INTRODUCTION: -Carbohydrates are the most abundant biomolecules on earth. Oxidation of carbohydrates is the central energy-yielding pathway in most non-photosynthetic cells. carbohydrates have the empirical formula (CH2O) they are the most abundant organic molecules in nature and are also referred to as "saccharides". The carbohydrates which are soluble in water and sweet in taste are called "sugars".

Definition: Carbohydrates are polyhydroxy aldehydes or ketones, or substances that yield such compounds on hydrolysis. A carbohydrate is a large biological molecule, consisting only of carbon (C), hydrogen (H), and oxygen (O), usually with a hydrogen: oxygen atom ratio of 2:1. Carbohydrates are technically hydrates of carbon, structurally it is more accurate to view them as polyhydroxy aldehydes and ketones.

Biological Importance: -

- Carbohydrates are chief energy source, in many animals, they are instant source of energy. Glucose is broken down by glycolysis/ kreb's cycle to yield ATP.
- Glucose is the source of storage of energy. It is stored as glycogen in animals and starch in plants.
- Stored carbohydrates act as energy source instead of proteins.
- Carbohydrates are intermediates in biosynthesis of fats and proteins.
- Carbohydrates aid in regulation of nerve tissue and is the energy source for brain.
- Carbohydrates gets associated with lipids and proteins to form surface antigens, receptor molecules, vitamins and antibiotics.
- They form structural and protective components, like in cell wall of plants and microorganisms.
- In animals they are important constituent of connective tissues. They participate in biological transport, cell-cell communication and activation of growth factors.
- Carbohydrates that are rich in fibre content help to prevent constipation. Also, they help in modulation of immune system.

Sources of carbohydrates: -

1) Grain Products Grain products are the leading source of carbohydrates in the diet. Grains naturally contain high concentrations of starch.
2) Starchy Vegetables and Beans and starchy vegetables, such as potatoes, yams, green peas, and corn, contain high levels of complex carbohydrates that our body digests into sugars.

3) Fruits All fruit and fruit juices contain carbohydrates in the form of natural sugars, such as glucose and fructose.
4) Dairy milk is the only significant source of dietary carbohydrates not derived from plants.
5) Sweets and added Sugars Eating candy and desserts markedly boosts the number of carbohydrates in our diet.

