Biomolecule - Part 1

Objectives

After going through this lesson, the learners following concepts:

- Primary Metabolites and Secondary Metabolites
- Difference between Primary Metabolites and Secondary Metabolites
- Biomacromolecules
- Polysaccharides

Content Outline

- Introduction
- Primary Metabolites and Secondary Metabolites
- Difference between Primary Metabolites and Secondary Metabolites
- Biomacromolecules
- Polysaccharides
- Summary

Introduction

There is a wide diversity in living organisms in our biosphere. Now a question that arises in our minds is: Are all living organisms made of the same chemicals, i.e., elements and compounds? If we perform elemental analysis on a plant tissue, animal tissue or a microbial paste, we obtain a list of elements like carbon, hydrogen, oxygen and several others and their respective content per unit mass of a living tissue. If the same analysis is performed on a piece of earth's crust as an example of non-living matter, we obtain a similar list. What are the differences between the two lists? In absolute terms, no such differences could be made out. All the elements present in a sample of earth's crust are also present in a sample of living tissue. However, a closer examination reveals that the relative abundance of carbon and hydrogen with respect to other elements is higher in any living organism than in earth's crust.

Table 9.1 A Comparison of Elements Present in Non-living and Living Matter*

Element	% Weight of	
	Earth's crust	Human body
Hydrogen (H)	0.14	0.5
Carbon (C)	0.03	18.5
Oxygen (O)	46.6	65.0
Nitrogen (N)	very little	3.3
Sulphur (S)	0.03	0.3
Sodium (Na)	2.8	0.2
Calcium (Ca)	3.6	1.5
Magnesium (Mg)	2.1	0.1
Silicon (Si)	27.7	negligible

* Adapted from CNR Rao, *Understanding Chemistry*, Universities Press, Hyderabad.

We can continue asking in the same way, what type of organic compounds is found in living organisms? How does one go about finding the answer? To get an answer, one has to perform a chemical analysis. We can take any living tissue (a vegetable or a piece of liver, etc.) and grind it in trichloroacetic acid (Cl_3CCOOH) using a mortar and a pestle. We obtain thick slurry. If we were to strain this through a cheesecloth or cotton we would obtain two fractions. One is called the filtrate or more technically, the acid-soluble pool, and the second, the retentate or the acid-insoluble fraction. Scientists have found thousands of organic compounds in the acid-soluble pool.

All the carbon compounds that we get from living tissues can be called ‘biomolecules’. The molecules involved in the maintenance and metabolic processes of living organisms. However, living organisms have also got inorganic elements and compounds in them. How do we know this? A slightly different experiment has to be done. One weighs a small amount of a living tissue (say a leaf or liver and this is called wet weight) and dry it. All the water evaporates. The remaining material gives dry weight. Now if the tissue is fully burnt, all the carbon compounds are oxidised to gaseous form (CO2, water vapour) and are removed. What is remaining is called ‘ash’. This ash contains inorganic elements (like calcium, magnesium etc). Inorganic compounds like sulphate, phosphate, etc., are also seen in the acid-soluble fraction. Therefore elemental analysis gives elemental composition of living tissues in the form of hydrogen, oxygen, chlorine, carbon etc. while analysis for compounds gives an idea of the kind of organic and inorganic constituents present in living tissues either they are sugars, amino acids, fats and oils or nucleotides. From a chemistry point of view, one can identify functional groups like aldehydes, ketones, aromatic compounds, etc. But from a biological point of view, we shall classify them into amino acids, nucleotide bases, fatty acids etc.

So, Biomolecules are molecules that occur naturally in living organisms. Biomolecules include macromolecules like proteins, carbohydrates, lipids and nucleic acids. It also includes small molecules like primary and secondary metabolites and natural products. Biomolecules consist mainly of carbon and hydrogen with nitrogen, oxygen, sulphur, and phosphorus. Biomolecules are very large molecules of many atoms, that are covalently bound together.
There are four major classes of biomolecules:

- Carbohydrates
- Lipids
- Proteins
- Nucleic acids

Primary and secondary metabolites

Metabolites are the products of metabolism and metabolism is a biochemical process which is an important process for energy production in the body. The term *metabolite* is usually restricted to small molecules. Metabolites have various functions, including fuel, structure, signaling, stimulatory and inhibitory effects on enzymes, catalytic activity of their own (usually as a cofactor to an enzyme), defense, and interactions with other organisms (e.g. pigments, odorants, and pheromones). Metabolites may be primary metabolites or Secondary metabolites.

A **primary metabolite** is directly involved in normal "growth", development, and reproduction. Ethylene is an example of a primary metabolite produced in large-scale by industrial microbiology.

A **secondary metabolite** is not directly involved in those processes, but usually has an important ecological function. For example antibiotics and pigments such as resins and terpenes etc. Some antibiotics use primary metabolites as precursors, such as actinomycin which is created from the primary metabolite, tryptophan. Some sugars that are metabolites; example: fructose or glucose in the metabolic pathways.

In animal tissues, one notices the presence of all such categories of compounds (Figure 9.1). Primary metabolites are involved in the growth and development of the body. However, when one analyses plant, fungal and microbial cells, one would see thousands of compounds other than these called primary metabolites, e.g., alkaloids, flavonoids, rubber, essential oils, antibiotics, coloured pigments, scents, gums, spices. These are called **secondary metabolites.**

TABLE 9.3 Some Secondary Metabolites

Pigments	Carotenoids, Anthocyanins, etc.
Alkaloids	Morphine, Codeine, etc.
Terpenoides	Monoterpenes, Diterpenes etc.
Essential oils	Lemon grass oil, etc.
Toxins	Abrin, Ricin
Lectins	Concanavalin A
Drugs	Vinblastin, curcumin, etc.
Polymeric substances	Rubber, gums, cellulose

While primary metabolites have identifiable functions and play known roles in normal physiological processes, we do not at the moment; understand the role or functions of all the 'secondary metabolites' in host organisms. However, many of them are useful to 'human welfare' (e.g., rubber, drugs, spices, scents and pigments).

