

THE CHEMICALS OF LIFE

Cells, tissues and organs are composed of chemicals, many of which are identical with those found in nonliving matter. Chemical compounds are divided into

(i) **Organic compounds**, include all complex compounds of carbon namely; *carbohydrates, lipids, proteins* and *nucleic acids*.

(ii) **Inorganic compounds**, include; *Acids, bases, salts* and *water*.

ACIDS, BASES AND SALTS.

(i) **Acid**: Is a compound which dissociate in water to liberate a hydrogen ion. For example: Hydrochloric acid, Sulphuric acid. The strength of an acid is determined by the extent to which it dissociates in aqueous solutions. The acidity of a solution is expressed as its **pH**. A pH of 7 represents *neutrality*, pH value less than 7 is *acidic* and pH greater than 7 is *Alkaline*.

(ii) **A base**: is a compound which can combine with hydrogen ions liberated by dissociation of an acid. For example; Sodium hydrogen carbonate. In so doing it a base acts as a **buffer** (compound which resist change in pH on dilution or addition of small amounts acid or Alkali). PH of body fluids should be kept as *constant* as possible *because*, cells and tissues can only function properly at around neutrality, they cannot tolerate fluctuations of pH.

(iii) **Salts**: In the body, some of the common solutes found dissolved in water are **mineral salts**, compounds of a metal with nonmetal or non-metallic radical, e.g. sodium chloride. Some nutrients are need by the body in large amounts and are called **Macronutrients** while other nutrients are needed in small amounts thus called **micronutrients**.

The *functions* of theses mineral salts and their relative derivatives are varied, but their roles can be summed up thus; (i) As constituents of various *chemicals*. (ii) As constituents of *structures*. (iii) As constituents of *enzymes*. (iv) As metabolic *activators*. (v) As constituents of certain *pigments*. (vi) As determinants of the *anion – cation balance* in cells. (vii) As determinants of *osmotic pressure*.

Inorganic ions and their importance in plants and animals.

<i>Macro element</i>	<i>Function</i>	<i>Notes and deficiency</i>
Nitrate NO_3^- Ammonium NH_4^+	(i) Nitrogen is a component of amino acids, proteins, vitamins, coenzymes, nucleotides and chlorophyll: (ii) some hormones contain nitrogen e.g. Auxins in plants and insulin in animals	In plants causes <i>chlorosis</i> (yellowing of leaves) and stunted growth.
Phosphate PO_4^{3-} Orthophosphate $\text{H}_2\text{PO}_4^{2-}$	(i) A component of nucleotide, ATP and some proteins used in phosphorylation of sugars in respiration. (ii) Constituent of bones and teeth. (iii) Component of cell membranes in form of phospholipids.	In plants leads to stunted growth, especially of roots, and formation of dull, dark green leaves: in animals, can result into bone malformation called <i>crickets</i> .
Sulphate SO_4^{2-}	Sulphur is a component of some proteins and certain coenzymes e.g. acetyl coenzyme A	Sulphur forms important bridges between the polypeptide chains of some proteins, giving them their tertiary structure. Deficiency causes <i>chlorosis</i> and poor root development.
Potassium K^+	(i) Maintains electrical, osmotic and anion / cation balance across cell membranes. (ii) Involved in	Potassium plays role in transmission of impulses.

	active transport of certain materials across cell membrane. (iii) Co factor in photosynthesis and respiration. (iv) Constituent of sap vacuoles in plants, maintains turgidity.	Deficiency leads to yellow edged leaves and premature death.
Calcium Ca^{2+}	In plants: (i) component of middle lamella. (ii) Aids translocation of carbohydrates and amino acids. In animals, (i) Constituent of bones, teeth and shells. (ii) Blood clotting. (iii) Muscle contraction.	In plants, death of growing points. In animals causes rickets.
Sodium Na^+	(i) Maintains electrical, osmotic and anion / cation balance across membranes. (ii) Active transport across membranes. (iii) Constituent of sap vacuole.	(i) Muscular clumps. (ii) deficiency rare in plants.
Chlorine Cl^-	(i) Maintains electrical, osmotic and anion / cation balance across membranes. (ii) Formation of hydrochloric acid in gastric juice. (ii) transport of carbon dioxide by blood (chloride shift)	Causes muscular clumps in animals. Deficiency rare in plants, common in soil.
Magnesium Mg^{2+}	(i) Constituent of chlorophyll. (ii) Activator of some enzymes e.g. ATPase. (iii) Component of bone and teeth.	Chlorosis in plants.
Iron Fe^{2+}	(i) Constituent of electron carriers e.g. cytochromes, needed in respiration and photosynthesis. (ii) A constituent of certain enzymes e.g. peroxidases, dehydrogenases, decarboxylases. (iii) Required in synthesis of chlorophyll. (iv) Forms part of haem group in respiratory pigments such as haemoglobin, haemoerythrin, myoglobin.	Chlorosis in plants and Aneamia in animals.
<i>Micronutrients / trace elements</i>		
Magnesium Mn^{2+}	(i) Activator of certain enzymes eg phosphatases. (ii) Growth factor ion bone development	Leaves with mottled with grey Bone deformation
Copper Cu^{2+}	(i) Constituent of some enzymes e.g. Cytochrome oxidase and tyrosinase. (ii) Component of haemocyanin (a respiratory pigment)	Young shoots die back at an early stage.
Iodine I^-	Constituent of hormone thyroxin.	Not required in higher plants. Causes cretinism in children and goiter in adults. Essential for metamorphic changes in some vertebrates.
Cobalt Co^{2+}	(i) Constituent of Vitamin B12, important in synthesis of RNA, nucleoprotein and red blood cells.	Anemia
Zinc Zn^{2+}	(i) Activator of certain enzymes, e.g. carbonic anhydrase. (ii) Required in plants for leaf formation, synthesis of auxins and alcoholic fermentation.	Carbonic anhydrase is important in transportation of carbon dioxide in vertebrates blood. In plants, produces malformations and sometimes mottled leaves.
Molybdenum Mo^{4+} Mo^{5+}	(i) Reduction of nitrate to nitrite in formation of amino acids.	Reduction in crop yields. Not vital in most animals.

Boron BO_3^{3+} B_4O^{2+}	(i) Required for uptake of Ca^{2+} by roots. (ii) Aids the germination of pollen grains and mitotic division in meristems.	Not required by animals. Death of young shoots and abnormal growth.
Fluorine F^-	Component of teeth and bones.	Not required by most plants. Teeth decay

CHECK UP:

By now you should be able to: (i) **Describe** properties of acids, bases and salts. (ii) **Explain** the role of acids, bases and salts in maintaining a stable internal environment for physiological processes.

WATER

Water is by far the most abundant component of organisms. Individual human cell contains about 80% water, and the whole body is made up of over 60%. Life originated in water and today numerous organisms make their home in it. Water provides the medium in which all biochemical reactions take place and has played a major role in the evolution of biological systems.

Some Biologically important functions of water.

<i>All organisms</i>	<i>Plants</i>	<i>Animals</i>
Structure - high water content of cells.	Osmosis and turgidity , (cell enlargement, guard cell mechanism, support)	Transport in vascular system, lymphatic and excretory system.
Solvent and medium for diffusion	Reagent in photosynthesis.	Osmoregulation .
Reagent for hydrolysis	Transpiration	Cooling by evaporation, such as sweating and panting.
Support for aquatic organisms.	Translocation of inorganic ions and organic compounds.	Lubrication , as in joints.
Fertilization by swimming gametes	Germination of seeds, swelling and breaking open of the testa and further development.	Support , Hydrostatic skeleton e.g. annelid worms.
Dispersal of seeds, gametes and larval stages of aquatic organisms and seeds of some terrestrial species e.g. coconuts.		Protection ; e.g. mucus, tears
		Migration in ocean currents

The importance of water as a medium for life comes from four of its properties:

(a) Its **solvent properties**.