Classification of carbohydrates: -

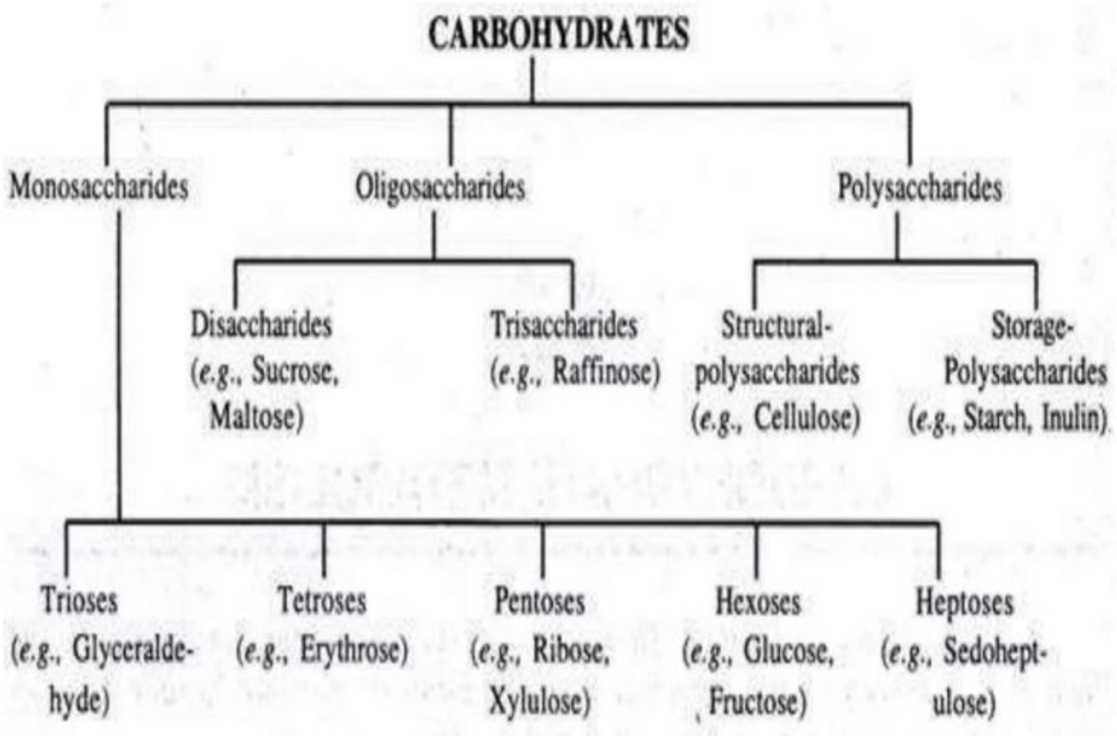


Fig. 13.1. Classification of the Carbohydrates

Monosaccharides: - The word "Monosaccharides" derived from the Greek word "Mono" means Single and "saccharide" means sugar. **Monosaccharides are polyhydroxy aldehydes or ketones which cannot be further hydrolysed to simple sugar**. Monosaccharides are simple sugars. They are sweet in taste. They are soluble in water. They contain 3 to 10 carbon atoms, 2 or more hydroxyl (OH) groups and one aldehyde (CHO) or one ketone (CO) group. The simplest group of carbohydrates and often called simple sugars since they cannot be further hydrolysed.

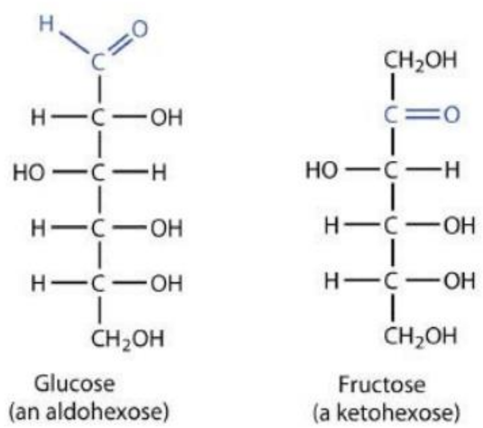
Monosaccharides are Colourless, crystalline solids that are soluble in water and insoluble in a non-polar solvent. The general formula is $C_n(H2O)_n$or $C_nH_{2n}O_n$.

They are classified according to the number of carbon atoms they contain and also on the basis of the functional group present. **Examples: Glucose, Fructose, Erythrulose, Ribulose**. Monosaccharides are classified in two ways. (a) First of all, based on the number of carbon atoms present in them. Depending on the number of carbon atoms monosaccharides are named as triose (C3), tetrose (C4), pentose (C5), hexose (C6), heptose (C7).

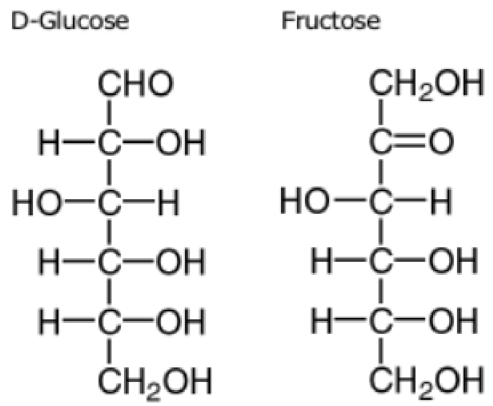
Classification by Carbon Atoms

Sugar	Structure formula	Aldoses	Ketoses
Triose	$C_3H_6O_3$	Glyceraldehydes	Dehydroxy acetone
Tetroses	$C_4H_8O_4$	Erythrose, Threose	Erthrulose
Pentoses	$C_5H_{10}O_5$	Xylose Ribose Arabinose	Ribulose
Hexoses	$C_6H_{12}O_6$	Glucose Galactose Mannose	Fructose

