# STRUCTURE AND FUNCTION OF BIOMOLECULES

Everything on earth, the living or non-living, is made up of chemical elements in various combinations. **Elements** are substances that cannot be broken down into other substances by ordinary means. About 92 elements occur naturally on Earth, however only 6 of them were selected in the course of evolution to form the complex, highly organized material of living organisms. These six elements, **carbon**, **hydrogen** **nitrogen**, **oxygen**, **phosphorus** and **sulphur**, make up 99 percent of the weight of all living matter.

## Organic Molecules

The molecules that contain carbon are called **organic molecules**. Millions of organic compounds are present which differ mostly because of chemical groups called **functional groups** attached to the carbon atoms. These include: hydrogen, hydroxyl, methyl, carboxyl, amino, aldehyde, ketone, phosphate and sulfhydrl groups. Thousands of different organic molecules are found in cells, however just four different types make up most of the dry weight of living organisms. These are **carbohydrates**, **lipids**, **proteins** and **nucleic acids**. All these molecules consist mainly of carbon and hydrogen and most of them contain oxygen as well. In addition proteins contain nitrogen and sulphur. Nucleic acids, as well as some lipids, contain nitrogen and phosphorus. **Water** makes up more than half of all living matter and more than 90 percent of the weight of most plant tissues.

# CARBOHYDRATES

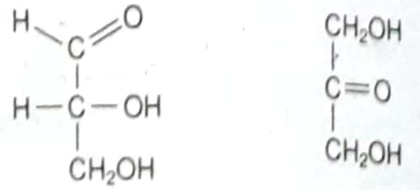
The carbohydrates are a large group of organic compounds made up of the elements carbon, hydrogen and oxygen. In carbohydrates the ratio of hydrogen to oxygen atoms is usually 2:1 as in water. This is why these are called **hydrated carbons**, i.e., "*carbon with water added*". Many carbohydrates have general formula $C_x(H_2O)_y$. Carbohydrates are the most abundant organic molecules in nature and are the primary energy storage molecules in most living organisms. They make up 60-90 percent of dry mass. In addition, they form a variety of structural components of living cells, for example the walls of young plants cells are made of carbohydrate cellulose embedded in a matrix of other carbohydrates and proteins.

Carbohydrates are formed from small molecules known as **sugars**. There are three principal kinds of carbohydrates, classified according to number of sugar subunits they contain: **monosaccharides**, **disaccharides** and **polysaccharides**.

## Monosaccharides

Monosaccharides are the simplest carbohydrates and consist of only one sugar molecule. They are made up of linked carbon atoms (carbon skeleton). The commonly occurring monosaccharides contain between three to seven carbon atoms in their carbon chains. A hydroxyl group (-OH) is attached to each carbon atom of carbon chain except one. The remaining carbon atom is in the form of a carbonyl group (-C=O). Both these groups are **hydrophilic** (water loving), therefore monosaccharides readily dissolve in water. The most frequently found monosaccharides found in nature are five-carbon sugars (**pentoses:** ribose, deoxyribose) and six-carbon sugars (**hexoses:** glucose, fructose). Monosaccharides are the building blocks, the **monomers**, from which living cells construct disaccharides, polysaccharides and other essential carbohydrates.

Trioses



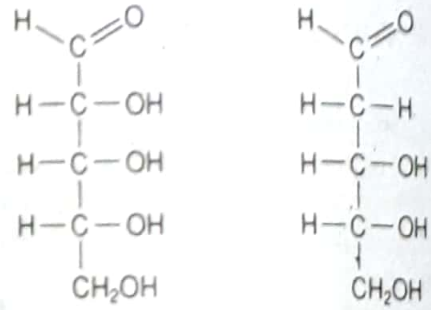
glyceraldehyde    dihydroxyacetone

### i. Trioses

Trioses are three-carbon sugars. The two naturally occurring trioses found both in plant and animal cells are **glyceraldehyde** and **dihydroxyacetone**. These are structurally simplest carbohydrates that occur naturally. They occur in phosphorylated form and play an important part in carbohydrate metabolism (respiration). It is an important energy source and provides the basic carbon skeleton for numerous organic molecules.

Pentoses

Ribose and deoxyribose occur as straight-chain structures



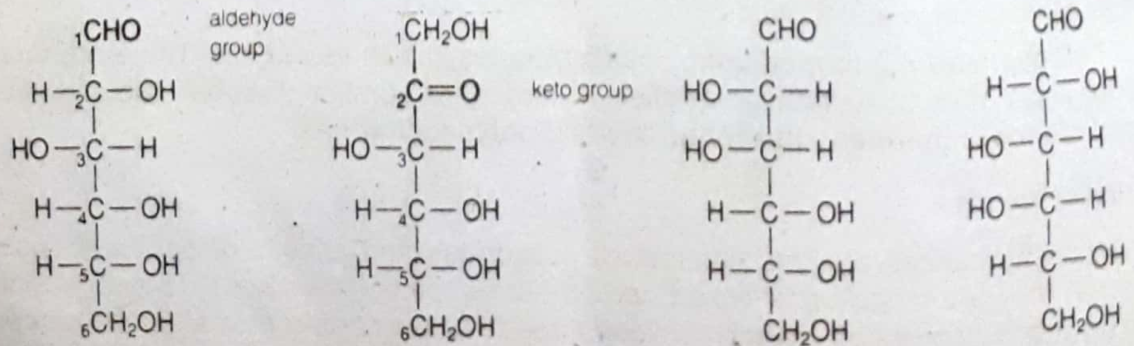
D(+) ribose    D(−) deoxyribose

### ii. Pentoses

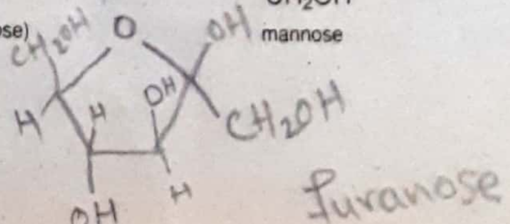
Pentoses are five-carbon sugars. Ribose and deoxyribose are commonly found pentoses in nature. Both exist in the furanose ring form (5-cornered). Ribose occurs in coenzymes, in ATP and in ribonucleic acid (RNA). Deoxyribose occurs in deoxyribonucleic acid (DNA).

