CHEMICALS OF LIFE

All living organisms made up of chemicals which constitute the protoplasm of their cells. These are known as the chemicals of life i.e. the chemicals which keep the cells alive.

The study of the chemicals of life and the chemical reactions in which they take place is known as **bio-chemistry.** These chemicals of life are divided into two categories; organic and inorganic chemicals of life.

The **organic chemicals of life** are all derived from carbon and include; carbohydrates, proteins, lipids, nucleic acids (DNA and RNA), waxes and steroids as well as vitamins. The **inorganic chemicals of life** include, water, mineral salts, acids and bases. All inorganic and organic chemicals of life must be supplied in appropriate quantities in the diet except nucleic acids and a few vitamins. Therefore there is need for a balanced diet to keep the cells alive.

INORGANIC CHEMICALS OF LIFE

These are mainly water and inorganic mineral salts such as calcium, magnesium, potassium, nitrates, chlorine, phosphates e.t.c.

WATER

Water is formed when two hydrogen atoms combine with an oxygen atom by sharing electrons. The result is a stable molecule, which is relatively unreactive. The shape of the water molecule is triangular rather than linear and the angle between the nuclei of the atoms is approximately 105^{o}.

Overall the molecule is electrically neutral, but in both of the oxygen-hydrogen bonds, the oxygen draws electrons away from the hydrogen nucleus. Thus there is a net negative charge on the oxygen atom and a net positive charge on the hydrogen atom. A molecule that carries an equal distribution of electrical charge is called a **polar molecule**.

Arrangement of atoms in a water molecule

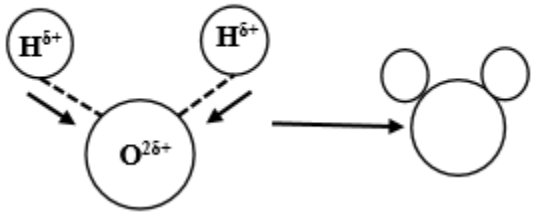


Fig 3.5 pg 80 Soper

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

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

1. Solvent properties

It is a universal solvent for polar substances (charged or ionisable substances) e.g. salt and it is also a solvent for non-polar substances e.g. sugar. This property enables water to carry out the following functions;

i. It is a lubricant e.g. in the joints where it forms the synovial fluid which enables protection against damages.

ii. It acts as a transport medium as blood, lymph, in the expiratory system as well as in the alimentary canal where it transports materials from one point to another.

iii. It is an important constituent of the excretory waste products, by which toxic materials are removed from the body.

iv. It is the largest constituent of the protozoan protoplasm of all cells where it contributes up to **60%.**

2. Water has a high heat capacity

Heat capacity refers to the amount of heat required to raise the temperature of 1 kg of water by $1^{O}C$. The high heat capacity of water means that the large increase in heat energy around water results into a relatively small rise in the temperature of water because much of the energy supplied to water is used in breaking the hydrogen bonds which restricts the movement of molecules. The temperature changes within water are therefore minimized as a result of its high heat capacity, this property is significant because;

i. It enables life processes such as temperature regulation and gaseous exchange to occur in organisms.

ii. Such a suitable temperature enables body enzymes to function well without denaturation and/or inactivation.

iii. It provides a constant internal and external environment for many cells and organisms.

3. High heat of evaporisation

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

a. It results into the cooling of the organisms so as to reduce body temperature.

b. It is an important heat sink where large bodies of water are responsible for modifying climate by absorbing heat from the sun.

NOTE.

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

4. High heat of fusion

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

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

5. Density and freezing properties

The density of water decreases below $4^{O}C$ and ice therefore floats on water. Water below $4\ ^{O}C$ tends to rise which maintains the circulation in large water bodies therefore this property is important because;

i. It makes water an important factor in the cycling of nutrients needed by living things.

ii. It makes water a suitable habitat for many aquatic organisms both plants and animals.

6. High surface tension and cohesion

Cohesion is the force of attraction between molecules of the same kind. At the surface of the liquid a force called surface tension exists between the molecules due to the cohesive forces between the molecules. This causes the water surface to occupy the list possible surface area. Water has a higher surface tension than any other liquid. This property is important as follows;

a. The high cohesion of water molecules enables the movement of water through the xylem to the leaves.

b. Surface tension enables small organisms to settle on water or skate over the water surface.

c. It enables the water to participate in the absorption of mineral salts from the soil.

7. Water as a reagent

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

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

b. Water is a medium in which most bio-chemical reactions take place.

c. Water is a pre-requisite for fertilization, where fertilization involves mobile gametes e.g. external fertilization in lower plants, fish, amphibians, and internal fertilisation in higher vertebrates and plants.

8. Incompressibility

This property enables water to carry out the following functions;

a. It forms the hydro-static skeleton of animals such as earthworms.

b. It provides support to the non woody plants e.g. herbaceous plants by maintaining turgidity of the cells.

c. Water provides stomata movement, movement of leaves, opening and closing the flowers e.t.c. to take place through changes in the turgidity of the cells.

9. High tensile strength

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

10. Water is transparent

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

Other biological functions of water include

i. Water enables dispersal of seeds and fruits such as coconut as well as dispersal of the gametes and larval forms of aquatic organism.

ii. It breaks the testa of seeds to allow embryo growth during germination.

MINERAL ELEMENTS

Mineral element	major dietary sources for humans	Major functions in the body	Symptoms of deficiency or excess in animals
MACRO ELEMENTS			
Calcium	Dairy products, dark green vegetables and legumes	bone and tooth formation , blood clotting, nerve and muscle function	Retarded growth, possibly loss of bone mass
			Stunted growth
Phosphorous	Dairy products, meats and greens	bone and tooth formation , acid-base balance, nucleotide synthesis	Weakness, loss of minerals from bones, calcium loss
			Stunted growth particularly of roots
Sulphur	Proteins from many sources	Proteins from many sources	Symptoms of protein deficiency
			Chlorosis
Potassium	Meats, dairy products, grains, many fruits and vegetables,	Acid-base balance , water balance and nerve function, cofactor in photosynthesis and respiration	Muscular weakness, paralysis, nausea , heart failure
			Yellow and brown leaf margins; premature death;
Chloride	Table salt	Acid-base balance, formation of gastric juice, nerve function, osmotic balance	Muscle cramps, reduced appetite
Sodium	Table salt	Acid-base balance, nerve function, water balance	Muscle cramps, reduced appetite
Magnesium		Co-factor, ATP synthesis	Nervous system disturbance

	Whole grains, green leafy vegetables		Chlorosis
Nitrogen	Lean meat, fish, milk	Synthesis of proteins, nucleic acids; formation of chlorophyll and a coenzyme	Stunted growth
			Stunted growth and strong chlorosis of old leaves
MICRO ELEMENTS			
Iron	Meats, eggs, legumes, whole grains, green leafy vegetables	Component of haemoglobin and of electron carriers in energy metabolism, enzyme cofactor	Iron-deficiency anaemia, weakness, impaired immunity
			strong chlorosis of young leaves
Fluorine	Drinking water, tea, seafood	Maintenance of tooth and bone structure	Higher frequency of tooth decay
Zinc	Meats, seafood, grains	Components of certain digestive enzymes and other proteins	Growth failure, skin abnormalities, reproductive failure, impaired immunity
			Malformed leaves e.g. in cocoa
Copper	Seafood, nuts, legumes, organ meats	Enzyme cofactor in iron metabolism, melanin synthesis, electron transport	Anemia, cardiovascular abnormalities
			Die back of shots
Manganese	Nuts, grains, vegetables, fruits, tea	Enzyme cofactor	Abnormal bone and cartilage
			Leaf flaking e.g. grey specks in oats
Iodine	Seafood, dairy products, iodized salt	Components of thyroid hormones	Goiter
Cobalt	Meats and dairy products	Component of vitamin B_{12}	None except as B_{12} deficiency
Selenium	Seafood, meats, whole grains	Enzyme cofactor; antioxidant functioning in close association with vitamin E	Muscle pain, possibly heart muscle deterioration
Chromium	Brewer's yeast, liver, seafood, meats, some vegetables	Involved in glucose and energy metabolism	Impaired glucose metabolism

Molybdenum	Legumes, grains, some vegetables	Enzyme cofactor	Disorder in excretion of nitrogen containing compounds

THE ORGANIC CHEMICALS OF LIFE

These are the chemicals of life which always contain carbon, hydrogen and oxygen as the major elements. The proteins and nucleic acids in addition to these elements also contain nitrogen. These organic chemicals of life are important because of the following reasons;

- They are the structural components of the bodies of organisms.
- They are regulators of chemical processes occurring in organisms.

These organic chemicals of life include the following; **carbohydrates, proteins, lipids, vitamins** and **nucleic acids**

Fig 3.4 pg 80 Soper

VITAMINS

Vitamins are organic molecules with diverse functions that are required in very small amounts. For humans, 13 essential vitamins have been identified and are classified as water-soluble or fat-soluble.

