CHEMICAL OF LIFE

Bodies of living organisms are made of chemicals which identical to nonliving matter. The study of chemical compounds living organisms and their reactions is called **biochemistry.** The study involving the structure and behavior of individual molecules is **molecular biology**.

Chemical compounds are either organic (30%) or inorganic (70%). The main organic compounds in the body include carbohydrates, proteins, lipids, nucleic acids and vitamins. Inorganic compounds are grouped as acids, bases, salts and water.

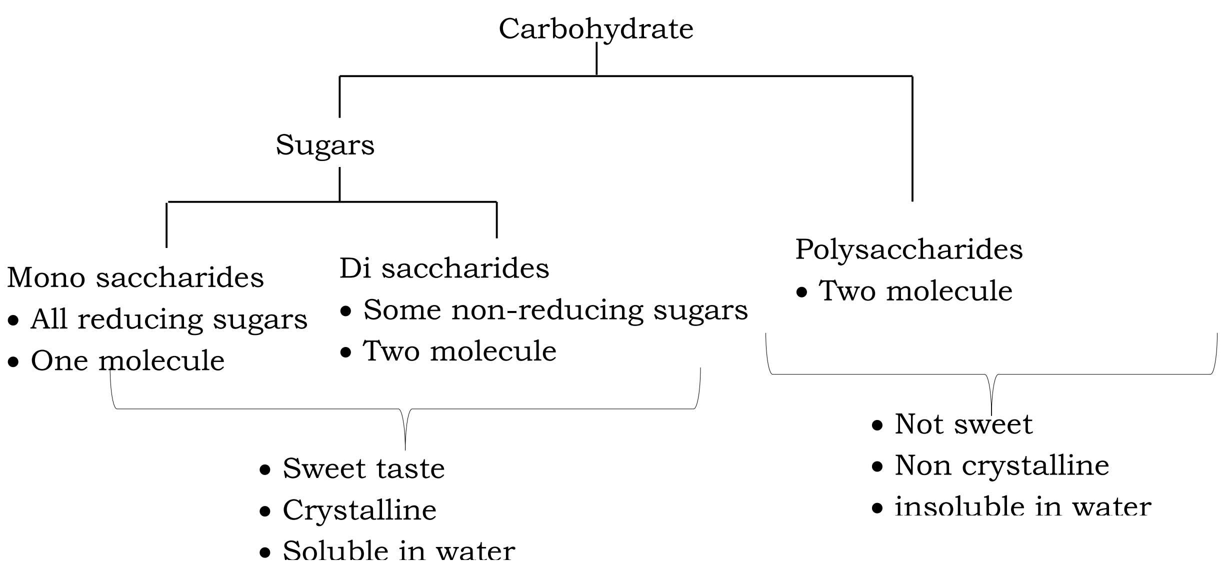
ORGANIC COMPOUNDS

Organic molecules are chemical compounds that contain carbon. Their framework consists mainly of carbon atoms bonded to other carbon atoms or to atoms of oxygen, nitrogen, sulfur or hydrogen. Since carbon has four valence electrons and so can form four covalent bonds, molecules containing carbon can form straight chains, branches, or even rings. All of these possibilities generate a wide range of molecular structures and shapes.

CARBOHYDRATES

Carbohydrates are defined group of molecules that contain carbon, hydrogen, and oxygen. Hydrogen and oxygen in these compounds are in a molar ratio of 2:1 which is similar to that of water hence the name carbohydrates. Their empirical formula is $C_x(H_2O)_y$, where x and y are whole number. Because they contain many carbon-hydrogen (C—H) bonds, which release energy when they are broken, carbohydrates are well suited for energy storage.

Classification of carbohydrate



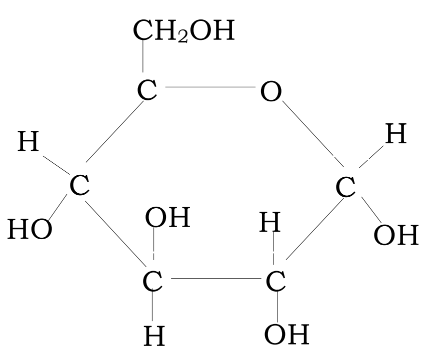
Mono saccharides (Greek mono, "single" + Latin saccharum, "sugar")

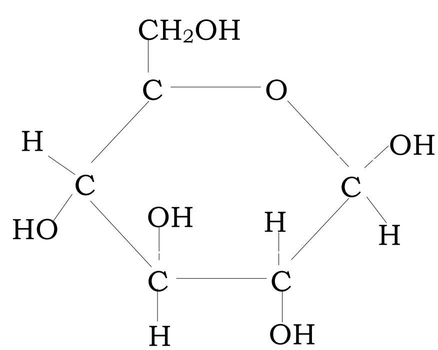
Mono saccharides are the simplest of the carbohydrates containing a single sugar molecule and are used as monomers (building blocks) larger carbohydrate molecules. They contain carbon, hydrogen and oxygen in a molar ratio 1:2:1. Their empirical formula is $(CH_2O)_n$ where n is the number of carbon atoms. They contain at least three carbon atoms and are classified basing on the number of carbon atoms.

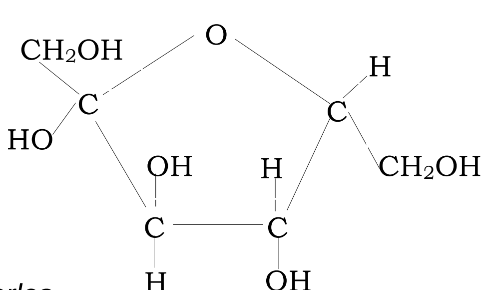
Number of carbon atoms	6	5	4	3
Monosaccharide	Hexose	Pentose	Tetrose	Triose

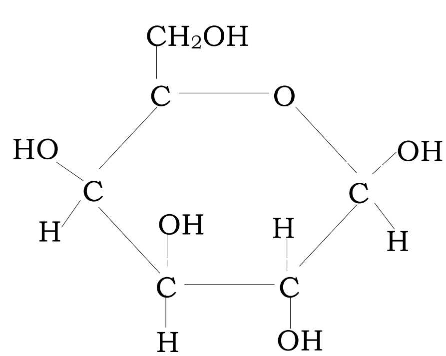
Trioses such as glyceraldyde are intermediates of cellular metabolism. The pentose sugars which include ribose and deoxyribose are components of nucleic acids, ATP, coenzymes and carbon dioxide acceptors which will be considered later.

The hexose sugar glucose is a component of large energy-storage molecules. Others are fructose and galactose. The empirical formula of hexose sugars is $C_6H_{12}O_6$ or $(CH_2O)_6$. This does not show how the atoms are arranged in the structure but in the structural formula, it is evident that hexoses can take up different shapes a phenomenon called **isomerism**. Each isomer the same molecular formula but arrangement of atoms in the structural formula is different from others. Hexoses can exist in a straight-chain form, but in an aqueous environment they almost always form rings. For instance, glucose can form a ring in two ways, with the hydroxyl group attached to the carbon where the ring closes being locked into place either below the plane forming alpha glucose or above the plane of the ring forming beta glucose.

