Chapter one
Carbohydrates

Carbohydrates are the most abundant organic molecules in nature. The name carbohydrate, means "carbon hydrate ", stems from their chemical composition, which is (C.H2O) n, where n=three or more. But later, it was found that some of carbohydrates, such as deoxyribose (C5H10O4) and rhamnose (C6H12O5) do not have the required ratio of hydrogen to oxygen (H2O). Furthermore, formaldehyde (CH2O), Lactic acid (CH3CHOHCOOH, C3H6O3) and acetic acid (CH3COOH, C2H4O2) which have C,H and O , and the ratio of H:O is also the same as in water, but are not a carbohydrate. In addition to carbon, hydrogen and oxygen, certain other carbohydrates are posses' nitrogen (e.g., glucosamine C6H13O5N), phosphorus or sulfur.

Glucose (blood sugar): $C_6H_{12}O_6$, or alternatively $C_6(H_2O)_6$

Sucrose (table sugar): $C_{12}H_{22}O_{11}$, or alternatively $C_{12}(H_2O)_{11}$

In plants, glucose is synthesized from carbon dioxide and water by photosynthesis and stored as starch or used to synthesize cellulose of the plant framework.

$$\underset{\textbf{Carbon dioxide}}{6\ CO_2} + \underset{\textbf{Water}}{6\ H_2O} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \underset{\textbf{Glucose}}{C_6H_{12}O_6} + \underset{\textbf{Oxygen}}{6\ O_2}$$

Animals can synthesize carbohydrate from lipid, glycerol and amino acids, but most animal carbohydrate is derived ultimately from plants.

Definition of carbohydrates:

Based on chemical constitution, the carbohydrates or saccharides are most simply defined as polyhydroxy aldehydes or ketones and their derivatives.

Functions of carbohydrates:

1- Source of energy e.g., glucose.

2- Storage form of energy, e.g., glycogen in animal tissue and starch in plants.

3- Serves as structural components, e.g., glycosaminoglycans in human, cellulose in plants and chitin in insects and crustacean.

4- Important components of nucleic acids RNA & DNA. e.g., ribose and deoxyribose sugar.

5- Carbohydrates are also involved in detoxification. e.g., Glucuronic acid.

6- Certain carbohydrates are the starting materials for the synthesis of fatty acids, amino acids…

7- Non digestible carbohydrates like cellulose, agar, gum and pectin serve as dietary fibers.

8- Carbohydrates also are used as drugs like cardiac glycoside /antibiotics.

9- Glycoprotein's and glycolipids are components of cell membranes.

Classification of carbohydrates:

Carbohydrates are generally classified into three groups:

1- Monosaccharide.

2- Oligosaccharides.

3- Polysaccharides.

Monosaccharides:

Monosaccharides are also called simple sugars and cannot be broken down into smaller sugars under mild conditions.

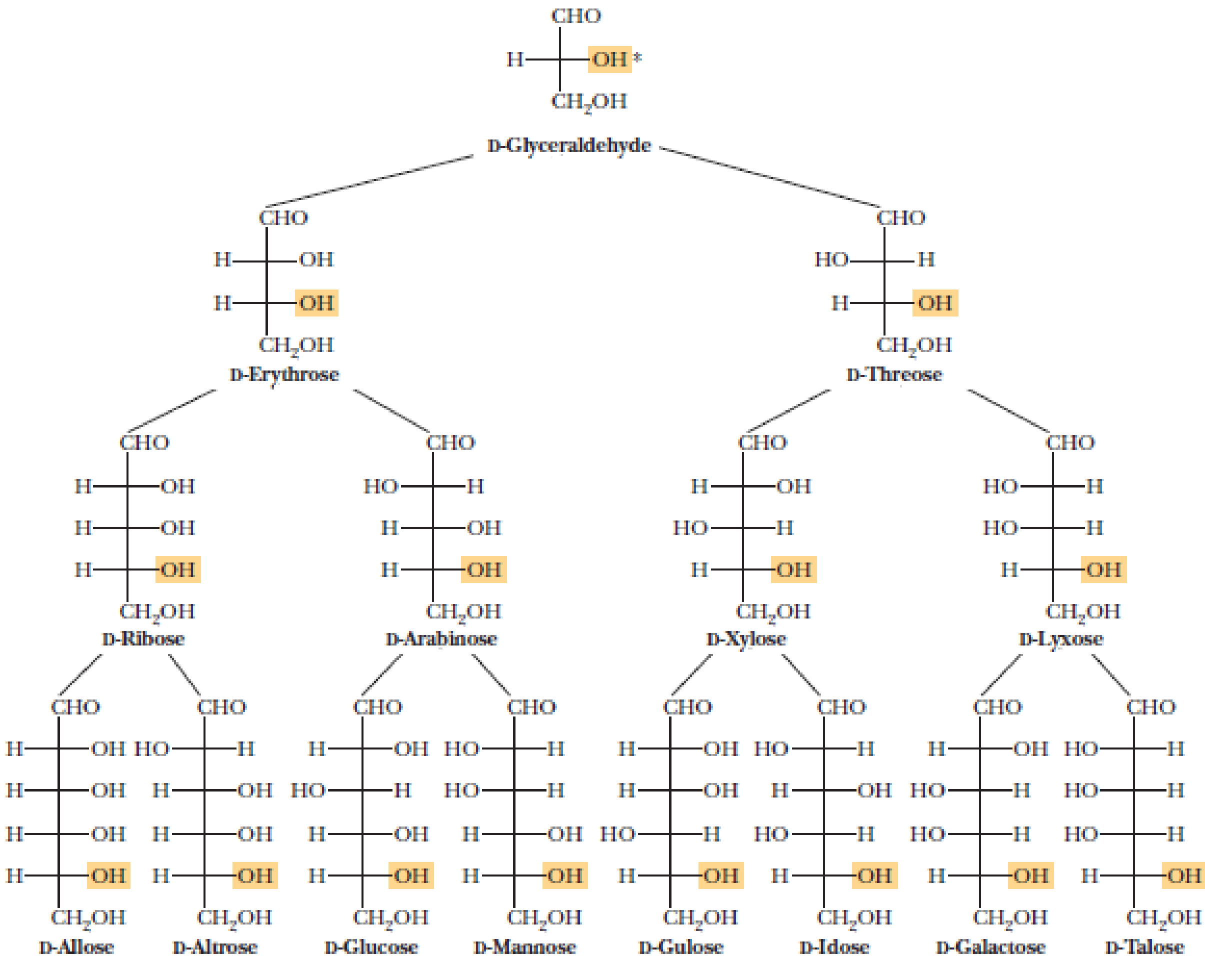
Monosaccharides may be classified as **trioses, tetroses, pentoses, hexoses,** or **heptoses,** depending upon the number of carbon atoms; and as **aldoses** or **ketoses** depending upon whether they have an aldehyde or ketone group.

