CHEMICALS OF LIFE

These are compounds needed in living organisms to maintain life. They are substances that control body processes and ensure that metabolic processes take place efficiently. They constitute the cell protoplasm and life cannot exist without them, hence they are called Chemicals of life.

i) The study of these chemicals and the reactions they undergo in the body is called biochemistry.
ii) The study of the structure and behaviour of individual molecule in living things is called molecular biology

Chemical compounds in the body are generally divided into two groups

i) Organic compounds, which are compounds of carbon

ii) Inorganic compounds, which are not complexes of carbon but derivative ions

Types of chemicals of life

Organic chemicals of life	***Inorganic chemicals of life***
Carbohydrates	***Water***
Proteins	***Acids***
Vitamins	***Bases***
Nucleic acids	***Mineral salts***
Lipids	

NB: The chemicals of life are taken in the bodies of living organisms in form of nutrients. Some nutrients are needed in bulk while others are needed in relatively small amounts. The nutrients needed in large amounts are called macro-nutrients and include

- Carbohydrates
- Proteins
- Lipids
- Water

The micro-nutrients include;

- Vitamins
- Nucleic acids
- Mineral salts.

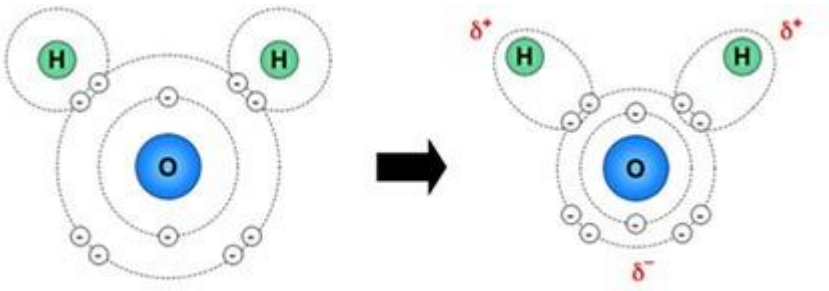
INORGANIC CHEMICALS OF LIFE

WATER

Water forms 75% of most of the cells and it is unique in the way that it has a range of important properties from the way in which the oxygen and hydrogen atoms are linked in the water.
Water has both chemical and physical properties that are rather unusual and these are due to:

i) Small size,
ii) Its Hydrogen bonds between the molecules
iii) Polarity

Polarity is uneven charge distribution within the molecule. In water one part or pole of the molecule is slightly negatively charged and the other slightly positive, this is known as dipole. it occurs because the oxygen atom has a greater electron attracting power (electronegativity) than the hydrogen atoms. As a result the oxygen atom pulls the bonding electrons from the hydrogen atom making it slightly negative relative to hydrogen atom

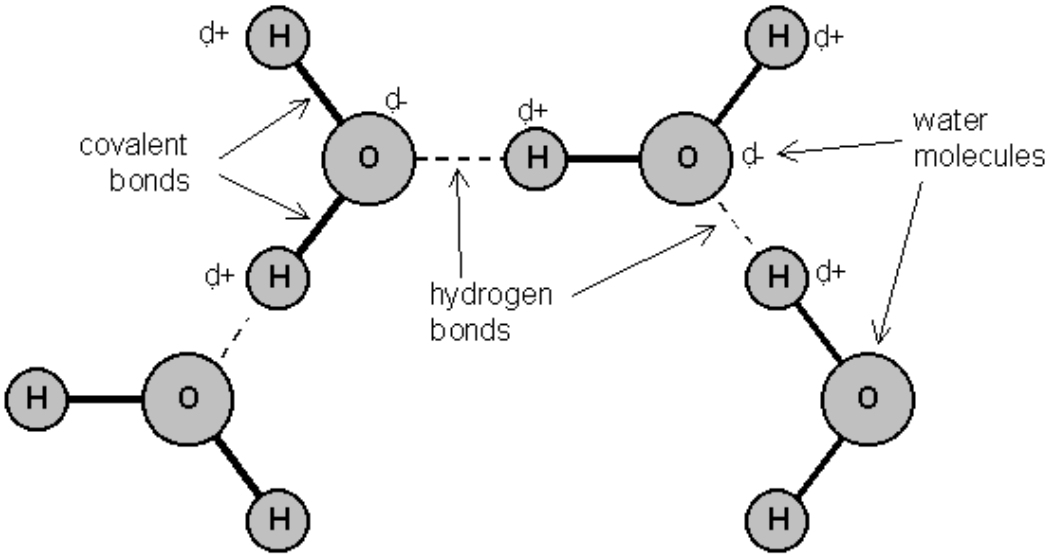


Water molecules therefore have a weak attraction for each other, with the opposite charges coming together and causing them to behave as if they are sticky like magnets. These attractions are not as strong as normal ionic or covalent bonds and are called Hydrogen bonds. They are constantly formed, broken and reformed in water although individually weak their collective effect is responsible for the unusual properties of water

Because of its size, and polarity, water is cohesive, adhesive and denser as a liquid than when it is a solid and absorbs large amounts of heat

Structure of water

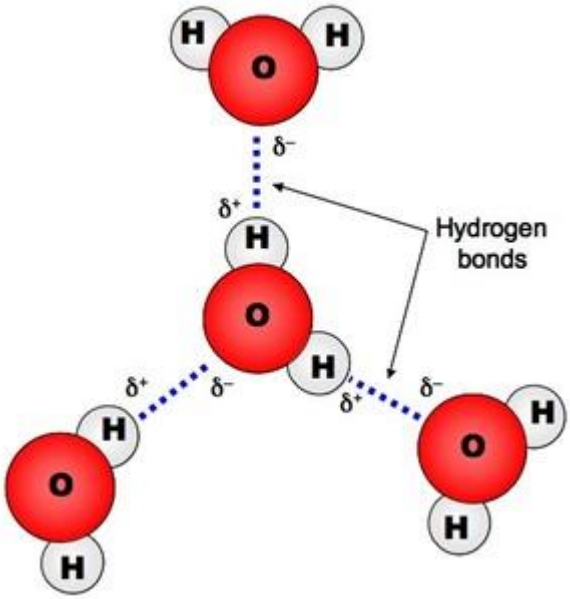
Water molecules are polar (charged), with the oxygen atom being slightly negative and the hydrogen atoms being slightly positive, thus the Oxygen atom tends to attract the single electrons of the two Hydrogen atoms. These opposite charges attract each other, forming hydrogen bonds. Water molecules therefore have electrostatic attractions for each other.



Properties of water that are of biological significance

1) **It is a universal solvent.** This implies that water can dissolve a variety of solutes as it is polar and most solutes are polar.

Consider the structure of a water molecule below;



This makes it an important transport medium in the bodies of living organisms and enables a variety of chemical reactions to occur in living organisms since these reactions occur in solution.

It is able to attract other polar substances, forming Hydrogen bonds with them, thereby dissolving them. Polar molecules such as salts, sugars and amino acids dissolve readily in water and so are called hydrophilic ("water loving"). Uncharged or non-polar molecules such as lipids do not dissolve so well in water and are called hydrophobic ("water hating").

Once any substance is in solution, its ions can freely move about thus making it more chemically reactive than it was as a solid.

The solvent properties of water also mean that it is a transport medium, as it is in blood, lymph, alimentary canal, excretory system, in mammals and Xylem and Phloem in plants.

Non-polar substances such as lipids are immiscible in water and serve to separate aqueous solutions into compartments.

2. **It has a high specific heat capacity**

Specific heat capacity. Specific heat capacity is the amount of heat required to raise the temperature of a kilogram of water by 1^{o}C. Water has a specific heat capacity of 4.2 J g^{-1} $°C^{-1}$, This is unusually high and it

means that water does not change temperature very easily because it requires a lot of heat input to register a temperature rise.

This maintains a constant temperature in living organisms, which live mainly in water in conditions of temperature fluctuations.

This minimises fluctuations in temperature inside cells, and it also means that large water body temperatures are remarkably constant, providing a conducive habitat for aquatic organisms. The chemical processes in organisms operate under a low range of temperature proceeding at normal rates and are less likely to be inhibited by external temperature.

3. **It has a high latent heat of vaporization.** This implies that a lot of heat must be supplied to the water in its liquid state to turn it into the vapour.

   Because the transition of water from a liquid to a gas requires the input of energy to break its many Hydrogen bonds, the evaporation of water from a surface causes cooling of that surface.

   This is made use of as a cooling mechanism (evaporative cooling) in animals (sweating and panting) and plants (transpiration). As water evaporates it extracts heat from around it, cooling the organism.

4. **High latent heat of fusion:**

Latent heat of fusion is the measure of the heat required to change a solid to liquid state at constant temperature. In this case ice with its high heat of fusion requires a large amount of heat to melt down. On the other hand water requires to lose a relatively high amount of heat to freeze.

This is important in that the contents of the cells and their environment are less likely to freeze. Ice crystals are particularly damaging if they develop inside the cell.

This implies that it requires a lot of heat to be removed before freezing occurs.

- It provides a sustainable habitat for aquatic organisms since the habitat does not easily get frozen in cold weather.

- It maintains an effective transport medium of materials in the body since it maintains its liquid form even in the cold weather.

5. **Water has a high surface tension.**

This implies that on the surface of water, strong forces of attraction (cohesion) hold the surface molecules, together. This forms a strong layer that enables aquatic organisms to move on the water.

- The strong cohesion force of attraction in the water molecular maintains the Transpiration steam and aid water movements in plants

Cohesion is a force whereby individual molecules of a substance stick together. Water molecules "stick together" due to their hydrogen bonds, so water has high cohesion. This explains why long columns of water can be sucked up tall trees by transpiration without breaking. It also explains why small animals walk on water.

Surface tension is the force that causes the surface of a liquid to contract so that it occupies the least possible area.

Small insects can walk on water because at the air-water interface all of the hydrogen bonds in water face downward, causing the molecules at the water surface to cling together.

Adhesion. Water is adhesive to any substance with which it can form hydrogen bonds. That is why substances containing polar molecules get “wet” when they are immersed in water, while those that are composed of nonpolar molecules (such as oils) do not.

6. **Low viscosity**

This is a measure of how resistant a liquid is to flowing. The lower the viscosity the easier the liquid flows. Water has a viscosity that is lower than that of ethanol. The ease with which water flows is important in the transport system of living organisms e.g. in blood as it flows through vessels.

- The significance of this property is that water can easily be pumped and moved in the small tubes of the body.
- Water also forms a medium within which swimming is made easy.

If too much water is lost from the body, then the viscosity of blood increases, flow slows and transport is less efficient.

Plants rely on the flow of water in the Xylem and Phloem vessels to transport substances around their bodies. Aquatic organisms too are able to swim in water because of the relatively low viscosity of water.

7. **Transparency**

Pure Water is transparent and this is important for aquatic organisms because it allows light to penetrate to some depth in clear water bodies. This enables growth of green plants and hence other organisms which depend on the plants. The transparency increases visibility for organisms in large volumes of water penetrated by light enabling them to find prey, mates and escape predators.

- Water allows sufficient amounts of light to pass though for the photosynthesis of aquatic organism.

8. **Density of water:**

Anomalous expansion of water i.e. density of water decreases below 4°C evenly forming ice at around 0°C. The ice floats on water leaving the relatively warm water below. This favors survival of aquatic organisms especially those living in temperate regions during winter.

The rising up of cold water over the warmer water also circulates nutrients in large water bodies, resulting into nutrient recycling and colonization of the water body to a greater depth.

9. **Incompressibility**

Water is incompressible. This is the basis of the hydro skeleton that some organisms depend on for both support and locomotion.

10. **pH**

Water itself is partially ionized $H_2O_{(l)} \longrightarrow H^+_{(aq)} + OH^-_{(aq)}$ so it is a source of protons (H^+ ions), and indeed many biochemical reactions are sensitive to pH (-log [H^+]). Pure water cannot buffer changes in H^+ concentration, so it is not a buffer and can easily be any pH, but the cytoplasm and tissue fluids of living organisms are usually well buffered at about neutral pH (pH 7-8).

BIOLOGICAL IMPORTANCE OF WATER TO ALL ORGAANISMS

METABOLIC ROLE OF WATER

i. **Hydrolysis**

Water hydrolyses many substances like proteins to amino acids, fats to fatty acids and glycerol, starch to maltose,

ii. **Medium for chemical reactions**

All biochemical reactions take place in aqueous medium provided by water.

iii. **Diffusion and Osmosis**

It is essential for the diffusion of materials across surfaces such as the lungs or the alimentary canal e.g. diffusion of food materials into the blood stream since such surfaces are moist to facilitate diffusion and the moisture is provided by water.

iv. **Photosynthetic substrate**

Water is a raw material for photosynthesis

WATER AS A SOLVENT

It dissolves other substances and is therefore used in the following ways;

i. **Transport**

Blood plasma, tissue fluid and lymph are all made up of water and dissolve a number of substances which can then be easily transported.

ii. **Removal of wastes**

Metabolic wastes like ammonia, urea, excess salts require water to be removed from the body in solution form.

iii. **Secretions**

They are transported from their place of secretion in solution form (aqueous form) e.g. most digestive juices have enzymes in solution, tears mainly consist of water, snake venoms have toxins in suspension composed of water,…

WATER AS A LUBRICANT

Water' properties especially its viscosity make it a useful lubricant. Lubricating fluids that have a component of water include;

- **Mucus** which externally facilitates movement in organisms like the snail and earthworm or internally in the walls of the gut and vagina
- **Synovial fluid** which lubricates movements in the joints of vertebrates.
- **Pleural fluid** which lubricates movements of the lungs during breathing
- **Pericardial fluid** which lubricates movements of the heart
- **Perivisceral fluid** which lubricates movements of internal organs like peristaltic movement of the alimentary canal

SUPPORTING ROLE OF WATER

With its large cohesive forces, water molecules lie close together due to the hydrogen bonds between them and therefore not easily compressed, making it a useful means of supporting organisms.

i. Hydrostatic skeleton

Animals like earthworms are supported by the pressure of the aqueous medium within them.

ii. Turgor pressure

Herbaceous plants and herbaceous parts of woody plants are supported by osmotic influx of water into their cells.

iii. Humours of the eye

Aqueous and vitreous humors give the shape of the eye and they are mainly made up of water.

iv. Amniotic fluid

It supports and protects the mammalian foetus during development and is mainly made up of water.

v. Erection of the penis

The pressure of blood which is mainly made up of water makes the penis erect for copulation to take place.

vi. Habitat

Water supports organisms that live in it. Very large organisms like whales return to water as their sizes make movement on land very difficult.

Other functions of water

- Medium of dispersal i.e. seed dispersal, gametes and larvae stages of some aquatic organisms
- Seed germination
- Osmoregulation
- Migration of aquatic organisms
- Fertilization, by transporting gametes
- Hearing and balance. The watery endolymph and perilymph in the mammalian ear plays a significant role in hearing and balancing.

ACIDS AND BASES

Acids

A compound which when dissolved in water ionizes to produce hydrogen ions as the only positive charged ions e.g. hydrochloric acid, nitric acid, Sulphuric acids e.t.c.

Note: The strength of the acid is determined by the extent to which it dissociates .e.g. HCl is considered to be a strong acid because it completely dissociates in solution to give hydrogen ions. Whereas ethanoic acid is a weak acid because it partially dissociates in solution

The acidity of the solution is expressed as its negative log concentration of H^+ in moles/litre. A PH of 7 represents neutrality while a pH below 7 represents acidity while that above 7 represents alkalinity or basis.

FUNCTIONS OF ACIDS

- They provide a suitable pH for the proper functioning of enzymes e.g. pepsin
- Acids like hydrochloric acids activate organic substances like pepsinogen
- Acids kill bacteria, which may be ingested together with food

BASE

A base is a compound, which can react with acids to produce a salt and water only. Some bases are alkalis. An alkali on the other hand is a substance which when dissolved in a solvent produces hydroxyl ions as the only charged ions. This implies that alkalis are bases but not all bases are alkaline.

Strong alkali completely ionize e.g.

$$NaOH(aq) \longrightarrow Na^{+}{}_{(aq)} + OH-$$

Weak alkali don't ionize completely e.g. ammonium hydroxide

FUNCTIONS OF BASES

- Provide an optimum pH range for enzyme activity e.g.in the duodenum
- They are buffers in the body

A buffer solution is any substance which resists change in the pH when small amounts of acids or bases are added. Consider the reactions below;

$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$

$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$

from the above equations, it is clear that $NaHCO_3$ removes ions from aqueous solutions thereby lowering the aqueous solutions acidity in so doing it is working as buffer.

However, although sodium hydrogen carbonate works as a buffer on its own, in most cases two or more compounds interact to form a buffer solution or system.

In case of increased acidity, the $NaHCO_3$ combines with free hydrogen ions as shown above if alkalinity is increased, it reacts with free hydroxyl ions to form carbonate ions and water.

$$HCO^-_{3(aq)} + OH^-{}_{(aq)} \longrightarrow CO^{2-}_{3(aq)} + H_2O_{(l)}$$

In the human body, bi-carbonate ions play a minor role as buffers. A more important role is by the appropriate salts e.g. K_3PO_4 Na_3PO_4 etc.

These combine with hydrogen ions to form $H_2PO_4^-$ Di-hydrogen phosphate.

$$H^+{}_{(aq)} + HPO^{2-}_{2(aq)} \longrightarrow H_2PO^-_{4(aq)}$$

Certain organic compounds like proteins and hemoglobin can also accept H^+ and are therefore important as buffer.

Since they occur in higher ions, than the phosphate salts they are even more important than the acids and the bases.

The biological importance of these buffers is that cells and tissues can only function properly at a narrow range of pH, which is usually around neutrality.

Acids and bases also provide rightful pH ranges for certain chemical reactions to effectively proceed in the body basicity.

NB: A number of acids are found in the body and these include

- Nucleic acid -amino acids
- succinic acid –lactic acid
- HCl –Uric acid

MINERAL SALTS

A salt is a compound which is formed when the hydrogen ions in an acid are either partially or fully replaced by a metal ions or NH_4^+eg.