### iii. Hexoses

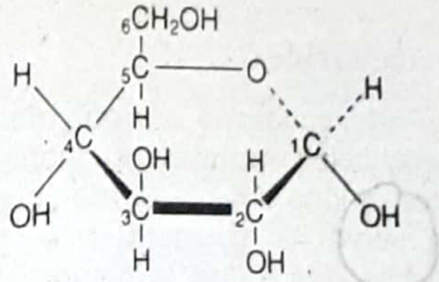
Hexoses are six-carbon sugars. Hexose sugars have a molecular formula of $C_6H_{12}O_6$. The relative position of –H and –OH groups along the carbon chain in hexoses is significant. The hexose sugars may be **aldose sugar** when an aldehyde group (-CHO) is attached to carbon one, or **ketose sugar** if a ketone group (-CO) is present at carbon one. Theoratically, eight possible **structural isomers** (compounds that have same component atoms in the molecules but differ in arrangement of atoms) of aldose form of hexose sugars exist. Only three of these namely **glucose, mannose** and **galactose** occur commonly in nature. Fructose is the only ketohexose to occur in nature. All hexose sugars exist in straight chain structures but they tend to form ring structures. The ring consisting of five carbon atoms and one oxygen atom is called a **pyranose** ring, e.g. glucose; whereas a ring that contains four carbon atoms and one oxygen atom is known as **furanose** ring, e.g., fructose. The fructose also exists as pyranose form.



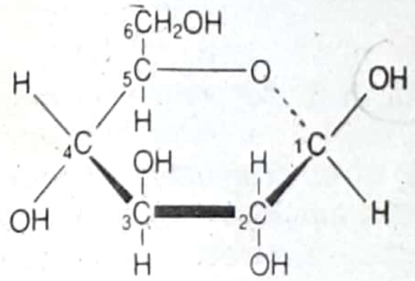

glucose (an aldose)    fructose (a ketose)    mannose    galactose



**Glucose:** The six-carbon sugar glucose serves important structural and transport roles in the cell. The terminal carbon nearest the double bond is designated carbon atom 1. In aqueous solution, glucose exist in two different ring structures, alpha and beta, which are in equilibrium with each other. The alpha form of glucose is converted into beta form through chain form as an intermediate. The sole difference in the two ring structures is the position of the hydroxyl (-OH) group attached to carbon atom 1. In the alpha form it is below the plane of the ring, and in the beta form it is above the plane. Glucose is the form in which sugar is transported in the circulatory system of humans and other vertebrate animals.




α D(+) glucose




β D(+) glucose

Pyranose

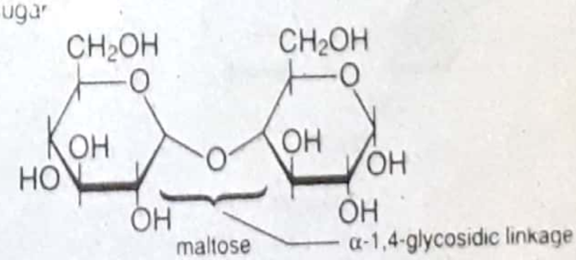
## Disaccharides

Disaccharides contain two sugar subunits linked covalently. Familiar examples are **sucrose** (table sugar), **maltose** (malt sugar), and **lactose** (milk sugar found in milk of mammals). Disaccharides are transport sugar in plants. In synthesis of a disaccharide from two monosaccharide molecules, a molecule of water is removed and a new bond is formed between the two monosaccharides. This type of reaction is called **dehydration synthesis**. The bond between monosaccharide units is **glycosidic bond**. In living cells the disaccharides may be hydrolyzed to constituent monosaccharides in the present of specific hydrolytic enzymes. This splitting is known as **hydrolysis**. Hydrolysis reactions are energy-yielding reactions and are important in energy transfers in cells.

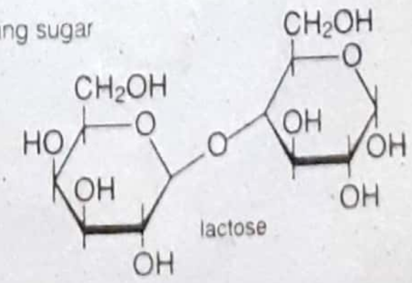
**Sucrose** is the disaccharide generally translocated in the phloem. It is also the sugar human's use most often. It is extracted industrially from sugar cane. Sucrose is made up of two monosaccharide subunits, one alpha-glucose and one beta-fructose, bonded in 1,2 linkage (the carbon 1 of glucose is linked to the carbon 2 of fructose). The formation of sucrose involves removal of a molecule of water. The linkage always involves an activated monomer such as uridine diphosphate glucose or UDP-glucose). Formation of sucrose from glucose and fructose requires an energy input of 5.5 Kcal per mole by the cell. Hydrolysis releases the same amount of energy.

**Maltose** is the product of starch hydrolysis. Industrially maltose is extracted from germinating barley (malt extract) and is used in brewing and food manufacturing.

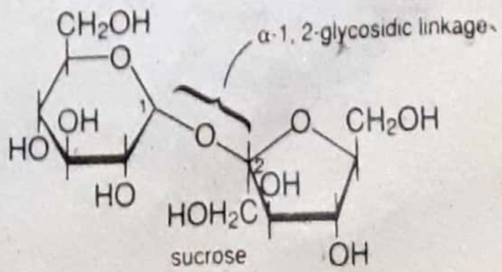
maltose is a reducing sugar




lactose is also a reducing sugar




sucrose is a non-reducing sugar



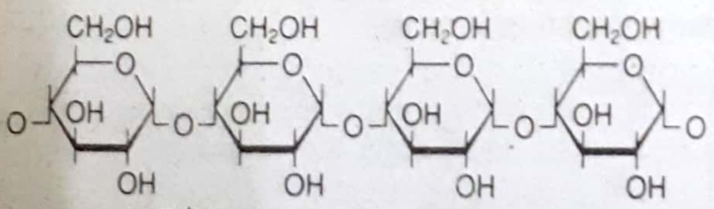
## Polysaccharides

Polysaccharides are **polymers** (compounds made up of similar or identical small subunits called **monomers**) made up of monosaccharides units (or residues) linked together in long chains. Some polysaccharides function as storage forms of sugar and others serve as structural role. Starch, glycogen, cellulose and chitin are familiar polysaccharides found in nature. Polysaccharides are hydrolyzed to monosaccharides and disaccharides before they can be used as energy sources or transported through living systems.

