CHEMICALS OF LIFE

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Syllabus extract

Content ***Acids, bases, salts and vitamins.***	**SPECIFIC OBJECTIVES** *The learner should be able to:*
• Properties of acids, bases, and vitamins • Functions of acids, bases, mineral salts and vitamins in organisms.	• Describe properties of acids, bases and vitamins. • Explain the role of acids, bases, salts and vitamins in maintaining a stable internal environment for physiological processes.
• Test for presence of mineral salts in food samples/extracts ***(refer to inorganic analysis in chemistry practical)*** • Testing for Vitamin C. • Effects of heat on vitamin C content in	***Mineral salts, to organic*** • Identify salts using quantitative and qualitative analysis. • Test for Vitamin C. • Demonstrate the effect of heat on vitamin C content in vegetables.

vegetables. • Effects of storage on quality of fresh foods.	• Demonstrate the effect of storage on quality of fresh foods.
• Molecular structure of water. • Functions of water. • Water as a solvent. • Role of water in the life of organisms (Biological significance in relation to properties water.) • Testing for water • Measuring water content in tissues • Field study on water habitats. ***(The natural relationship of water and organisms).***	***Water & practical*** • Describe the molecular structure of water. • State functions of water. • Explain the importance of water as a solvent. • Relate the water properties to its role in the life of organisms ***(biological significance)*** • Test for water • Curry out dry weight technique to determine water content in tissues • Explain the natural relationship of water and organisms in a habitat (including humans)
• Structure and components of carbohydrates. • Properties of carbohydrates. • Importance of carbohydrates: monosaccharide, disaccharides, polysaccharides • Condensation of carbohydrates. • Hydrolysis of carbohydrates.	**Structure of Carbohydrates** • Describe the structure and components of various carbohydrates • Explain properties of carbohydrates. • Explain the functions of carbohydrates in organisms. • Describe condensation of carbohydrates. • Describe hydrolysis of carbohydrates.
• Testing for carbohydrates • Hydrolysis of non-reducing sugars to reducing sugars	**Test for carbohydrates Practical** • Carry out food test for carbohydrates on food samples / extracts. • Demonstrate hydrolysis of non reducing sugars.
• Structure and components of lipids molecules. • Properties of lipids. • Importance of lipids • Steroid structure. • Effects of lipids and Steroids to organisms • Condensation of fatty acids and glycerol to form lipids. • Hydrolysis of lipids to fatty acids and glycerol.	**Structure of Lipids.** • Describe the structure and components of lipid molecules. • State properties of lipids. • Explain the functions of lipids in the organisms. • Describe structure of steroid. • Explain effects of lipids and steroids to organisms • Describe the condensation of fatty acids and glycerol.

• Comparison between waxes and lipids. • Importance of cholesterol in organisms.	• Describe the hydrolysis of lipids. • Compare waxes and lipids. • State the importance of cholesterol in organisms.
• Tests for Lipids • Food samples /extracts containing lipids	**Test for lipids practical** • Carry out food tests for lipids on food samples extracts/ extracts • Identify food samples/extracts containing lipids.
• Structure and components of proteins • Properties • Importance of proteins • Functions of proteins (buffer, enzymes/catalytic, growth, carriers e.t.c.) • Condensation of amino acids • Hydrolysis of proteins • Effects of heat on peptide bond linkages or formation in amino acids/ proteins	**Structure of proteins** • Describe the structure and components of proteins. • Describe the properties of proteins • Explain the importance of proteins • Explain the functions of proteins to organisms. • Describe condensation of amino acids. • Describe hydrolysis of proteins. • Explain effects of heat/temperature changes on proteins.
• Testing for proteins.	**Test for proteins practical** • Carry out food tests for proteins on food samples / extracts
• Criteria of naming enzymes. (Use of suffix –ase, intracellular and extracellular.) • Characteristics of enzymes: Protein in nature i.e. can be denatured. • Properties of enzymes relating to factors affecting enzyme activities. Catalytic/change rates of reactions. Work in small amounts. Specific to reactions they catalyze. Reversible reactions. Can be inhibited. Affected by temperature, pH, concentration of substrate and enzymes. • Factors affecting enzyme action pH, temperature, inhibitors, substrate concentration etc. • The lock and key mechanism of enzyme action. **Induced fit** • Role of enzymes in living organisms including inhibition,	**Enzymes** • Describe the criteria for naming enzymes • Explain characteristics of enzymes • Explain the properties of enzymes • State factors that affect enzyme action • Explain the lock and key mechanism of enzyme action • Explain the role of enzymes in the organisms' life

competitive/noncompetitive, reversible/non reversible	
• Enzyme properties relating to factors (temperature and pH, concentration of substrate and enzyme) affecting enzymes' activities. • Enzymes in the different parts of the gut based on their actions on different food substances. • Food tests using the animal gut contents and enzymes.	**Enzymes** • Demonstrate properties of enzymes action in specific temperature, pH range, substrate/enzyme concentration. • Identify enzymes in the different parts of the gut based on their actions on different food substances. • Carry out food test on gut contents.

Introduction

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 acids, bases, water and inorganic mineral salts such as calcium, magnesium, potassium, nitrates, chlorine, phosphates e.t.c.

ACIDS AND BASES

Acids

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

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

A PH of 7 represents neutrality while a pH below 7 represents acidity while that above 7 represents alkalinity or basis.

Functions of acids

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

Bases

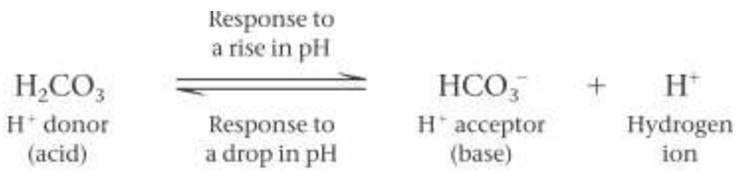
A base is a compound, which can react with acids to produce a salt and water only. Some bases are alkalis. An alkali on the other hand is a substance which when dissolved in a solvent produces hydroxyl ions as the only charged ions. This implies that alkalis are bases but not all bases are alkaline. Strong alkalis completely ionize e.g. $NaOH(aq) \longrightarrow Na^{+}{}_{(aq)} + OH-$ Weak alkali don't ionize completely e.g. ammonium hydroxide	**Functions of bases** • Provide an optimum pH range for enzyme activity e.g.in the duodenum • They are buffers in the body

Buffers

A buffer is a substance that minimizes changes in the concentrations of H^+ and OH^- in a solution when small amounts of acids or bases are added.

The internal pH of most living cells is close to 7. Even a slight change in pH can be harmful because the chemical processes of the cell are very sensitive to the concentrations of hydrogen and hydroxide ions. The pH of human blood is very close to 7.4, which is slightly basic.

Carbonic acid (H_2CO_3), which is formed when CO_2 reacts with water in blood plasma dissociates to yield a bicarbonate ion ($HCO3^-$) and a hydrogen ion (H^+):



The chemical equilibrium between carbonic acid and bicarbonate is a pH regulator, the reaction shifting left or right as other processes in the solution add or remove hydrogen ions.

Thus, the carbonic acid–bicarbonate buffering system consists of an acid and a base in equilibrium with each other. Most other buffers are also acid-base pairs.

Consider the reactions below;

$HCO3^-_{(aq)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)} + OH^-_{(aq)}$

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

from the above equations, it is clear that $NaHCO_3$ removes ions from aqueous solutions thereby lowering the aqueous solutions acidity in so doing it is working as buffer however, though sodium hydrogen carbonate works as a buffer on its own, in most cases two or more compounds interact to form a buffer solution or system.

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

Salts e.g. K_3PO_4 Na_3PO_4 etc combine with hydrogen ions to form $H_2PO_4^-$ (Di-hydrogen phosphate).

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

Certain organic compounds like proteins and haemoglobin can also accept H^+ and are therefore important as buffer. Since they occur in higher ions, than the phosphate salts they are even more important than the acids and the bases. The biological importance of these buffers is that cells and tissues can only function properly at a narrow range of pH, which is usually around neutrality.

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

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

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

MINERAL ELEMENTS

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

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

Functions of mineral salts

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

The mineral ions in the body can be grouped as major or minor ions depending of their need in the body. **Major/ macro** ions are needed fairly in large amounts than **minor ions**.

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,		Muscular weakness, paralysis, nausea , heart failure

	many fruits and vegetables,	Acid-base balance , water balance and nerve function, cofactor in photosynthesis and respiration	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	Whole grains, green leafy vegetables	Co-factor, ATP synthesis	Nervous system disturbance 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

WATER

a) Structure

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 (*figure 1*) and the angle between the nuclei of the atoms is approximately 105°. Overall the molecule is electrically neutral, but in both of the oxygen-hydrogen bonds, the oxygen draws electrons away from the hydrogen nucleus. Thus there is a net negative charge on the oxygen atom and a net positive charge on the hydrogen atom. A molecule that carries an equal distribution of electrical charge (*figure 2*) is called a **polar molecule**. **Polarity** is uneven charge distribution within the molecule. In water one part or pole of the molecule is slightly negatively charged and the other slightly positive, this is known as **dipole**. This occurs because the oxygen atom has a greater electron attracting power (electronegativity) than the hydrogen atoms. As a result, the oxygen atom pulls the bonding electrons more towards itself than towards hydrogen. These attractions are not as strong as normal ionic or covalent bonds and are called **Hydrogen bonds**.

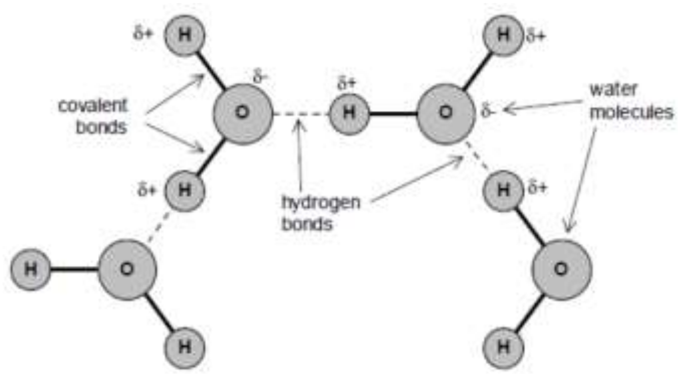


Figure 1

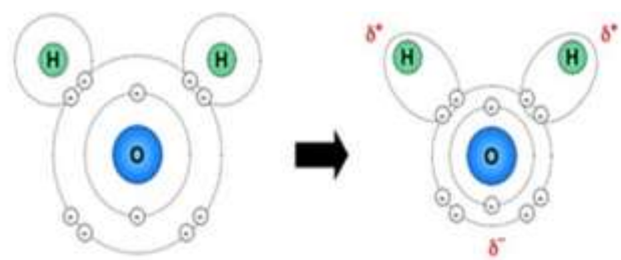


Figure 2

They are constantly formed, broken and reformed in water although individually weak their collective effect is responsible for the unusual properties of water.

Because of this charge separation, water is an overall neutral molecule. Water molecules form relatively weak **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.

b) Functions

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

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 specific 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 vaporization

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. The transition of water from a liquid to a gas requires the input of energy to break its many hydrogen bonds, the evaporation of water from a surface causes cooling of that surface. This is made use of as a cooling mechanism (evaporative cooling) in animals (sweating and panting) and plants (transpiration). As water evaporates it extracts heat from around it, cooling the organism. 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 from ice to liquid water. 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 relatively warmer water below. 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 least 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 (*figure 3*)

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

Figure 3

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.