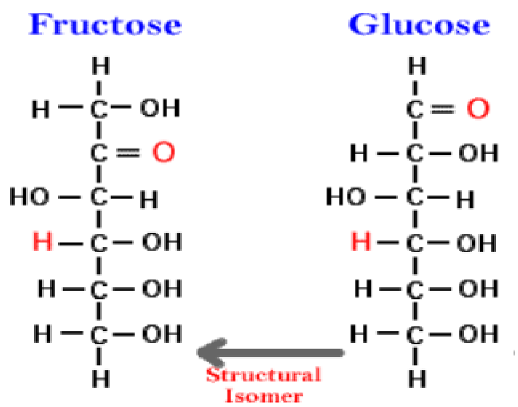
(b) **secondly based on the presence of functional group**. Those monosaccharides that contain an aldehyde functional group are called aldoses; those containing a ketone functional group on the second carbon atom are ketoses.



ISOMERISM OF MONOSACCHARIDES: -Isomerism is the phenomenon in which more than one compounds have the same chemical formula but different chemical structures. Chemical compounds that have identical chemical formulae but differ in properties and the arrangement of atoms in the molecule are called **isomers**. Therefore, the compounds that exhibit isomerism are known as isomers. The word "isomer" is derived from the Greek words "isos" and "meros", which mean "equal parts". This term was coined by the Swedish chemist Jacob Berzelius in the year 1830.As an example both glucose and fructose are hexoses ($C_6H_{12}O_6$) but they have different chemical and physical properties. These types of compounds are called isomers.

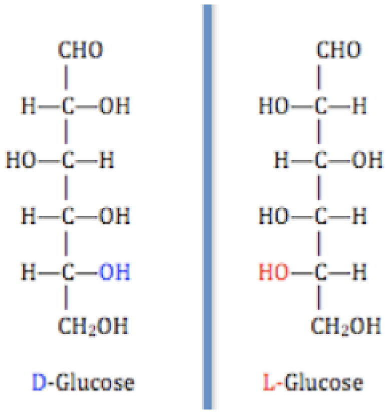


Structural isomers: -They have same molecular formula but different in the position of functional group. Glucose has the functional group on the first carbon atom whereas the fructose has the functional group on the second carbon atom.

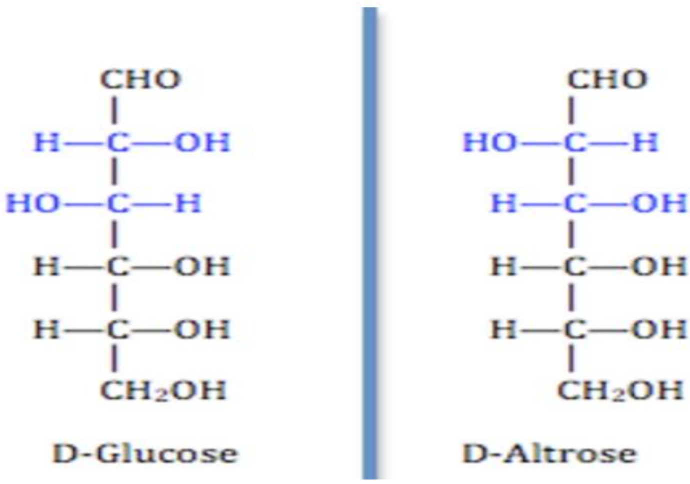


Stereoisomers: -Stereoisomers have the same molecular formula and chemical bonds but they have different spatial arrangements. Stereoisomers can be subdivided into two parts that are. **1. Enantiomers 2. Diastereomers**

1. Enantiomers: Two carbohydrates are said to be **enantiomers** if they are nonsuperimposable mirror images of one another. It is also known as inversional isomerism. Eg:-D-glucose-glucose are examples of enantiomers, in D-glucose OH is present on right hand side whereas in L-glucose the OH group is present on the right-hand side.