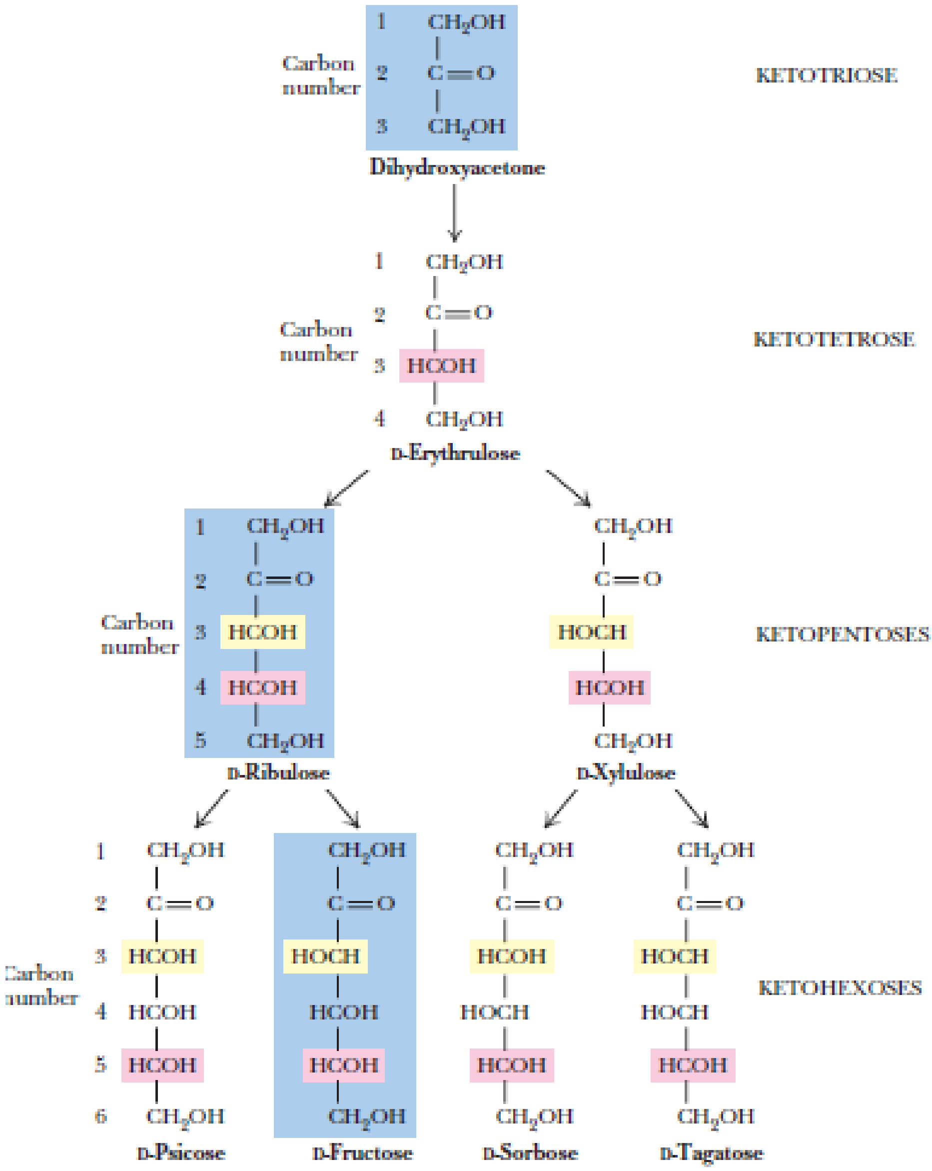
The suffix (-oses) is used for aldose and the suffix (-ulose) is used for ketoses. Thus ribose is a pentose, and ribulose is a pentulose. However, a few ketoses are named otherwise, such as fructose.

Classification of important sugars.

	Aldoses	Ketoses
Trioses ($C_3H_6O_3$)	Glycerose	Dihydroxyacetone
Tetroses ($C_4H_8O_4$)	Erythrose	Erythrulose
Pentoses ($C_5H_{10}O_5$)	Ribose	Ribulose
Hexoses ($C_6H_{12}O_6$)	Glucose	Fructose

The biochemically important aldoses and ketoses are shown below:

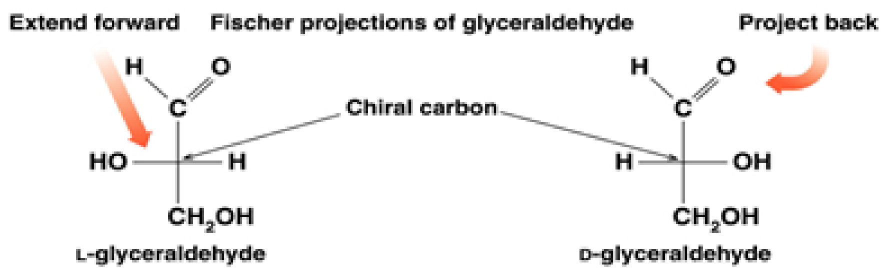

D-Glyceraldehyde
D-Erythrose
D-Threose
D-Ribose
D-Arabinose
D-Xylose
D-Lyxose
D-Allose
D-Altrose
D-Glucose
D-Mannose
D-Gulose
D-Idose
D-Galactose
D-Talose



General properties of monosaccharide:

<u>Asymmetric carbon:</u>

Asymmetric carbon (chiral carbon) is the carbon, which attached to 4 different groups or atoms. Any substances containing one or more asymmetric carbon atom is optically active



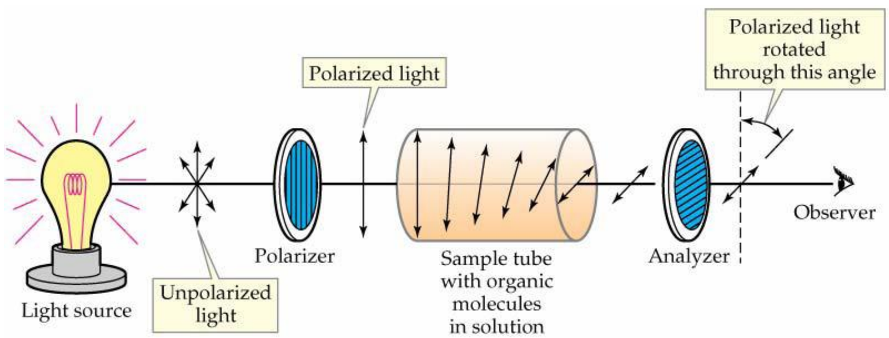
Optical activity:

The presence of a symmetrical carbon atom causes optical activity. When a beam of plane-polarized light is passed through a solution of carbohydrates, it will rotate the light either to right or to left. Depending on the rotation, molecules are called dextrorotatory (+) or (d) when it rotate the plane of polarized light in a clockwise. However, the molecules are called levorotatory (-) or (l) when it rotate the plane of polarized light in the opposite or counter clock wise (anti clockwise).

When an equal amount of d and l isomers are present, the resulting mixture has no optical activity. Since the activity of each isomer cancel one another, such a mixture is said to be a racemic or dL mixture.

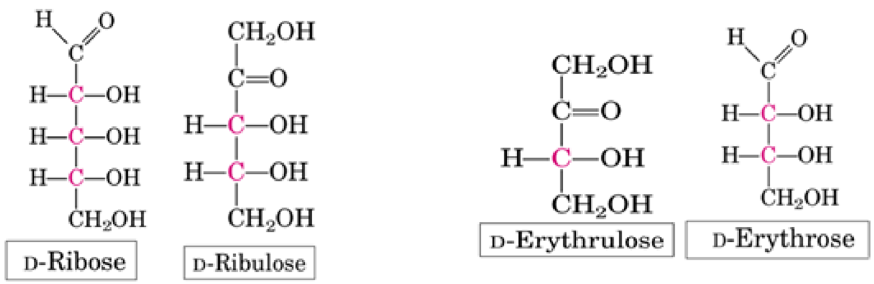
D-fructose is levorotatory so it is sometimes called levulose., while D-glucose is dextrorotatory so it is sometimes named dextrose.

Many biologically important molecules are chiral and optically active.

