CARBOHYDRATES

Carbohydrates are essential components of all living organisms and are, in fact, the most abundant class of biological molecules. The name carbohydrate, which literally means “hydrates of carbon,” stems from their chemical composition, which is roughly (CH2O)*n*, where *n* is 3 or more. The basic units of carbohydrates are known as monosaccharides.

Carbohydrates may be defined as polyhydroxyaldehydes or ketones or compounds which produce them on hydrolysis.

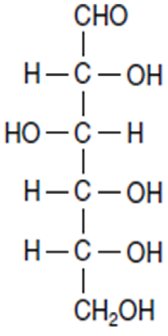
Classification

Based on number of sugar units carbohydrates are classified into three major groups-

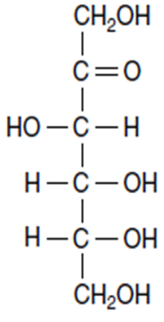
1) **Monosaccharides** **2) Oligosaccharides** **3) Polysacharides**

Monosaccharides

Monosaccharides are classified according to the chemical nature of their carbonyl group and the number of their C atoms. If the carbonyl group is an aldehyde, as in glucose, the sugar is an aldose. If the carbonyl group is a ketone, as in ribulose, the sugar is a ketose. The smallest monosaccharides, those with three carbon atoms, are trioses. Those with four, five, six, seven, etc., C atoms are, respectively, tetroses, pentoses, hexoses, heptoses, etc. These terms may be combined so that, for example, glucose is an aldohexose, whereas ribulose is a ketopentose. Dihydroxyacetone, D-fructose, D-ribulose, and D-xylulose are the biologically most prominent ketoses. Sugars that differ only by the configuration about one C atom are known as epimers of one another. Thus D-glucose and D-mannose are epimers with respect to C2, whereas D-glucose and D-galactose are epimers with respect to C4. However, D-mannose and D-galactose are not epimers of each other because they differ in configuration about two of their C atoms. D-Glucose is the only aldose that commonly occurs in nature as a monosaccharide.