HCL	NaCl, KCl, NH_4Cl
H_2CO_3	Na_2CO_3, $NaHCO_3$
CH_3COOH	CH_3COONa

In the body, some of the most common salts are found in H_2O as salts. The salts are therefore ionic compounds and since they decomposed by electricity, their free ions are able to cost electric currents and they therefore referred to as electric.

The mineral ions in the body can be grouped as major or minor ions depending of their need in the body.

Major/ macro ions are needed fairly in large amounts than minor ions.

Functions of mineral salts (General functions of mineral)

1. They form body structures e.g. the bones, the teeth, etc. Comprise calcium ions, phosphate ions etc. They also form connective tissue and other structures a body.
2. They form body pigments e.g. Hemoglobin contains Iron, cytochromes contain copper and chlorophyll contains magnesium.
3. They form chemicals in the body e.g., Sulphur and Nitrogen form proteins, nucleic acids, ATP etc.
4. They are metabolic activators. Certain ions activate enzymes e.g. magnesium activates enzymes that are involved in phosphorylation of glucose.
5. They are constituents of enzymes e.g. nitrogen in proteins.
6. Constituents of various chemicals e.g. ATP contains phosphorous while thyroxin contains iodine.
7. They are determinants of osmotic pressure. Mineral salts and other solutes determine the osmotic pressure of cells and body fluid. The osmotic pressure must not be allowed to fluctuate beyond narrow limits since much of the physiology is directed to preventing this.

Macronutrients

ELEMENT	***FUNCTIONS***	***DEFFICIECY***
Nitrogen	Nitrogen is a component of amino acids, proteins. Vitamins, co-enzymes, nucleotides and chlorophyll,l Hormones like auxin in plants and insulin in animals.	Chlorosis (yellowing of leaves) and stunted growth.
Phosphorous	Component of nucleotides ATP and some proteins used in phosphorylation on the sugars in respiration. A major constituent of bone and teeth, components of cell membranes in form of phospholipids. They work as buffers mainly in the salt form.	Deficiency of phosphates in plants lead to stunted growth especially of roots and the formation of dull, dark green leaves. In animal's deficiency can result in a form of bone

		malformation called rickets.
Sulphur	Sulphur is a component of some proteins and certain co-enzymes e.g. acetyl co-enzyme A.	Forms important bridge between the polypeptide chains of some proteins giving them their tertiary structure. Deficiency in plants causes chlorosis.
Potassium	Maintain the electrical and anion/cation balance across all membranes. Assists active transport of certain materials across the cell membrane. Necessary for protein synthesis and perspiration. A constituent of sap vacuoles in plants also helps to maintains turgidity.	Potassium plays role in the transmission of nerve impulses.
Calcium	In plants calcium is a major compound of the middle lamella of cell wall and therefore necessary for their proper development, it also aids the translocation of carbohydrates and amino acids. In animals it's the main constituent of bones, teeth and shells. Needed for blood clotting and contraction of muscles.	In animals, its deficiency may cause muscular cramp also common that deficiency is rare.
Chloride Cl^-	It is important for regulation of osmotic pressure. Chloride helps to maintain water balance and pH balance They activate salivary amylase. it is needed for the formation of HCl in gastric juice. Assists in the transport of CO_2 by blood(chloride shift)	In animals, deficiency may cause mussel Its wide spread in soils makes deficiency in plants practically unknown.

	Assist in active transport.	
Magnesium ion Mg^{2+}	A constituent of chlorophyll an activator for some enzymes e.g. ATP one component of bones and teeth	Deficiency in plants leads to chlorosis
Iron Fe^{2+} or Fe^{3+}	A constituent of electron carriers e.g. cytochromes needed in respiration and photosynthesis. A constituent of certain enzymes e.g. dehydrogenase, decarboxylase and Catalase required in breakdown of hydrogen peroxide. Forms part of haem group in respiratory pigments such as haemoglobin haemoerythrin,myoglobin chlorocuoron	Deficiency in plants leads to chlorosis and in animals to anaemia
Micro nutrients manganese Mn^{2+}	/trace elements. Activators of certain enzyme. E.g. phosphates. A growth factor in bone development.	Deficiency in plants produces leaves with grey spots and in animals, bone deformation.
Copper Cu^{2+}	A constituent of electron carried e.g. cytochromes needed in respiration and photosynthesis. A constituent of certain enzymes e.g. dehydrogenase, decarboxylase peroxide and Catalase required in the synthesis of chlorophyll. Forms part of haem group.	
Iodine I^-	A constituent of the hormone thyroxin, which controls metabolism in animals.	Iodine is needed by higher plants. Deficiency in humans causes tension in children as goitre in adults, in some vertebrates it is for metamorphosis.
Cobalt Co^{2+}	Constituent for vit B_{12} which is important in the synthesis of RNA, and red blood cell.	Deficiency causes perinea anaemia

Zinc Zn^{2+}	Development of phosphate gland. An activator of certain enzyme, carbonic amhydrase required in plants for leaf formation the synthesis of iodole acetic acid (auxin) and anaerobic respiration (alcoholic fermentation)	Carbonic vital in the formation of CO_2 in vertebrates deficiency in plants produces and sometimes leaves.
Boron B	Required for the uptake of ca^{2+} by roots. Aids the germination of pollen grains and meiotic cell division in meristem Nitrogen fixation.	Boron isn't required in animals. Deficiency in plants causes --------- and young shoots growth may cause diseases such as cork of apples of beet and cells.
Molybdenum $MO^{4+}MO^{5+}$	Required by plants for reduction of nitrates to nitrites in the formation of anino acids. Essential for nitrogen fixation by prokaryotes uric acid formation. Strengthening of teeth	Deficiecny production in plants yield. Not vital in most animals.

ORGANIC COMPOUNDS AS CHEMICALS OF LIFE

1. **Carbohydrates**

These are organic compounds made up of carbon, hydrogen, and oxygen. They have a general formula of $Cx(H_2O)y$ where x and y are variables. The ratio of carbon atoms to hydrogen to oxygen is 1:2:1. There are 3 main classes of carbohydrates i.e. Monosaccharide, disaccharides and polysaccharides.

Chemically carbohydrates have the following properties;

i. They are either aldehydes or ketones.
ii. They contain hydroxyl groups.

Monosaccharide

They are single sugar units with the general formular of (CH_2O)n where n = number of carbon atoms and has a value between 3 and 9

- They are sweet.
- They are readily soluble in water.
- Their names end with a suffix -ose.
- They are very small molecules.
- They are crystalline.

NATURALLY OCCURRING MONOSACCHARIDES

No. of Carbon atoms in the molecule	Molecular formula	Name of the monosaccharide
3	$C_3H_6O_3$	Triose sugar
4	$C_4H_8O_4$	Tetrose sugar
5	$C_5H_{10}O_5$	Pentose sugar
6	$C_6H_{12}O_6$	Hexose sugar
7	$C_7H_{14}O_7$	Heptose sugar

However, the pentoses and Hexoses are most commonly found in special form of bacteria.

Trioses	Pentoses	Hexoses
glyceraldehyde Dihydroxyacetone	Ribose, Arabinose ribulose	Mannose, galactose, glucose, fructose

Monosaccharide can also be grouped basing on their reducing groups e.g

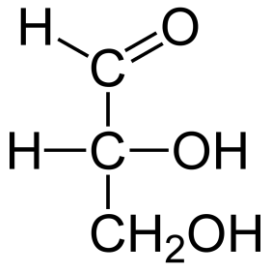
Ketoses (Ketones) e.g dihydoxyacetone

Aldose (aldehyde) e.g glyceraldehyde

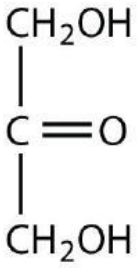
Ketone (Ketones) and Aldoses

The structure of glyceraldehydes

Aldose

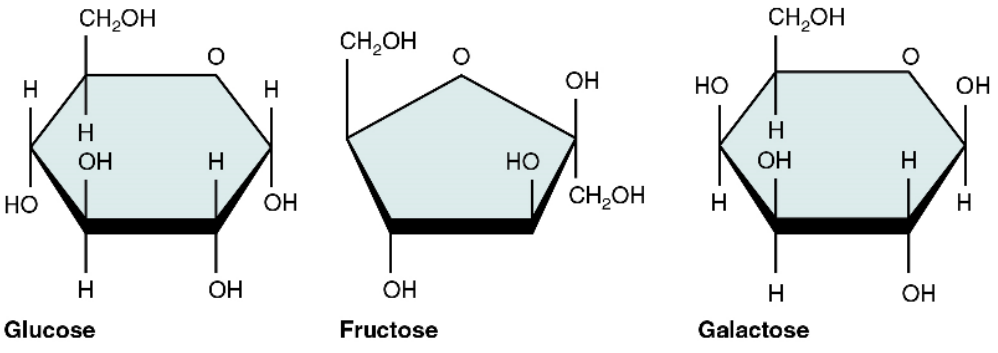


Dihydrocyacetone



NB: The carbon atom with a double bond in Aldehydes is at the end of the chain while in Ketones it is on the second carbon or on the carbon next to last (middle).

Both Aldoses and Ketones are reducing sugars together with a few disaccharides like maltose, lactose that have the capacity to reduce the copper II in copper II Sulphate to insoluble copper (I) oxide.



(a) Hexoses

Ring structures of monosaccharide

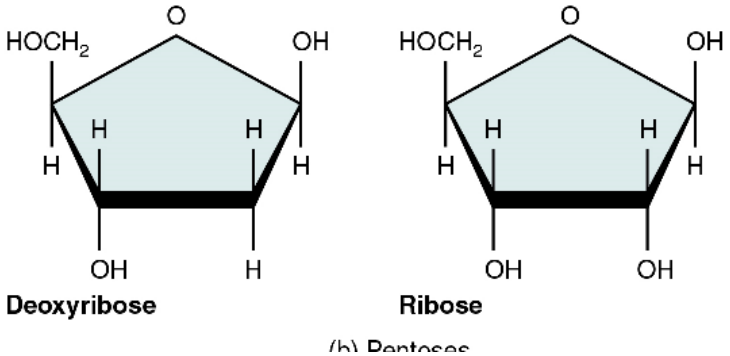
Most pentose and Hexose sugars can exist in rings in addition to their basic straight chain.

There are 2 alternate ring forms i.e. α and β the carbon atom (i) is got from the right hand side connected to carbon atom 5 to give a 6 numbered structure. The structure of α and β differ only in position hydrogen and hydroxyl groups attached to the first atom.

In α, the OH is below the ring while in β above.

ILLUSTRATION OF α AND β GLUCOSE RINGS.

Existence of α and β rings gives a greater chemical verity and helps in building up the complex carbohydrate atom on the 4th carbon atom to give a 5 member ring called fructose ring. In the Hexoses, it is a 6-member ring called pyranose. Consider the ribose ring above.



(b) Pentoses

D-glucose (dextrose or blood sugar) is found in fruits, vegetables, and honey. It is a building block of the disaccharides like sucrose, lactose, and maltose, and polysaccharides such as amylose, cellulose, and glycogen.

Galactose is found in milk and milk products. In a condition called galactosemia, an enzyme needed to convert galactose to glucose is missing. The accumulation of galactose in the blood and tissues can lead to cataracts, mental retardation, and cirrhosis (a chronic liver disease marked by degeneration of cells, inflammation, and thickening of tissue) The treatment for galactosemia is the removal of all galactose-containing foods, mainly milk and milk products, from the diet.

Fructose (fruit sugar), is the sweetest of the carbohydrates, twice as sweet as sucrose (table sugar).

	Sweetness Relative to Sucrose
Monosaccharides	
Galactose	30
Glucose	75
Fructose	175

IMPORTANCE OF MONOSACCHARIDES

Trioses $C_3H_{10}O_5$ e.g glyceraldehydes, dihydroxyacetone are intermediates in respiration, photosynthesis and other branches of carbohydrate metabolism

Pentoses $C_5H_{10}O_5$ e.g ribose, ribulose deoxyribose

i. Synthesis of nucleic acid; Ribose is a constituent of RNA, deoxyribose of DNA.
ii. Synthesis of some co-enzymes e.g. ribose is used in the synthesis NADP and NAD, FAD.
iii. Synthesis of ATP, ADP AMP also requires ribose
iv. Ribulose bis phosphate is the CO_2 acceptor and is made from a 5C sugar ribulose

Hexoses e.g. glucose, fructose, galactose

Source of energy when oxidized in respiration; glucose is the most common monosaccharide

v. Synthesis of disaccharides; two monosaccharide can link together to form a disaccharide.
vi. Synthesis of polysaccharides (pentosanes); glucose is particularly important in this role

Chemical test for monosaccharides

They are all reducing sugars. When heated with standard reagents like Benedict's solution (made up of Sodium carbonate, Sodium citrate and Copper (II) sulphate or Fehling's solution (they give either of

those colours: green, yellow, orange and brown, depending on the concentration of the sugar. Both tests involve the use of an alkaline solution of

$CuSO_4$ (blue in colour) which is reduced to insoluble Cu_2O (Copper (I) Oxide)

$$Cu^{2+}_{(aq)} + e^- \rightarrow Cu^+$$

$$(blue\ soln) \qquad (\text{Brown ppt})$$

Main functions of carbohydrates

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

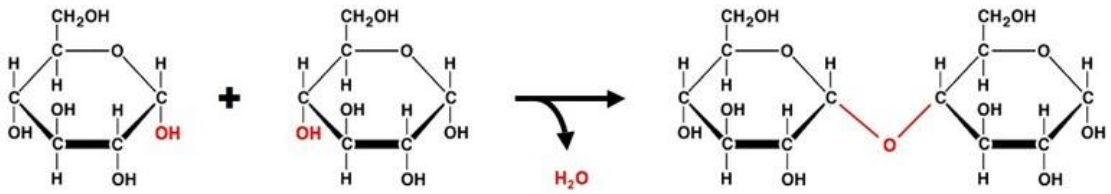
DISACCHARIDES ($C_{12}H_{22}O_{11}$)

These are sugars which consist of two monosaccharide units joining to form a single molecule by condensation reaction. They are sometimes called double sugars. The bond formed between the two molecules is called a glycosidic bond and is normally found between carbon atoms 1 and 4. Disaccharides include maltose, from α glucose + α glucose.

Characteristics

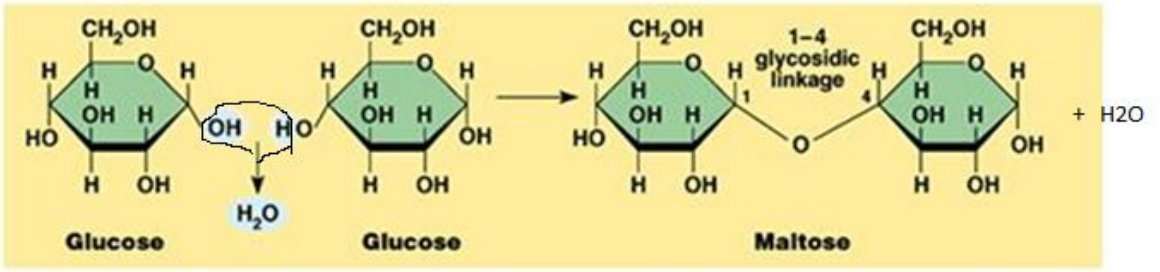
- They are small molecules with a low molecular mass
- They are readily soluble in water
- Have a sweet taste
- They exist in crystalline form
- They are made by combining two monosaccharides in a condensation reaction

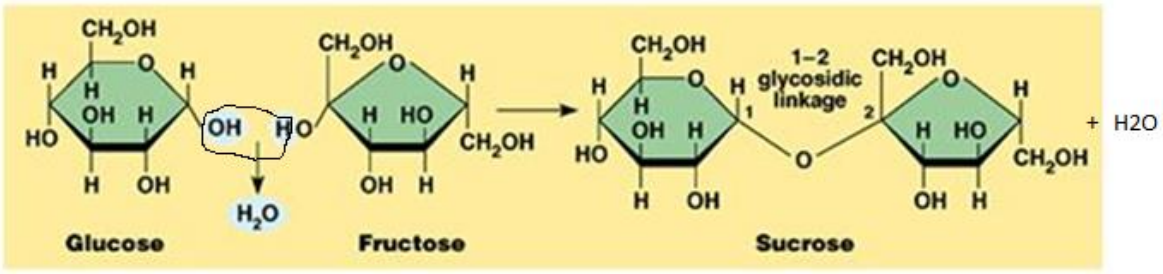
The equation for disaccharide formation (maltose) is below.



α-Glucose α-glucose maltose

Synthesis of a disaccharide





The bond formed between two monosaccharides is known as a glycosidic bond. It usually forms between the 1st and 4th neighbouring carbon units.

Examples of Disaccharides

The most common disaccharides are:

Maltose: which is formed by a combination of two glucose molecules

Lactose: formed from glucose and galactose

Sucrose: formed from glucose and fructose

The main natural sources of these disaccharides are:

Maltose:

Action of amylases on starch during digestion in animals

Germinating seeds

Lactose:

Found in milk, hence called the milk sugar

Sucrose:

Translocated in large amounts through the phloem of plants tissues e.g. sugar cane, beets.

Chemical test for disaccharides

Maltose and Lactose are reducing sugars and have the same chemical test as monosaccharides.

Sucrose is non-reducing and so it must be first hydrolised to its constituent reducing sugars, to give a positive test in Benedicts' or Fehling's solution.

A solution with a non-reducing sugar is hydrolised by boiling it with a dilute acid for about 2 minutes followed by a base to neutralize the acid. After hydrolysis, the Benedicts' test is carried.

How is the sweetness of sugar determined?