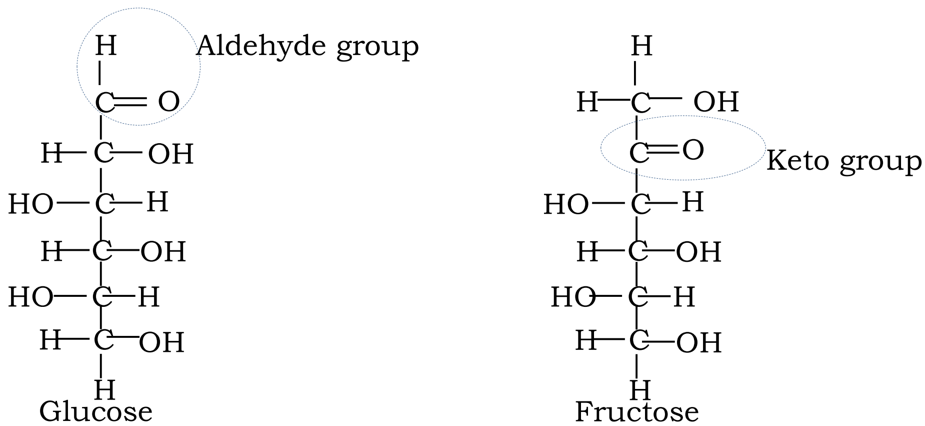

α-glucose


β-glucose


Fructose


Galactose

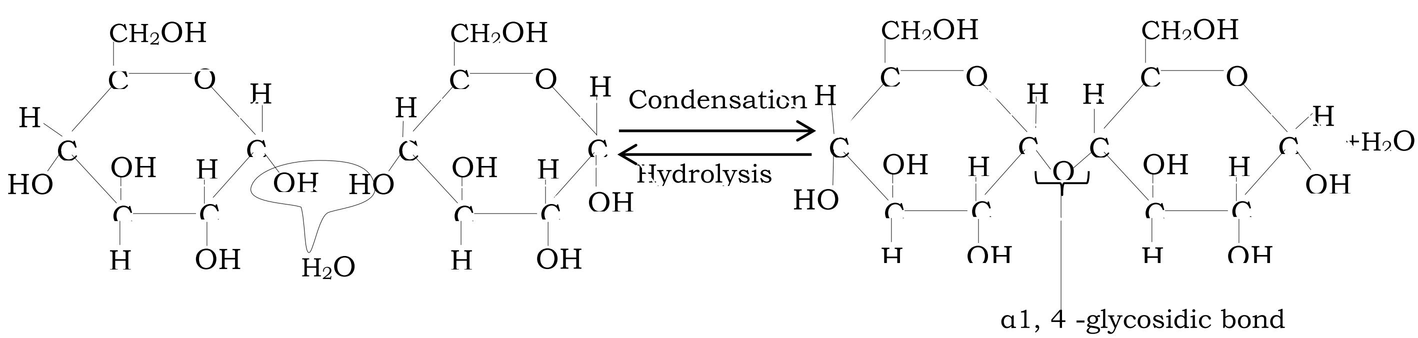
In straight chains of mono saccharides, all the carbon atoms are attached to the hydroxyl groups except one. The remaining carbon atom is attached to a carbonyl group which is either aldehyde group in **aldose sugars** or keto group in **ketose sugars.**



Assignment: explain the importance of monosaccharide

Disaccharides

Disaccharides are formed by combination of two monosaccharides in a process called **condensation**. During the process, hydroxyl group on one monosaccharide reacts with hydrogen on the hydroxyl group of another monosaccharide forming a water molecule. The two monosaacharides are linked by a covalent bond called **glycosidic bond**. Two alpha glucose molecules for instance combine to form maltose. In a reverse process of hydrolysis, a disaccharide can be split into the respective monosaccharides. During the process a water molecule is split.



Disaccharides are used as transport sugars in plants. These are made by linking glucose with either its self or other monosaccharide. Sucrose for instance is a transport form of sugars in plants. In such a form the sugar remains very soluble but less readily metabolized (used for energy) during transport since glucose utilizing enzymes cannot break the bond linking the two monosaccharide subunits. The common disaccharides are summarized in the table below.

Disaccharide	Monosaccharide sub units	Importance and source
Maltose	Glucose	Product of hydrolysis of starch found in germinating seeds and serve as an effective reservoirs of glucose
Lactose (milk sugar)	Glucose and galactose	Provides a steady source of energy to young mammals since it digested slowly.
Sucrose	Glucose and fructose	Transport sugar widely distributed in phloem of plant

Tests for reducing and non-reducing sugars

All monosaccharides and some disaccharides are reducing sugars. Reducing sugars can carry out reduction reactions because they contain a carbonyl group which is exposed to participate in this reaction. In non-reducing sugars the carbonyl group is locked in the glycosidic bond and does not easily participate in reaction.

The two tests for reducing sugars (Benedict's and Fehling's) make use of the ability of the carbonyl group of sugars to reduce copper (ii) ions to copper (i) ions and its self-oxidized to a carboxylic acid. There is no specific test for non-reducing sugars but they can be first hydrolyzed to constituent monosaccharides by boiling with dilute hydrochloric acid and then followed by test for reducing sugars. However, the excess acid need to be neutralized for reaction like Benedict's solution cannot work in acid. These tests are summarized in the table below.

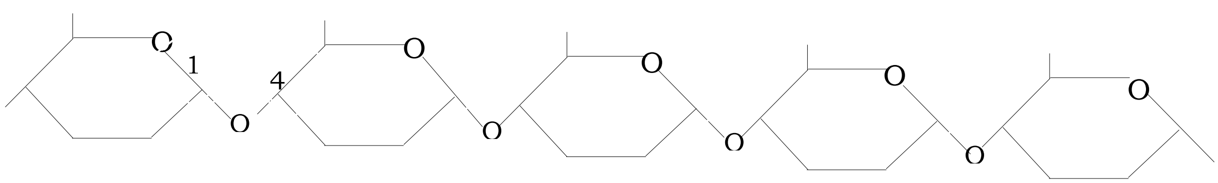
Type of sugar	**Test**	**Observation**	**Deduction**
Reducing sugar	To 1cm^3 of test solution, add 1cm^3 of Benedict's solution and boil		
Non reducing sugars	To 1cm^3 of test solution, add 1cm^3 of dilute hydrochloric acid and boil. Cool the mixture and add 1cm^3 dilute sodium hydroxide solution followed by 1cm^3 Benedict's solution and boil.		

Polysaccharides

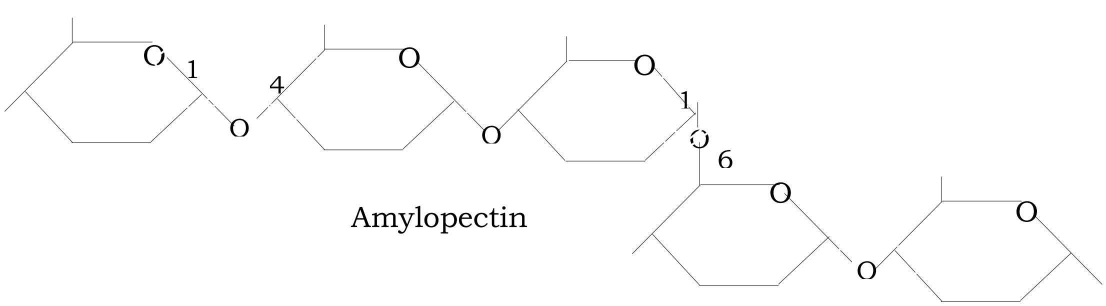
These are macromolecules made up of many monosaccharide subunits. They are formed by condensation of many monomer units of monosaccharides mainly hexoses linked by glycosidic bonds. Many polysaccharides serve as energy storage compounds in plants and animals while others serve as structural material for cells. Storage polysaccharides are insoluble long polymers such as starch in plants and glycogen in animals deposited in specific parts. Structural carbohydrates are chains of sugars that are not easily digested. They include cellulose in plants and chitin in arthropods and fungi.