2. Diastereomers: -These do not mirror images of each other. These are also known as geometrical isomers. These isomers are non-identical, do not show mirror images, and hence are non-superimposable on-mirror images. Diastereomers show similar, but not identical chemical properties. Examples D-glucose and D-altrose have the same number and type of atoms. The difference is in their arrangement. They are diastereomers because they are not identical, and also do not show mirror images of each other. As it is apparent from the image, the difference is in the first two carbon atoms in the skeletal structure (highlighted in blue). This also makes them non-superimposable,



3) Optical isomerism: -

'When a beam of plane -polarized light is passed through a solution of an optical isomer, it will be rotated either to the right-or left in accordance to the type of compound and it is called optical activity.

A compound which causes rotation of plane polarized light to the right is said to be dextrorotatory (+) isomer, and 'd' is used to designate the fact. Rotation of the plane polarised light to the left is called levorotatory isomer and designated by a (-) sign and 'l' is used to designate to the fact. The naturally occurring form of fructose is the D (-) isomer. When equal amounts of D and L isomers are present, the resulting mixture has no optical activity, since the activities of each isomer cancel one another. Such a mixture is said to be a racemic or DL mixture. Two important monosaccharides whose isoforms are biologically active –L fucose and L iduronic acid.

Example: -Glucose is dextrorotatory while fructose is levorotatory. Glucose also called dextrose & fructose also called laevulose because of optical activity.

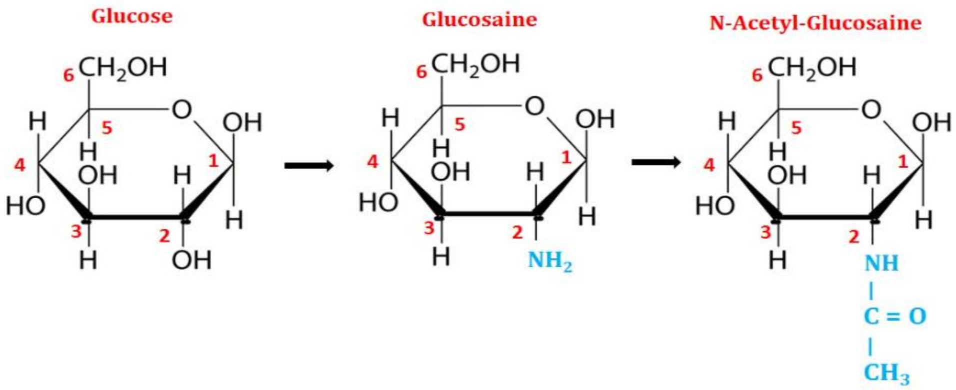
When equal amounts of d & l isomers are present, activity of each isomer will cancel one another. Such a mixture is called racemic mixture.

The carbohydrates can be structurally represented in any of the three forms:

1) Open chain structure.
2) Hemi-acetal structure.
3) Haworth structure.

Open chain structure – It is the long straight-chain form of carbohydrates.
Hemi-acetal structure – Here the 1st carbon of the glucose condenses with the -OH group of the 5th carbon to form a ring structure.
Haworth structure – It is the presence of the pyranose ring structure.

Amino sugars:-An amino sugar is a sugar molecule in which one of the hydroxyl groups is replaced by an amine group. The attached amino group is acetylate and named as N-acetyl. Example:-D-Glucosamine-Galacotosamine and D-Mannosamine.



Biological importance: -

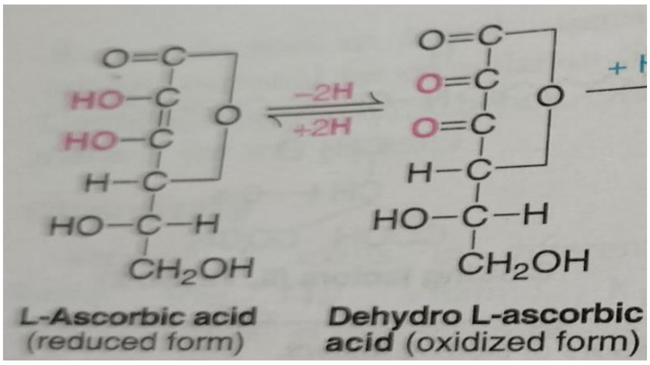
- Glucosamine is an essential component of glycoproteins found in joint synovial fluid and connective tissue.
- Glucosamine is used as drug or a nutraceutical. It has been approved for the treatment of osteoarthritis (OA).
- Glucosamine build tendons, ligaments and fluid joints surrounding the joints.
- Glucosamine is a important component of bacterial cell wall and is important in the repair of cartilage tissue.
- These sugars are the important component of chitin-a polysaccharide (important component of cell wall), heparin (clotting factor).