Difference between Primary and Secondary metabolites

Primary metabolites formed as a result of energy metabolism and play an important role in growth of an organism. These are widely used in industries for cosmetic production, food production, alcohol, beer, wine production.

Secondary metabolites are modified primary metabolites. They do not play a role in growth and development. Secondary metabolites act as antibiotics. Erythromycin and bacitracin are important and are the common antimicrobials. Pigments like carotenoids, anthocyanins, alkaloids like morphine, codeine, terpenoides, essential oils, toxins, lectins, drugs, polymeric substances like rubber, gums, cellulose.

Unlike secondary metabolites, Primary metabolites are essential to cell growth, and they are involved directly in metabolic reactions such as respiration and photosynthesis.Most primary metabolites are identical among most organisms, whereas secondary metabolites are numerous and widespread, unlike the primary metabolites.Secondary metabolites are derived by pathways in which primary metabolites are involved. Therefore, secondary metabolites are considered as the end products of primary metabolites.

Primary metabolites are produced during the growth phase of the cell while secondary metabolites are produced during the non- growth phase of the cell.Secondary metabolites are accumulated by plant cells in very small quantities than primary metabolites.

The growth phase where primary metabolites are produced is sometimes called 'trophophase', whereas the phase during which secondary metabolites are made is called 'idiophase'.Most of the secondary metabolites are involved in defense reactions, unlike the primary metabolites.Proteins, carbohydrates, and lipids are the main primary metabolites, whereas, secondary metabolites are alkaloids, phenolics, sterols, steroids, essential oils and lignins etc.

Biomacromolecules

A **macromolecule** is a very large molecule, such as protein, commonly created by polymerization of smaller subunits (monomers). They are typically composed of thousands of atoms or more. The most common macromolecules in biochemistry are biopolymers (nucleic acids, proteins, carbohydrates and polyphenols) and large non-polymeric molecules (such as lipids and macrocycles). Synthetic macromolecules include common plastics and synthetic fibres as well as experimental materials such as carbon nanotubes.

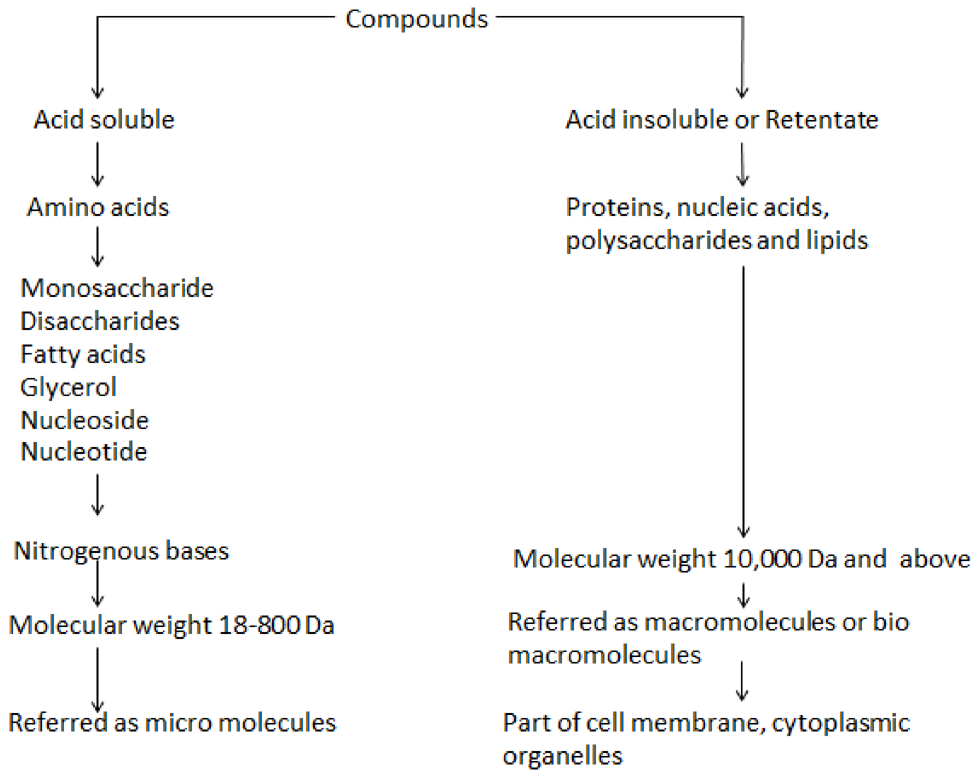
There is one feature common to all those compounds found in the acid soluble pool. They have molecular weights ranging from 18 to around 800 daltons (Da) approximately. The acid insoluble fraction has only four types of organic compounds i.e., proteins, nucleic acids, polysaccharides and lipids.

