

Carbohydrates1: Monosaccharide and Disaccharide

Carbohydrate



Carbohydrate Can Be Divided up Into 3 Groups



¶ Sugar
Glucose + Sucrose

· Starch

₍ Cellulose

Why do we need carbohydrate?



Carbohydrate

**Compounds contain C, H, O with
general formula of $C_m(H_2O)_n$**

All have C=O and -OH functional groups

Classified based on

Size of base carbon chain

Number of sugar unit

Location of C=O group

Stereochemistry

Types of Carbohydrates

Classification based on the number of sugar units in the total chain

Monosaccharides

Single sugar unit

Disaccharides

Two sugar units

Trisaccharides

Three sugar units

Oligosaccharides

up to 10/13/ sugar units

Polysaccharides

> 13 sugar units

Chaining relies on the glycosidic bonds

Why are they Important?

- Carbohydrates are important in cells as a usable energy source and important in human foods around the world.
- They are also important for storing energy and they form an important part of the cell wall in plants, fungi and bacteria.
- General names for carbohydrates include sugars, starches, saccharides, and polysaccharides.
- The term saccharide is derived from the Latin word " sacchararum" from the sweet taste of sugars and the name "carbohydrate" means a "hydrate of carbon."
- The name derives from the general formula of carbohydrate is $C_x(H_2O)_y - x$ and y may or may not be equal and range in value from 3 to 12 or more.
 - **For example glucose is: $C_6(H_2O)_6$ or is more commonly written, $C_6H_{12}O_6$**

Where do they come from?

- Carbohydrates are formed in the plants by photosynthesis from carbon dioxide and water in the presence of sunlight



- Animals, on the other hand, can synthesize carbohydrates from lipids, glycerol and amino acids.
- They can also obtain carbohydrates from the plant kingdom by consuming plant based foods.

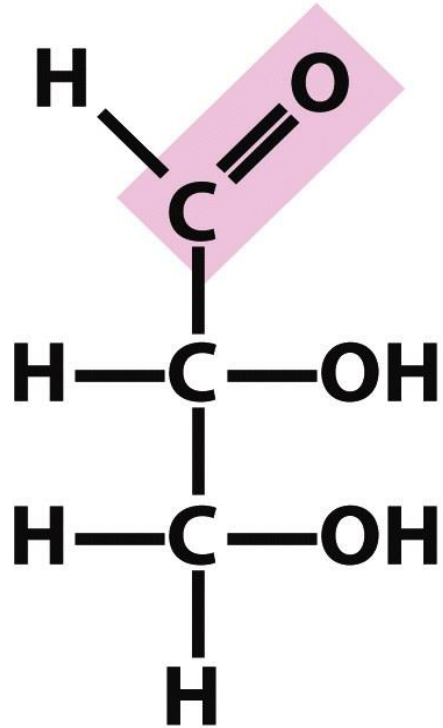
Monosaccharides

- What are Monosaccharides?
- The simplest form of carbohydrates is the monosaccharide. 'Mono' means 'one' and 'saccharide' means 'sugar'.
- They may be classified on the basis of the nature of carbonyl group.
- They can also be classified by the number of carbon atoms in the carbon chain.

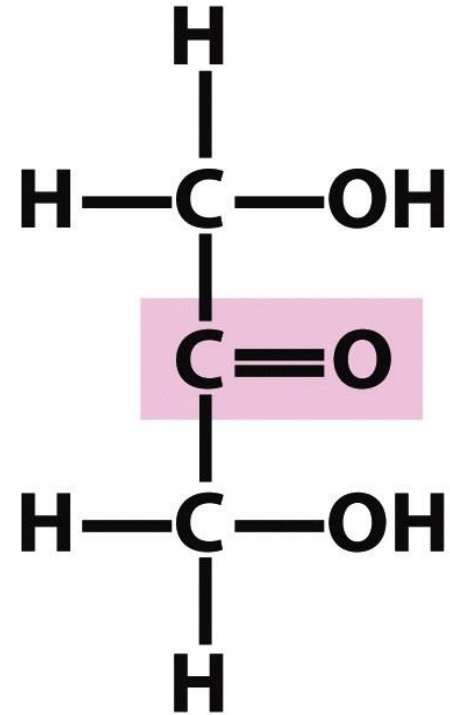
Structure of Monosaccharides

- All the monosaccharides have the formula as $(\text{CH}_2\text{O})_n$. Here, the two hydrogen atoms and one oxygen atom associate itself to the central carbon molecule.
- A hydroxyl group is formed when oxygen will bond with hydrogen.
- Several carbon molecules bond together because 4 bonds can form on carbon.
- One of the carbon will form a double bond with oxygen in the chain, which is termed as a **carbonyl group**.
- Depending upon its position, if it is formed at the end of the chain, then, the monosaccharides are said to belong to the **aldose family** and if it formed in the middle of the chain, then it belongs to the **ketose** family.

Representative monosaccharides. (a) Two trioses, an aldose and a ketose. The carbonyl group in each is shaded.



**Glyceraldehyde,
an aldotriose**



**Dihydroxyacetone,
a ketotriose**

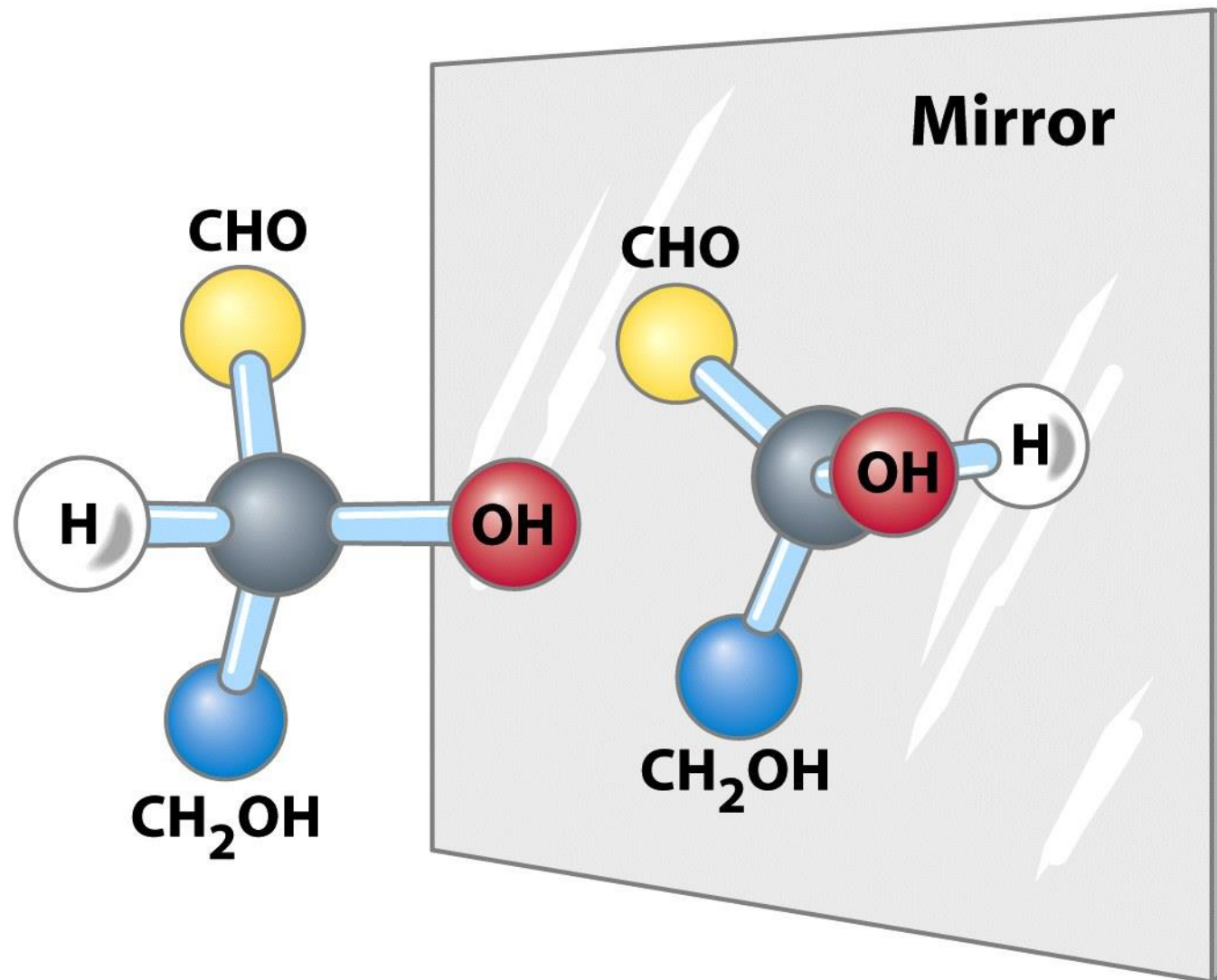
Structure of Monosaccharides

- The aldoses and ketoses are further divided based on the number of carbons present in their molecules, as trioses, tetroses, pentoses, hexoses etc. They are referred to as aldotrioses, aldotetroses, aldopentoses, aldohexoses, ketohexoses etc

Number of Carbons	General term	Aldehyde	Ketone
3	Triose	Aldotriose	Ketotriose
4	Tetrose	Aldotetrose	Ketotetrose
5	Pentose	Aldopentose	Ketopentose
6	Hexose	Aldohexose	Ketohexose
7	Heptose	Aldoheptose	Ketoheptose

Monosaccharides Have Asymmetric Centers

- All the monosaccharides except dihydroxyacetone contain one or more asymmetric (chiral) carbon atoms and thus occur in optically active isomeric forms.
- The simplest aldose, glyceraldehyde, contains one chiral center (the middle carbon atom) and therefore has two different optical isomers, or **enantiomers**.
- one of the two enantiomers is, by convention, designated the D isomer, the other the L isomer.
- As for other biomolecules with chiral centers, the absolute configurations of sugars are known from x-ray crystallography.

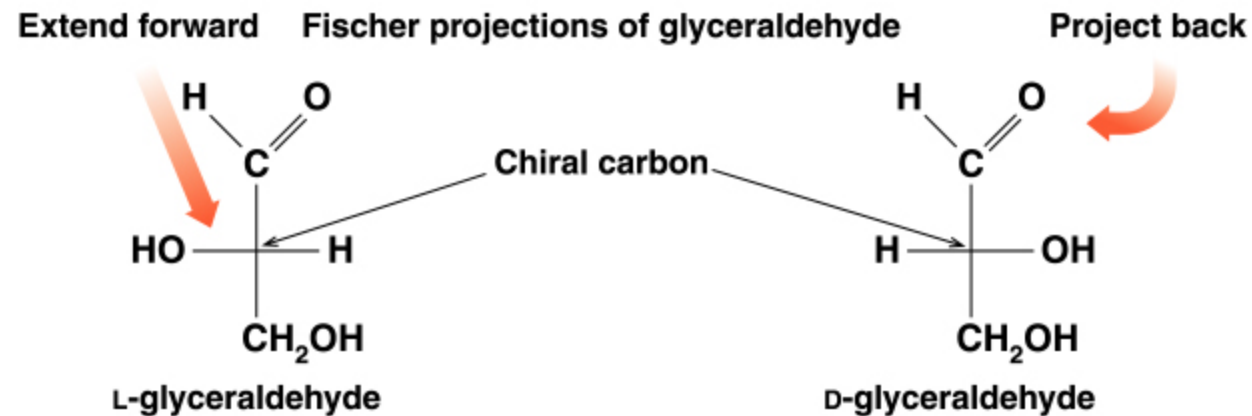


Ball-and-stick models

Figure 7-2 part 1
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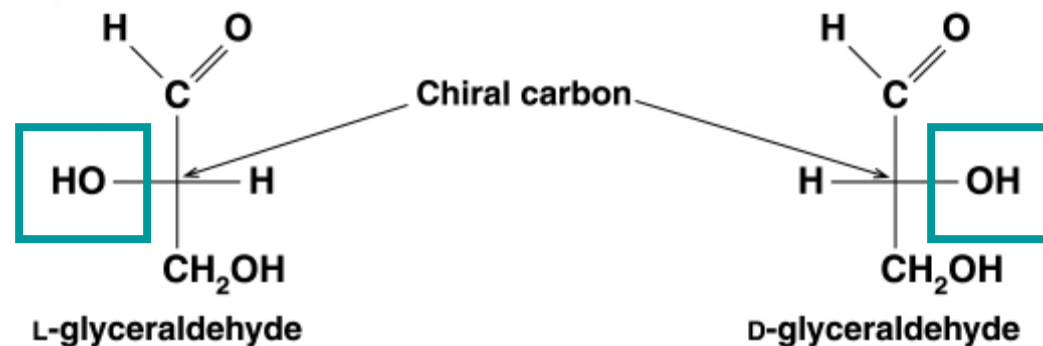
Fischer Projections

- Used to represent carbohydrates (chiral carbons)
- Places the most oxidized group at the top (C1)
- Uses horizontal lines for bonds that come forward
- Uses vertical lines for bonds that go back



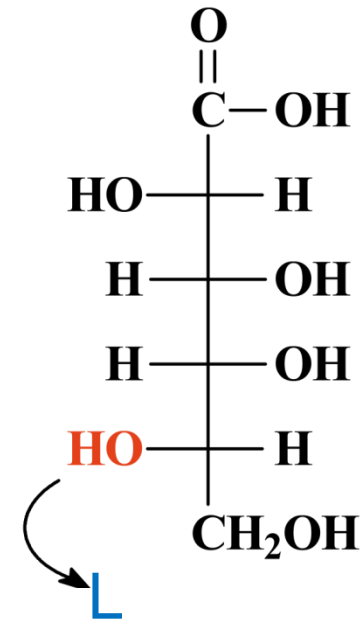
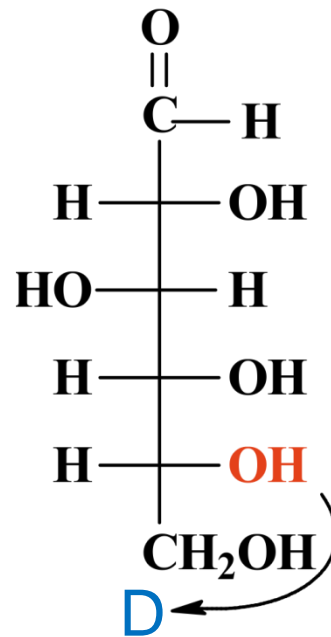
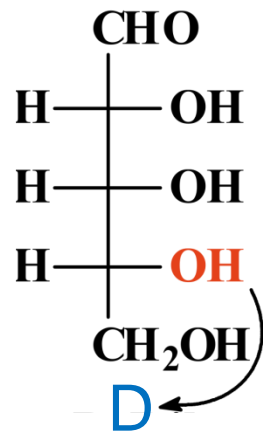
Structures: D and L Notations

- By convention, the letter **L** is assigned to the structure with the —OH on the left
- The letter **D** is assigned to the structure with —OH on the right