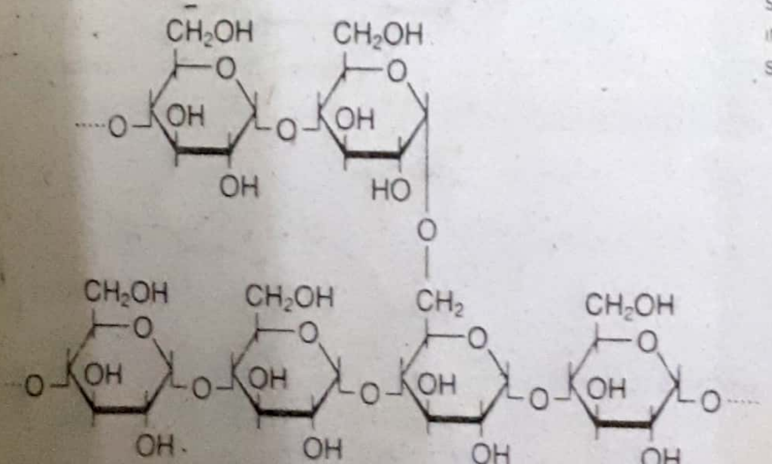
### Starch

Starch is the primary storage polysaccharides in plants. It consists of chains of glucose molecules linked through 1,4-glcosidic bonds. Starch occurs in two forms: amylose, which is an unbranched molecule and amylopectin, which is branched. A single molecule of **amylose** may contain 1000 or more alpha-glucose monomers with carbon 1 of one glucose molecule is linked to carbon 4 of the next to form a long, unbranched chain which wind to form a uniform coil. **Amylopectin** constitute about 70 percent of starch. A molecule of amylopectin may contain 1000 to 6000 or more alpha-glucose monomers. Short chains of about 8 to 12 alpha-glucose monomers branch off the main chain at intervals of about every 12 to 25 alpha-glucose monomers. Amylose and amylopectin are stored as starch grains within plant cells. Perhaps because of their coiled nature, starch molecules tend to cluster into grains.

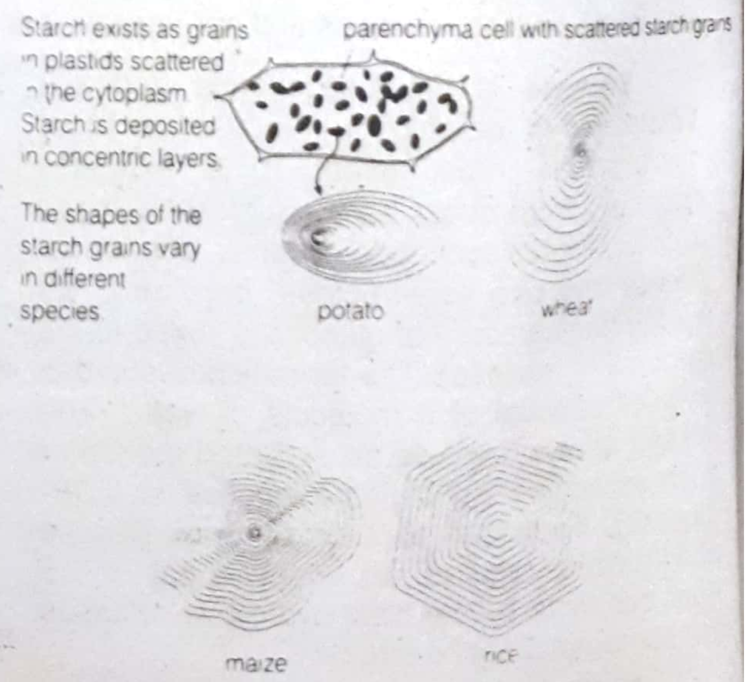
Starch gives a characteristic blue-black colour with iodine solution. The colour is the result of a complex formed between the amylose helix and the iodine molecules. Both amylose and amylopectin are sparingly soluble in water; amylose is slightly more soluble than the two. In the laboratory starch can be hydrolyzed to glucose by heating with dilute acids. In plants and animals *amylases* catalyze the hydrolysis of starch.



amylose



amylopectin

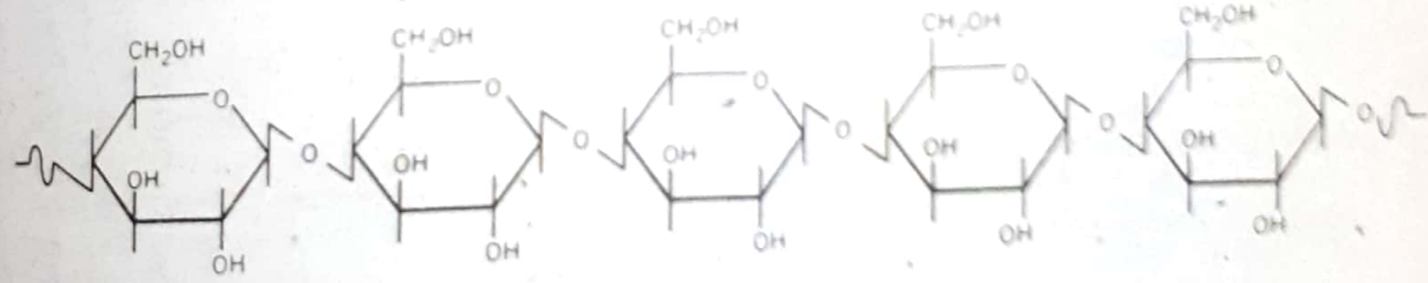


## Cellulose

Cellulose is the principal component of the cell wall in plants. About half of all the organic carbon in the biosphere is contained in cellulose, making it the most abundant organic compound known. Wood is about 50 percent cellulose, and cotton fibres are nearly pure cellulose.