FUNCTIONS OF DISSACCHARIDES

i. They are food reserves in organisms and when they are hydrolysed to monosaccharide and used in cell metabolism.
ii. Storage materials in some plants like sugar canes.
iii. They are energy reserves.
iv. They are the main forms of transport of organic substances in the phloem. Sucrose is particularly important as the main form of transport of organic solutes in the phloem. This is because sucrose is soluble but metabolically inert hence does not cause an osmotic pressure in plant cells. Glucose is not transported because it's soluble and metabolically active hence causing an osmotic potential in plant cells which can affect the movement of water in plant cells.
v. Lactose, also called milk sugar, is the nutritional source of energy for infants during nursing. Lactose makes milk taste sweet and is an ingredient in many processed foods that contain dairy such as breads, cookies, cakes, doughnuts, breakfast bars and ice cream.

NB: Starch is hydrolysed in plants to maltose so as; -

i. To be transported easily because it's soluble in water.
ii. Maltose is less reactive hence won't be used.

POLYSACCHARIDES ($C_6H_{10}O_5$) n (not sugars)

These are formed as a result of the **condensation** of many monosaccharide units to form chains.
They are complex carbohydrate with a large number of molecules consisting of chains of monosaccharide units. They are normally used for food storage because; -

i. They can be easily hydrolysed to sugars when required for production.
ii. They fold into compact shapes which cannot diffuse out of the cells.
iii. They exert no osmotic or chemical influence on the cell.
iv. They have large sizes that make them insoluble in water.
v. They are non diffusible i.e. they don't leave sites of storage
vi. Making structures compact e.g. cellulose.

The monosaccharide polymer may be branched, unbranched or coiled. In cells they exist as granules or grains.
Most polysaccharides are formed from the hexose sugars and have a general formula: $\left(C_6H_{10}O_5\right)_n$ where n is greater than 40.

COMMON TYPES OF POLYSACCHARISES

1. Starch

It is a main food storage form of plants and it is a polymer of α glucose it exists as grains in the cells. It is mainly found in seeds, leaves and tubers.
It comprises of amylose 20 to 30%, Amylopectin 70 to 80% together with other substances (1%) e.g. phosphate. the polymer is a straight chain joined by 1,4 glycosidic bonds and the branches involve 1, 6 glycosidic bonds. It has a straight chain component called amylose and a branched chain component called amylopectin.
The main difference between the two is that amylose has a straight chain structure (unbranched) made up of between 200 – 1000 glucose residues linked by only α 1,4 glycosidic bonds whereas amylopectin is branched forming 1,6 glycosidic bonds. The molecule takes the form of a helix. Because of its tightly packed structure (it takes up less space than amylopectin), amylose is more resistant to digestion than other starch molecules.

Amylopectin is soluble and contains from 2000 to 200,000 α-glucose units per molecule.

These components are coiled to form a helix. In this helix, the ¯ OH group points into the interior and they are not free to take part in its bonding. For this reason, there are no cross linkages in starch. It is therefore not strong enough to form structured polysaccharides like cellulose.

Starch is a storage polysaccharide of plants and is normally stored in form of large molecules called starch granules because it can't diffuse out of cells and has little or no osmotic effects.

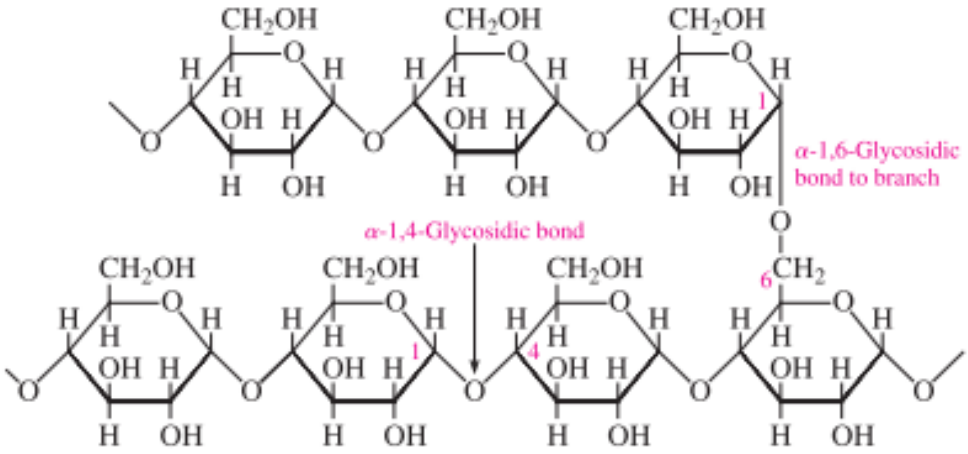
N.B

Amylopectin is a soluble molecule that can be quickly degraded as it has many end points onto which enzymes can attach. In contrast, amylose contains a straight chain. This causes amylose to be hydrolyzed more slowly, but have higher density and to be insoluble.

STRUCTURE OF AMYLOSE

(a) Unbranched chain of amylose

STRUCTURE OF AMYLOPECTIN



(b) Branched chain of amylopectin

Differences between amylose and amylopectin

Amylose	Amylopectin
Stains blue with iodine	Stains red-purple with iodine
Has an RMM, maximum 50,000	Has a high RMM up to 500000
Has between 200 to 3,000 glucose units	Has between 2,000 to 200,000 glucose units
Has unbranched helical chain	Has branched chain between glucose unit 24 and 30
Has 1,4 but lacks 1,6 glycosidic bonds	Has both 1,4 and 1,6 glycosidic bonds
Has 20 to 30% composition in starch molecule	Has 70 to 80% composition in starch molecule

GLYCOGEN (ALSO FOUND IN FUNGI)

It is the animal equivalent of starch, being a storage polysaccharide made from α-glucose.

It is a storage polysaccharide mostly found in animal cells and fungi. It comprises of α-glucose monomers. It is more profusely branched compared to amylopectin. It has a molecular structure similar to that of amylopectin.

It is mostly stored in the liver and muscles that provides a useful energy reserve.

Glycogen is more soluble in water than starch and in the cytoplasm it exists as tiny granules.

CELLULOSE

This is the most abundant molecule on earth virtually confined in plants although it is found in some invertebrates and ancestral fungi. This consists of approximately 10,000 β- glucose units. It is very stable due to possession of many cross linkages. It is hardly digested by organisms i.e. only a few bacteria and protozoans can digest it. The chains of β- glucose are unbranched but with many cross linkages between chains which are parallel. It contains 1, 4 glycosidic bonds. It is found in cell walls where it has strengthening role .it forms 50% of the plant cell wall but in cotton it makes 90%.

It consists of straight chains of molecules which project both sides of the chain at alternative positions i.e. alternating heads up and tails down.

Shape of the cellulose molecule

Chains of β-glucose associate in groups of 60 - 70 to form microfibrils. The chains in microfibrils are held together by lignin, which is composed of amino acids and sugars. Microfibrils associate in groups to form macrofibrils.

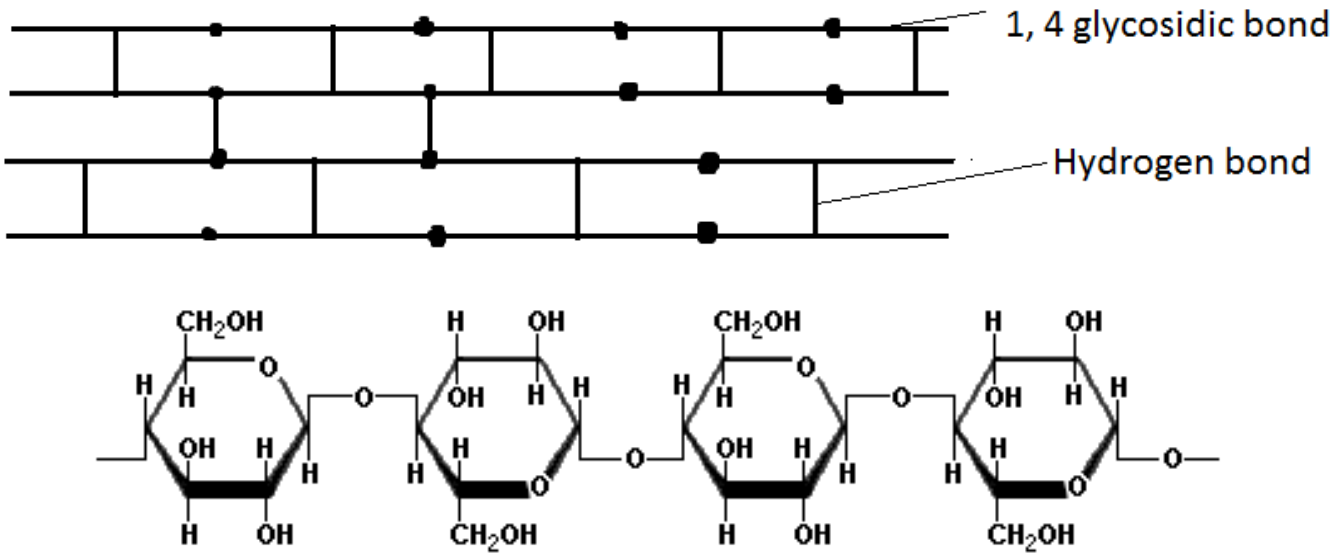
The microfibril and the macro fibrils are held together by hemicellulose that gives them great tensile strength. It consists of straight chains of molecules which project both sides of the chain at alternative positions i.e. alternating heads up and tails down.

The plant cell wall is permeable to water because the matrix has minute water channels through which diffusion occurs. Salts, sugars, and other polar molar molecules can easily disuse through these minute channels. Cellulose is hydrophilic and this makes the cell walls always saturated with water.

The structural properties of cellulose combine the strength of glycosidic bonds and hydrogen bonds to make cellulose such a strong polysaccharide suitable for conferring strength with the cell walls of plants. Further strength is usually provided by the combination of cellulose with Calcium pectates especially in the middle lamella.

The pectates are formed from pectins which are a group of polysaccharides made up of galactose found in the cell walls.

Structure of cellulose showing Hydrogen bonds and cross- linkages.



NB: Lignin is a polymer of amino acids and various sugars and is deposited in spaces between cellulose making cellulose rigid and fairly waterproof. This makes the protoplasm of such lignified and the whole process is referred to as lignification.

USES OF CELLULOSE

- It is commercially used for manufacture of paper, plastics, tyre cords, cellophane, and in making packaging materials.
- It is a constituent of cotton.
- It is food for some bacteria, protozoon.
- Celluloids are used in photographic films and cellulose derivatives.

COMPOUNDS CLOSELY RELATED TO POLYSACCHARIDES

CHITIN (β-Glucose monomers with amino acids group attached)
The chemical structure and nature of chitin is like that of cellulose but the OH group is replaced by aminoacyl group ($NHOCCH_3$). Carbon 2
Its major structural function is to form exo-skeleton of insects as well as crustaceans. It is also found in fungi

INULIN (α-fructose)
This is a major storage form of carbohydrates in plants like Dahlia (Jerusalem artichoke). It is a polymer of fructose molecules. It comprises 1,2 glycosidic bonds and has unbranched chain of fructose molecules.

PECTIN (galactose and galactonic acid residues)
This is a major component of the middle lamella of plants cell and its major role is to provide strength in structures where it is found

HEMICELLULOSE (Pentose Sugar and Sugar Acids)
This material binds microfibrils in chitin forming microfibrils. Its major role is to provide strength

MUCO POLYSACCHARIDE
This material is a lubricant. It is found in connective tissues of vertebrates and it comprises monomers of sugar, which are condensed with amino acids.

LIGNIN

Chemically, it resembles mucopolysaccharides. It is a polymer formed from sugars and amino acids. It is rigid involving chain molecules which are condensed and it binds cellulose chains to form microfibrils.
Lignin impregnates the cell walls of water transporting tubes (xylem) to forma an impermeable lining, a process called lignification.
It also prevents rot, infections and decay.

Carbohydrates have a variety of structural features which account for the wide variety of polysaccharide formed and these include:

- Both pentoses and hexoses can be used to make polysaccharides though normally one type of monosaccharides is used in each polysaccharide type like hemicellulose, nucleic acid sugars may be aldoses and ketoses.
- Capacity to form 1, 4 and 1, 6 glycosidic bonds are common between sugar units e.g in cellulose. This accounts for the case of branching and hence formation of different types of polysaccharides.
- Capacity to form chains of various length and branching
- Existence of alpha and Beta forms of monosaccharide account for the variation of polysaccharides e.g. starch, alpha glucose monosaccharide while cellulose made of beta glucose units.
- Sugars may be Ketoses or aldoses, these increase the polysaccharide variation like inulin is made of Ketose monosaccharide units while starch and glycogen are made of aldose monosaccharide units.
- The high chemical reactivity of sugar and OH groups and their variation in exposure increases polysaccharide variability.

Chemical tests for polysaccharides

Starch

The iodine test is the standard test for starch. Addition of Iodine to a starch containing substance results to a blue-black colour and absence of starch is manifested by the colour of Iodine remaining unchanged.

Cellulose

The chemical test for cellulose is using the Schultz solution which when added to a cellulose containing substance turns violet in colour. An alternative test would be conc. Sulphuric acid and Iodine and if the substance contains cellulose, a bright blue colour is observed.

Glycogen

It turns violet with Iodine solution.

A suspension of Amylopectin in water also gives a violet colour with Iodine solution

LIPIDS

They are larger groups of organic compounds like carbohydrates. They contain carbon, hydrogen and oxygen but the proportion of oxygen in lipids is small.

Lipids include natural fats which are solid at room temperature and oils (liquid at room temperature).
They are insoluble in water but soluble in organic solvents. The solubility is from the fact that they have a low oxygen content. i.e. the number of polar OH groups are few. It is those that normally confer solubility in water to the carbohydrates.
They are made up of glycerol molecule onto which 3 fatty acid molecules are combined in a condensation reaction. The combination forms a triglyceride (lipid molecule) as well as 3 water molecules

Characteristics of lipids.

1. They are made up of carbon, hydrogen and oxygen. They are composed of 3 fatty acids and glycerol (3 -CH_3 groups). The general formula of glycerol is $C_3H_8O_3$. The fatty acids contain the carboxylic acid carboxyl group (-COOH) and a hydrocarbon group.

2. They have a high proportion of hydrocarbon groups in their molecules.

3. They are insoluble in H_2O but soluble in organic solvents e.g. benzene and chloroform, alcohol. This is because lipids have a low O_2 and the numbers of polar hydroxyl groups are few and this decreases their solubility in H_2O.

4. They are either solids (fats) or liquids (oils) at room temperature.

5. The higher the proportion of unsaturated fatty acids, the lower will be their melting points.

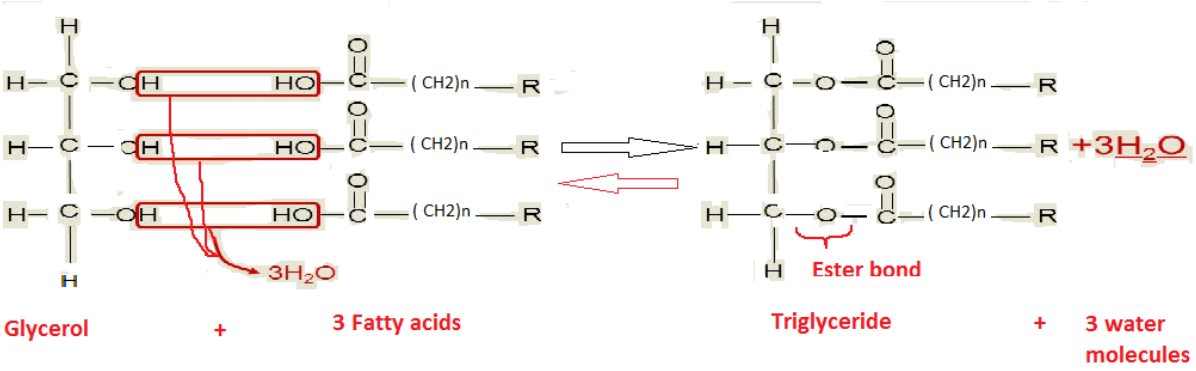
6. They are non-polar and this makes them effective storage materials. They are less dense than H_2O and this helps the aquatic organism to float on H_2O.

7. They have a functional group -COOH composed of fatty acids glycerol.

FORMATION OF LIPIDS

In the formation of lipids, 3 fatty acids and one glycerol molecule combine to form a triglyceride accompanied by removal of 3 H_2O molecules and formation of 3 ester bonds.

The fat or oil formed depends on the fatty acid involved i.e. they could be saturated or unsaturated as shown below.



Lipids are better storage compounds than carbohydrate because;

- More energy is produced when they are oxidized i.e. they have a high calorific value.
- Relatively more stable than carbohydrates.
- Compact hence taking little space
- Insoluble in water and so do not dissolve away
- They are light (have low density) which minimizes weight especially of aquatic animals. This contributes to buoyancy of aquatic organisms like whales and seals.

FATTY ACIDS

Fatty acids occur as saturated or unsaturated

Unsaturated fatty acids are ones where the hydrocarbon part contains one or more double bonds like in linoleic acid and oleic acid. The saturated don't contain double bonds. The saturated fatty acids have a high boiling or melting points compared to the unsaturated of the same molecular mass.

Fatty acids	*Formula*	*Saturation*	*Sources*
Linolenic acid	$C_{17}H_{31}COOH$	Unsaturated	Vegetable oil
Linoleic acid	$C_{17}H_{31}COOH$	Unsaturated	Sunflower oil
Oleic acid	$C_{17}H_{33}COOH$	Unsaturated	Olive oil
Palmitic acid	$C_{15}H_{31}COOH$	Saturated	Palm oils
Stearic acid	$C_{17}H_{35}COOH$	Saturated	Adipose fats
Arachidonic acid	$C_{19}H_{31}COOH$	Unsaturated	Meat, eggs, fish
Lauric acid	$C_{11}H_{23}COOH$	Saturated	Coconut oil

LIPIDS AND THE DIET

There are two groups of fatty acids;

a) Essential fatty acids

They cannot be synthesized in the body. Therefore, they have to be obtained from the diet. Their deficiency results into retarded growth, reproductive deficiency and kidney failure. These are **alpha-linolenic acid** (an omega-3 fatty acid) and **linoleic acid** (an omega-6 fatty acid).

b) Non-essential fatty acids

The body synthesizes some fatty acids and they are synthesized from compounds of protein and carbohydrate metabolism.