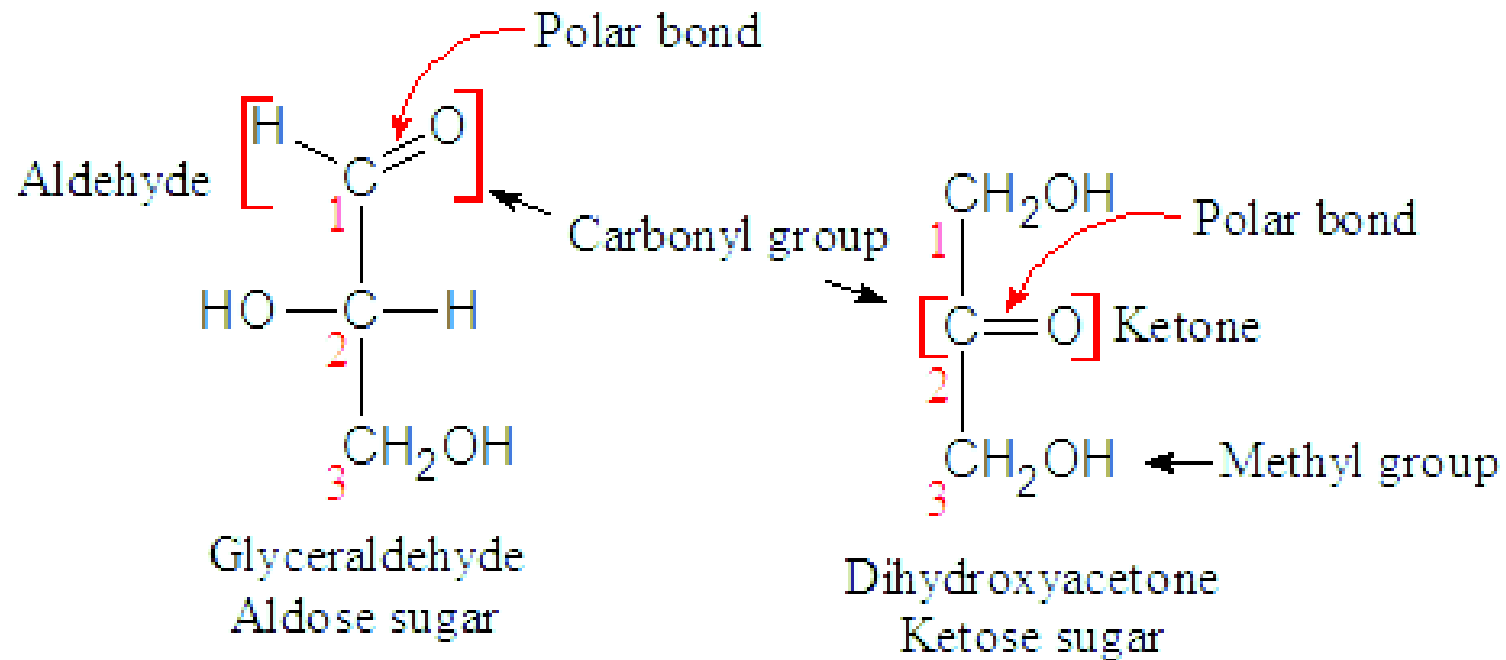
D and L Monosaccharides

- Stereochemistry determined by the asymmetric center farthest from the carbonyl group
- Most monosaccharides found in living organisms are D

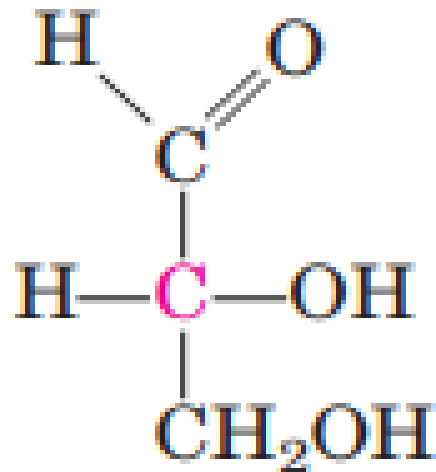


Triose sugars: These molecular structures have the general formula $C_3H_6O_3$

- The specific examples are **Glyceraldehyde** and **dihydroxyacetone**.
- These molecules form important intermediate molecules in the processes of respiration and photosynthesis.
- The two simplest monosaccharides are **glyceraldehyde** and **dihydroxyacetone** shown below

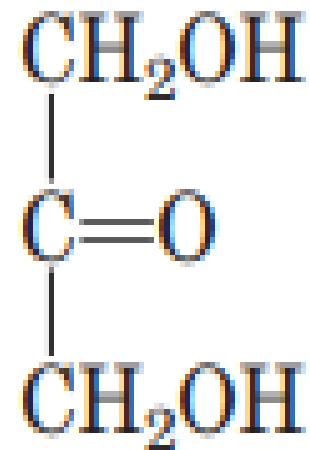


Three carbons

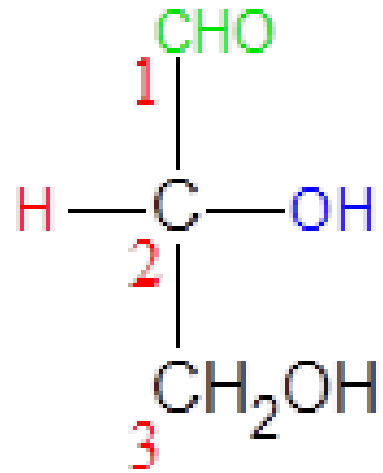


D-Glyceraldehyde

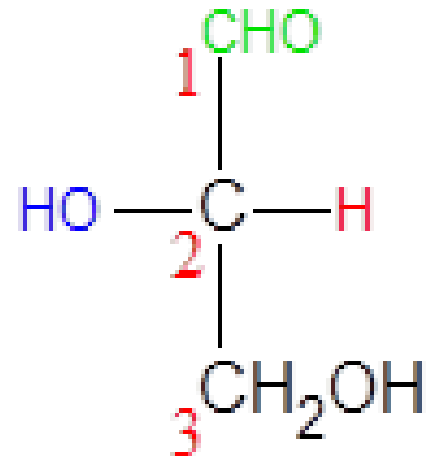
Three carbons



Dihydroxyacetone

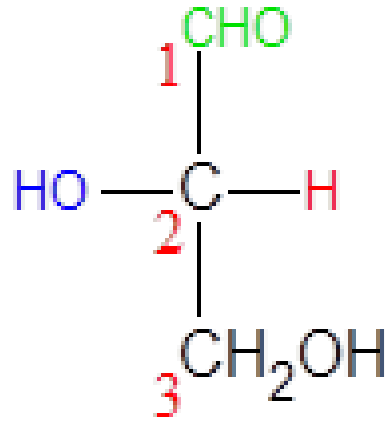
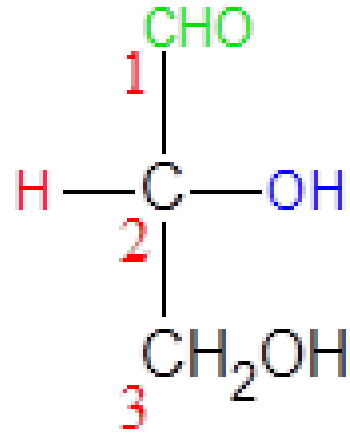


D (+)-Glyceraldehyde



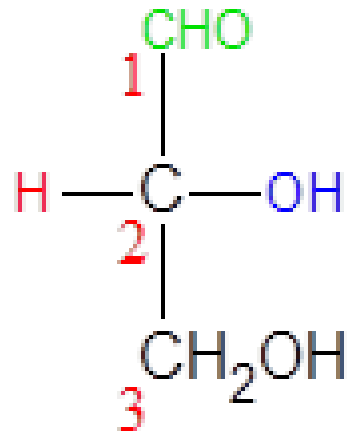
L (-)-Glyceraldehyde

- All carbon atoms except one have hydroxyl groups attached, which forms part of the functional group.
- The double bond in the aldehyde group of glyceraldehyde is polar making the aldehyde group the reactive site of the molecule.
- In the case of dihydroxyacetone the double bond in the ketone group is polar making that part of the molecule the reactive site.

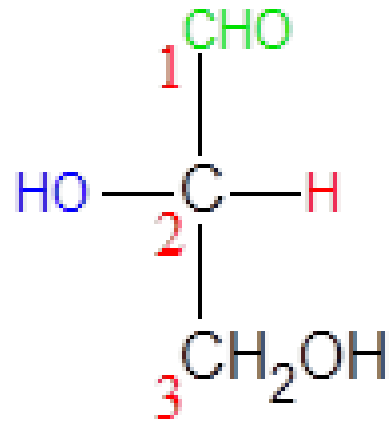


D (+)-Glyceraldehyde L (-)-Glyceraldehyde

- The central carbon C-2 is bonded to four different groups of atoms (-CHO, -OH, H, and -CH₂ OH) making it asymmetric.
- This means there are two possible arrangements of groups of atoms about C-2 in space, forming two optical isomers (mirror images) of the compound.
- Hence the position of the hydroxyl (-OH) group on the carbon C-2 determines whether glyceraldehyde is dextrose (D) or Laevulose (L).



D (+)-Glyceraldehyde



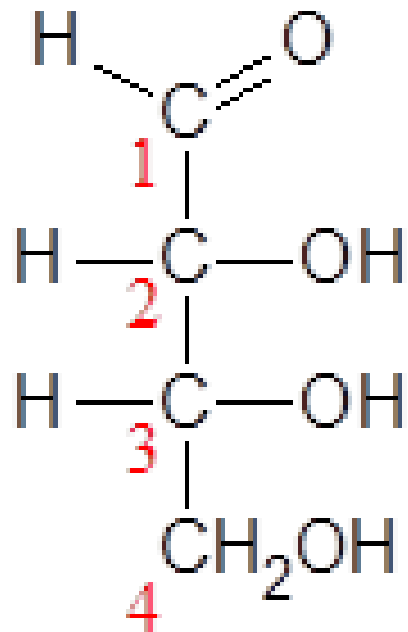
L (-)-Glyceraldehyde

- The number of atoms in both examples of molecules is the same.
- Therefore these are molecules with identical chemical formulae because they contain the **same number** and **kinds of atoms** ($\text{C}_3\text{H}_6\text{O}_3$) and yet they are **different molecules** because the atoms in each molecule are arranged differently.
- This is an example of **structural isomers** as was observed in **glyceraldehyde** and **dihydroxyacetone**
- This is another factor contributing to the diversity of life molecules

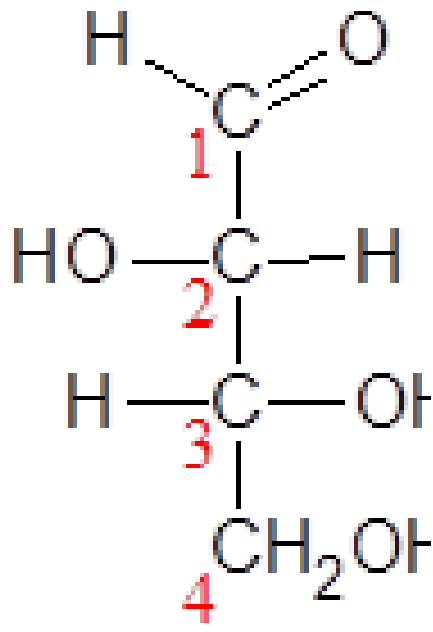
- In general, a molecule with n chiral centers can have 2^n stereoisomers.
- Glyceraldehyde has $2^1 = 2$; the aldohexoses, with four chiral centers, have $2^4 = 16$ stereoisomers.
- Of the 16 possible aldohexoses, eight are D forms and eight are L.
- Most of the hexoses of living organisms are D isomers.

Tetrose sugars: These molecules have the general formula $C_4H_8O_4$.

- These molecular structures are only important in the bacteria. Examples of tetroses are **Erythrose** and **Threose**



D-Erythrose

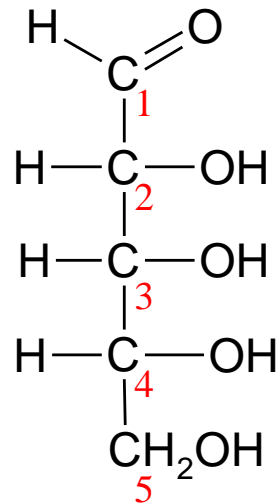


D-Threose

Pentose sugars: The formula for pentose sugars is $C_5H_{10}O_5$

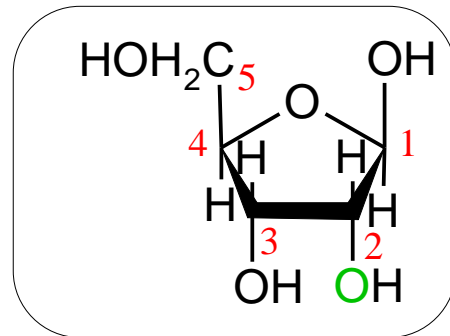
- These molecules are important as building units for the synthesis of **nucleic acids** and **coenzymes**. Examples include **ribose** and **deoxyribose**.

Fischer projection
(open chain)

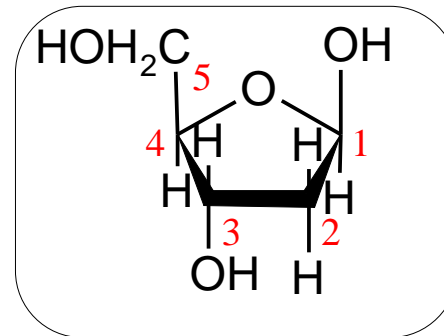


D-Ribose

Furanose projections
(ring forms)

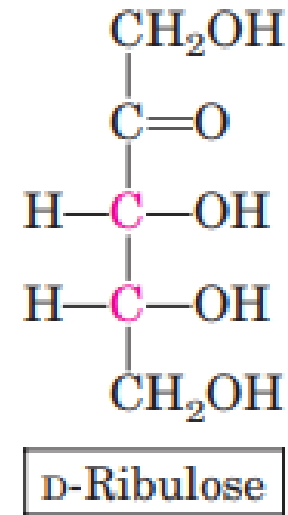


Ribose



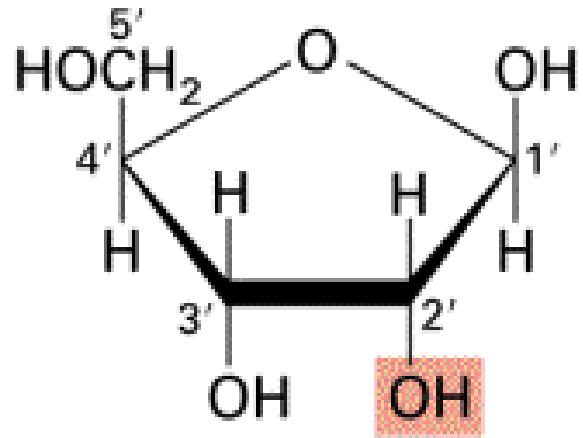
Deoxyribose

Oxygen at carbon C-2 of
Deoxyribose is absent.

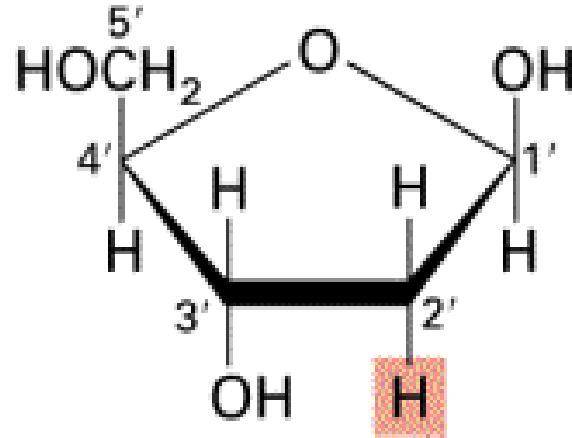


**Ribulose is an important
CO₂ acceptor during
photosynthesis**

Examples of open and ring forms of pentose sugars



Ribose



2-Deoxyribose

- These two molecules are identical with the only difference being that deoxyribose is an atom of oxygen less at carbon 2 of the molecule.
- Therefore deoxyribose sugar is an exception to the general formula for pentose sugars. Its empirical formula instead is $(C_5H_{10}O_4)$.
- It is the ribose sugar that is used in the synthesis of ribonucleic acid (RNA) whereas the deoxyribose is used for the synthesis of deoxyribonucleic acid (DNA).

Hexose sugars: These are molecules that have a general formula of $C_6H_{12}O_6$.

- They are important raw materials in the process of respiration.
- They are also important for the synthesis of disaccharides as well as polysaccharides.
- The most important hexose sugars are **glucose**, **fructose**, and **galactose**.
- They have a common formula, $C_6H_{12}O_6$, but differ in the spacial arrangement of atoms.
- The different structural arrangements cause the molecules to have different chemical characteristics.
- The most common sugar in cells is glucose. It is a hexose sugar, which means that it consists of a chain of six carbon atoms.
- Glucose has an aldehyde group at the first carbon.
- It also has five hydroxyl groups attached to other five carbon atoms.

