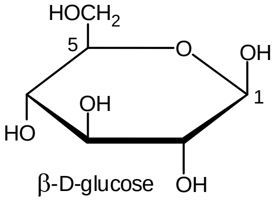
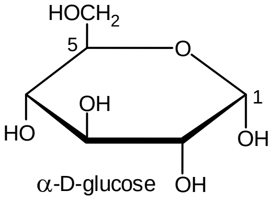
# № 42. DISACCHARIDES – TYPES, PROPERTIES, REPRESENTATIVES.

**I. Characteristics and structural types**. Disaccharides are carbohydrates whose molecules may be presented as originating from condensation of **two monosaccharides** (identical or different) by removing one molecule of water. The monosaccharide units in a disaccharide may be identical, as in maltose, or may be different, as in lactose and saccharose. When more monosaccharide units are connected to each other, polysaccharides are obtained. Thus, knowledge of disaccharides' structure and properties provides a bridge to understanding polysaccharides' structure and function. Polysaccharides may be the most diverse biomolecules in Nature. This fact comes from the possible variations when connecting two monosaccharides. For instance, from one six-carbon hexopyranose sugar, such as glucose, is possible to make 11 different disaccharides and 8 of those lead to infinite polymers, depending on the link position. In contrast, from one amino acid or nucleotide is possible to obtain only a single dimer A-A.



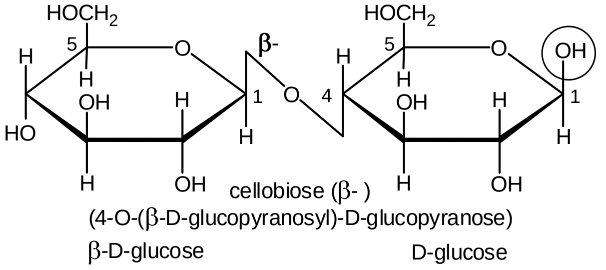


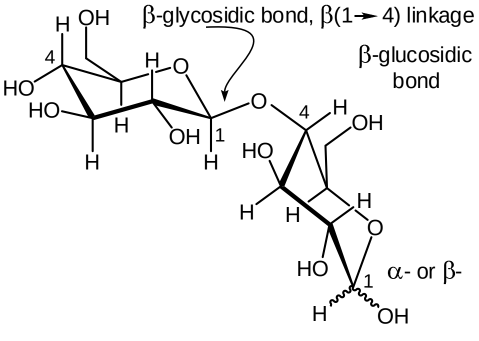
Disaccharides are carbohydrates that yield two monosaccharide molecules on hydrolysis. Structurally, **disaccharides are glycosides in which the alkoxy group attached to the anomeric carbon is derived from a second sugar molecule**. In principle, the glycosidic bond might be between the anomeric carbon of one sugar and a hydroxyl group at any position of the other sugar. In naturally occurring disaccharides, however, there are three major types of glycosidic linkages:

- 1,4'-link (the anomeric carbon C-1 is bonded to oxygen on C-4 of the second sugar, indicated with ');
- 1,6'-link (the anomeric C-1 carbon is connected to C-6 of the second sugar);
- 1,1'- or 1,2'-link (the anomeric carbon of one sugar unit is bonded through oxygen to the anomeric carbon of the second sugar unit).

**II. Representative examples of the 1,4-linkage in cellobiose, maltose, and lactose**. The most common glycosidic linkage in disaccharides is 1,4.

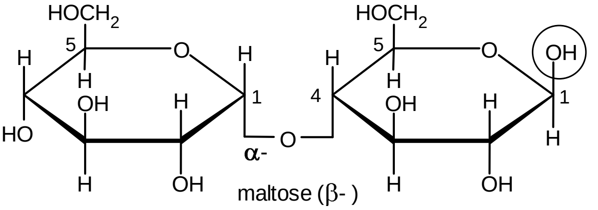
**Cellobiose.** This disaccharide is obtained by partial hydrolysis of cellulose. Cellobiose contains two glucose monosaccharide units where the anomeric carbon of one glucose is connected through an equatorial C–O glycosidic bond to C-4 of the second glucose unit. The stereochemistry and points of connection are designated by β(1,4). Such linkage is called **β(1,4)-glycosidic linkage**. The letters α and β designate the stereochemistry at the anomeric position while the numerals specify the ring carbons that are connected.