11. Water is denser than air

Water supports organisms as large as whales. It also supports and disperses reproductive structures such as larvae and large fruits e.g. coconuts.

12. pH

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

13. Water has a low viscosity

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

- The significance of this property is that water can easily be pumped and moved in the small tubes of the body.
- Water also forms a medium within which swimming is made easy.
- Water can flow freely through narrow vessels.
- Watery solutions can act as a lubricant

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

Plants rely on the flow of water in the xylem and phloem vessels to transport substances around their bodies.

Aquatic organisms too are able to swim in water because of the relatively low viscosity of water.

BIOLOGICAL IMPORTANCE OF WATER TO ALL ORGANISMS

Metabolic role of water

i. Hydrolysis
Water is used to hydrolyse many substances like proteins to amino acids, fats to fatty acids and glycerol, starch to maltose,

ii. Medium for chemical reactions
All biochemical reactions take place in aqueous medium provided by water.

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

iv. Photosynthetic substrate
Water is a raw material for photosynthesis

Water as a solvent

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

i. Transport
The solvent properties of water mean that it is a transport medium, as it is in blood plasma, tissue fluid, lymph, in mammals and Xylem and Phloem in plants. They are all made up of water and dissolve a number of substances which can then be easily transported.

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

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

Water as a lubricant

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

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

Supporting role of water

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

i. Hydrostatic skeleton
Animals like earthworms are supported by the pressure of the aqueous medium within them.
ii. Turgor pressure
Herbaceous plants and herbaceous parts of woody plants are supported by osmotic influx of water into their cells.
iii. Humours of the eye
Aqueous and vitreous humours give the shape of the eye and they are mainly made up of water.
iv. Amniotic fluid
It supports and protects the mammalian foetus during development and is mainly made up of water.
v. Erection of the penis
The pressure of blood which is mainly made up of water makes the penis erect for copulation to take place.
vi. Habitat
Water supports organisms that live in it. Very large organisms like whales return to water as their sizes make movement on land very difficult.

Other biological functions of water include

- Water enables dispersal of seeds and fruits such as coconut as well as dispersal of the gametes and larval forms of aquatic organism. Medium of dispersal i.e. seed dispersal, gametes and larvae stages of some aquatic organisms
- Seed germination
- Osmoregulation
- Migration of aquatic organisms
- Fertilization, by transporting gametes
- Hearing and balance. The watery endolymph and perilymph in the mammalian ear plays a significant role in hearing and balancing
- It breaks the testa of seeds to allow embryo growth during germination.
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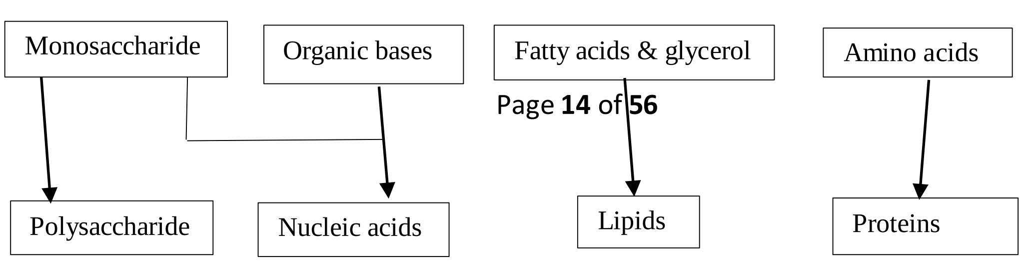
THE ORGANIC CHEMICALS OF LIFE

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**

The building blocks of life



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. The word carbohydrate suggests that these organic compounds are hydrates of carbon. 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, $C_5H_{10}O_4$

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.

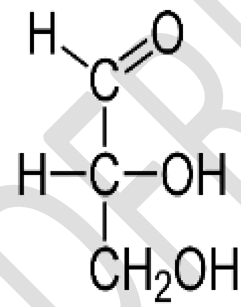
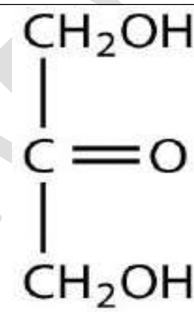
Chemically carbohydrates have the following properties;

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

There are 3 groups of carbohydrates namely;

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

MONOSACCHARIDES

These are a group of sweet, soluble, crystalline molecules of relatively low molecular mass made of a single sugar. They 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*** (*figure 4*) such as glyceraldehyde**.** If they contain a ketone  group in their molecules, they are called ***ketoses*** or ***keto-sugars*** (*figure 5*) such as dihydroacetone**.**). **Note:** The carbon atom with a double bond in Aldehydes is at the end of the chain while in Ketones it is on the second carbon or on the carbon next to last	 *Figure 4*	 *Figure 5*

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*** (e.g. glyceraldehyde and dihydroxyacetone), where n=5, ***pentose sugar*** (e.g. Ribulose and ribose) and when n=6 ***hexose sugar*** (e.g. mannose, fructose, galactose, glucose, sorbose).

The names of monosaccharides end with a suffix – ose.

Monosaccharides have ringed structure (*Figure 6*) 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.

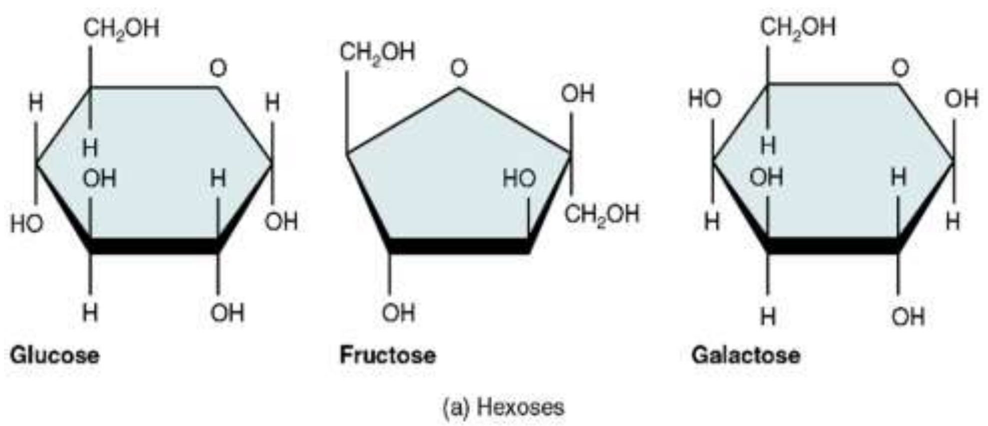


Figure 6

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.

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

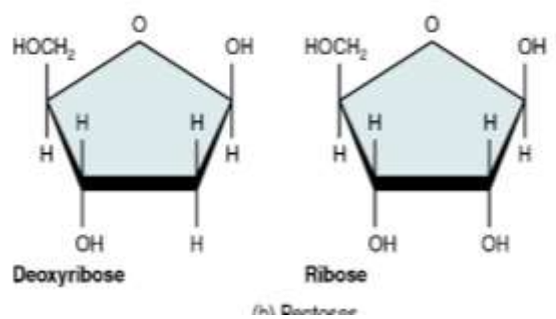


Figure 7

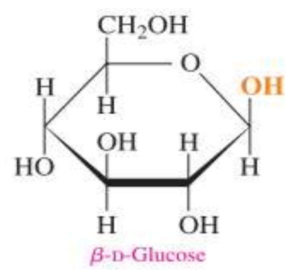
Most of the monosaccharides are the ***reducing sugars*** because they reduce Cu^{2+} in Benedict's solution to Cu^{+} ions giving an orange precipitate of copper (1) oxide (Cu_2O). They have an aldehyde group or a free ketone group. Ketoses first isomerise to aldoses before they can act as reducing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

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

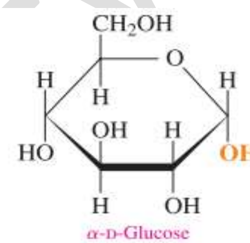
GLUCOSE ($C_6H_{12}O_6$)

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

β - glucose (beta glucose)

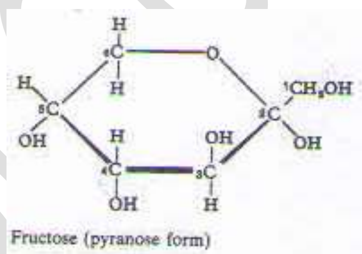


α- glucose (Alpha glucose)



Fructose ($C_6H_{12}O_6$)

Pyranose (β – fructose)



Furanose (α- fructose)

Importance of monosaccharides

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

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

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

Hexoses e.g. glucose, fructose, galactose

v. Source of energy when <u>oxidised</u> in respiration; glucose is the most common monosaccharide.
vi. Synthesis of disaccharides; two monosaccharide can link together to form a disaccharide.
vii. Synthesis of polysaccharides; glucose is particularly important in this role

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** through the loss of small molecules usually water**.** A condensation reaction between the hydroxyl groups at carbon 1 of one monosaccharides and carbon 4 of the other results in a bond called **1-4 glycosidic bond.** If the reaction is between the hydroxyl groups at carbon 1 and carbon 4, **1-6 glycosidic bond.**

The addition of water, under suitable conditions, is necessary if the disaccharide is to be split into its constituent monosaccharides. This is called ***hydrolysis*** i.e. breakdown by water.

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.

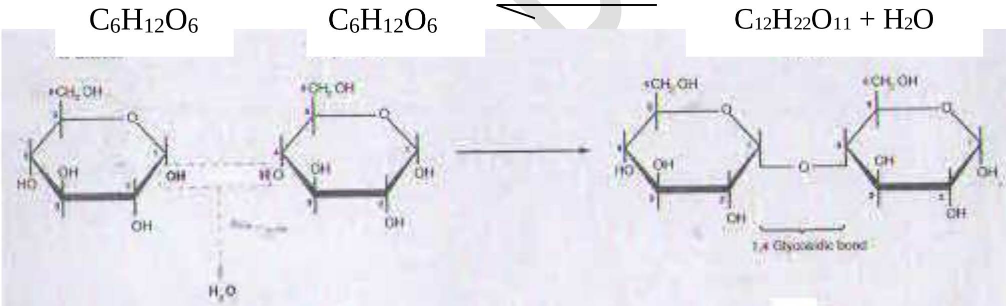
Like monosaccharides, disaccharides are also sweet, soluble in water and crystalline like monosaccharides

Formation of disaccharides

This is illustrated by the following example

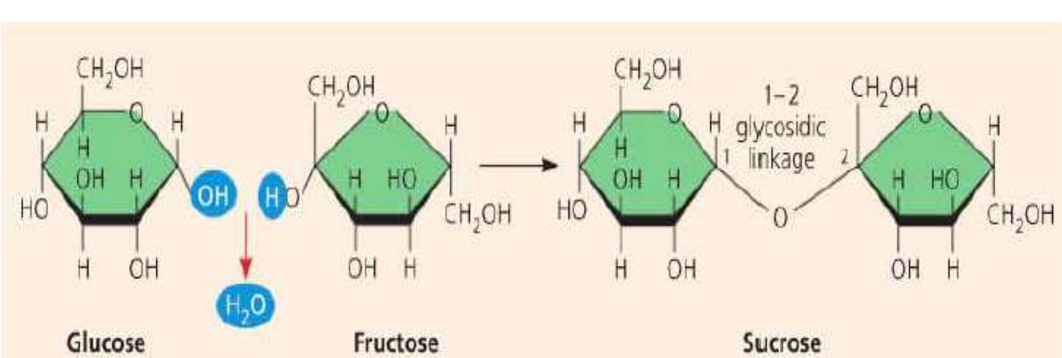
α- glucose + **α- glucose** $\rightleftharpoons$ **α- maltose + water**