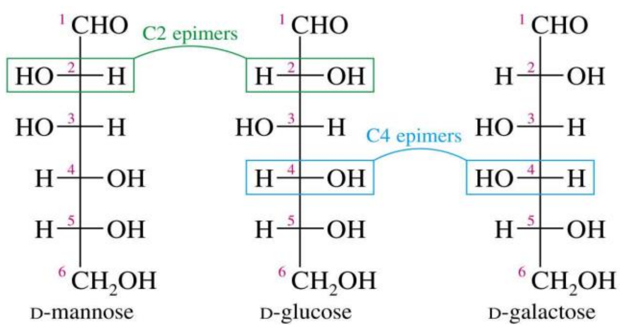


Isomers and epimers:

Compounds that have the same chemical formula but have different structures are called **isomers**. For example, ribose, ribulose are all isomers of each other, having the same chemical formula, $C_5H_{10}O_5$ and erythrose and erythrulose are also isomers to each other and having the chemical formula $C_4H_8O_4$

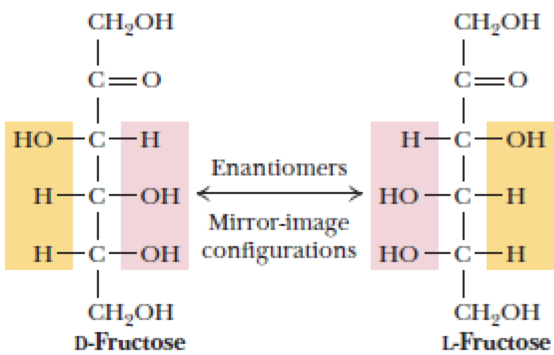


The two sugars, which differ from one another only in configuration around one carbon atom, are called **epimers**. For example, glucose and galactose are epimers, which differ only in carbon number 4. Similarly, mannose and glucose are epimers in carbon number 2. However, galactose and mannose are not epimers with each other because they differ at two carbon atoms 2 and 4. Ribose and xylose are epimers differing in C number 3.



Enantiomers:

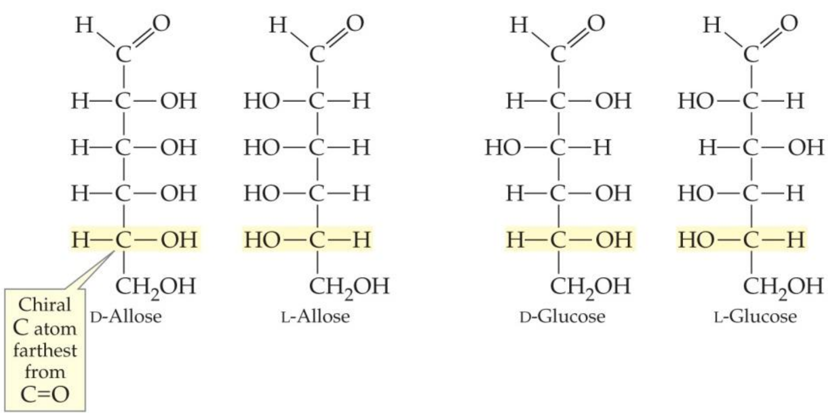
Enantiomers are the stereoisomers that are mirror images of each other.



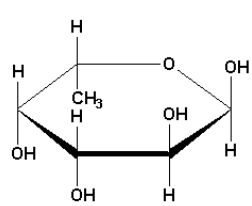
L & D isomerism:

L & D isomerism depends on the configuration of asymmetric carbon farthest from the carbonyl group (the aldehyde or ketone group).

When the OH group around the carbon atom adjacent to the terminal primary alcohol carbon (e.g., carbon atom 5 in glucose) is on the right of the sugar is D-form (D-isomer). However, when it is on the left, it is L-form (L-isomer).



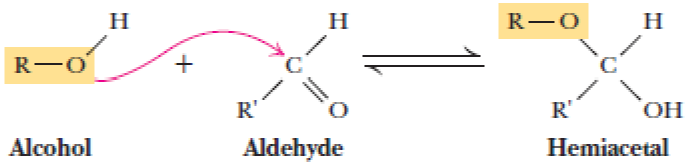
Most of the monosaccharides occurring in the nature belong to the D- form, except some sugars like L- fucose found in glycoprotein and L- iduronic acid found in glycosaminoglycans.



L-Fucose

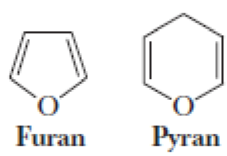
α and β- anomerism (Cyclization of monosaccharides):

An aldehyde can react with an alcohol to form a hemiacetal.



Simple sugars or monosaccharides have hydroxyl and carbonyl groups in the same molecule and their interaction can form five- and six-membered cyclic hemiacetals. For example: aldohexose such as glucose, the C-1 aldehyde in the open-chain form of glucose reacts with the C-5 hydroxyl group to form six-membered cyclic hemiacetal **(α –D- glucopyranose and β-D- glucopyranose)** or the C-1 aldehyde of glucose react with the C-4 hydroxyl group to form a five-membered cyclic hemiacetal (**α –D- glucofuranose and β-D- glucofuranose).**

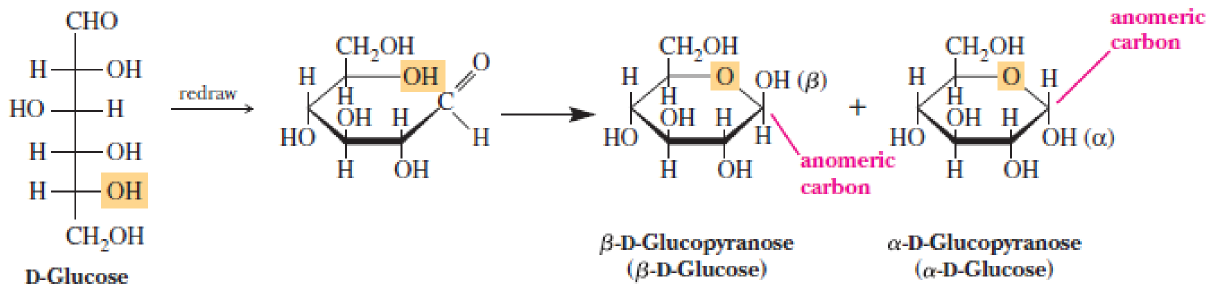
The six-membered ring is called a **pyranose**, the five-membered ring is called a **furanose**, and these two terms (pyranose and furanose) are used because monosaccharide five- and six-membered rings correspond to the heterocyclic compounds **furan** and **pyran**.



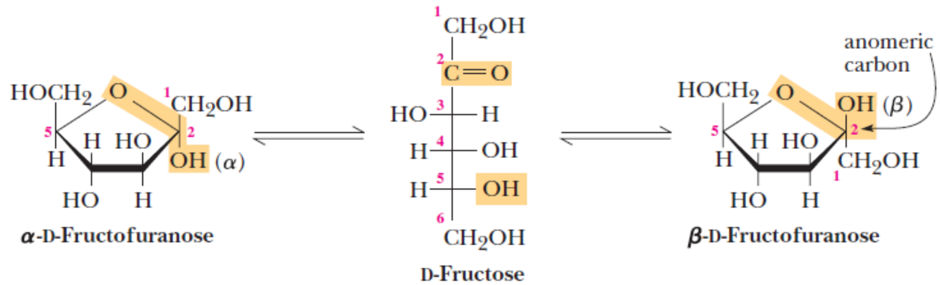
The designated α means that the OH group attached to C-1 is bellow the plane of the ring. β means that it is above the plane of the ring. The C-1 carbon is called the **anomeric carbon** atom, and so α and β forms are **anomers**.

Thus the **anomeric** carbon: is asymmetric carbon atom obtained from active carbonyl sugar group: carbon number 1 in aldoses and carbon number 2 in ketoses.

And **anomers**: are isomers obtained from the change of position of hydroxyl attached to the anomeric carbon e . g . α and β glucose are 2 anomers .

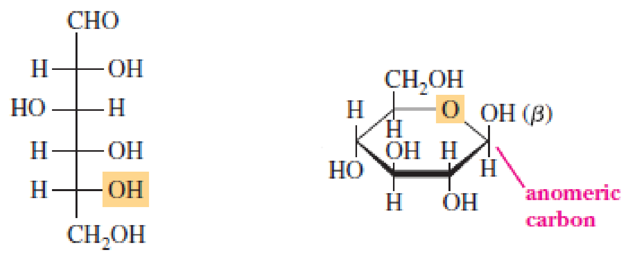


The C-2 keto group in the open-chain form of a ketohexose, such as fructose, can form an intramolecular hemiketal by reacting with either the C-6 hydroxyl group to form a six-membered cyclic hemiketal **(α –D- fructopyranose and β-D-fructopyranose)** or the C-5 hydroxyl group to form a five-membered cyclic hemiketal **(α –D- fructofuranose and β-D- fructofuranose)**.