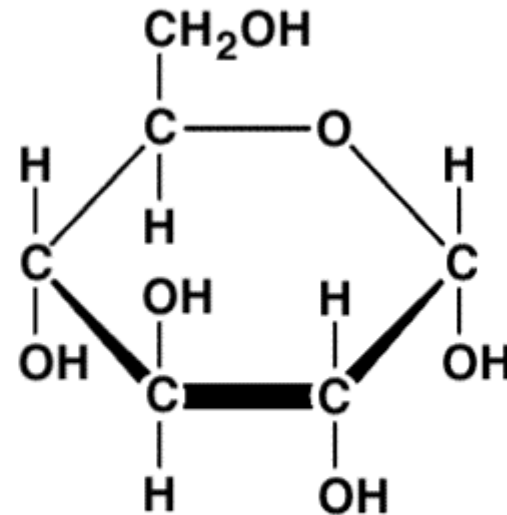
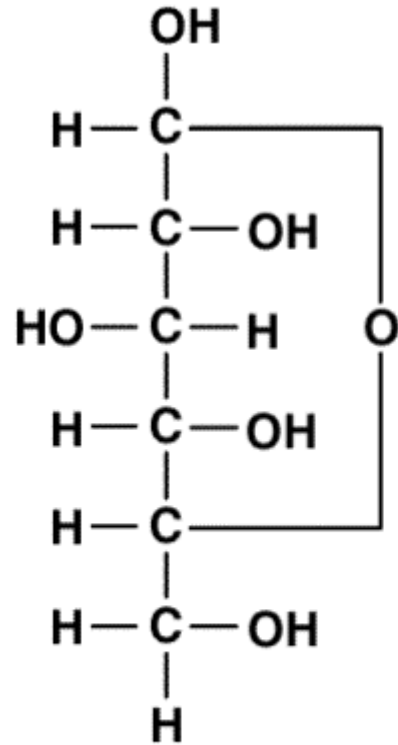
Examples of Monosaccharides

1. Glucose

- **Glucose molecules can be broken down by glycolysis in the process of cellular respiration.**
- **Glucose can be connected in long strings of monosaccharides to form polysaccharides. In plants, this thing is produced as [cellulose](#).**
- **In plants, each cell is surrounded by cellulose that helps plants stand tall and turgid.**

Where can we find Glucose?

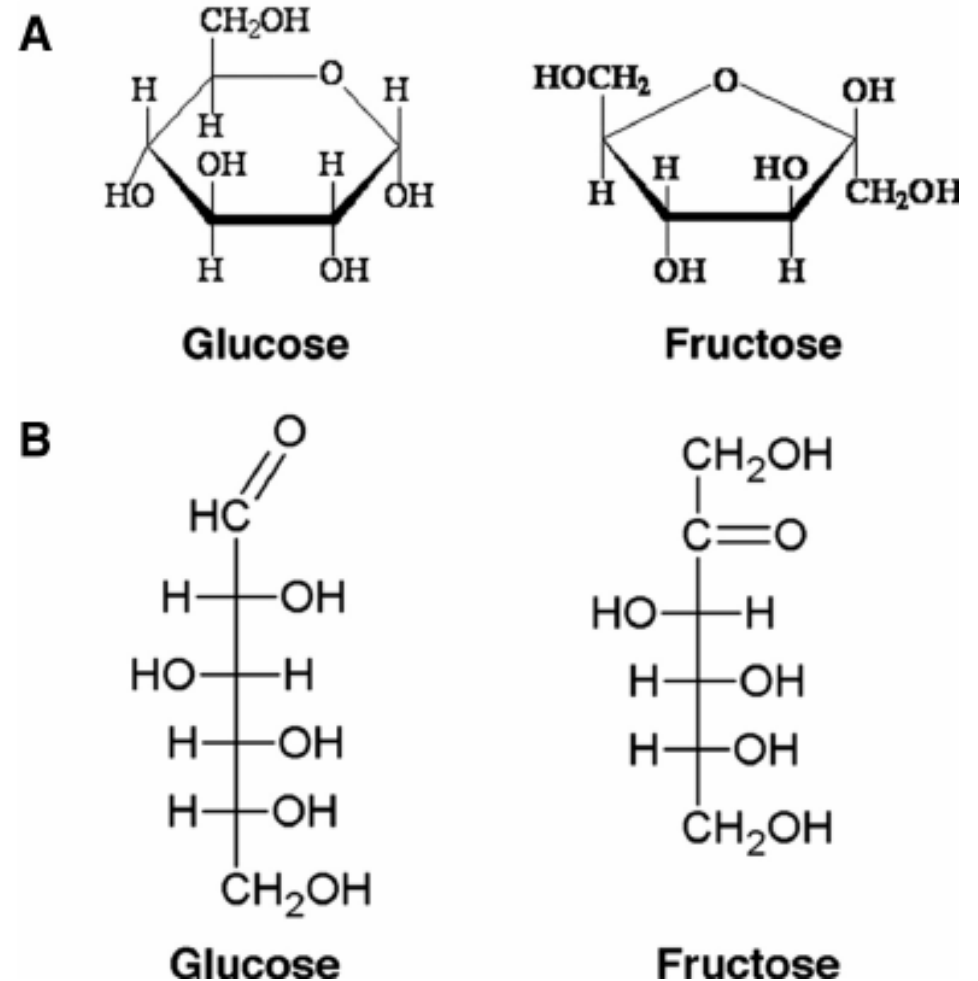
Glucose occurs in both combined and in the free state in nature. We can find this in sweet fruits and in honey. Glucose present in ripe grapes in a large amount.



Glucose

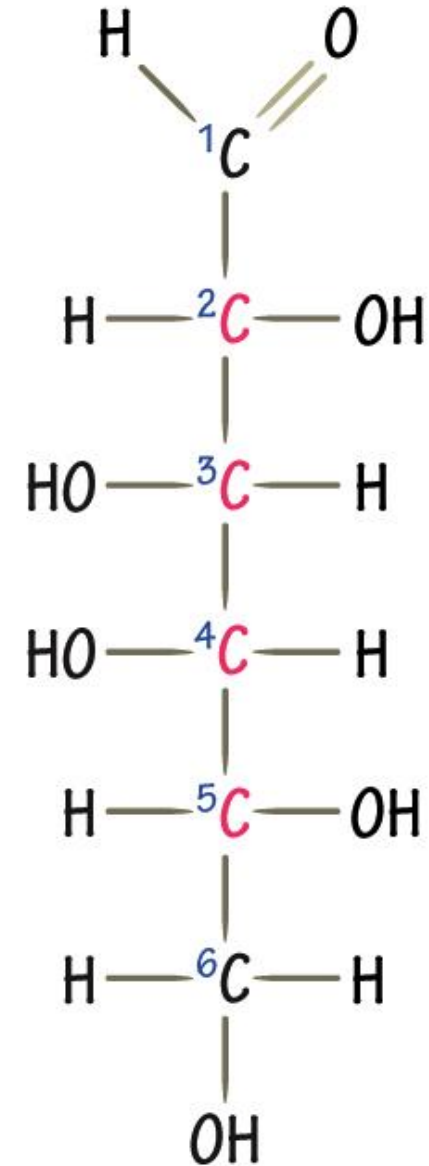
2. Fructose

- Fructose belongs to the ketose group.
- Differently shaped monosaccharides can break down by the specific enzyme.
- If fructose, combines with other monosaccharides then they form oligosaccharides.
- Sucrose has a fructose molecule joined with a glucose molecule with the help of a glycosidic bond.



3. Galactose

- Galactose is produced by mammals in the form of milk.
- Lactose holds a lot of energy in its bonds and for breaking down the bonds apart, specific enzymes are developed by off springs of mammals.



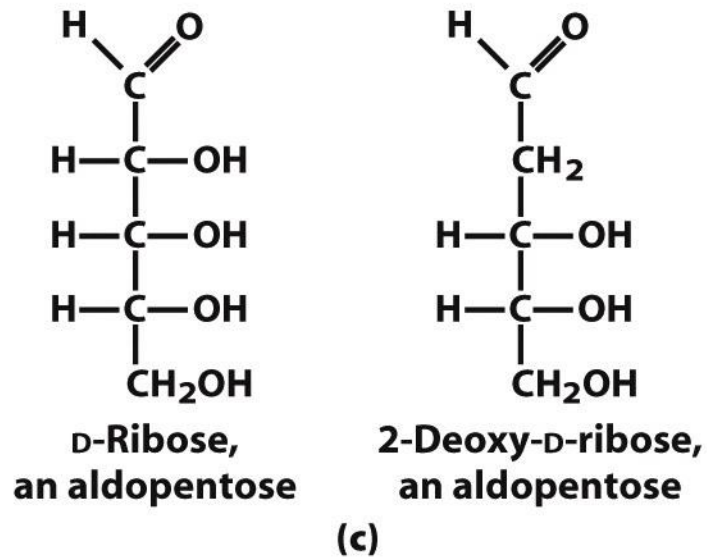
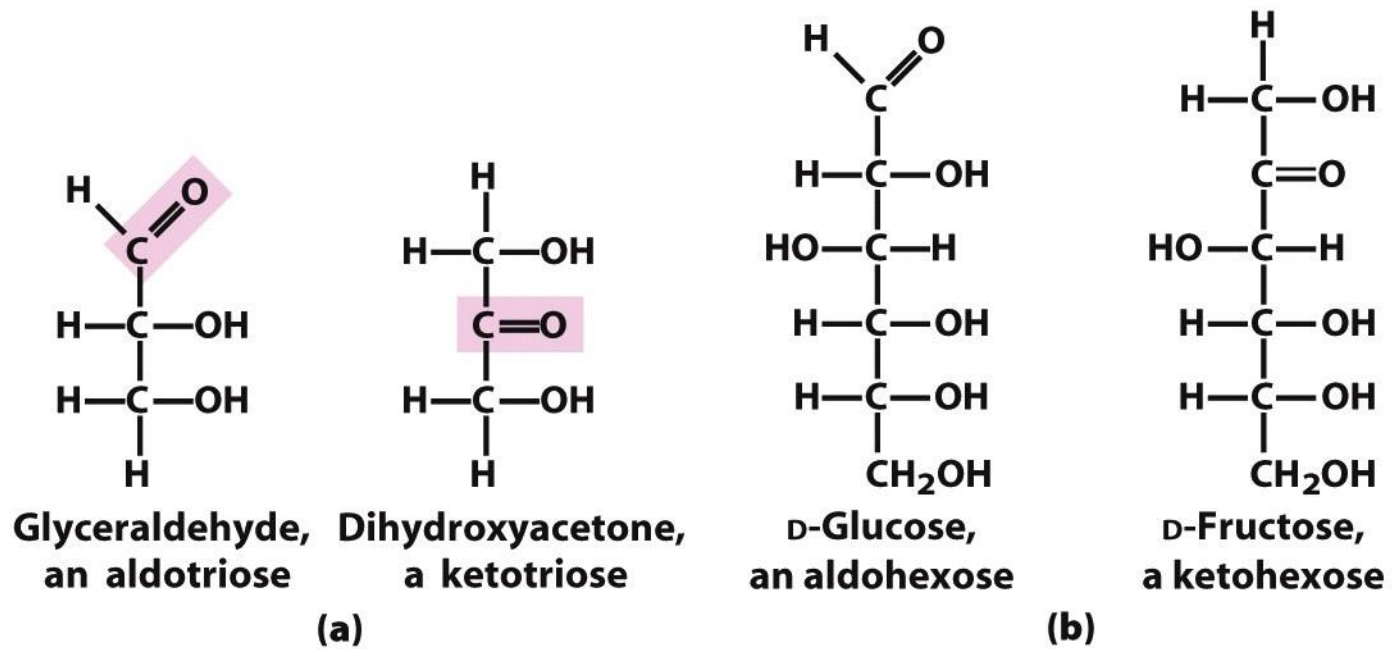
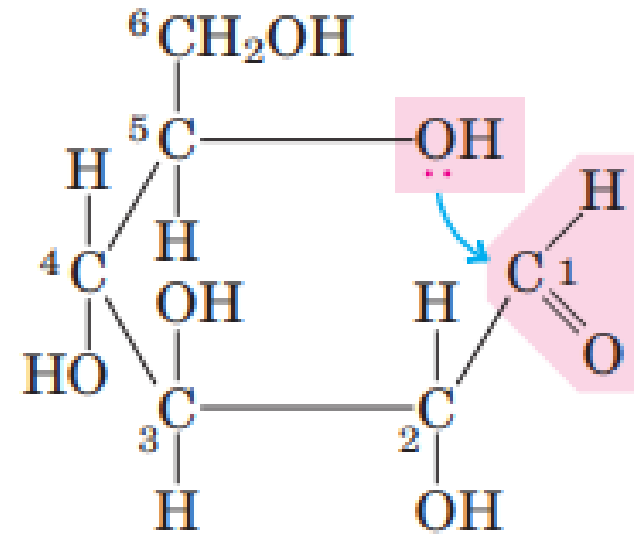
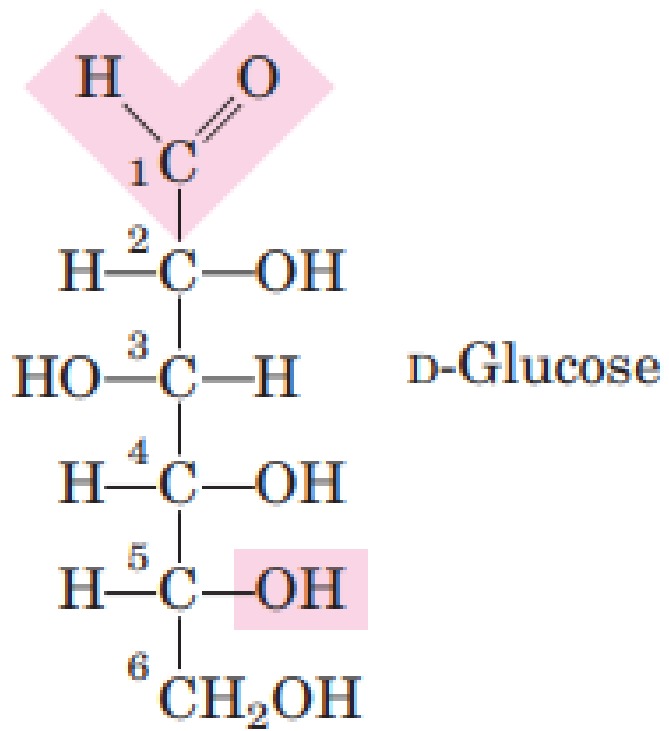


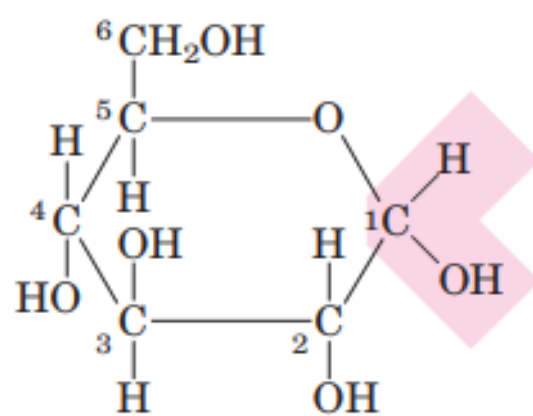
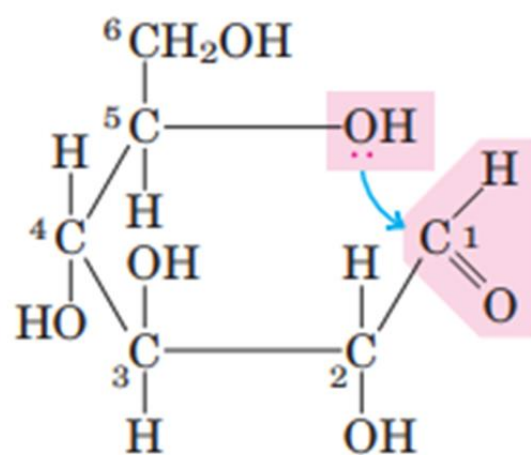
Figure 7-1
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The Common Monosaccharides Have Cyclic Structures

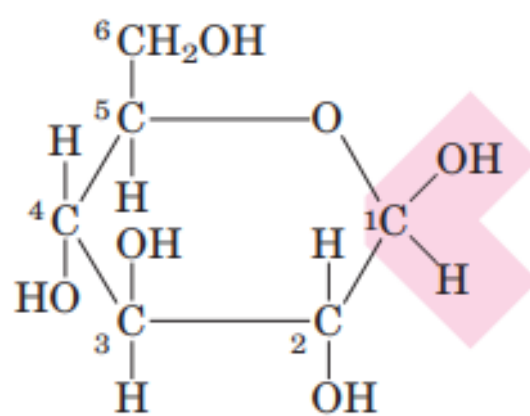
- In aqueous solution, aldotetroses and all monosaccharides with five or more carbon atoms in the backbone occur predominantly as cyclic (ring) structures in which the carbonyl group has formed a covalent bond with the oxygen of a hydroxyl group along the chain.
- The formation of these ring structures is the result of a general reaction between alcohols and aldehydes or ketones to form derivatives called hemiacetals or hemiketals,
- which contain an additional asymmetric carbon atom and thus can exist in two stereoisomeric forms.