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

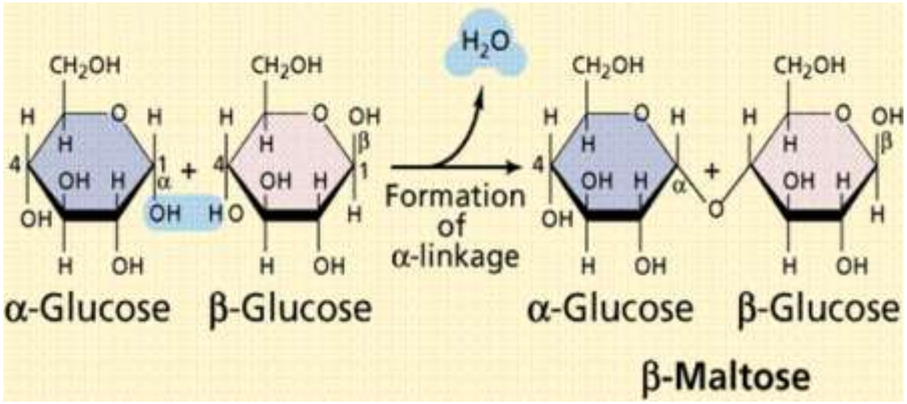


α- glucose + **α- fructose** $\rightleftharpoons$ **α- sucrose + water**

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



β- glucose		**β- glucose**		**β- maltose + water**
$C_6H_{12}O_6$	+	$C_6H_{12}O_6$	⇌	$C_{12}H_{22}O_{11} + H_2O$



Note. Monosaccharide monomers may also combine other types of molecules to form **conjugated molecules.** Chains of monosaccharide units can combine with lipids to form glycolipids, or with proteins to form glycoproteins. These molecules are important in the cell membrane.

Functions of disaccharides

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

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

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

POLYSACCHARIDES

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 in organisms because they cannot diffuse out of the cell and they do not affect the osmotic potential of the cells.

The most common polysaccharides are ***starch, cellulose*** and ***glycogen***. Other polysaccharides include inulin and chitin. All polysaccharides are non- reducing sugars.

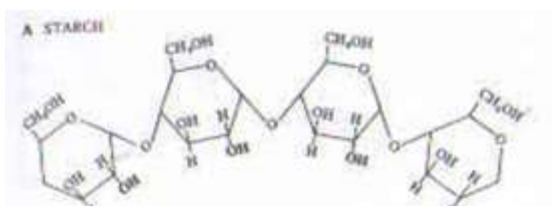
Upon hydrolysis, polysaccharides can be converted into their constituent monosaccharides such as glucose, ready for use as a respiratory substrate.

Polysaccharides are normally used for food storage because; -

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

STARCH

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.

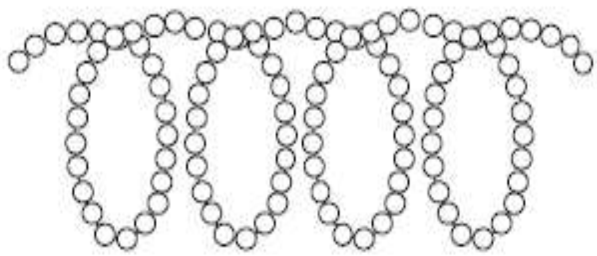
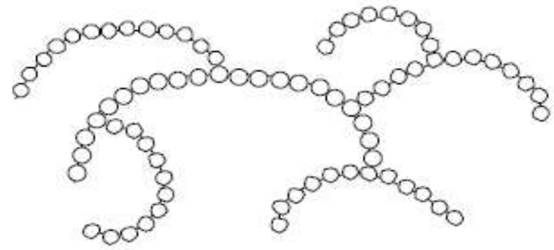


Starch is made up of many **alpha glucose** molecules which is found in most parts of the plant. Starch is made from excess glucose produced during photosynthesis and it is the reserve food in plants. It is common in the seeds of most plants such as maize where it forms the food supply for germination.

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

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.
	

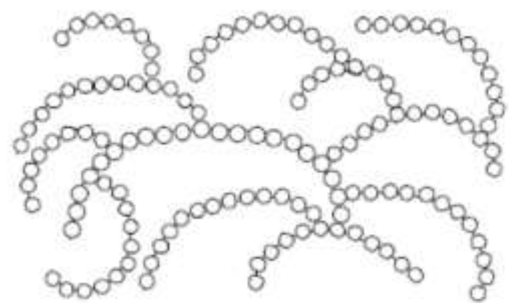
GLYCOGEN

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.



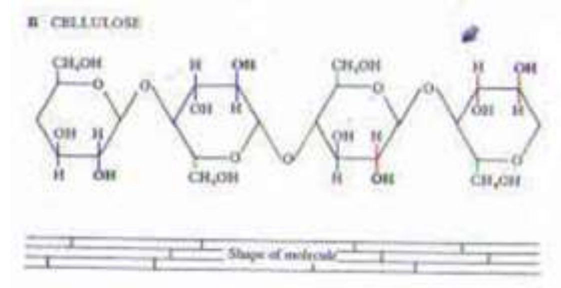
CELLULOSE

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

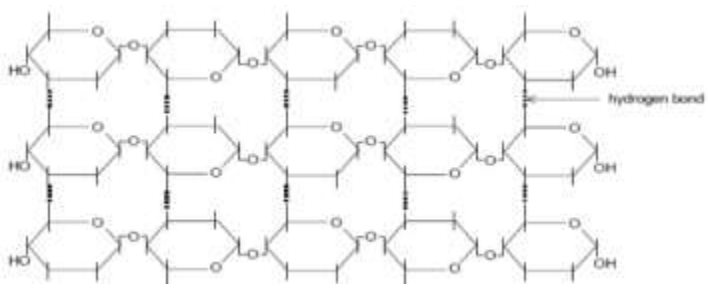
It is mainly found in plants because it is the main structure material in plant cell walls and in cotton it makes up to 90%.

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.



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. It is also food for some bacteria and protozoans

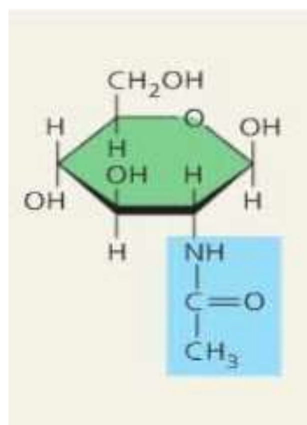
OTHER POLYSACCHARIDES

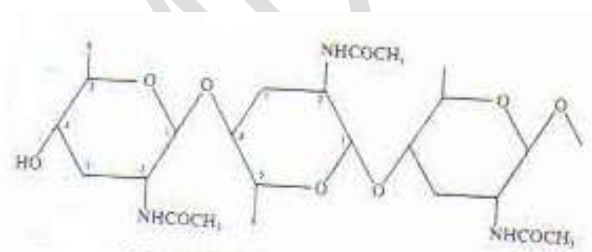
These include the following;

CHITIN

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

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.





Structure of chitin.

2. SUGAR DERIVATIVES

Some compounds contain sugar molecules linked with other non-sugar compounds, such compounds are called sugar derivatives. Some of these are described below;

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.***

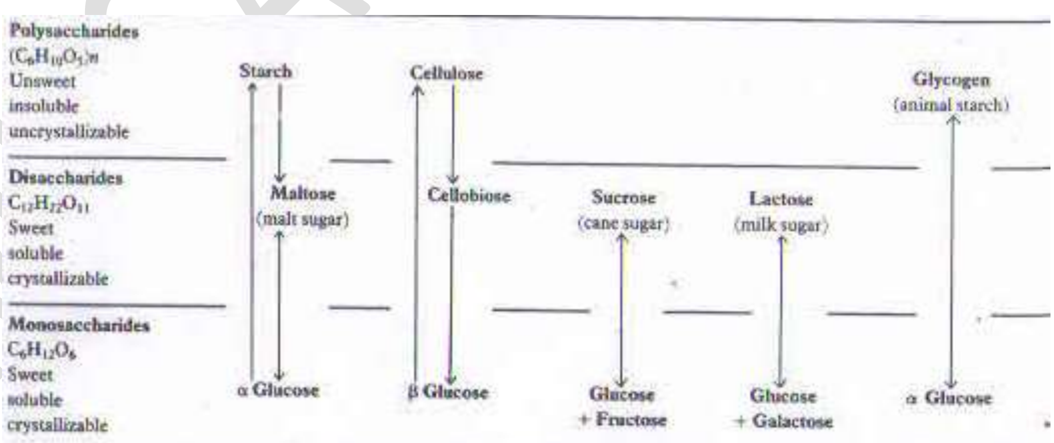
   ii. Other mucopolysaccharides are mainly found in the cell walls of prokaryotes such as bacteria.

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).

3. **Inulin** is an unbranched chain of fructose with 1-2 glycosidic bonds found as a storage carbohydrate in some plants

4. **Chitin** is an unbranched chain of β-acetylglucosamine units with 1-4 glycosidic bonds

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



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

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

Main functions of carbohydrates

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

Chemical tests for polysaccharides

Starch

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

Cellulose

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

LIPIDS (fats and oils)

Lipids are 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. 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, benzene, acetone, alcohols e.t.c. 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. Lipids also include **waxes**, **steroids** and phospholipids.

CONSTITUENTS OF LIPIDS

Lipids are made up of ***esters*** called fatty acids and an alcohol of which glycerol is the most common.

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.

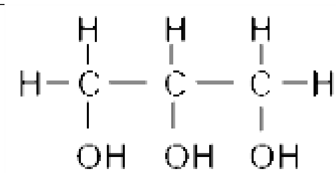
Fatty acids	***Formula***	***Saturation***	***Sources***
Linolenic acid	$C_{17}H_{31}COOH$	Unsaturated	Vegetable oil
Linoleic acid	$C_{17}H_{31}COOH$	Unsaturated	Sunflower oil
Oleic acid	$C_{17}H_{33}COOH$	Unsaturated	Olive oil
Palmitic acid	$C_{15}H_{31}COOH$	Saturated	Palm oils
Stearic acid	$C_{17}H_{35}COOH$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

Fats differ from oils in two fundamental ways;

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

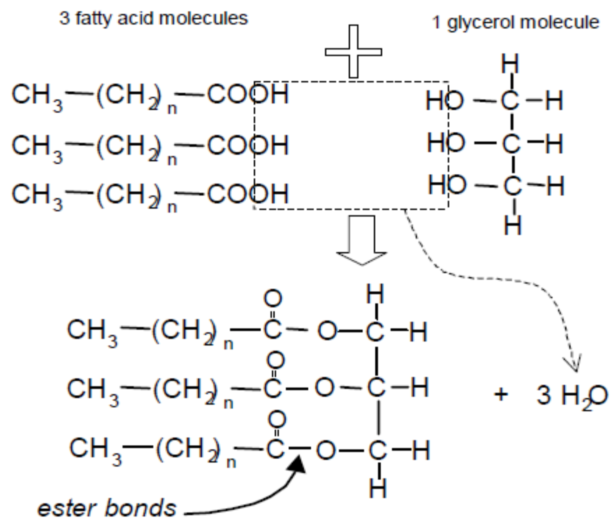
GLYCEROL (Propan-1, 2, 3-triol)

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 **on the right**



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 on the right;



a) 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.