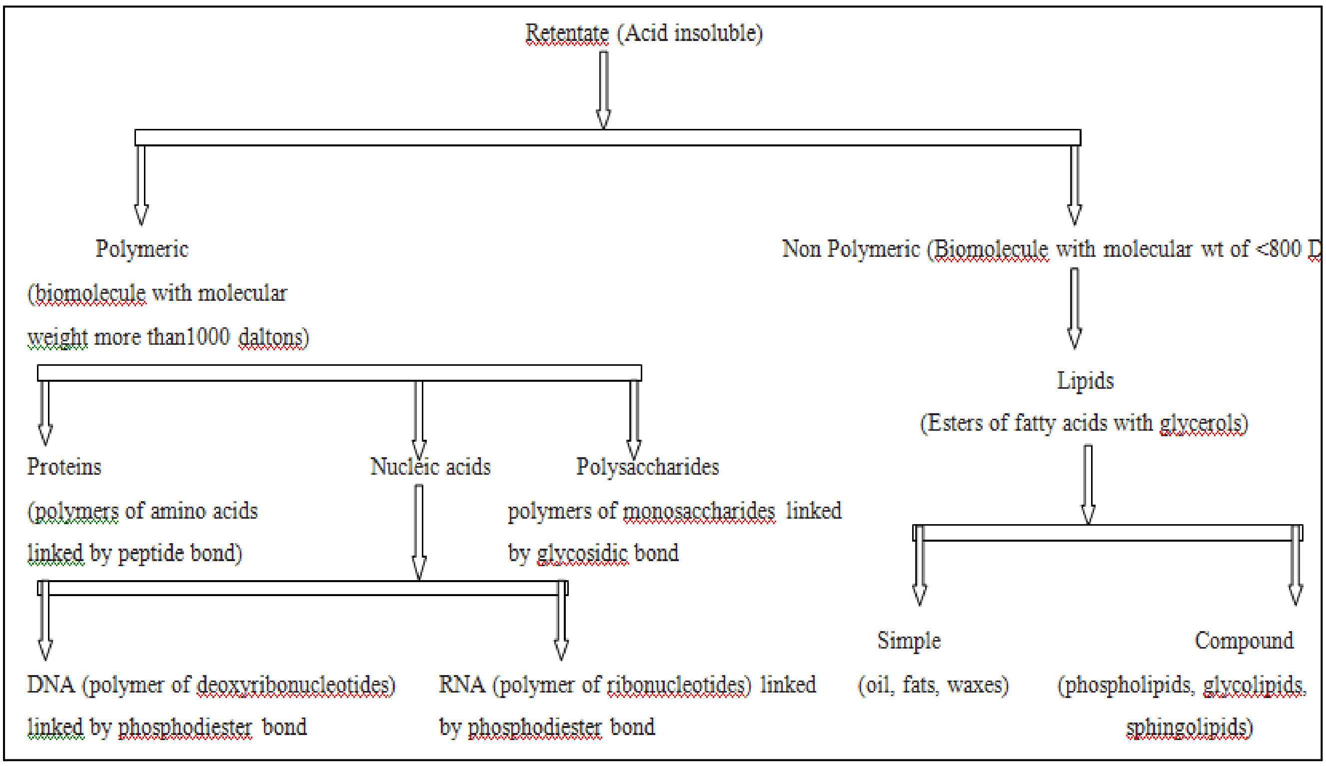
These classes of compounds with the exception of lipids have molecular weights in the range of ten thousand daltons and above. For this very reason, biomolecules, i.e., chemical compounds found in living organisms are of two types. One, those which have molecular weights less than one thousand dalton and are usually referred to as macromolecules or simply biomolecules while those which are found in the acid insoluble fractionare with molecular weight above thousand dalton called macromolecules or **biomacromolecules**. The molecules in the insoluble fraction with the exception of lipids are polymeric substances. Now, a question arises here, why do lipids, whose molecular weights do not exceed 800 Da, come under acid insoluble fraction, i.e., macromolecular fraction? Lipids are indeed small molecular weight compounds and are present not only as such but also arranged into structures like cell membrane and other membranes. When we grind a tissue, we are disrupting the cell structure. Cell membranes and other membranes are broken into pieces, and form vesicles which are not water soluble. Therefore, these membrane fragments in the form of vesicles get separated along with the acid insoluble pool and hence in the macromolecular fraction. Lipids are not strictly macromolecules. The acid soluble pool represents roughly the cytoplasm composition. The macromolecules from cytoplasm and organelles become the acid insoluble fraction. Together they represent the entire chemical composition of living tissues or organisms. In summary, if we represent the chemical composition of living tissue from abundance point of view and arrange them class-wise, we observe that water is the most abundant chemical in living organisms (Table 9.4).

TABLE 9.4 Average Composition of Cells

Component	% of the total cellular mass
Water	70-90
Proteins	10-15
Carbohydrates	3
Lipids	2
Nucleic acids	5-7
Ions	1

So, in a nutshell,

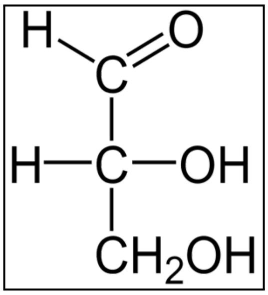




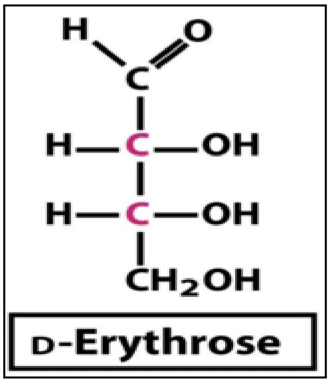
Polysaccharides

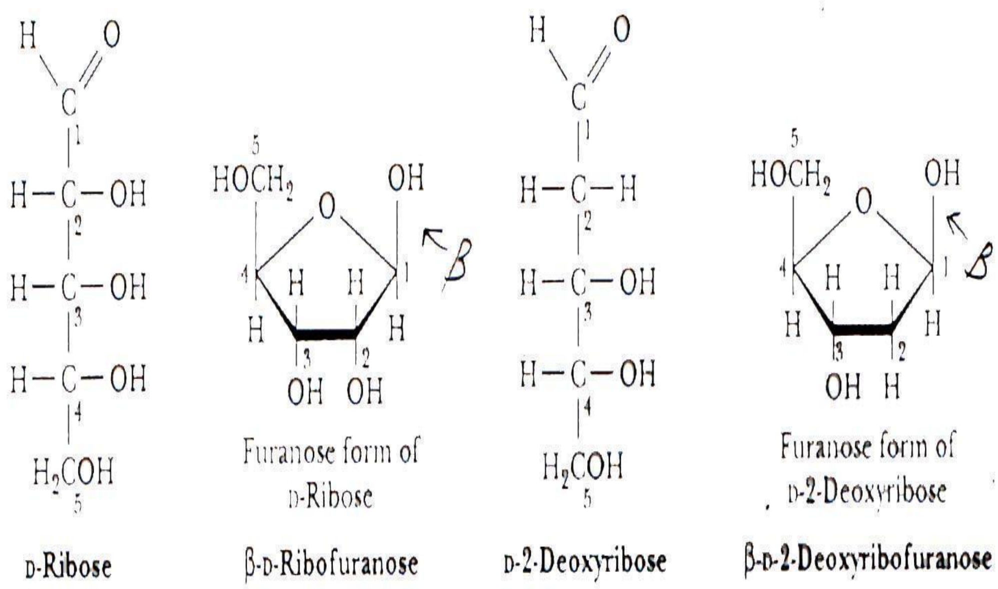
The word Polysaccharide consists of two parts “Poly” and “Saccharide” Poly means many and Saccharide which is from Greek origin, means Sugar. The acid insoluble pellet also has polysaccharides (carbohydrates) as another class of macromolecules. Polysaccharides are long chains of sugars or the monosaccharides. The *mono*saccharides (one sugar unit) are the simplest type of carbohydrates. Monosaccharides (with either a free aldehyde (CHO) or a ketone (CO) group.