Water's properties as a solvent depend on the fact that it is a **polar molecule** (the distribution of electric charge is such that the centers of negative and positive charges are separated by a short distance). Because structure of a water molecule; instead of being arranged in a straight line, the hydrogen and oxygen atoms are situated asymmetrically (V – shape). The molecule as a whole shows **polarity**. Because Oxygen part has a net negative charge and hydrogen parts a net positive charge. **Consider**: if sodium chloride is placed in water, having both positive and negative charges, water attracts both ions of the molecule breaking it and clustering around it. **Because** of this: (i) water is a **good solvent**, ionic solids and polar molecules readily dissolve in it, this is of a very biological importance because all chemical reactions taking place in a cell occur in aqueous solution. (ii) Water molecules associate with each other (positive hydrogen atom of one

molecule maybe attracted to negative oxygen atom of another) forming **hydrogen bonds** important in holding organic molecules together.

(b) Thermal properties:

Heat capacity, is the amount of heat required to raise the temperature of 1g by 1°C. Water has very high heat capacity compared with other liquids. Therefore a large increase in heat results into a comparatively small rise in temperature of water. This implies water is good at maintain its temperature constant irrespective of changes in temperature of the surrounding environment. This is biologically important because; **(i)** Biochemical processes proceed in very narrow range of temperatures, and most organisms cannot tolerate wide variations of temperature. **(ii)** High thermal capacity of water keeps the temperature constant, thus making it an ideal for plant and animal life. **(iii)** Water has remarkably high boiling point, thus hardly evaporate.

(c) Surface tension.

This is the force that causes the surface of liquid to contract so that it occupies the least possible area. It is due to inward – acting cohesive forces between molecules at the surface being caused by polarity of water. Water has high surface tension and molecules dissolved in water tend to lower its surface tension and collect at the interface between liquid and other phases. This is biologically important in: **(i)** Development of plasma membrane and movement of molecules across it. **(ii)** Movement of water up the capillary like vessels and tracheid in the stems of plants. **(iii)** Enables the surface film to support and provide habitat for certain aquatic organisms.

(d) Freezing properties:

When water is cooled below a certain temperature, its volume increases and its density decreases. This means ice tends to float than to sink. When the temperature drops the coldest water is at the surface and being less dense than the slightly warmer water lower down, tends to remain at the surface. So ice forms at the surface first, and bottom later. Organisms which live towards the bottom of fresh water lakes are protected from freezing increasing their survival.

CHECK UP:

By now you should be able to: (i). **Describe** the molecular structure of water. (ii). **State** functions of water. (iii). **Explain** the importance of water as a solvent. (iv). **Relate** the water properties to its role in the life of organisms.

A. CARBOHYDRATES

These are food substances which contain elements; **carbon, hydrogen** and **Oxygen**. They have a general formula $C_x(H_2O)_y$, where X and Y are variable numbers. Their name **Hydrate of carbon** is derived from the fact that Hydrogen and oxygen are present in the same proportions as in water, namely two hydrogen atoms per oxygen atom. In addition: (i) All carbohydrates are either **aldehydes** or **ketones**. (ii) All contain several **hydroxyl groups**. Carbohydrates are divided into three main classes namely; **(i)** Monosaccharaides **(ii)** Disaccharides **(iii)** polysaccharides.

1. Monosaccharaides;

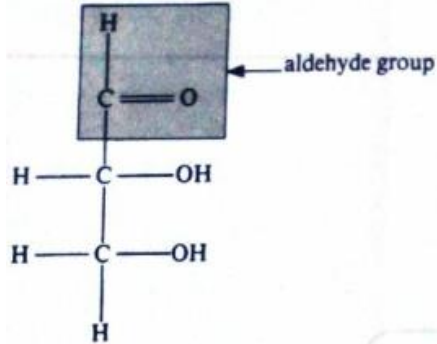
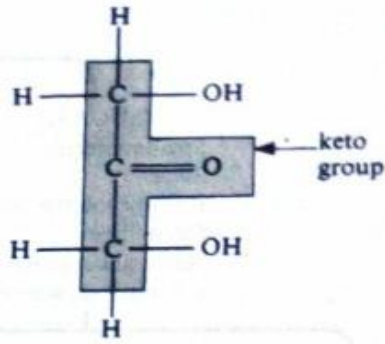
These are **single** sugar units. Their general formula is $(CH_2O)_n$, Where **n** is variable number.

Properties: (i) sweet. (ii) Soluble in water. (iii) Crystalline. (iv) Low molecular weight.

Classification: They are classified according to number (n) of carbon atoms. Example: (i) **Trioses**, 3 carbon atoms, e.g. Glyceraldehyde. (ii) **Pentoses**, 5 carbon atoms, e.g. Ribose, Deoxyribose. (iii) **Hexoses**, 6 carbon atoms e.g. Glucose, Fructose, Galactose.

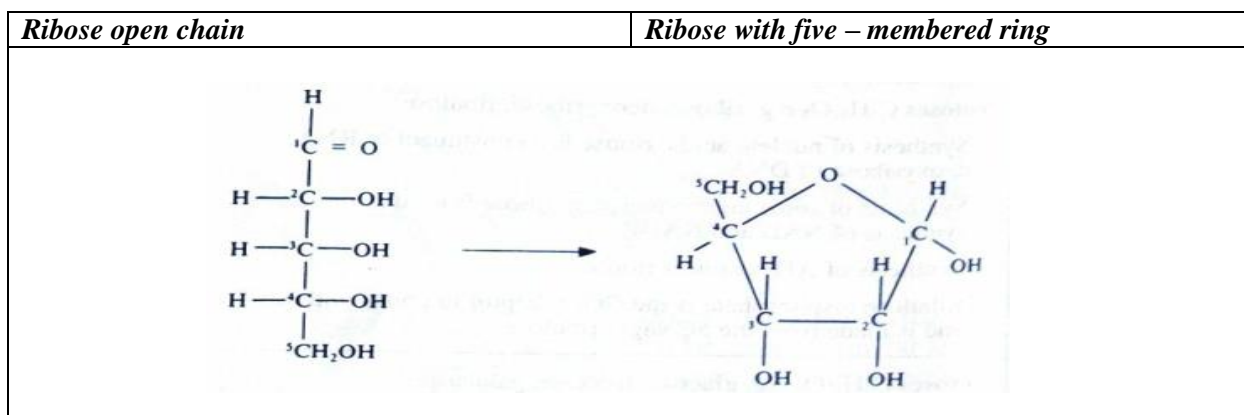
Aldoses and ketoses: In monosaccharides, all carbon atoms except one having a hydroxyl group attached, the remaining carbon is either part of an **aldehyde** group, and the monosaccharide is called **aldose** or **aldo sugar**, or is part of a **keto** group, monosaccharide called **ketose** or **keto sugar**. **Aldoses** include: Glyceraldehyde, Ribose, and Glucose. And **Ketoses** include: Dihydroxyacetone, Ribulose, and fructose.