- For example, D-glucose exists in solution as an intramolecular hemiacetal in which the free hydroxyl group at C-5 has reacted with the aldehydic C-1, rendering the latter Carbon asymmetric and producing two stereoisomers, designated α and β .
- The designation α indicates that the hydroxyl group at the anomeric center is, in a Fischer projection, on the same side as the hydroxyl attached at the farthest chiral center,
- whereas β indicates that these hydroxyl groups are on opposite sides.





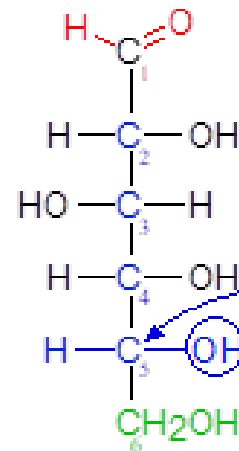
α -D-Glucopyranose



β -D-Glucopyranose

Linear and Pyranose forms of Glucose

Open/Straight chain
Fischer projection



D-Glucose
(Dextrose)

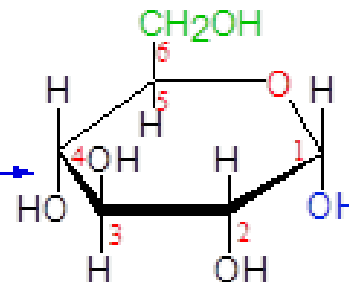
The open chain is thermodynamically unstable. It readily converts to the cyclic state.

Carbon atoms 2, 3, 4 and 5 are asymmetric, making them stereo centres, for two possible arrangements of atoms around each carbon, resulting in 2^4 aldose isomers (16).

The hydroxyl group on asymmetric centre C-5, furthest from the aldehyde group, normally reacts with the aldehyde to form cyclic glucose.

When the hydroxyl group (-OH) on the right side of asymmetric carbon C-5 in the fischer projection, makes aldose sugar a D-Glucose and an L-Glucose when -OH is on the left side.

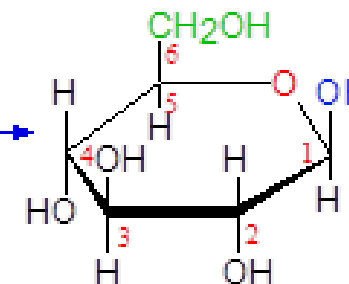
Ring forms
Pyranose



α -D-Glucose

Hydroxyl group on carbon C-1 is below the plane of the ring.

During conversion from a straight chain to a cyclic form (hemiacetal), the carbon atom C-1 with a carbonyl oxygen, called anomeric carbon, becomes a stereogenic centre with 2 possible configurations, resulting in two stereo isomers called anomers.

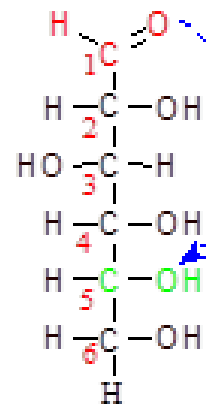


β -D-Glucose

Hydroxyl group on carbon C-1 is above the plane of the ring.

Linear and Pyranose forms of Glucose

- Glucose does not exist in a linear form because it is thermodynamically unstable in that state.
- The exposed aldehyde group at carbon C-1 reacts with the hydroxyl group on carbon C-5.
- The double bond on the aldehyde group of carbon C-1 is reduced to one bond.
- Electrons of the broken bond are released to form a tetrahedral bond between oxygen of carbon C-5 and carbon C-1.
- Tetrahedral bond angles of carbon C-1 result in a bent carbon chain.
- The ends of the molecule approach one another with the aldehyde group forming a hemiacetal (half aldehyde) compound through an oxygen bridge with carbon C-1 leading to a pyranose ring of glucose.

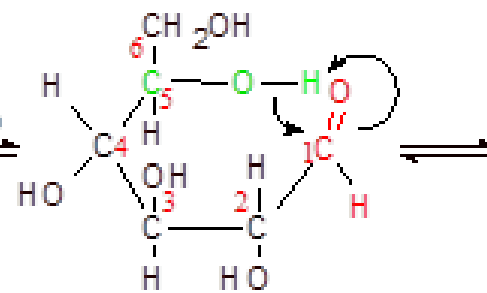


D-Glucose

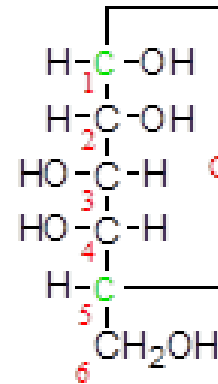
1. Open chain is in equilibrium with several of its cyclic isomers but more as a pyranose (99%) than the open chain (25%)

2. In this reaction the methyl group is forced on top of the ring because the hydroxyl group on C-5 is on the right side of the Fischer projection making the structure dextrorotary (D).

3. If the hydroxyl group on C5 in the Fischer projection was on the left side the methyl group would have been forced below the ring making it laevorotatory (L).

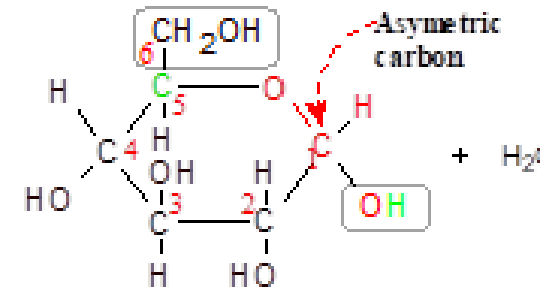


4. The molecule bends over in solution and a reaction results between a hydroxyl group of C-5 and the carbonyl oxygen on C-1. This results in ring structures of glucose.

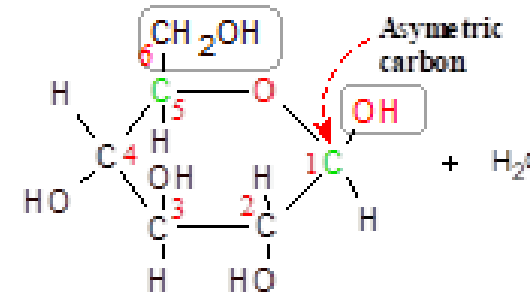


5. Generalised form

6. The tetrahedral bond angles of carbon C-1 with four groups of atoms around it result in a bent carbon chain, the pyranose form



7. Trans arrangement in which -CH₂OH and -OH on carbon C-1 are on opposite sides of the plane of the ring



8. Cis arrangement in which -CH₂OH and -OH on carbon C-1 are on opposite sides of the plane of the ring.

In a Fischer projection

- the carbonyl group is always placed on the top position for monosaccharide.
- From its structure, if the -OH group attached to the bottom-most asymmetric center (the carbon that is second from the bottom) is on the right, then, the compound is a D-sugar.
- If the -OH group is on the left, then, the compound is a L-sugar.
- Almost all sugars found in nature are D-sugar.

D-Aldoses

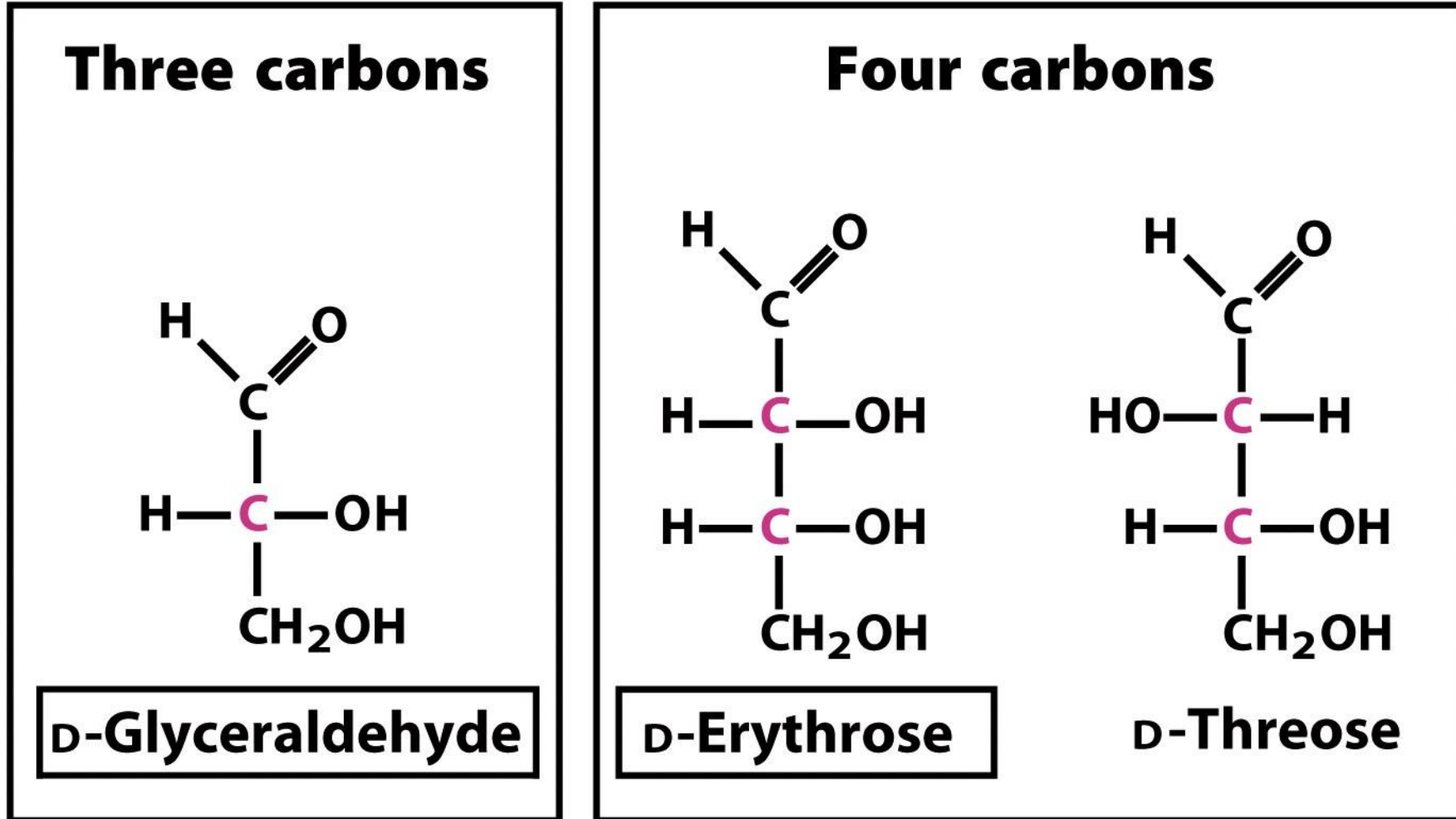


Figure 7-3a part 1
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D-Aldoses