N.B

1. Carboxylic acids have two ends; the alpha end (-COOH) and the Omega end (CH_3) and so Omega -3 fatty acids have a double bond on carbon number 3 and omega 6 have the double bond on carbon number 6.

2. Gram per gram, fat stores more energy than glycogen. The C - H bonds of fatty acids make them a richer source of chemical energy than glycogen, because glycogen has many C - OH bonds. i.e. glycogen has more Oxygen molecules than fat. Therefore, nearly all animals use fat in preference to glycogen for long-term energy storage.

FUNCTIONS/ IMPORTANCES OF LIPIDS.

Physiological functions

i) They are energy sources and stores and so they yield a lot of energy when oxidized. i.e. they have a high calorific value than carbohydrates of similar molecular mass. i.e. 1g of lipids yields 38kJ (9k) calories 1g of carbohydrates yields 17kJ (4 kCal.)

ii) They provide a lot of metabolic water to desert animals when oxidized e.g. in camels where they are heavily deposited in the hump and also developing birds and reptiles while enclosed in their shells.

Structural functions

iii) Lipids are insulators since they are poor conductors of heat. In animals, they are found below the skin. They are mostly found in animals living in cold climates and aquatic mammals with very thick subcutaneous fat (also called BLUBBER in seals and whales)

iv) They are constituents of the plasma membrane when they combine with phosphoric acids to form phospholipids.

v) They form a component of the waxy cuticle of plants and arthropods hence water proofing the organisms and thus reducing water loss since they are insoluble in water

Protection

vi) They cushion delicate body organs and protect them from physical damage. They also absorb shock since they are packaged around these organs.

Other functions

vii) Buoyancy function in that they help the aquatic organism to float and the oils on bird feathers help the aquatic varieties to float.

viii) Formation of plant scents for attracting insects for pollination

ix) Formation of bee wax for constructing and repairing honey combs

x) Storage of fat soluble vitamins (A, D, E and K)

LIPID DERIVATIVES

WAXES:

These are made of ester bonds by linking one fatty acid+ a long chain of alcohol. Instead of glycerol.

Waxes are used as water proof material by plants and animals. They are also used as additional protective layers on the surface or epidermis of some plant organs like leaves.

They make exoskeletons of arthropods and bee wax is a constituent of the honeycomb of bees.

PHOSPHOLIPIDS (LIPIDS WITH PHOSPHATE).

They are components of the cell membrane. They are made up of two molecules of fatty acids linked to a molecule of glycerol as in fats. But the third position is occupied by a phosphate group.

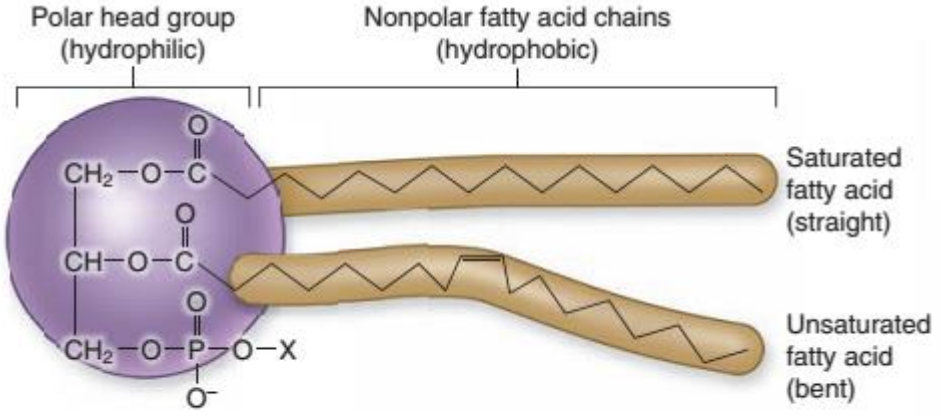


Figure 30: A Phospholipid Molecule

The molecules consist of a phosphate head and two hydrocarbon tails (fatty acids). The polar ends of the molecule being soluble enter the water while the insoluble hydrocarbon chain project out wards at right angles to the surface. This property of the phospholipids is important in determining the structure and functions of the cell membrane.

GLYCOLIPIDS

They are lipids with a carbohydrate attached by a glycosidic bond. Their role is to serve as markers for cellular recognition. The carbohydrates are found on the outer surface of all eukaryotic cell membranes

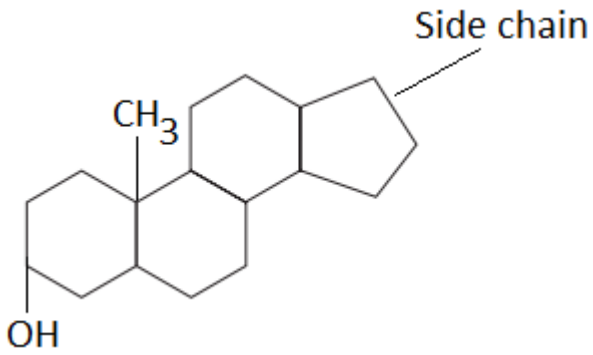
LIPOPROTEINS

This forms part of the cell membranes and it is the chemical form in which lipids are transported.

STEROIDS

These are lipids whose molecules contain 4 rings of Carbon and Hydrogen atoms. Three of the rings are six numbered and one of them is five numbered. All together there are 17 carbon atoms, six of which are shared between the rings and they are saturated hydrocarbons. They cannot be hydrolysed. Some are formed by the smooth ER of cell membranes

The structure of cholesterol



EXAMPLES OF STEROIDS	***FUNCTION***
i. Cholesterol	It's a major component of cell membrane and it's a raw material for many other steroids but it is absent in plants
ii. Bile acids (e.g. glycolic acid)	They form bile salts, which emulsify fats during digestion.
iii. Adrenal corticosteroids	These are hormones produced in the cortex region of the adrenal gland, important in coordination, especially in stress responses.
iv) Sex hormones like Oestrogen and progesterone in females and	They are reproductive hormones in females which regulate the menstrual cycle and control

	testosterone in males	pregnancy. In males Testosterone controls sexual behavior and spermatogenesis.
v)	Calciferol (Vitamin D)	It promotes calcium and phosphate absorption and metabolism
vi)	Ecydsone.	It's a hormone responsible for ecdysis (moulting in insects / shedding off of the exoskeleton) to allow growth.

TEST FOR LIPIDS

1. ***Ethanol test. (emulsion test)***

To $1cm^3$ of food substance add 5 drops of ethanol then add 3 drops of distilled water and shake.

Observation

Presence of lipids is shown when the colourless solution turns to a creamy milky emulsion.

Absence of lipids is when the colorless solution remains clear or when no emulsion appears.

2. ***Sudan (III) Reagent***

To $1cm^3$ of the lipid in the test tube is added 3 drops of Sudan (III) reagent and shake the mixture. Leave to mixture to stand for 2 minutes. The oil layer which settles at the top is red in colour and water beneath remains this indicates presence of lipids.

Translucent paper mark test.

If a drop of a liquid is smeared on a piece of paper and later the spot dried. A translucent mark will remain on the paper suggesting that lipids were present in the smeared drop.

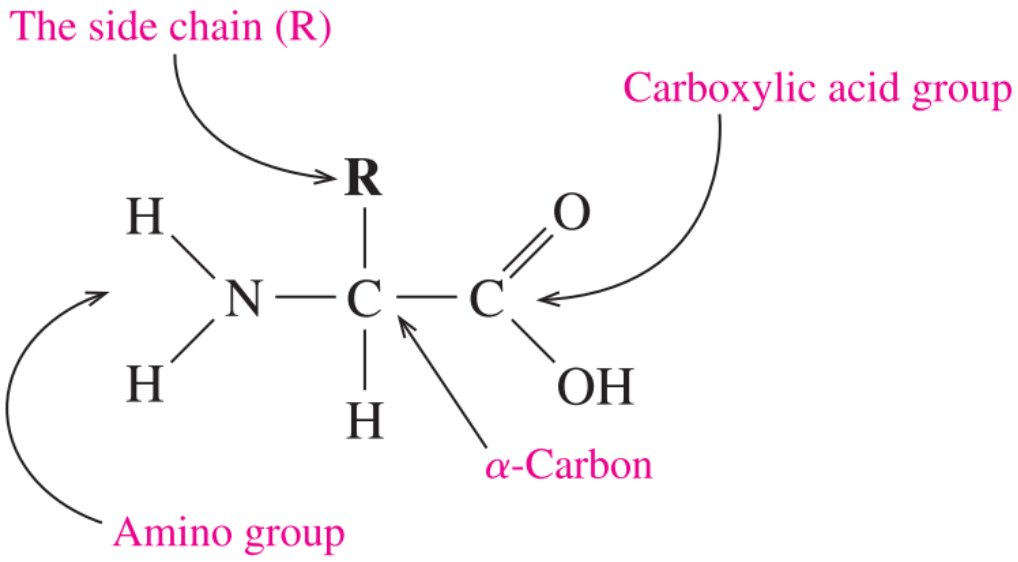
PROTEINS

Proteins are complex organic compounds of large molecular mass made up of small units called amino acids. They are composed mainly of carbon, hydrogen, oxygen, and nitrogen and sometimes Phosphorous and Sulphur. The variety of proteins is unlimited because the sequence of amino acids in each protein molecule which is genetically determined by DNA within cells during protein synthesis.

The structural diversity of proteins enables them provide a range of structural and metabolic activities within the organisms. The number of amino acid sub-units may range between several thousands to millions e.g. β-lactoglonin found in milk has a molecular formula of $C_{1642}H_{2652}O_{492}N_{420}S_{18}$

AMINO ACIDS

GENERAL STRUCTURE OF AMINO ACIDS



Proteins are built from amino acids and there are over 100 naturally occurring amino acids of which 20 commonly occur in proteins. General formula $RCHNH_2COOH$

All amino acids have an amino group ($-NH_2$) and a carboxyl group (-COOH).

Majority of amino acids possess one acidic or carboxylic group and one basic or amino group and hence they are termed as neutral amino acids.

However, in some cases there may be more than one amino group present, giving rise to basic amino acids or more than one carboxylic group giving rise to acidic amino acids.

Amino acids differ in the nature of the R- group and it is responsible for the unique properties they display.

The simplest amino acid is glycerine where the R –group is H- atom. In alanine, the R –group is CH_3 and when R is substituted with C_3H_7, the amino acid formed is Valine

PROPERTIES OF AMINO ACIDS

They are colourless crystalline solids

- They are generally soluble in water but insoluble in organic solvents

- They are amphoteric in nature i.e. possess both basic and acidic groups.

They can donate a proton like acids and also accept protons like bases.

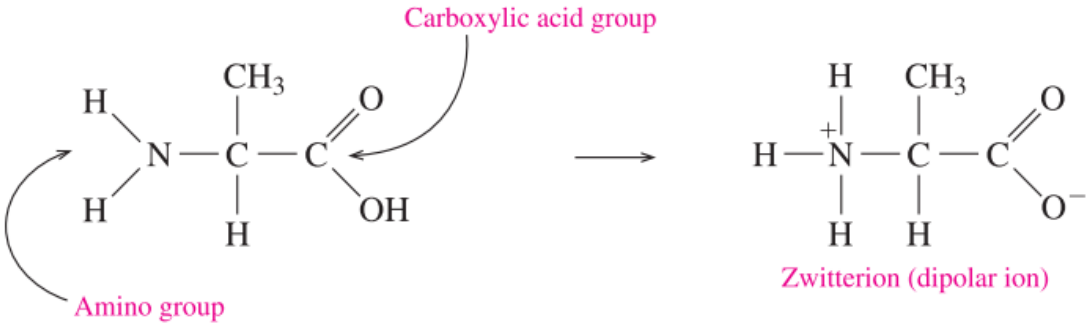
The amphoteric nature is used biologically in PH buffering in body solutions. They do this by accepting protons as PH decreases and donating protons as PH increases, so that the PH is kept optimum or near neutral.

AMINO ACIDS AS BUFFERS

Amino acids are amphoteric because they have both basic and acidic properties. The acidic property is derived from the carboxyl group (-COOH) which donates a proton (H^+) so that the molecule becomes negatively charged

The basic property is derived from the amino group ($-NH_2$) which can take up a proton so that the molecule becomes positively charged therefore the amino acid carries a (+) amino group and a (-) carboxyl group which qualifies it to be a dipolar substance And because of the above property the amino acid buffer solutions.

In this form, they form Zwitterions.



CLASSIFICATION OF AMINO ACIDS

The 20 common Amino acids are classified as essential or non-essential. The essential amino acids are important in the body but cannot be synthesized by body or their rates of synthesis are not sufficient to meet the body needs. They have to be got from the diet.

Essential amino acids include:

1. Lysine
2. Histidine
3. Isoleucine
4. Methionine
5. Tryptophan
6. Arginine

7. Thiamine
8. Leucine
9. Valine
10. Phenylalanine

NB: Histidine and Arginine are only essential in children.

Foods containing all the amino acids are known as first class proteins and they include all animal proteins and some plant proteins. Foods lacking one or more amino acids are second class proteins.

NON-ESSENTIAL AMINO ACIDS

These can be synthesized in sufficient amounts in the body of animals and therefore are not required in diet. They are as useful as the essential amino acids and absence of one or more results in retarded growth. The process of synthesis of amino acids involve a process called **Transamination** which is carried out by transaminase enzymes.

The raw materials for the process are the essential amino acids provided in the diet and carbohydrate derivatives (keto- acids) like the intermediate compounds of carbohydrate metabolism e.g. Pyruvic acid.

Non-essential amino acids include:

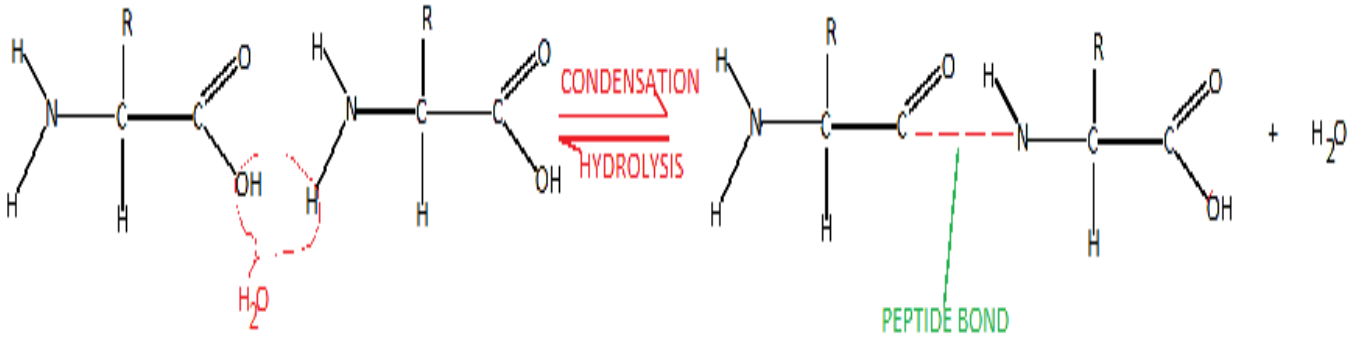
1. Glycine (R is -H)
2. Alanine (R is -$CH_{3)}$
3. Aspartic acid (R is -CH_2COOH)
4. Asparagine
5. Proline.
6. Glutamic acid
7. Cysteine(R is -CH_2-S-H)
8. Serine
9. Tyrosine
10. Glutamine.

BUILDING UP OF PROTEINS

Amino acids combine to form dipeptides by condensation reaction, releasing water molecules and forming peptide bonds.

The first step involves the combination of two amino acids. A reaction occurs between the amino group of one and the carboxylic group of another. A molecule of water is removed i.e. condensation.

Continued condensation leads to the addition of more amino acids resulting into the formation of a long chain called a polypeptide. It is illustrated below.



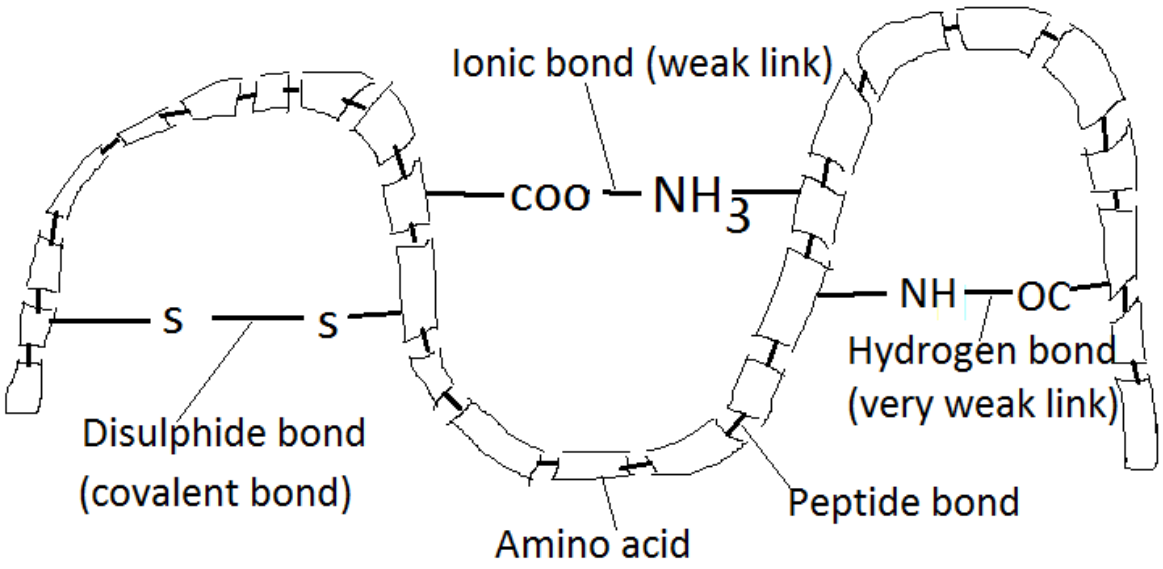
A protein may consist of several polypeptide chains which may be straight, folded, branched or cross linked at intervals.