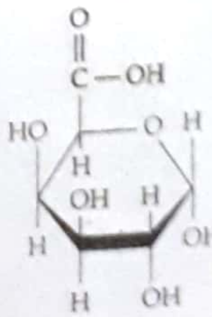
Cellulose is a straight chain polymer composed of between two and three thousand monomers of beta-glucose. Carbon atom 1 of one beta-glucose links up with carbon atom 4 of the next (**1,4- linkage**) to produce a long unbranched chain. Cellulose molecules form the fibrous part of the plant cell wall. The long, rigid cellulose molecules combine to form microfibrils, each consisting of hundreds of cellulose chains linked through –OH groups of glucose monomers forming hydrogen bonds with –OH groups on neighbouring glucose monomers. Cellulose microfibrils are extremely strong and are able to resist tension stress. In plant cell walls, the cellulose microfibrils are embedded in a matrix containing two other complex branched polysaccharides pectins and hemicelluloses.

Cellulose is hydrolyzed chemically to glucose only with difficulty (heating with concentrated acid is required to achieve this). Certain fungi, bacteria produce a *cellulase* enzyme which catalyses the hydrolysis, usually forming glucose or sugar acids.

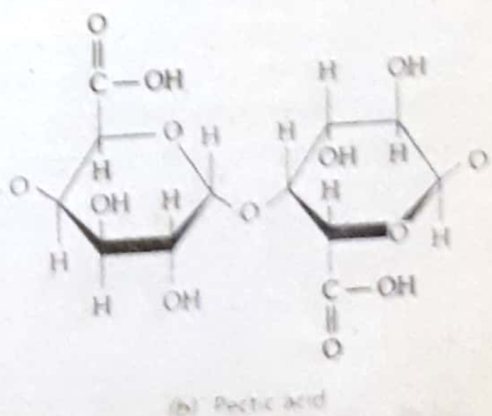


### Pectins and Hemicelluloses

Pectins and hemicelluloses are polysaccharides found in plant cells walls and contribute to mechanical strength of the organisms. **Pectins** are polysaccharides of galactose and alpha-galacturonic acid residues (a derivative of glucose). Pectins become bound together by calcium ions (calcium pectate), and are important components of the middle lamella. Calcium and magnesium salts of pectic acid make up most of the middle lamella.



*(a)* alpha-Galacturonic acid



(b) Pectic acid

The building block sugar of the **hemicellulose** is **xyloglucan**. The backbone of xyloglucan consists of a chain of beta-glucose subunits to which side chains of xylose are attached. The xyloglucans play an important role in stabilizing the primary cell wall by hydrogen bonding to the cellulose microfibrils.

**Glycogen:** Glycogen is common storage product in prokaryotes, fungi and animals. It is made up of branched chains of glucose molecules. It resembles amylopectin but is more highly branched. It is insoluble in water and is readily hydrolyzed by enzyme action to produce glucose.

**Chitin:** Chitin is the principal component of fungal cell walls and exoskeletons of insects and crustaceans. The chitin monomers are **glucosamine**, a glucose in which one –OH is replaced by $-NHCOCH_3$.

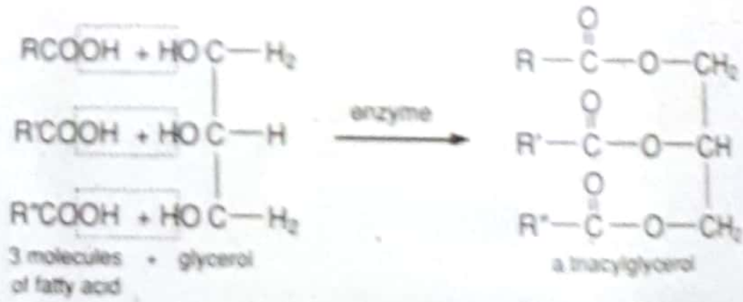
**Inulin:** Inulin is an unbranched nutrient polysaccharide found in bulbs of dahlias and dandelions. It consists of repeating fructose unit in beta-linkage.

## LIPIDS

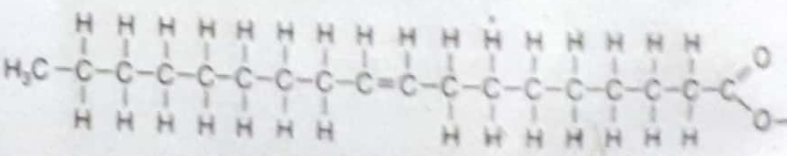
The lipids are diverse group of chemicals that are fats and oily substances, which are extremely hydrophobic (water hating) and water insoluble. These contain carbon, hydrogen and oxygen, as in carbohydrates, but in lipids the proportion of oxygen is much less (often having only two oxygen atoms at one end of a long molecule). The lipids are soluble in organic solvents such as ethanol and ether. The addition of water to a solution of lipid in ethanol produces a cloudy white emulsion of tiny lipid droplets. Lipids can be classified as: simple lipids, the **animal fats**, the **vegetable oils** and the **waxes**, complex lipids; **phospholipids** and related compounds; and **steroids**. The fats and oils serve as energy storage molecules (fats yield about 9.1 Kcals of energy per gram) especially in seeds and fruits, whereas phospholipids and waxes play structural role (components of cellular membrane).

### The Fats and Oils

Fats and oils have similar chemical structure. A fat or oil molecule consists of three fatty acid molecules bonded to one glycerol molecule. Each of these bonds is formed by dehydration synthesis (condensation reaction), which involves removal of a molecule of water. The product is a molecule of **triacylglycerol**, also known as **triglyceride**. These contain non-polar (hydrophilic) groups that cluster together in water, for example on the surface of chicken soup.