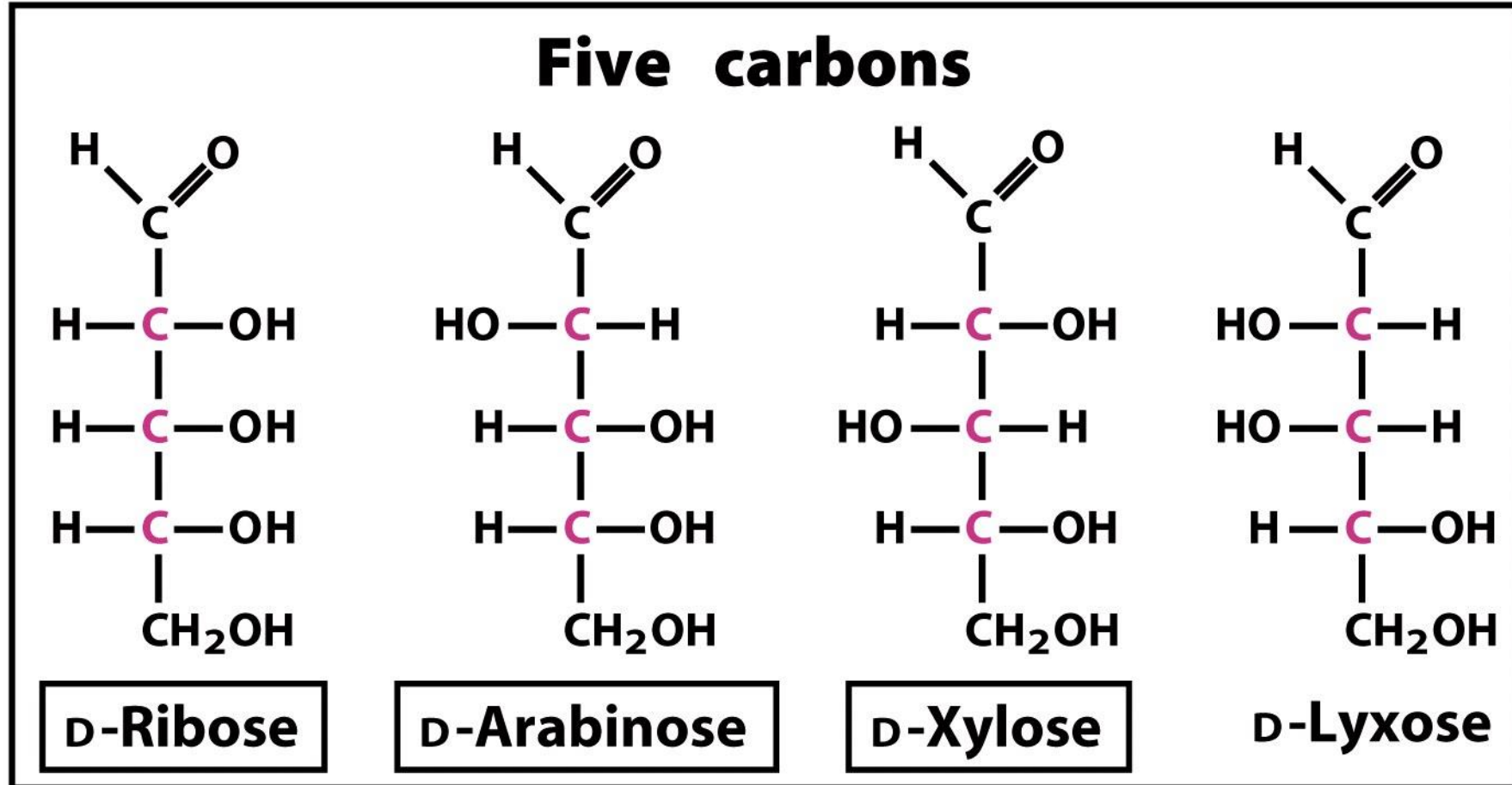


Figure 7-3a part 2

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D-Aldoses

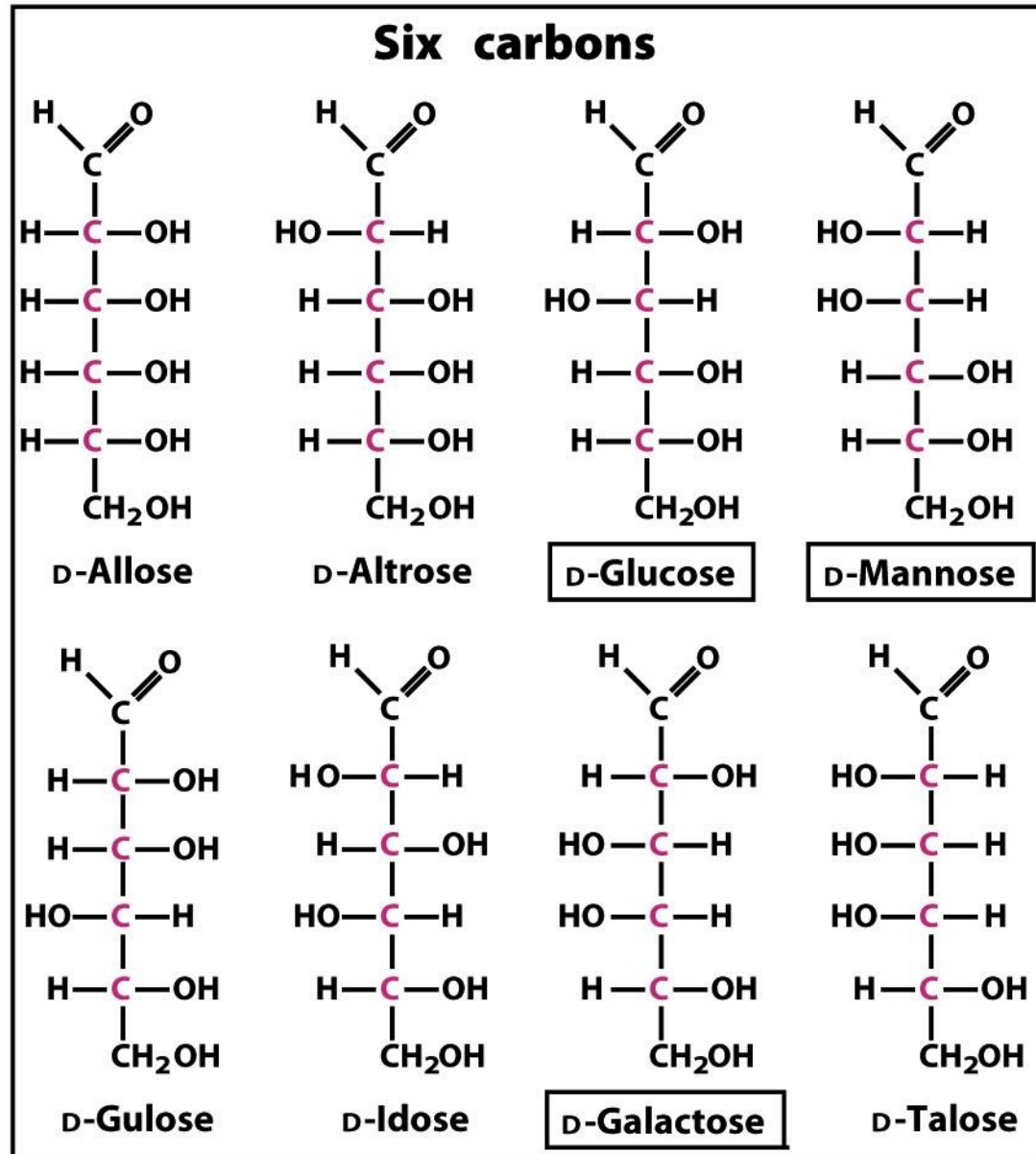


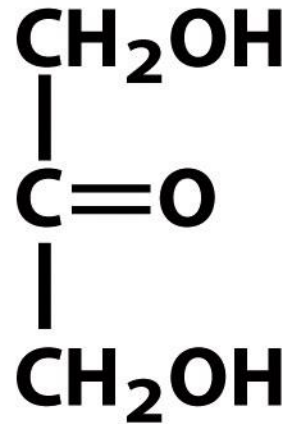
Figure 7-3a part 3

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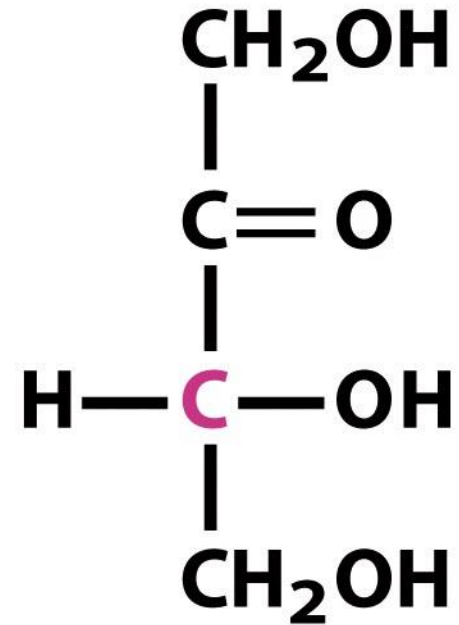
D-Ketoses

Three carbons



Dihydroxyacetone

Four carbons



D-Erythrulose

Figure 7-3b part 1

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D-Ketoses

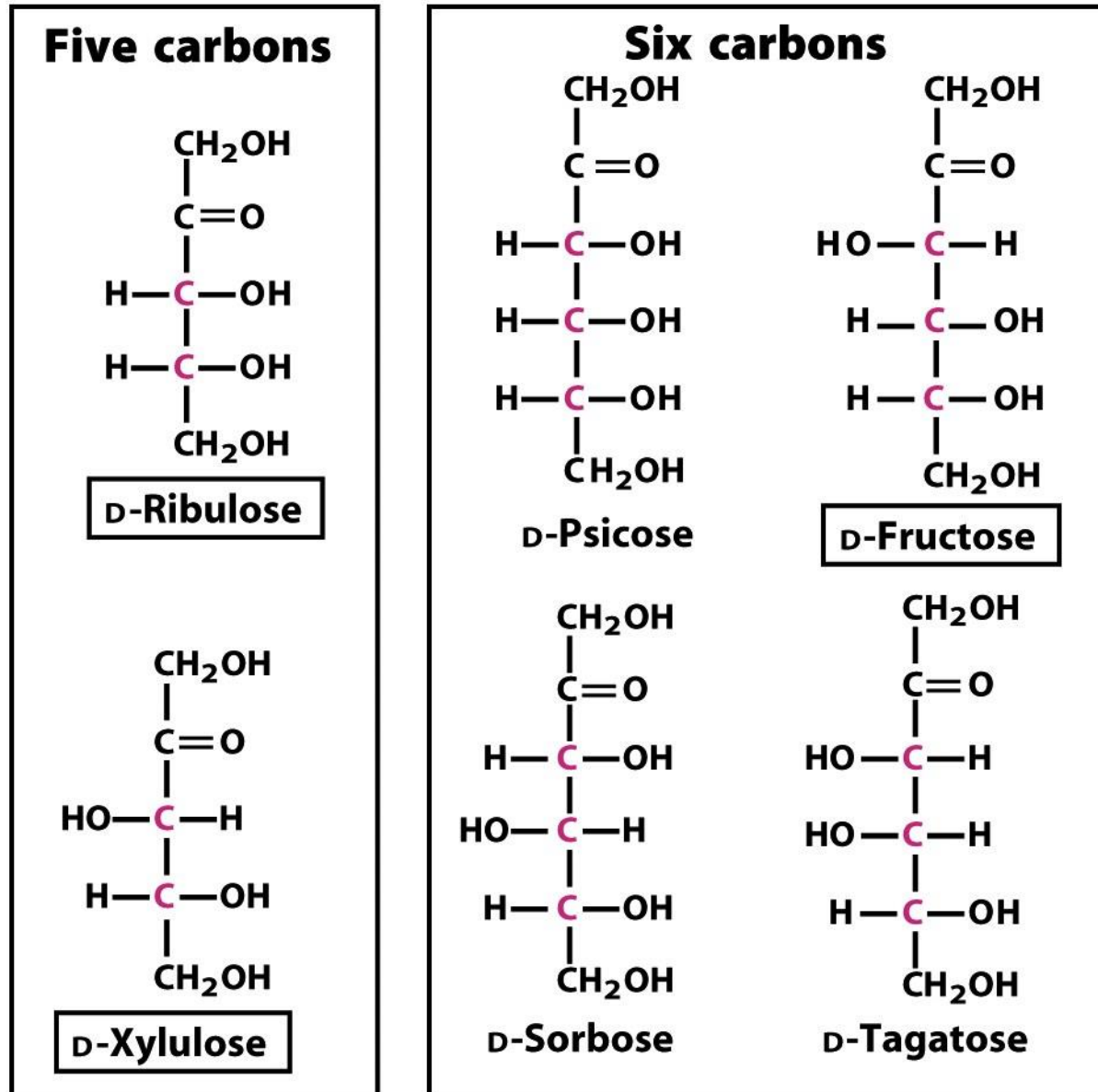
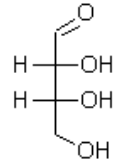
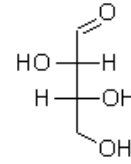


Figure 7-3b part 2
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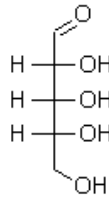
Aldose



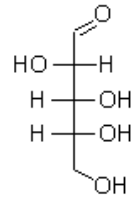
D-Erythrose



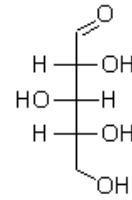
D-Threose



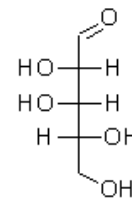
D-Ribose



D-Arabinose

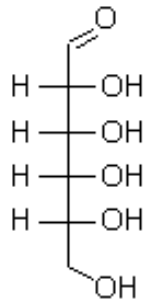


D-Xylose

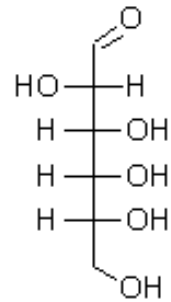


D-Lyxose

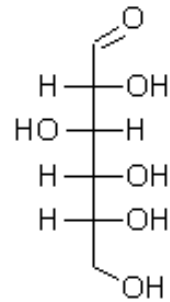
Royal Arabian Xylophonists Lyricize



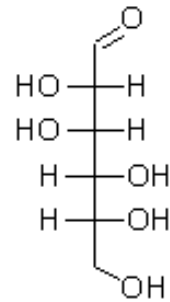
D-Allose



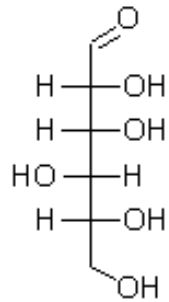
D-Altrose



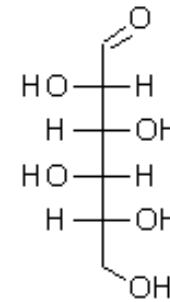
D-Glucose



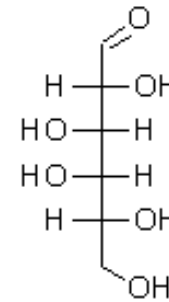
D-Mannose



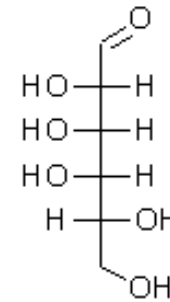
D-Gulose



D-Idose



D-Galactose



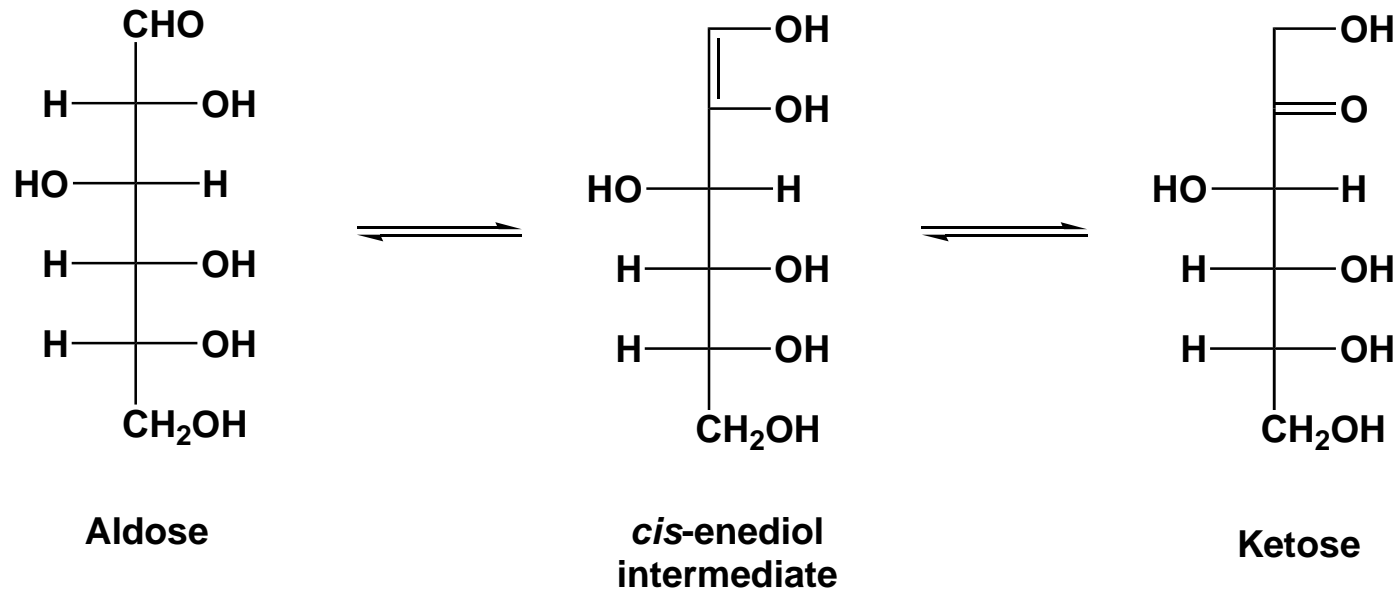
D-Talose

All Altruists Gladly Make Gum In Gallon Tanks

Ketone Sugars

Ketones are not easy to oxidize except for ketoses

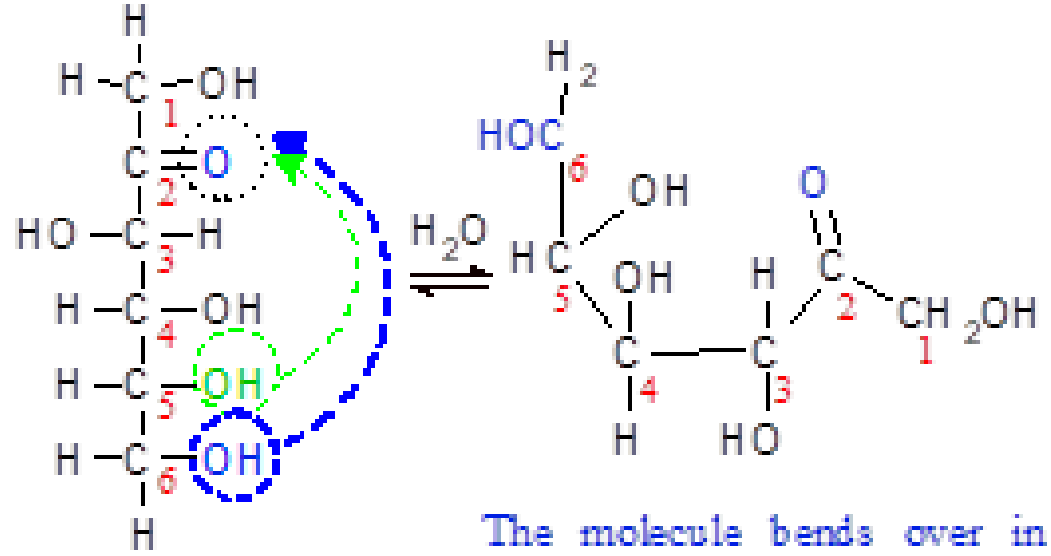
Enediol reaction -- All monosaccharides are reducing sugars