Vitamins	**Major dietary sources**	**Major functions in the body**	**Symptoms of deficiency** ***Extreme excess***
Water soluble vitamins			
Vitamin B_1 Thiamine	Pork, legumes, peanuts, whole grains	Coenzymes used in removing carbon dioxide from organic compounds	Beriberi (nerve disorders, emaciation anemia)
Vitamin B_2 Riboflavin	Dairy products, meats, enriched grains, vegetables	Component of coenzymes FAD and FMN	Skin lesions such as cracks at corners of the mouth
Vitamin B_3 Niacin	Nuts, meats, grains	Component of coenzymes NAD^+ and $NADP^+$	Skin and gastrointestinal lesions, nervous disorders *Liver damage*
Vitamin B_6 Pyridoxine	Meats, vegetables, whole grains	Coenzyme used in amino acid metabolism	Irritability, convulsions, muscular twitching, anemia *Unstable gait, numb feet, poor coordination*

Vitamin B_5 Pantothenic acid	Most foods: meats, dairy products, whole grains e.t.c.	Component of coenzyme A	Fatigues, numbness, tingling of hands and feet
Vitamin B_9 Folic acid (folanin)	Green vegetables, oranges, nuts, legumes, whole grains	Co enzyme in nucleic acid and amino acid metabolism	Anemia, birth defects *May mask deficiency of vitamin B_{12}*
Vitamin B_{12}	Meats, eggs, dairy products	Co enzyme in nucleic acid metabolism, maturation of red blood cells	Anemia, nervous system disorders
Biotin	Legumes, other vegetables, meats	Coenzyme in synthesis of fat, glycogen, and amino acids	Scaly skin inflammation, neuromuscular disorders
Vitamin C Ascorbic acid	Fruits and vegetables especially citrus fruits, cabbage, tomatoes, green pepper	Used in collagen synthesis (such as for bone, cartilage, gums); antioxidant; aids in detoxification; improves iron absorption	Scurvy (degeneration of skin, teeth, blood vessels), weakness, delayed wound healing, impaired immunity *Gastrointestinal upset*
fat soluble vitamins			
Vitamin A Retinol	Beta-carotene (pro-vitamin A) in green and orange vegetables, retinal in dairy products	Component of visual pigments, maintenance of epithelial tissues, antioxidant, helps prevent damage to cell membranes	Blindness and increased death rate *Headache, irritability, vomiting, hair loss, blurred vision, liver and bone damage*
Vitamin D	Dairy products, egg yolk; also made in human skin in presence of sunlight	Aids in absorption and use of calcium and phosphorous; promotes bone growth	Rickets (bone deformities) in children, bone softening in adults *Brain, cardiovascular, and kidney damage*
Vitamin E Tocopherol	Vegetable oils, nuts, seeds	Antioxidant; helps prevent damage to cell membrane	Desecration of the nervous system
Vitamin K phylloquinone	Green vegetables, tea; also made by the colon bacteria	Important in blood clotting	Defective blood clotting *Liver damage and anemia*

CARBOHYDRATES

These are organic compounds made up of carbon, hydrogen and oxygen, in which the ratio of hydrogen to oxygen is 2:1 as in water.

They have a general formula of $C_n(H_2O)_m$ where m and n are either the same or different units (n = number of carbon atoms). Most examples of carbohydrates do conform to the general formula e .g.

Glucose	$C_6H_{12}O_6$	$C_6(H_2O)_6$	n = 6	m = 6
Sucrose	$C_{12}H_{22}O_{11}$	$C_{12}(H_2O)_{11}$	n = 12	m = 11

Some few carbohydrates do not conform to the general formula e. g. Deoxyribose sugar,

Deoxyribose sugar $C_5H_{10}O_4$

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

There are 3 groups of carbohydrates namely;

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

MONOSACCHARIDES

These are a group of sweet, soluble, crystalline molecules of relatively low molecular mass made of a single sugar.

Monosaccharides may contain either an aldehyde group or a ketone within their molecule. If they contain an aldehyde group (-CHO) they are called ***aldoses*** or ***aldo-sugars.*** If they contain a ketone (C=O)group in their molecules, they are called ***ketoses*** or ***keto-sugars.***

The general formula for Monosaccharides is $(CH_2O)_n$ where n = number of carbon atoms. Where n=3, the sugar is called a ***triose sugar***, where n=5, ***pentose sugar*** and when n=6 ***hexose sugar***.

As shown above the names of monosaccharides end with a suffix – ose.

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

The structures of the various isomers of monosaccharides include the following;

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

α- glucose (Alpha glucose)

Fig 2.1 pg 13 Toole OR Fig 9.7 pg 126 Monger

β - glucose (beta glucose)

Fig 1 pg 26 Kent OR Fig 5.4 pg 65 Kent OR Fig 9.7 pg 126 Monger

β - Glucose differs from α-glucose in that at carbon 1 in β – glucose, the -OH group faces upwards while α - glucose it faces downwards.

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

Furanose (α- fructose)

Fig 2.1 pg 13 Toole OR Fig 9.7 pg 126 Monger

Pyrenose (β – fructose)

Fig 5.5 pg 65 Roberts OR Fig 9.7 pg 126 Monger

NOTE:

Monosaccharides can link together to form larger molecules i.e. they form building units used to form complex sugars. Some monosaccharides act as a source of energy when oxidized in respiration e.g. glucose.

Most of the monosaccharides are the ***reducing sugars*** because they reduce Cu^{2+} in Benedict's solution to Cu^{+} ions giving an orange precipitate of copper (1) oxide (Cu_2O). They have an aldehyde group or a free ketone group. Ketoses first isomerise to aldoses before they can act as reducing sugars.

DISACCHARIDES

A disaccharide is a sugar formed as a result of the combination of two monosaccharides sugars. Because of this reason they are also known as **double sugars**.

General formula $C_{12}H_{22}O_{11}$ and not $C_{12}H_{24}O_{12}$ as expected because these formations involve the loss of one water molecule as shown in the equation below;

$$C_6H_{12}O_6 + C_6H_{12}O_6 \rightleftharpoons C_{12}H_{22}O_{11} + H_2O$$

Such a reaction which involves the loss of a water molecule during the synthesis of a new compound, is known as a ***condensation reaction.***

The two monosaccharide units in a disaccharide are held together by a covalent bond known as a **glycosidic bond.**

Most disaccharides are reducing sugars however there are some few which are non-reducing sugars e.g. sucrose because they lack the reducing group in these molecules.

Like monosaccharides, disaccharides are also sweet, soluble in water and crystalline like monosaccharides

FORMATION OF DISACCHARIDES

This is illustrated by the following example

α- glucose + **α- glucose** ⇌ **α- maltose + water**

$C_6H_{12}O_6$ + $C_6H_{12}O_6$ ⇌ $C_{12}H_{22}O_{11} + H_2O$

Fig 2.2 pg 16 Toole

β- glucose + **β- glucose** ⇌ **β- maltose + water**

$C_6H_{12}O_6$ + $C_6H_{12}O_6$ ⇌ $C_{12}H_{22}O_{11} + H_2O$

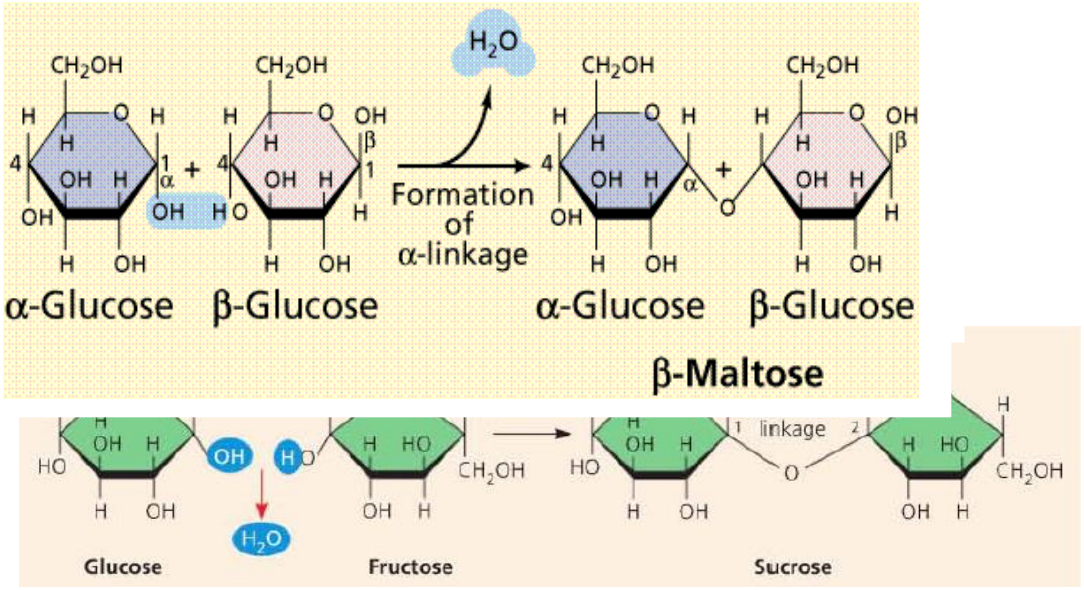


Fig 6.13 pg 134 Clegg

POLYSACCHARIDES

These are the sugars formed when many monosaccharides combine as a result of condensation reactions to form chains.

The chains in polysaccharides may be of;

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

Most polysaccharides are formed from hexose sugars and the general formula of $(C_6H_{10}O_5)$ n where n is a number greater than 40.

Characteristically polysaccharides are un-sweet, insoluble in water and non-crystalline. Due to their insolubility in water, they form good storage compounds inn organisms because they cannot diffuse out of the cell and they do not affect the osmotic potential of the cells.

The most common polysaccharides are ***starch, cellulose*** and ***glycogen***.

Upon hydrolysis, polysaccharides can be converted into their constituent monosaccharides such as glucose, ready for use as a respiratory substrate.

All polysaccharides are non- reducing sugars.