Apart from the peptide bonds, amino acids are able to form a variety of other chemical bonds with other reactive groups and this is what leads to further elaboration in the polypeptide chain to form a protein.

LINKAGES IN POLYPEPTIDES

i. Disulphide bonds.
ii. Ionic bonds.
iii. Hydrogen bonds.
iv. Hydrophobic bonds

illustration



1. IONIC BOND

At a suitable pH, an interaction may occur between joined amino acid and a carboxylic group and the result is the formation of an ionic bond.

Ionic bonds give a polypeptide molecule its particular shape. These bonds are relatively weaker than covalent bonds.

2. Disulphide bonds

Some amino acids have a Sulphur group on the R-Group. When 2 molecules with a Sulphur group are lined up alongside each other, the S-H groups are oxidized to form a disulphide bond e.g. in when cysteine amino acids come together.

The disulphide bonds make the molecule fold into a particular shape such that these molecules are strong and not easily broken.

The bonds can be formed between different amino acids or between different parts of the same amino acid chain.

Disulphide bonds are very strong.

3. HYDROGEN BOND

When hydrogen is part of the P-H / N-H groups taking part in a reaction, it becomes slightly positive charged and is therefore attracted to the negatively charged neighbouring oxygen atom. The hydrogen bond is very weak but plays a role in maintaining the shape and stability of the polypeptide molecule

4. HYDROPHOBIC INTERACTION

Within a polypeptide chain, hydrophobic interactions or bonds can be registered. They arise in situations where the R-groups are non-polar and therefore hydrophobic. The polypeptide chain will tend to fold so that the maximum number of hydrophobic groups come into close contact and exclude water. This is how many globular proteins fold up. The hydrophobic groups tend to point inwards towards the centre while the hydrophilic groups face outwards in the aqueous environment making protein soluble. They are also weak bonds.

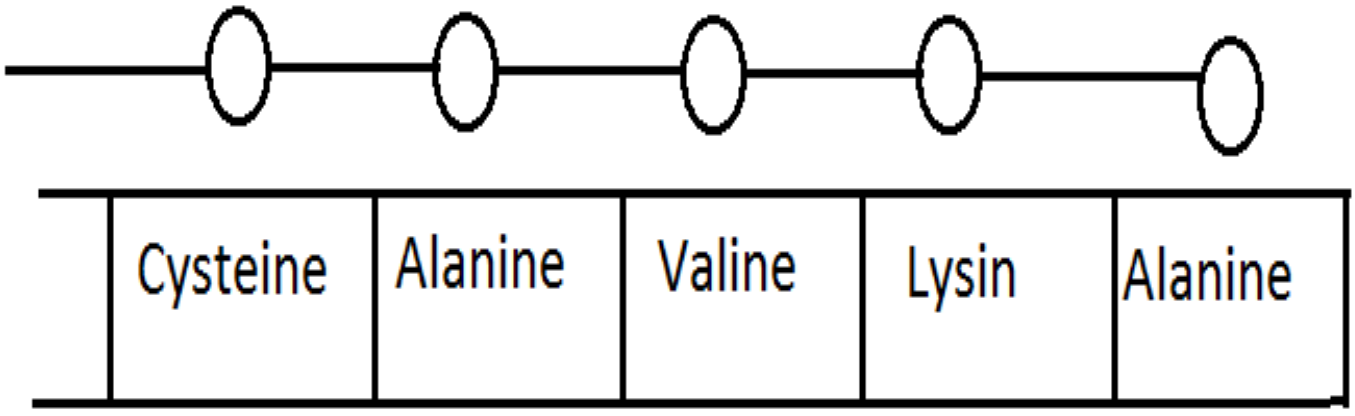
Classification of proteins

Proteins can be classified according to structure, composition and function.

According to structure proteins are classified into the following

Primary structure

This structure shows the number and sequence of amino acids in the protein molecule, held together by peptide bonds in a polypeptide chain. It is determined by the specific DNA sequence of that protein. E.g. the primary structure of Myoglobin is composed of a single polypeptide chain of 153 amino acids, the haemoglobin molecule is made up of **four** polypeptide chains: **two** alpha chains of **141** amino acid residues each and **two** beta chains of **146** amino acid residues each. The alpha and beta chains have different sequences of amino acids, but fold up to form similar three-dimensional structures

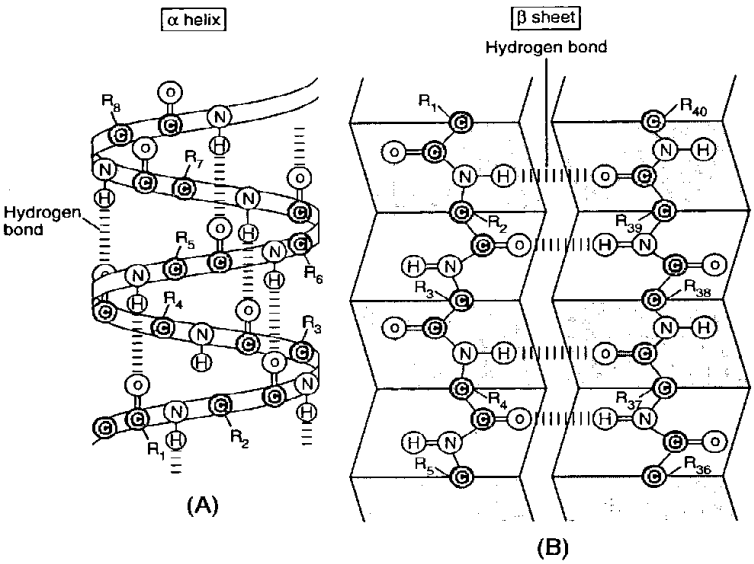


SECONDARY STRUCTURE

This refers to the coiling or folding up of the polypeptide chain of a protein into a helix structure, maintained by Hydrogen bonds formed between adjacent CO- and -NH groups (NH------OC) along the chain. start

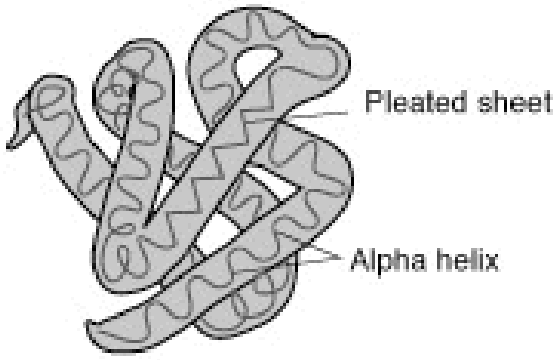
The chain could be made of α-helixes or β- pleated sheets. The Hydrogen bonds in the chain stabilize the helix.

Structure of alpha helix



TERTIARY STRUCTURE

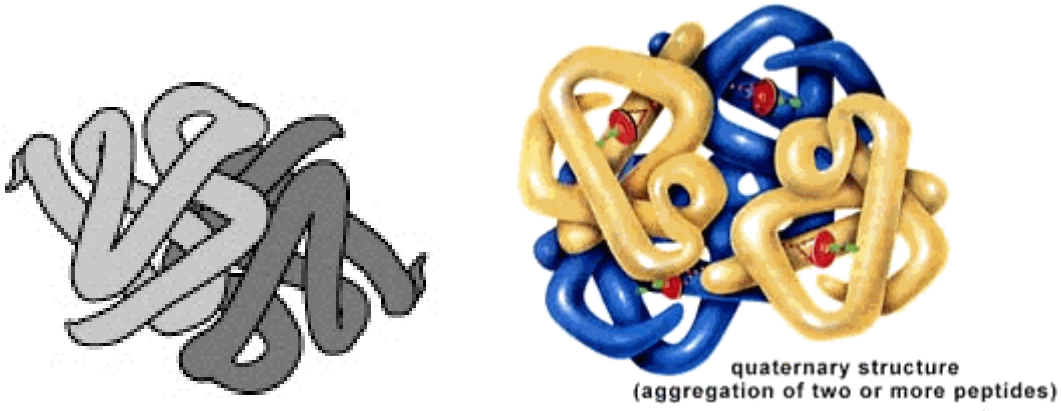
This is how the helically coiled chains are folded to form compact shapes. It is due to the bending and twisting of the polypeptide helix (secondary structural helix). This results in the formation of cross linkages which are maintained by the interaction of 3 types of bonds i.e. ionic, disulphide and hydrogen bonds. Common example include myoglobin. All these contribute to the maintenance of the tertiary structure.



QUARTENARY STRUCTURE

This is formed when two or more polypeptide chains are clumped together. The separate chains are held together by hydrophobic, ionic and hydrogen bonds.

An example of this structure is found in haemoglobin consisting of 4 different polypeptide chains i.e. 2 α – Alpha and 2 β Beta polypeptide chains arranged around an Iron containing Haem group. They also consist of non-protein structures called the **prosthetic group** other examples include; mucin, casein, cytochromes



SUMMARY

Structural Level	Characteristics
Primary	The sequence of amino acids
Secondary	The coiled α helix, β-pleated sheet, or a triple helix form by hydrogen bonding between peptide bonds along the chain
Tertiary	A protein folds into a compact, three-dimensional shape stabilized by interactions between R groups of amino acids
Quaternary	Two or more protein subunits combine to form a biologically active protein

TYPES OF PROTEINS

There are 3 basic forms of proteins i.e. globular proteins, fibrous proteins, and intermediate proteins.

GLOBULAR PROTEINS

Properties

- Relatively soluble in water
- Their polypeptide chains are tightly folded to form spherical shapes or helixes
- They do not form true solutions but exist as colloidal suspensions.

Occurrence

They are found in the blood plasma where they work as buffers e.g. Haemoglobin and Myoglobin.

They are also found in cells where they are important in maintaining the composition of the protoplasm.

They are found in the plasma membrane as structural constituents but also as carrier proteins and passage proteins. Examples; Enzymes, some hormones (like insulin and glucagon, adrenal corticotropic hormone), globulin of blood, haemoglobin, myoglobin, antibodies and immunoglobulins.

Function

Regulation through enzymes, hormones, antibodies, haemoglobin.
They are also structural components of cell membranes.

FIBROUS PROTEINS

They are large parallel polypeptide chains that are cross-linked at intervals to form fibres or tissues.

Properties

They are insoluble in water
They have parallel polypeptide chains or cross linked at many points due to hydrogen bonds and other bonds and because of the cross linkages between the parallel chains, fibrous proteins are physically tough.
The main structure is the secondary one.

Occurrence;
They are found in structures like hair, hooves, horns, nails, connective tissue and muscles.

Examples;
Keratin (hair), collagen (connective), elastin (connective), Myosin and actin (muscles)

INTERMEDIATE PROTEINS

They are fibrous but soluble proteins e.g. Fibrinogen which can form insoluble fibrin during blood clotting.

NB: Proteins can also be conjugated to form complex compounds consisting of globular proteins and tightly bound non-protein materials. This non-protein material is called a **prosthetic group**. E.g. the prosthetic group in haemoglobin is the Haem group.

What are the Differences between Globular and Fibrous proteins? Give any 8 (both structural and functional)

CHARACTERISTICS OF PROTEINS

1. They are colloidal in nature

In solution, proteins form colloids since they have large sizes, they do not go into true solutions but form colloidal suspensions. A colloidal is a particle which remains suspended in solution rather than dissolving, settling down or floating. I.e. too small to settle out under gravity but also too large to dissolve.

The importance of colloids being dispersed in solution is that it gives them a large surface area which makes them very reactive. This is important in enzymes.

2. They have amphoteric properties

Proteins are amphoteric i.e. they have basic and acidic properties. The basic and acidic properties.

3. They are made of large molecules
4. They show specificity e.g. in enzymes which are specific in nature
5. On hydrolysis, they yield a mixture of amino acids.
6. They are insoluble in organic solvents.

CLASSIFICATION OF PROTEINS ACCORDING TO COMPOSITION

Simple proteins

These are made up of amino acids only examples include albumen, globulin, fibrinogen, antibodies, and histones

Conjugated proteins

These are complex proteins consisting of globular proteins tightly bound together to non-protein materials (prosthetic groups) examples include: phosphoproteins found in casein of milk

Glycoprotein with carbohydrates as the prosthetic group and these are components of cell membranes

PROTEIN	***Prosthetic group***	***Functions***
Glyco protein e.g. in saliva	Carbohydrates	Components of mucus in saliva
Lipoprotein	Lipids	Forms of lipid transports of the cell membrane
Chromo proteins e.g. Haemoglobin	Haem (iron containing)	Transport of oxygen in the body
Flavo proteins	FAD	Essential in the electron transport chain of respiration
Nucleic proteins	Nucleic	Components of Ribosomes and chromosomes.

CLASSIFICATION OF PROTEINS ACCORDING TO FUNCTIONS

Enzymes:

These are biological catalysts which control chemical reactions in organisms e.g. amylase

Structural proteins

These form part of the body of organisms e.g. collagen which makes up tendons and ligaments. Keratin is a major component of hair and nails

Signal proteins

These carry messages around the body e.g. insulin hormone and glucagon involved in controlling glucose levels in blood

Contractile proteins

These are involved in movement after contraction e.g. actin and myosin which are proteins that aid muscle contraction

Storage proteins

These keep materials e.g. albumen in the egg which nourishes the chick while it is still inside the egg.

Defensive proteins

E.g. antibodies, thrombin, fibrinogen which are important for fighting infections.

Transport proteins e.g. haemoglobin which carries oxygen around the body

FUNCTIONS OF PROTEINS

- They form structures in the body e.g. the plasma membrane, hair, skin, horns.
- They regulate the internal environment of living things as hormones e.g. Insulin and glucagon and as buffers e.g. haemoglobin.
- They regulate and catalyse the rate of metabolism as enzymes.
- They are involved in the transportation and storage of respiratory gases e.g. Haemoglobin which transports Oxygen and Carbon dioxide and Myoglobin which stores Oxygen in the muscles.
- They are important in the body movements like muscle contraction, Actin and Myosin.
- They defend the body against diseases in form of antibodies and Immunoglobulins.
- In extreme cases of starvation, they can be hydrolysed to release energy for other metabolic processes.

DENATURATION AND RENATURATION

Protein denaturation is the loss of its 3-dimensional structure which makes it unable to carry out its normal Biological functions

A protein is said to be denatured when its 3-dimensional structure is lost. This is due to the breaking of the weak hydrogen and ionic bonds that support it.

Renaturation

This is the reconstruction of a protein that has been denatured to a small extent such that its molecules regain the original 3 dimensional configuration and function by providing them with the ideal conditions of mainly the pH, and temperature. If the degree of denaturation is great, renaturation cannot take place even if the ideal conditions are provided.

AGENTS THAT CAUSE DENATURING OF PROTEINS.

Factor	Explanation	Example
High temperature or radiations	Increases kinetic energy which makes atoms of the proteins to vibrate rapidly, thus breaking hydrogen and ionic bonds resulting into coagulation	Coagulation of albumen (boiling eggs makes the white more fibrous and hence insoluble)
Acid	Addition H^+ in acid which combine with COO-groups on amino acids and form COOH. Ionic bonds are broken.	The souring of milk by acid e.g. lactobacillus bacterium produces lactic acid.
Strong acids, bases, salts and high salt concentration	Breakdown bonds disrupt ionic bonds hence coagulation of proteins. Peptide bonds can also break if the protein is mixed with a reagent for long.	
Heavy metals	The ions of heavy metals such as Hg and silver are highly electropositive. They combine with COO-groups and disrupt	Many enzymes are inhibited, denatured in presence of certain ions e.g. cytochrome oxidase

	ionic bonds. Similarly, highly electronegative ions e.g. cyanide (CN^-) combine with amino groups and disrupt ionic bonds.	(respiratory enzymes) is inhibited by cyanide (CN^-)
Organic solvents and detergents	These disrupt hydrophobic bonds and form bonds with hydrophobic groups which eventually disrupt the Hydrogen bonding	Alcohol denatures certain bacteria proteins. This is what makes it useful for sterilization
Mechanical force	Physical movement may break hydrogen bonds.	Stretching the hair breaks the H_2 bonds in the Keratin helix. The helix is extended and hair stretches. If released, the hair returns to the normal length. If however wetted and dried under tension, it keeps its new length.

CHEMICAL REACTIONS IN CELLS (BIOCHEMICAL REACTIONS)

In cells, there are chemical reactions (metabolic reactions) catalysed by enzymes. The molecules that take part in the reactions are termed as metabolites.

Metabolic reactions in the body proceed in small steps because;

- Violent reactions can endanger and kill the cell. To reduce heat generation which would denature enzymes and kill the living cells, the process occurs slowly.

- Long metabolic reactions but in small gradient steps ensures that the cell achieves maximum products from the reaction.

e.g. i) It ensures that energy is derived from the reaction at rates that are sufficient for maintenance and repair of body tissues.

ii) Food stuffs are partially broken down in steps so as to supply building blocks at rates that are required for maintenance and repair of body tissues.

TYPES OF METABOLIC REACTIONS

There are two types of metabolic reactions i.e.

1. CATABOLIC REACTIONS

These involve the metabolic breakdown of large molecules in living organisms into smaller ones usually with energy release. These reactions are exergonic.

The energy liberated by catabolic reactions is required to do the following; -

i. To drive the cell's anabolic reactions e.g. protein synthesis, synthesis of storage compounds.
ii. To do work e.g. muscle contraction, transmission of nerve impulses, secretion by glands etc.
iii. For maintenance of a constant internal environment for the normal body functioning

Catabolic reactions also break down worn out cells, fight pathogen.

2. ANABOLIC REACTIONS

These involve metabolic synthesis of larger compounds from smaller, simpler units (precursors)

They are also called endergonic reactions because they need energy to take place. They are mainly concerned with building up of body tissue, formation of storage compounds, repairing damaged and worn out tissue.