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

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 reduction in the growth rate, reproductive deficiency and even kidney failure.

STEROIDS AND WAXES

WAXES	STEROIDS
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. They may also be used as a form of storage in a few compounds such as castor oil and in fish.	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	

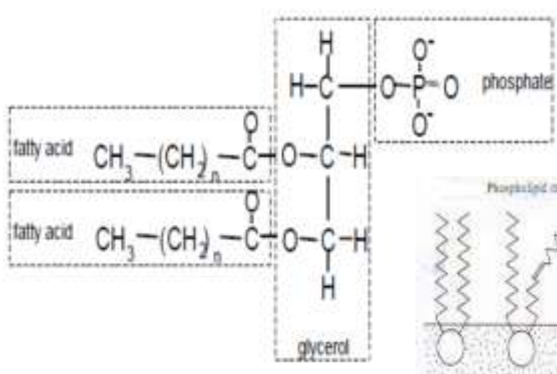
a. Oestrogen and progesterone b. Testosterone	These are reproductive hormones in female mammals which regulate the menstrual cycle and controlling pregnancy This is a reproductive hormone in male mammals controlling sexual behavior and sperm production.
Vitamin D (Calciferol)	It promotes calcium and 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)

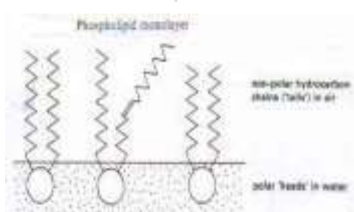
PHOSPHOLIPIDS

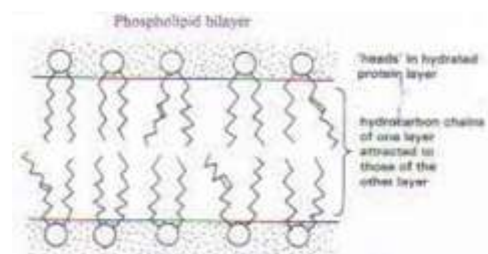
A phospholipid differs from having a phosphate group (PO_4^{3-}) group attached to one of the hydroxyl groups of glycerol such that they have two fatty acids linked to glycerol by condensation reaction instead of three fatty acids.

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 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. In water, phospholipid molecules collect together in a single layer (monolayer) with the hydrophilic head poking into the water. In cells, both the intracellular environment and immediate external environment are watery. This causes phospholipids to form a double layer, with the hydrophobic tails pointing inwards, away from the watery environment. The phospholipids bilayer gives cell membranes their fluid properties and allows lipid soluble substances to pass easily through them







1. **Glycolipids**
   They are lipids with a carbohydrate attached by a glycosidic bond. Their role is to serve as markers for cellular recognition. The carbohydrates are found on the outer surface of all eukaryotic cell membranes
2. **Lipoproteins**
   This forms part of the cell membranes and it is the chemical form in which lipids are transported.
3. **Steroids**
   These are lipids whose molecules contain 4 rings of Carbon and Hydrogen atoms. Three of the rings are six numbered and one of them is five numbered. All together there are 17 carbon atoms, six of which are shared between the rings and they are saturated hydrocarbons. They cannot be hydrolysed. Some are formed by the smooth ER of cell membranes

Functions of lipids

1. An energy source.
   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 weight to the minimum
   - They have a high calorific value i.e. they have a high energy content
   - They are compact and therefore they take up very little space in the cells
   - Lipids are poor conductors of heat in the body
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. Aquatic mammals, e.g. whales, seals and manatees, have an extremely thick subcutaneous fat, called blubber, which forms an effective insulator.
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. Plant scents are fatty acids or their derivatives and so aid in the attraction of pollinators
8. 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
   - Bees use wax in constricting their honey combs

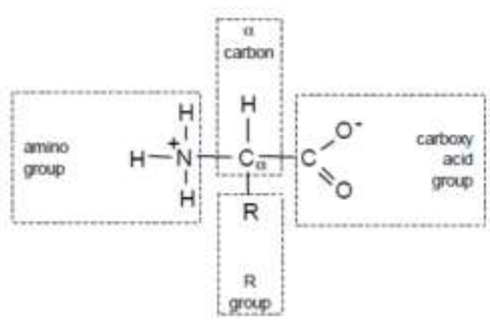
PROTEINS

Proteins are complex organic compounds with a large molecular mass made of small units called **amino acids**. Amino acids consist of carbon, oxygen, hydrogen, nitrogen and in some cases sulphur. They are not truly soluble in water, but form colloidal suspensions. Proteins are rarely stored by organisms except in eggs or seeds where they are used to form the new tissue. The variety of proteins is unlimited because the sequence of amino acids in each protein molecule which is genetically determined by DNA within cells during protein synthesis.

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

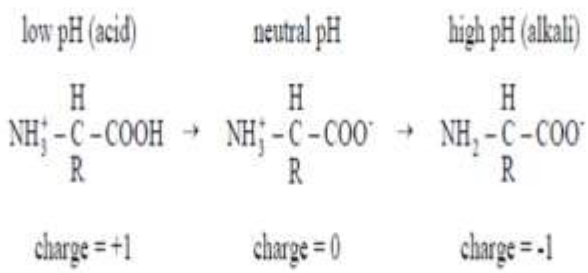
1. A hydrocarbon group (-CH)
2. A carboxyl group (COOH)
3. An amino group (NH_2)
4. An R group. It is in this R group of the amino acid that lies the difference in the amino acid e.g. in amino acids, glycerine which is the simplest amino acid, R is a hydrogen atom while it's a methyl group (CH_3) in amino acid alanine.

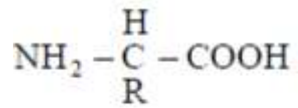
Amino acids are soluble in water but insoluble in organic solvents. At neutral pH (found in most living organisms), the groups are ionized as shown above, so there's a positive charge at one end of the molecule and a negative charge at the other end. The overall net charge on the molecule is therefore 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's these changes with change in pH, that explain the effect of pH on enzymes. A solid, crystallised amino acid has the uncharged structure,  , but this form never exists in solution, and therefore doesn't exist in living things (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 4. Leucine 7. Lysine
2. methionine 5. threonine 8. phenylalanine
3. tryptophan 6. 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

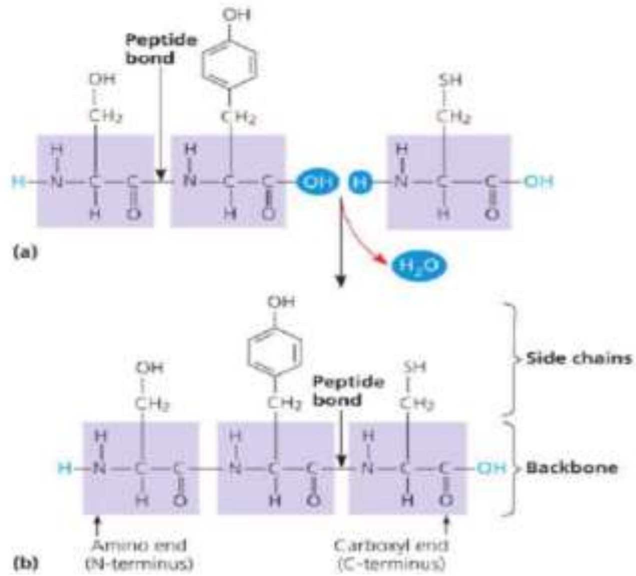
1. Alanine 4. Aspartic acid 7. Glutamic acid
2. Glycine 5. Proline 8. Serine 10. Tyrosine
3. Cysteine 6. Asparagine 9. Glutamine

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

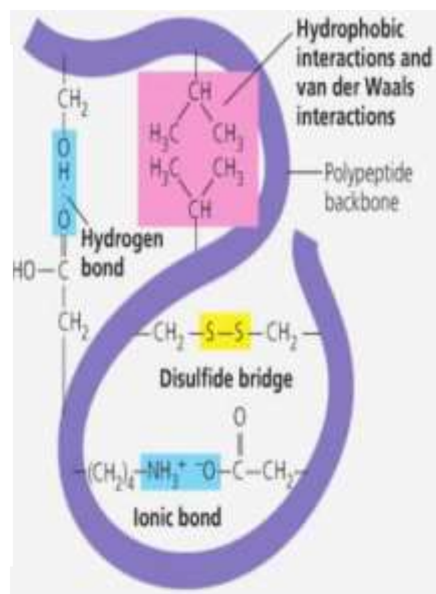
FORMATION OF A POLYPEPTIDE

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 chin 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 on the right



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.

4. Hydrophobic interaction

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

All the three types of bonds above are shown in the image above;

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.

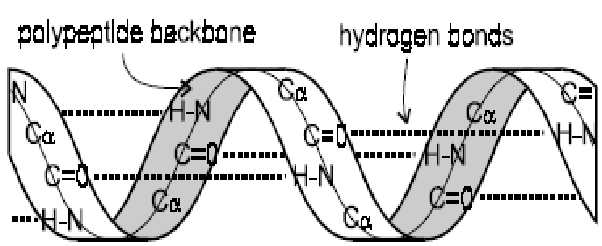
The primary structure is clearly shown by insulin hormone.

SECONDARY STRUCTURE

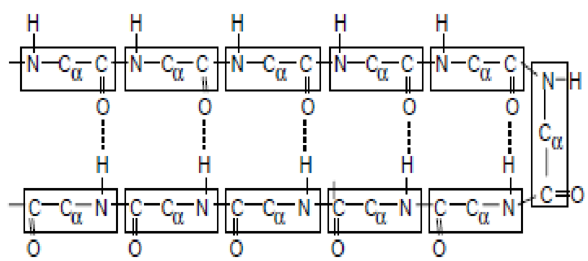
This refers to the regular arrangement of the polypeptide chains of the proteins as a result of hydrogen bonding which can be either **alpha-helix** or **beta-pleated sheets**. This is because after their formation, the chain of amino acids in the polypeptide folds spontaneously to make complex configurations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



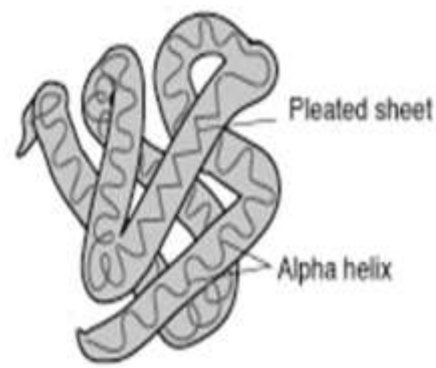
The hydrogen bonds stabilise the helix by joining together the amino group of one turn and a carboxyl group of another turn. Therefore, the importance of the secondary structure is that it maintains a particular shape of a protein keeping it stable by twisting it.

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.