The conformational structure clearly shows that both connecting bonds at C-1 and C-4' are equatorial; the equatorial former β-OH of one glucose is connected to equatorial C-4' former OH of the second glucose. The complete systematic name for cellobiose, 4-O-(β-D-glucopyranosyl)-D-glucopyranose, indicate that the left-hand six-membered ring is the substituent at β anomeric position in the right-hand ring at C-4. The left-hand ring is an acetal (C-1 is bonded to two oxygens) whereas the ring on the right – in hemiacetal. The configuration at the free anomeric center is variable and may be either α or β. The wavy lines mean that the stereochemistry of this OH group is undefined. Because cellobiose has this glucose unit in the hemiacetal form, and therefore in equilibrium with its open-chain, aldehyde form, cellobiose is a reducing sugar (through an open form). **Cellobiose and maltose** are closely related – they **are diastereomers at C-1**.

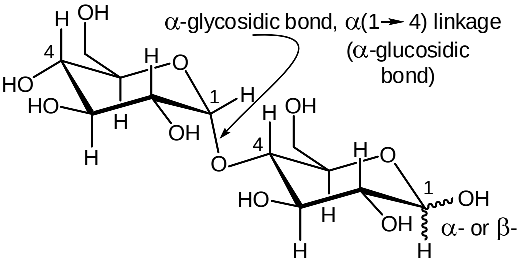
**Maltose**. Maltose is a disaccharide obtained by the hydrolysis of starch. Maltose possesses also two glucose monosaccharide units and 1,4-glycosidic bond but it is an **α(1,4)-linkage**. The difference between cellobiose and maltose is in the configuration of the anomeric acetal carbon. It is α in maltose, i.e. maltose is an α-glycoside. Like cellobiose, maltose has also a free anomeric hydroxyl group that is not involved in in a glycoside bond. Due to this OH in hemiacetal (at C-1′) which equilibrates with open-chain aldehyde form, maltose also is a reducing sugar and gives positive Tollens and Fehling tests. Two stereoisomeric forms are possible for this OH, and they have been indeed isolated; one has its anomeric hydroxyl group in an equatorial orientation (β-), while the other has an axial anomeric hydroxyl (α-).



maltose (β- )

(4-O-(α-D-glucopyranosyl)-D-glucopyranose)

α-D-glucose D-glucose



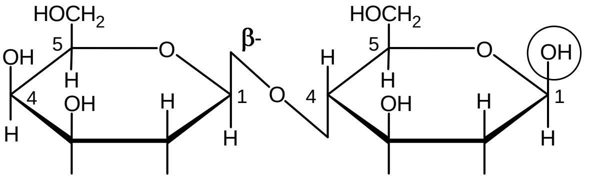
No matter how seemingly small the difference between maltose and cellobiose is, they differ in structure, and therefore in properties. One notable difference is their behavior toward enzyme-catalyzed hydrolysis. Enzymes that break glycosidic bonds (glycoside hydrolases) typically can act either on α- or on β-glycosidic bonds, but not on both. An enzyme known as *maltase* catalyses the hydrolytic cleavage of the α-glycosidic bond of maltose but is without effect in promoting the hydrolysis of the β-glycosidic bond of cellobiose. A different enzyme produces the opposite result. It catalyses the hydrolysis of cellobiose but not of maltose. A group of enzymes are specific for hydrolysis of α-glycosidic bond, whereas other group specializes in hydrolysis of β-glycosidic bond. The specificity of such enzymes can be used in structure determination in that it allows assignment of the stereochemistry of glycosidic linkages.

Humans can not assimilate cellobiose and, correspondingly – cellulose, because they lack digestive enzyme that can cleave the β-glycosidic bond in cellobiose.

- The 1,4′-β-D-glucopyranosyl linkage in cellobiose is not attacked by any digestive enzyme
- The 1,4′-α-D-glucopyranosyl linkage in maltose is a substrate for digestive enzymes and cleaves to give glucose. Therefore maltose has nutritional value.

The enzymes that can hydrolyse β-glucosidic bond – beta-glucosidases are found in some fungi, bacteria, termites that can consume cellulose. Cows and sheep assimilate cellulose due to symbiotic anaerobic bacteria in the flora of the gut wall, and these bacteria produce enzymes to break down cellulose.