Vitamin C (ascorbic acid):-Ascorbic Acid belongs to the monosaccharide family and has a chemical formula $C_6H_8O_6$. Vitamin C is a key vitamin for animals and plants. Vitamin C is a water soluble versatile It plays an important role in human health and disease.

Many animals can synthesize ascorbic acid from glucose through uronic acid pathway. However, man, cannot synthesize ascorbic acid due to the deficiency of a single enzyme namely L-gulonolactone oxidase. It is a vitamin C and should be obtained in the diet as it cannot be produced by humans

Source: -Ascorbic Acid is found in leafy vegetables, potatoes, and tomatoes. It is present in citrus fruits, strawberries, broccoli, raw bell pepper, kiwifruit, brussels sprouts etc.

Chemistry: -Ascorbic acid is a hexose (6 carbon) derivative and closely resembles monosaccharides in structure). The acidic property of vitamin C is due to the enolic hydroxyl groups. It is a strong reducing agent. L-Ascorbic acid undergoes oxidation to form dehydroascorbic acid and this reaction is reversible.



Structure of vitamin-C

Recommended allowance (RDA): -About 60-70 mg meet the adult requirement.

Uses of Ascorbic Acid: -

- **Collagen formation**: Vitamin C plays the role of a coenzyme in hydroxylation of proline and lysine while protocollagen is converted to collagen (i.e. post-translational modification). The hydroxylation reaction is catalysed by lysyl hydroxylase (for lysine) and prolyl hydroxylase (for proline). This reaction is dependent on vitamin C, molecular oxygen and a-ketoglutarate
- **Bone formation**: Bone tissues possess an organic matrix, collagen and the inorganic calcium, phosphate etc. Vitamin C is required for bone formation.
- **Tryptophan metabolism**: Vitamin C is essential for the hydroxylation of tryptophan (enzyme-hydroxylase) to hydroxytryptophan in the synthesis of serotonin.
- Vitamin C is useful in the reconversion of methemoglobin to haemoglobin. The degradation of haemoglobin to bile pigments requires ascorbic acid.

- Vitamin Cused in the treatment of scurvy, It fights against bacterial infections
- Vitamin C acts as detoxifying reactions
- It is used in the treatment of stomach ulcers caused by Helicobacter pylori, prevention gallbladder disease

The deficiency of ascorbic acid results in scurvy. This disease is characterized by spongy and sore gums, loose teeth, anemia, swollen. joints, blood fragile vessels, decreased immunocompetence, delayed wound healing, sluggish hormonal function of adrenal cortex and gonads, haemorrhage, osteoporosis etc. Most of these symptoms are related to impairment in the synthesis of collagen and/or the antioxidant property of vitamin C.

Disaccharides/oligosaccharide: -Sugars that contain 2-10 monosaccharide units are called as oligosaccharides general formula for oligosaccharides is Cn+1(H2o)n.

Glycosidic linkage: -The linkage between two monosaccharide sugar is called glycosidic bond or linkage.