	Trioses ($C_3H_6O_3$)	Pentoses ($C_5H_{10}O_5$)	Hexoses ($C_6H_{12}O_6$)
Aldoses (- CHO) (Aldo – sugar)	Glyceraldehyde	Ribose	Glucose, Galactose
Ketoses (C=O) (keto sugars)	Dihydroxyacetone	Ribulose	Fructose

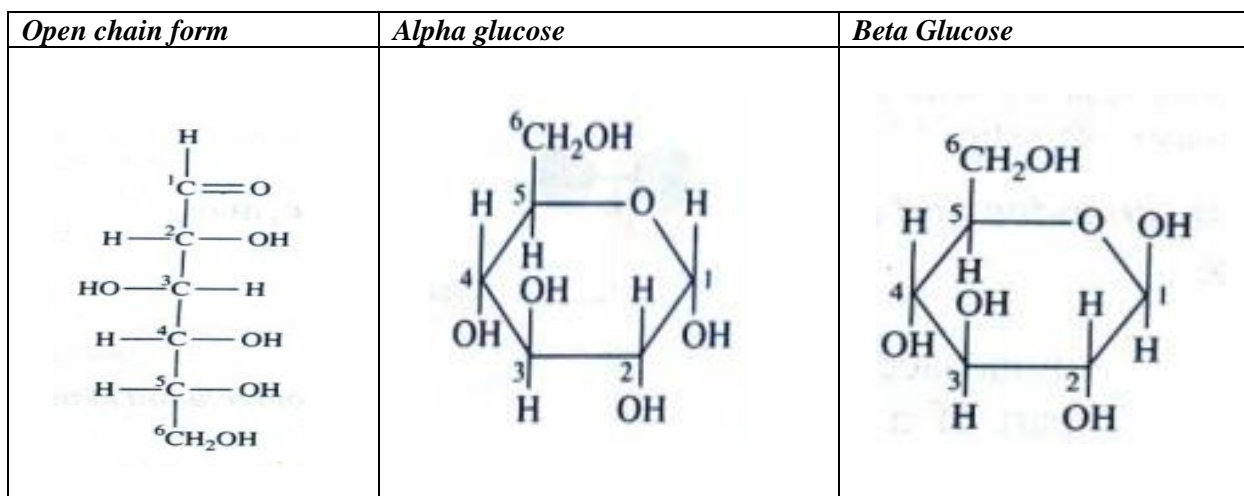
Glyceraldehyde	Dihydroxyacetone.
	

Open chain and ring forms.

The open chain form can be straight, Because of bond angles between carbon atoms, hexoses and pentoses, bend to form a **stable ring** structures. In **hexoses** like glucose, First carbon atom combines with the oxygen on carbon atom five to give a **six – membered ring**. Note that oxygen is part of the ring and one carbon atom, carbon atom number 6, sticks up out of the ring. In **Pentoses**, the first carbon atom combines with oxygen atom on the fourth carbon atom forming a **five – membered ring**. These ring structures are the forms used to make disaccharides and polysaccharides.



Glucose: Is a common monosaccharide, It a *hexose* sugar ($C_6H_{12}O_6$). Has *open chain* structure and *ring* structure. In Ring structure, has two isomers namely; *Alpha* and *Beta isomers*. The hydroxyl group on carbon atom 1 can project *below* the ring forming *Alpha* glucose or *above* the ring forming the *Beta* glucose. Alpha glucose is used in making polysaccharide starch, Beta glucose is used in making polysaccharide cellulose.

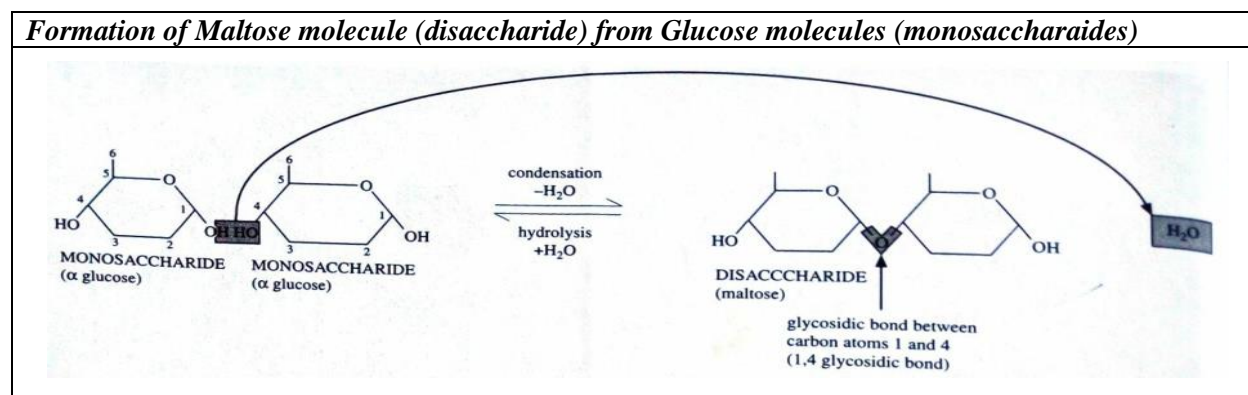


Functions of monosaccharaides:

Monosaccharides	Examples	Functions
Trioses	Glyceraldehyde Dihydroxyacetone	Intermediates in respiration (Glycolysis) , Photosynthesis (dark reactions) and other branches of carbohydraye metabolism.
Pentoses	Ribose Deoxyribose Ribulose	(i) Synthesis of nucleic acids. (ii) Synthesis of some coenzymes (Ribose is used in synthesis of NAD and NADP). (iii) Synthesis of ATP requires ribose. (iv) Ribulose biphosphate is the CO2 acce[ptor in photosynthesis, made from ribulose.
Hexoses	Glucose Fructose Galactose	(i) Source of energy when oxidized in respiration. (ii) Synthesis of disaccharides. (iii) Synthesis of polysaccharides

2. Disaccharides:

These are **double** sugar units formed when **two monosaccharaides** usually hexoses combine by means of a chemical reaction called **condensation**. This means removal of water. The bond formed between two monosaccharaides as a result of condensation is called **Glycosidic** bond and it normally forms between carbon atom 1 and 4 of neighboring units (1,4 bond or 1,4 linkage). The monosaccharide molecules are called **residues** once they have been linked. Maltose molecule contains two glucose residues. Common disaccharides are; (i) **Maltose** (Glucose + Glucose). (ii) **Lactose** (Galactose + Glucose). (iii) **Sucrose** (Fructose + Glucose).



Addition of water to a disaccharide under suitable conditions, splits into monosaccharaides and this called **Hydrolysis** (splitting by water). Like monosaccharaides, disaccharides are: (i) sweet. (ii) Soluble in water. (iii) Crystalline.

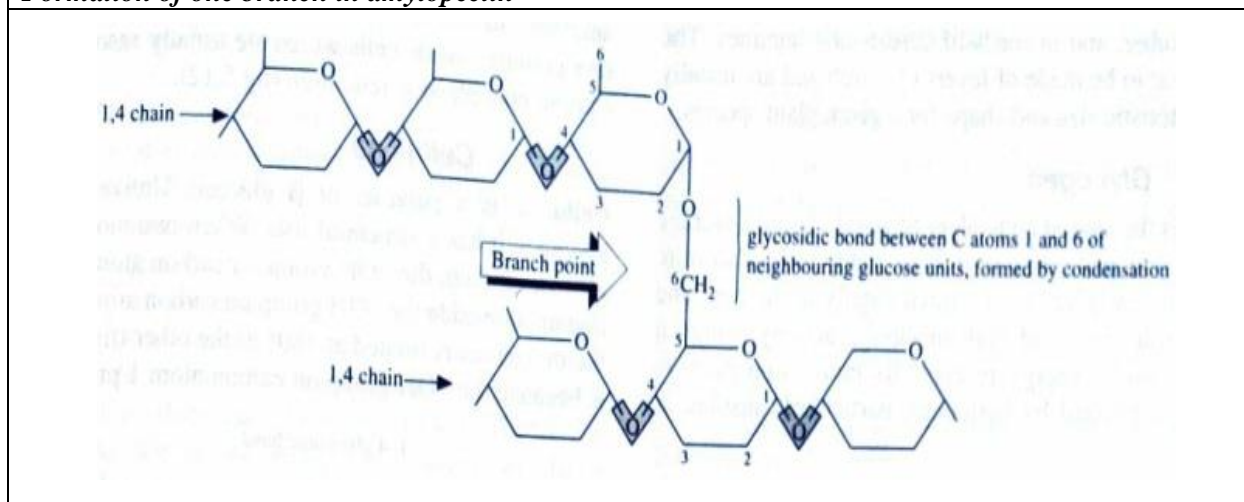
Reducing sugars: All monosaccharaides and some disaccharides (Maltose and Lactose) are reducing sugars, meaning they can carry out a type of chemical reaction called **Reduction**. Sucrose is the only common non reducing sugar. Two common tests for reducing sugars; (i) Benedict's test. (ii) Fehling's test, make use of the ability of these sugars to reduce copper from a valency of 2 to a valency of 1. Both tests involve use of alkaline **blue solution** of copper (II) sulphate which is reduced to insoluble **brick-red precipitate** copper (I) oxide.