Starch

It is a polymer of alpha glucose consisting of two components amylose (25%) and amylopectin (75%). Amylose is made up of alpha glucose molecules joined by α1, 4-glycosidic bond. This forms long unbranched chains which tend to coil in water. Amylopectin (‘*pectin’-branched polysaccharide*) is made of short branched chains of alpha glucose residues. The glucoses in the backbone chains are linked by α1, 4-glycosidic bond and branching occurs at the 25th glucose molecule and α1, 6-glycosidic bonds are formed. The structure of starch is compact which makes it a suitable storage compound. The branching and cross-linking render the polymer insoluble and protect it from degradation during storage.



Amylose



Amylopectin

a) State the structural differences between amylose and amylopectin
b) Describe how you can test for presence of starch in solution

Glycogen

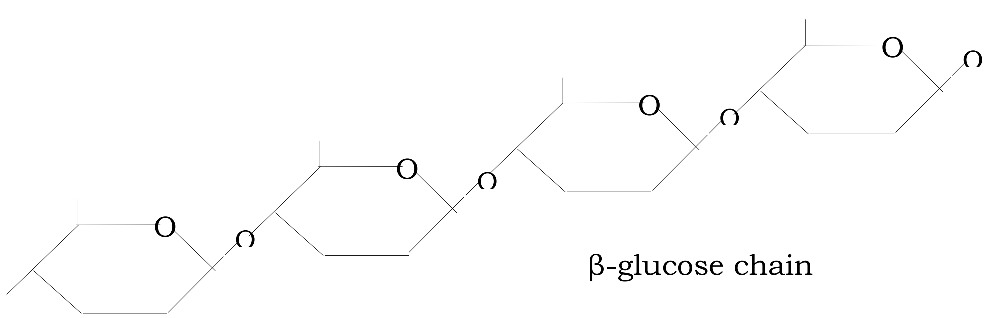
Like amylopectin, glycogen is an insoluble polysaccharide containing branched chains of alpha glucose sub units. However, glycogen has much longer chains that are much more branched than those of starch because it has more α1, 6-glycosidic bonds. This makes less dense and more soluble than starch. Glycogen is a major storage form of excess carbohydrates in humans and other vertebrates. It is deposited in the liver and in muscle cells but readily hydrolyzed to glucose when the demand for energy in a tissue increases under the influence of hormones.

Cellulose

Consist of un-branched chains of beta-glucose subunits linked by β1, 4-glycosidic bonds. This causes the chain to be straight with hydroxyl groups projecting outwards from each chain in all directions. The construction of chain in cellulose allows them to be closely packed and cross linked by hydrogen bonds forming bundles (of about 60-70 cross linked chains) called **microfibrils** which are also arrange in larger bundle called **macrofibrils.** These have a high tensile strength an important property in plant cell wall which prevents plant cell from bursting due to pressure developing inside as they absorb water by osmosis. When the cell becomes turgid due to osmosis it provides support to non woody plants.

Cellulose is also an import source of energy those organisms that are able to digest it e.g. bacteria, fungi and protozoans. Certain organisms which cannot digest cellulose can still make use of cellulose by harboring bacteria, fungi and protozoans which produce cellulase. Cellulase catalyzes digestion of cellulose to sugars or sugar acids which are absorbed by the host as source of energy. However the starch-digesting enzymes that occur in most organisms cannot the bonds between two beta-glucose sugars found in cellulose.

In plants that form wood, **lignin** (a polymer of sugar and amino acids) is deposited in spaces between cellulose making the cell wall more rigid and impermeable to water. Lignified cells eventually become dead since the protoplasm ceases to absorb materials outside the cell. However, lignified tissues provide mechanical support as well as transport of water and salts due to loss of protoplasm.



β-glucose chain

Chitin

This is the structural building material in exoskeleton of insects, and walls of fungal hyphae. Chitin is chemically similar to cellulose but with one hydroxyl group of glucose units replaced by nitrogen containing groups. Therefore chin is one of the mucopolysaccharides (with amino sugars) When cross-linked by proteins, it forms a tough, resistant surface material that serves as the hard exoskeleton of arthropods such as insects and crustaceans.

Write short notes about the following polysaccharide

a) Hemicellulose
b) Pectin
c) Anulin

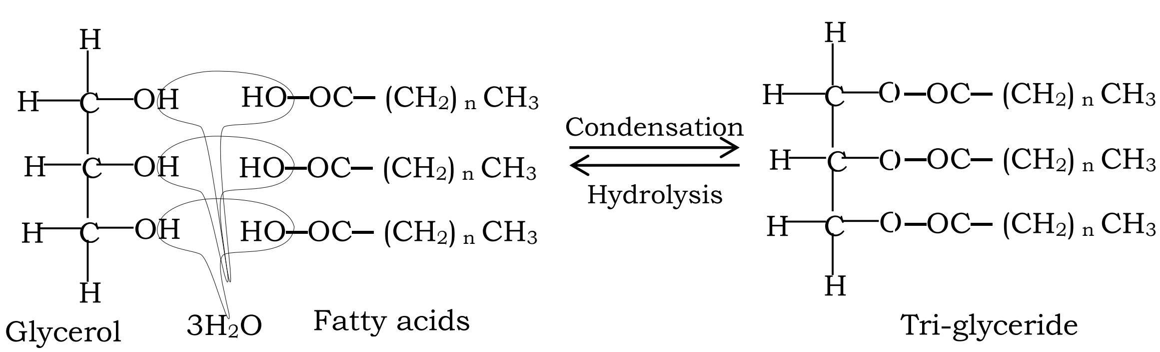
LIPIDS

Lipids are groups of compounds made of the elements carbon, hydrogen and oxygen, though with a much lower proportion of oxygen than carbohydrates. They are insoluble in water but soluble in organic solvents. The most commonly known lipids are the fats and oils but other forms may include waxes, phospholipids and steroids.

Fats and oils

Fats and oils have the same basic chemical structure but differ in their physical state at room temperature (20°C). Fats are solids at this temperature and while oils are liquids. Both fats and oils are esters made from glycerol and fatty acids

Fatty acids contain long unbranched hydrocarbon chains, $CH_3\ (CH_2)_n$ ending with a carboxyl group, COOH. Glycerol molecule is an alcohol containing three hydroxyl groups attached its carbon atoms. When these two components react, they form mono, di or triglycerides depending on how many hydroxyl groups are involved in reaction. Triglycerides for instance are formed when condensation reactions occur between one glycerol and three fatty acids. The hydroxyl groups of glycerol combine with the carboxyl groups of the fatty acids to form an ester linkage (ester bond) and releasing three water molecules.