Triose are monosaccharides having a chain of three carbon atoms. Example glyceraldehydes



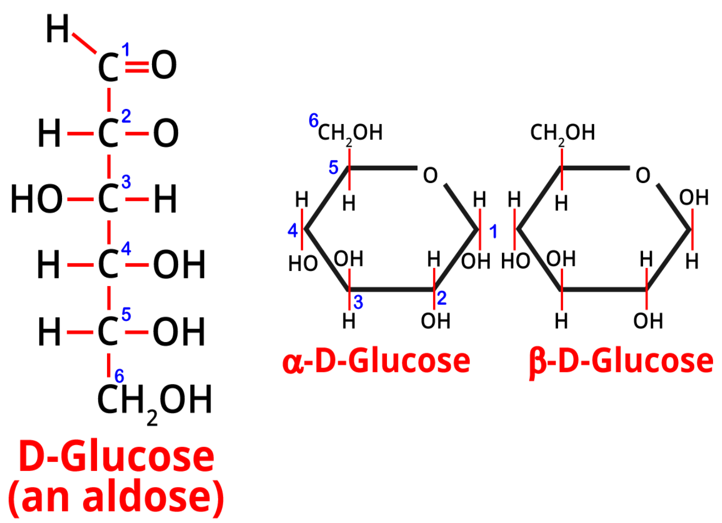
Tetrose has a chain of four carbon atoms, for example Erythrose.