In general, the pyranose form is favored for aldohexose sugars, and furanose structures are more stable for ketohexoses.

The planner form of sugars is called **Fischer formula or Fischer projection** and the cyclic form of sugars are called **Haworth projections**.



D-Glucose
Fischer projection

***β*-D-Glucopyranose**
Haworth projection

Mutarotation:

Mutarotation is defined as the change in specific rotation of an optically active solution without any change in other properties. A freshly prepared aqueous solution of α-D-glucose has a specific rotation +112.2°. In addition, when this solution is allowed to stand, the rotation falls to 52.7° and remains constant at this value. A fresh solution of β-D-glucose, on other hand, has a rotation value of 18.7°, on standing; it also changes to the same value 52.7°. This change of rotation is called mutarotation.

Mutarotation occurs due to cyclisation of open chain form of glucose into α and β – form with an equal probability. This α and β cyclic form of glucose have different optical rotation. These cyclic forms are in the equilibrium with open chain structure in aqueous solution.

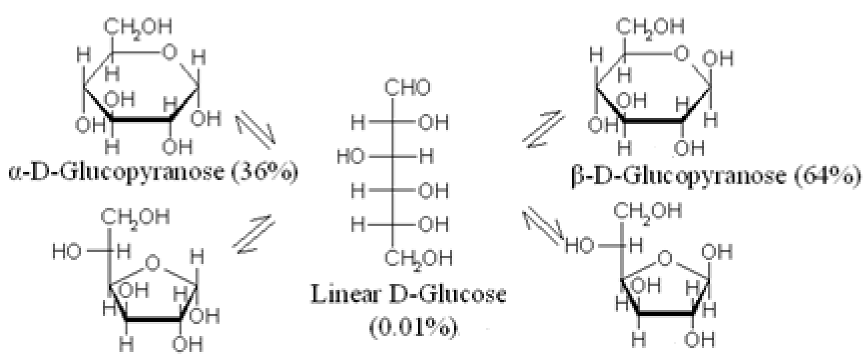
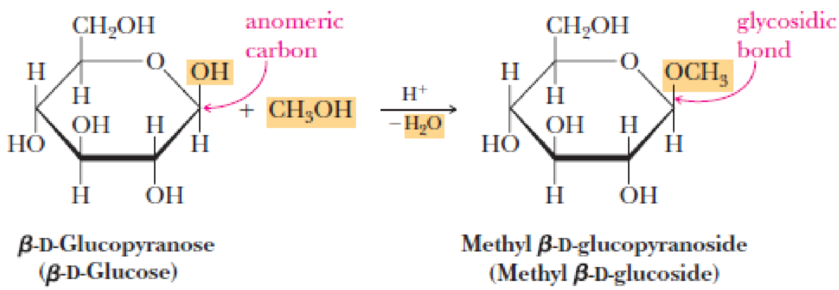


Diagram of Glucose mutarotation in solution.

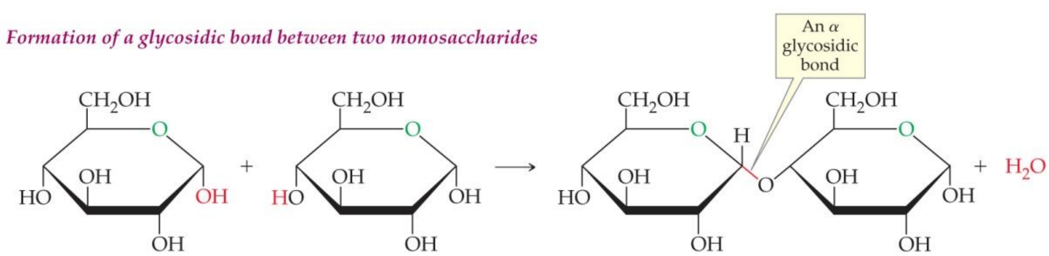
Formation of Glycosides (Acetals):

The treatment of an aldehyde or ketone with one molecule of alcohol gives a hemiacetal and that treatment of the hemiacetal with a molecule of alcohol gives an acetal.

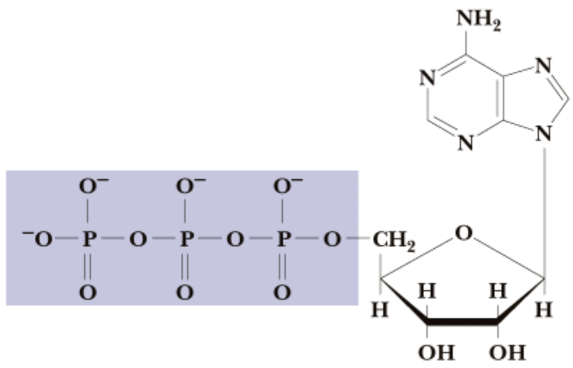
Treatment of monosaccharide in an acidic catalyzed reaction, the anomeric hydroxyl group (hemiacetal) condenses with alcohols to form acetal. A cyclic acetal derived from a monosaccharide is called **a glycosides**, and the bond from the anomeric carbon to the -OR group is called **a glycosidic bond**.



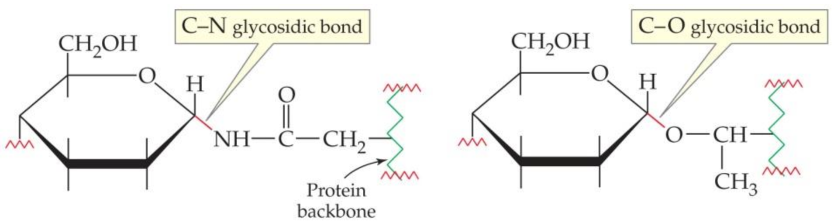
The monosaccharides held together by O- glycosidic bonds to form oligo or polysaccharides.



N- Glycosidic bonds are found in nucleotides. In Adenosine Tri Phosphate (ATP), the nitrogenous base Adenosine is linked to the sugar Ribose via N-glycosidic bond.



Adenosine-5'-triphosphate



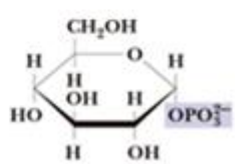
.

Biologically important sugar derivatives of monosaccharide:

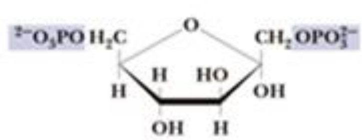
Some important sugar derivatives of monosaccharide are:

1- Sugar Esters (Sugar phosphate):

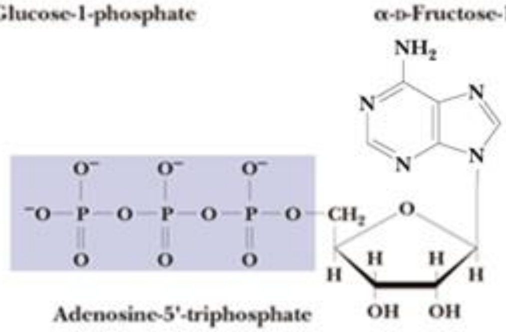
Phosphate derivatives of monosaccharides are found in all living cells, in which they serve as important intermediates in carbohydrate metabolism.



α-D-Glucose-1-phosphate



α-D-Fructose-1,6-bisphosphate



Adenosine-5'-triphosphate

2-Deoxy sugars:

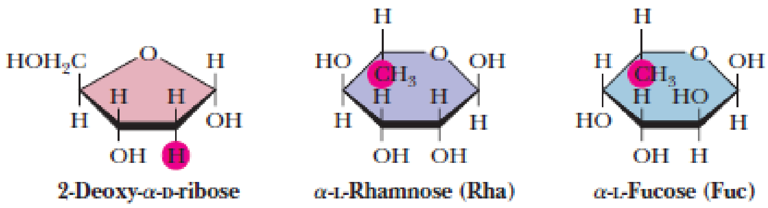
Are sugars in which one of the hydroxyl groups has been replaced by hydrogen atoms.