Triglycerides (fats) can be either **saturated** or **unsaturated**, depending on the composition of the fatty acid chains. Unsaturated fats are triglycerides made from fatty acids with a short hydrocarbon tail containing one or more double bonds. These have low melting points and are usually oils or soft fats at room temperature. Saturated fats are those made from saturated fatty acids

Role of triglycerides

i) They are compact, insoluble long term stores of energy. They can be stored at high concentration without requiring water as a solvent and since they are light they do not greatly affect the weight of the organism when stored. Table below compares the storage properties of carbohydrates and lipids

Property	**Carbohydrate e.g. glycogen**	**Lipids (triglycerides)**
Storage	Short term energy storage	Long term energy storage
Solubility	Soluble as monomers and easy to transport in blood streams	insoluble (hydrophobic) and difficult to transport
Osmolality	More effect on osmotic pressure of the cell	Less effect on osmotic pressure
Digestion	More easily digested and utilize. are used to for aerobic and anaerobic respiration	Less easily digested and are used to for only aerobic respiration
ATP yield	Yield less than lipids energy per unit mass	Yield twice as much energy than carbohydrates per unit mass(high calorific value) since it contains higher proportion of hydrogen and low proportion of oxygen

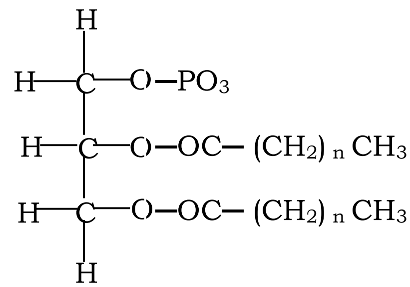
ii) Fats provide metabolic water when oxidized. This kind of water for young birds and some desert animals such as kangaroo rat.

iii) Fats are a common food store in animals living in cold places. It contributes to buoyancy of aquatic mammals such as wales. Hibernating animals also store fats as their source of energy. Plants usually store oils rather than fats in seeds.

iv) Fat deposits in the dermis of the skin are used for insulation of the body against heat loss

Phospholipids

They are similar to triglycerides with a glycerol 'backbone' and fatty acid (tails) but the third fatty acid group has been replaced by a phosphate group (head). This renders the molecule to have both hydrophobic properties of the fatty acid hydrocarbon chains and hydrophilic properties of the phosphate group. Phospholipids are important structural components of the cell membrane and their properties are important for the functioning of the cell membrane. They are a source of acetyl choline and are also used in transport fats between the gut and liver



Steroids

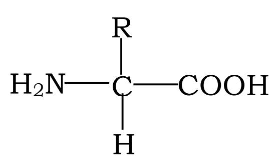
Steroids are a type of lipid composed of four carbon rings joined together to structure different from that of triglycerides. **Cholesterol** is a typical steroid is a component of the plasma membrane which readily mixes with lipids and makes them to easily absorb water. It is also of the most widely spread steroid in animal tissue is used to make bile salts, sex hormones and hormones of the adrenal cortex. cholesterol is converted to vitamin D by ultraviolet light.

PROTEINS

Proteins contain carbon, hydrogen, oxygen and nitrogen. They may also contain sulphur, iron and other trace elements. Although living organisms have variety proteins in their body, they are all polymers of only 20 amino acids linked by peptide bonds in a specific order. This order is determined by the gene (arrangement of bases) from which the protein was made.

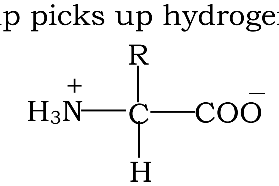
Structure and properties of amino acids

An amino acid is a molecule containing an amino group (—NH_2), a carboxyl group (—COOH), and a hydrogen atom, all bonded to a central carbon atom:

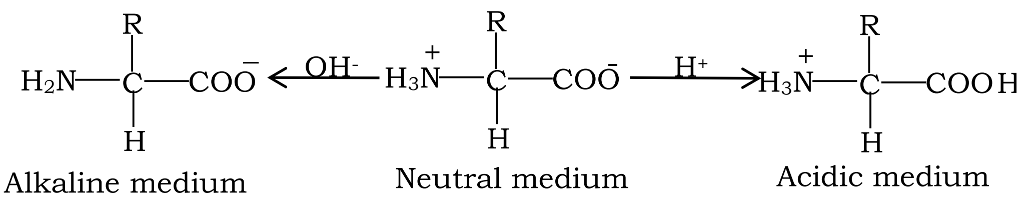


Each amino acid has unique chemical properties determined by the nature of the side group (indicated by R) covalently bonded to the central carbon atom. For example, when the side group is —CH_2OH, the amino acid (serine) is polar and when the side group is simply H, the amino acid (glycine) is uncharged polar but when the side group is —CH_3, the amino acid (alanine) is nonpolar

Amino acids are amphoteric because of possessing both basic and acidic part. They exist as ions and carry positive charge on basic part and negative charge on acidic part when the amine group picks up hydrogen ion from the medium while carboxyl group releases it.

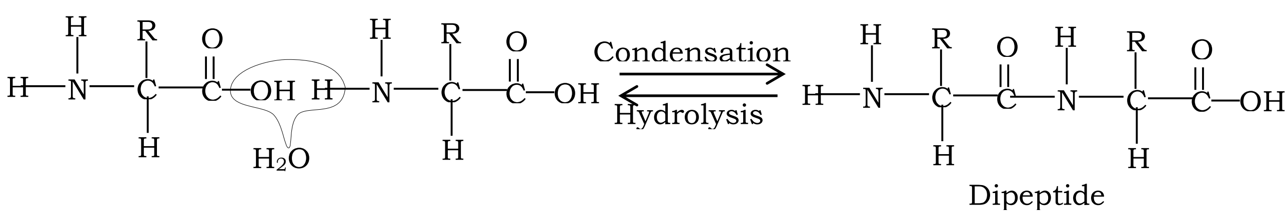


Such ions are described as dipolar and the charge on ion changes with PH. In acidic conditions the amino acid takes up H^+ ions and becomes positively charged while in alkaline medium the amino acid takes up OH^- ions and becomes negatively charged. Therefore amino acids tend to stabilize PH of solutions in which they are present. They act as buffers preventing PH changes, a property they retain when incorporated in a polypeptide chain.



Formation of protein from amino acids

Amino acids combine to form a protein. The first step involves combination of two amino acids in a condensation reaction. The reaction occurs between carboxyl group of one amino acid and amine group of another and a molecule of water is removed. The two amino acids are joined by a peptide link to form a dipeptide, which contains a free carboxyl group at one end and a free amine group at the other. Continued condensation of further amino acids results into formation of a long polypeptide chain. A protein is therefore composed of one or more polypeptide chains composed of amino acids linked by peptide bonds.



Structure of a protein

The structure of proteins is traditionally discussed in terms of four levels of structure, as primary, secondary, tertiary, and quaternary.

Primary structure: The specific linear amino acid sequence of a protein is its primary structure. This sequence is determined by the nucleotide sequence of the gene that encodes the protein.

Secondary structure: polypeptide chains may be folded or twisted to either coil into alpha helix or fold into beta sheets. These are maintained by weak hydrogen bonds. Proteins contain different proportions of alpha helix structures but one with a great deal of it is keratin, a component of hair, horns, beaks, hooves, nails, feathers etc. The beta sheets are flat zig- zag chains mainly occurring in insoluble proteins. It occurs in silk and fibroin which is entirely this form.

Tertiary structure: The polypeptide chain is intensively folded to form a compact globular shape maintained by ionic bonds, hydrogen bonds, disulphide bonds and hydrophobic interactions. The tertiary structure shows the three dimensional shape of the protein. On basis of their tertiary structure, proteins are classified as fibrous and globular proteins globular

Fibrous proteins consist of parallel polypeptide chains cross linked at intervals to form long fibres or sheets. They are insoluble in water and usually tough which suits them for their mainly structural functions. These structural proteins include **keratin** found in hair, hooves, horns and feathers and the connective tissue proteins **elastin** and **collagen** found in muscles.

In globular proteins the polypeptide chains are tightly folded to form a spherical shape. The folding is in such a way that the hydrophobic groups face inside while hydrophilic groups face outside. This makes these proteins to be relatively soluble and readily go into solution. They are found in blood plasma where they play vital function of buffering. They are vital components of the cell membrane and are used in construction of microtubules and microfilaments. They are also in formation of enzymes, antibodies and hormones.