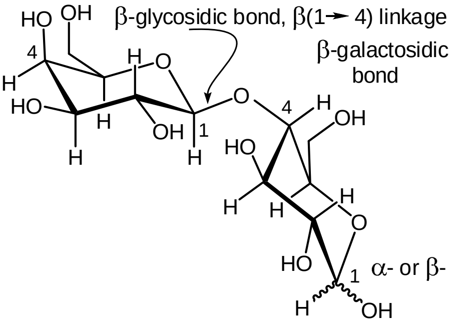
**Lactose** is a disaccharide in which C-1 of D-galactose and C-4 of D-glucose are linked by a **β(1,4)-glycosidic bond**. Lactose is found in amounts 2-6% in milk and is known as “milk sugar”. The galactose ring as an acetal is linked by a β-glycosidic bond to the position C-4 of the glucose ring. The latter has free anomeric OH group, therefore lactose is a reducing sugar.



lactose (β- )

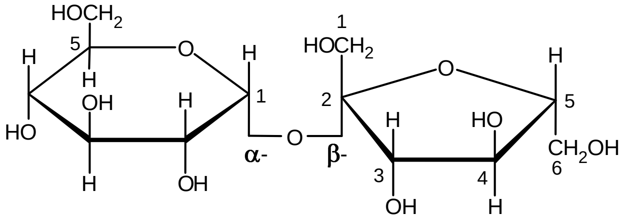
(4-O-(β-D-galactopyranosyl)-D-glucopyranose)

β-D-galactose D-glucose

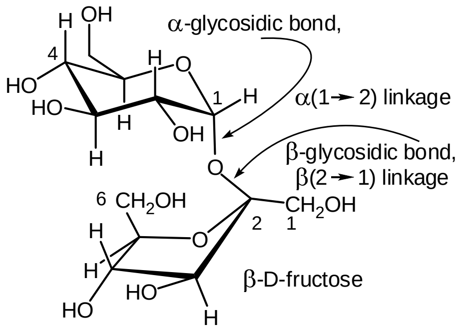


Digestion of lactose is facilitated by the β-glycosidase *lactase*. Some humans synthesize enough lactase, others do not. A deficiency of this enzyme makes it difficult to digest lactose and causes abdominal discomfort after milk consumption. Lactose intolerance (90% in some African and Asian countries) is usually caused by genetic inability to metabolize lactose. It is treated by restricting the amount of milk in the diet.

**III. The 1,2-linkage in sucrose**. The best known of all carbohydrates is probably **sucrose**, the common table sugar. Sucrose is a disaccharide in which D-glucose and D-fructose are joined at their anomeric carbons by a glycosidic bond. Because fructose is a ketose and its anomeric carbon is C-2, the linkage in sucrose is **α(1,2)-glycosidic bond**. The designator α- shows the axial location of the glycosidic bond with respect to the glucose ring whereas the glycosidic bond to the fructose anomeric carbon is β-.



sucrose (saccharose)
(β-D-fructofuranosyl-(2→1)-α-D-glucopyranoside)
α-D-glucose β-D-fructose



Both of the monosaccharide units of sucrose are present as acetals, or glycosides. Therefore, there is no free anomeric hydroxyl group. Neither ring can equilibrate with an open-chain aldehyde or ketone form which in this case is impossible. Therefore, sucrose is a non-reducing sugar and does not undergo mutarotation.

Sucrose is contained and obtained industrially from cane or sugar beets. After extraction and purification from these sourses, sucrose is offered on the market and used in various foods as sweetener. Sucrose is hydrolyzed by enzymes called invertases found in honeybees and in yeasts. The result of this enzyme-catalyzed hydrolysis is a mixture of glucose + fructose. The mixture is known as “inverted sugar syrup” because the rotation value $[a]_D$ inverts from (+) to (–). Honey is supersaturated invert sugar; mixture of fructose and glucose. In contrast, the cheaper high-fructose corn syrup is sweetener obtained by enzymatic isomerization of glucose into fructose.

The molecules of disaccharides consist of two monosaccharide residues. Trisaccharides contain three monosaccharide residues, and oligosaccharides are formed by bonding of several sugar residues. Quite interesting properties are known for some cyclic hexa-, hepta, and octa-glucosides. They are named α-, β-, γ-cyclodextrins, respectively.

Polysaccharides are carbohydrates that contain many monosaccharide units joined by glycosidic bonds.