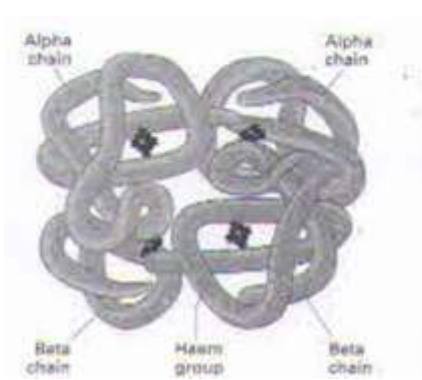
QUATERNARY STRUCTURE

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 bonds.

The structure of haemoglobin is shown below;



Summary

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

Proteins are classified into two main groups on the basis of their tertiary structure

a) **Fibrous proteins.** These have a primary structure of regular repetitive sequences. They form long chains which may run parallel to one another, being linked by cross bridges. They are very stable molecules and have structural roles with organisms e.g. collagen.
b) **Globular proteins**. They have irregular sequences of amino acids in their polypeptide chains. They are compact and are far less stable and have metabolic roles within organisms. All enzymes are globular proteins.
c) **Conjugated proteins**. These are proteins with other chemicals incorporated within their structure and the non-protein part is referred to as the prosthetic group. 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**.

Examples of conjugated proteins

Name of protein	Location	Prosthetic group
Haemoglobin	Blood	Haem (containing iron)
Mucin	Saliva	Carbohydrate
Casein	Milk	Phosphoric acid
Cytochrome oxidase	Electron carrier pathway of cells	Copper
Nucleoprotein	Ribosomes	Nucleic acid

Comparison of globular proteins and fibrous proteins

Fibrous proteins	Globular proteins
Repetitive regular sequence of amino acids	Irregular amino acid sequence
Actual sequence may vary slightly between two examples of the same protein	Sequence highly specific and never varies between two examples of the same protein
Polypeptide chains form long parallel strands	Polypeptide chains fold into a spherical shape
Length of chain may vary between two examples of the same protein	Length always identical in two examples of the same protein
Stable structure	Relative unstable
Insoluble	Soluble
Support and structural functions	Metabolic functions
e.g. collagen and keratin	e.g. enzymes, hormones and haemoglobin

CHARACTERISTICS OF PROTEINS

1. They are colloidal in nature

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

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

2. They have amphoteric properties

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

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

Protein denaturation

The three-dimensional structure of a protein is, in part at least, due to fairly weak ionic and hydrogen bonds. Any agent which breaks these bonds will cause the three-dimensional shape to be changed. In many cases, the globular proteins revert to a more fibrous form. This process is called **denaturation**. The actual sequence of amino acids is unaltered; only the overall shape of the molecule is changed. This is still sufficient to prevent the molecule from carrying out its usual functions within an organism. Denaturation may be temporary or permanent and is due to a variety of factors as shown in the table below;

Factor	Example	Explanation
Heat	Coagulation of albumen (boiling eggs makes the white more fibrous and less soluble)	Causes the atoms of the protein to vibrate more due to increased kinetic energy, thus breaking the hydrogen and ionic bonds
Acids	The souring of milk by acid e.g *Lactobacillus* bacterium produces lactic acid, lowering the pH and causing it to denature the casein, making it insoluble and thus forming curds	Additional H^+ ions in acids combine with COO^- groups on amino acids and form COOH, ionic bonds are hence broken.
Alkalis		Reduced number of H^+ ions causes NH_3^+ to lose H+ ions and form HN_2, hence ionic bonds are broken.
Inorganic chemicals	Many enzymes are inhibited by being denatured in the presence of certain ions, e.g. cytochrome oxidase	The ions of heavy metals such as mercury and silver are highly electropositive. They combine with COO^- groups and disrupt ionic bonds. Similarly, highly electronegative ions e.g.

	(respiratory enzyme) is inhibited by cyanide.	cyanide (CN^-), combine with NH_3^+ groups and disrupt ionic bonds.
Organic chemicals	Alcohol denatures certain bacterial proteins. This is what makes it useful for sterilization.	Organic solvents alter hydrogen bonding within proteins.
Mechanical force.	Stretching hair breaks the hydrogen bonds in the keratin helix. The helix is extended and hair stretches. If released, the hair returns to its normal length. If, however, it is wetted and then dried under tension, it keeps its new length-the basis of hair styling.	Physical movement my break hydrogen bonds.

Renaturation

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

Functions of proteins

Vital activity	**Protein function**	**Function**
Nutrition	Digestive enzymes, e.g. trypsin	Catalyses the hydrolysis of protein to polypeptides
	Amylase	Catalyses the hydrolysis of starch maltose
	Lipase	Catalyses the hydrolysis of fats to fatty acids and glycerol
	Fibrous proteins in granal lamellae	Help to arrange chlorophyll molecules in a position to receive maximum amount of light for photosynthesis
	Mucin	**(1)** Assists trapping of food in filter feeders. **(2)** Prevents autolysis. **(3)** Lubricates guts wall.
	Casein	Storage protein in milk
	Ovalbumin	Storage protein in egg white
Respiration and transport	Haemoglobin/ haemoerythin/ haemocyanin/ chlorocruorin	Transport of oxygen
	Myoglobin	Stores oxygen in muscle
	Prothrombin/fibrinogen	Required for the clotting of blood

	Mucin	Keeps respiratory surface moist
	Antibodies	Essential to the defence of the body, e.g. against bacterial invasion
Growth	Hormones, e.g. thyroxine	Controls growth and development
Excretion	Enzymes, e.g. urease, arginase.	Catalyses reactions in the ornithine cycle thus useful in protein breakdown and urea formation
Support and movement	Actin/myosin	Needed for muscle contraction
	Ossein	Structural support in bones
	Collagen	Gives strength with flexibility in tendons and cartilage
	Elastin	Gives strength and elasticity in ligaments
	Keratin	Tough for protection, e.g. in scales, claws, nails, hooves, skin.
	Sclerotin	Provides strength in insects exoskeleton
	Lipoproteins	Structural components of all cell membranes
Sensitivity and coordination	Hormones, e.g. insulin/glucagon, adrenocorticotrophic hormone, vasopressin	Controls blood sugar level Controls the activity of the adrenal cortex Controls blood pressure
	Rhodopsin/opsin	Visual pigments in the retina, sensitive to light
	Phytochromes	Plant pigments important in control of flowering, germination, e.t.c.
Reproduction	Hormones e.g. prolactin	Induces milk production in mammals
	Chromatin	Gives structural support in chromosomes
	Gluten	Storage protein in seeds, nourishes the embryo
	Keratin	Forms horny and antlers which may be used for sexual display

CLASSIFICATION OF PROTEINS ACCORDING TO FUNCTIONS

1. **Enzymes.** These are biological catalysts which control chemical reactions in organisms e.g. amylase
2. **Structural proteins.** These form part of the body of organisms e.g. collagen which makes up tendons and ligaments. Keratin is a major component of hair and nails
3. **Signal proteins.** These carry messages around the body e.g. insulin hormone and glucagon involved in controlling glucose levels in blood
4. **Contractile proteins.** These are involved in movement after contraction e.g. actin and myosin which are proteins that aid muscle contraction

5. **Storage proteins.** These keep materials e.g. albumen in the egg which nourishes the chick while it is still inside the egg.
6. **Defensive proteins** such as antibodies, thrombin, fibrinogen which are important for fighting infections.
7. **Transport proteins** e.g. haemoglobin which carries oxygen around the body

ENZYMES

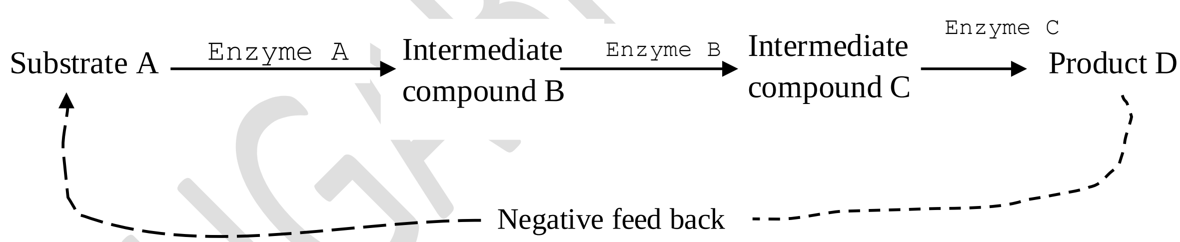
An enzyme is an organic catalyst protein in nature which speeds up the rate of metabolic reactions in an organism without itself undergoing a permanent change.

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 D 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 feedback 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;

a. It allows energy to be derived in usable form from many small catabolic reactions than it would be in a single large reaction.
b. 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.
c. 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.
d. It increases the ability of the cell to control the products made in anabolic pathways when the reactions in them proceed in small steps.

CLASSIFICATION OF ENZYMES

TYPES OF ENZYMES

An enzyme name is based on two criteria;

a. The **name of the substrate acted** upon by the enzyme e.g. succinate dehydrogenase acts on succinic acid. In most cases an enzyme is named by attaching the suffix "ase" to the name of the substrate on which it acts for example; **(1)** Proteins to protease **(2)** Lipids to lipase **(3)** Maltose to maltase **(4)** Sucrose to sucrase	b. The **type of the reaction** it catalyses e.g. dehydrogenation, hydrolysis, polymerization, decarboxylation e.t.c. **(1)** DNA polymerase which catalyze the formation of DNA by polymerization of DNA nucleotides **(2)** RNA polymerase which catalyses the formation of RNA by polymerization of RNA nucleotides. **(3)** Cytochrome oxidase catalyses oxidation reactions of cytochrome proteins
However, enzymes like Pepsin and Trypsin do not follow this naming convention	

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
Isomesales	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

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.

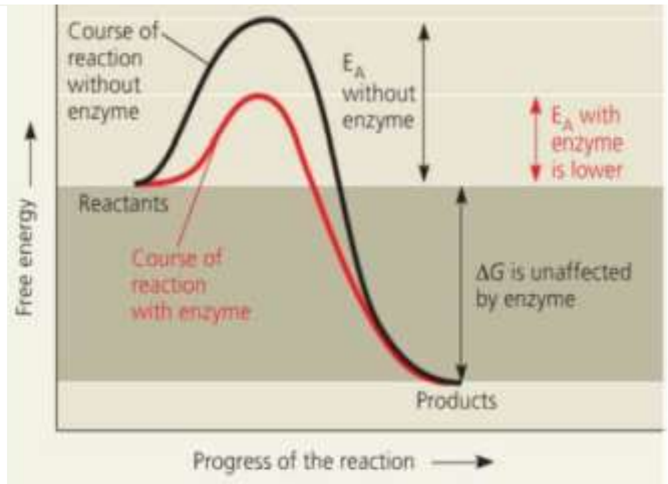
Even though the enzyme molecule is normally larger than the substrate molecule it acts upon, only a small part of the enzyme molecule actually comes into contact with the substrate. This region of the enzyme molecule which comes into contact with the substrate is called the ***active site***.

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.