The important deoxy sugars are:

1- Deoxyribose (a constituent of DNA)

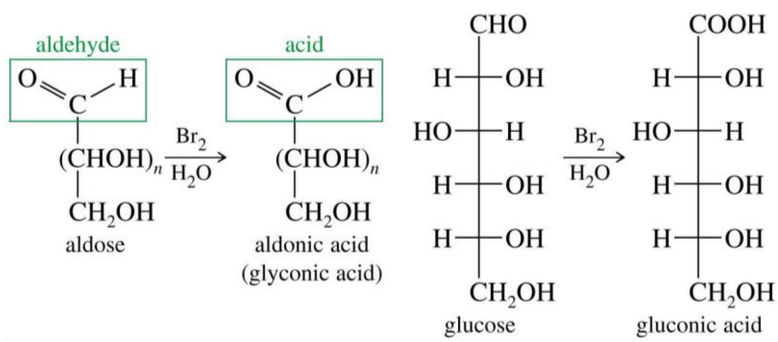
2- L-Fucose (6-Deoxy-β-L-Galactose) present in many glycoproteins like the blood group substances.

3- L-mannose (L-rhamnose) which is present in many plant polysaccharides.

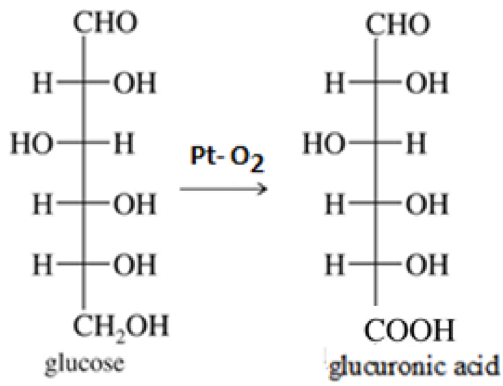


3- Sugar acids:

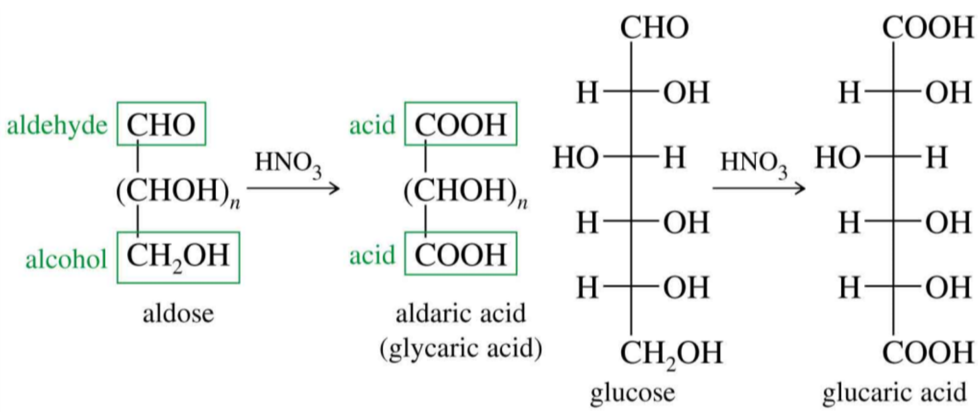
a. Aldonic acids: Under mild oxidation conditions, Bromine oxidizes aldehyde (but not ketone or alcohol) to the carboxylic acid (aldonic acid) such as gluconic acid.



b. Alduronic acids: Oxidation of the terminal primary alcoholic group of sugar by **Platinum- oxygen** catalyst gives uronic acid. The uronic acids are components of many polysaccharides. For example, D-Glucuronic acid is important components of many polysaccharides of connective tissues. It is also used by the body, to detoxify foreign hydroxyl containing compounds, such as phenols and alcohols.

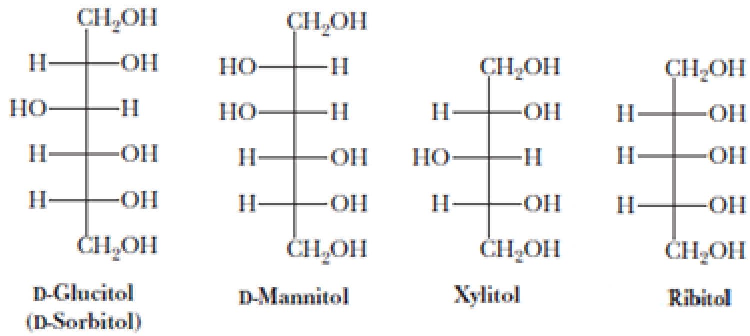


c. Saccharic acid (Aldaric acids): These are dicarboxylic acids produced by oxidation of both carbonyl carbon and last hydroxyl carbon by strong oxidation agents like HNO_3.



4- Sugar alcohols:

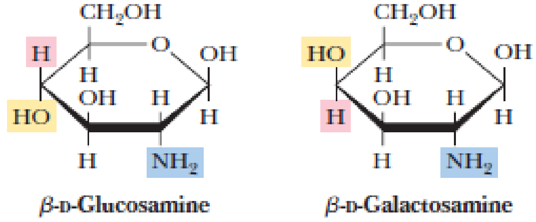
The carbonyl group of a monosaccharide can be reduced to a hydroxyl group by a variety of reducing agents, including sodium borohydride and hydrogen in the presence of a transition metal catalyst. The reduction products are known as alditols. Sugar alcohols are not metabolically very active, but have some medical importance in that they are used as non-glucose forming sweeteners in fruit stuffs for diabetics; sorbitol is an important food additive, usually added to prevent dehydration of foods and other materials on exposure to air because it binds water strongly. However, xylitol is used as a sweetening agent in "sugarless" gum, candy, and sweet cereals, while Ribitol is a constituent of vitamin B_2.



5- Amino sugar:

These are sugars in which the hydroxyl group at the C-2 has been replaced by amino or an acetylamino group. For example, glucosamine, N-acetyl glucosamine, galactosamine …

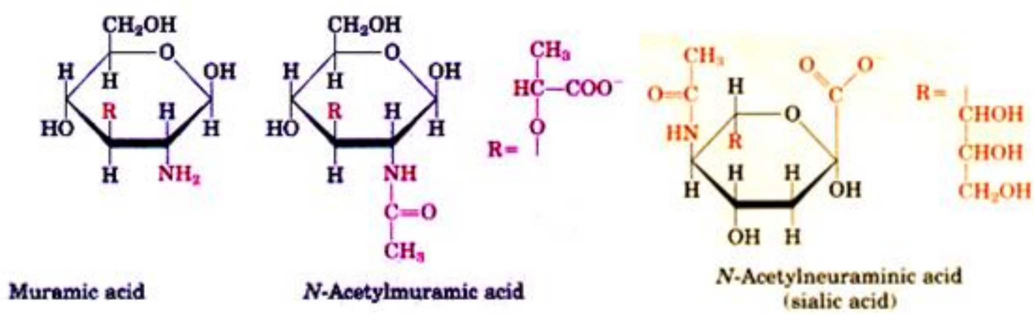
D-Glucosamine occurs in many polysaccharides of vertebrate tissues and is also a major component of chitin (a polysaccharide in the exoskeletons of crustaceans and insects). D--Galactosamine is a component of glycolipids and of the major polysaccharide of cartilage, chondroitin sulfate. In addition, several antibiotics contain amino sugars like erythromycin.



6- Muramic acid and neuraminic acid:

Muramic acid and neuraminic acid are glucosamines linked to three-carbon acids at the C-1 or C-3 positions. Muramic acid is D-glucosamine to which a lactic acid moiety is attached at C-3. Neuraminic acid is derived from D-mannosamine and pyruvic acid by an aldol condensation.

The two compounds are usually acetylated. N-acetylmuramic acid is a component of bacterial cell wall material. The acetylated derivative of neuraminic acid (NANA), known as sialic acid, is a component of glycoproteins glycolipids (ganglioside) present widely in bacteria and animal cell membrane.