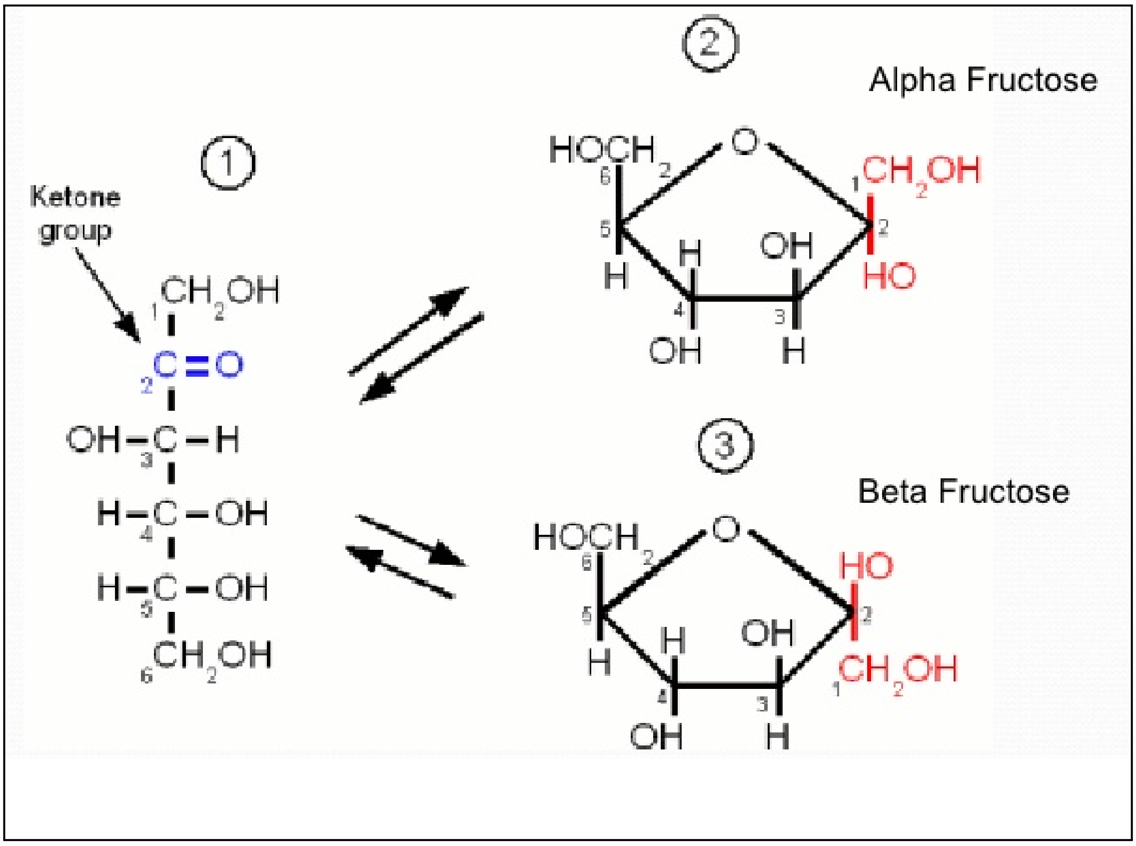




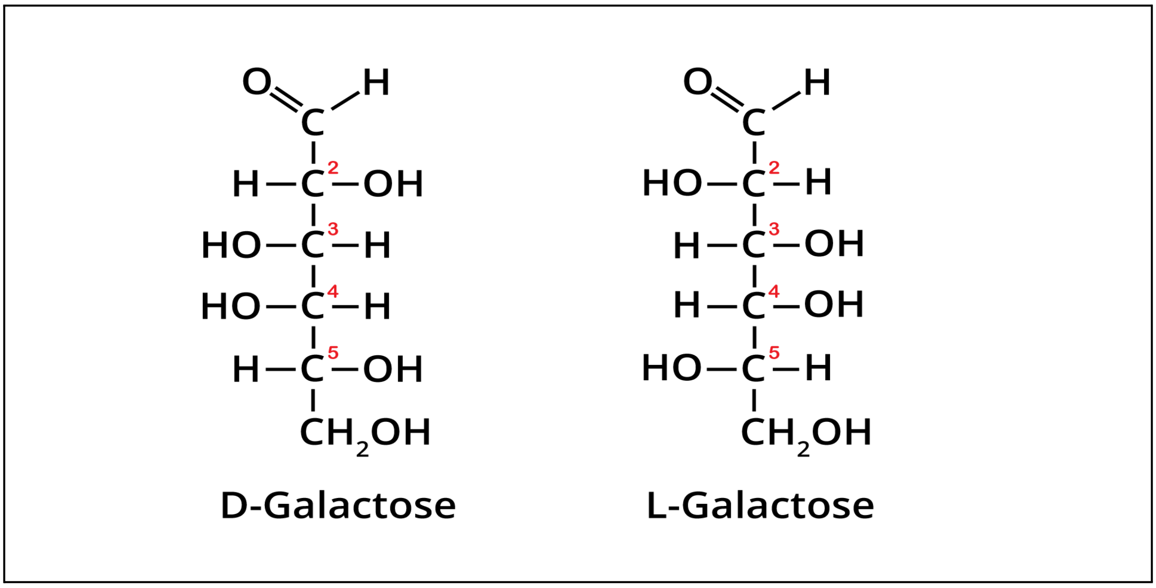
Pentose having a chain of five carbon atoms example ribose and deoxyribose.

Hexose has a chain of six carbon atoms, for example glucose, fructose, galactose.

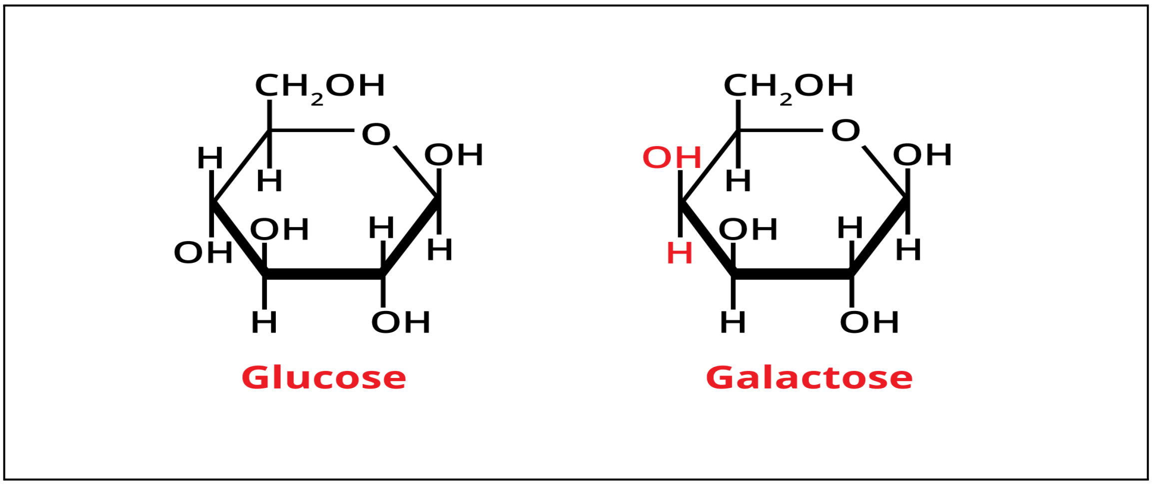




Alpha Fructose
Ketone group
Beta Fructose



D-Galactose
L-Galactose



Heptose has a chain of seven carbon atoms, for example sedoheptulose. Monosaccharides have at least two —OH groups bonded to their carbon backbone and one aldehyde or ketone group. These tend to dissolve easily in water. When dissolved in water the chain form gets converted into ring form. Disaccharides formed of two sugar monomers. An important example of sugar in nature is sucrose which is formed of a glucose and fructose.Individual monosaccharides are linked by a **glycosidic bond**. This bond is formed by dehydration. This bond is formed between two carbon atoms of two adjacent monosaccharides. Lactose, a disaccharide in milk, with one glucose and one galactose unit.