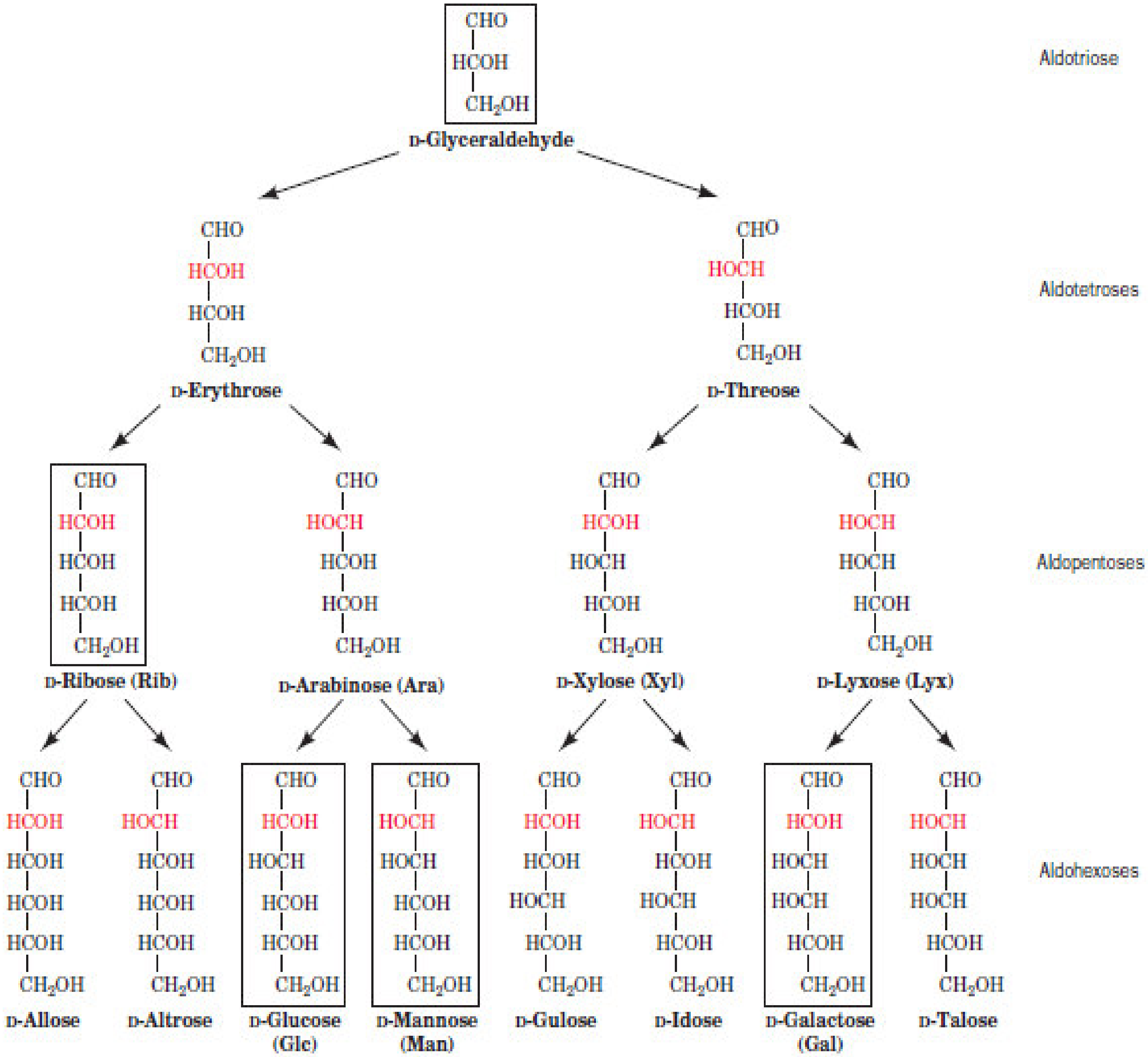


D-Glucose



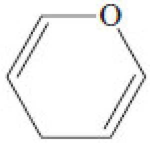
D-Fructose

The stereochemical relationships, shown in Fischer projection, among the D-aldoses with three to six carbon atoms

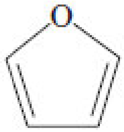


Configurations and Conformations

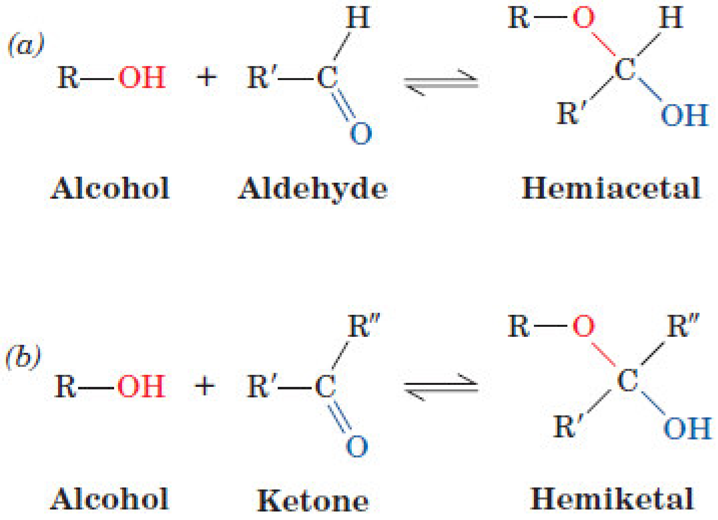
Alcohols react with the carbonyl groups of aldehydes and ketones to form hemiacetals and hemiketals, respectively. The hydroxyl and either the aldehyde or the ketone functions of monosaccharides can likewise react intramolecularly to form cyclic hemiacetals and hemiketals. The configurations of the substituents to each carbon atom of these sugar rings are conveniently represented by their Haworth projection formulas. A sugar with a six-membered ring is known as a pyranose in analogy with pyran, the simplest compound containing such a ring. Similarly, sugars with five-membered rings are designated furanoses in analogy with furan. The cyclic forms of glucose and fructose with six- and five membered rings are therefore known as glucopyranose and fructofuranose, respectively.