Oligosaccharides:

Oligasaccharides are sugars consist of short chains of monosaccharide units (two to ten units) joined by glycosidic linkages.

Depending on the number of monosaccharide units that are linked, the oligosaccharides are further classified as disaccharides (two sugar units), trisaccharides (three sugar units), tetrasaccharides (four sugar units), etc. Amongst these, disaccharides are the most important class because of their biological role and relative abundance in natural products.

Disaccharides:

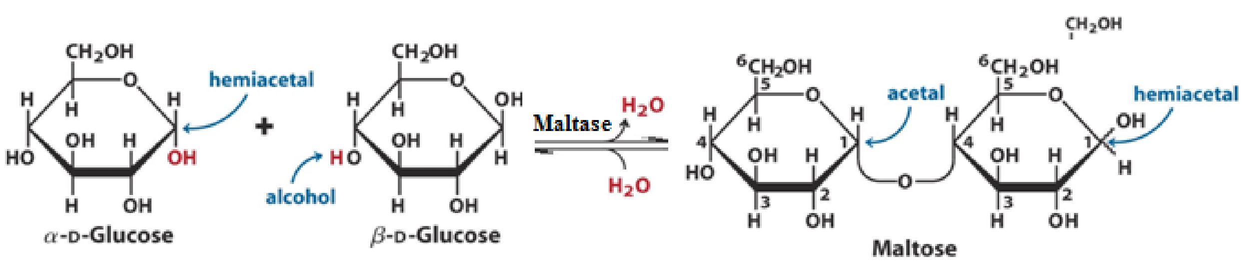
Disaccharides are a group of compound sugars composed of two monosaccharides linked by the glycosidic bond with the elimination of one molecule of water. Sucrose, maltose, and lactose are the most physiologically important disaccharides.

Maltose:

Maltose, often called malt sugar, is present in fermenting grains and can be prepared by enzyme-catalyzed degradation of starch.

Maltose is a disaccharide, contains two glucose units, joined by an α (1→4) glycosidic bond between C-1 (the anomeric carbon) of one glucose residue and C-4 of the second glucose. Maltose is a reducing sugar because it has one free hydroxyl group at C-1 (the anomeric carbon).

Maltose is not found in the free form in the body. It is formed during the starch digestion of α-amylase enzyme in the small intestine and then hydrolyzed to glucose by a maltase enzyme.

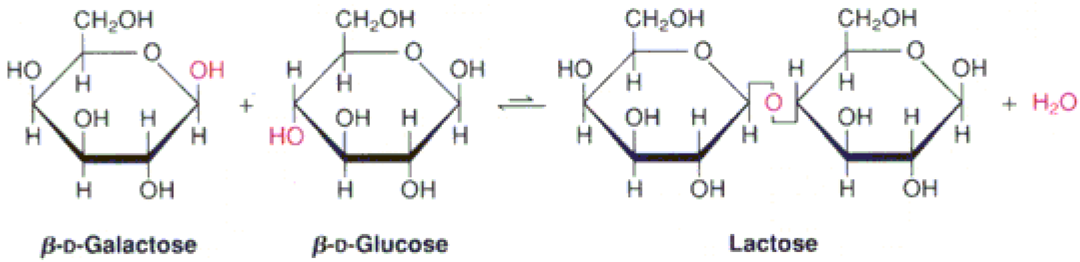


O-α-D-Glucopyranosyl-(1→4) β-D-Glucopyranoside

Lactose:

Lactose is a disaccharide found in the milk. Lactose contains a galactose molecule joined to a glucose molecule by a β (1→4) glycosidic bond. It has a free anomeric carbon atom and so is a reducing sugar.

Lactose is hydrolyzed to glucose and galactose by lactase enzyme in human.

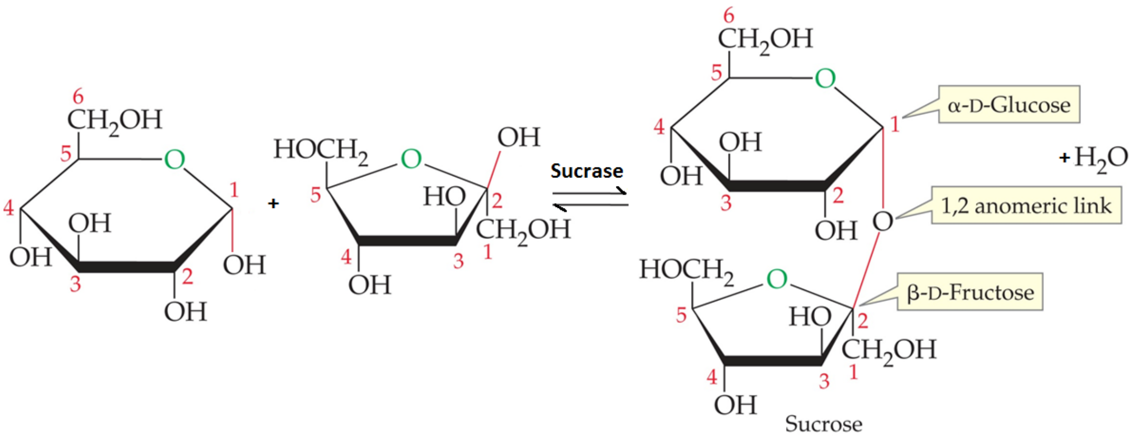


O-β-D-galactopyranosyl-(1→ 4)-β-D-glucopyranoside

Sucrose (Cane sugar, common table sugar):

Sucrose is the sweetening agent known as cane sugar. It is present in cane sugar and various fruits.

Sucrose is a disaccharide contains glucose molecule and fructose molecule linked by α (1→2) glycosidic bond. On hydrolysis, sucrose yields one molecule of D-glucose and one molecule of D-fructose by sucrase enzyme present in intestinal juice. Sucrose has no free carbonyl group (because both the anomeric carbons; carbon 1 of α-glucose and carbon 2 of β -fructose are involved in glycosidic bond), so sucrose is not a reducing sugar.



O-α-D-glucopyranosyl-(1→2)-β-D-fructofuranoside

Polysaccharides

Polysaccharides are carbohydrates composed of more than ten monosaccharide units (or their derivatives like amino sugar) joined together by glycosidic linkages. These are the most commonly encountered carbohydrates in nature. They mainly act as the food storage or structural materials. Polysaccharides differ from each other in the identity of their recurring monosaccharide units, in the length of their chains, in the types of bonds linking the units, and in the degree of branching.

Polysaccharides are often called as glycans. Those containing glucose are called as glycans (starch and glycogen); those containing mannose are called mannans and those containing galactose units are called galactans.

Functions of polysaccharides:

Polysaccharides serve two main functions in the living organisms as:

1. Storage form of cellular fuel and
2. Structural elements in animal, plant and microbial system

Classification of polysaccharides:

Polysaccharides can be classified into major classes:

1- Homopolysaccharides (homo glycans)

2- Heteropolysaccharides (hetero glycans

Homopolysaccharides (homoglycans):

These are made up of single kind of monosaccharide residues or their derivatives. On hydrolysis, yield one type of monosaccharides. The most common homopolysaccharide are starch, dextrin, glycogen, dextrons, inulin and dietary fiber cellulose.

Some homopolysaccharides serve as a storage form of monosaccharide used as fuel, like starch and glycogen. While others serve as structural elements in plant, like cellulose.

Starch:

Starch is the most principlal storage polysaccharide in plant kingdom, and it’s found in potatoes, rice, corn, Wheat, …….