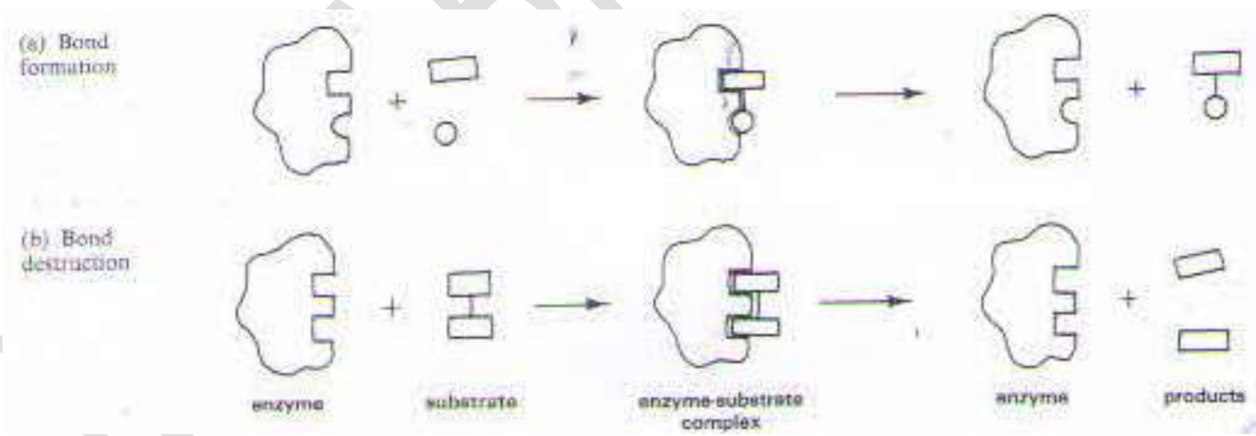
How an enzyme lowers activation energy of the reaction is explained by a number of mechanisms described below;

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.**



When the substrate binds with the enzyme molecule, the substrate molecules become slightly distorted putting a strain on the bonds of the substrate molecules which results into breaking of these bonds and rejoining them using less energy.

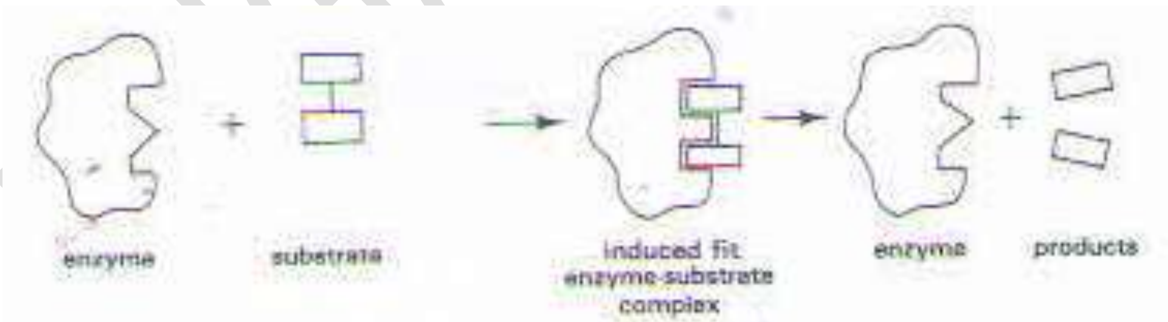
The enzyme-substrate molecule forms an enzyme-end product complex which splits into the enzyme and the end products. The enzyme remains unchanged while the products are released from the active sites since they have a different shape from the substrate.

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

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.

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).

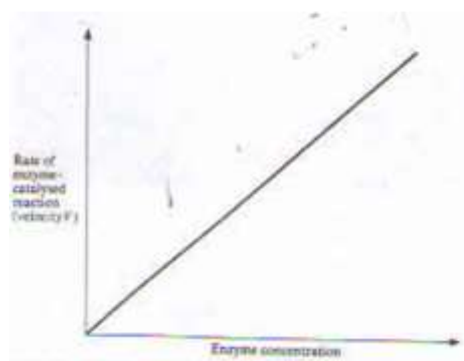
THE RATE OF ENZYME CONTROLLED REACTIONS

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

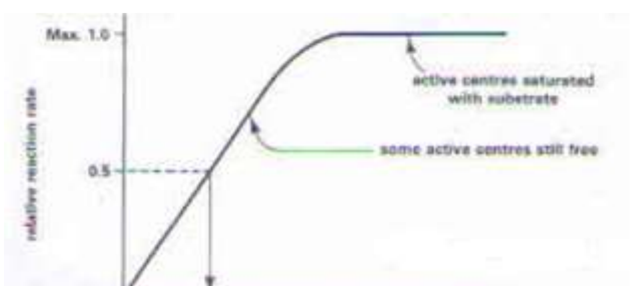
Provided that the substrate concentration is maintained at a high level and other conditions such as pH and temperature are maintained constant, the rate of a reaction increases with increase in enzyme concentration until when the rate remains constant. Usually the enzyme concentration is much lower 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.



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



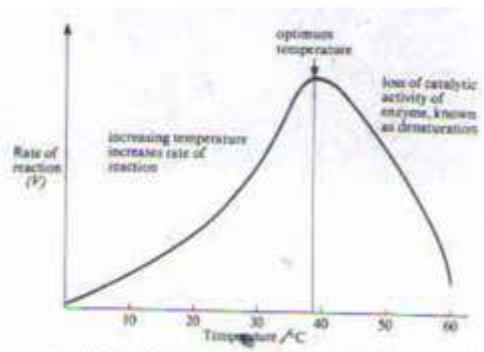
3. **Temperature**

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

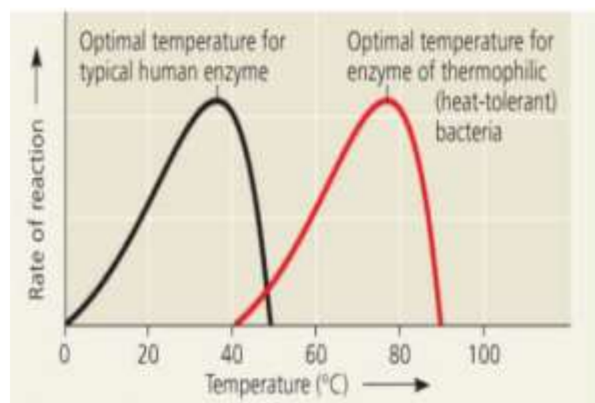
a. As the temperature increases the kinetic energy of the substrate and enzyme molecules also increases and so they move fast. The faster these molecules move, the more they collide with one another and therefore the greater the rate of reaction.

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 properties. 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.

Note. The optimum temperature for an enzyme varies considerably. Many arctic and alpine plants have enzymes which function at a temperature 10^0C, whereas those in algae inhabiting some hot springs continue to function at temperatures around 80^0C. For many enzymes, the optimum temperature lies around 40^0C and denaturation occurs at about 60^0C.

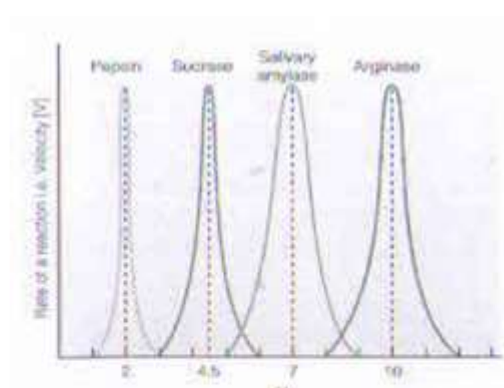


Effect of temperature on the rate of an enzyme-controlled reaction.



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.



Inhibition

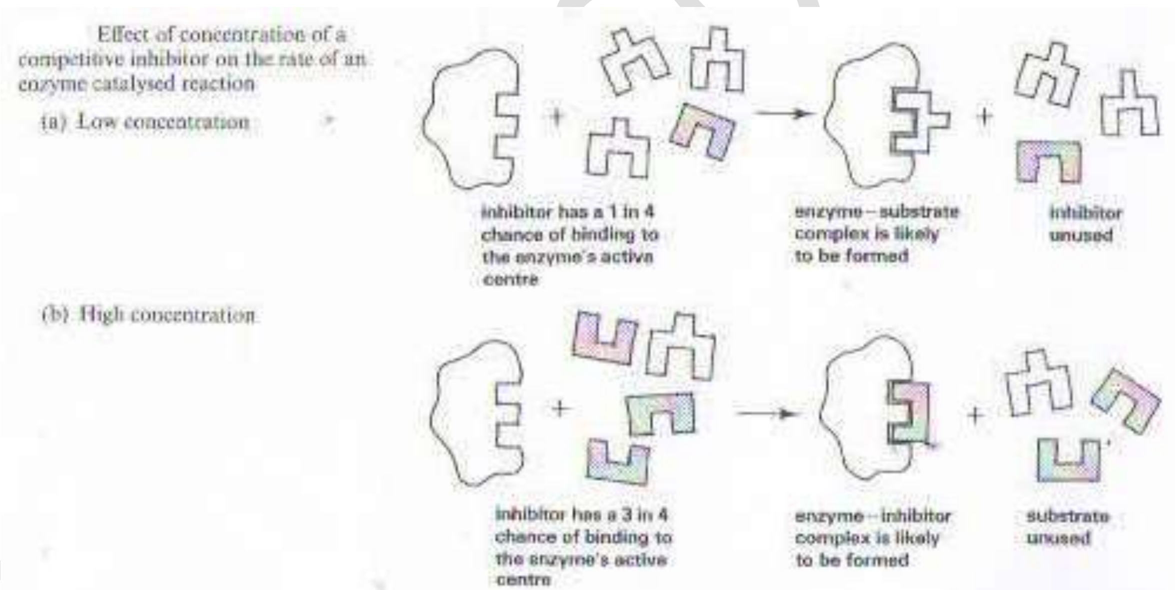
The rate of enzyme controlled reaction may be decreased by the presence of inhibitors. There are two types of inhibition namely;

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

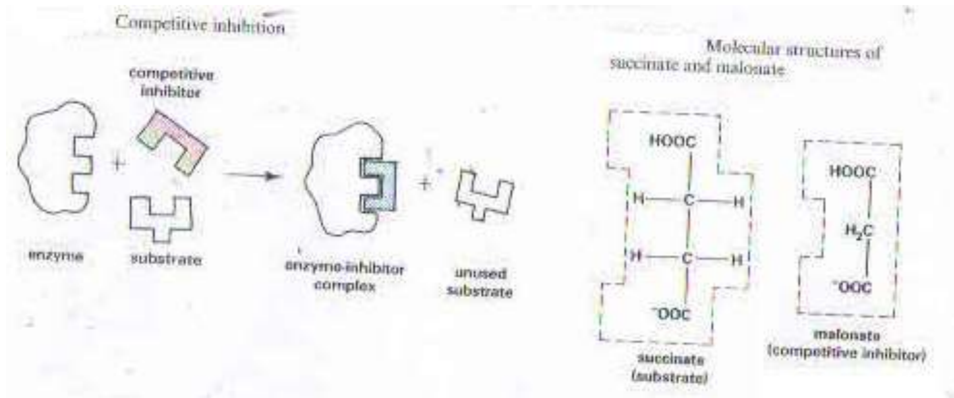
Competitive inhibition

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



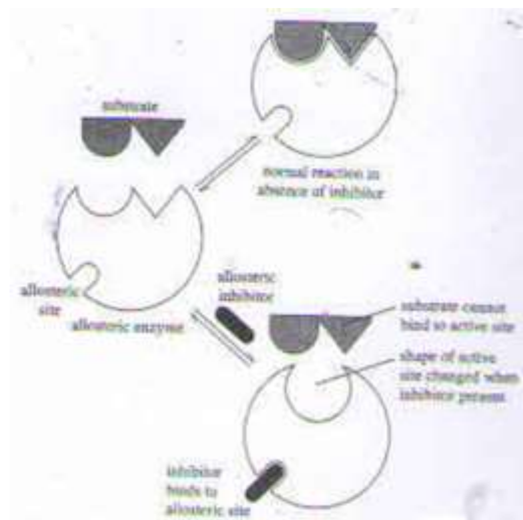
Once the inhibitor combines with the enzyme active site it prevents the substrate molecules from occupying the active site and so reduces the rate of the reaction. Melanic acid is an example of a competitive inhibitor.