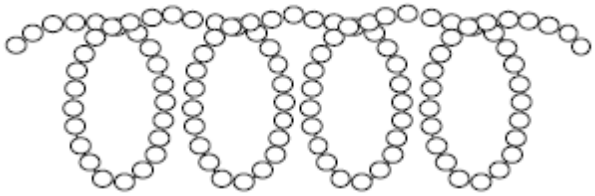
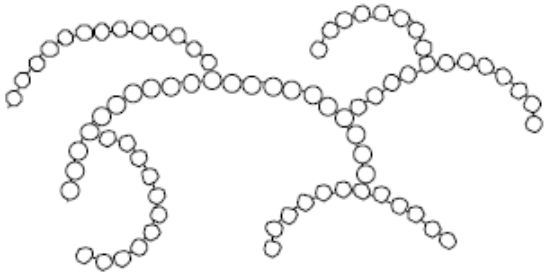
STARCH

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

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

Amylose consists of unbranched chains while amylopectin consists of branched chains. These chains are coiled to form a helix in amylopectin where the -OH groups project into the interior and cannot therefore be free to take part in hydrogen bonding. For this reason amylopectin has no cross linkages as amylase whose -OH groups point outwards and can therefore form hydrogen bonds. Therefore starch is not strong enough as a structural polysaccharide like cellulose. Due to its branching and numerous ends, amylopectin can easily be broken down to maltose by amylase enzyme at a higher rate as compared to amylose

Fig 5.8A pg 67 Roberts

Amylose	Amylopectin
	

DIFFERENCES BETWEEN AMYLOSE AND AMYLOPECTIN

AMYLOSE	AMYLOPECTIN
It has only 1-4 glycosidic bonds	It has both 1-4 and 1-6 glycosidic bonds
It stains deep blue with iodine.	It stains red to purple with iodine.
Its related molecular mass is 50,000.	Its relative molecular mass is 500,000.
It is made up of un branched helical chains.	It is made up of branched helical chains.

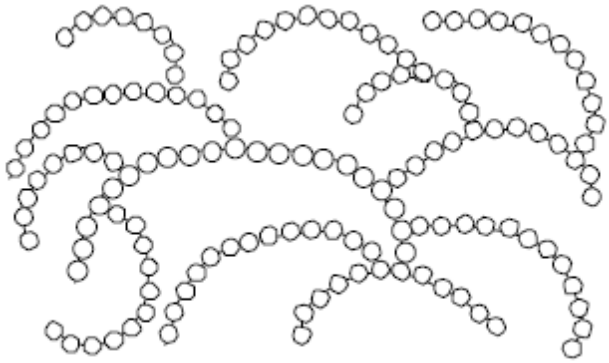
It is made up of 300 glucose units.	It is made up of 1300 glucose units.

GLYCOGEN

This is the major polysaccharide storage material in **animals** and **fungi**. It is stored mainly in the liver and muscles this is mainly because it provides energy more readily than fat within the active tissues of the muscles and the liver.

Besides glycogen can be used during anaerobic respiration to provide energy in the muscles e.g. during heavy and physical exercise.

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



It is more soluble in water than starch.

CELLULOSE

This is a polysaccharide made of many beta glucose molecules that form long unbranched parallel chains.

It is mainly found in plants because it is the main structure material in plant cell walls and in cotton it makes up to 90%.

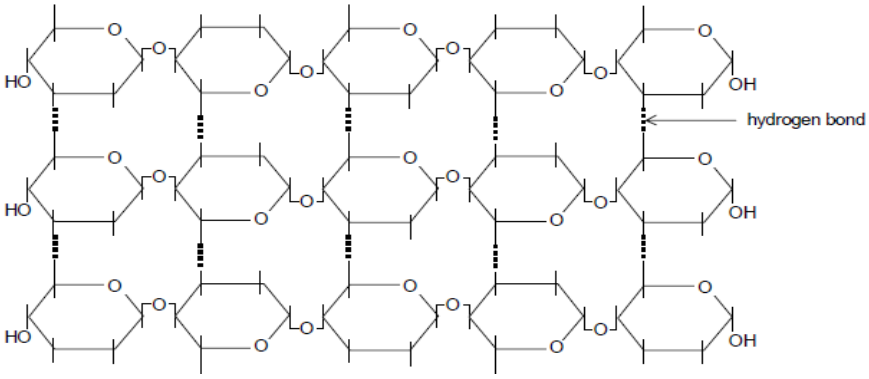
Many chains run parallel to each other and have cross linkages between them. These cross linkages give cellulose its considerable stability which makes it a valuable structural material. This stability also makes it difficult for animals to digest cellulose and therefore it is not such a valuable food source to the animals.

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

Fig 5.8B pg 67 Roberts OR Fig 9.13 pg 130 Monger

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

Cellulose is commercially used in textiles in the making of papers, cellophane, tyre cords and celluloid that is used in making photographic films because its chains are linked by hydrogen bonds to make cellulose microfibrils which are very strong and rigid and therefore give strength to plant cells and young plants.



OTH

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Chemically and structurally chitin resembles cellulose however it differs from cellulose in possessing an acetyl group instead of one of the hydroxide groups in beta glucose.

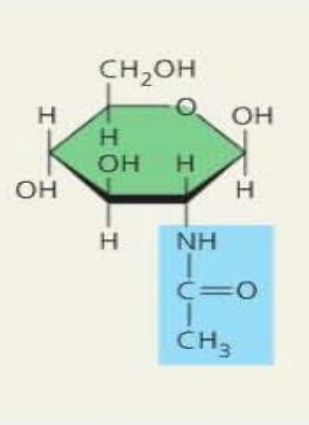


Fig 3.15 pg 89 Soper

Like cellulose, it has a structural function and it is the major component of the exo-skeleton of insects and crustaceans. It is also found in fungal cell walls.

2. SUGAR DERIVATIVES

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

a. **Mucopolysaccharides.** These are formed from amino sugars e.g. glucose amine. An amino sugar is a sugar containing nitrogen. Examples of mucopolysaccharides include the following;

i. ***Hyaluronic acid:*** this forms part of the vertebrate connective tissues. It is therefore found in cartilage, bones, vitreous humor of the eye and in the synovial fluid. Hyaluronic acid is also found in anti-coagulant called ***heparin.***

ii. Other mucopolysaccharides are mainly found in the cell walls of prokaryotes such as bacteria.

b. **Nucleotides**. A nucleotide is where pentose sugars join with organic bases. Nucleotides are the basic building blocks of nucleic acids such as DNA on which heredity depends and RNA on which protein synthesis depends. Other nucleotides are mainly used in respiration and these include Adenosine Tri Phosphate (ATP), Nicotinamide Adenine Dinucleotide (NAD), and Flavine Adenine Dinucleotide (FAD).

LIPIDS (fats and oils)

Lipids are basically natural fats and oils made up of carbon, hydrogen and oxygen but the ratio of hydrogen to oxygen in not 2:1 as in carbohydrates instead the hydrogen atoms are far more than the oxygen atoms.

Lipids also include waxes, steroids and phospholipids.

Generally all lipids have a high proportion of hydro carbon group (CH_2) in their molecules. They are insoluble in water but can dissolve in organic solvents such as chloroform and benzene.

The low solubility of lipids is due to the low oxygen content and very many CH_2 groups, the numbers of polar -OH groups that are present in the molecule are very few thus preventing dissolving. It is these polar groups that normally confer solubility in water (H_2O) through ion interaction with water in the case of carbohydrates.

Fats are solids at room temperature whereas oils are liquids.

CONSTITUENTS OF LIPIDS

Lipids are made up of ***esters*** called fatty acids and an alcohol called glycerol.

Glycerol has three hydroxyl groups (-OH) and each of these may combine with separate fatty acids forming triglyceride. This combination occurs by **condensation reaction** in which three water molecules are formed and therefore the hydrolysis of the triglyceride will again yield glycerol and 3 fatty acids.

Fatty acids have a general formula of $C_nH_{2n}O_2$. Their structural formula can be summarized as below $R(CH_2)_nCOOH$. Where n is any even number between 4 and 24. R can be CH_3CH_2, $CH_3CH_2CH_2$ e.t.c.

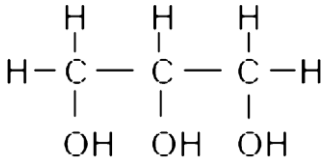
Fatty acids can be classified as **unsaturated** if they contain one or more double bonds e.g. oleic acid. Fatty acids lacking double bonds are said to be **saturated** e.g. steoric acid. Unsaturated fatty acids melt at a much lower temperature than saturated fatty acids. Consequently, saturated fatty acids are normally found in fats while unsaturated fatty acids are commonly found in oils. Lipids vary due to the presence of many fatty acids. Fats differ from oils in two fundamental ways;

i. Fats are made from saturated fatty acids while oils are made from unsaturated fatty acids.

ii. Fatty acids in oils are smaller than those in fats.

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

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



FORMATION OF A TRIGLYCERIDE

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

Fig 1 pg 30 Kent OR Fig 6.15 pg 134 Clegg

NOTE:

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

b) Because fatty acids are synthesized from fragments containing two carbon atoms, the number of carbon atoms in the lipid chains is always an even number.

c) Lipids require too much oxygen to be oxidized in respiration as compared to glycogen and are therefore used in respiration.

Fig 1 pg 30 Kent

ESSENTIAL AND NON-ASSENTIAL FATTY ACIDS

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

STEROIDS AND WAXES

1. **WAXES**

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

2. STEROIDS

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

The functions of some important steroids are given below;

STEROID	FUNCTION
Cholesterol	It is a major component of the cell membrane. It is a raw material for many other steroids.
Bile acids (glycocholic acid and taurocholic acid)	These are used in emulsification of fats during digestion.
sex hormones a. Oestrogen and progesterone	These are reproductive hormones in female mammals which regulate the menstrual cycle and controlling pregnancy
b. Testosterone	This is a reproductive hormone in male mammals controlling sexual behavior and sperm production.
Vitamin D (Calciferol)	It promotes calcium and phosphate absorption and metabolism It is also important for the hardening of bones and teeth
Ecdysone (Moulting hormone)	It causes moulting (shedding off the cuticle in arthropods)

PHOSPHOLIPIDS

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

Other groups including nitrogenous bases could even be attached to this phosphate group to make the structure even more complex.