Depending on the number of monosaccharide units, oligosaccharide are classified as:-

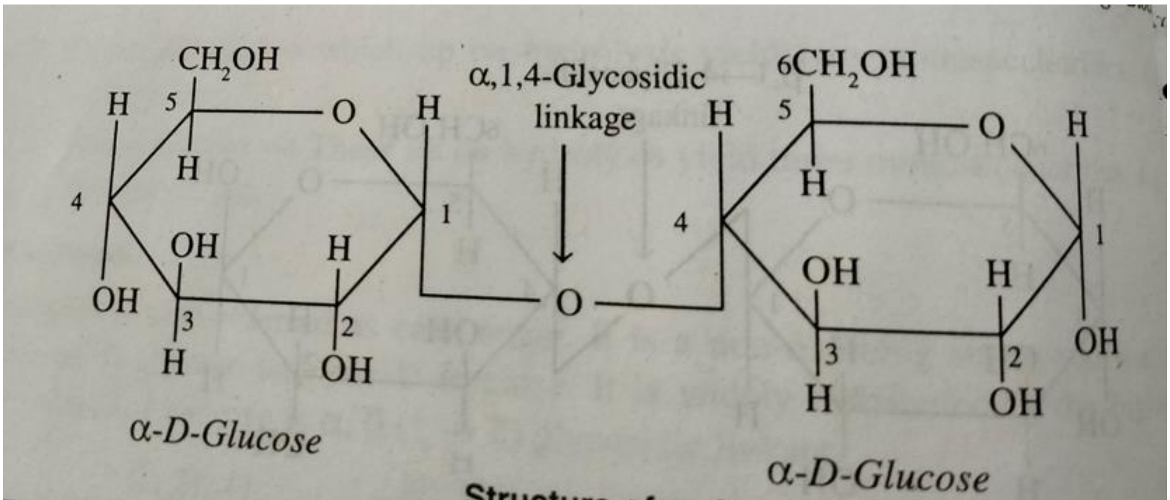
1) **Disaccharides: -Which upon hydrolysis yields two monosaccharides: Maltose, Sucrose, Lactose.**
2) **Trisaccharide: - Which upon hydrolysis yields three monosaccharides. Example:-Raffinose,Rhamnose.**

a) Maltose is a type of carbohydrate that is also called **maltobiose or malt sugar**. The chemical or molecular formula of maltose is $C_{12}H_{22}O_{11}$. It is a disaccharide formed from two units of alpha-D glucose that are linked by an alpha-1,4 glycosidic bond. It is composed of carbon, hydrogen, and oxygen atoms. It is a white crystalline, odourless, sweet-tasting powder. **Maltose is a reducing sugar and undergoes mutarotation**.

Maltose = glucose + glucose

Source: -It occurs naturally in germinating seeds and can also be prepared in the presence of the enzyme **diastase** by the hydrolysis of starch.

Structure of Maltose: -The chemical or molecular formula of maltose is $C_{12}H_{22}O_{11}$. It is a disaccharide formed from two units of alpha-D glucose that are linked by an alpha-1,4 glycosidic bond. Isomaltose is an isomer of maltose, where the two units of alpha-D glucose are linked by an alpha-1,6 glycosidic bond



Structure of maltose

Chemical Properties of Maltose: -

- Maltose is a reducing sugar because one of its glucose units has a free aldehyde group.
- On treating maltose with sulphuric acid, carbon dioxide, water, and sulfur dioxide are formed as the by-products.

  - $C_{12}H_{22}O_{11} + 24H_2SO_4 \rightarrow 12CO_2 + 35H_2O + 24SO_2$

  - Hydrolysis of maltose results in the production of ethanol and carbon dioxide.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 4C_2H_5OH + 4CO_2.$$

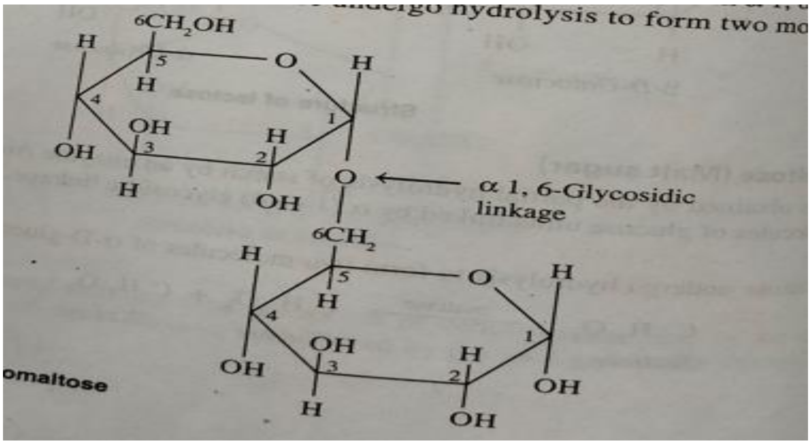
The hydrolysis reaction of maltose in the presence of the maltase enzyme gives two molecules – alpha D-glucose.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$$