Molecules are synthesised or linked together to form complex compounds e.g. Monosaccharides link up to form disaccharides, polysaccharides like starch, glycogen, fats and proteins.

During a biochemical reaction, reactants are kept in continuous random motion which enables them to collide, react and form products.

Any factors therefore, which increase the frequency of collision of the reactants increases the biochemical reaction to form products.

FACTORS AFFECTING BIOCHEMICAL REACTIONS

Substrate concentration

Increase in substrate concentration increases the rate of a biochemical reaction. This is because of increase of reacting particles which increase chances of collision.

Temperature

Increase in temperature increases the kinetic energy of the reactants hence increasing chances of collision, in order to react and form products

Presence and concentration of an enzyme

Most biochemical reactions are too slow to sustain life and need a catalyst in form of an enzyme to speed them up.

Enzymes work by lowering the activation energy of the reactants.

Provided other factors are constant, increase in enzyme concentration increases the rate of a Biochemical reaction.

ENZYMES

These are biological catalysts, protein in nature which alter the speed of chemical reactions in living cells but remain unchanged at the end of the reaction.

NOTE

Most enzymes speed up chemical reactions. Enzymes are important because in their absence reactions in the cell would be too slow to sustain life.

PROPERTIES OF ENZYMES

- All are globular proteins and therefore relatively soluble in water.
- They are very efficient in small amounts i.e. a very small amount brings about a large change of amount of substrates to products.
- Enzymes lower the activation energy of the reactions they catalyse
- They are specific in nature i.e. an enzyme will catalyse only a single reaction e.g. Catalase will only catalyse the decomposition of hydrogen peroxide to water and Oxygen.
- Enzymes catalyse reversible reactions. They can catalyse in a reverse order.
- Their activity is affected by pH i.e. they work in a narrow range of pH, temperature, pressure, substrate concentration, presence of inhibitors and co-factors
- They are produced in living cells.

NOMENCLATURE OF ENZYMES

Normally an enzyme is named by attaching the suffix "ase" to the name of the substrate on which it acts for example

i. Proteins to protease.
ii. Lipids to lipase
iii. Maltose to maltase
iv. Sucrose to sucrase

However, enzymes like Pepsin and Trypsin do not follow this naming convention

CLASSIFICATION OF ENZYMES

Enzymes group	***Type of Reaction (Role)***	***Enzyme example***
Oxido-reductases	They catalyse biological oxidation and reduction reactions i.e. removal of Oxygen or Hydrogen atoms/ ions or electrons from one molecule to another	Dehydrogenase (Oxidation reaction), oxidase (reduction reaction)
Transferases	Transfer of a chemical group from one substance or molecule to another. Such groups include alkyl, amino, phosphate.	Transaminases Phosphorylases
Hydrolases	Catalyse reactions involving addition of water (hydrolysis) and loss of water molecules (condensation)	Proteases, Lipases
Lyases	These catalyse breakdown of chemical bonds without addition of water or a new group to the free bonds. They result into formation of double bonds	Decarboxylase, Carboxylase
Isomerases	These catalyse the rearrangement of groups within a molecule. i.e. conversion of one isomer into another.	Isomerases
Ligases	Catalyse formation of bonds between two molecules using energy derived from the breakdown of ATP	Phosphokinases, DNA ligase

ENZYME AND ACTIVATION ENERGY

This is the minimum energy required for a reaction to take place.

In many reactions, reactant molecules come together and chemical bonds are broken and formed producing products.

Before a reaction can take place, it must overcome an energy barrier by exceeding its activation energy.

Enzymes work by lowering the activation energy and thus permit the reaction to occur more readily.

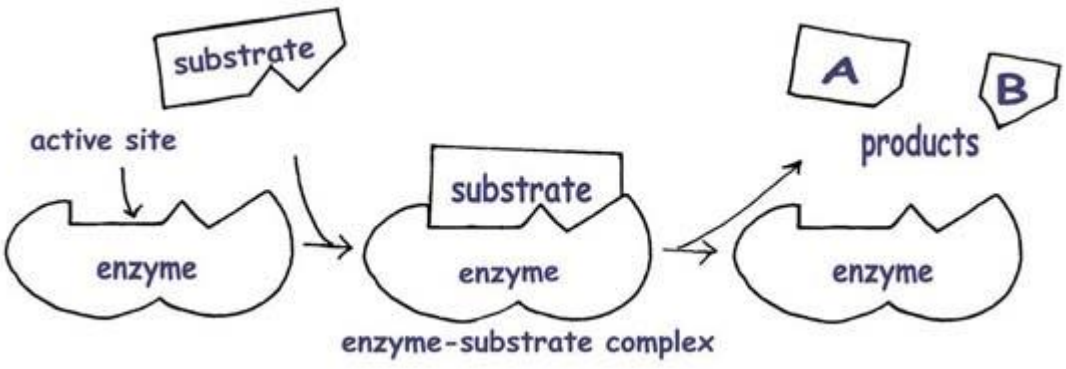
MECHANISM OF ENZYME ACTION

Enzymes generally work by lowering the activation energy needed to initiate the reaction. They make it easy for a reaction to take place than it would without them.

LOCK AND KEY HYPOTHESIS

This hypothesis is based on the fact that all enzymes have a complex globular shape with a specific surface configuration consisting of a specific site known as an **active site** on which substrates of similar complementary configuration can fit just as a key fits into a lock.

In this hypothesis, an analogy is made where the lock represents the enzyme and the key represents the substrate. It's assumed that once in the active site, reactions occur which results in the formation of enzyme substrate- complex and later the enzyme product complex after which the products are released and active sites set free for the next reaction.



ADVANTAGES OF LOCK AND KEY HYPOTHESIS

It explains the following

a) The specificity of enzymes. Only substrates with complementary shapes to that of the active sites can fit at the active site of the enzyme.

b) Why enzymes can be used over and over again. This is because after the products are formed the active sites of the enzymes are left free.
c) Why the rate of enzyme-controlled reactions is limited by increasing the substrate concentration. This is because all the active sites of the enzyme may be occupied.
d) How the enzymes reduce the activation energy of a normal reaction by showing that when a substrate binds to the active site, the substrate molecules become slightly stretched, which strains the bonds and so less energy is needed to break the bonds.
e) It explains how and why enzymes can be inhibited.
f) It explains how enzymes can be inactivated by high temperatures pH changes i.e. increase in temperature denatures the enzyme by changing the shape of its active site such that substrates can no longer bind on it.

INDUCED FIT HYPOTHESIS

It's an alternative mechanism proposed in line with more recent evidence that the lock and key are actually not static but may change their shapes during formation of the enzyme-substrate complex so that the two fit each other properly.

The enzyme initially has a binding configuration which attracts the substrate. on binding to the enzyme, the substrate causes change of the shape of the enzyme and causes it to assume a new configuration that is catalytically active. The change in shape may stretch or compress the bonds so that the reaction proceeds by lowering its activation energy.

ENZYME INHIBITORS

Many small molecules exist which can slow down or stop the enzyme catalysed reactions. These are called inhibitors. Inhibitors can be **competitive** or **non-competitive**.
Non-competitive inhibitors may be **reversible** or **irreversible**.

COMPETITIVE INHIBITORS

A competitive inhibitor is usually a substrate structurally similar to the normal substrate and it can bind with an enzyme's active site though it is unable to react.

When both the substrate and inhibitor molecules are present, they compete for the same active site
For this reason, the degree of inhibition depends on the relative concentration of both the substrate and the inhibitor and if the concentration of the substrate is high the rate of reaction is not greatly affected and this offers a means of reducing the inhibitors.

If the concentration of the inhibitors is high, the reaction is slowed down. Competitive inhibitors are not permanent and can be reversed.
This kind of inhibition can be overcome by increasing the concentration of substrate so that as active sites become available, /more substrate molecules than inhibitor molecules are around to gain entry to the sites.

For example

1. In the oxidation of succinic acid. The enzyme catalysing this reaction is succinic dehydrogenase. However, malonic acid has a molecular configuration similar to that of succinic acid. If it's added to the system; the rate of reaction is reduced. This is because malonic acid is so similar to succinic acid that it fits in the active site of the enzyme. Thereby competing with the normal substrate for the active site. When it is attached by the enzyme, it prevents the normal substrate from doing so. This is known as competitive inhibition.

2. Anti-biotic drugs called Sulphonamides are competitive inhibitors to a substance called Para- amino benzoate (PAB) which is used by some harmful bacteria in the synthesis of folic acid. Sulphonamides compete with PAB for the active site so if sufficient sulphonamide is present, the enzyme will be inhibited and the bacteria will become deprived of folic acid and hence it dies.

3. Ribulose bisphosphate carboxylase catalyses the reaction of Carbon dioxide and an acceptor molecule in photosynthesis is competitively inhibited by Oxygen.

NON –COMPETITIVE INHIBITORS

This is the type of inhibition in which inhibitors attach themselves to the enzyme molecule at a point other than the active site. It brings about inhibition by causing the enzyme to change the shape of the active site thereby preventing the active site from fitting its substrate. i.e. **Examples of non-competitive inhibitors** include most poisons like; Cyanide, Phosphate insecticides, arsenic neuro gases, and heavy metals like Zinc, mercury and silver, etc.

Non-competitive inhibitors can reversible or irreversible inhibitors.

REVERSIBLE INHIBITION

This type of inhibitor has no structural similarity to the substrate and combines with an enzyme at a point other than the active site. It does not affect the ability of the substrate to bind to the enzyme but it makes it impossible for catalysis to take place. The rate of reaction decreases with increasing inhibitor concentration and when the inhibitor saturation is reached, the rate of reaction will be almost nil. The inhibitors generally bind with the substrate with weak bonds such as Hydrogen bonds which are easily broken. Such inhibitors affect an enzyme so long as they are attached to it. As soon as they are detached, an enzyme can function normally again.

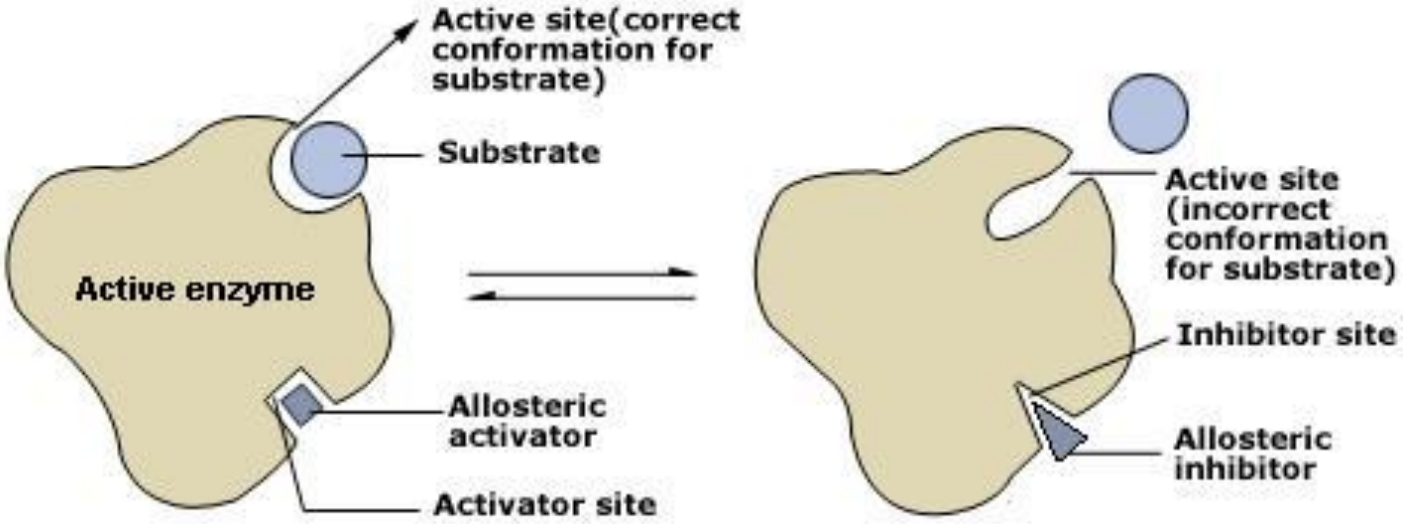
IRREVERSIBLE INHIBITION

This is where once the inhibitor molecule has combined with the enzyme it leaves it permanently damaged and unable to carry out its catalytic function.

ALLOSTERIC ENZYMES

One of the commonest ways of regulating metabolic pathways in the body cells is by means of allosteric enzymes. These are enzymes which are designed to change shape when they are regulated by enzymes which act as non-competitive inhibitors or stimulators. These compounds bind to the enzyme at specific sites (allosteric sites) away from the active site. They modify the enzyme activity by causing a reversible change in the structure of the enzyme's active site.

The inactive form of an enzyme is shaped in such a way that the substrate will not bind into the active site. For the enzyme to work it must be transformed into the active form and this means/involves changing its shape so that the substrate will fit into the active site.



IMPORTANCE OF ENZYME INHIBITORS

i. They provide important information about shapes and properties of the active sites of enzymes.
ii. They can be used to block particular reaction thereby enabling bio chemists to construct metabolic pathways.
iii. Can be used in medicine and agriculture for drugs and pesticides respectively.
iv. They control metabolic pathways by regulating the stages e.g. end point inhibition and allosteric inhibition.

ENZYME CO-FACTORS.

These are non-protein substances required by enzymes for their efficient activity. Co-factors may vary from simple inorganic ions to complex organic molecules and may either remain unchanged at the end of the reaction or be regenerated by a later process

The co-factors are under the following groups.

i. Prosthetic group.
ii. Co-enzymes
iii. Activators/ inorganic ions.

PROSTHETIC GROUP

These are non-protein groups that are permanently attached on to the enzyme. They function by transferring atoms from the active site of enzymes to other sites. The prosthetic group may be organic (such as a vitamin, sugar, or lipid) or inorganic (such as a metal ion)

e.g. The Fe^{2+} containing Haem group is permanently attached to Haemoglobin

ACTIVATORS (INORGANIC IONS)

These are inorganic chemicals like metal ions e.g. zn^{2+} for dehydrogenase, Cu^{2+} for Cytochrome Oxidase, Mg^{2+} for phosphotransferase, Cl^{-} for salivary amylase, Fe $^{2+}$ for Cytochrome, etc. which bind the enzyme to the substrate to form an enzyme substrate complex thereby increasing the chances of a chemical reaction e.g. the activity of salivary amylase is increased by the presence of chloride ions. Enzyme thrombokinase which converts Prothrombin to thrombin during blood clotting is activated by calcium ions

Coenzymes

These are complex organic non-protein molecules which function as carriers for transferring chemical groups or atoms from one enzyme to another. All co enzymes are derived from vitamins e.g. NAD is derived from nicotinic acid, a member of vitamin B complex, NADP, Co enzyme A, FAD is derived from Riboflavin (vitamin B2)

Examples;

1. NAD is a coenzyme to dehydrogenase by accepting a hydrogen ion (hydrogen acceptor). It can exist in both reduced and oxidized form.

2. During photosynthesis, $NADP^{+}$ accepts electrons and a hydrogen ion derived from water and later passes them by way of a metabolic pathway to carbon dioxide, forming glucose.

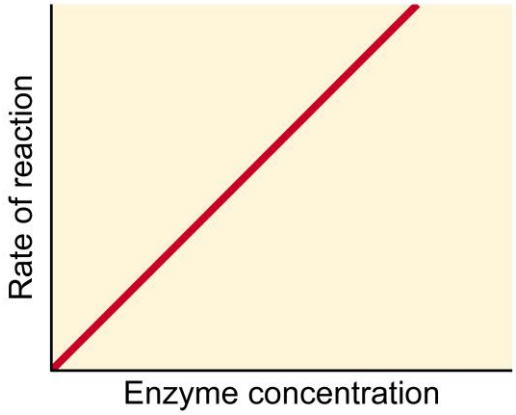
$$NADP^{+} + 2\,e^{-} + H^{+} \longrightarrow NADPH$$

FACTORS WHICH AFFECT ENZYME ACTIVITY / REACTION

ENZYME CONCENTRATION

Provided that the substrate concentration is maintained at a high level and other conditions like pH and temperature are kept constant, the rate of the reaction is proportional to the enzyme concentration. As the enzyme concentration increases, the rate of enzymatic reaction also increases.

A graph showing relationship between the rate of enzyme catalysed reaction and enzyme concentration.

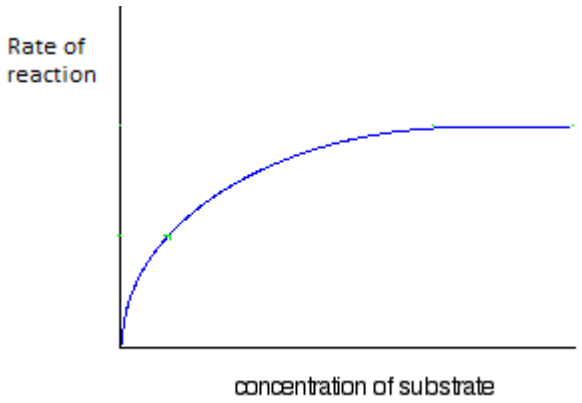


SUBSTRATE CONCENTRATION

For a given enzyme concentration, the rate of an enzymatic reaction increase with increasing substrate concentration.

But there comes a point when any further increase in substrate concentration produces no significant concentration because the active sites of the enzyme molecule at any given moment are virtually saturated with the substrate. Therefore, in such circumstances any extra substrate has to wait until the enzyme substrate complex has dissociated into products and freed enzymes' active sites. It may then bind with the enzyme's active site for the reaction to proceed. Therefore, at high substrate concentration, both enzyme concentration and the time it takes for dissociation of the enzyme-substrate complex limit the rate of the reaction.

A graph showing the effect of substrate concentration on enzyme-controlled reactions.