3. Polysaccharides:

Polysaccharides are formed when monosaccharaides polymerize in a **condensation** reaction between two hydroxyl groups, resulting in a covalent interaction called a **glycosidic** linkage. The large size of the molecules makes them insoluble, thus suitable for storage function. Examples of polysaccharides include:

(a) Starch: [A storage polysaccharides in animals]

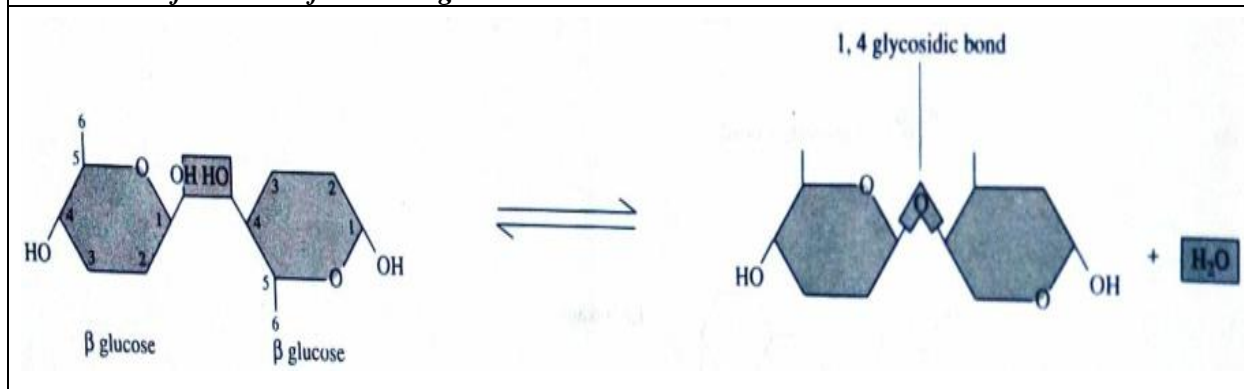
Is a polymer of **Alpha glucose**. It is the major fuel store in plants and absent in animals where its equivalent is glycogen. Can be easily converted back to glucose and used for respiration. Starch has two components: (i) **Amylose**, this has straight chain structure consisting of several thousand glucose residues joined by 1, 4 bonds. (ii) **Amylopectin**, is compact with many branches, formed by 1, 6 glycosidic bonds. It has up to twice as many glucose molecules as amylose. In **iodine** (potassium iodide solution); (i) Amylose suspension gives a blue black colour. (ii) Amylopectin Suspension gives a red – violet colour. Starch molecules accumulate to form starch grains found in; many plant cells (chloroplast of leaves), Storage organs (tubers), seeds of cereals and legumes.

Formation of one branch in amylopectin**(b) Glycogen: [Highly branched storage polysaccharides in animals]**

This is an animal equivalent of starch, being a storage polysaccharide made from **Alpha glucose**, many fungi also store it. In invertebrates, it's stored mainly **in liver and muscles**, both centers of high metabolic activity, where it provides a useful energy reserve. Similar to amylopectin, but shows **more branching**.

(c) Cellulose: [A structural polysaccharide in plants]

Cellulose is a polymer of **β -glucose** monomers, joined by **β -1,4glycosidic linkages**. In plants, cellulose is the major component of the **cell wall**. The geometry of the linkage is such that each glucose monomer in the chain is flipped in relation to the adjacent monomer. The flipped orientation is important because (i) it generates a **linear molecule**, rather than the helix seen in starch; and (ii) it permits **multiple hydrogen bonds** to form between adjacent, parallel strands of cellulose. As a result, cellulose forms long, parallel strands that are joined by hydrogen bonds. The linked cellulose fibers are **strong** and give the cell structural **support**.

Formation of Cellulose from Beta glucose.**(d) Chitin: [A structural polysaccharide in fungi and animals].**

Chitin is similar to cellulose, but instead of consisting of glucose monomers, the monosaccharide involved is one called **N-acetylglucosamine (NAG)**. These NAG monomers are joined by **β -1, 4-glycosidic linkages**. As in cellulose, the geometry of these bonds results in every other residue being flipped in orientation. Like the glucose monomers in cellulose, the NAG subunits in chitin form hydrogen bonds

between adjacent strands. The result is a tough sheet animals. It is, for example, the most important that provides *stiffness* and *protection*. Chitin is a polysaccharide that stiffens the cell walls of *fungi*. It is also found in a few types of *protists* and in many component of the external skeletons of *insects* and *crustaceans*.

(e) Peptidoglycan: [A Structural Polysaccharide in Bacteria]

Peptidoglycan is the *most complex* of the polysaccharides discussed thus far. It has a long backbone formed by two types of monosaccharaides that alternate with each other and are linked by **β -1,4-glycosidic linkages**. Most bacteria, like all plants, have cell walls. But unlike plants, in **bacteria** the ability to produce cellulose is extremely rare. Instead, peptidoglycan gives bacterial cell walls *strength* and *firminess*.

CHECK UP:

By now you should be able; **(i)**. Describe the structure and components of various carbohydrates. **(ii)**. Explain the properties of carbohydrates. **(iii)**. Explain the functions of carbohydrates in organisms. **(iv)**. Describe condensation of carbohydrates. **(v)**. Describe the hydrolysis of carbohydrates.

TRY THIS

1. What is the difference between a monosaccharide, an oligosaccharide, and a polysaccharide? A. the number of carbon atoms in the molecule. B. the type of glycosidic linkage between monomers. C. the spatial arrangement of the various hydroxyl residues in the molecule. D.the number of monomers in the molecule
2. What are three ways monosaccharides differ from one another?
3. What type of bond is formed between two sugars in a disaccharide? A. glycosidic linkage B. phosphodiester bond C. peptide bond D.hydrogen bond
4. What holds cellulose molecules together in bundles large enough to form fibers? A. the cell wall. B.peptide bonds. C. hydrogen bonds. D.hydrophobic interactions between different residues in the cellulose helix
5. What are the primary functions of carbohydrates in cells? A. energy storage, cell identity, structure, and building blocks for synthesis. B.catalysis, structure, and energy storage. C. information storage and catalysis. D.source of carbon, information storage, and energy storage
6. What is responsible for the difference in potential energy between carbohydrates and carbon dioxide?
7. Which of the differences listed here could be found in the same monosaccharide? A. different orientation of a hydroxyl in the linear form. B.different number of carbons. C. different orientation of a hydroxyl in the ring form. D.different position of the carbonyl group in the linear form
8. What would most likely occur if the galactose in lactose were replaced with glucose? A. It would not be digested by human infants or adults. B.It would be digested by most adult humans. C. It would be digested by human infants, but not adults. D.It would be digested by human adults, but not infants.
9. Explain how the structure of carbohydrates supports their function in displaying the identity of a cell.
10. Give three reasons why researchers have concluded that polysaccharides were unlikely to play a large role in the origin of life.
11. Compare and contrast the structures and functions of starch and glycogen. How are these molecules similar? How are they different?
12. A weight-loss program for humans that emphasized minimal consumption of carbohydrates was popular in some countries in the early 2000s. What was the logic behind this diet? (Note: This diet plan caused controversy and is not endorsed by some physicians and researchers).