Uses of Maltose

- As maltose is not as sweet as sucrose, it is not often used as a sweetener. But it is extensively used in the manufacturing of beer and the industrial production of alcohol.
- During the barley malting process, maltose is used to add sweetness to the beer.
- It is used as a bulking agent and diluent in bakeries, soft drinks, sweets, alcoholic beverages, and baby formula.
- The shelf life of food is increased by adding maltose.
- It provides energy for a variety of bodily functions, allowing us to carry out our day-to-day tasks.
- As maltose has similar compaction properties to lactose, it can be used as a substitute for lactose in the pharmaceutical industry.
- It is one of the nutrients that helps our body function effectively and allows us to carry out our day-to-day tasks. In humans, maltose is broken down into two glucose molecules by various maltase enzymes. They are broken down further to provide energy or stored as glycogen.

Isomaltose: -Molecular formula: C_12H_22O11.Isomaltose is a disaccharide formed by the two molecules of glucose, with a 1, 6 - linkage Isomaltose is a reducing sugar. When isomaltose undergo hydrolysis to form two molecules of glucose.



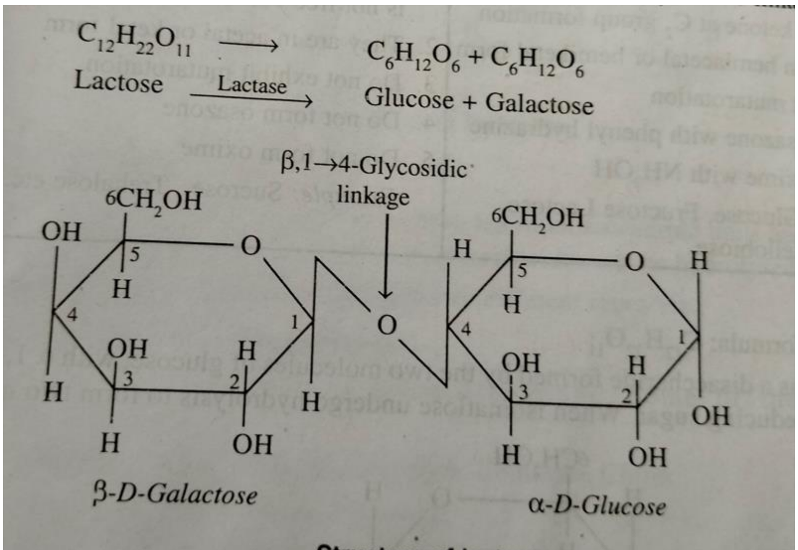
Structure of isomaltose

Biological importance: -

Isomaltose is a disaccharide comprised of glucose, which can be metabolized to produce chemical energy. Thus, isomaltose can serve as a source of energy. It may be obtained from the digestion of starch or food containing IMO or isomaltose. Most of the dietary isomaltose, though, is not obtained naturally.

Lactose: -Lactose is a type of carbohydrate that is also called milk sugar and lactobiose. It is a disaccharide that is synthesized from galactose and glucose subunits. The "lactase" enzyme breaks lactose into glucose and galactose when it is absorbed in the intestine.The molecular formula of lactose is $C_{12}H_{22}O_{11}$, i.e., it is composed of 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms. It is a white solid that has a mild sweet taste. Lactose is a reducing sugar

Lactose (milk sugar) = glucose + galactose



Structure of lactose

Chemical Properties of Lactose

- Lactose on hydrolysis with 2% H_2SO_4 yields 1 mole of D-glucose and 1 mole of D-galactose.
- ***$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6$ (glucose) + $C_6H_{12}O_6$ (galactose).***

- Polyhydric alcohol named lactitol is produced by the catalytic hydrogenation of lactose. Lactose undergoes hydrogenation in the presence of a Raney-Nickel catalyst, resulting in the formation of lactitol.