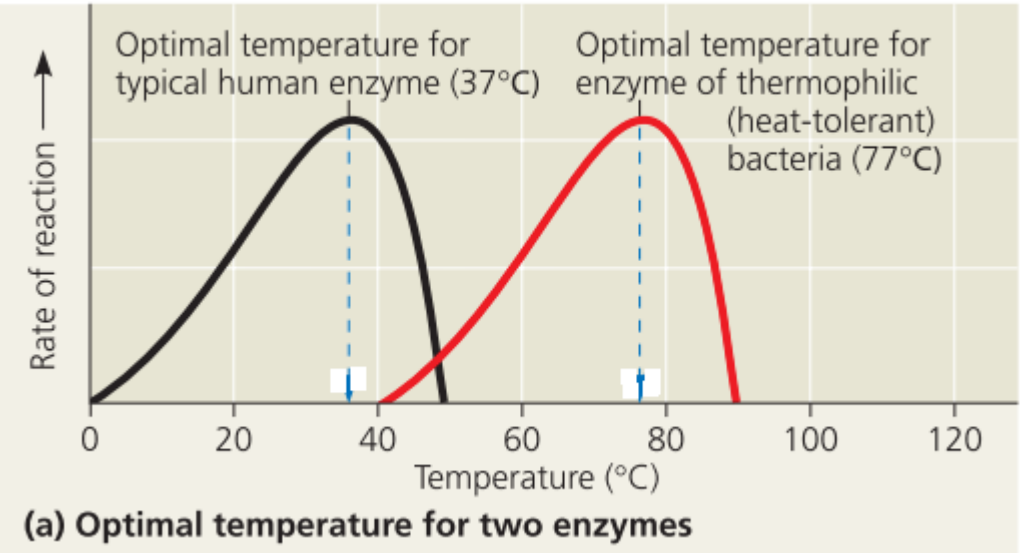


TEMPERATURE

An increase temperature increases, the kinetic energy of the substrate and enzyme molecules. The rate of enzyme controlled reaction doubles for every rise of $10^{o}C$. The faster these molecules move, the more often they collide with one another and the greater the rate of formation of enzyme-substrate complexes. The temp that promotes maximum activity is known as optimum temperature. If the temperature increases above this level, then a decrease in the rate of reaction occurs despite the increasing frequency of collisions. This is because the secondary and tertiary structure of enzyme has been disrupted and the enzyme is said to be denatured. In effect, the enzyme unfolds and the active site precise structure is lost as a result of breaking the bonds which are most sensitive to temperature like hydrogen bonds. If the temperature is reduced to near or below the optimum range, enzymes are inactivated.

At the temperature beyond the optimum, where no enzyme activity is registered, it implies that all enzymes have been denatured.

A group showing the effect of temperature in the activity of enzyme such as salivary amylase.

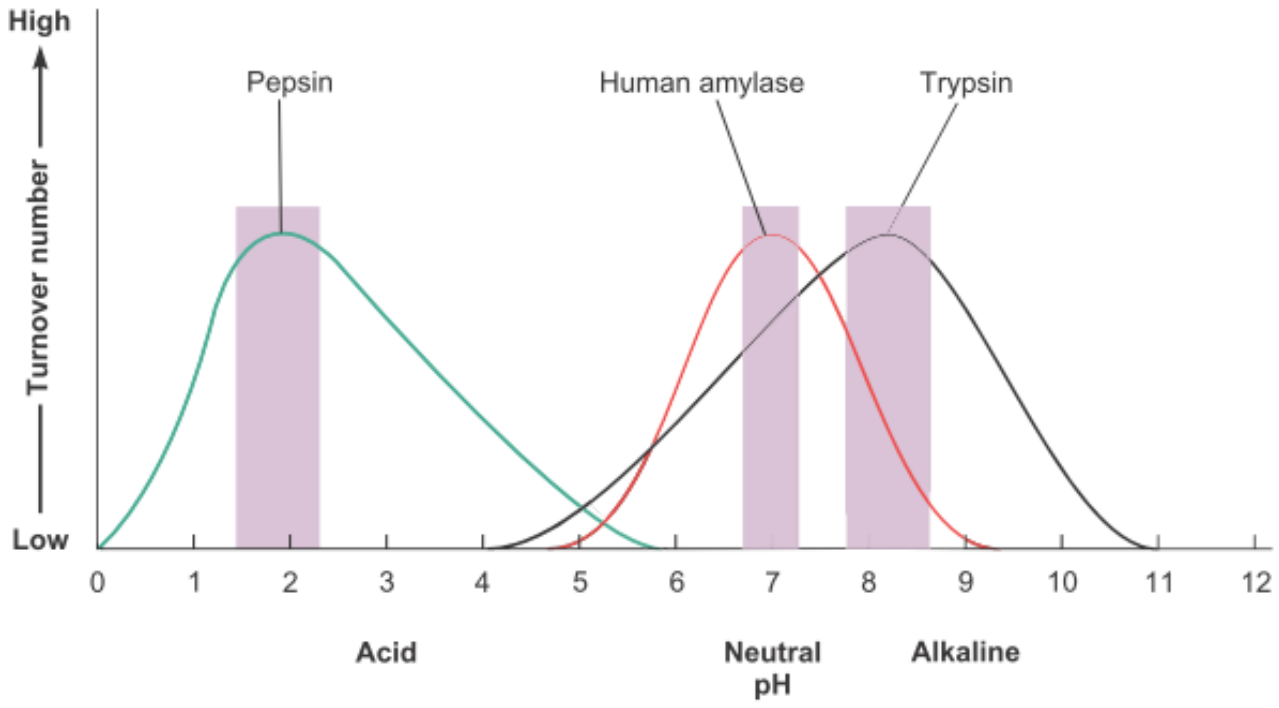


pH

Under conditions of constant temperature every enzyme function must be efficient over a narrow pH range. The optimum pH is that at which the maximum rate of reaction occurs. As pH decreases, acidity and concentration of H^+ ions increases. This increases the positive charge in the medium. The change in pH alter the ionic charge of the acidic or basic groups therefore disrupting ionic bond which maintains the specific shape of the enzyme including its active site.

If extremes of pH are encountered by an enzyme, then it will be denatured.

Graph showing effect of pH on enzyme controlled reaction.



NB:

Enzymes work best on specific pH ranges however most of them work best in neutral pH values. Consider the enzymes below and their corresponding pH values.

Enzyme	Optimum pH
Pepsin	2.0
Sucrase	4.5
Enterokinase	5.5
Salivary amylase	5.8
Catalase	7.6
Pancreatic lipase	9.0
Arginase	9.1

REGULATION OF ENZYME- ACTIVITY

Describe how enzyme activity is regulated in cells

-By allosteric regulation in case of allosteric enzymes

Enzyme action can be allosterically activated; or inhibited by the products of a metabolic sequence or by intermediates / i.e. end product inhibition; whereby e.g. during a chemical reaction, accumulation of the product e.g. ATP inhibits one of the enzymes at the start of the reaction by attaching itself at the allosteric site; changing shape of the active site; thereby slowing down the rate of reaction e.g. (glycolysis); and when the end product consumption increases, the inhibition is abolished;

-By use of allosteric activators; which bind to the allosteric site; of an enzyme and change shape of the active site; so as to effectively bind with the substrate;

-By use of enzyme activators; e.g. inorganic ions like chloride or magnesium which mould the shape of either the enzyme; or substrate; into a shape that allows enzyme - substrate complex to be formed;

-By means of regulator enzymes known as kinases; These enzymes can transfer a phosphate group; from a high energy phosphate such as ATP to an organic molecule; and this phosphorylation is normally required to activate the molecule;

NUCLEIC ACIDS

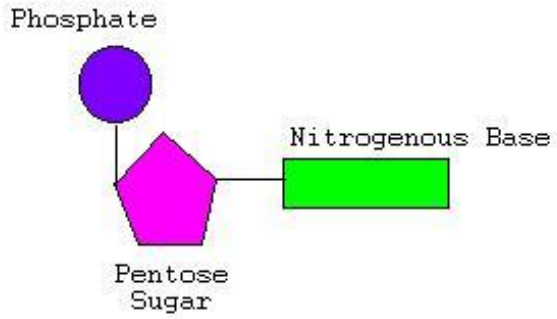
Carbohydrates, proteins and lipids form the essential structure and working parts of cells. But the operations are controlled by nucleic acid which were first discovered in the nucleus. Nucleic acids are made up of sub units (monomers) called nucleotides.

NUCLEOTIDES

Each nucleotide contains;

1. An organic base which contains Nitrogen
2. Phosphoric acid (A phosphate group (PO_4^{3-}))
3. A five carbon (pentose) sugar

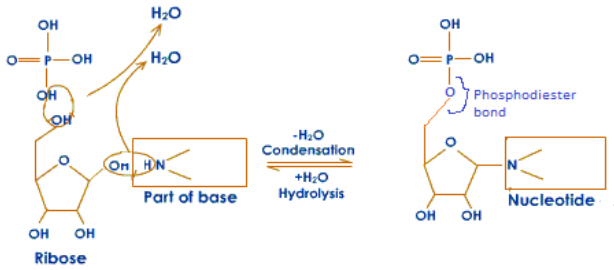
GENERAL STRUCTURE OF NUCLEOTIDE MOLECULE

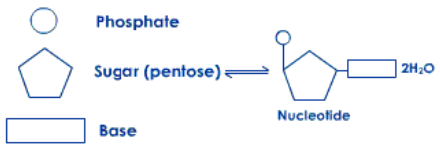


FORMATION OF A NUCLEOTIDE

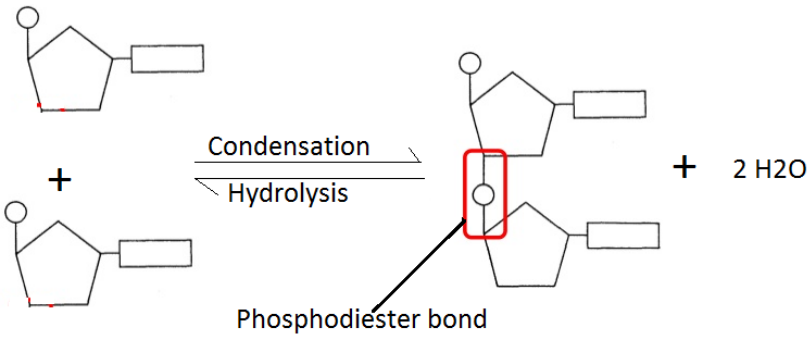
The phosphate group, 5 carbon sugar and the base undergo a condensation reaction with loss of a water molecule (dehydration reaction). The phosphate attaches itself on the sugar on carbon number 5 and the base is attached on the first carbon atom.

The pentose sugar first combines with an organic base to form a Nucleoside, with elimination of a water molecule. The nucleoside then combines with Phosphoric acid to form a nucleotide with elimination of another water molecule.





Formation of a dinucleotide



1. *PENTOSE SUGAR*

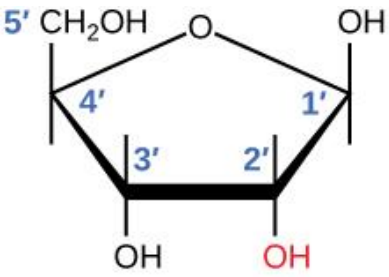
The pentose sugar is either ribose or deoxyribose sugar.

The deoxyribose sugar has 1 oxygen atom less than the ribose on carbon number 2 of the structure.

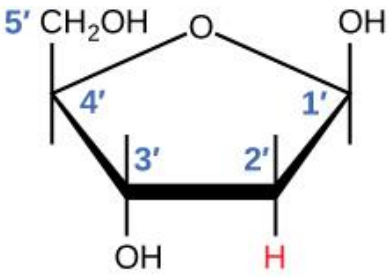
The sugars have five carbons and therefore are called pentose.

Different nucleotides are formed according to the sugars and bases used. Nucleotides are not only used as building blocks of nucleic acids but also form several important coenzymes like AMP, ATP, Coenzyme A, cyclic AMP, NAD, FAD

There are two types of nucleic acids depending on the pentose sugar they possess they contain. Those containing Ribose are called Ribonucleic Acid (RNA) and those containing a deoxyribose sugar are called Deoxyribonucleic Acid (DNA)



Ribose



Deoxyribose

2. *ORGANIC BASES (NITROGENOUS BASES)*

These determine the particular character of a nucleotide. Each nucleic acid contains four different bases which are derived from either Purines or Pyrimidines.

The nitrogen in the ring gives the molecules their basic nature. The bases in the purines are;

Adenine (A) and Guanine (G)

The Pyrimidines are;

Cytosine (C), Thymine (T) and Uracil (U)

PURINES

They have a double ring structure comprising of hexose sugar (6 carbon sugar) and a pentose ring (6 carbon ring).

PYRIMIDINES

They have a single hexose ring and they include cytosine and uracil and thymine

Cells continuously produce nucleotides and they form a pull form which nucleotides can be used when required.

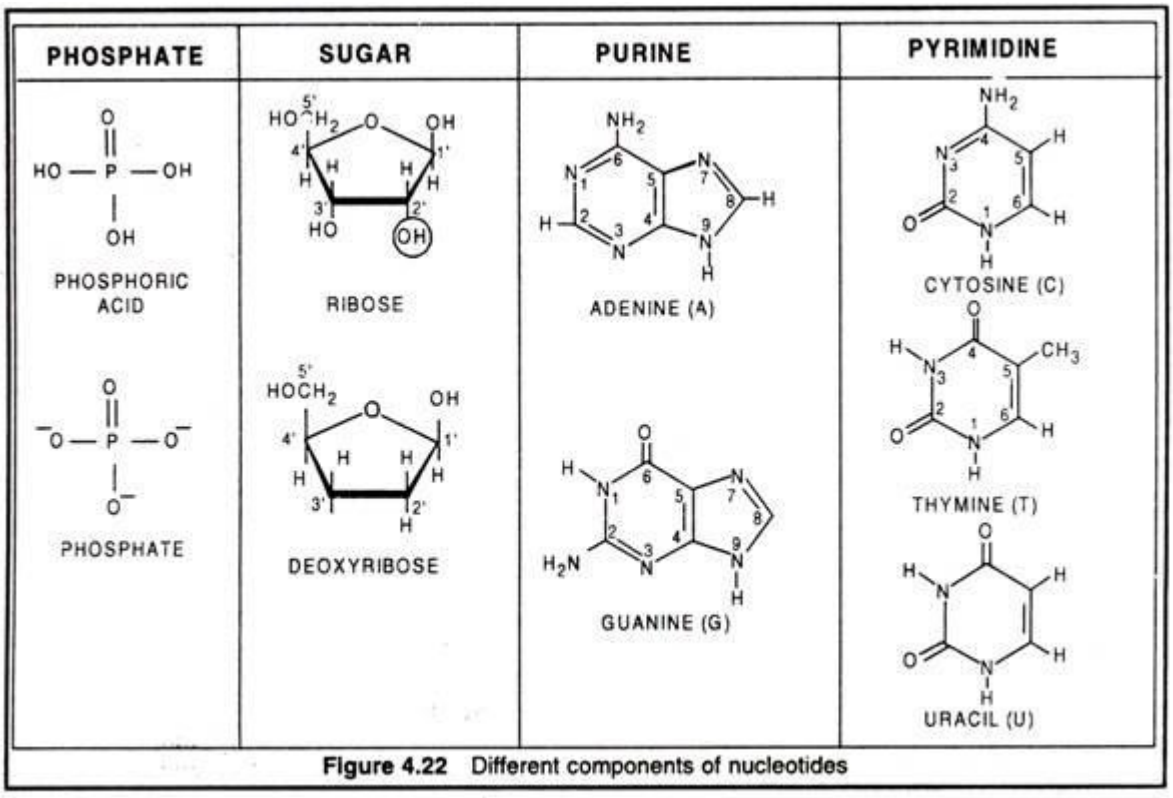


Figure 4.22 Different components of nucleotides

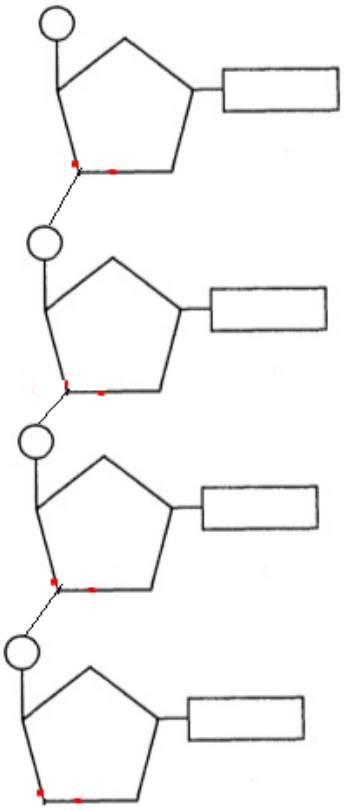
3. PHOSPHORIC ACID

   This gives the nucleic acid their acidic property.