The phosphate group is electrically charged (PO_4^{3-}) and therefore polar when and so unlike fatty acids dissolve in water. Phospholipids are therefore able to dissolve in both water and organic substances i.e. phospholipids are both hydrophilic and hydrophobic. This property of phospholipids is important in determining the structure and functioning of the cell membrane

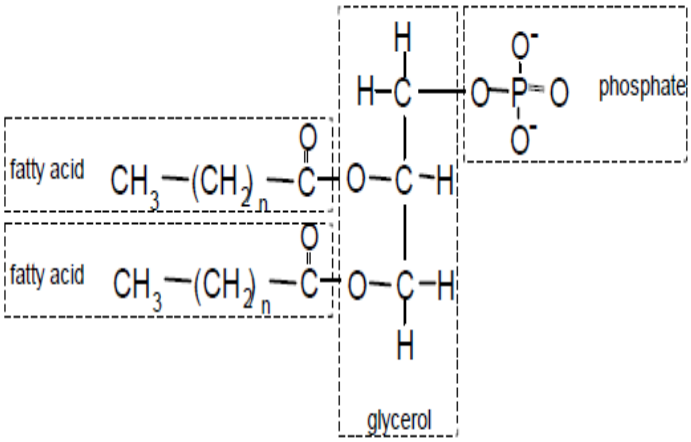


Fig 3.18 pg 92 Soper OR Fig 2.6 pg 21 Toole

Functions of lipids

1. Lipids store more energy than similar quantities of carbohydrates.
   Upon hydrolysis lipids yield more energy than carbohydrates i.e. lipids yield $38KJg^{-1}$ of energy compared to $17KJg^{-1}$ for the carbohydrates. This is so because of many covalent bonds of carbon to carbon (C-C) and carbon to hydrogen (C-H) type that are present in lipids due to many hydrogen atoms they contain. These bonds contain large quantities of energy that can be released and used by the cell when required.
   Therefore carbohydrates yield less energy for the cell but are readily hydrolysed than lipids.
2. Storage of materials
   Lipids are good storage compounds in the body e.g. they store a lot of water and fat soluble vitamins e.g. A, D, E and K. Lipids are good storage compounds because of the following reasons;
   - They are insoluble in water and therefore cannot dissolve away and cannot affect the osmotic potential of the cells
   - They are much lighter than carbohydrates so as to keep the Wight to the minimum
   - They have a high calorific value i.e. they have a high energy content
   - They are compact and therefore they take up very little space in the cells
   - Lipids are poor conductors of heat in the body
3. Lipids insulate the body against heat loss as they are poor conductors of heat. This explains why the major fat deposits of the body are found under the skin as subcutaneous fat layer, and around vital organs such as the heart, kidneys, lungs, intestines e.t.c. whose temperatures should not vary much.
4. Fats are used as packing material around delicate organs of the body such as kidneys, heart, lungs and intestines so as to protect them from physical damage by acting as shock absorbers.
5. Lipids speed up impulse transmission along nerves using the myelin sheath
6. Lipids are useful source of metabolic water for desert animals when broken down in respiration
7. Lipids form very important structures in organisms, the structures include;
   - They form the phospholipid layer of the cell membrane by combining with phosphorous to form the phospholipids
   - They form the subcutaneous fat layer beneath the dermis of the skin
   - They form the waxy cuticle of the insects and plants which prevent excessive water loss

- They form the adipose tissue usually around the delicate organs such as the heart
- They form suberin in plant cell walls especially in endoderm cells

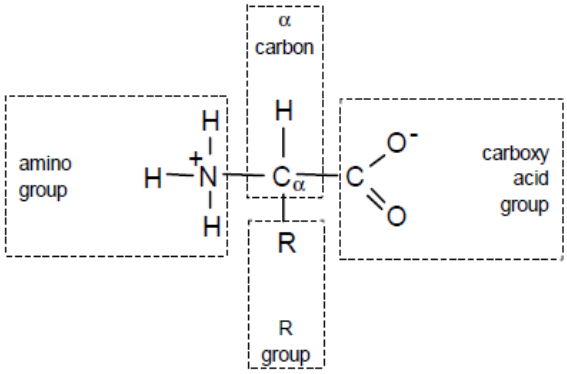
PROTEINS

Proteins are complex organic compounds with a large molecular mass made of carbon, oxygen, hydrogen, nitrogen and in some cases sulphur.

Proteins are the most abundant molecules to be found in the cells and comprise over 50% of their total dry weight. They are therefore an essential component of the diet of animals and may be converted to both fats and carbohydrates by the cells. All proteins are composed of basic structural molecules known as **amino acids.**

AMINO ACIDS

There are 20 common naturally occurring amino acids whose different combinations result in a great variety of the proteins since each amino acid has its own set of properties. The general formula of amino acids is $RCHNH_2COOH$ whose structure is shown below;



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

i) A hydrocarbon group (-CH)

ii) A carboxyl group (COOH)

iii) An amino group (NH_2)

iv) An R group. It is in this R group of the amino acid that lies the difference in the amino acid e.g. in amino acids, glycerine which is the simplest amino acid, R is a hydrogen atom while it's a methyl group (CH_3) in amino acid alanine.

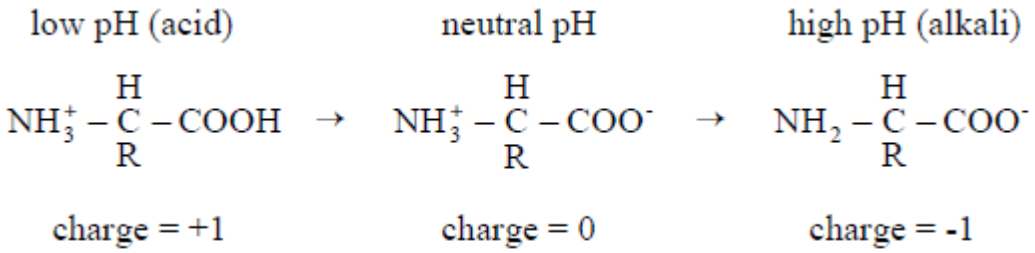
Amino acids are generally soluble in water but insoluble in organic solvents. At neutral pH (found in most living organisms), the groups are ionized as shown above, so there's a positive charge at one end of the molecule and a negative charge at the other end. The overall net charge on the molecule is therefore zero.

The presence of an amino group which is **basic** and a carboxyl group which is **acidic** in all amino acids accounts for the name amino acids and also confer on the amino acids on **amphoteric** nature i.e. amino acids have both acidic and basic properties. This implies that amino acids can donate hydrogen ion (protons) as acids do and also can

accept hydrogen ions (protons) as bases do. In amino acids, these abilities to donate or receive protons are conferred by a carboxyl and amino groups respectively.

Their amphoteric nature is useful biologically as it means that they can act as **buffers** in solutions thereby resisting changes in the pH of the solution. A buffer solution is the one which is able to resist changes in the pH of the solution. Amino acids therefore can donate hydrogen ions as the pH increases so as to lower the pH and also accept hydrogen ions from the solution as the pH decreases so as to raise the pH. Amino acids therefore play an important role as buffer in the tissue fluid and in the cytoplasm of most cells thereby maintaining the pH within the narrow limits needed for normal metabolism and efficient enzyme functioning. This is because changes in pH denature enzyme which can be fatal to the living organism.

The charge on the amino acid changes with pH as shown below;



It these changes in change with pH, that explain the effect of pH on enzymes. A solid, crystallised amino acid has the uncharged structure, $NH_2-\underset{R}{\overset{H}{C}}-COOH$, but this form never exists in solution, and therefore doesn't exist in living things (although it is the form given in most text books)

AMINO ACIDS AND DIET

Amino acids are classified into two groups namely; essential and non essential amino acids.

Essential amino acids

These are the amino acids which cannot be synthesized by the body and therefore must be obtained from the diet. These amino acids include the following;

1. isoleucine
2. leucine
3. lysine
4. methionine
5. phenylalanine
6. threonine
7. tryptophan
8. valine
9. arginine
10. histidine

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

The non-essential amino acids

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

1. Alanine
2. Aspartic acid
3. Glutamic acid
4. Glycine
5. Proline
6. Serine
7. Tyrosine
8. Cysteine
9. Asparagine
10. Glutamine

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

FORMATION OF A POLYPEPTIDE

Initially two amino acids are united in a condensation reaction to form a dipeptide with the loss of a water molecule. Later several dipeptides combine in several condensation reactions to form polypeptides which consist of up to 500 amino acids or more. The individual amino acids within the polypeptide change are linked by peptide bonds to form a protein.