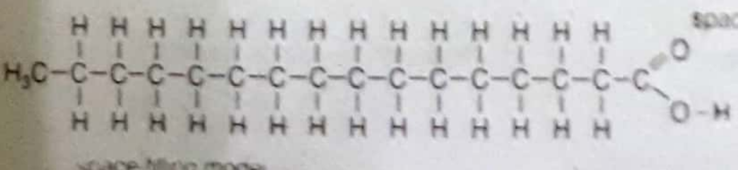



unsaturated fatty acids e.g. oleic acid $C_{17}H_{33}COOH$



space-filling model

saturated fatty acids e.g. palmitic acid $C_{15}H_{31}COOH$

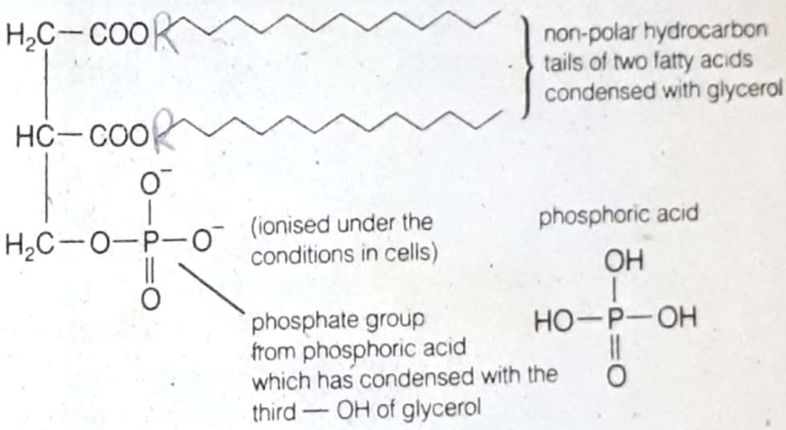


space-filling model

**Fatty acids** are long chain monocarboxylic acids. Some are **saturated fatty acids** (a fatty acid in which there are no double bonds between carbon atoms, e.g., linolenic acid and oleic acid), while others may be **monounsaturated** (possess one double bond between carbon atoms) or **poylunsaturated** (possess more than one double bonds between carbon atoms, e.g., stearic acid). Triglycerides made of unsaturated fatty acids have shorter hydrocarbon chains, low melting point, and are liquid at room temperature in temperate climate. These are called **oils**, for example peanut oil, corn oil, etc. Triglycerides made from saturated fatty acids have longer hydrocarbon chain and are solid at room temperatures are termed **saturated fats**, for example coconut oil. **Animal fats** and their derivative, such as butter and lard, contain highly saturated fatty acids and are usually solid at room temperature.

## Phospholipids

A phospholipid molecule consists of two fatty acid molecules linked to a glycerol molecule, as in a triglyceride, but the third carbon of glycerol is linked to the phosphate group of a phosphate-containing molecule. The letter "**R**" is used to denote the atom or group of atoms that makes up the "rest of the molecule". The phosphate group is negatively charged therefore the phosphate end of the molecule is hydrophilic and soluble in water, whereas the fatty acid end is hydrophobic and insoluble. Thus, phospholipid molecule consists of a polar "**head**" and a non-polar "**tail**".




If phospholipids are added to water, they tend to form a film along its surface, with their hydrophilic "heads" under the water and hydrophobic "tails" protruding above the surface. If phospholipids are surrounded by water as in the watery interior of the cell, they tend to align themselves in double layers, with their phosphate heads directed outward and their fatty acids tails oriented toward one another. Such configurations are important to the structures of cellular membranes and their functions. Phospholipids have three roles in living things: in membrane structure, as a source of acetylcholine, and in the transport of fat between gut nd liver in mammalian digestion.

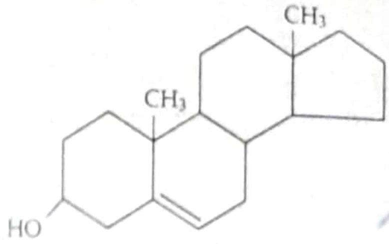
## Cutin, Suberin and Waxes

Cutin and suberin are unique lipids that are important structural components of many plant cell walls. **Cutin** forms a protective **cuticle** that covers the outer walls of epidermal cells of leaves and stems. Cutin and suberin form a matrix in which waxes are embedded. **Waxes** are esters of fatty acids formed with complex alcohols used as water-proofing materials by both plants and animals. The waxes are the most water-repellent of the lipids and embedded in cutin form a layer of **epicuticular wax** that covers cuticle. Suberin is a major component of the walls of cork cells, the cells that form the outermost layer of bark.

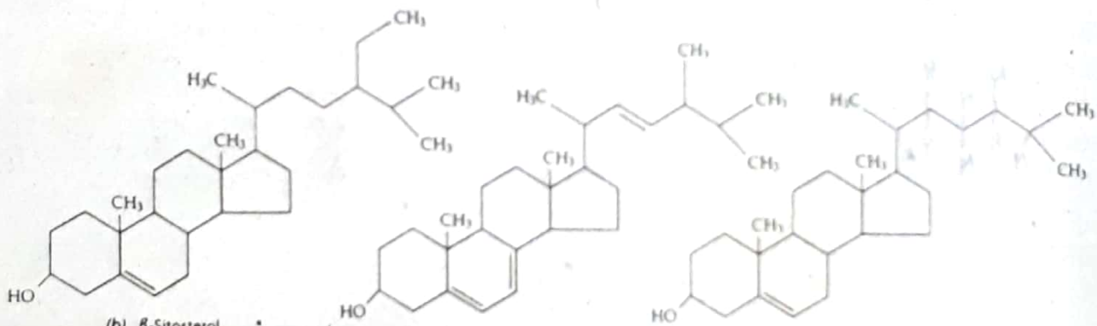
## Steroids

Steroids are lipids that occur both in plants and animals. These are important components of membranes in all organisms except prokaryotes where they stabilize the phospholipids tails. The steroids differ from other classes of lipids by presence of four interconnected hydrocarbon rings. Hydrocarbon chains of various lengths as well as hydroxyl and/or carbonyl groups may be attached to this skeleton, making possible a large variety of molecules.

When a hydroxyl group is attached at carbon-3 position, the steroid is called a **sterol**. **Sitosterol** is the most abundant sterol in green algae and plants, and **ergosterol** is found frequently in fungi. **Cholesterol** is commonly found in animals and is present in only trace amounts in plants. Steroids may also function as hormones, for example the sterol **antheridiol** serves as a sex-attractant in the aquatic fungus *Achyla bisexualis*, and a group of steroid derivatives called **brassins** promote the growth of certain stems.