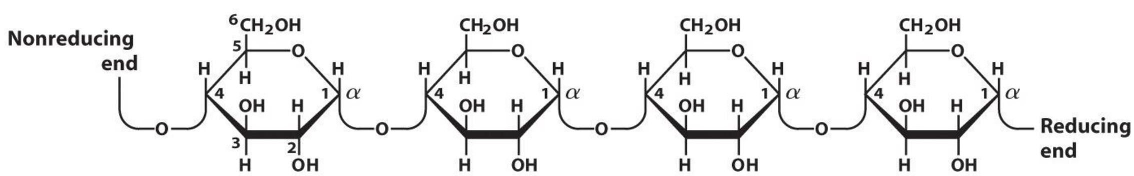
Starch is consists of two types of polysaccharides:

1- Amylose.

2- Amylopectin.

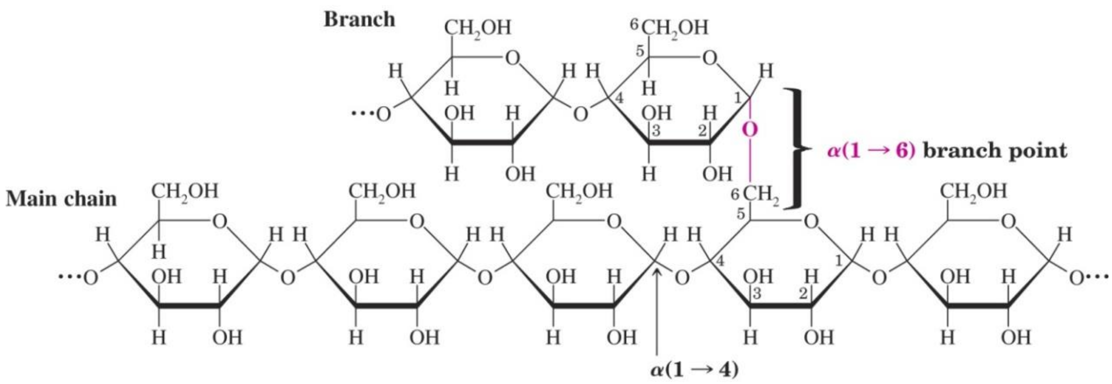
Amylose:

Amylose is a liner polymer of D-glucose units joined by α(1→4) glycosidic linkage. The molecular weight ranges from several thousand to half a million. Amylose gives blue color with iodine solution. Amylose is hydrolyzed by α-amylase.



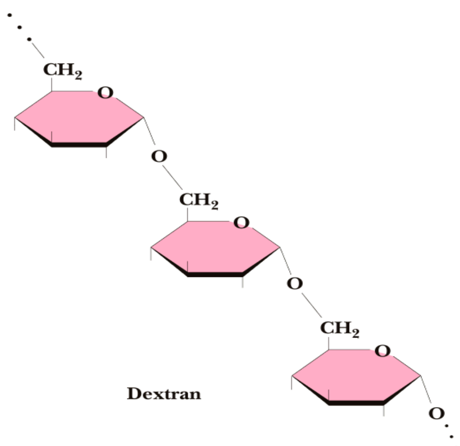
Amylopectin:

Amylopectin, the other component of starches, is highly branched chain of glucose unit. Branches occur in these chains on an average of 24 to 30 glucose units. The molecular weights of amylopectin molecules can range up to 100 millions. The linear linkages of amylopectine are α(1→4) glycosidic linkage, where as the branched linkages are α(1→6) glycosidic linkage. Amylopectin is water insoluble and gives violet color with iodine.



Dextran:

These are storage polysaccharides of some yeasts and bacteria. They consist of D-glucose units joined by are α(1→6)- glycosidic bonds.



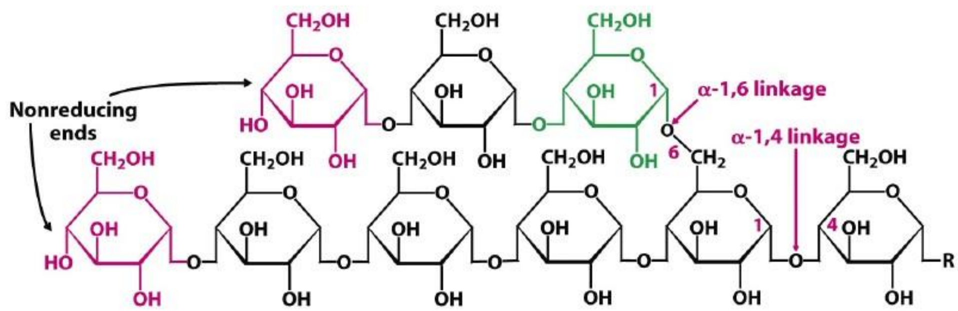
Because the main polymer chain is α(1→6) linked, the repeating unit is isomaltose, Glc α(1→6)-Glc. The branch points may be 1→2, 1→3, or 1→4 in various species. The degree of branching and the average chain length between branches depend on the species and strain of the organism. Bacteria growing on the surfaces of teeth produce extracellular accumulations of dextrans, an important component of dental plaque.

Dextrin:

Dextrins are intermediates in the hydrolysis of starch by acid or α- amylase. Dextrins are present in the plant tissue during synthesis and degradation of starch. Dextrins formed from amylose have a liner chains, while these formed from amylopectins are branched. Dextrins are water-soluble and react with iodine.

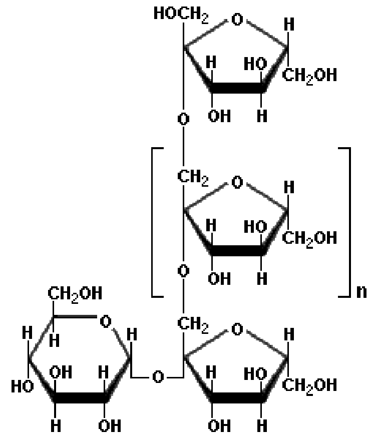
Glycogen (Animal starch):

Glycogen is the major form of storage polysaccharide in animals. Glycogen is found mainly in liver and muscle. About 5% by weight of liver and 0.5% by weight of s a muscle is glycogen. Glycogen is a highly branched chain in which glucose units in addition to linear α(1→4) are also linked by an α(1→6) at the branched points. This branching repeats after every 8-10 glucose unit. Glycogen is similar in structure to amylopectin except for more branch points. Glycogen can be hydrolyzed by both α and β- amylase yielding glucose and maltose, respectively as products.



Inulin:

It is a storage polysaccharide in the Compositae family (artichokes, dahlias, dandelions, etc). It is a homopolymer made of D-Fructose units linked by α (1→2) bonds. It occurs in the tubers and roots of some plants such as oinine and garlic. Inulin is not hydrolyzed by α – amylase and not undergoes any metabolic change in the body. It is no dietary importance in human. It is used to studies of kidney function test.



Cellulose:

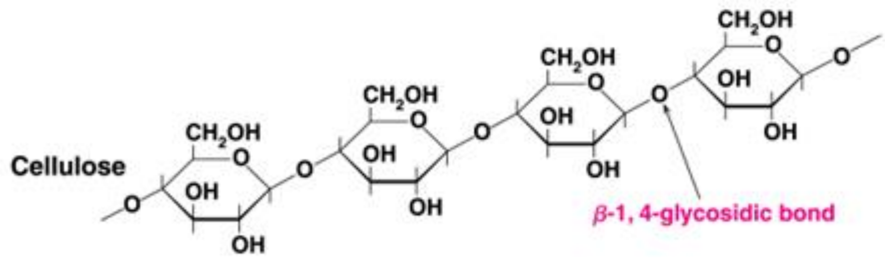
Cellulose is the most abundant organic compound of our planet accounting for about 50% of all carbon. It is the principal constituent of cell walls in higher plants forming the main structural element. It is a linear homopolymer of β-D-glucose units linked by β (1→4) glycosidic bonds.

It is insoluble in water and all organic solvents and gives no color with iodine.