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

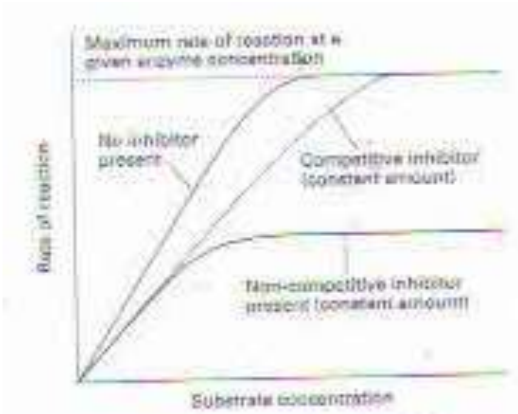
These inhibitors attach themselves on the surface of the enzyme other than the active site thereby changing the shape of the active site which is at another location of the enzyme molecule. This change of the active site is achieved by an **allosteric** change and these inhibitors prevent the enzyme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



Allosteric inhibition

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

Irreversible non-competitive inhibitors 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



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.

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.

Control of enzyme activities

a) Secretion in inactive form like pepsinogen which is only activated at the site of action
b) Precursor activation where accumulation of a potential substrate causes particular reaction pathways to be opened up
c) Enzymes are contained in membranes like lysosome being released only when there is work to be done
d) Dynamic regulation like negative feedback where the end-products inhibit the initial reactions
e) Through genetic control where the information stored in the nucleus is used to determine which enzymes are synthesised which in turn determines the limits of cell metabolism

INDUSTRIAL APPLICATIONS OF ENZYMES

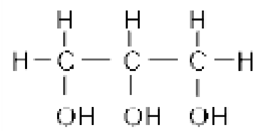
i. They are used in making biological detergents which are usually made using proteases produced in an extra-cellular form from bacteria
ii. They are used in baking industry in which fungal α-amylase enzymes which catalyses the breakdown of starch in the flour to be used.
iii. They are used in making 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.

REVISION QUESTIONS

1. Fat and glycogen are energy storage compounds in animals.

a. State the properties of both compounds as energy storage compounds. (4 marks)
b. State the advantages of storing fat over glycogen. (3 marks)
c. Why is glycogen a more suitable energy compound than fat? (3 marks)

2. (a) Using the structural formula below and $CH_3(CH_2)_nCOOH$, show how a triglyceride is formed. (03 marks)



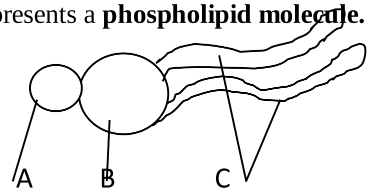
(b) What properties do lipids posses as storage food substances? (03 marks)

(c) Give the adaptations of the following to their functions

i. Cellulose (02 marks)

ii. Starch (02 marks)

3. The diagram represents a **phospholipid molecule.**



a) i) Name the parts of the molecule A,B and C (03 marks)

ii) Explain how the phospholipid molecules form a double layer in a cell membrane. (06 marks

b) Give two functions of the protein molecules in the cell membranes. (02 marks)

4. (a) Giving an example in each case; explain what is meant by;

(i) Aldose sugar. *(1½ marks)*

(ii) Ketose sugar. *(1½ marks)*

(b) Explain how the storage property of starch is related to its molecular structure. *(04 marks)*

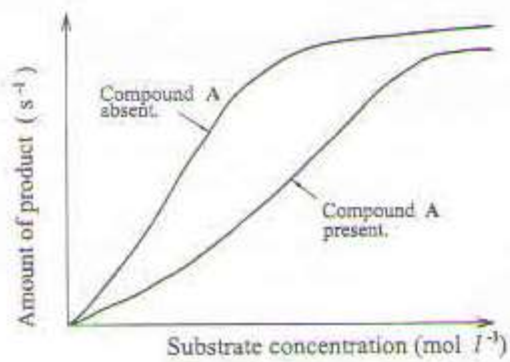
(c) Although chitin and cellulose are both tough structural polysaccharides, chitin is a more suitable component of insects' exoskeleton than cellulose. Explain this statement. *(03 marks)*

5. a) describe how polypeptide chains may be arranged to form protein molecules 4marks

b) Explain how inhibitors can alter the rate of reaction acting indirectly 3mar

c) Suggest why amylase breaks down starch but it does not break down cellulose 3marks

6. *Figure 7* below shows the effect of varying substrate concentration on an enzyme catalysed reaction, in absence and presence of compound **A**.



(a) Explain the relationship between rate and substrate concentration

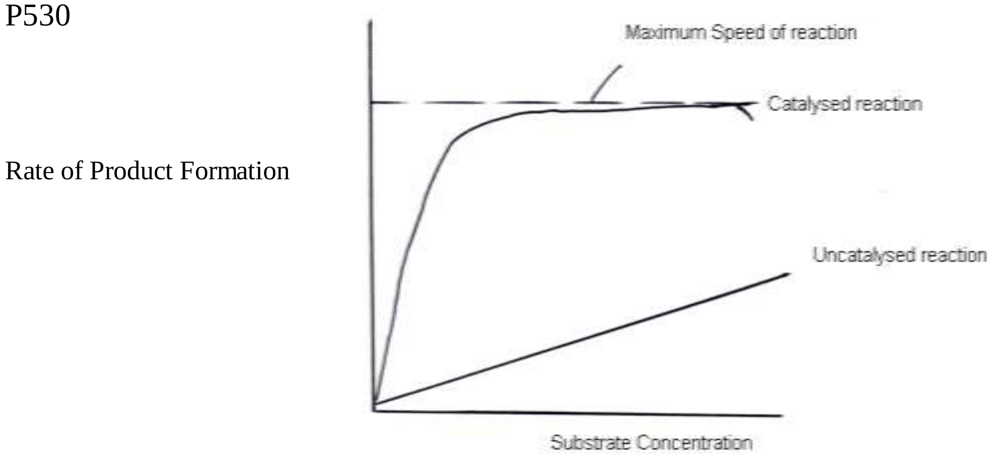
(i) in absence of compound **A** *(03 marks)*

(ii) in presence of compound A *(04 marks)*

(b) state two factors which would have to be kept constant in this experiment (01)

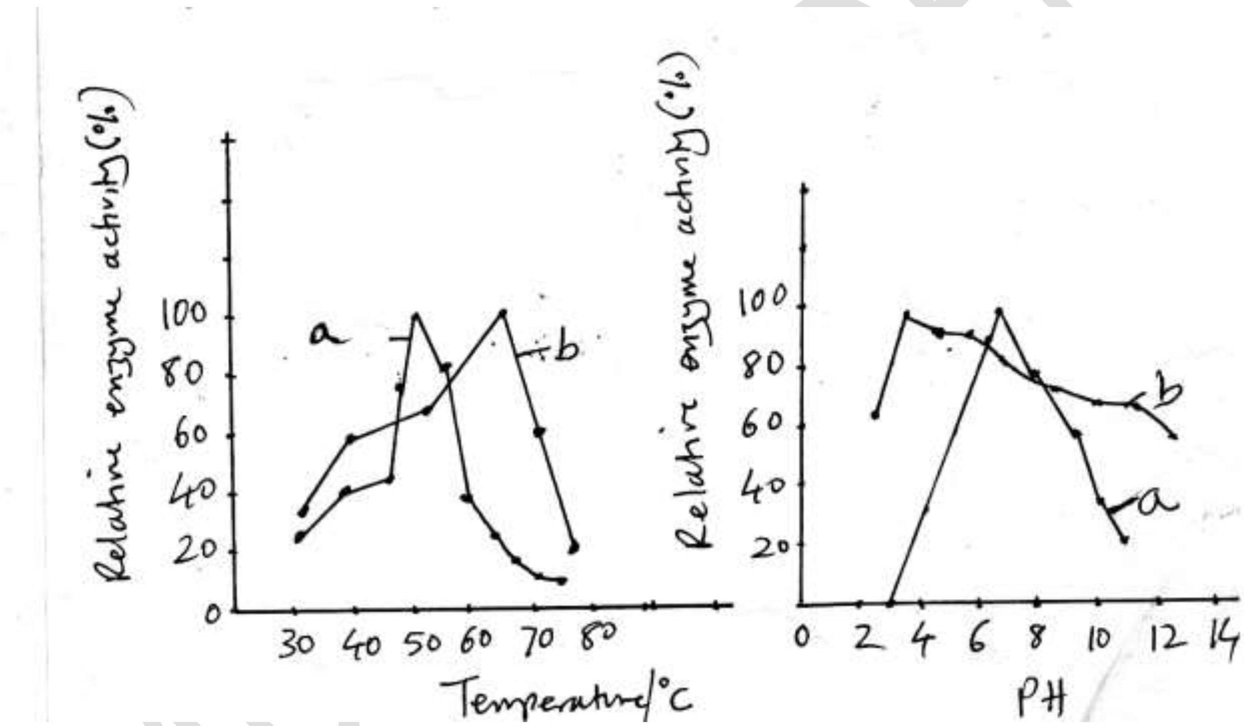
(c) What would be the effect of increasing the concentration of compound A in the experiment? *(02 marks)*

7. Figure **7** shows the effect of substrate concentration on enzyme activity



a) Compare the differences in the rate of reaction in catalyzed and uncatalysed reactions (*05 marks*)
b) Explain why the enzyme catalyzed reaction finally levels off (*02 marks*)
c) Describe any **three** substances that help enzymes to perform their catalytic activity (*03 marks*)

8. Figure **3** shows the activity of bacterial enzymes at different PH and temperature



(a) Which graph represents the bacteria that live in

(I) cool and neutral conditions……………………………………………………. (1/2 mark)

(ii) hot and acidic conditions………………………………………………………… (1/2 mark)

(b) Compare the changes in enzyme activity with temperature and PH for organisms that live in hot and acidic environment to those that live in cool and neutral environment(04 marks)

(c) With reference to enzyme structure explain how the following factors affect enzyme activity