*(a)* General structure of a sterol




(b) β-Sitosterol (most abundant sterol in green algae and plants)

(c) Ergosterol (found frequently in fungi)

(d) Cholesterol (common in animals)

# PROTEINS

Proteins are versatile polymers of amino acids. These are most abundant organic molecules in living organisms and make up 50 percent or more of the dry weight of an organism, however the plants possess less than 50% because of high cellulose contents. Proteins perform a diversity of functions in living systems. In structure, the proteins are polymers of nitrogen-containing molecules known as amino acids, arranged in a linear sequence. Proteins are large and complex molecules that contain several hundred monomers of 20 different kinds of amino acids. Sulphur is often present in protein molecules. Some proteins combine with other substances to form complexes containing phosphorus, iron or certain trace elements. In plants the largest concentration of proteins is found in certain seeds, in which as much as 40 percent of the dry weight may be protein.

## Amino Acids

Amino acids are the building blocks of proteins. More than 150 different types of amino acids are known to occur in cells, but only twenty or so are used to make proteins. Amino acids exhibit following characteristics.

i. Every amino acid contains a basic amino group ($-NH_2$) and an acidic carboxyl group ($-COOH$) bonded to a central carbon atom (alpha carbon) except in proline and hydroxyproline. A hydrogen atom and a side group (R) are also bonded to the alpha carbon.

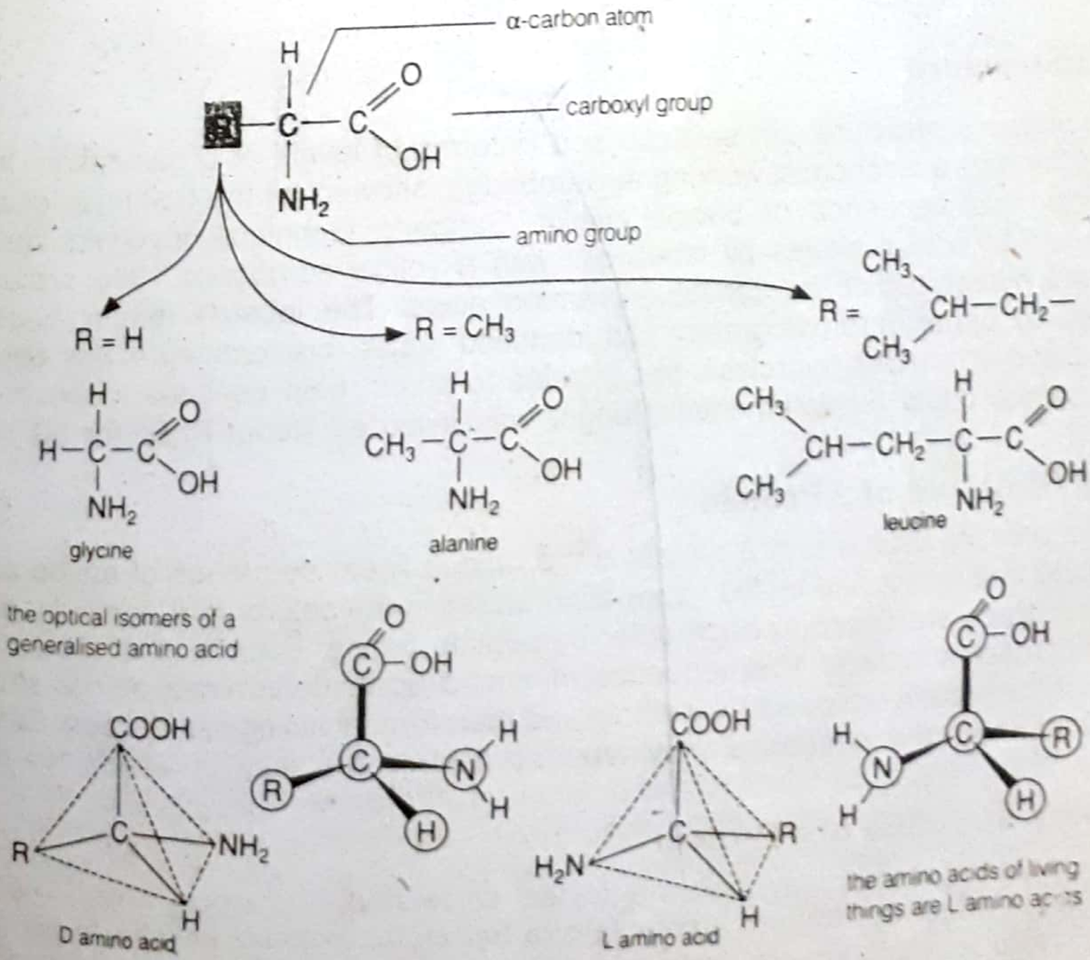
ii. The basic structure is the same in all amino acids, but the R side group is different in each kind of amino acid. Those amino acids with acidic (negatively charged) and basic (positively charged) R groups are very polar. Amino acids with nonpolar R group's are hydrophobic and as the proteins fold into their three dimensional structure, these amino acids tend to aggregate on the inside of proteins. Amino acids with polar, charged R groups are hydrophilic and are always found on the surface of protein molecules.

iii. Most amino acids have a single amino group and a single carboxyl group and are called **neutral amino acids**. Some contain additional amino groups and are known as **basic amino acids** (arginine, histidine). The others have additional carboxyl group therefore called **acidic amino acids** (aspartic acid, glutamic acid).

iv. Amino acids are crystalline solids that dissolve in water but are insoluble in organic solvents. At pH 7 both the amino and the carboxyl groups are ionized, therefore in a neutral solution the amino acid molecule exists as dipolar ion (**zwitterions**).

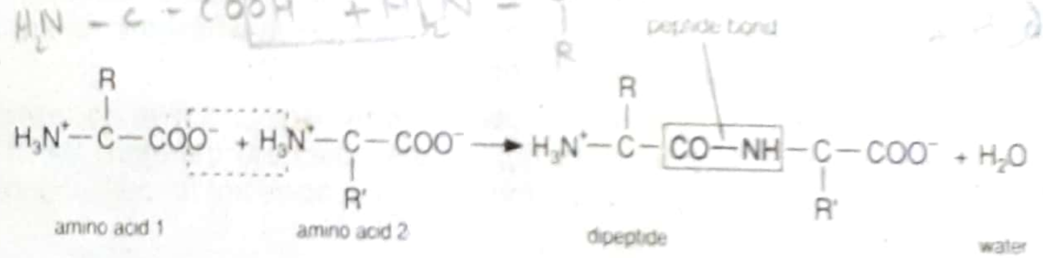
v. In an acid solution (low pH) the amino acid picks up $H^+$ ions and becomes positively charged, while in an alkaline solution (high pH) the amino acid donates $H^+$ ions to the medium and becomes negatively charged. The pH at which the amino acid is electrically neutral is called the **isoelectric point**.

vi. All amino acids except glycine show **optical isomerism** (possess an asymmetric carbon atom to which four different groups are attached) therefore exist in two forms: **L-form** and **D-form**. Only the L-form of amino acids are found living things.