These polypeptides made are then folded and twisted in an appropriate way as directed by a particular gene (DNA) which also determines the sequence of amino acids in the chain. This is illustrated below;

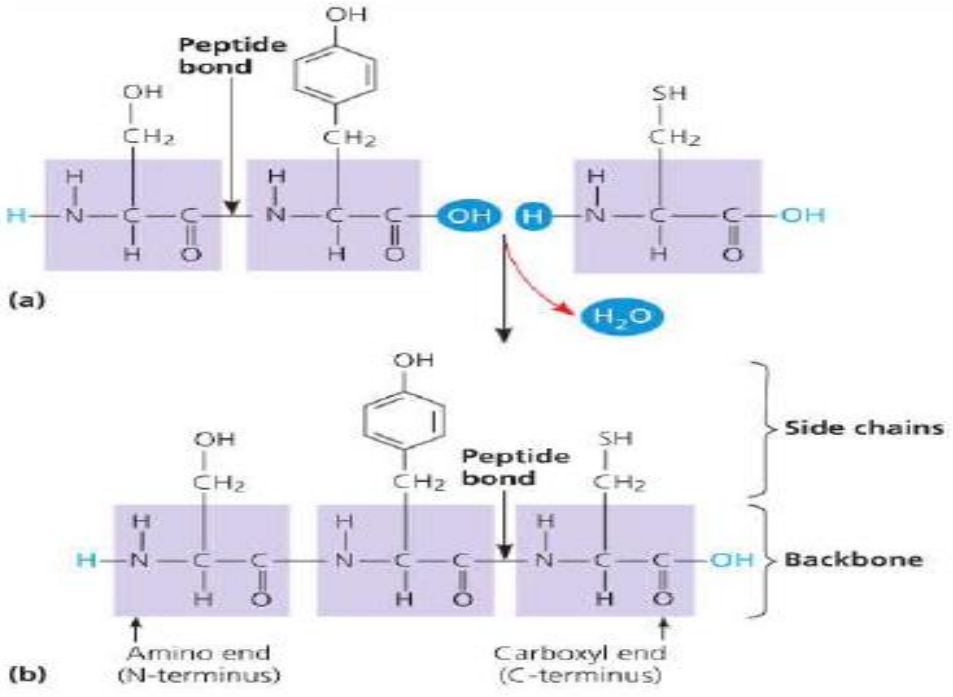


Fig 3.22 pg 95 Soper OR Fig 2.9 pg 28 Toole

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

1. **the ionic bond**

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

2. **the disulphide bond**

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

3. **the hydrogen bond**

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

   All the three types of bonds above are shown below;

Fig 2.11 pg 28 Toole OR Fig 9.28 pg 140 Monger

CLASSIFICATION OF PROTEINS

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

PRIMARY STRUCTURE

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

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

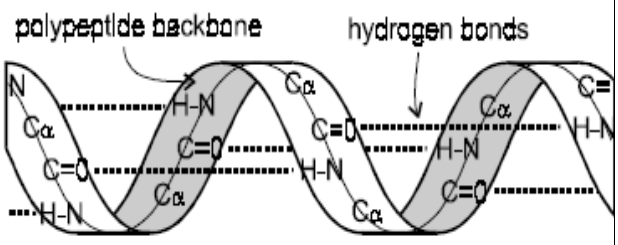
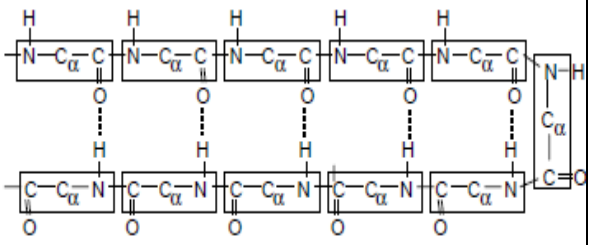
One major importance of the primary structure of the protein in relation to function is found in enzymes, in which the structural configuration of the active site of the enzymes determines whether a particular substrate will fit in the active site of that enzyme.

The primary structure is clearly shown by insulin hormone.

SECONDARY STRUCTURE

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

An alpha-helix is the one in which the polypeptide chain is loosely coiled into a regular spiral shape joined by numerous hydrogen bonds. It is regular in that the repeating constituents of the polypeptide backbone in the spirals are at a specific distances. The β-pleated sheets are chains of polypeptides arranged in a zigzag format with antiparallel strands held together by hydrogen bonds.

α-helix	**β- helix**
	

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

This secondary structure is of greater importance in the biological function of proteins particularly enzymes and antibodies whose efficiency depends on maintaining a particular shape. It is also important in the formation of fibrous proteins which are insoluble in water and are resistant to changes in temperature and pH.

The secondary structure of a protein is of particular importance in the formation of ***structural proteins*** such as keratin, silk and collagen. Keratin is a ***fibrous protein*** found in the hair, nails, horns, feathers and wool. Collagen is also a ***fibrous protein*** found in mammalian connective tissue such as bones, cartilage, tendons and the skin. Both keratin and collagen contain a secondary structure in the form of an alpha –helix.

TERTIARY STRUCTURE

This is a structure resulting from other uniform coiling and folding of the polypeptide helix in to a very compact structure.

For this to happen all the three types of bonds namely, ionic, hydrogen and disulphide bonds must be present in the protein so as to contribute to the maintenance of the structure.

It is the structure which explains the complex molecular shape of some proteins especially ***globular proteins,*** especially enzymes, myoglobin and insulin. This structure contains many cross linkages formed by many bonds within the polypeptide chains which make the proteins strong molecules.

These are soluble in water because they consist of polar groups and amino acids which congregate outside and interact with water. There hydrophobic chains contain non polar amino acids and are usually pushed inwards into the centre of the molecules.

QUATERNARY STRUCTURE

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

Structurally haemoglobin consists of 2 α-polypeptide chains and 2 β-polypeptide chains arranged around a complex ion containing prosthetic groups called haem groups. Such polypeptide chains are normally fitted together in such a way that they form larger and more complex protein structure.

The 4 polypeptide chains in heamoglobin are called globin. Each chain in haemoglobin carries a haem group to which one molecule of oxygen buys.

The structure of haemoglobin is shown below;

Fig 3.36 pg 104 Soper

NOTE

A **prosthetic group** is an organic or inorganic compound fixed on the proteins. If the prosthetic group in a protein is organic in nature then such a group is called a **co-enzyme**. If the prosthetic group is inorganic in nature then such a group is called a **co-factor**.

NUCLEIC ACIDS

These are nitrogen containing organic acids important for making the genetic material and proteins of all organisms.

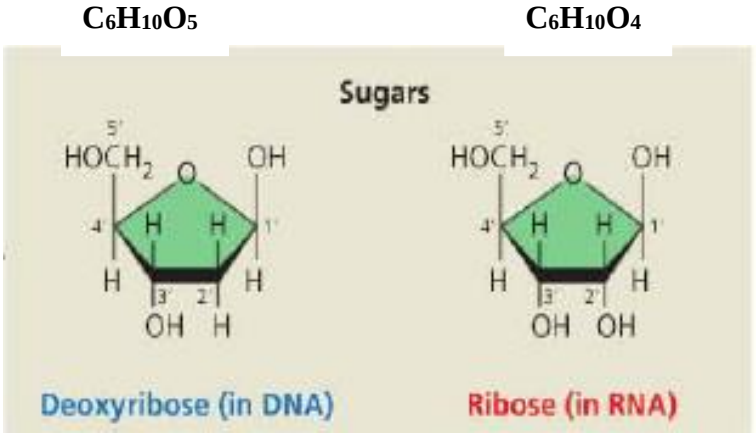
Nucleic acids are made of short chains called **nucleotides**. Nucleic acids include Deoxyribose Nucleic Acid (DNA) and ribonucleic acid (RNA).

THE STRUCTURE OF NUCLEOTIDES

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

A. PENTOSE SUGAR

The pentose sugars in nucleic acids are of 2 types namely; ribose sugar in RNA and deoxyribose sugar in DNA. The only difference between these two sugars is that deoxyribose lacks an oxygen atom on the second carbon atom in the ring; hence the name *deoxyribose*.

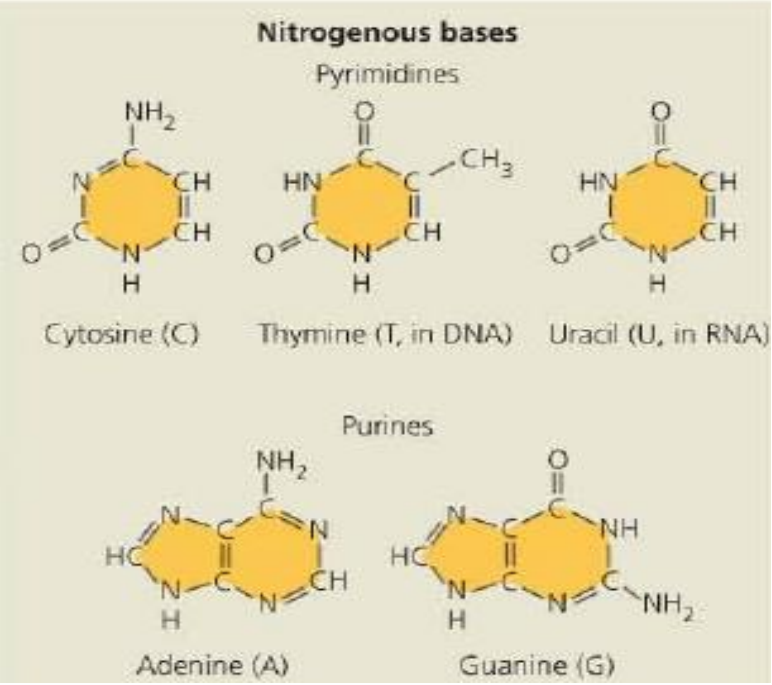


B. NITROGENOUS BASES

Each nucleic acid contains four different bases of which two are derived from ***purines*** and another two are derived from **pyrimidines.** The nitrogen in the rings gives the molecules their basic structure. These bases are;

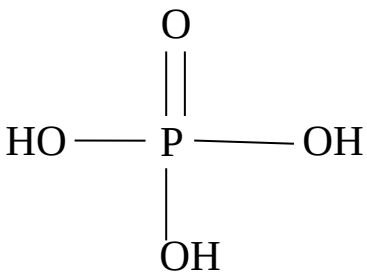
Pyrimidines	Cytosine (C)	Thymine (T)	Uracil (U)
	DNA contains C and T while RNA contains C and U		
Purines	Adenine (A)	Guanine (G)	
	The purines A and G are found in both DNA and RNA		

Purines have two rings in their structure while the pyrimidines have one ring in their structure i.e. purines are larger than pyrimidines. These bases are commonly represented by their initial letters A, G, C, T and U.