Fructose is an isomer of glucose

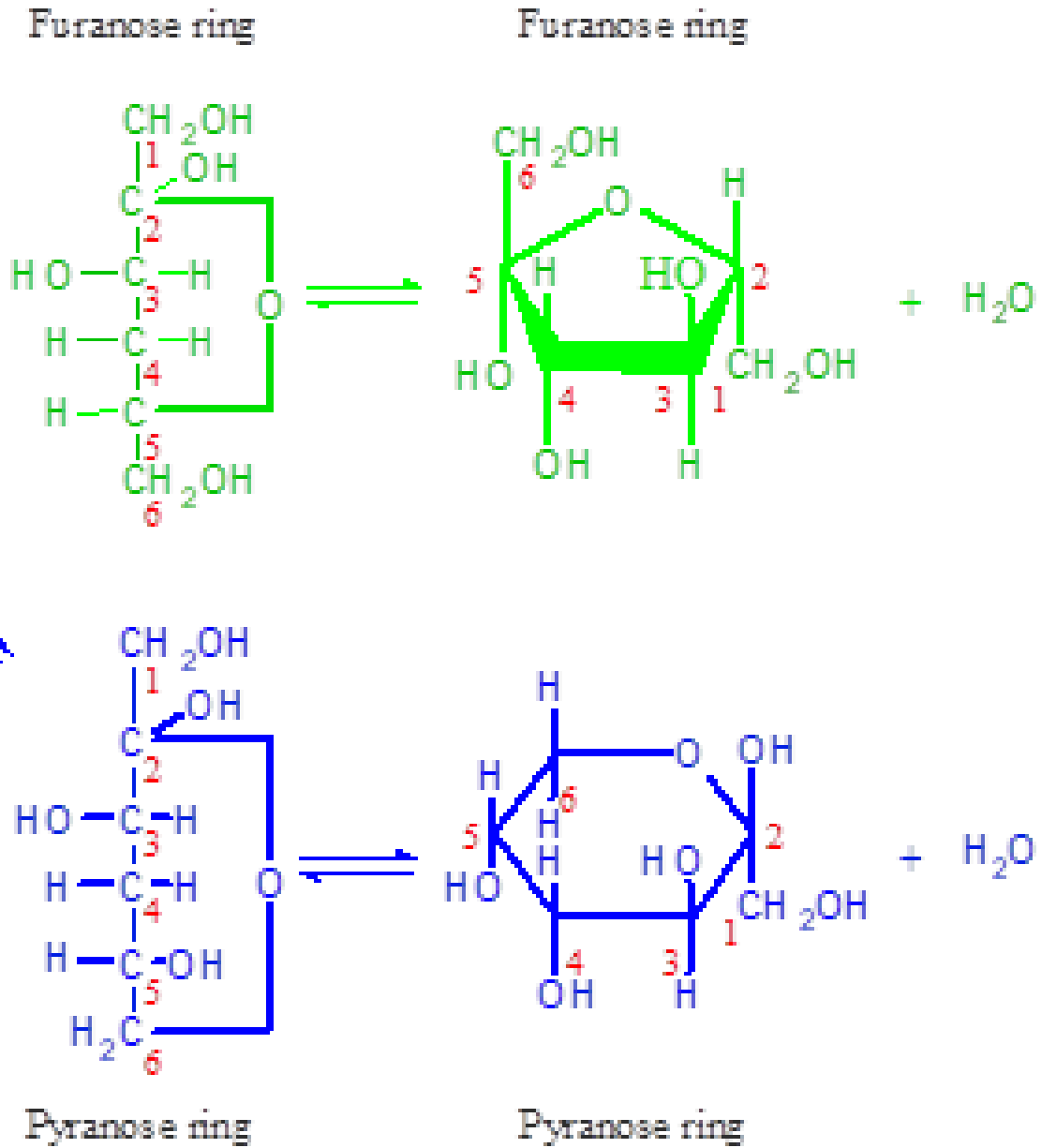
- In the case of a hexose such as D-fructose, the five member ring exists because the exposed carbonyl function is on C-2, and the oxygen bridge is formed most easily with C-5,
- though the pyranose form is known in which there is interaction between C-2 and C-6
- Glucose and fructose are isomers.
- Chemical structures are important because enzymes are substrate specific. Enzymes that hydrolyse fructose do not work on glucose, which is its isomer.
- Although the two are isomers, fructose is sweeter because it stimulates its specific receptors more than glucose

The molecule bends over in solution and a reaction results between oxygen on carbon C-2 and the hydroxyl group on carbon C-5. This results in a furanose ring.



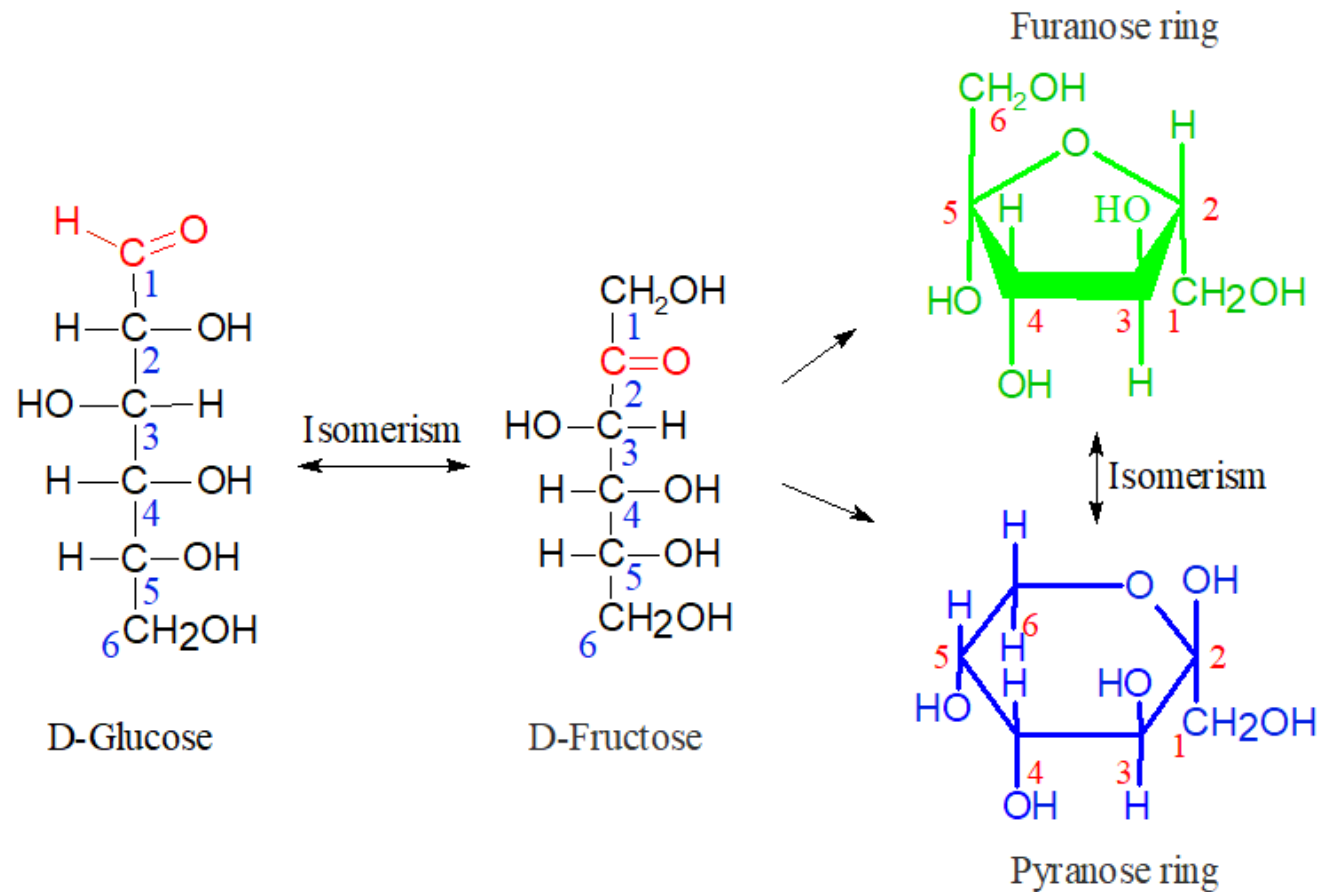
Fructose open chain

The molecule bends over in solution and a reaction results between oxygen on carbon C-2 and the hydroxyl group on carbon C-6. This results in a pyranose ring.



Pyranose ring

Pyranose ring



1. Note that the functional group on glucose is on C-1 and it is on C-2 in fructose.
2. When the ketose group of fructose reacts with a -OH on C-5 the reaction leads to the formation of a furanose ring.
3. When the ketose group of fructose reacts with a -OH on C-6 the reaction leads to the formation of a pyranose ring.

Functions of monosaccharides

- **Glucose**
- Glucose also referred to as dextrose and sometimes “blood sugar”, is the immediate source of energy for cellular respiration in plants and animals.
- It is present in vegetables and fruits as a moderately sweet sugar. It is a building unit for the synthesis of disaccharides and polysaccharides.
- It is the basic structure to which all carbohydrates break down, when it is transported through vessels to all cells of the organism.
- During fermentation (breakdown of glucose in the absence of oxygen in the cytoplasm) by zymase in yeast, glucose breaks down to carbon dioxide and ethyl alcohol.
- The aerobic break down of glucose takes place in the mitochondrion and yields carbon dioxide and water.

Glucose

- Glucose in solution is nonreactive. Therefore it does not readily react with amine groups of amino acids, like other hexose sugars, in a process called glycosylation.
- Glycosylation reduces or destroys the function of many enzymes. In the presence of glucose the rate of glycosylation is low.
- This factor reduces the occurrence of long term health complications such as diabetes, blindness, kidney failure and peripheral neuropathy etc.
- Human beings have a digestive system, which breaks down carbohydrates into glucose.
- Glucose is absorbed into the blood stream through the intestinal wall.

Glucose

- When blood sugar concentration in the blood stream is high, **beta** cells in the **pancreas** release a hormone called **insulin** into the blood stream.
- Insulin makes our cells assimilate blood sugar for immediate use as energy or for storage when there is excess of it.
- This action by insulin helps to reduce the sugar level in the blood stream.
- Some of the glucose goes directly to provide the brain cells with energy. The excess is directed to the **liver** and **muscles**, where it is stored as **glycogen** (“animal starch”) and some of it is sent to the fat cells where it is stored as **fat**.
- When glucose levels in blood drop below a critical concentration, alpha cells in the pancreas release a hormone called **glucagon**.
- The liver is induced to release stored glycogen for breakdown to glucose, so that blood sugar is raised to a required concentration once again.

Glucose

- Therefore insulin and glucagon work together to regulate the concentration of glucose in the blood stream, particularly for the brain cells, which cannot metabolise any other energy source material.
- As insulin reduces high blood glucose levels, glucagon helps to restore it to the required concentration in the blood stream, when it falls below a critical level.
- Carbohydrates which quickly raise blood sugar are said to have a high *glycemic index*, while those that have a gentler effect on blood sugar levels have a lower *glycemic index*.

Fructose

- Fructose is found in fruits, honey, and the only sugar in bull and human semen.
- It is the sweetest of sugars because it is able to excite the taste buds more than any other sugar.
- Fructose is a source of energy, although it is not the first choice for respiratory processes.
- It does not raise blood sugar levels tremendously because it has a low glycemic index.
- There is evidence that a little of it as contained in vegetables and fruits is good for the efficient utilization of glucose in the body.
-

Fructose

- However, Consuming too much of fructose is not good for one's health, especially consumption of food that contain sugar additives.
- Unlike glucose which is regulated in the blood stream with the help of insulin, fructose is processed in the liver.
- The liver is unable to process it quickly enough for the body to use it as sugar. Consequently, the liver diverts it for the manufacture of lipids (triglycerides), which are released into the blood stream where they cause sclerosis (blockage of blood vessels).
- High concentrations of triglycerides in the blood increase the chance of developing heart disease.

Galactose

- Galactose is not normally found in nature, although it is a natural compound.
- It is mostly a basic component of many compounds such as milk and many others found in fruits and vegetables.
- These compounds yield galactose upon hydrolysis.
- Although not very water-soluble, and less sweet than glucose, it forms part of glycolipids and glycoproteins, which is found in many tissues.
- The body can change glucose to galactose in order to enable the mammary glands to produce lactose.
- In plants, glycosidically bonded galactose is an important component of various lectins.
- Lectins have the ability to bind to sugar-containing structures, but have no enzymatic function.

Galactose

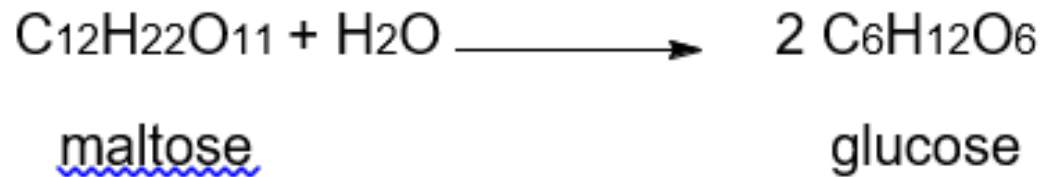
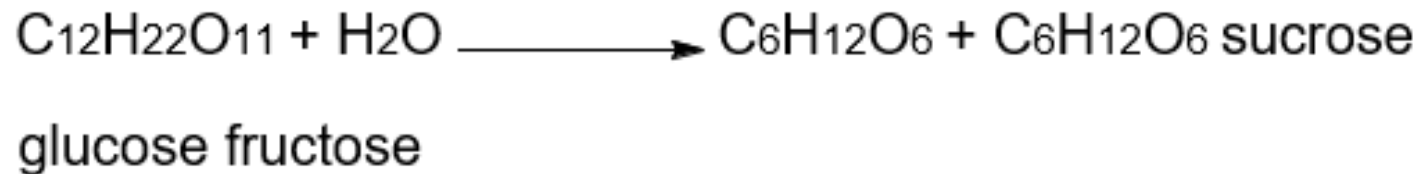
- Galactose has different properties of its own compared to other sugars.
- These properties make it easier to lose and maintain weight;
- they are useful in preventing adult-onset diabetes;
- they give much steadier energy through time,
- and they provide the basis for products for athletes, which allow them to perform better and for longer periods.
- There is only one product range in the world that uses galactose as a basic food and drink ingredient, and that is a brand new range of energy drinks.
- Galactose is a remarkable undiscovered sugar for the new Millennium.

Oligosaccharides

- Carbohydrates that produce two to ten monosaccharide units during the hydrolysis are called oligosaccharides.
- They can be further classified based on the number of monosaccharide units formed on hydrolysis.

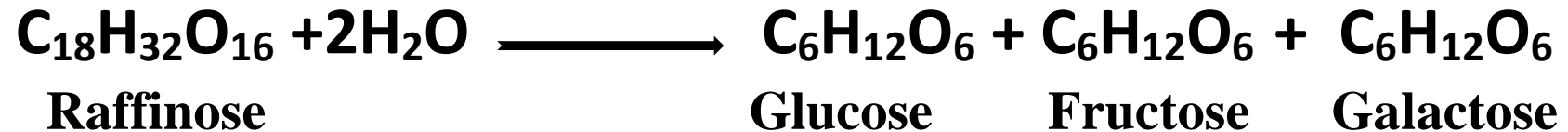
Disaccharides:

- They give two monosaccharide units on hydrolysis, which may be the same or different.
- For example, sucrose on hydrolysis gives one molecule each of glucose and fructose, whereas maltose gives two molecules of glucose



Trisaccharides:

- These carbohydrates yield three molecules of monosaccharides units on hydrolysis



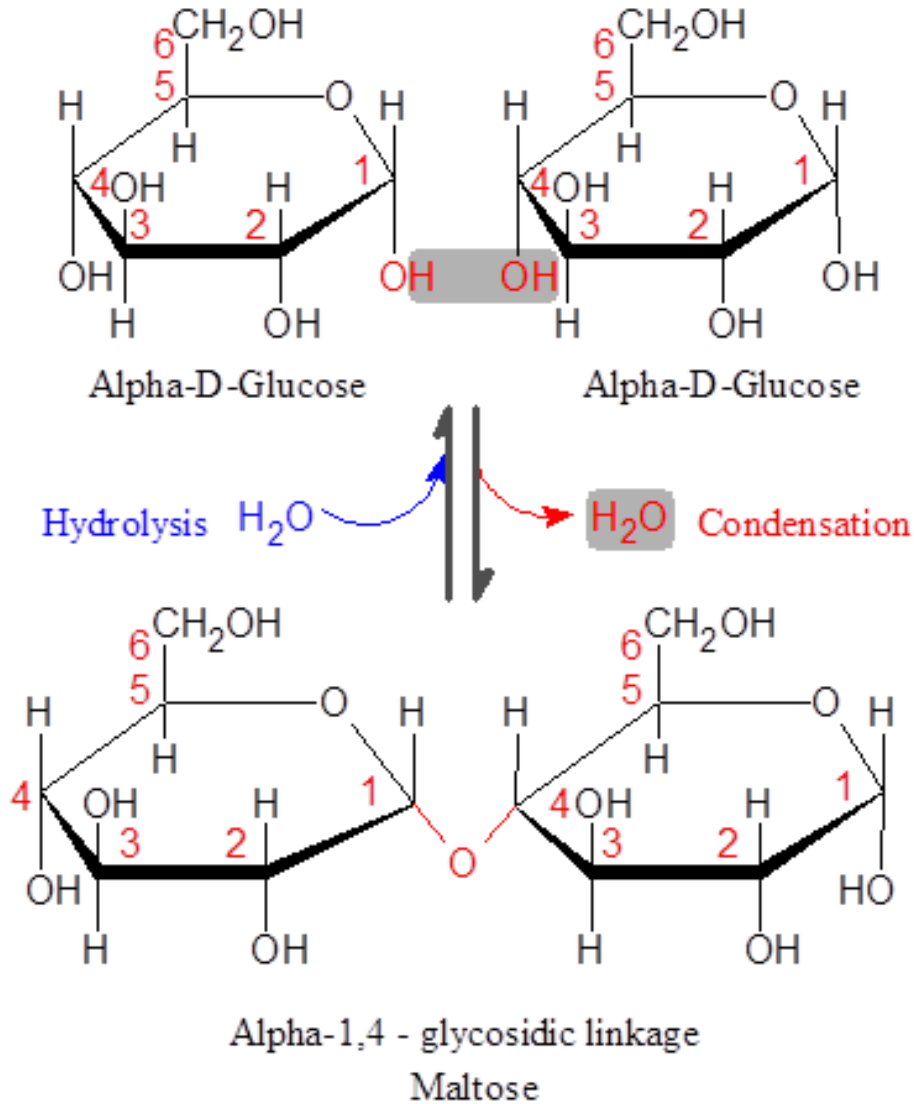
Disaccharides

- Disaccharides are formed by condensation (dehydration) reactions between two monosaccharide sugars.
- This is a process where a bond is formed between two reacting molecules by the removal of a water molecule forming what is called a **glycosidic bond**.
- The bond forms between carbon 1 (C1) of one hexose sugar and carbon 4 (C4) of the second sugar unit.
- The synthesis process removes a hydroxyl group (OH) from the asymmetric carbon (C1) and a hydrogen atom (H) from C4 of the second sugar molecule.
- The hydrogen and hydroxyl groups react with each other to form a molecule of water (H₂O) as a **byproduct** of the synthesis process.
- The removal of hydrogen and hydroxyl group creates reactive sites on the two sugar units to form an oxygen bridge that holds the two reacting monosaccharides.