Partial hydrolysis, cellulose yields β (1→4) disaccharide cellobiose

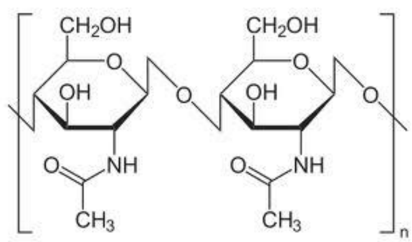
Humans cannot digest cellulose because it does not possess the cellulase an enzyme in the gastrointestinal tract which cleavage β (1→4) linkages. Indeed, only a few animals, such as termites, cows, and goats, are able to digest cellulose. These animals have, within their digestive tracts, microorganisms that produce the enzyme cellulase. Then cellulose from fruits and vegetables serves as fiber in the diet and good for health. But only a few animals such as cow, camel and goat are able to digest it, because these animals have, within their digestive tracts, microorganisms that produce the enzyme cellulose.

In plant cell walls, cellulose micro-fibrils are cemented together by other substances important among them being pectin and hemicellulsoe. Pectins contain arabinose, galactose and glacturonic acid while hemicelluloses are homopolymers of D-xylose linked by β (1→4) bonds. The important sources of cellulose are cotton fibers (98%), jute (50-70%), wood (40-50%), algae and bacteria. Cellulose and its derivatives are widely used in textiles, films and plastics.



Chitin:

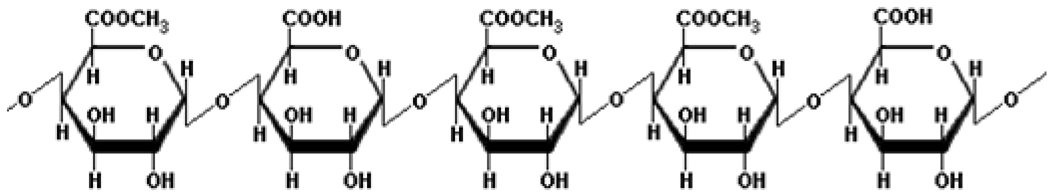
Chitin is probably the most abundant polysaccharide of nature after cellulose on earth. It is structural polysaccharide present in the cell walls of fungi, exoskeleton of crustaceans, insects, spider, and in mushrooms. Chitin is a polymer of N-Acetyl-D-glucosamine units linked by β (1→4) bonds. On hydrolysis, chitin yields two products, glucosamine and acetic acid.



Pectin:

Pectins are found as intercellular substances in the tissues of young plants and especially in ripe fruits such as apples and pears.

Pectin is a polysaccharide of α-D- galacturonic acid where some of the free carboxyl groups are, either partly or completely esterified with methyl alcohol and others are combined with calcium or magnesium ions. Pectin plays in plant stability and solidity. Chemically they are called polygalacturonic acid.



Pectin

Peptidoglycan (murein):

It is a structural heteropolysaccharide present in bacterial cell walls. The repeating unit of peptidoglycan is the muropeptide which is a disaccharide composed of N-acetyl- D-glucosamine (NAG) and N-acetyl muramic acid (NAMA) joined by a β (1→4) glycosidic bond. NAMA consists of a NAG unit which has its C-3 hydroxyl group joined to the hydroxyl group of lactic acid by an ether linkage. In the peptidoglycan the carboxyl group of each lactic acid moiety is in turn linked to a tetrapeptide consisting of L-alanine, D-isoglutamine, L-lysine and D-alanine. The terminal D-alanine residue of the side chain of one polysaccharide chain is joined covalently with the peptide side chain of an adjacent polysaccharide chain, either directly as in *E.coli* or through a short connecting peptide, e.g. The pentaglycine in *Staphylococcus aureus* The peptidoglycan structure of the bacterial cell wall is resistant to the action of peptide-hydrolyzing enzymes, which do not attack peptides containing D-amino acids. However, the enzyme lysozyme, found in tears and in egg white, hydrolyzes the β (1→4) glycosidic bonds of the polysaccharide backbone of the peptidoglycan structure.

Heteropolysaccharides (heteroglycans):

Hetero polysaccharides are polymers that contain two or more different types of monosaccharide units or their derivatives. e.g. Hyaluronic acid, heparin, pectins, gums, chondroitins, etc.

Mucopolysaccharides (Glycosaminoglycans GAGs):

A mucopolysaccharides or glycosaminoglycans are linear polymers composed of repeating disaccharide units (acidic sugar- amino $sugar)_n$ contains at least one negatively charged sulfate or carboxylate group.

The amino sugar is either N-acetylglucosamine or N-acetylgalactosamine; the acidic sugar is either a D-glucuronic acid or L-iduronic acid. In some glycosaminoglycans, one or more of the hydroxyls of the amino sugar is esterified with sulfate. The combinations of these sulfate groups and the carboxylate groups of the uronic acid residues give the glycosaminoglycans a very high density of negative charge. .

The physiologically most important glycosaminoglycans are hyaluronic acid, dermatan sulfate, chondroitin sulfate, heparin, heparan sulfate, and keratan sulfate.

Most of the glycosaminoglycans act as structural support material for connective tissue or mucous substance of the body. They serve both as a lubricant and as a cementing substance.

Structure and function of mucopolysaccharides

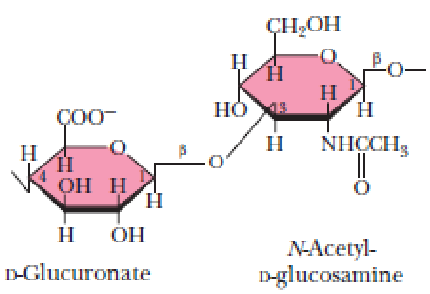
Name	Source	Function	Monosaccharide units	Linkage
Hyaluro-nic acid	Higher animals	Component of connective tissues & viscous fluids of the body	D-Glucuronic acid & N-acetyl-D-glucosamine	β(1→3) and β(1→4)
Chondroitin sulfate	Higher animals	Component of cartilage, tendons & skin	D-glucoronic acid, N-acetyl-D-galactosamine with sulfate esters at 4th or 6th carbon atom of galactosamine	β(1→3) and β(1→4)
Heparin	Mast cells, lungs	Anticoagulant properties	L-Iduronic acid, D-glucuronic acid & N-sulfo-D-glucosamine with several O-sulfate groups	α(1→4)

Hyaluronic acid:

It is a heteropolysaccharide, composed of repeating disaccharide units linked by β (1→4) linkages.The repeating disaccharide units that consist of D-glucuronic acid and N-acetyl-D-glucosamine linked by β (1→3) bond.

Hyaluronic acids are hydrolyzed by hyaluronase, that hydrolyze β (1→4) linkages and hyaluronase occurs in a varity of animal tissues, in bacteria, snake and insect toxins.

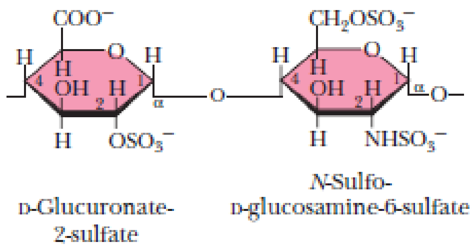
Hyaluronic acid is an important glucosaminoglycan component of the vitreous humor in the eye and of synovial fluid, the lubricant fluid of joints in the body.



Heparin:

Heparin is a heteropolysaccharide composed of D-glucuronic acid units, most of which are esterified at C-2 and D-glucosamine-N-sulfate units with an additional O-sulfate group at C-6. Both the linkages of the polymer are α in (1→4).

Heparin acts as an anticoagulant. It prevents coagulation of blood by inhibiting the conversion of prothrombin to thrombin in which heparin binds strongly to a blood-clotting factor and in this way prevents clot formation. Thus stimulates the effect of thrombin on fibrinogen.



Chondroitin:

Another acid mucopolysaccharide is chondroitin, which is nearly identical in structure to hyaluronic acid the only difference is that it contains N-acetyl-D-galactosamine instead of N-acetyl-D-glucosamine residues. The sulfuric acid derivatives, chondroitin-4-sulfate (chondroitin A) and chondroitin-6-sulfate (chondroitin C) are major structural components of cell coats, cartilage, bone, cornea and other connective tissues in vertebrates.