Many proteins can be fully unfolded ("denatured") and will spontaneously refold back into their characteristic shape (renatured). Denaturation involves loss of three dimensional shape of a protein which renders it unable to perform its function. This may be caused by heat, strong acids or alkalis and concentrated salts, heavy metals and organic solvents. All these interrupt the bonds that maintain the three dimensional shape of a protein

Quaternary structure: when two or more polypeptide chains associate and are highly folded to form a functional protein, a quaternary results. It is maintained by bonds described above. An example is haemoglobin which has two alpha and two beta chains. Haemoglobin also contains four haem groups within the molecule and the protein with such non protein material is called a **conjugated protein** and the non-protein part is called a prosthetic group.

Functions of proteins

Role of protein	Occurrence and function
Structural / support	Fibrous, or threadlike, proteins play structural roles; these structural proteins include keratin in hair, fibrin in blood clots, and collagen, which forms the matrix of skin, ligaments, tendons, and bones

Homeostasis	Soluble proteins act as buffers stabilizing PH in solutions where they occur in the body.
Enzyme catalysis	Enzymes are proteins that speed up the chemical reaction in the body of organisms.
Defense/ protection	Antibodies use their shapes to “recognize” foreign microbes and cancer cells. These cell surface receptors form the core of the body’s hormone and immune systems.
Transport	A variety of globular proteins transport specific small molecules and ions. The transport protein hemoglobin, for example, transports oxygen in the blood, and myoglobin, a similar protein, transports oxygen in muscle. Iron is transported in blood by the protein transferrin.
Movement	Muscles contract through the sliding motion of two kinds of protein filament: actin and myosin. Contractile proteins also play key roles in the cell’s cytoskeleton and in moving materials within cells.
Regulation	Hormones serve as intercellular messengers in animals. Proteins also play many regulatory roles within the cell, turning on and shutting off genes during development, for example. In addition, proteins also receive information, acting as cell surface receptors.
Storage	Casien in milk and aleurone protein in seeds

Assignment:

a) Distinguish between essential and non-essential amino acids
b) Describe the general function of proteins to in the body
c) How does the structure of proteins relate to their function?

Analysis of proteins

	Test	**Observation**	**Deduction**
Biuret test	To 1cm^3 of test solution, add 1cm^3 sodium hydroxide solution followed by 2 drops of copper(ii) sulphate solution.		
Millon’s test	To 1cm^3 of test solution, add 1cm^3 of millon’s reagent and boil.		

VITAMINS

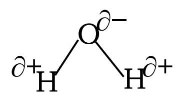
Vitamins are sometimes referred to as accessory growth factors because they are needed in small quantities in the body. They are divided into water soluble vitamins and fat soluble vitamins. Water soluble vitamins such as vitamin B and vitamin C are not stored in the body therefore need to be consumed regularly. Fat soluble vitamins such as vitamin A, vitamin D, vitamin E and vitamin K are stored in liver and need not to be consumed regularly.

Vitamin	Source	Function	Deficiency symptoms and diseases
Vitamin A (retinol)	Green/orange vegetables, carrots, fish liver oil, animal liver	Growth and function of epithelia especially secreting mucus Component of visual pigment	Dry skin Night blindness
Vitamin B_1 (thiamine)	Liver, un polished rice, lean meat, yeast etc.	Release of energy from carbohydrates (coenzyme in decarboxylation)	Degeneration of nerves called beriberi
Vitamin B_2 (riboflavin)	Milk	Release of energy from carbohydrates (coenzyme in electron transport system).	
Vitamin B_3 (nicotinic acid)	Yeast extract, whole meal bread, coffee	Release of energy from carbohydrates (component of NAD and NADP).	Skin disease called pellagra
Vitamin B_6	Meat, eggs, whole cereal	Essential for metabolism of amino acids.	
Vitamin B_{12}	Liver, yeast extracts	Synthesis of nucleic acids(RNA and DNA)	Pernicious anemia
Vitamin C (ascorbic acid)	Citrus fruits, vegetables potatoes	Maintenance of connective tissues	Bleeding from small blood vessels scurvy
Vitamin D (calciferol)	Fish liver oil, egg yolk, butter, margarines	Maintenance of the level of calcium and phosphorous by enhancing absorption and regulating exchange between bones and blood.	Failure of bones to calcify leading to bow legs and knock knees(rickets) in children Pain full bones which fracture easily in adults.
Vitamin E (tocopherol)	Plant oils	No conclusive evidence for function in human	
Vitamin E (phyloquinone)	Dark green leafy vegetables, it is also made by bacteria in intestines	Normal clotting of blood	Delay in blood clotting mechanism

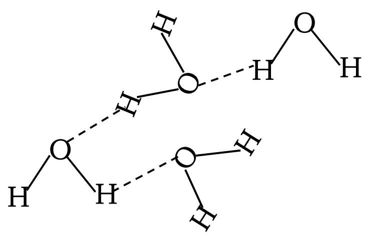
INORGANIC COMPOUNDS

WATER

Water is a molecule made up of two hydrogen atoms and one oxygen atom. It has the formula H_2O. When oxygen and hydrogen combine (H-O-H) they form a v-shaped triangular molecule. Though water molecules have no overall charge, there is uneven distribution of charge on oxygen and hydrogen. The oxygen atom draws bonding electrons away from hydrogen making oxygen slightly negatively charged and the two hydrogen atoms are slightly positively charged. Therefore water is described as a dipolar molecule.



Opposite poles attract one each therefore the positive pole of one water molecule usually attract the negative pole of another. The attractive force between these opposite charges is called a **hydrogen bond.** This is weaker force than the covalent bond but together they form important forces that cause water molecules to stick together and determine almost every physical property of water and many of its chemical properties too.



Properties of water

Universal solvent: Water can dissolve more substances than any other liquid. These substances are either ionic or polar molecules. This is important because chemical reactions take place in aqueous medium. This property of water also allows for the transport of nutrients vital to life in animals and plants.

High surface tension and strong cohesion and adhesion: Water molecules stick to each other due to strong intermolecular forces and the hydrogen bonds formed between them. Those at the surface have a much greater attraction for each other than for molecules in the air. This cohesiveness creates a high surface tension at the surface of the water. The water molecules at the surface crowd together, producing a strong layer as they are pulled downward by the attraction of other water molecules beneath them. High surface tension makes water surface hold weight that would normally sink. Some aquatic insects such as the water strider or pond skater rely on surface tension to land and walk on water in form of water column.

Water molecules strongly adhere to other polar substances (strong adhesion). This is how water makes things wet. Strong cohesion and adhesion prevents water column from braking under tension important in movement up the xylem

High specific heat: Large amount of energy required to raise the temperature of water by one degree Celsius. Much energy is used to break hydrogen bonds which restrict mobility of water molecules. As a result, water is slow to heat up or cool down. This minuses temperature changes and therefore stabilizes temperature in aquatic environments and the bulk body fluids of organisms despite changes in the environmental temperature.

High heat of vaporization: Much heat is absorbed by water as it changes from a liquid to a gas. This is because many hydrogen bonds have to be broken to evaporate water on top of intermolecular forces. Evaporation of water during sweating or panting in animals and transpiration in plants causes cooling which is important in temperature regulation.

High latent heat of fusion: very high amount of heat needed to melt ice is and freeze water to make ice hence aquatic environments and cell components are slow to freezing.

Anomalous behavior during freezing: Most liquids contract on cooling reaching their maximum density at their freezing point. Water is unusual in reaching its maximum density at $4^{o}C$. When water freezes, ice formed is less dense than water and floats on water and it's the only substance whose solid form has density lower than liquid form. This is because water molecules in ice are far apart due to hydrogen bonds. This property is important for survival of aquatic organisms as water bodies freeze from top to bottom and not from bottom to top. The ice formed forms a layer on top of water which insulates water beneath it delaying it from freezing.

Incompressibility: water is difficult to compress due to ……………a property that allows it to act as a skeleton called hydrostatic skeleton which provides support in worms and plants.