Pyran



Furan

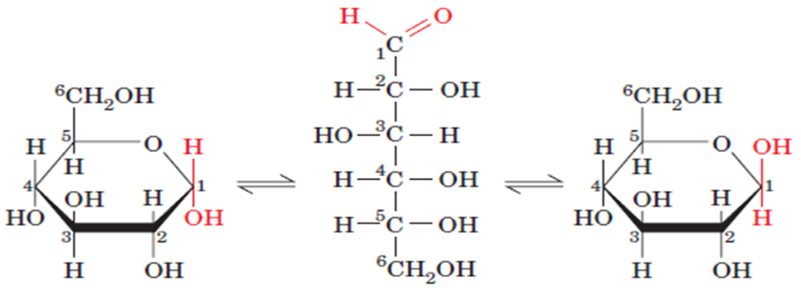


The reactions of alcohols with (*a*) aldehydes to form hemiacetals and (*b*) ketones to form hemiketals.

Cyclic Sugars Have Two Anomeric Forms

The cyclization of a monosaccharide renders the former carbonyl carbon asymmetric. The resulting pair of diastereomers are known as anomers and the hemiacetal or hemiketal carbon is referred to as the anomeric carbon. In the α anomer, the OH substituent to the anomeric carbon is on the opposite side of the sugar ring from the CH2OH group at the chiral center that designates the D or L configuration (C5 in hexoses). The other anomer is known as the β form

The two anomers of D-glucose, as any pair of diastereomers, have different physical and chemical properties. For example, the values of the specific optical rotation, for α -D-glucose and β -D-glucose are, respectively, +112.2° and +18.7°.When either of these pure substances is dissolved in water, however, the specific optical rotation of the solution slowly changes until it reaches an equilibrium value of = +52.7°. This phenomenon is known as mutarotation; in glucose, it results from the formation of an equilibrium mixture consisting of 63.6% of the β anomer and 36.4% of the α anomer (the optical rotations of separate molecules in solution are independent of each other so that the optical rotation of a solution is the weighted average of the optical rotations of its components). The interconversion between these anomers occurs via the linear form of glucose.



α-D-Glucopyranose

D-Glucose Linear form

β- D-Glucopyranose

Oligosaccharides

Oligosaccharides contain 2-10 monosaccharides molecules which are liberated on hydrolysis. Among the oligosaccharides, disaccharides are the most common.

Disaccharides

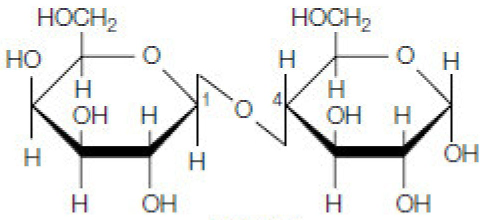
The aldehyde or ketone group on the anomeric carbon atom of one monosaccharide can react with the hydroxyl group of a second monosaccharide to form a disaccharide. The covalent bond formed is called a glycosidic bond. They are often associated with proteins (glycoproteins) and lipids (glycolipids) in which they have both structural and regulatory functions (glycoproteins and glycolipids are collectively called glycoconjugates).

Maltose is a disaccharide formed between the C-1 and C-4 positions of two glucose units. However, here the configuration of the anomeric carbon atom involved is the α form and hence the bond is called an α (1→4) bond or abbreviated as α 1–4.

Lactose or milk sugar occurs naturally only in milk, where its concentration ranges from 0 to 7% depending on the species. Lactose is a disaccharide formed between the anomeric carbon (C-1) of D-galactose and C-4 of D-glucose. Since the anomeric carbon of the galactose molecule is involved in the bond and is in the β configuration, this is called a β (1→4) bond which can be abbreviated as β 1–4. The free anomeric carbon of its glucose residue makes lactose a reducing sugar. Infants normally express the intestinal enzyme lactase that catalyzes the hydrolysis of lactose to its component monosaccharides for absorption into the bloodstream.