Uses of Lactose

- Lactose is used as a nutrient in preparing modified milk and is also added to infants' food to match the composition of human milk.
- It helps the body to absorb calcium and a variety of other minerals, like magnesium, copper, and zinc.
- Because of its physical and functional properties, lactose is added as an ingredient in pharmaceutical products like an excipient and diluent for tablets and capsules.
- It is used in the food industry as a flavouring agent.
- It is used in baked goods and also in fermentation for the production of cheese, yogurt, and sour milk.
- It is also used as a chromatographic adsorbent in analytical chemistry.

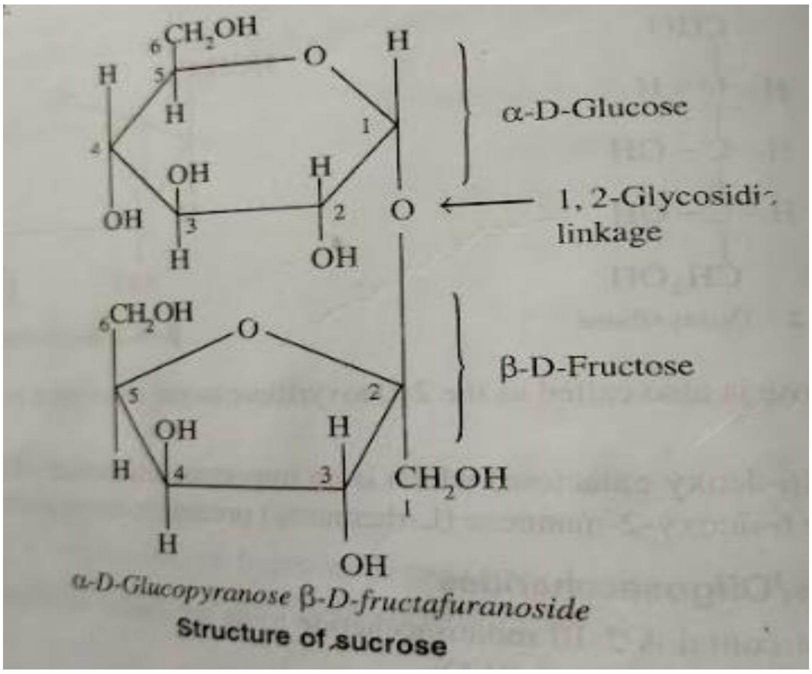
Sucrose] (table sugar) = glucose + fructose. Sucrose, commonly known as "table sugar" or "cane sugar", is a carbohydrate formed from the combination of glucose *and* fructose. **It is a non-reducing sugar.**

Chemical Properties of Sucrose

- Sucrose can undergo a combustion reaction to yield carbon dioxide and water.
- When reacted with chloric acid, this compound yields hydrochloric acid, carbon dioxide, and water.
- Upon hydrolysis, the glycosidic bond linking the two carbohydrates in a $C_{12}H_{22}O_{11}$ molecule is broken, yielding glucose and fructose.
- Sucrose can be dehydrated with the help of H_2SO_4 (which acts as a catalyst) to give rise to a black solid which is rich in carbon.

Uses of Sucrose

- Sucrose is one of the most important components of soft drinks and other beverages.
- This compound is used in many pharmaceutical products.
- It serves as a chemical intermediate for many emulsifying agents and detergents.
- It also serves as a food thickening agent and as a food stabilizer.
- The shelf lives of many food products, such as jams and jellies, are extended with the help of this compound.
- The use of sucrose in baking results in the brown colour of the baked products.
- This compound also serves as an antioxidant (a compound that inhibits oxidation).
- Sucrose is widely used as a food preservative.



α-D-Glucopyranose β-D-fructafuranoside
Structure of sucrose