Low viscosity: Water flows freely and water molecules can easily slide over each other. It can flow freely through narrow vessels. Therefore watery solutions act as lubricants.

Transparency: Pure water is colourless and very transparent a property that allows sunlight to penetrate the water so that aquatic plants can photosynthesize under water. The transparency of water is important for vision of animals in water.

Biological importance of water

- Constituent of protoplasm of cells
- Medium in which most biochemical reactions proceed
- A raw material involved in processes photosynthesis, hydrolysis etc.
- Fertilization by swimming gametes
- Dispersal of seeds, gametes etc.

Plants

- Osmosis and turgidity
- Reagent in photosynthesis
- Transpiration
- Translocation of inorganic ions and organic compounds
- Germination of seeds, swelling and breaking open of the testa and further development

Animals

- Transport in blood vascular system, lymphatic system, excretory system
- Osmoregulation
- Lubrication
- Cooling by evaporation in sweating, panting
- Lubrication as in joints
- Support- hydrostatic skeleton e.g. annelids
- Protection e.g. tears, mucus,
- Migration in ocean current

ACIDS, BASES AND SALTS

An acid is a compound which when dissociates in water, liberate a hydrogen ion.

$$HCl \rightarrow H^+ (aq) + Cl^- aq)$$

A base is a compound which combines with hydrogen ions liberated by dissociation of an acid.

$$NaHCO_3 \rightarrow Na^+ (aq) + HCO_3^- (aq)$$

$$H^+ (aq) + HCO_3^- (aq) \rightarrow H_2CO_3 (aq)$$

Importance of acids and bases

- Bases act as buffers hence maintaining the PH of tissue fluid constant
- HCl used in hydrolysis of sucrose
- Acids and bases provide optimum conditions for action of enzymes
- acids defend the body against disease causing germs e.g. HCl kills germs in food

- acids activate enzymes for digestion

MINERAL SALTS

They are compounds of metals with nonmetals or nonmetallic radicals. They are ionic compounds which dissociate in water to give their respective ions.

ENZYMES

An enzyme is a protein molecule that functions as a biological catalyst (speeds up the rate of chemical reactions in the body). Chemicals which enzymes work on are called **substrate.** An enzyme combines with its substrate to form enzyme-substrate complex. The complex rapidly converts to converts to enzyme and products. The enzyme remains unchanged and free to combine with other substrates and the end of the reaction.

Enzyme + substrate→ enzyme-substrate complex →enzyme product complex→ enzyme +products

Enzymes and metabolic pathways

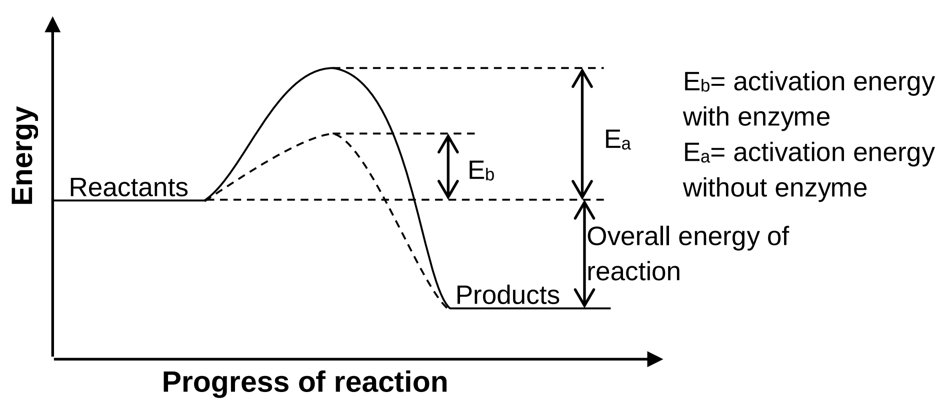
All chemical reactions that occur in the cell are referred to metabolism and the molecules involved are called metabolites. Metabolic reactions occur in a series of chain reactions called metabolic pathway. Occurring in steps rather than haphazardly has advantages. It prevents heat from being produced so quickly that can damage the cell. Secondly it allows energy to be derived from the reaction in a usable form. The food substrate broken down partially can provide building blocks for repair of body tissues.

Many metabolic path ways are ongoing in the cell in an efficient and orderly manner due specific nature of enzymes. Each step in a metabolic pathway is catalyzed by a specific enzyme.

Assignment: Describe the two types of metabolic pathways in cells.

Enzymes and activation energy

Activation energy is the energy required to make substances to react. Enzymes like other catalysts work by reducing this energy therefore allowing a large number of molecules to react. Enzymes provide an alternative pathway with minimal energy expenditure.



Properties of enzymes

i) They are protein in nature; Enzymes are all complex globular protein molecules with a high molecular weight compared to the molecular weight of the substances they catalyze. Therefore their other properties reflect those of proteins.
ii) Enzymes are very efficient (work very rapidly); the number of substrate molecules converted by an enzyme to products per minute (turn over number) is higher than that of other catalysts. This is because enzymes achieve a greater lowering of activation energy than inorganic catalysts
iii) Enzymes are highly specific much more than inorganic catalysts; an enzyme catalyzes one reaction or a particular type of reaction. Some enzymes exhibit absolute specificity catalyzing only one reaction e.g. amylase , sucrase, catalase etc. while others show relative specificity by catalyzing a number of related substrates e.g. pancreatic lipase on any lipid.
iv) Catalyze reversible reaction; enzymes speed up the forward and backward reactions equally but do not affect the equilibrium position.
v) Enzymes are not destroyed by the reactions they catalyze since they do not take part in the reaction
vi) Enzymes are sensitive to temperature. They are inactivated by excess cold temperature and denatured or destroyed by excess.
vii) Enzymes are sensitive to pH. Each enzyme has its optimum pH range at which it works best. Some enzymes work best under acidic, neutral or alkaline (basic) pH.

Comparison between enzymes and inorganic catalysts

Both enzymes and inorganic catalysts

- Are needed in minute quantities
- Speed up the rate of reactions but do not initiate a reaction
- Lower activation energy
- Are not chemically changed in the reaction they catalyze
- Temporarily combine with the substrate
- Do not alter the nature of products
- Do not affect the equilibrium position

However, enzymes differ from inorganic catalysts in properties shown in the table

	Enzyme	Inorganic catalyst
Chemical nature	Complex proteins	Simple inorganic substances
Specificity	Very specific	Catalyze a wide range of reaction
Molecular mass	Very high	Low
Speed of action	Very high turnover	Less efficient than enzyme
Effect of heat	Denatured	Not effect by heat
Effect of pH	Restricted range of pH	Not affected
Effect of inhibitors	Reduce their action	No effect

Classification and naming of enzymes

Basing on their area of action, enzymes are classified as

i) Intracellular enzymes which occur in cells where they control metabolism
ii) Inter cellular enzymes which are produced by cells but catalyze reactions outside cells. They include digestive enzymes.

Basing on their substrate, enzymes are named by adding a suffix 'ase' on the name of the substrate

Substrate	Enzyme
Maltose	Malt**ase**
Urea	Ure**ase**
Arginine	Arginine**ase**
Amylose	Amyl**ase**

However enzymes renin and pepsin work on proteins and are called proteases. This implies that enzymes can also be named based on a group of compounds they catalyze e.g. carbohydr**ase**s for carbohydrates, lipases for lipids etc.