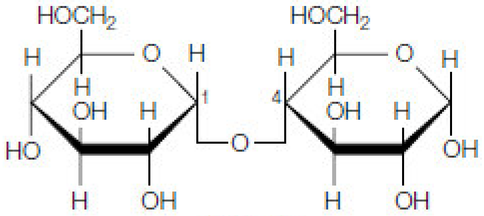
Sucrose, the most abundant disaccharide, occurs throughout the plant kingdom and is familiar to us as common table sugar. Sucrose is a disaccharide formed by bond formation between the anomeric C-1 of glucose and the anomeric C-2 of fructose so that sucrose lacks a free reducing group. Thus it is not a reducing sugar. Hydrolyzed sucrose is sometimes called invert sugar and the enzyme that catalyzes this process, named invertase.

Structure of common disaccharides



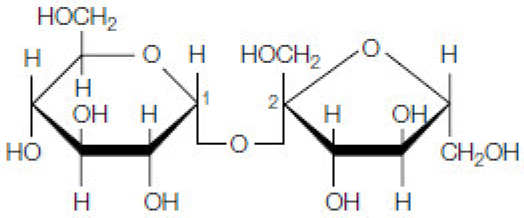
Lactose
(Gal β1→4 Glc)

(b)



Maltose
(Glc α1→4 Glc)

(c)



Sucrose
(Glc α1→2 Fru)

Polysaccharides

Polysaccharides or simply glycans consist of repeat units of monosaccharides with high molecular weight (up to a million). They are usually tasteless and form colloids with water They are primarily concerned with two important functions – structural and storage of energy.

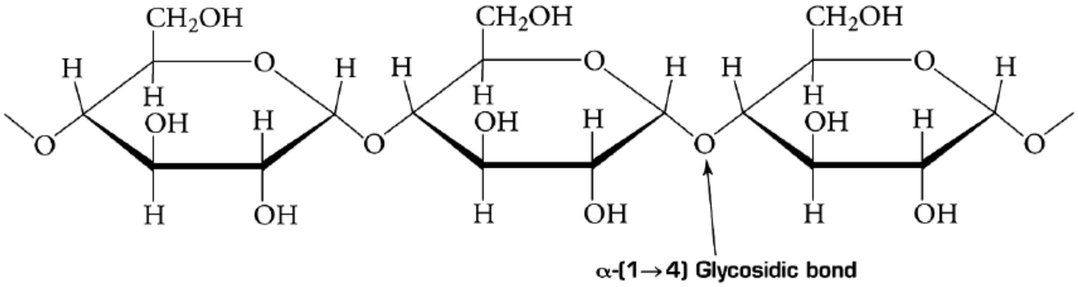
Polysaccharides are linear as well as branched polymers. Polysaccharides are of two types:-

1. **Homopolysaccharides** which on hydrolysis yield only a single type of monosaccharide. They are named based on the nature of the monosaccharide unit.

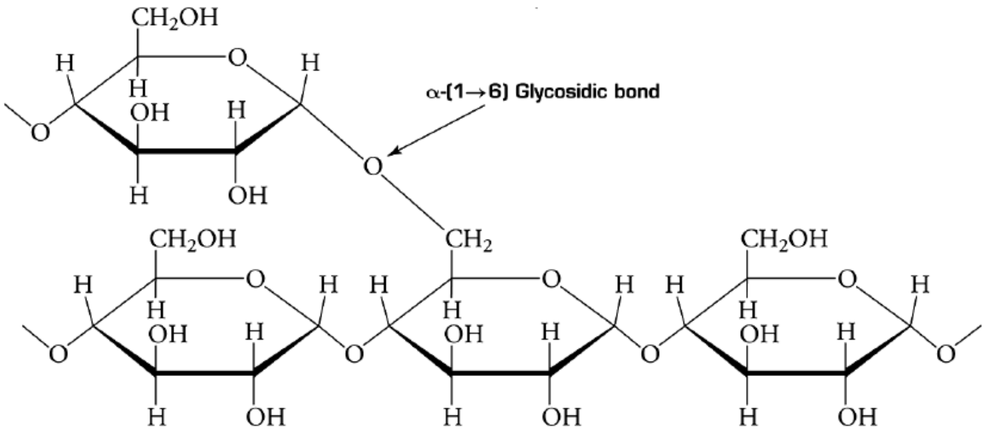
2. **Hetropolysaccharides** on hydrolysis yield a mixture of a monosaccharide or their derivatives.