## Peptides, Polypeptides and Proteins

Amino acids can react with each other by condensation. The amino group of one amino acid molecule reacts with the carboxyl group of another amino acid. A molecule of water is removed during the reaction (dehydration synthesis). The bond formed is called **peptide bond** and the resulting compound is a **dipeptide**. Three amino acids link to form a **tripeptide** and many amino acids join in this way to form a **polypeptide**. A polypeptide is a chain of 20 or more amino acids residues linked together by peptide bonds, while a **protein molecule** is hundreds of amino acid residues long and may contains several separate polypeptide chains linked together, for example insulin contains 51 amino acid residues arranged in two polypeptide chains. However, there is no hard and fast dividing line between polypeptides and proteins. The protein synthesis occurs on the ribosomes of cells. It requires a supply of amino acids (from the pool of amino acids in the cytoplasm), energy obtained by reaction with ATP, and information coded in linear sequence of bases in DNA.




## Protein Structure

A protein's structure can be described in terms of levels of organization. In 1953 Fredrick Sanger, a biochemist working at Cambridge, showed for the first time, elucidated the amino acid sequence of bovine insulin. Sanger's technique involved identifying terminal amino acid residues by labeling it with a yellow compound. The protein was completely hydrolyzed to its constituent amino acids. The labeled amino acids were separated by paper chromatography and identified. Later this technique was combined with acid and enzymatic hydrolysis the proteins to short chain peptides in which amino acid sequence could be determined. Sanger was awarded Nobel Prize for his work in 1959.

### Primary Structure of a Protein

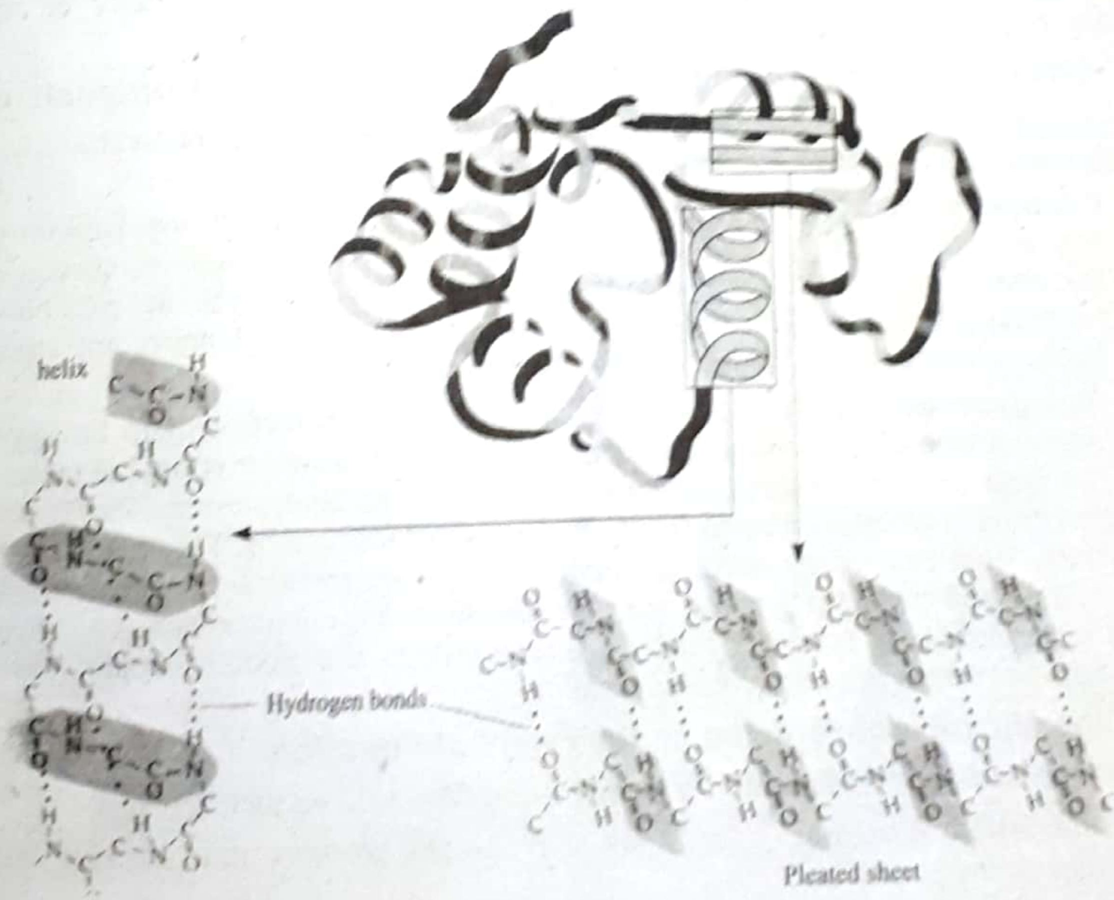
The primary structure of a protein is the unique linear sequence of amino acids in its molecule that is dictated by the information stored in the cell for that particular protein. The amino acids are linked to each other by peptide bonds. Each kind of protein has a different primary structure. The sequence of amino acids determines all the structural features of the protein molecule as a whole and therefore its biological function. Even one small variation in the sequence may alter or destroy the way in which the protein functions.