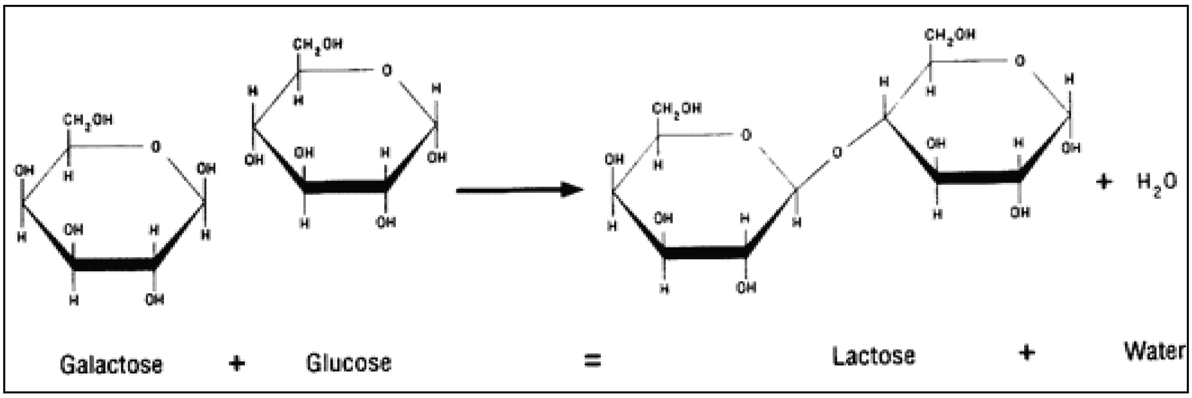
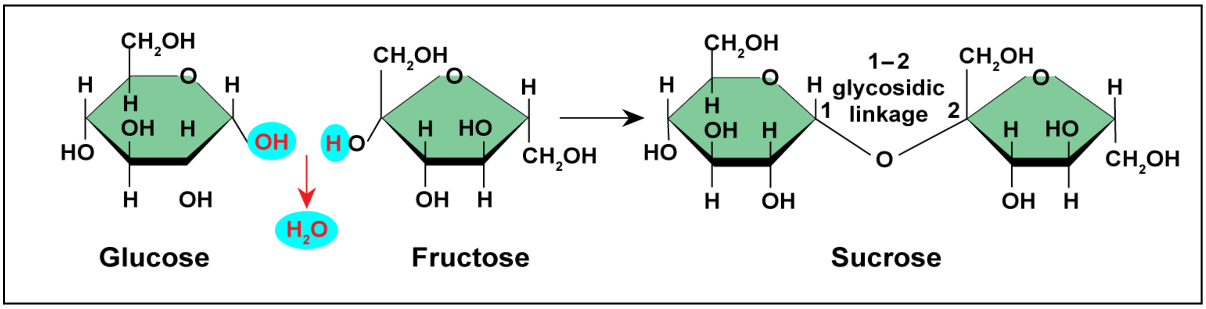
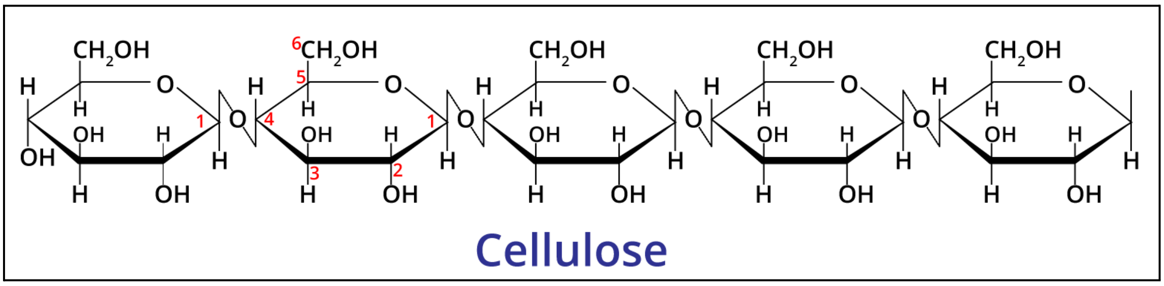
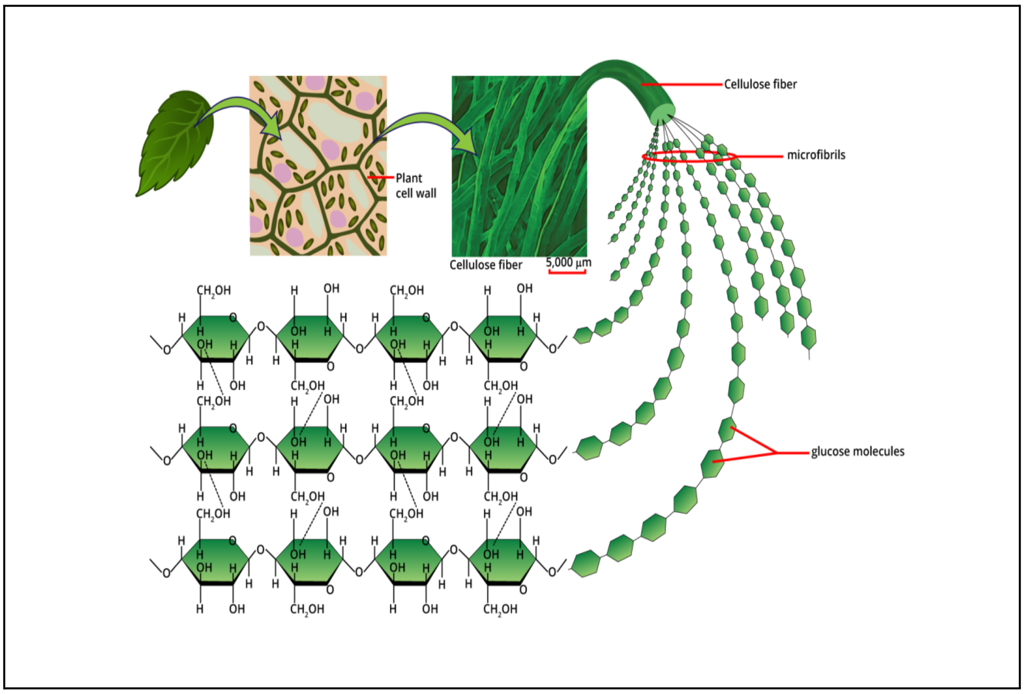


Table sugar that we use commonly in our homes is sucrose extracted from sugarcane and sugar beets.