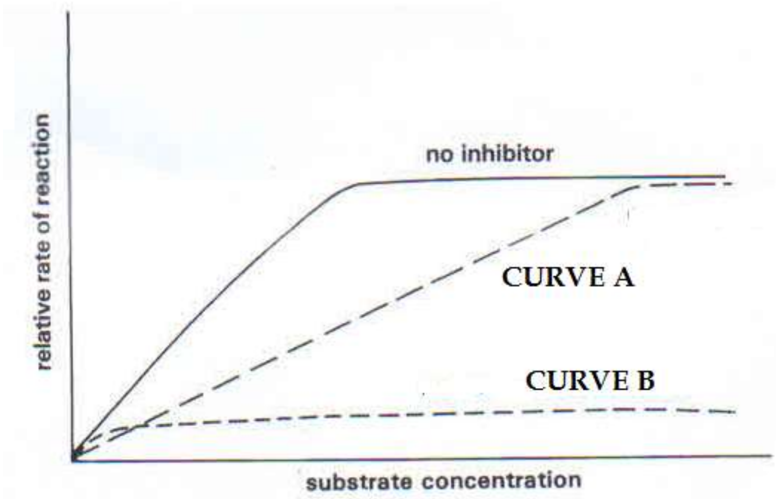
(i) PH (02 marks)

(ii) temperature(01 mark)

(d) Explain why the same enzyme may be able to work at different optimum PH and temperature conditions in similar organisms living in different environments (02 marks)

9. Figure 3 is a graph that shows the comparative effects of non-competitive and competitive inhibitor on the rate of an enzyme-catalysed reaction

Figure 3



a) Identify the curve that shows the effect of (02 marks)

i. A competitive inhibitor

ii. A non-competitive inhibitor

b) Explain the changes in relative rate of reaction in;

i. Curve A (03 marks)

ii. Curve B (03 marks)

c) State any **two** applications of enzyme inhibitors (02 marks)

10. (a) Clearly distinguish between the following
(i) The primary structure and the secondary structure of proteins. *(02marks)*
(ii) Co-enzyme and a prosthetic group. *(02marks)*
(b) How is the structure of a protein used in regulation of blood pH? *(03marks)*
(c) Explain how excess proteins lead to kidney stones. *(03marks)*

11. Locusts are insects that are capable of flying for relatively long periods of time. When flying, locusts use carbohydrates and lipids as energy sources. An experiment was carried out to investigate changes in the concentration of monosaccharides and lipids in the blood of a locust during flight. Measurements were made of the concentrations of monosaccharide and lipid at the beginning of the flight and at 60 minutes intervals during the flight. The results are shown in table 4 below.

Time during flight in minutes.	Concentration in gmm^{-3} of	
	monosaccharide	Lipid
0	30	3.0
60	13	10.0
120	12	19.0
180	11.5	20.0

240	11.0	20.0
300	11.0	20.0

(a) Compare the changes in the concentration of monosaccharide with the changes in the concentration of lipid during flight. (04 marks)

(b) Suggest an explanation for the changes in the concentrations of both of these compounds during flight (05 marks)

(c) In this investigation, the mass of stored glycogen in the locust was also measured and was found to decrease by 390 during flight. Suggest an explanation for this change in the mass of glycogen. [01 mark]

12. a) Describe the induced fit hypothesis of enzyme action. (08 marks)

b) Explain how the following affect enzyme activity

i. temperature (06 marks)

ii. competitive inhibition (06 marks)

13. (a) Explain how temperature affects enzyme activity in a metabolic reaction. (12 marks)

(b) Describe the induced fit hypothesis of enzyme action. (08 marks

14. (a) What are the ways in which lipids differ from carbohydrates? (05 marks)

(b) With examples describe the functions of lipids in organisms. (10 marks)

(c) Why do animals store lipids instead of carbohydrates? (05 marks)

15. (a) Compare the suitability of lipids and carbohydrates as storage compounds in organisms. (06 marks)

(b) With examples, describe the functions of lipids in organisms. (14 marks)

16. (a) Distinguish between the lock and key and induced fit hypothesis of enzyme action. (05 mark

(b) Explain how temperature affects the activity of an enzyme. (10 marks)

(c) How are enzymes activities controlled? (05 marks)

17. A group of students carried out an experiment to compare the properties of two enzymes. Catalase and carbonic anhydrase. The concentrations of the substrate and enzyme were the same at the beginning of the experiment and temperature was maintained at 37ºC. Catalase hydrolysed substrate A while carbonic anhydrase hydrolysed substance B. The students determined the mass of substrates A and B every 10 minutes intervals to establish the rate of reactions A and B. The results are shown in the table below.

Time in minutes	**Mass of substrate in g**		**Rate of reaction**	
	A	**B**	**A(g min $^{-1}$)**	**B(gmin $^{-1}$)**
0	200	200	0	
10	192	182	19.2	
20	184	176	18.4	
30	170	165	17.0	
40	162	150	16.2	
50	104	98	10.4	
60	80	30	8.0	
70	30	10	3.0	
80	10	5	1.0	

a) Copy and complete the table by calculating the rate of enzyme controlled reaction B at every 10 minutes intervals (04 marks)

b) Plot a suitable graph to compare the rate of enzyme controlled reactions A and B. (10 marks)

c) Which of the enzymes has a higher turnover number? Give reasons for your answer. (02 marks

d) (i) suggest the names of the substances used in reactions a and B. (02 marks)

(ii) Explain the changes in the rates of reactions A and B shown by your graph. Illustrate your explanation with equations. (05 marks)

e) Explain what would happen

(i) If mercury was added to reaction B (08 marks)

(ii) Malonic acid was added to reaction A (08 marks)

f) Why was temperature kept constant? (01 mark

18. (a). Describe the structure of the protein molecule. ***[7mks]***
(b). Compare the structure of proteins to those of carbohydrates ***[9mks]***
(c). What structural features of carbohydrates account for the wide Variety of polysaccharides? ***[4mks]***

19. a) Give an account of the chemical nature and variety of carbohydrates *(10 marks)*
b) Outline the role of carbohydrates in the life of a plant. *(10 marks*

20. a) What is meant by the term protein? (03 mark)
b) Discuss with suitable examples the variety of functions of proteins. (12 marks)
c) Explain how their structure permits this wide variety of functions. (6 marks)

21. a) Describe the structure of the following. (10mks)

i) Starch ii) Cellulose

b) Show how a triglyceride is formed. (4mks)
c) Outline the importance of triglycerides in living organisms. (11mks

22. a) Why is calcium ion important in the human body? (5mks)
b) Water is essential for life. Explain in what ways this statement is true for plants and animals. (15 mks)

23. An experiment was carried out to investigate the effect of alcohol on the activity of pancreatic amylase. Dilutions of ethanol in water were prepared in order to give a range of percentage concentrations from 0% to 70%.
To each of the 8 test tubes was added 1cm^3 of the appropriate concentration of ethanol, followed by 2cm^3 of a 1%starch solution. 2% of pancreatic extract were added to each test tube and the time, in seconds, required for starch hydrolysis was recorded. The table below shows the results:

Test tube	% concentration of ethanol added to each test tube.	Time required for complete starch hydrolysis/seconds.
1	0	100
2	10	80
3	20	90
4	30	100
5	40	130
6	50	190
7	60	240
8	70	300

a) Calculate the initial mass, in mg, of starch per test tube.

b) Calculate the ;

i) % of ethanol in the reaction mixture for each test tube.

ii) rate of starch hydrolysis in each test tube, in milligrams per minute.

c) Draw a graph to show the relationship between ethanol concentration and the rate of starch hydrolysis.

d) Give reasons for the change in the rate of starch hydrolysis with increasing ethanol concentration

e) Organic solvents like ethanol are known to alter the three dimensional structure of globular proteins. Explain, in terms of enzyme structure and function, the effect of concentrations of ethanol greater than 6% in the reaction mixture.

24. The browning which occurs when many types of vegetables and fruits are peeled is caused by enzymes called *phenol oxidases*. These catalyse the relatively slow conversion of naturally phenolic compounds into dark brown melanins.

Phenols → Quinones → Melanins

(Colourless) (Yellow) (Dark brown)

The results in the table below were obtained from investigation into the browning of cubes of apples. Study the information and use it to answer the questions that follow

Cube number	Contents of cube (cm^3)					Appearance of cube contents after 10 minutes at room temperature
	Catechol	Apple extract	Buffer (pH = 7)	Dilute acid	Dilute base	
1	2	-	5	-	-	Colour less
2	-	2	5	-	-	Light brown
3	2	2	3	-	-	Dark brown
4	2	2	-	3	-	Colour less
5	2	2	-	-	3	Light brown
6	2	2 (boiled)	3	-	-	Colour less

a. From the information given in the table, what type of substance do you think catechol is, and what purpose it serves in this investigation? (2 marks)

b. Use the results above to;
   i) Suggest two ways in which apples, once peeled, can be prevented from turning brown? (2 marks)
   ii) State what the apple extract contains? (2 marks)

c. Explain your answer in b (i) above (10 marks)

25. The rate of hydrolysis of starch by amylase enzyme was used to investigate the effect of a competitive inhibitor on enzyme action. A fixed amount of the enzyme and inhibitor was used at varying concentrations of the substrate. The data in the table below was obtained from the investigation. Use it to answer the questions that follow.

Substrate concentration (mol)		0.0	0.1	0.25	0.5	0.75	1.0	1.25	1.50
Rate of reaction (arbitrary units)	No inhibitor present	0.0	0.20	0.40	0.63	0.78	0.93	0.93	0.93
	Inhibitor present	0.0	0.15	0.30	0.45	0.60	0.73	0.80	0.92

(a) Represent the data on a suitable graph. *(10 marks)*

(b) Explain the shape of the graph obtained when,
   (i) Only the enzyme was used? *(4 marks)*
   (ii) The inhibitor was present? *(4 marks)*

(c) (i) Indicate on your graph, the results that could have been obtained if a non- competitive inhibitor was used instead of a competitive inhibitor? *(2 marks)*
   (ii) Explain your answer in c (i) above? *(5 marks)*

(d) Use the lock and key hypothesis to explain the mode of action of amylase enzyme *(8 marks)*

(e) Explain how gastric juice affects the action of amylase enzyme? *(7 marks)*

26. Give an account of the diversity of polysaccharides? (20 marks)

27. (a) Give an account of the structure of starch, and explain how structure is related to functioning?.
(b) Explain why:
(i) animal cells store glycogen and not starch as an energy source.
(ii) many organisms store fats rather than carbohydrates in their bodies

28. (a) Compare the suitability of lipids and carbohydrates as storage compounds in organisms. (06 marks)
(b) With examples, describe the functions of lipids in organisms (14 marks)

29. Briefly describe how starch and cellulose molecules form from their monomer subunits. (10 marks)
b) Explain the role of carbohydrate molecules in plant life. (10 marks)

30. a) Outline the functions of carbohydrates in animals (05 marks)
b) Starch is the major storage form of carbohydrates in plants. Describe;
i) the structure of starch and
ii) how the structure is related to function (15 marks)

31. a)Describe how starch and cellulose are formed from their monomer units (10 marks)
b) Explain the importance of carbohydrates in plants (5 marks
c) Explain why certain organisms store lipids as the main storage form of energy instead of starch. (5 marks)

32. a)Distinguish between enzymes and inorganic catalysts. (05 marks)
b) Give an account of how substrate concentration, pH and temperature can affect rate of enzyme catalyzed reactions. (15 marks)

33. (a). Describe the biological function of amino acids. (*05marks)*
(b). Describe how amino acids form a polypeptide. (*09marks*
(c). How do inhibitors change the rate of enzyme controlled reactions? (*06marks*)

34. Describe the various characteristics of the carbon atom that makes possible the building of a variety of biological molecules. (06 marks)
(b) What structural features of carbohydrates account for the wide variety of polysaccharides? (07 marks)
(c) How is cellulose different from glycogen? (07 marks)

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