Common disaccharides

- Common disaccharides are **sucrose** which is table sugar, **lactose** the sugar found in milk, and **maltose**, which is used in brewing.
- Sucrose is made up of glucose and fructose; Lactose is made of glucose and galactose, and Maltose is made of glucose units only.
- The linkage between monosaccharides in a disaccharide is referred to as a glycosidic linkage and is named according to the number of the carbon at which the linkage begins and the carbon on the second monosaccharide at which the linkage ends.
- The glycosidic linkage is also designated α or β , depending upon whether the conformation at the anomeric carbon is up or down.

Formation of a disaccharide maltose from 2 α -glucose molecules

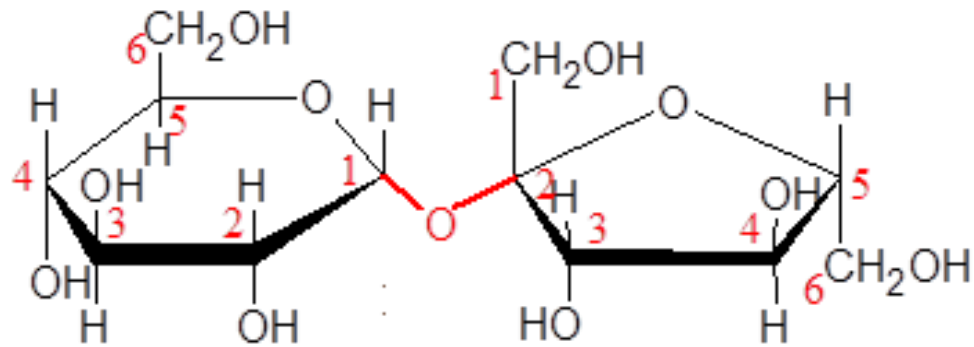
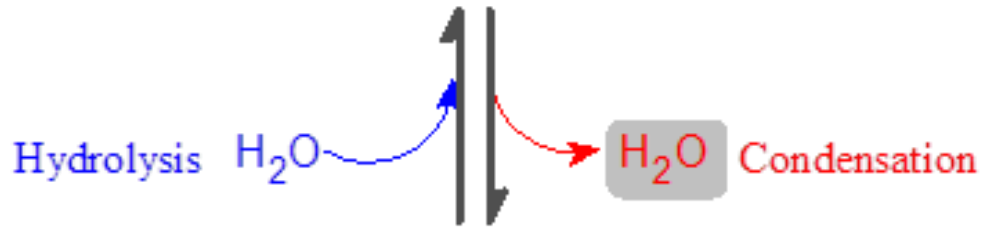
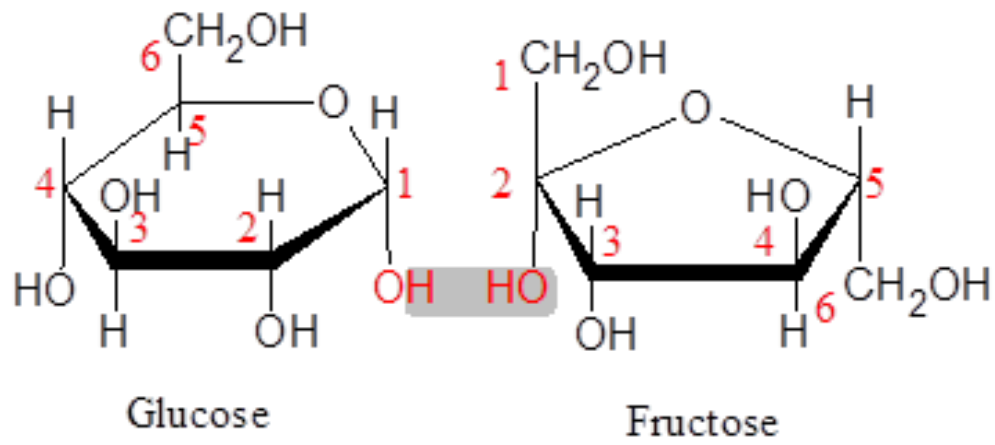


- Maltose is not a common naturally occurring disaccharide but it is the major product of the hydrolysis of starch.
- A disaccharide of maltose is produced by joining 2 monosaccharide (single sugar) units.
- This reaction is given below in which 2 α -glucose molecules are combined using a condensation reaction, with the removal of water.
- In this case a hydroxyl group on C-1 of a glucose molecule reacts with a hydroxyl group on C-2 of fructose to form water (H_2O).
- The reaction creates an α 1-4 glycosidic bond between opposite sides of the 2 glucose units.
- The glycosidic bond formed is referred to as an oxygen bridge

- The stable asymmetric C1 in the second glucose molecule is still free to participate in another chemical reaction.
- Therefore the reducing power of the aldehyde is still present in the new molecule.
- It is for this reason maltose is said to be a reducing sugar.

Formation of the disaccharide sucrose from glucose and fructose molecules

- The most familiar disaccharide is ordinary table sugar, or **sucrose**.
- It is widely distributed in plants and can be obtained commercially from sugar beets.
- It is found abundantly in plants both as a storage substance and as a transport material of carbohydrates in plants.
- It is highly soluble in water and it is nonreactive.
- These properties of sucrose make it suitable for transport of carbohydrates in plants and a suitable storage form of carbohydrates.



Alpha-1,2 - glycosidic linkage

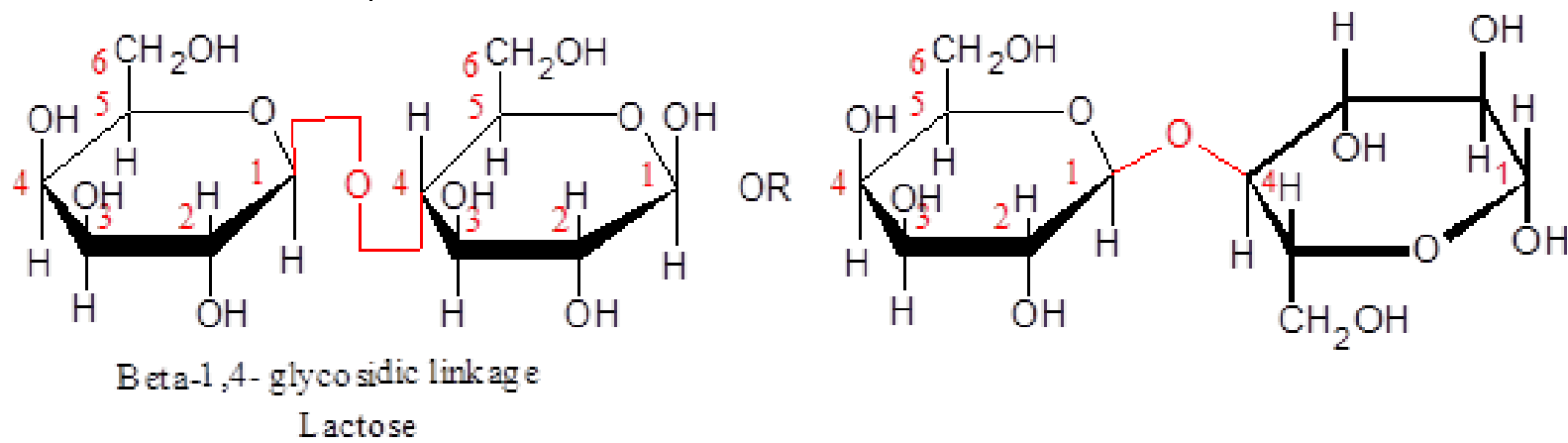
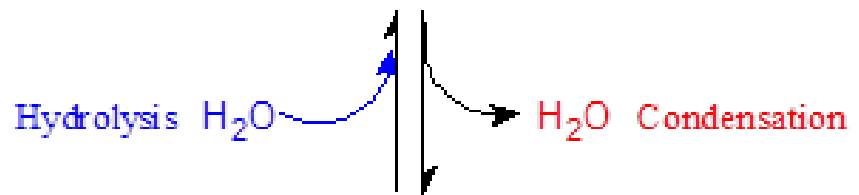
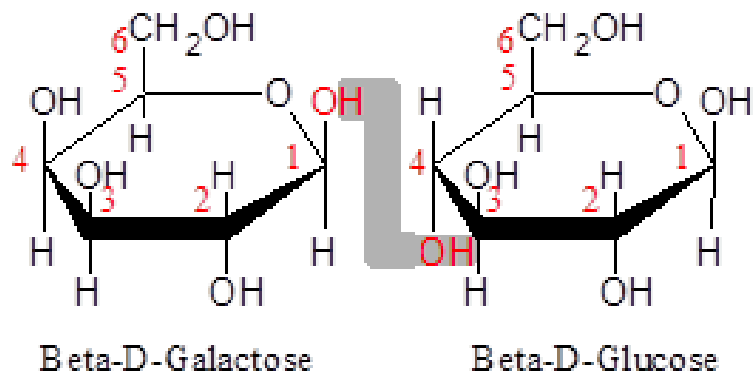
Sucrose

- A disaccharide of sucrose is produced by joining monosaccharide (single sugar) units of glucose and fructose.
- In this chemical reaction, one α -glucose molecule is linked to a β -fructose molecule using a condensation reaction, with the removal of water.
- The hydroxyl group on C1 of glucose reacts with the hydroxyl group on C-2 of fructose to form water (H_2O) as a byproduct.
- The reaction leaves behind an α 1-2 glycosidic oxygen bridge between the two reacting molecules

- It is clear from the molecule of sucrose that both its asymmetric carbon atoms on glucose (C-1) and fructose (C-2) are both engaged.
- The molecule does not have a free functional carbon that can participate in a chemical reaction.
- Therefore, sucrose is referred to as a non-reducing sugar.
- Hydrolysis of the molecule is what would restore the reducing capacity of sucrose, but in form of its original monomer sugar units of glucose and fructose.

Formation of lactose from glucose and galactose molecules

- Another common disaccharide is **lactose** or milk sugar.
- It accounts for about 5% of the solid portion in milk of most mammals.
- It is a compound of α -D-glucose linked to β -D galactose.
- The reaction is between a hydroxyl group on C-1 of a glucose molecule and a hydroxyl group on C-4 of the galactose molecule, with a removal of water (H_2O).
- The reacting molecules form a disaccharide molecule of lactose forming α 1-4 bond through an oxygen bridge.
- It is a reducing sugar because the hydroxyl group on C-1 in the second hexose molecule of glucose is still free to participate in a chemical reaction

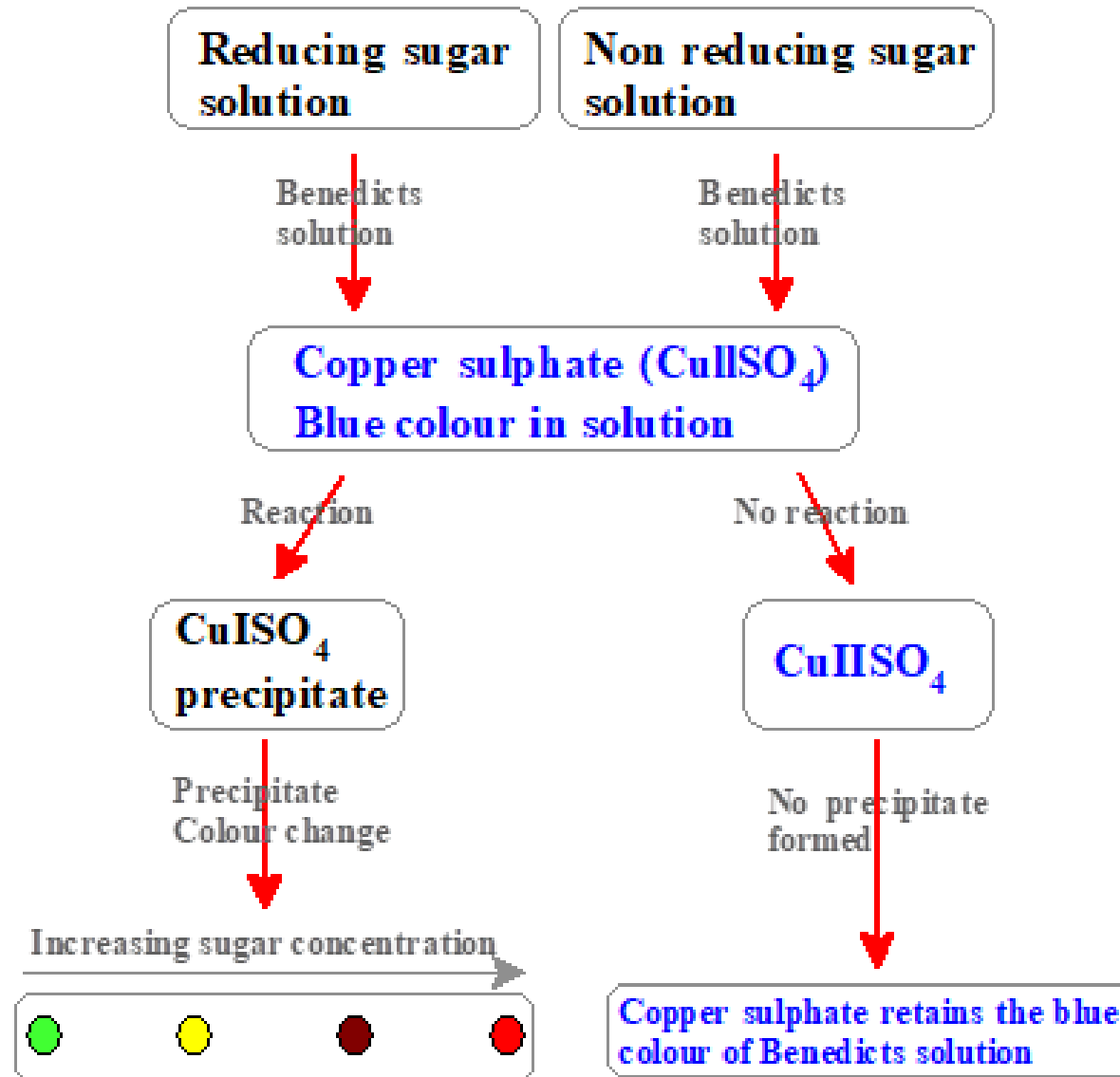


The chemistry of reduction

- is related to the activity of the aldehyde group of the aldose group ketone group of the ketose sugars.
- In non-reducing sugars, these groups are occupied and therefore cannot participate in any chemical reaction.
- Reducing sugars in Fehlings or Benedicts test reduce copper from a valency of 2 to a valency of 1.
- Copper sulphate (CuSO_4) is soluble in water.
- In the presence of a reducing sugar the soluble form is reduced to Cu_2O , which is insoluble.
- The precipitate formed produces a colour intensity which is dependent on the concentration of the sugar molecules in solution.