### Secondary Structure of a Protein

Polypeptide chains may become folded or twisted in various ways. The most common ways are to coil to form a helix (**alpha helix**), for example **keratin** found in hair, wool, etc; or to fold into sheets (**beta pleated sheets**). These forms are referred to as **secondary structure** of protein.

i. **Alpha Helix:** X-rays diffraction analysis shows that there are 3.6 amino acid residues per turn of alpha helix. The helical shape is maintained by hydrogen bonds. In some proteins, the entire molecule is in the form an alpha helix. In other proteins only certain regions of the molecule have this secondary structure.

ii. **Beta Pleated Sheets:** The beta sheets commonly occur as flat zigzag chain in insoluble structural proteins. In beta pleated sheet polypeptide chains are lined up parallel to each other and are linked by hydrogen bonds between NH and CO groups in the adjacent chains, resulting in a zigzag shape. The pleats result from the alignment of the zigzag pattern of the atoms that form the backbone of the polypeptide chains. In some proteins two or more polypeptide chains are aligned with one another to form a pleated sheet. In other proteins, a single polypeptide chain loops back and forth in such a way that adjacent portions of the chain form a beta-pleated sheet.

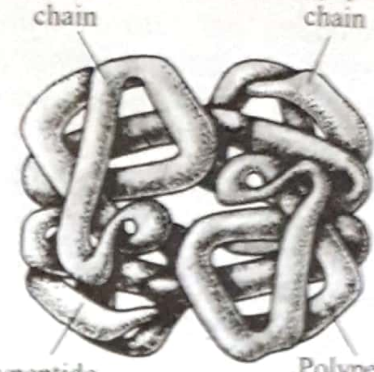



## Tertiary Structure of a Protein

The tertiary structure is formed as a result of complex interactions among the R groups in the individual amino acids. These interactions include attractions and repulsions between nonpolar R groups and the surrounding water molecules. In addition, the sulphur-containing R groups of the amino acid cysteine can form covalent bonds with each other. These bonds are known as **disulfide bridges**, lock portions of the molecule into a particular position. Most of the interactions that give a protein its tertiary structure are not covalent therefore relatively weak. They can be disrupted quite easily by physical or chemical changes in the environment, such as heat or increased acidity (**denaturation**).

## Quaternary Structure of Proteins

Many proteins, e.g., haemoglobin, are composed of more than one polypeptide chain. Hydrogen bonds, disulfide bridges, hydrophobic forces or attractions between positive and negative charges, or a combination of these types of interactions may hold these chains together. This level of organization of proteins, the interactions of two or more polypeptides, is called a **quaternary structure**.




## Classification of Proteins

The diversity and importance of proteins make a single classification of proteins impossible. They can are classified according to either their secondary or tertiary structure or their composition; and on the basis of their function

### A. Classification of Proteins on the Basis of Structure or Composition

The proteins can be classified on the basis of their secondary or tertiary structure or composition into **fibrous proteins** and **globular proteins**.

i. **Fibrous Proteins:** These proteins are very strong and tough, insoluble in water and are made of long polypeptide chains or sheets, often with numerous cross linkages. These exist for most of their length in a helical or pleated-sheet secondary structure. The fibrous proteins play a variety of important structural roles, providing support and shape in organisms.

ii. **Globular Proteins:** Globular proteins are structurally complex, often having more than one type of secondary structures folded into globular or spherical molecules. The core of many globular proteins is formed of pleated sheets. The secondary structures in globular proteins fold to form a tertiary structure. These are soluble in water. Most biologically active proteins, such as enzymes, antibodies, membrane proteins and transport proteins are globular. Also, the microtubules are composed a large number of spherical subunits, each of which is a globular protein. Similarly, some hormones are also globular proteins.

### B. Classification of Proteins on the Basis of Function

On the basis of their function the proteins can be classified as followings:

i. **Homeostatic Proteins:** These are soluble proteins that stabilize the pH wherever they occur.

ii. **Structural Proteins:** These are insoluble proteins that take part in formation of structures such as tendon (collagen of connective tissues), and skin and hair (keratin).

iii. **Hormonal Proteins:** Peptide hormones such as Insulin and glucagon help regulation of glucose metabolism.

iv. **Enzymic Proteins:** Enzymes are large, complex globular proteins that act as catalysts, e.g., respiratory enzymes, enzymes of Calvin cycle and digestive enzymes.

v. **Transport Proteins:** The proteins involved in transport of metabolites and ions across the membrane, e.g., cell membrane protein and protein of membranes of cell organelles. Another common transport protein is haemoglobin involved in transport of oxygen in animals.

vi. **Contractile Proteins:** The proteins concerned with movements are contractile proteins, e.g., those present spindle microtubules (chromosome movements), and muscle cells of animals (actin and myosin).

vii. **Storage Proteins:** The proteins that serve the purpose of storage, e.g., aleurone proteins in seeds (grain of maize) and casein in milk.

viii. **Protection:** Certain proteins provide protection, e.g., antibodies that react with foreign proteins and some other molecules, and fibrinogen and thrombin responsible for blood clotting mechanism.

### Denaturing of a Protein

Denaturation is the loss of the three-dimensional structure of a protein molecule. High temperature and various chemical treatments will denature a protein, causing it to lose its conformation (shape) and ability to function. For example, alteration in pH changes the distribution of the charged groups along the polypeptide chain. This alters the bonds that maintain the secondary and tertiary structure of the protein. The protein molecule may begin to unfold, and the properties of the protein that depend upon shape are lost. Reversal of the mildly denaturing conditions will allow the protein to return to its normal shape and so regain its properties. Heating proteins usually denatures the protein irreversibly, leading to precipitation from solution. An example is the irreversible coagulation of egg white on boiling.

## NUCLEIC ACIDS

Nucleic acids are polymers of nucleotides. They contain information for inheritance and act as genetic material of all living things as well as of viruses. The instructions that govern all cellular activities and enzyme synthesis are coded within the structure of nucleic acids. Two types of nucleic acids are found in living cells: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Most of the DNA is in nucleus, while most RNA is in cytoplasm particularly in the ribosomes and some in the nucleus. Some nucleic acid also occurs in chloroplasts and mitochondria.

### Nucleosides and Nucleotides

The combination of a pentoses sugar with a base forms a compound known as **nucleoside**. The combination of a nucleoside with a phosphate group results in a **nucleotide**. Thus, a nucleotide consists of a phosphate group, a five-carbon sugar and a nitrogenous base. It is the phosphate group that gives nucleic acids their acidic properties. Nucleotides are building blocks of DNA and RNA molecules.