C. PHOSPHORIC ACID

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



The three components of nucleotides are combined together by two condensation reactions to give a nucleotide whose structure is shown below

Fig 1 pg 36 Kent OR Fig 3.38 (diagramatically) 106 Soper

By similar condensation reactions between the sugar and a phosphate group of two nucleotides a di-nucleotide is formed. Continued condensation reactions lead to formation of a polynucleotide as shown below;

Fig 6.32 pg 146 Monger

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

RNA (ribonucleic acid)

RNA is a single stranded polymer of nucleotides where the pentose sugar is always ribose and the organic bases are adenine, cytosine, guanine and thiamine.

There are many types of RNA found in cells, 3 of which are involved in protein synthesis. These include the following;

a) Ribosomal RNA (rRNA)

b) Transfer RNA (tRNA)

c) Messenger RNA (mRNA)

RIBOSOMAL RNA (rRNA)

This is a large complex molecule made up of both double and single helices.

Although it is manufactured by the DNA of the nucleus it is mainly ***found in cytoplasm*** where it makes up more than half of the mass of the ribosomes. It comprises of more than a half of the mass of the total RNA of the cell and its sequence is similar in all organisms.

Ribosomes are the site of protein synthesis, at the ribosomes the mRNA code is translated into a sequence of amino acids in a growing polypeptide chain. This is possible because ribosomes are often found in clusters linked together by strands of mRNA. This cluster of ribosomes is known as ***poly-ribosome*** or ***polysome*** and this enables several molecules of the same polypeptide chain to be produced simultaneously.

TRANSFER RNA (tRNA)

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

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

Fig 30.11 pg 493 Roberts OR Fig 23.25 pg 801 Soper

There are at least 20 types of tRNA each one carrying a different amino acid.

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

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

MESSENGER RNA (mRNA)

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

DNA

This is a double stranded molecule containing a base called thymine in addition to other bases.

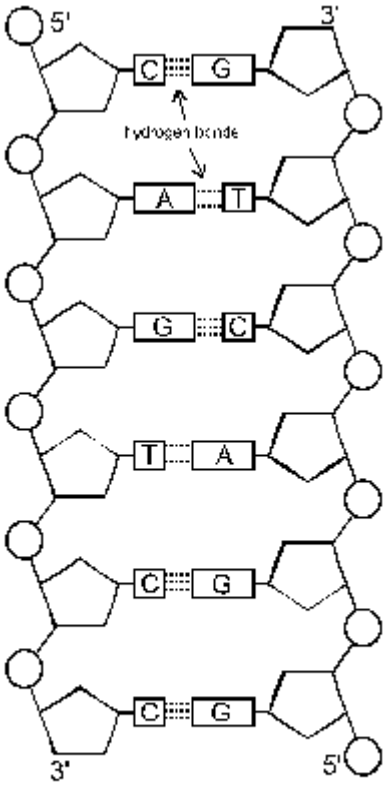
THE STRUCTURE OF THE DNA

(The Watson - Crick Model of the DNA)

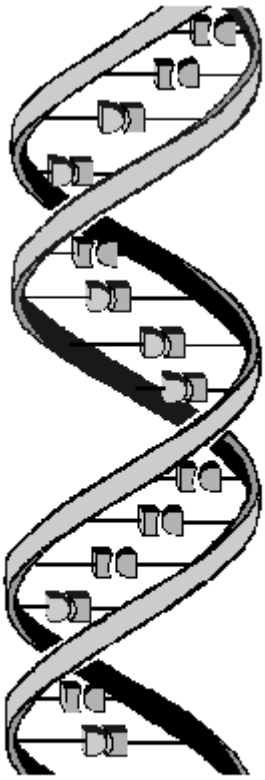
According to Watson and crick, DNA consists of two very long nucleotide chains (DNA double strands) made of repeated nucleotides. Each nucleotide contains a phosphate, deoxyribose sugar and an organic base.

Each chain forms a ***right handed helical spiral*** and the two chains coil around each other to form a double helix. These chains run in opposite directions and the strands making up these chains are joined together by nitrogenous bases between them held by hydrogen bonds between these bases. During which a pyrimidine base must combine with a purine base. Therefore adenine must combine with thymine and cytosine must combine with guanine.

The chains form the sugar phosphate back bone which is made of alternating deoxyribose sugar and phosphates. With this effect, DNA is like a ladder where the alternating deoxyribose and phosphate units form the uprights and the organic base pairing to form the rungs. However, the strands are twisted instead of being like a ladder into a double helix so that each upright winds around the other. Such a double helix structure is shown below;



DNA showing the complementary base pairing between antiparallel strands



DNA showing the double helix

NOTE: the width between the two strands is constant and equal to the width of the base pair i.e. the width is equal to the purine plus the pyrimidine. Two purines would be too large and two pyrimidines would be too small to span the gap between the two chains of DNA. Therefore, adenine must combine with thymine while guanine must combine with cytosine.

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

The amount of guanine is equal to the amount of cytosine in DNA and similarly, the amount of adenine is equal to that of thymine e.g. if a DNA molecule contains 40% of its bases as adenine and thymine, how many bases will be guanine in a DNA molecule?

A and T=40%

G and C=100-40 = 60%

Since the amount of C = the amount of G.

Then the number of guanine bases=60/2=30%

DIFFERENCES BETWEEN RNA AND DNA

RNA	DNA`
It contains fewer nucleotides	It contains very many nucleotides i.e. it is longer than RNA
It is single stranded	It is double stranded
It may be a single or a double helix.	It is always a double helix
The pentose sugar is ribose	The pentose sugar is deoxyribose
It contains uracil	It contains thymine
The ratio of adenine to uracil and cytosine to guanine varies.	The ratio of adenine and thymine to cytosine guanine is constant
It is manufactured in the nucleus but found throughout the cell	It is found almost entirely in the nucleus
The amount varies from cell to cell and within the cell according to metabolic needs.	The amount is constant for all cells of the species except for the gametes where it is half
It exists in three basic forms; tRNA, mRNA and rRNA.	It exists in only one basic form but with an almost infinite variety within that form
It is chemically less stable.	It is chemically more stable.
It may be temporary for short periods	It is permanent.

DNA REPLICATION

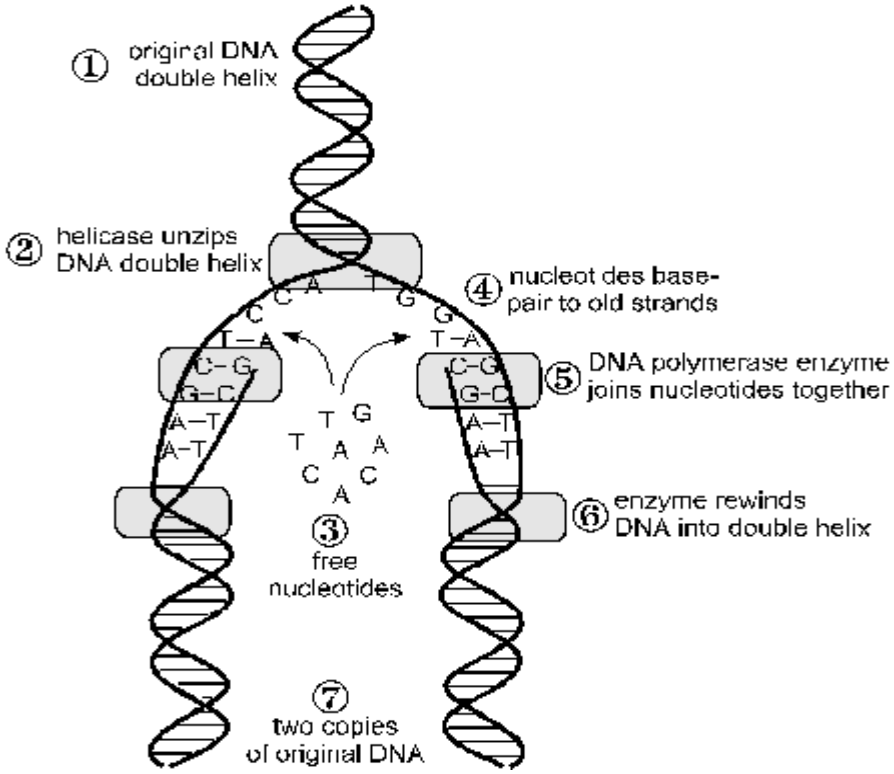
This is the process by which two DNA molecules make exact copies of its self.

This enables the transmission of the same genetic information from cell to cell and generation to generation. Replication is controlled by an enzyme ***DNA polymerase*** which links the DNA nucleotides to form long strands of DNA and ***helicase enzyme*** which causes the unwinding (opening up) of the DNA double strands.

The unzipping (Unwinding or separating) of the DNA double helix is done by helicase enzyme which breaks up the hydrogen bonds between the two complementary bases of DNA. DNA polymerase attaches itself to a single DNA strand. DNA polymerase then starts to move along the strand where it is attached. Each time this enzyme meets the next base on DNA a complementary base is inserted to a growing DNA strand e.g. if this enzyme meets T, A is inserted and if it meets C, G is inserted.