13. Galactosemia is a potentially fatal disease that occurs in humans who lack the enzyme that converts galactose to glucose. To treat this disease, physicians exclude the monosaccharide galactose from the diet. Which of the following would you also predict to be excluded from the diet? A.maltose. B.starch. C.mannose. D.lactose

14. If you hold a salty cracker in your mouth long enough, it will begin to taste sweet. What is responsible for this change in taste?

15. Lysozyme, an enzyme found in human saliva, tears, and other secretions, catalyzes the hydrolysis of the β -1,4-glycosidic linkages in peptidoglycan. Predict the effect of this enzyme on bacteria, and explain the role its activity plays in human health.

LIPIDS

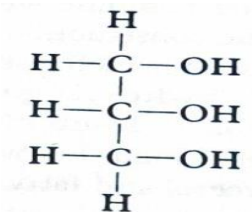
Lipids include **Fats** (solids at room temperature) and **Oils** (Liquids at room temperature). Like carbohydrates, lipids contain Carbon, Hydrogen and oxygen **BUT** a lipid molecule contain smaller proportion of oxygen than carbohydrate molecule.

Constituents of lipids. Lipids are made up of;

(a) **Fatty acids**

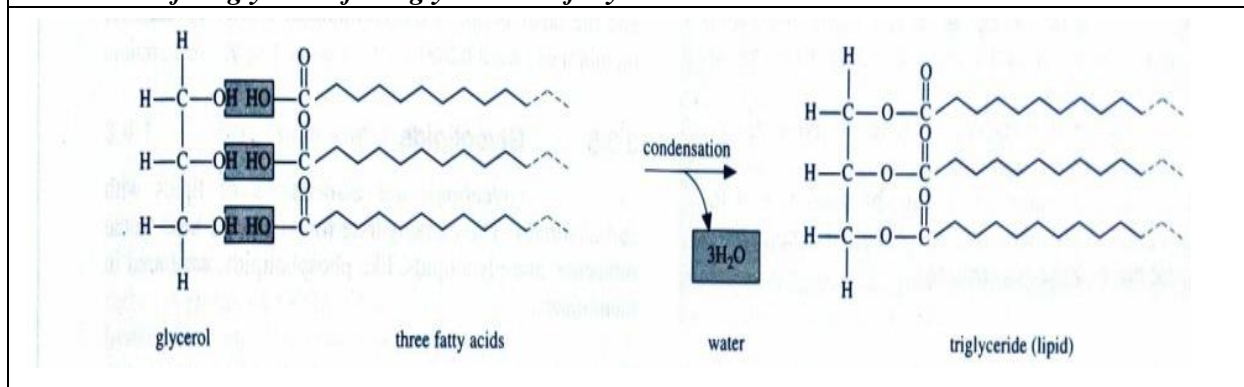
These contain the acidic group -COOH (Carboxyl group). Named so because larger molecules in the series occur in fats. General formula of **R.COOH** where **R** is a hydrogen or group (-CH_3 , $\text{-C}_2\text{H}_5$ etc increasing by -CH_2 for each subsequent member of the series). Fatty acids have a long chain of long chain of carbon and hydrogen atoms forming a **hydrocarbon tail**. The tail determines many properties of lipids including solubility in water. The tails are **Hydrophobic** (*Hydro*, water; *Phobos*, fear), water hating. Fatty acids can be: (i) **Saturated**, lack double bonds. (ii) **Unsaturated**, Contain one or more double bonds ($\text{C}=\text{C}$).

(b) **Glycerol:**

	<p>The formula of glycerol is $\text{C}_3\text{H}_8\text{O}_3$, This shows no variation and is the same in all lipids. Glycerol has three hydroxyl groups of which can condense with a fatty acid. Usually all the three undergo condensation and the lipid formed is called a triglyceride.</p>
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Formation of a lipid

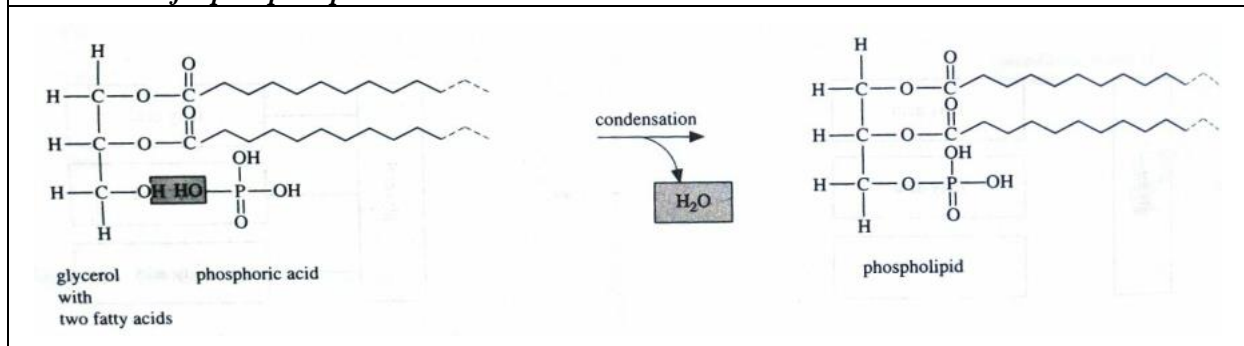
Three fatty acid molecules combine with **one glycerol** molecule to form a **Triglyceride**. In the reaction, three water molecules are lost thus **condensation** reaction. An oxygen bond called **Ester bond** is established between glycerol and fatty acid. The resulting Lipid depends on the nature of fatty acids added.

Formation of Triglyceride from glycerol and fatty acids.**Properties of lipids**

Lipids are **nonpolar** and **hydrophobic** (they do not dissolve readily in water). Dissolve, in nonpolar organic compounds (Ether, Chloroform, and Benzene). Because they have a significant hydrocarbon component. **Hydrocarbons** are nonpolar *because* electrons are shared equally in C-H bonds (approximately equal electronegativity of carbon and hydrogen). Since these bonds form no partial charges, hydrocarbons are **hydrophobic**.

Phospholipids

Phospholipids consist of a glycerol that is linked to a phosphate group and two hydrocarbon chains of fatty acids. Has phosphate head which is Hydrophilic (water loving) and water hating tails. This is important in formation of cell membranes.

Formation of a phospholipid.**Glycolipid:**

Are associations of lipids with carbohydrates. The carbohydrate forms a polar head to the molecule. Glycolipids like phospholipids are found in membranes.

Waxes:

Waxes are formed by combination of fatty acids with **alcohol** other than glycerol. Alcohol is much larger than glycerol therefore waxes have more complex chemical structure. Waxes are important for; **(i)** Waterproofing in plants and animals. **(ii)** Form Storage compounds in few organisms like castor oil and in fish.

Steroids:

Steroids are a family of lipids distinguished by the bulky, four-ring structure. The various steroids differ from one another by the functional groups or side groups attached to different carbons in those hydrophobic rings. **Cholesterol** is common steroid in animals. It's important for: **(i)** limit uncontrolled leakage of small molecules (ions and water) in and out of the plasma membranes. **(ii)** Constituent of myelin, facilitates movement of impulse along neuron. **(iii)** Formation of steroid hormones and bile salts.

Functions of lipids:

(i) An *energy source*, upon oxidation provides more energy than carbohydrates. **(ii)** *Insulation*, conducts heat slowly, in endotherms such as mammals fats deposited beneath the skin (subcutaneous) retains body heat. **(iii)** *Protection*, to delicate organs, fat around kidney protect them from physical damage. **(iv)** *Buoyancy*, Being less dense than water, aquatic vertebrates such as sharks have extremely fatty livers for buoyancy. **(v)** *Waterproofing*, Terrestrial plants and animals conserve water by producing oil secretions e.g. from sebaceous glands of mammals. **(vi)** *Cell membranes*, phospholipids, cholesterol, glycolipids are components of cell membrane and contributes to many of its properties. **(vii)** *Other functions*, components of plant scents to attract pollinators, wax used by bees in constructing their honey combs.

