of mRNA, the sequence of bases read in blocks of three that correspond to a particular sequence of amino acids without any overlapping of bases .e.g. if the bases from the start are AUGCCAAUC the sequence of the codons is AUG/CCA/AUC and not AUG/ GCC/AAU.

6. **The code is comma less**

From the start of mRNA, the sequence of bases never involves skipping of any base along the chain.

7. **The code is non-Ambiguous**

There is no any one codon that can code more than one amino acid.