This enzyme continues to move in the 5^1 to 3^1 direction along one strand meeting one base at a time and instructing a complementary base to be added to the new DNA strand growing as this enzyme moves. This replication is possible because the unwinding enzyme helicase moves along the DNA just infront of DNA polymerase separating and unwinding the two DNA strands by breaking the hydrogen bonds between complementary bases.

During replication another enzyme called ***DNA ligase*** closes up the gaps there by joining the 5^1 end of one strand to 3^1 end of the other strand so as to form the new DNA double helix.



Replication is divided into 3 major types mainly;

1. Conservative
2. Semi-conservative
3. Dispersive replication

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

Fig 30.8A pg 488 Roberts OR Fig 4.12 pg 59 Monger

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

Fig 30.8B pg 488 Roberts OR Fig 4.12 pg 59 Monger

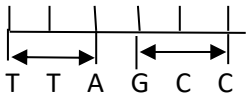
In **dispersive replication**, two new strands are formed each containing alternating old and new bases of nucleotides;

Fig 30.9 pg 489 Roberts

THE GENETIC CODE

The genetic code is the sequence of bases in DNA which codes for the sequence of amino acids in protein molecules. DNA provides the code (Genetic message) for the formation of proteins in an organism which may in turn determine the characteristics of that organism.

Every species possesses different DNA and therefore produces different enzymes. The DNA of the different species therefore differs not in the chemicals which it comprises but in the sequence of base pairs along its length. This sequence of triplet base pairs in DNA and mRNA is the code that determines which proteins are manufactured.



Triplet of bases

DETERMINING THE FIXING OF ONE AMINO ACID IN A POLYPEPTIDE

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

The genetic code is therefore a triplet code of word. Each word specifying the position of an amino acid in the corresponding protein chain

Each word specifies the position of an amino acid in the corresponding protein chain. The triplet code constitutes the codons of mRNA as these codons are directly made from DNA. For example;

This triplet code is also called ***a degenerate code*** since there is more than one triplet for most amino acids i.e. it is a degenerate code because a given amino acid may be coded for by more than one code

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

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

In addition, the genetic code is ***non-over lapping*** e.g. each triplet of bases is read separately UACACCAUGGGC is read as UAC-ACC-AUG-GGC.

Table 23.4 pg 799 OR Table 30.1 pg 498 Roberts

PROTEIN SYNTHESIS

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

There are three main stages in the formation of a protein namely;

1. Transcription
2. Amino acid activation
3. Translation

The process of protein synthesis is summarized in the diagram below;

Fig 23.26 pg 801 Soper

TRANSCRIPTION

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

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

The cistron comes into existence during replication when it unwinds. This unzipping is due to the breaking down of hydrogen bonds between the base pairs in the DNA double helix by ***helicase enzyme***. The unzipping exposes the bases along the cistron.

RNA polymerase then travels along the DNA cistron and new nucleotides complementary to those in the DNA strand are inserted into the growing mRNA strand. When this enzyme encounters thymine, adenine is inserted into mRNA and when it encounters cytosine, guanine is inserted into mRNA.

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

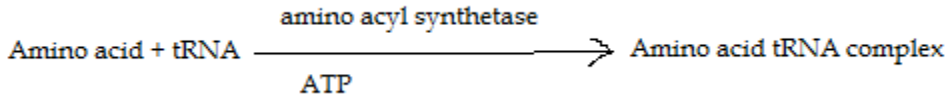
At the end of transcription RNA polymerase recognizes the ***stop sequence*** on the cistron and becomes detached from the cistron at this point.

Being too large to diffuse across the nuclear membrane, mRNA instead diffuses through the nuclear pores to the cytoplasm where it attaches itself on the ribosomes. In this way the instructions needed for protein synthesis is transferred into the cytoplasm inform of **mRNA codon**.

Fig 23.27 pg 802 Soper OR Fig 30.12 pg 494 Roberts

AMINO ACID ACTIVATION

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



TRANSLATION

This is the mechanism by which the codons of mRNA are converted into a specific sequence of amino acids in a polypeptide chain on the ribosomes.

During this process mRNA attaches itself on a group of ribosomes (like beads on a string) to form a structure called ***polysome.*** Within the ribosomes there are two tRNA sites where the mRNA codon can become attached by complementary base pairing to a molecule of tRNA baring the anti-codon.

Fig 23.29 pg 803 Soper OR Fig 30.12 (4) pg 494

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

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

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

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

The following is the evidence to show that DNA is a genetic material

a. The chromosomes which play a role in cell division are made of DNA and histone proteins only. This implies that when a cell divides DNA is carried to the daughter cells formed.

b. DNA is constant in amount in all cells within the species except in gametes where it is a half.

c. It undergoes mutations which are inherited and without which it remains very stable so that the code instructions it contains remains unchanged from generation to generation.

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

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

ENZYMES

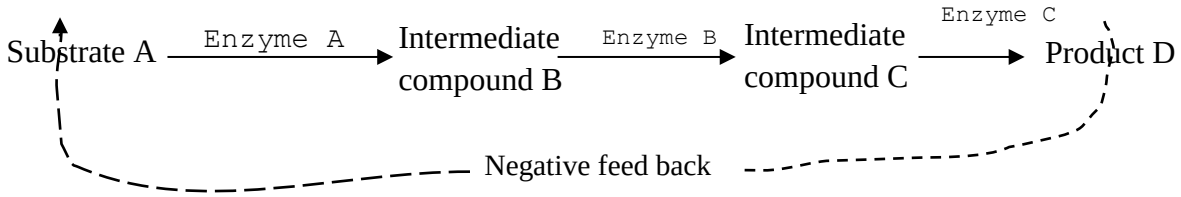
An enzyme is an organic catalyst protein in nature which speeds up the rate of metabolic reactions in an organism without itself undergoing a permanent change.

Without enzymes the reactions that occur in living organisms would proceed so slowly, if at all, to cope up with the rates required for maintenance in life. Also increasing the rate of a body reaction would be by increasing the temperature of the body. This would denature proteins, disrupt membranes and be very expensive in terms of energy expenditure. Enzymes therefore enable metabolic reactions to proceed rapidly and at low temperatures.

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

THE CONTROL OF METABOLIC PATHWAYS

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



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

A single enzyme will catalyse only a single reaction, therefore enzymes serve to control the chemical reactions that occur within the cells and ensure that these reactions proceed at an efficient rate. The cells also make use of the properties of enzymes to exercise control over metabolic pathways as illustrated in the example above. The high concentration of the end product of the pathway may inhibit the enzyme at the start of the pathway this is called ***end product inhibition.***

In the example illustrated above, end product B acts as an inhibitor to enzyme A. If the level of product D falls, this inhibition is greatly reduced and so more of substrate A is converted to B, more of B is converted to C, and finally more of C is converted to D. If the level of end product D rises above normal, inhibition of enzyme A increases greatly and so the level of D is reduced. This is because substrate A will no longer be converted to intermediate compound B. In this way homeostatic control of D is achieved. The mechanism is termed as **negative feedback** because the information from the end of the pathway which is fedback to the start of the pathway has a negative effect i.e. a high concentration of product D reduces its own production rate.

Control of the metabolic pathways has the following advantages;

I. It allows energy to be derived in usable form from many small catabolic reactions than it would be in a single large reaction.
II. It allows substrates to be partially broken down so as to provide raw materials for other reactions in the cell. Some of the intermediate compounds formed in the pathway have increased functions to perform within the cell.
III. It allows the synthesis of complex organic compounds from simple raw materials using the genetic conditions prevailing in the cells which would not be synthesized in one step pathway.
IV. It increases the ability of the cell to control the products made in anabolic pathways when the reactions in them proceed in small steps.

THE STRUCTURE AND MECHANISM OF ACTION OF ENZYMES

ENZYME STRUCTURE

Structurally an enzyme is a complex three dimensional ***globular protein*** some of which have other associated molecules.

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

Only a few of the amino acids of the enzyme molecule actually make up the specific sequence of amino acids that make up the active site. The rest of the amino acids in the enzyme molecule are used to maintain the globular structure of the enzymes.

The specific sequence of amino acids in the active site gives the active site of a **specific configuration**. It is the active site configuration which controls enzyme functioning and properties. It is at the active site that bonding of substrates occurs.

THE MECHANISM OF ENZYME ACTION

Enzymes generally work by lowering the activation energy. Enzymes therefore make it easier for a reaction to take place than it would without them.

Fig 3.2 pg 36 Toole OR Fig 1 pg 42 Kent OR Fig 4.1a pg 117

How an enzyme lowers activation energy of the reaction is explained by a number of mechanisms described below;

THE LOCK AND KEY HYPOTHESIS

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

The substrate molecules combine with an enzyme molecule to form a compound called enzyme substrate complex **complex substrate**. When the substrate binds with the enzyme molecule, the substrate molecules become slightly distorted putting a strain on the bonds of the substrate molecules which results into breaking of these bonds and rejoining them using less energy.

The enzyme-substrate molecule forms an enzyme-end product complex which splits into the enzyme and the end products. The enzyme remains unchanged while the products are released from the active sites since they have a different shape from the substrate.