CHECK UP

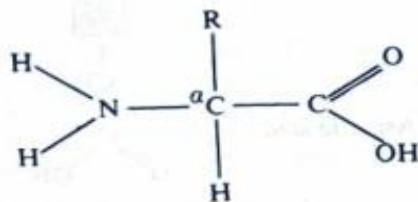
By now you should be able to: (i) **Describe**: Structure and components of lipid molecules, structure of steroids, condensation of fatty acids and glycerol to form lipids, Hydrolysis of lipids to fatty acids and glycerol, properties of lipids. (ii) **Explain**: Functions of lipids in organisms, effects of lipids and steroids to organisms, importance of cholesterol in organisms. (iii) **Compare**: waxes and lipids.

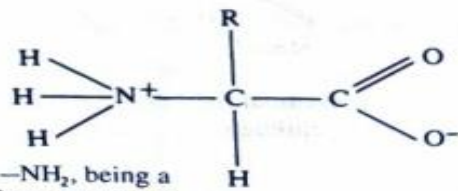
Try this

1. How is the structure of saturated fats different from that of unsaturated fats? A. All of the carbons in the hydrocarbon tails of saturated fats are bonded to one another with double bonds. B. Saturated fats have three hydrocarbon tails bonded to the glycerol molecule instead of just two. C. The hydrocarbon tails in a saturated fat have the maximum number of hydrogens possible. D. Saturated fats have no oxygens present.
2. What distinguishes amphipathic lipids from other lipids? A. Amphipathic lipids have polar and nonpolar regions. B. Amphipathic lipids have saturated and unsaturated regions. C. Amphipathic lipids are steroids. D. Amphipathic lipids dissolve in water.
3. Cooking oil lipids consist of long, unsaturated hydrocarbon chains. Would you expect these molecules to form membranes spontaneously? Why or why not? Describe, on a molecular level, how you would expect these lipids to interact with water.
4. Explain why phospholipids form a bilayer in solution, and why the process is spontaneous.

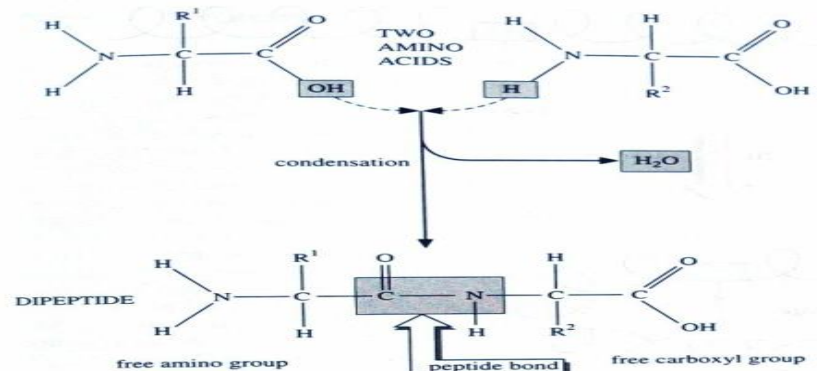
B. PROTEINS

Proteins contains Carbon, hydrogen, oxygen and *Nitrogen* but sometimes *sulphur* and *phosphorus*. Proteins are built up from amino acids.

 <p>The diagram shows the general structure of an amino acid. A central carbon atom (labeled 'a' for alpha) is bonded to a hydrogen atom (H) on the left, an R group on top, a hydrogen atom (H) on the bottom, and a carboxyl group (C=O and OH) on the right. The central carbon is also bonded to a nitrogen atom (N) on the left, which is bonded to two hydrogen atoms (H).</p>	<p>All amino acids have; (i) Central carbon atom. (ii) Amino group (NH₂). (iii) Hydrogen atom. (iv) Carboxyl group (COOH). (v) R group, this varies from one amino acid to another. The simplest amino acid is glycine in which R is a hydrogen atom.</p>
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<i>Neutral zwitterion form of an amino acid</i>		
<p>-NH₂, being a base, possess a high affinity for H⁺ ions.</p>	<div style="display: flex; align-items: center;">  <div style="margin-left: 10px;"> <p>the acidic COOH dissociates, releasing H⁺ ions which can attach to the basic amino group, giving it a positive charge</p> </div> </div> <p>-NH₂, being a base, possesses a high affinity for H⁺ ions</p>	<p>The acidic COOH dissociates, releasing H⁺ which can attach to the basic amino group, giving it a positive charge.</p>

Amino acids polymerize when a bond forms between the carboxyl group of one amino acid and the amino group of another. The C-N covalent bond that results from this condensation reaction is called a **peptide bond**. When a water molecule is removed in the condensation reaction, the carboxyl group is converted to a carbonyl functional group (C=O) in the resulting polymer, and the amino group is reduced to an N-H. Peptide bonds are stable because a pair of valence electrons on the nitrogen is partially shared in the C-N bond. When fewer than 50 amino acids are linked polymer is called an **oligopeptide** ("few peptides") or a **peptide**. Polymers that contain 50 or more amino acids are called **polypeptides** ("many peptides"). **Protein** is used to describe any chain of amino acid residues, complete, functional form of the molecule.

<i>Formation of a dipeptide by a condensation reaction between amino acids.</i>	
 <p>The diagram illustrates the condensation reaction between two amino acids to form a dipeptide. At the top, two amino acids are shown: one with R¹ and another with R². The carboxyl group of the first amino acid (COOH) and the amino group of the second amino acid (NH₂) are highlighted. An arrow labeled 'condensation' points down to the resulting dipeptide. A water molecule (H₂O) is shown being released. The dipeptide structure shows the first amino acid's nitrogen bonded to the second amino acid's carbonyl carbon, forming a peptide bond (C-N). The first amino acid's carboxyl group is now a carbonyl (C=O), and the second amino acid's amino group is now an NH group. Labels include 'TWO AMINO ACIDS', 'condensation', 'H₂O', 'DIPEPTIDE', 'free amino group', 'peptide bond', and 'free carboxyl group'.</p>	

There are three key points to note about the peptide bonded backbone: (i) **R-group orientation**; the side chains in each residue extend out from the backbone, making it possible for them to interact with each other and with water. (ii) **Directionality** There is an amino group (NH₃⁺) on one end of the backbone (*N-terminus, or amino-terminus*) and a carboxyl group (COO⁻) on the other (*C-terminus, or carboxyl-terminus*). (iii) **Flexibility** although the peptide bond itself cannot rotate because of its double-bond nature, the single bonds on either side of the peptide bond can rotate.

Properties:

(a) **Functional Groups Affect Reactivity:** Several of the side chains found in amino acids contain carboxyl, sulfhydryl, hydroxyl, or amino functional groups. These participate in chemical reactions. For example, amino acids with a sulfhydryl group (SH) in their side chains can form disulfide (S-S) bonds that help link different parts of large proteins. Such bonds naturally form between the proteins in your hair; curly hair contains many cross-links and straight hair far fewer. Some amino acids contain side chains that rarely participate in chemical reactions.

(b) **The Polarity of Side Chains Affects Solubility:** The nature of its R-group affects the polarity, and thus the solubility, of an amino acid in water. **Nonpolar** side chains lack charged or highly electronegative atoms capable of forming hydrogen bonds with water. These R-groups are hydrophobic. **Polar** or charged side chains interact readily with water and are hydrophilic. Amino acid side chains distinguish the different amino acids and can be grouped into four general types: (i) **Acidic**, side chain has a negative charge, has lost a proton. (ii) **Basic**, has a positive charge, has taken on a proton. (iii) **Uncharged polar**, side chain uncharged, has an oxygen atom, the highly electronegative oxygen will result in a polar covalent bond and thus is uncharged polar. (iv) **Nonpolar**. Side chain has no charge and has no oxygen atom.

Structure of proteins.

Each protein contain a characteristic three dimensional shape, its **conformation**. There are four separate levels of structure and organization as shown.