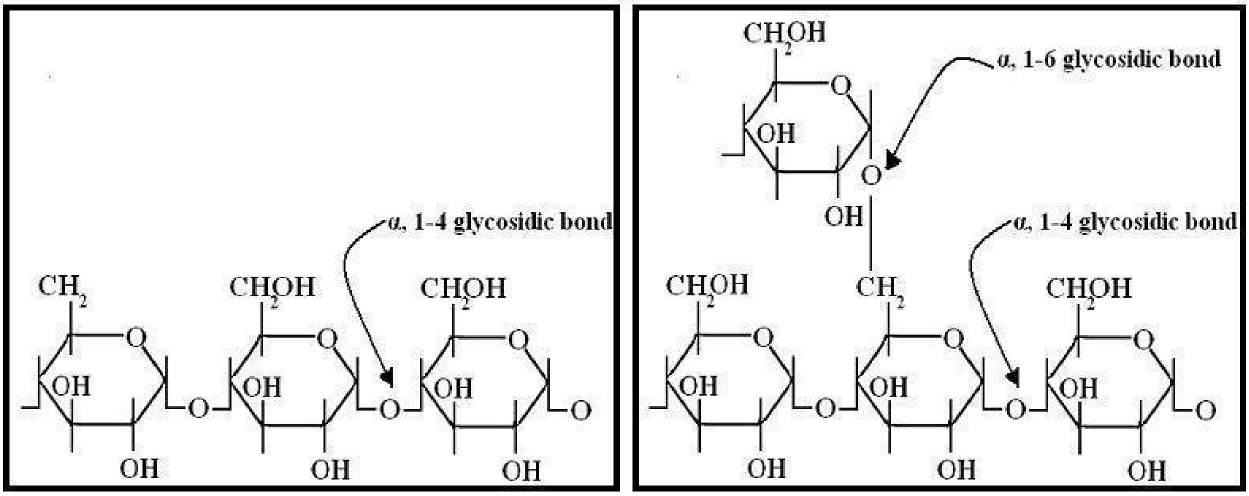


In a Polysaccharide the monosaccharide is also linked by a **glycosidic bond**. They are threads (literally a cotton thread) containing different monosaccharides as building blocks. Polysaccharide are straight or branched chains of monosaccharides Polysaccharides formed from the same monosaccharide are homopolymers whereas from different monosaccharides are heteropolymers. For example, cellulose is a polymeric polysaccharide consisting of only one type of monosaccharide i.e., glucose. Cellulose is a homopolymer, meaning formed of the same monosaccharides.



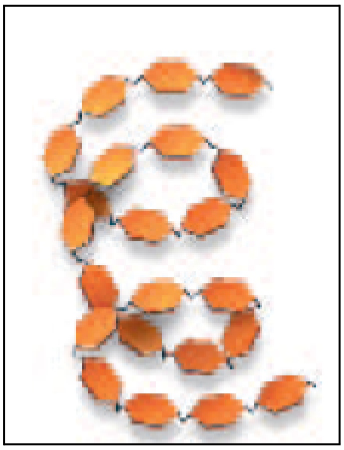


Cellulose does not contain complex helices and hence cannot hold I_2. Plant cell walls are made of cellulose. Paper made from plant pulp and cotton fibre is cellulosic. In cellulose, glucose chains are arranged parallel to one another and form a sheet. This bonding arrangement where chains are stretched stabilizes the chains in a tightly bundled pattern that resist hydrolysis by most enzymes. This is the main feature of the plant cell walls, having fiber sheets of cellulose which gives toughness, insoluble, and resistant to weight loads and mechanical stress, like strong winds against stems. Starch is a variant of this but present as a storehouse of energy in plant tissues. Plants store their photosynthesis active product glucose in the form of starch