Basing on the type of reaction the catalyze enzymes are categorized into six major groups

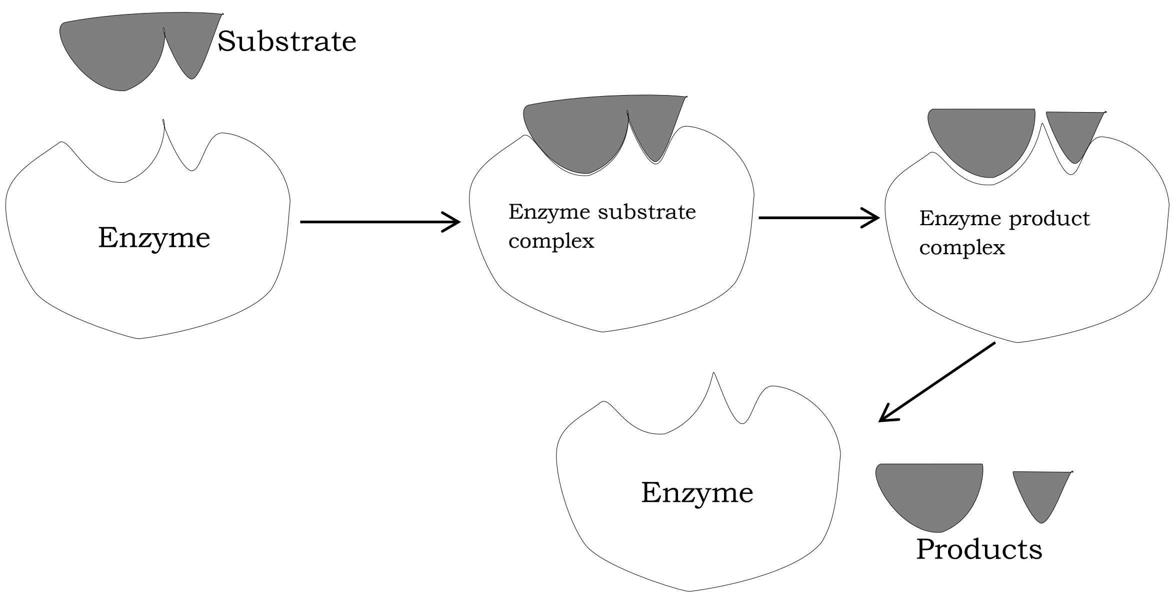
Type of enzyme	Type of reaction catalyzed and examples
Hydrolases	Hydrolysis which involve splitting of large substrate into smaller products and water is involved in the reaction e.g. amylase lactase etc.
Oxidoreductases	Redox reactions which involve oxidation and reduction by transfer of oxygen, hydrogen or electrons from one molecule to another. Those involve in removal of hydrogen are dehydrogenases
Transferases	Transfer of a group from one compound to another e.g. amino transferase catalase transamination reaction
Isomerases	Rearrangement of groups with in a molecule so that its structure conform to a particular pattern.
Ligases	Joining two molecules with simultaneous hydrolysis of ATP e.g. amino acyl transfer RNA synthetase
Lyases	Non hydrolytic addition or removal of a chemical group from a substrate e.g. pyruvate decarboxylase catalyzes formation of ethanol and carbon dioxide from pyruvate

Assignment With reference to intracellular reactions, state the significance of enzymes in metabolism

MODE OF ACTION OF ENZYMES

Lock and key hypothesis

Most enzymes are globular proteins larger than their substrate but enzyme molecules have a very precise three dimensional shape (tertiary structure) with a precise place on its surface, the active site to which the substrate molecule fits. The shape of the active site and the different chemical groups in it ensure that only substrate with complementary structure can bind to enzyme at the active site to form enzyme substrate complex held by hydrogen bonds, and ionic bonds. The enzyme catalyzes change the substrate into products. Once formed products no longer fit into the active site therefore leave the active site free to combine with other substrates. According to lock and key hypothesis, the shape of the substrate must exactly fit into a rigid active site just like a key fits into a lock. This explains why enzymes are specific and any slight change in shape affect their effectiveness.

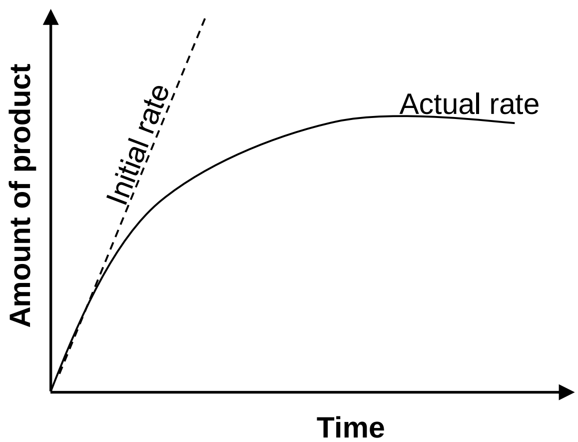


Induced fit theory

The enzyme and its active site are flexible structures that can be modified as the enzyme interacts with its substrate. The shape of active site is affected by the substrate just like that of gloves is affected by the hand wearing it. According to this theory, as the substrate combines with the enzyme it induces a slight change in the shape of the enzyme to enable the substrate fit into the active site. Amino acids that make up the active site are molded into a precise shape to enable the enzyme perform its catalytic function. In some cases the substrate changes shape slightly as it enters the active site before binding.

Factors affecting enzyme activity

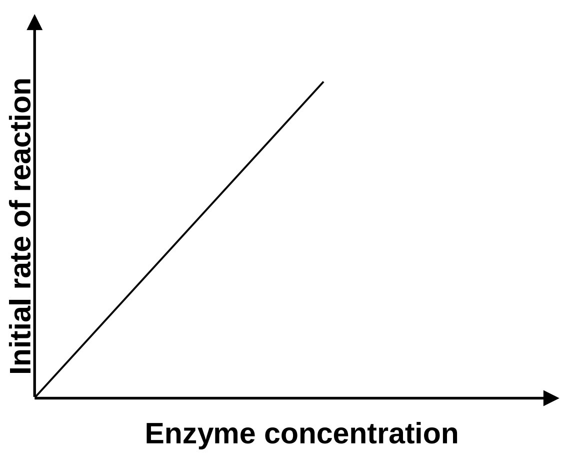
The rate of reaction is measured by the amount of substrate used or amount of product formed over a period of time. The rate is determined by drawing a tangent to the curve in the initial stages of reaction (initial rate)



A number of factors affect the rate of enzyme activity and when investigating the effect of one factor, all the other factors have to be kept constant and at optimum levels. Initial rate only should be measured because if measured over a period of time, the rate decreases due to reduction in substrate concentration as the substrate gets used up.

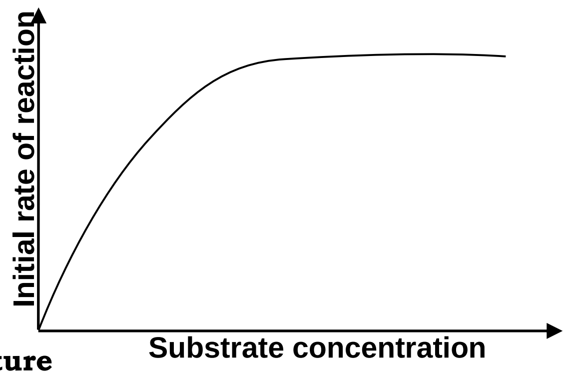
Enzyme concentration

Provided there is enough substrate and the other conditions are kept at optimum level, the rate of reaction is increases with increasing enzyme concentration.