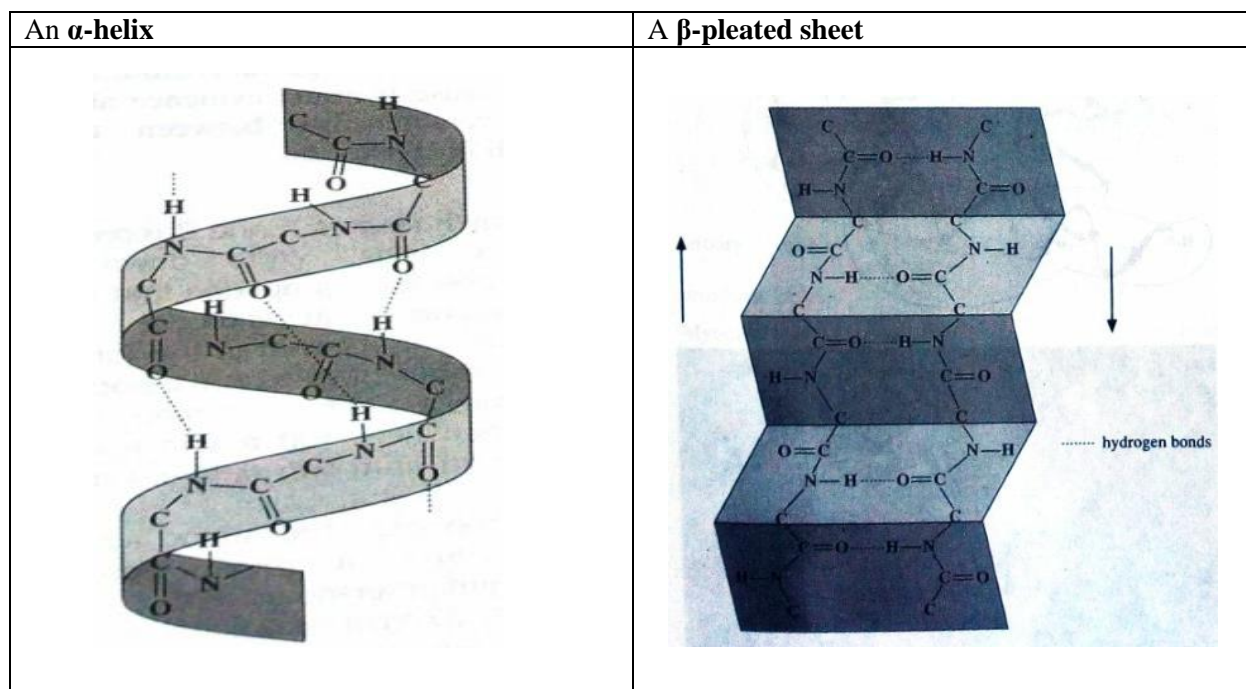
(a) Primary structure.

This is the **sequence of amino acids** in polypeptide chain. The sequence of amino acids of a protein dictates its biological function. Primary structure is also fundamental to the higher levels of protein structure: secondary, tertiary, and quaternary.

(b) Secondary structure.

Secondary structure is created in part by **hydrogen bonding** between components of the peptide-bonded backbone. They are distinctively shaped sections of proteins that are stabilized largely by hydrogen bonding that occurs between the oxygen on the C=O group of one amino acid residue (oxygen has a partial negative charge due to its high electronegativity) and the hydrogen on the N-H groups of another (has a partial positive charge because it is bonded to nitrogen, which has high electronegativity).

Hydrogen bonding between sections of the same backbone is possible only when a polypeptide bends in a way that puts C=O and N-H groups close together. The possible structures are: (i) An **α -helix** (alpha-helix), in which the polypeptide's backbone is coiled; (ii) A **β -pleated sheet** (beta-pleated sheet), in which segments of a peptide chain bend 180° and then fold in the same plane. In most cases, secondary structure consists of α -helices and β -pleated sheets. Which one forms, if either, depends on the molecule's primary structure, specifically, the geometry and properties of the amino acids in the sequence.



(c) Tertiary structure.

Tertiary (Overall) structure, is as result from interactions between R-groups or between ***R-groups and the backbone***. These side chains can be involved in a wide variety of bonds and interactions. In addition, the amino acid residues that interact with one another are often far apart in the linear sequence. **Because** each contact between R-groups causes the peptide-bonded backbone to bend and fold, each contributes to the distinctive three dimensional shape of a polypeptide. Five types of interactions involving side chains are particularly important:

(i) **Hydrogen bonding:** Hydrogen bonds form between polar R-groups and opposite partial charges either in the peptide backbone or other R-groups.

(ii) **Hydrophobic interactions:** In an aqueous solution, water molecules interact with the hydrophilic polar side chains of a polypeptide and force the hydrophobic nonpolar side chains to coalesce into globular masses. When these nonpolar R-groups come together, the surrounding water molecules form more hydrogen bonds with each other, increasing the stability of their own interactions.

(iii) **van der Waals interactions:** Once hydrophobic side chains are close to one another, their association is further stabilized by electrical attractions known as ***van der Waals interactions*** because the constant motion of electrons gives molecules a tiny asymmetry in charge that changes with time. If nonpolar molecules get extremely close to each other, the minute partial charge on one molecule induces an opposite partial charge in the nearby molecule and causes an attraction. Although the interaction is very weak relative to covalent bonds or even hydrogen bonds, a large number of van der Waals attractions can significantly increase the stability of the structure.

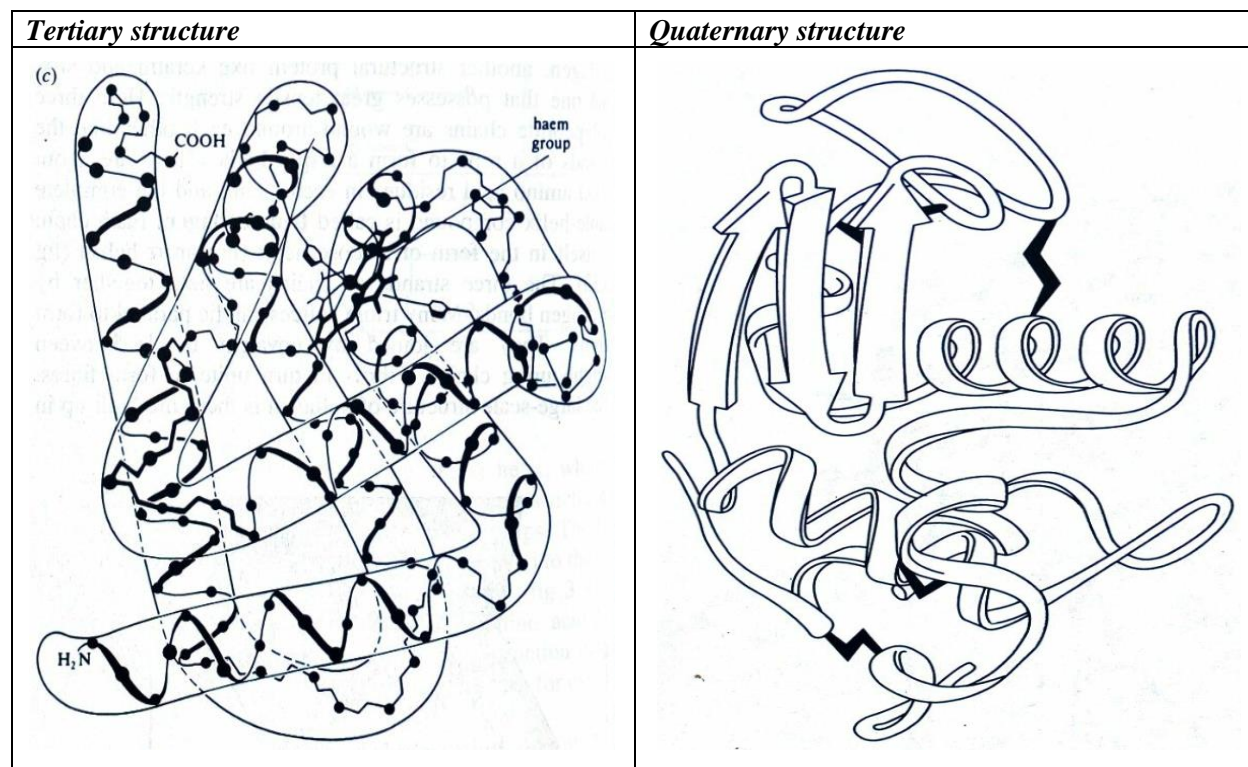
(iv) **Covalent bonding:** Covalent bonds can form between the side chains of two cysteines through a reaction between the sulfhydryl groups. These disulfide (“two-sulfur”) bonds are frequently referred to as bridges, because they create strong links between distinct regions of the same polypeptide or two separate polypeptides.