Homopolysaccharides

Starch is a homopolymer of glucose forming an α- glycosidic chain, called a glucosan or glucan. Starch exists in plants as insoluble starch granules in the cytoplasm. It is the most abundant dietary carbohydrate in cereals, potatoes, legumes, and other vegetables. The two main constituents are amylose (15–20%), which has a non-branching helical structure; and amylopectin (80–85%), which consists of branched chains composed of 24–30 glucose residues united by 1 → 4 linkages in the chains and by 1 → 6 linkages at the branch points.



Amylose



Amylopectin

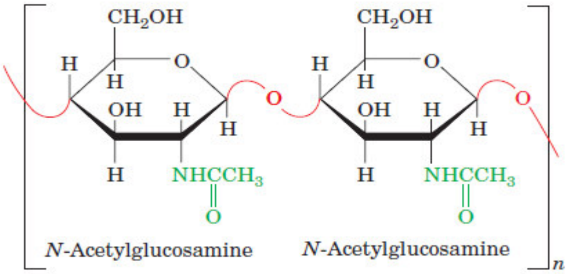
Glycogen is the storage polysaccharide in animals. It is a more highly branched structure than amylopectin, with chains of 12–14 α-D-glucopyranose residues [α1 → 4]-glycosidic linkage, with branching by means of (α1 →6)-glycosidic bonds.

Inulin is a polysaccharide of fructose (and hence a fructosan) found in tubers and roots of dahlias, artichokes, and dandelions. It is readily soluble in water and is used to determine the glomerular filtration rate.

Dextrins are intermediates in the hydrolysis of starch.

Cellulose is the chief constituent of the framework of plants. It is insoluble and consists of β-D-glucopyranose units linked by β(1 → 4) bonds to form long, straight chains strengthened by cross-linked hydrogen bonds. Cellulose cannot be digested by mammals because of the absence of an enzyme that hydrolyzes the β linkage. It is an important source of "bulk" in the diet. Microorganisms in the gut of ruminants and other herbivores can hydrolyze the β linkage.

Chitin is a structural polysaccharide in the exoskeleton of crustaceans and insects and also in mushrooms. It consists of *N*-acetyl-D-glucosamine units joined by β (1 →4)-glycosidic linkages.



Chitin is (β1→ 4)-linked homopolymer of *N*-acetyl-D-glucosamine

Heteropolysaccharides

Glycosaminoglycans (mucopolysaccharides) are complex carbohydrates characterized by their content of amino sugars and uronic acids. When these chains are attached to a protein molecule, the result is a proteoglycan. Proteoglycans provide the ground or packing substance of connective tissues. Their property of holding large quantities of water and occupying space, thus cushioning or lubricating other structures, is due to the large number of -OH groups and negative charges on the molecules, which, by repulsion, keep the carbohydrate chains apart. Examples are hyaluronic acid, chondroitin sulfate, and heparin.

Hyaluronic acid is an important GAG component of ground substance, synovial fluid (the fluid that lubricates the joints), and the vitreous humor of the eye. Hyaluronic acid molecules are composed of 250 to 25,000 β (1→ 4)-linked disaccharide units that consist of D-glucuronic acid and *N*-acetyl-Dglucosamine linked by a β(1→3) bond.

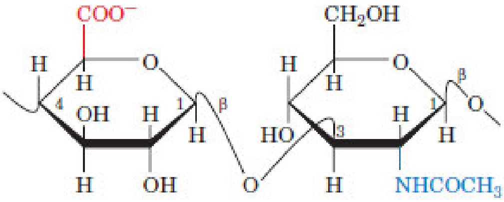
Chondroitin-4-sulfate (Greek: *chondros,* cartilage), a major component of cartilage and other connective tissue, has *N*-acetyl-D-galactosamine-4-sulfate residues in place of hyaluronate's *N*-acetyl-D-glucosamine residues.