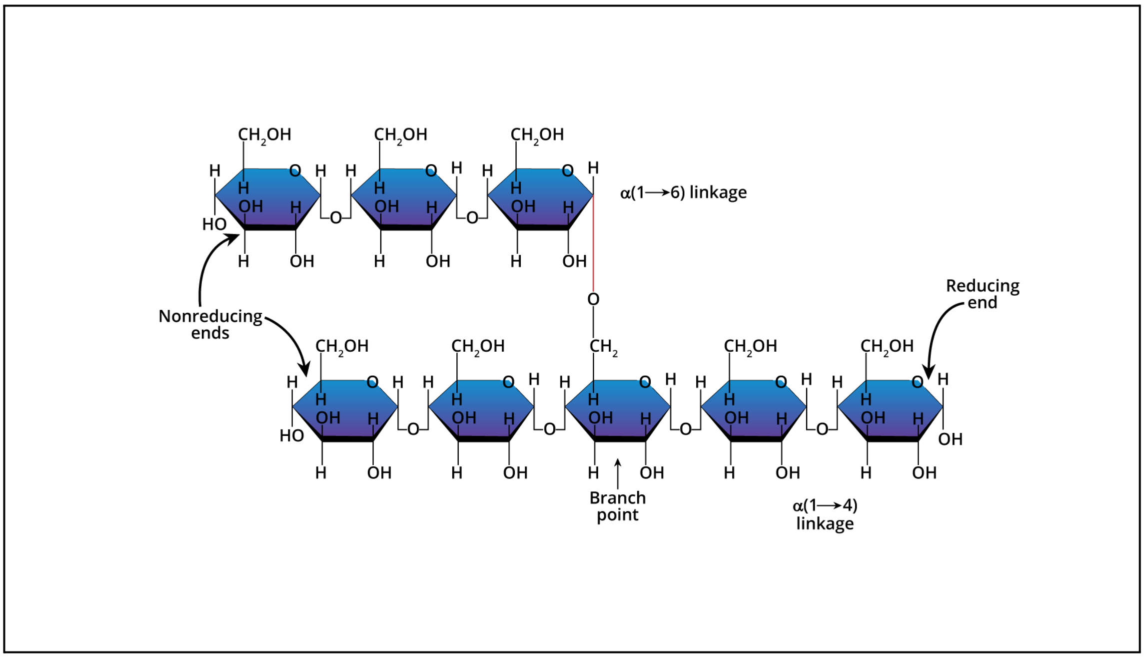
(a) amylose (b) amylopectin

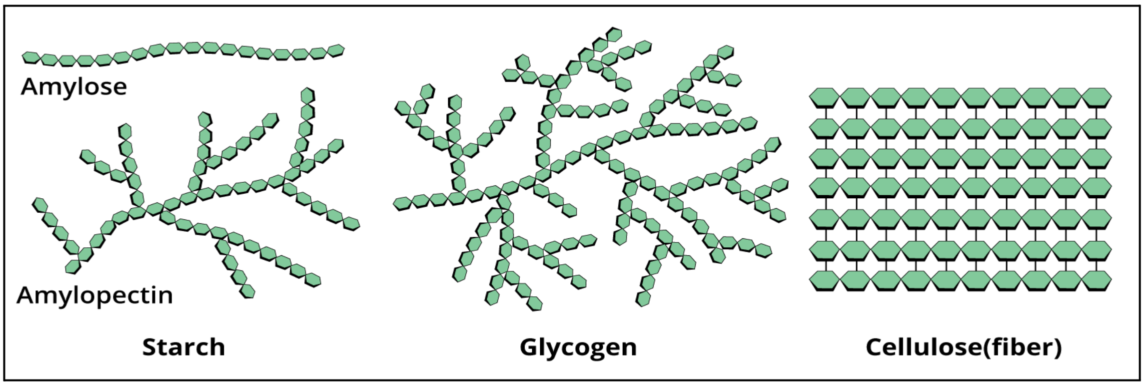
Starch forms helical secondary structures.



In fact, starch can hold I_2 molecules in the helical portion. The starch-I_2 is blue in color. This is a test done for the presence of starch in food.

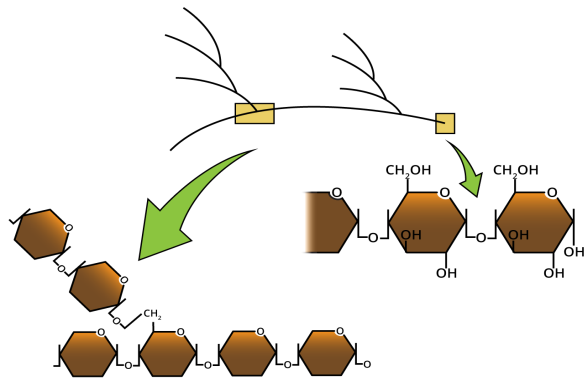
Animals have another variant called glycogen.





In a polysaccharide chain (say glycogen), the right end is called the reducing end and the left end is called the non-reducing end. In animals, glycogen is the storage polysaccharide which is equivalent to starch in plants. Muscle and liver cells of animals have lots of storage of glycogen. At the time of decrease in blood glucose level liver cells degrade glycogen, and the released glucose enters blood.

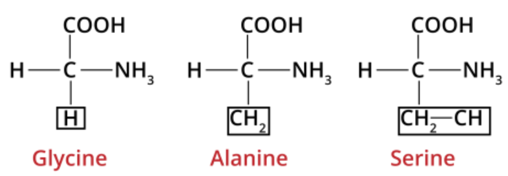
Insulin is a polymer of fructose. It has branches as shown in the form of a cartoon (Figure 9.2).



There are more complex polysaccharides in nature. They have as building blocks, amino-sugars and chemically modified sugars (e.g., glucosamine, N-acetyl galactosamine, etc.). Exoskeletons of arthropods, for example, have a complex polysaccharide called chitin. These complex polysaccharides are heteropolymers. In Chitin there is a side group containing a nitrogenous base which is attached to its glucose unit. This polysaccharide aids in strengthening the external skeletons and other hard body parts of many animals, like in crabs, earthworms, crustaceans, insects, spiders, and ticks. It also gives strength to the cell walls of fungi.

Summary

Amino acids are organic compounds containing an amino group and an acidic group as substituents on the same carbon i.e., the α-carbon. Hence, they are called α-amino acids. They are substituted methanes. There are four substituent groups occupying the four valency positions. These are hydrogen, carboxyl group, amino group and a variable group designated as R group. Based on the nature of the R group there are many amino acids. However, those which occur in proteins are only of twenty types. The R group in these proteinaceous amino acids could be a hydrogen (the amino acid is called glycine), a methyl group (alanine), hydroxy methyl (serine), etc. Three of the twenty are shown in Figure:



Amino acids

The chemical and physical properties of amino acids are essentially of the amino, carboxyl and the R functional groups. Based on the number of amino and carboxyl groups, there are acidic (e.g., glutamic acid), basic (lysine) and neutral (valine) amino acids. Similarly, there are aromatic amino acids (tyrosine, phenylalanine, and tryptophan). A particular property of amino acids is the ionizable nature of $–NH_2$ and –COOH groups. Hence in solutions of different pH, the structure of amino acids changes.

B is called zwitterionic form. Lipids are generally water insoluble. They could be simple fatty acids. A fatty acid has a carboxyl group attached to an R group. The R group could be a methyl ($–CH_3$), or ethyl ($–C_2H_5$) or higher number of $–CH_2$ groups (1 carbon to 19 carbons). For example, palmitic acid has 16 carbons including carboxyl carbon. Arachidonic acid has 20 carbon atoms including the carboxyl carbon. Fatty acids could be saturated (without double bond) or unsaturated (with one or more C=C double bonds). Another simple lipid is glycerol which is trihydroxy propane. Many lipids have both glycerol and fatty acids. Here the fatty acids are found esterified with glycerol. They can then be monoglycerides, diglycerides and triglycerides. These are also called fats and oils based on melting point. Oils have lower melting point (e.g., gingelly oil) and hence remain as oil in winters. Can you identify a fat from the market? Some lipids have phosphorus and a phosphorylated organic compound in them. These are phospholipids. They are found in cell membranes. Lecithin is one example. Some tissues, especially the neural tissues, have lipids with more complex structures.

Living organisms have a number of carbon compounds in which heterocyclic rings can be found. Some of these are nitrogen bases – adenine, guanine, cytosine, uracil, and thymine. When found attached to a sugar, they are called nucleosides. If a phosphate group is also found esterified to the sugar they are called nucleotides. Adenosine, guanosine, thymidine, uridine and cytidine are nucleosides. Adenylic acid, thymidylic acid, guanylic acid, uridylic acid and cytidylic acid are nucleotides. Nucleic acids like DNA and RNA consist of nucleotides only. DNA and RNA function as genetic material.