(v) **Ionic bonding:** Ionic bonds form between groups that have full and opposing charges, such as the ionized acidic and basic side chains.

The overall shape of many proteins depends in part on the presence of secondary structures like α -helices and β -pleated sheets. Thus, tertiary structure depends on both primary and secondary structures.

(d) **Quaternary structure:**

The combination of multiple polypeptides, referred to as subunits, gives a protein **quaternary structure**. The individual polypeptides are held together by the same types of bonds and interactions found in the tertiary level of structure. The key thing to note is that protein structure is hierarchical. Quaternary structure is based on tertiary structure, which is based in part on secondary which is based on primary.



Classification of proteins

Because of the complexity of protein molecules, and their diversity of function, it is very difficult to classify them into a single, well defined fashion. Three alternative methods include:

(a) **Classification according to structure.**

Type	Nature	Function
Fibrous	(i) Secondary structure most important, little/no tertiary structure. (ii) Insoluble in water. (iii) Physically tough . (iv) Long parallel polypeptide chains cross linked at intervals forming long fibres or sheets.	Structural functions in cells and organisms: (i) Collagen (tendons, bone, connective tissue). (ii) Myosin in muscle. (iii) Silk in spider's web. (iv) Keratin (hairs, nails, feathers, horn)
Globular	(i) Tertiary structure most important. (ii) Polypeptide chains tightly folded to form spherical shape. (iii) Easily soluble	Form enzymes, antibodies and some hormones.

Intermediate	Fibrous but soluble	Fibrinogen (forms insoluble fibrin when blood clots)
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(b) Classification according to composition.

They can be: (i) **Simple**, Only amino acids form their structure. (ii) **Conjugated**, complex compounds consisting of globular proteins and tightly bound non – protein material (*prosthetic group*).

<i>Conjugated protein</i>	<i>Prosthetic group</i>	<i>Location</i>
Phosphoprotein	Phosphoric acid	Casein in milk. Vitellin of egg yolk
Glycoprotein	Carbohydrate	Membrane structure, mucin in saliva
Nucleoprotein	Nucleic acid	Component of viruses, chromosomes
Chromoprotein	Pigment	Haemoglobin, phytochrome, cytochrome
Lipoprotein	Lipid	Membrane structure
Flavoprotein	FAD (flavin adenine dinucleotide)	Electron transport chain in respiration.
Metalprotein	Metal	E.g. Nitrate reductase.

(c) Protein classification according to function.

<i>Type</i>	<i>Examples, Occurrence and function.</i>
Structural	(i) Collagen , component of connective tissue, bone, tendon, cartilage. (ii) Keratin : Skin, feathers, hairs, nails, horns. (iii) Elastin : Elastic connective tissue (ligaments). (iv) Viral coat proteins , wraps up nucleic acid of virus.
Enzymes	(i) Ribulose biphosphate carboxylase, catalyses carboxylation. (ii) Glutamine Synthetase, catalyses synthesis of glutamine from glutamic acid + ammonia. (iii) Trypsin, catalyses hydrolysis of proteins.
Hormones	(i) Insulin and Glucagon, Regulate sugar metabolism. (ii) ACTH, stimulates growth and activity of adrenal cortex.
Pigment	(i) Haemoglobin, transports oxygen in blood. (ii) Myoglobin, stores oxygen in muscles.
Transport	Serum albumin, Transport of fatty acids and lipids in blood.
Protective	(i) Antibodies, complexes with foreign proteins. (ii) Fibrinogen, forms fibrin in blood clotting. (iii) Thrombin, involved in blood clotting.
Contractile	(i) Myosin, moving filaments in myofibrils of muscles. (ii) Actin, Stationary filaments in myofibrils of muscles.
Storage	(i) Ovalbumin, Egg white protein. (ii) Casein, Milk protein.
Toxins	(i) Snake venom, enzymes. (ii) Diphtheria toxin, made by diphtheria bacteria.

Denaturation and renaturation of proteins.

Denaturation is the loss of specific three dimensional shape of a protein molecule. The amino acid sequence of the molecule remains unaffected, the molecule unfolds and can no longer perform its normal biological function. This may be due to:

(i) **Heat or radiation**; infra-red, UV light, kinetic energy is supplied to protein causing its atoms to vibrate violently, disrupting weak hydrogen and ionic bonds. Coagulation of the protein then occurs.

(ii) **Strong acids, Alkalies and high concentration of salts**. Ionic bonds are disrupted and the protein coagulated. Long exposure to the reagents, break the peptide bonds.

(iii) **Heavy metals:** Cations (Positively charged ions) of heavy metals form strong bond with carboxyl groups (negatively charged) of R-groups and disrupt the ionic bonds. Reduce protein's polarity and increases its insolubility. This causes the protein to participate out of solution.

(iv) **Organic solvent and detergents:** Disrupt the hydrophobic interactions and form bonds with non-polar groups disrupting hydrogen bonding in the protein. When alcohol is used as a disinfectant, it denatures the protein of any bacteria present.

Renaturation: This is the spontaneous refolding of the protein into its original structure after denaturation under suitable conditions.

CHECK UP:

By now you should be able to: (i) **Describe:** structure and components of proteins, Properties of proteins, Condensation of amino acids to form proteins, Hydrolysis of proteins to amino acids. (ii) **Explain:** Importance of proteins, functions of proteins in living organisms, effect of heat and temperature changes on proteins.

Try this:

1. What two functional groups are present on every amino acid? A. a carbonyl (C=O) group and a carboxyl group. B. an N-H group and a carbonyl group. C. an amino group and a hydroxyl group. D. an amino group and a carboxyl group
2. Twenty different amino acids are found in the proteins of cells. What distinguishes these molecules?
3. By convention, biologists write the sequence of amino acids in a polypeptide in which direction? A. carboxy- to amino-terminus. B. amino- to carboxy-terminus. C. polar residues to nonpolar residues. D. charged residues to uncharged residues
4. In a polypeptide, what bonds are responsible for the secondary structure called an α -helix? A. peptide bonds. B. hydrogen bonds that form between the core C=O and N-H groups on different residues. C. hydrogen bonds and other interactions between side chains. D. disulfide bonds that form between cysteine residues
5. Where is the information stored that directs different polypeptides to fold into different shapes?
6. What is an active site? A. the position in an enzyme where substrates bind. B. the place where a molecule or ion binds to a protein to induce a shape change. C. the portion of a motor protein that is involved in moving cargo in a cell. D. the site on an antibody where it binds to bacterial cells or viruses.
7. Explain how water participates in the development of the interactions that glue nonpolar amino acids together in the interior of globular proteins.
8. If amino acids were mixed together in a solution, resembling the prebiotic soup, would they spontaneously polymerize into polypeptides? Why or why not?
9. Provide an example of how a specific shape of a protein is correlated with its function.
10. A major theme in this chapter is that the structure of molecules correlates with their function. Use this theme to explain why proteins can perform so many different functions in organisms and why enzymes are such effective catalysts.