Molecule	Function
1. Adenosine monophosphate (AMP) 2. Adenosine diphosphate (ADP) 3. Adenosine triphosphate (ATP)	Co-enzyme in making energy available to cells for metabolic activity, muscle contraction, …

Nicotinamide adenine dinucleotide (NAD) Flavin adenine dinucleotide (FAD)	Electron (hydrogen carriers) in respiration
Nicotinamide adenine dinucleotide phosphate (NADP)	Electron (hydrogen carriers) in photosynthesis
Coenzyme A	Coenzyme important in respiration

Formation of a polynucleotide



BUILDING UP OF NUCLEIC ACIDS

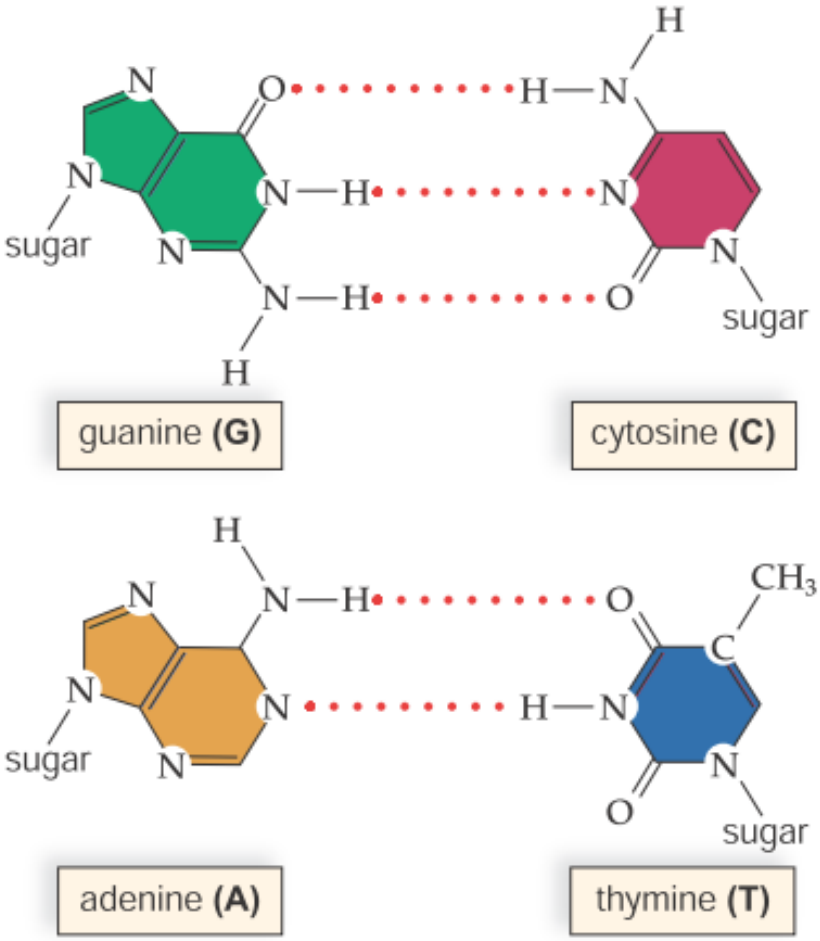
There are two linkages.

1. The sugar group is bonded to the phosphate of another and this forms a covalently bonded sugar phosphate back bone.
2. The second type of linkage is called base pairing which involves formation of a hydrogen bond between the bases. In DNA, Adenine pairs with Thymine and Guanine pairs with Cytosine. In RNA, Adenine pairs with Uracil and Guanine with Cytosine.

Adenine and Thymine are linked by 2 Hydrogen bonds while Guanine and Cytosine are linked by 3 Hydrogen bonds. It is observed that in the bases one belongs to the purine family while the other belongs to the

pyrimidine so the overall length of all the pairs is the same. If two purines linked up, they would occupy too much space, whereas if two pyrimidines linked up, too much space would be left.

FORMATION OF HYDROGEN BONDS BETWEEN ADENINE AND THYMINE, GUANINE AND CYTOSINE



STRUCTURE OF DNA

THE WATSON-CRICK HYPOTHESIS

Like proteins, polynucleotides can be regarded as having a primary structure and a three- dimensional structure. The structure of DNA that is widely accepted is that which was put forward by Sir James Watson and Francis Crick.

DNA consists of two polynucleotide chains and each chain forms a right handed helical spiral and the two chains coil around each other to form a double helix. The chains run in opposite directions, that is to say, they are anti-parallel whereby, the 3' end of one is opposite the 5' end of the other.
Each chain has a Phosphate-sugar backbone with bases projecting at 90^0 (at right angles) and Hydrogen bonds which join the bases of the opposite chains across the double helix.

The width between the two backbones is constant and it is equal to the width of the base pair i.e the width of the purines and pyrimidines. Two purines would be too large and two pyrimidines would be too small to fit in the gap between the two chains.
Along the axis of the molecule, the base pairs are 0.3µm apart. The base pairing is such that Cytosine always pairs with Guanine and Adenine always pairs with Thymine. This is what is termed as complementary base pairing. The Adenine-Thymine base pair has two Hydrogen bonds and the Cytosine-Guanine Pair has three Hydrogen bonds
Watson and crick discovered that the ratio of thymine to adenine and of guanine to cytosine is always constant in all forms of DNA and that the overall size and shape of the base pairs was identical, being 3 rings wide. Hydrogen bonding between other combinations of bases though possible is much weaker

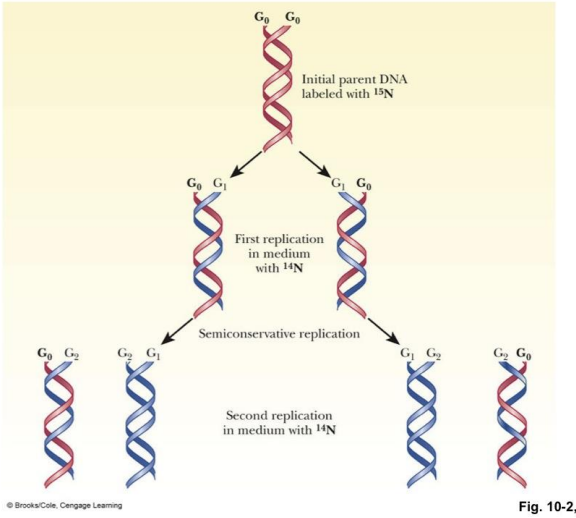
DNA REPLICATION

DNA is a unique molecule which is able to reproduce itself exactly. This process is called replication and it is the means by which new genes are made.
It occurs during interphase of cell cycle and it is essential if DNA is to work effectively as a genetic material because it ensures that an exact copy of the genetic information is passed onn from cell to cell during growth and from generation to generation during reproduction. It is therefore essential for the continuation of life. For replication to occur, the nucleus must have the following;

- DNA to act as a template for making of other DNA molecules
- Energy source, i.e. ATP and ATpase enzyme.
- A supply of free nucleotides of all the four types of the bases.
- The appropriate enzymes like DNA- polymerase, DNA ligase and DNA- helicase.

Watson and Crick proposed that the two strands were capable of unwinding (unzipping) and separating, acting as templates to complementary sets of nucleotides to attach by base pairing and in the process each original DNA molecule would give rise to two copies with identical structures.
There are three hypotheses suggested to explain DNA replication

- Semi-conservative hypothesis
- Conservative
- Dispersive hypothesis



DNA molecule Unzipped DNA Molecules joining to form a A new complementary strand

FORMS OF DNA REPLICATION

SEMI CONSERVATIVE REPLICATION

It explains that the point of weakness of the DNA molecule is the Hydrogen bond that links the bases. During replication, the DNA helix unzips because the Hydrogen bonds holding the two strands together break, catalysed by the enzyme DNA helicase. This leaves the unpaired bases exposed on each strand.

After the DNA double helix unwinds, each old strand serves as a template for the formation of the new strand. Complementary nucleotides available in the cell, pair with those of the old strand and then are joined together to form a strand basing on the rules of base pairing, whereby Adenine bonds to Thymine and Guanine bonds with.

Once the nucleotides with their bases are lined up, they join together and this requires energy from the Hydrolysis of ATP. The linking up of the nucleotides is catalysed by DNA polymerase and if there are any gaps, these are sealed off by DNA ligase to form a complete chain. As a result, two molecules of DNA are formed where each new double helix retains one of the DNA double helix. i.e. half of the original parent molecule is retained. This replication therefore preserves or conserves half of the original DNA molecule within the daughter DNA molecule.

CONSERVATIVE HYPOTHESIS

In conservative hypothesis, it is proposed that the double helix remains intact and in some way stimulates the synthesis of an entire new double helix alongside the original parent one. The result is that in each generation, one of the DNA molecules is exactly the same as the original parent molecule.

SEMI CONSERVATIVE ***CONSERVATIVE***

DISPERSIVE

Newly synthesised DNA strands will be a mixture of the parental and the newly formed strand pieces. Here replication involves fragmentation of a parent double helix and intermixing of pieces of the parent strands with newly synthesised strands.

Research question:

Describe the difference in DNA replication between prokaryotic cells and eukaryotic cells.

GENETIC CODE

A gene is a piece of DNA which codes for a protein or polypeptide chain. The sequence of bases in the DNA is a code for the sequence of amino acids in a protein molecule. Hence it is known as the genetic code.

In otherward it gives the relationship between bases, and amino acids in a protein.

A code is comprised of three organic bases known as a triplet code e.g. ACC, CAC, CAA. This means that three bases code for one amino acid.

CHARACTERISTICS FOR GENETIC CODE

- It is universal i.e. the same triplet of bases codes for the same amino acid in all organisms.
- It is a triplet code.
- It is non overlapping whereby each triplet is read separately e.g. CUGAGCUAG is read as CUG, AGC, UAG **BUT not** CUG, UGA, GA, …
- It is degenerative, i.e. a given amino acid may be coded for by more than one codon where by only the first two letters in a codon matter. E.g. Valine is coded for by UG and any of the other four bases.

N.B: Methionine is coded for by AUG and Tryptophan by UGG. These two amino acids have only one codon specifying for each.

- It is punctuated. i.e. UAA, UAG and UGA are the stop codons and determine the end of the code message i.e. they are Nonsense codons and do not code for amino acids.

AUG for Methionine is the start codon or signal for instruction of formation of a polypeptide chain.
Therefore, all proteins have their starting amino acids as Methionine.

STRUCTURE OF RNA

RNA is the second most important nucleic acid, made in the nucleus but found in the cytoplasm. It exists as a single stranded molecule in all living cells and it differs from DNA by possessing the pentose sugar Ribose instead of Deoxyribose and a Pyrimidine Uracil instead of Thymine.

Analysis of the RNA content of cells has shown the existence of three types of RNA molecules
Messenger RNA (mRNA)
Ribosomal RNA (rRNA)
Transfer RNA (tRNA)

MESSENGER RNA (MRNA)

These are all synthesised directly from DNA which acts as the template and the amount of RNA in each cell is directly related to the amount of proteins synthesised. 3 – 5% of the total RNA of the cell is mRNA.
It is a single stranded molecule formed from a single strand of DNA by a process called Transcription.
In the formation of mRNA, only one strand of DNA serves as a template or is copied. The double helix of DNA unzips in the relevant region and free RNA nucleotides align themselves according to the rules of base pairing to form a messenger RNA polynucleotide strand under the influence of RNA polymerase. Once assembled, the mRNA molecule peels off its DNA template and moves out of the nucleus through the pores in the nuclear membrane into the cytoplasm.

It is produced in the nucleus from coded instructions in DNA; it enters the cytoplasm and attaches itself on the ribosomes. It consists of a single strand of nucleotides. Process of its making is called transcription. Carries DNA from the nucleus to the cytoplasm. The two DNA strands zip up again reforming the double helix and the protective Histone proteins are added again.

ii) Transfer RNA (Trna)

This is the smallest of all RNA molecules with an average of 80 nucleotides per molecule. It constitutes about 15% of the total RNA. It forms a Clover shape with one end of the chain ending in Cytosine-Cytosine-Adenine (CCA) sequence.

It is at this point that an amino acid attaches itself. The 5' end always ends in the base Guanine. Each amino acid has its own tRNA molecule which transfers it from the cytoplasm to the ribosome. Consequentially tRNA is an intermediate molecule between the triplet code of mRNA and the amino acid sequence of the polypeptide chain.

At an intermediate point along the RNA chain is a sequence of bases called anticodon which is directly related to the amino acid carried by that tRNA molecule and an appropriate codon on mRNA molecule during protein synthesis.

GENERAL STRUCTURE OF tRNA

RIBOSOMEAL RNA (rRNA)

It is made inside the nucleus and it is the major component of ribosomes. It is a large complex molecule.

Question

Give a comparison between DNA to RNA

similarities

- Both are composed of nucleotides as their building blocks
- Both are involved in protein synthesis
- Both contain phosphoric acid molecules

- Both may have or form a double helix i.e. tRNA and DNA form a double helix.

DIFFERENCES BETWEEN RNA AND DNA

RNA	DNA
1. Single stranded polynucleotide chain	Double stranded polynucleotide chain.
2. Small molecular mass	Larger molecular mass
3. May have a single or double helix	Always has a double helix.
4. Pentose sugar in nucleotides in ribose	Pentose in nucleotides sugar is deoxyribose.
5. Organic bases present are Adenine, Guanine, Cytosine and Uracil	Organic bases present are Adenine, Cytosine, Guanine and Thymine.
6. Ratio of Adenine and Uracil to Cytosine and Guanine varies.	Ratio of adenine and Thymine to Cytosine and Guanine is one.
7. Manufactured in nucleus but found throughout the cell	Found entirely in the nucleus
8. Amount varies from cell to cell (and within a cell according to the metabolic activity)	Amount is constant for all cells of a species (except gametes and spores)
9. Chemically less stable.	Chemically very stable.
10. May be temporary existing for short periods only.	- Permanently exists.
11. Three basic forms mRNA, tRNA and Rrna	- Only one basic form
12.	-

DNA AS A CODE FOR PROTEINS

The role of DNA is to instruct the cell on what kind of proteins to make. How might this be done?
A typical protein contains at least 20 types of amino acids arranged in a specific sequence. There may be as many as 500 amino acids in a protein.
The DNA molecule with its four different bases A, G, T and C has got to determine the sequence in which the twenty types of amino acids are arranged.

PROTEIN SYNTHESIS

The only molecules capable of being synthesised directly from the hereditary material of the cell are the proteins. The instructions for the manufacture of these proteins are located in DNA which is located in the nucleus but the actual synthesis occurs in the cytoplasm and involves ribosomes.

There are four stages of proteins formation

i. Amino acid synthesis.
ii. Transcription (formation of MRNA from the unpaired DNA)
iii. Activation of Amino acids.
iv. Translation (formation of a polypeptide chain)

AMINO ACID SYNTHESIS

In plants, amino acids formation occurs in the mitochondria and chloroplasts in a series of stages which include:

i. Absorption of nitrates from the soil.
ii. Reduction of nitrates to amino groups ($NO_3^- \longrightarrow NH_2$)
iii. Combination of the amino group with a carbohydrate skeleton
iv. Transfer of the amino group from one carbohydrate skeleton to another (transamination). The 20 different kinds of amino acids are formed this way.

Animals obtain their amino acids from their diet although some have the ability to synthesise their own non-essential amino acids.

TRANSCRIPTION

This is a process by with the base sequence of DNA strand section representing a gene is converted into a complementary base sequence of mRNA.

It is the method by which the information in a section of the DNA is copied into a smaller mRNA molecule.

The mRNA is got from a short region or section of DNA molecule and this region is called a **cistron.**

The histone coat protecting the DNA double helix is stripped away, exposing the polynucleotide sequence of the DNA molecule.

The DNA double helix unwinds by breakage of the relatively weak hydrogen bonds thereby exposing the single strands of DNA. This is under the influence of an enzyme called DNA helicase.

Only one of these strands can be selected as a template for the formation of complementary single strand of mRNA. Each base on this strand attracts its complementary RNA nucleotide according to the rules of base pairing however in RNA, Uracil replaces Thymine and so, Cytosine (C) pairs with Guanine and Adenine pairs with Uracil. RNA polymerase enzyme moves along the DNA cistron adding complementary RNA nucleotides at a time to the unwound portion of DNA by condensation (dehydration reaction)

The nucleotides are activated by energy derived from hydrolysis of ATP. At the end of transcription when several molecules of RNA have been made, RNA polymerase recognises the stop codon and becomes detached from the gene region.

ACTIVATION OF AMINO ACIDS

This is a process by which amino acids combine with tRNA using energy form hydrolysis of ATP. This is catalysed by **aminoacyl tRNA synthetase enzyme**.

Each type of tRNA binds with a specific amino acid which means there are at least 20 types of tRNA molecules. Each type differs among other things in the composition of a triplet of bases called **anti codon**.

All transfer RNA have in common a free end which terminates in the triplet CCA, where individual amino acids get attached.

TRANSLATION

This is the process by which the triplet base (codon) sequences on mRNA are converted into a sequence of amino acids in a polypeptide.

This occurs on the ribosomes in the cytoplasm. Each ribosome is composed of a small and a large subunit. mRNA forms a reversible attachment to the surface of the small sub unit in the presence of Magnesium ions. Having become attached to the ribosome, two messenger RNA codons are exposed to the larger sub unit of the ribosome. The first codon attracts the first tRNA molecule, having a complementary anticodon and which is carrying the first amino acid of the polypeptide being synthesised. The second codon then attracts a tRNA amino acid complex having a complementary anticodon (i.e. in the cytoplasm, the tRNA molecules which bear a triplet of bases each correspond to a particular amino acid).

Once a new amino acid has been added to the growing polypeptide chain, the ribosome moves along the mRNA to enclose other codons.

The tRNA molecule that was previously first attached to the polypeptide chain now leaves the ribosome and passes back to the cytoplasm to be reconverted into a new aminoacyl transfer RNA complex. This sequence of the ribosome reading and translating the mRNA codons continues until it comes to a codon signalling stop.

The terminating codons are UAG, UGA and UAA. At this point, the polypeptide chain now with its primary structure, determined by the DNA, leaves the ribosome and translation is complete. The polypeptide so formed must be assembled into proteins either by folding, spirals, … to give a secondary structure and tertiary structure. It can combine with other polypeptides to give a quaternary structure.

N.B

Several ribosomes may become attached to a molecule of mRNA like beads on a string and the whole structure is called a **polysome**

The advantage of such a complex is that it allows several identical polypeptides to be synthesised simultaneously. Peptide bonds form between adjacent amino acids and the polypeptide chain grows longer by addition of an amino acid at a time. The ribosome is a framework which holds the mRNA and the aminoacyl transfer RNA complex together until a peptide bond forms between adjacent amino acids.

Genetic significance of DNA

- It can bring about big variation especially in meiosis.
- It ensures consistency of species i.e. during DNA replication, more DNA is found which will divide into two to maintain the original DNA on the parents.
- It is another way in which all necessary hereditary material is passed unto the new offspring.