Fig 2 pg 43 Kent OR Fig 4.2a pg 117 Soper

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

a) It explains the specificity of enzymes because it shows that only substrates with complementary shapes to the active sites can actually fit into the active sites to form products.
b) It explains how enzymes can be used over and over again. In other words, it shows that once the active site is set free at the end of the reaction, another substrate can combine with it to form an enzyme substrate complex.
c) It explains why to some extent the rate, of an enzyme controlled reaction is limited by increasing the substrate concentration. This is so because the reaction is inhibited when all the active sites of an enzyme have been bonded to.
d) It explains why and how enzymes can be inhibited this is because inhibitors having a similar shape to that of the active site of the enzyme may occupy the active site before the substrate and prevent the substrate from occupying the active site hence inhibiting the reaction.
e) It further explains how heating lowers the rate of a controlled reaction. This is because heating denatures the enzyme their by changing its shape which prevents the substrate from fitting into the active site.
f) Also changes in PH break the bonds which maintain the three dimensional shape of the enzyme and as a result change the active site configuration. This makes the substrate fail to fit through the active site.
g) It explains why enzymes are protein in nature because the structure of proteins is based on a sequence of amino acids in their primary structures which sequence also exists in the active sites of enzymes thereby determining the properties of enzymes.
h) It explains how enzymes reduce the activation energy of a chemical reaction by showing that when a substrate binds to the enzyme, substrate molecule becomes slightly distorted which strains the bonds in it and as a result less energy is needed to break the bond.

THE INDUCED FIT HYPOTHEISIS

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

The enzyme in this hypothesis has a binding site configuration which attracts the substrate. On binding to the enzyme the substrate disturbs the shape of the active site and causes it to assume a new configuration. It is this new

configuration which allows the substrate to suit properly in the active site and this enables the formation of an enzyme substrate complex in which the substrate molecules become slightly distorted. This strains the bonds in a substrate and as a result less energy is needed to break these bonds to form an enzyme product complex.

Fig 4.3 (a) pg 118 Soper

PROPERTIES OF ENZYMES

The properties of enzymes can be explained in relation to the lock and key hypothesis and the induced fit hypothesis. These properties include the following;

a) They are protein in nature.
b) They are all produced in living cells.
c) They are soluble in water like any other globular proteins.
d) They are not used up in the reactions they catalyse and therefore can be used over and over again.
e) They work in very small quantities.
f) They remain chemically unchanged by the reactions they catalyse.
g) They are usually specific in their actions.
h) They are denatured at higher temperatures beyond the optimum temperature and inactivated by lower temperatures.
i) They are sensitive to change in pH. PH ranges out of the range in which enzymes work best denature enzyme and make them unable to catalyse reactions.
j) They can work in either direction and this means that their reactions are reversible.
k) Their reactions can be inhibited.
l) They generally work very rapidly in their reactions. Their speed of action is known as the **turn over number** i.e. defined as the number of substrate molecules which molecules of an enzyme turn into products per minute. Some of the fastest enzymes are catalase (turn over number is 6 million) and carbonic anhydrase (turn over 36 million).

THE RATE OF ENZYME CONTROLLED REACTIONS

The rate of an enzyme controlled reaction is measured by the amount of substrate changed into products or

The factors affecting the rate of reactions include the following;

1. The concentration of an enzyme

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

Fig 3.4 pg 37 Toole OR Fig 6.7 pg 70 Roberts OR Fig 4.6 pg 120 Soper

2. Substrate concentration

The rate of enzyme controlled reaction increases with increase in the substrate concentration for a given quantity of an enzyme until such a concentration when all the active sites of an enzyme are saturated. At such concentration the rate of reaction becomes constant or levels. After leveling of the rate of the reaction,

the rate can only be increased by increasing enzyme concentration which would provide new active sites for the substrate.
The increase in substrate concentration increases the interaction between the enzyme molecules and the substrate molecules which increases the rate of collision between the enzyme and the substrate so as to form the products.

Fig 3.5 pg 38 Toole OR Fig 4.7 pg 120 OR Fig 1 pg 44 Kent

3. Temperature

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

a. As the temperature increases the kinetic energy of the substrate and enzyme molecules also increases and so they move fast. The faster these molecules move, the more they collide with one another and therefore the greater the rate of reaction.
b. Secondly as temperature increases more atoms which make up the enzyme molecules vibrate. These vibrations break the hydrogen bonds and other forces which hold the molecules in there precise shape hence changing enzyme active sites. The three dimensional shape of the enzyme molecules is therefore changed by these vibrations as the bonds, hydrogen bonds and hydrophobic interactions, which were holding it get broken to such an extent that the active site no longer allows the substrate to fit. Under these conditions the enzyme is said to be ***denatured*** by the increasing temperature and therefore loses its catalytic x-tics. Therefore increasing the temperature beyond the optimum temperature rapidly denatures enzymes and very low temperatures ***inactivate*** enzymes. At the optimum temperature enzymes attain there maximum activity thereby providing the maximum rate of the reaction. Inactivated enzymes are not denatured and therefore they can regain their catalytic properties when higher temperatures are provided.

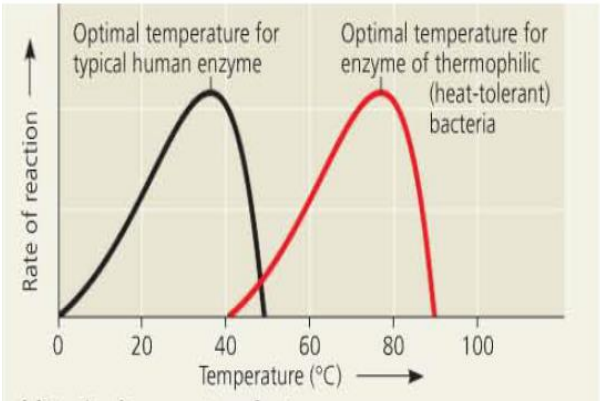


Fig 3.6 pg 38 Toole OR Fig 6.6 pg 89 OR Fig 4.8 pg 120 Soper

4. PH

The hydrogen bonds which make up the three dimensional molecular shape of the enzyme may be broken by the concentration of hydrogen ions present. PH is the measure of the hydrogen ion concentration. By breaking the hydrogen bonds which give enzyme molecules their shape, any change in the pH can effectively denature enzymes. Each enzyme works best at a particular pH and deviations from this optimum pH may result into denaturing of these enzymes.

Fig 3.7 pg 39 Toole OR Fig 4.9 pg 121 Soper

5. Inhibition

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

I. Competitive inhibition.
II. Non- competitive inhibition.

Competitive inhibition

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

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

Melanic acid is an example of a competitive inhibitor.

Fig 3.8 Pg 39 Toole OR Fig 1 pg 46 Kent OR Fig 4.12a pg 124 Soper

Non- competitive inhibition

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

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

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

Fig 2 pg 46 Kent OR Fig 3.9 pg 39 Toole OR Fig 4.14 pg 125 Soper

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

Fig 4 pg 47 Kent

Importances of enzyme inhibitors

i. They provide important information about the shapes and properties of the active site of an enzyme.

ii. They can be used to block particular reactions thereby enabling bio-chemists to re-construct metabolic pathways

iii. They can be used in medicine and agriculture e.g. as drugs and pesticides respectively.

iv. Enzyme inhibition is also used to control the metabolic pathways by regulating the steps in them. This usually occurs during end product inhibition.

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

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

CLASSIFICATION OF ENZYMES

TYPES OF ENZYMES

An enzyme name consists of the following;

a. The name of the substrate acted upon by the enzyme e.g. succinate dehydrogenase acts on succinic acid.
b. The type of the reaction it catalyses e.g. dehydrogenation, hydrolysis, polymerization, decarboxylation e.t.c.
c. Suffix-ase. This is illustrated by the following examples;
    i. DNA polymerase which catalyze the formation of DNA by polymerization of DNA nucleotides
    ii. RNA polymerase which catalyses the formation of RNA by polymerization of RNA nucleotides.
    iii. Cytochrome oxidase catalyses oxidation reactions of cytochrome proteins

ENZYME GROUP	TYPE OF REACTION CATALYSED	EXAMPLES
Oxido reductase	These catalyse the transfer of oxygen and hydrogen atoms between substances i.e. they catalyse redox reactions	Oxidase Reductase
Transferases	These catalyse the transfer of one chemical group from one substance to another.	Transaminases Phosphorylase
Hydrolases	These catalyse hydrolysis reactions	Lipases Peptidases Phosphatases

Lyases	These catalyse the addition or removal of a chemical group other than hydrolysis.	Decarboxylases
Isomesares	These catalyse the re-arrangement of groups within a molecule. In other words it converts one isomer into another	Isomesales Mulales
Ligases	This catalyses the formation of bonds between two molecules using energy derived from the breakdown of ATP	Synthetases

ENZYME CO-FACTORS

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

Activators

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

$$\text{Prothrombin} \xrightarrow[Ca^{2+}]{\text{Thrombokinase}} \text{Thrombin}$$

Co-enzymes

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

Prosthetic group

This is a non-protein organic or inorganic substance which is essential for the efficient functioning of some enzymes and it bound to the enzyme.

INDUSTRIAL APPLICATIONS OF ENZYMES

i. They are used in making biological detergents which are usually made using proteases produced in an extra-cellular form from bacteria
ii. They are used in baking industry in which fungal α-amylase enzymes which catalyses the breakdown of starch in the flour to be used.
iii. They are used in making baby foods which contain trypsin used to pre-digest the baby foods.
iv. They are used in the brewing industry which uses enzymes produced from cereals during beer production to produce simple sugars from starch which is used by the yeasts during fermentation to enhance alcohol production.
v. They are used in the dairy industry where an enzyme rennin derived from the stomach of young ruminant animals is used to manufacture cheese. In addition lactose breaks down lactose glucose and galactose.
vi. The rubber industry uses catalase enzyme to generate oxygen from peroxides so as to convert latex to form rubber.

vii. They are used in the paper industry which uses amylase to degrade starch to a lower viscosity product needed for sizing and coating paper.

viii. They are used in the photographic industry which uses protease to dissolve gelatin away from the scrop films thereby allowing the recovery of the silver present.

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