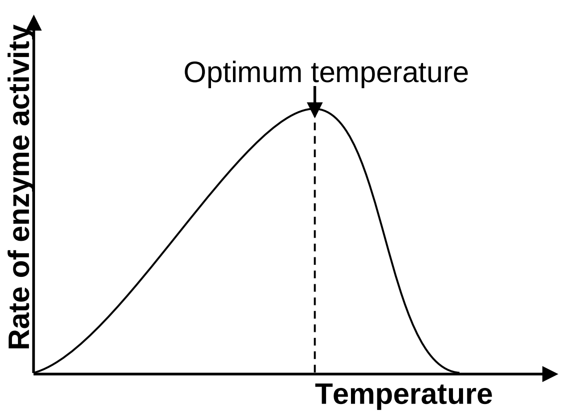
Substrate concentration

For a given enzyme concentration, the rate of enzyme reaction increases with increase in substrate concentration up to a certain substrate concentration. This is because the frequency of collision between the enzyme and substrate increases when substrates increase as more substrates fit into the active site of enzymes and more products formed per unit time until active sites of the enzyme are fully occupied. When substrate concentration is further increased, the rate remains constant since all the active sites of the enzyme are occupied.



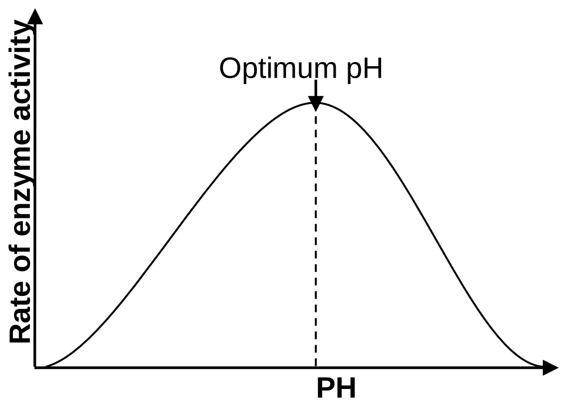
Temperature

Very low temperatures below the freezing point reduce the rate of reaction since the enzymes become inactivated. Increase in temperature (between 0and 40^{o}C) almost doubles the rate of reaction for every 10^{o}C rise. This is because heating increases kinetic energy (motion) of both the enzyme and substrate molecules thus increasing the probability of collision between substrate and active site of enzyme which increases the rate of reaction. However this is only true up the optimum temperature, which produces the maximum rate of reaction. Beyond the optimum temperature, further increase in temperature rapidly reduces the rate of reaction because excess heat denatures the enzyme. Since enzymes are proteins excess heat destroys the hydrogen bond and hydrophobic interaction which maintain the three dimensional structure of the enzyme (tertiary structure of protein) changing its shape and eventually destroying the active site.



PH

Enzymes usually have a narrow range of pH under which they work best. The optimum pH is that at which the rate of reaction is maximum and this varies from enzyme to enzyme. Enzyme can have their optimum under alkaline, acidic or neutral condition depending on the structure. Change in pH conditions away from the optimum reduces the rate of enzyme activity. It alters the ionic charge on the acidic and basic groups which disrupts ionic bonds that maintain the specific shape of the enzyme. This alters the shape of the active site preventing the substrate from effectively binding to the substrate.



Assignment: draw a graph to show how pH affects the activity of amylase, pepsin and trypsin enzymes. In which part of the alimentary canal would you expect to find each of these enzymes?

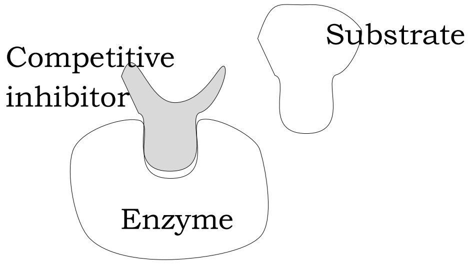
Enzyme inhibitors

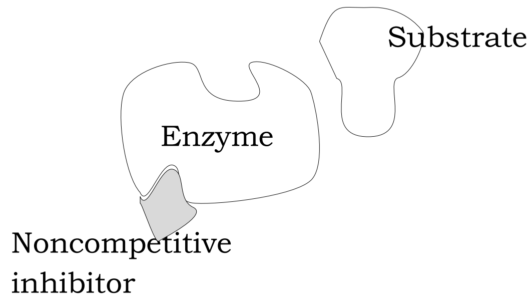
Competitive and noncompetitive inhibitors

These are small molecules which bind to enzymes and reduce their rate of action inhibitors are classified as competitive and non-competitive basing on where they attach during inhibition.

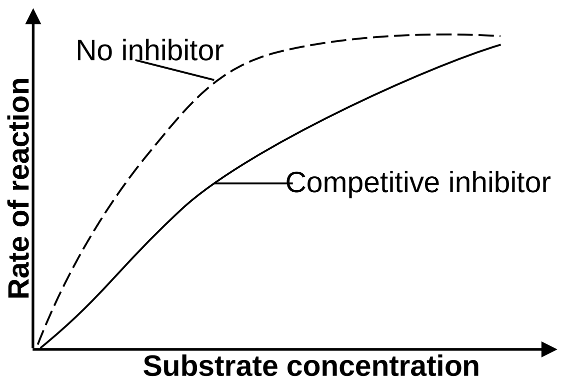
Competitive inhibitors have a shape similar to that of the substrate molecule. They compete with the normal substrate for the active site and when they bind to the active site preventing the enzyme from binding with the substrate which gradually reduces the rate of reaction. However, when the substrate concentration is increased their effect reduces and the rate of reaction increases. This is because higher concentration of substrate molecules outcompete the inhibitors.

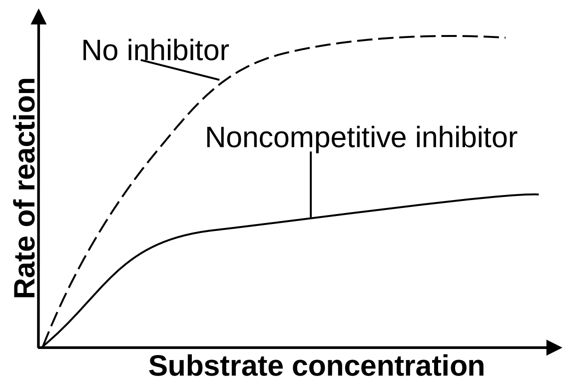
Non-Competitive Inhibitors bind to the enzyme outside the active site but prevent substrate from effectively binding with the active site. Therefore substrate no longer fits in active site which slows down rate of reaction rapidly. Increase in substrate concentration has no effect on this type of inhibition.





Graphs to show effect of inhibitors concentration on enzyme activity at increasing substrate concentration





Assignment: explain using the graphs above the difference in the effect of two kinds of inhibitors.

Reversible and irreversible inhibitors

Enzyme inhibitors vary in how firmly they attach on to the enzyme molecules. **Reversible inhibitors** bind less tightly and temporarily to an enzyme with weak hydrogen bonds which are easily broken. They do not destroy the enzyme but only affect the enzyme when they are still attached to it and as soon as they detach from it functions normally again. Some occur naturally in the cells where they have a role in regulation of metabolism. **Irreversible inhibitors** bind tightly and permanently to an enzyme with strong covalent bonds which are difficult to break without damaging the enzyme. Consequently their effect is permanent.

Assignment: describe the role of end product inhibition in a metabolic pathway.

Enzyme cofactors

These are non-protein compound that increase the efficiency of enzymes. They include

i) **Coenzyme:** are small organic molecules that are not attached to the enzyme but are carrier molecules which bring the substrate to enzyme and taking away the product. They include NAD, NADP and ATP which derived from vitamin. These will be considered later

ii) **Prosthetic groups:** are organic molecules permanently bound to the enzymes to increase their efficiency e.g. FAD and haem
iii) **Activators:** these are inorganic ion or metal ions which mold either the substrate or enzyme the shape that allows enzyme substrate complex to be formed.