Chondroitin-6-sulfate is instead sulfated at the C6 position of its *N*-acetyl-D-galactosamine residues. The two chondroitin sulfates occur separately or in mixtures depending on the tissue.

Dermatan sulfate (Greek: *derma,* skin), which is so named because of its prevalence in skin, differs from chondroitin- 4-sulfate only by an inversion of configuration about C5 of the β-D-glucuronate residues to form α-L-iduronate. This results from the enzymatic epimerization of these residues after the formation of chondroitin. The epimerization is usually incomplete, so dermatan sulfate also contains glucuronate residues.

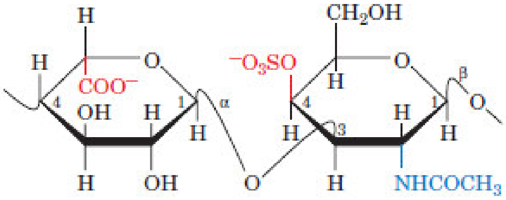
Keratan sulfate (Greek: *keras,* horn; not to be confused with the protein keratin) consists mainly of alternating β(1 →4)-linked D-galactose and *N*-acetyl-D-glucosamine-6- sulfate residues (and hence lacks uronic acid residues). It is a component of cartilage, bone, cornea, as well as hair, nails, and horn. Keratan sulfate is the most heterogeneous of the major GAGs in that its sulfate content is variable and it contains small amounts of fucose, mannose, *N*-acetylglucosamine, and sialic acid.

Heparin is a variably sulfated GAG that consists predominantly of alternating α-(1 → 4)-linked residues of L-iduronate- 2-sulfate and *N*-sulfo-D-glucosamine-6-sulfate. It has an average of 2.5 sulfate residues per disaccharide unit, which makes it the most negatively charged polyelectrolyte in mammalian tissues.



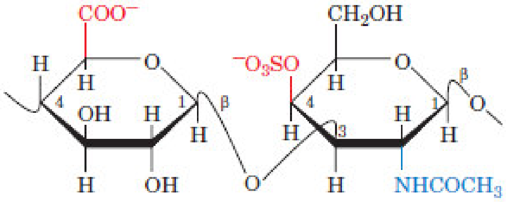
D-Glucuronate N-Acetyl-D-glucosamine

Hyaluronate



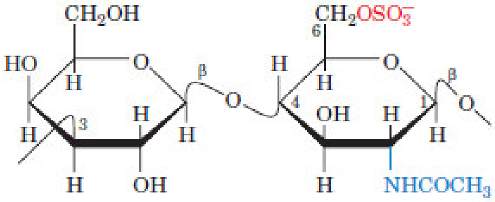
L-Iduronate N-Acetyl-D-galactosamine-4-sulfate

Dermatan sulfate



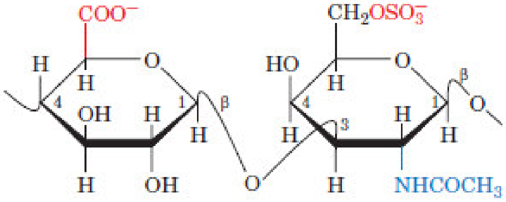
D-Glucuronate N-Acetyl-D-galactosamine-4-sulfate

Chondroitin-4-sulfate



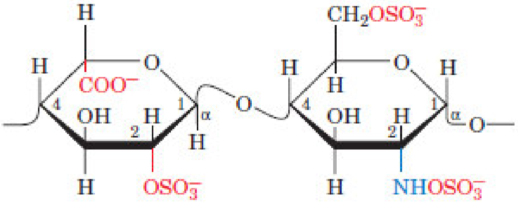
D-Galactose N-Acetyl-D-glucosamine-6-sulfate

Keratan sulfate



D-Glucuronate N-Acetyl-D-galactosamine-6-sulfate

Chondroitin-6-sulfate



L-Iduronate-2-sulfate N-Sulfo-D-glucosamine-6-sulfate

Heparin