- Sucrose is a non reducing sugar because it is not reactive.
- Therefore it has no effect on the copper solution.
- However, its capacity to react with the copper in solution is restored when it is hydrolysed into its unit forms of glucose and fructose.
- Glucose and fructose are both reducing sugars because their asymmetric carbon atoms are reactive.
- Therefore their presence in copper sulphate solution is able to reduce the copper II in the solution to CuI resulting in a precipitate.

The chemistry of reduction of copper sulfate by sugar molecules.



Polysaccharides

- Starch, glycogen, cellulose, chitin and agar are all examples of common polysaccharides.
- They differ primarily in the three-dimensional pattern in which the monomers are bonded to each other.
- They may be coiled or branched.
- These are large carbohydrate molecules of high molecular weight because they are made up of many monosaccharide units linked together through glycosidic bonds.
- Long chains of polysaccharides are sometimes referred to as polymers.
- They are widely distributed in plants and to a lesser extent in animals.
- They serve as structural components of cell walls.
- Polysaccharides act as carbohydrate storage products in seeds, fruits, roots and leaves.

Polysaccharides are represented by the general formula $(C_6H_{10}O_5)_n$

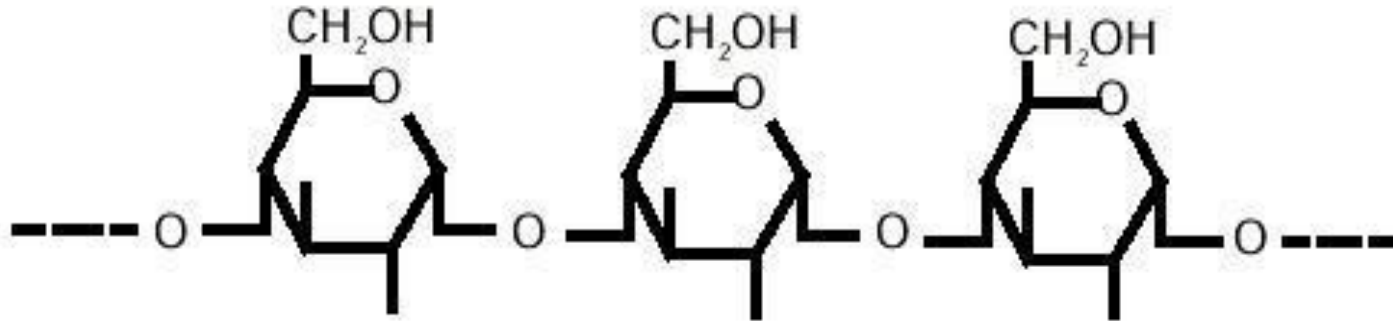
- where 'n' is equal to or greater than two.
- The formula in brackets represents a monosaccharide ring, which is missing two hydrogen atoms and one oxygen atom.
- These are the atoms that participated in a dehydration synthesis process that led to the formation of water as a byproduct.
- The 'n' represents the number of repeating monosaccharide units in a polysaccharide chain.
- Each polysaccharide is different from one another.
- The difference is in the number of monosaccharide units in a chain and the type of glycosidic bond involved.
- Polysaccharide polymers have different conformations depending on the number of polysaccharide units involved in the molecule and or the type of bond involved in the chain.
- Some are straight, helical, coiled or spiral or branched.

- Polysaccharides do not have a sweet taste.
- They are relatively insoluble in water.
- It is for this reason, these molecules cannot be crystallised, a property which makes them good storage molecules.
- The most important polysaccharides are cellulose, chitin, glycogen and the starches.
- These are nutrient polysaccharides that serve as a source of nutrition for various organisms

Starches

- Starches are the reserve substances for glucose.
- They give the cell a way of storing this important food molecule in a form that is compact, yet available for break down by specialised enzymes when need arises.
- Plant products (naturally occurring starch) are the true starches.
- These come in two forms, **amylose** and **amylopectin**.
- The two starches are found together in starch granules

AMYLOSE



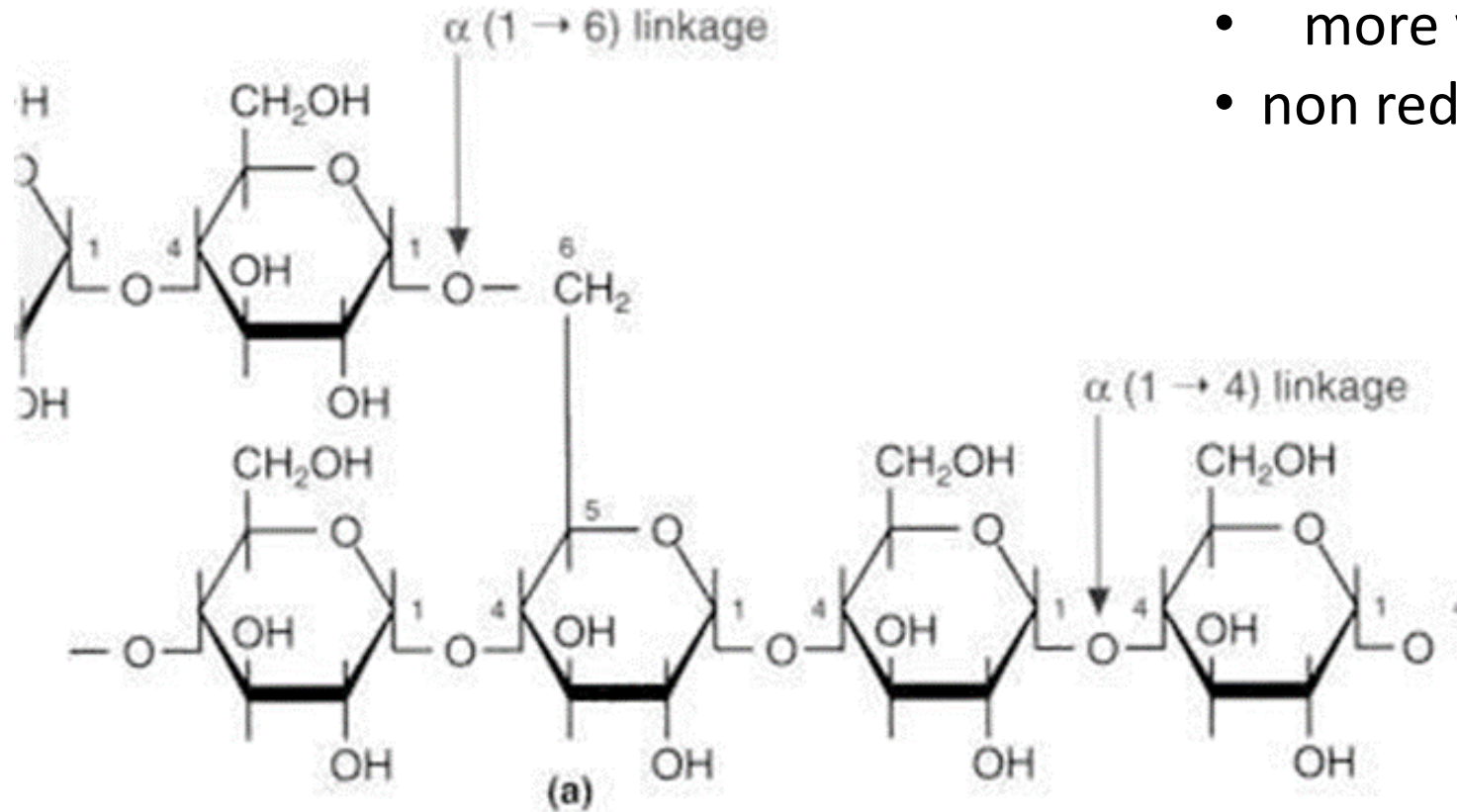
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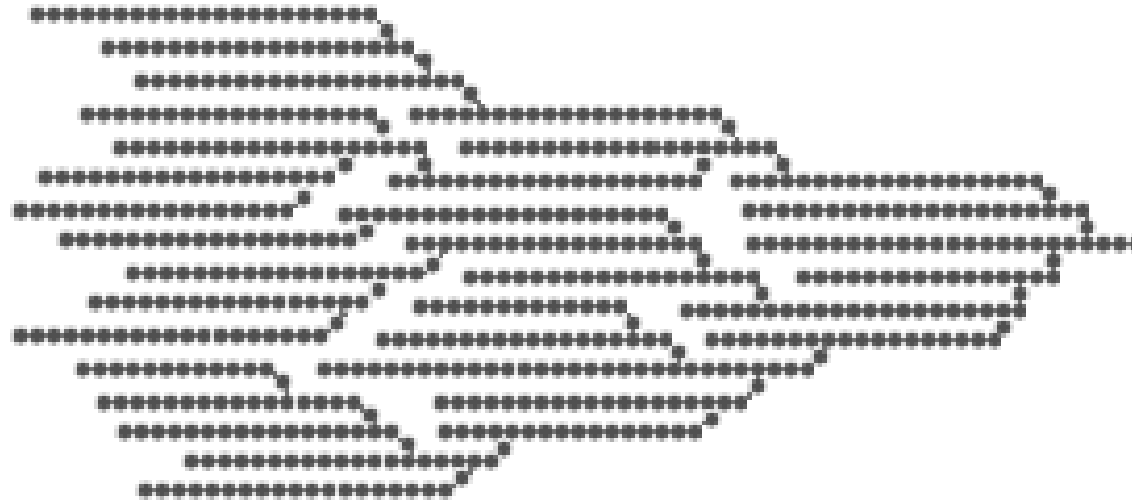
(NO BRANCHING, α -1 \rightarrow 4 LINKAGES)

- **Amylose** is an un-branched α -1,4-polymer of glucose.
- glucose linear molecule coils up
- less water soluble
- non reducing sugar

Amylopectin

- $\alpha(1\text{---}4)$ and $\alpha(1\text{---}6)$ glucose branched molecule
- open spiral molecule
- more water soluble
- non reducing sugar





- is a branched molecule of 20-30 glucose units in each length.
- The branches in amylopectin are formed between two parallel linear chains of glucose polymers joined through a condensation reaction between a hydroxyl group of carbon C-1 of one polymer chain and carbon C-6 of the other polymer chain of glucose molecules through an α (1-6) branch covalent bond.
- The outer layers of the molecule are less highly branched than the ones at the centre.

The role of starch in plant cells

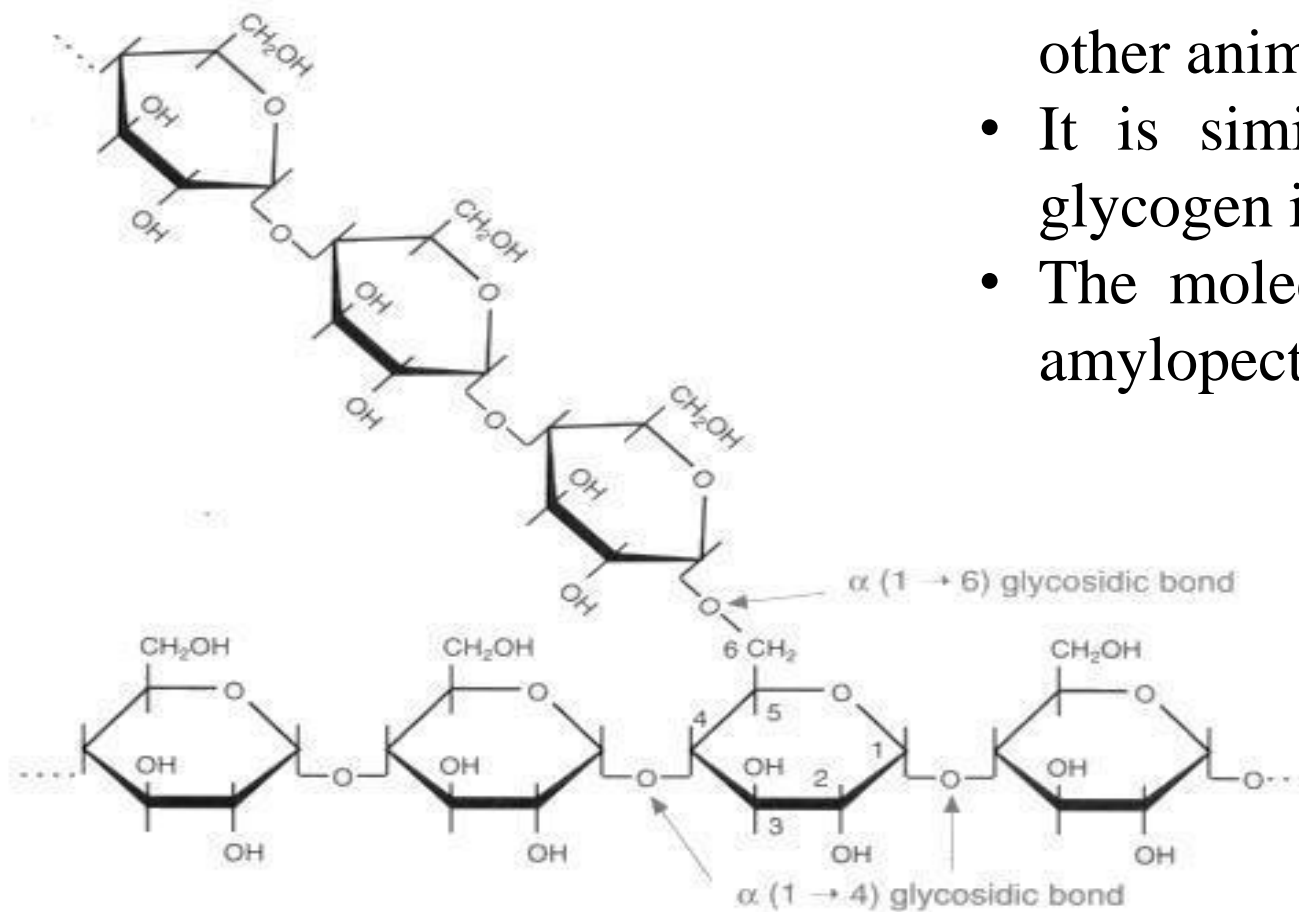
- Starches are important because they serve as a storage form of sugar.
- Surplus sugar can be converted into starch which is insoluble and can therefore be stored.
- They are an ideal storage product, because they are insoluble.
- Starch exerts no osmotic pressure on a cell, while the product is in storage.
- It is an inert material and therefore good as a storage product.

How do animals benefit from starch stored in plants?

- Human beings have survived on carbohydrate as plant starch in the form of cereals (maize, rice, wheat) and tubers (cassava, potatoes and sweet potatoes).
- The long chains of starch are digested into simpler sugar units by appropriate enzymes.
- This is achieved in the presence of water and starch related enzymes called **amylases** in a process called hydrolysis.
- This is a reverse process of condensation.
- Amylases hydrolyse starches into disaccharides called maltose.
- Another enzyme called **maltase** can hydrolyse maltose into two glucose molecules, which subsequently get absorbed into the body.
- Glucose is the ultimate source of energy for a cell when it is broken down in the process of respiration.

Glycogen – animal starch

- is a starch produced by human beings including other animals.
- It is similar in structure to amylopectin, but glycogen is more highly branched (Fig. 33).
- The molecular size is also higher than that of amylopectin (up to 100 000 000).



- Glycogen is present in fungi and the lower animals.
- In humans it is found in the liver and muscle cells in particles which are much smaller than starch granules in plant cells.

The role of glycogen in animal cells.



- When a human being consumes glucose in excess of the body needs, some of the surplus is converted to starch.
- It is for this reason, glycogen is sometimes referred to as animal starch, because it is similar in structure to amylopectin.
- Human beings store glycogen in the liver and muscle cells.
- In these locations it is quickly available for break down into glucose and subsequent energy production in the absence of an immediate energy source.
- Glycogen is not however, the major storage form of energy in humans.
- Fat deposits on the other hand play a major role as an energy reserve.

- When glycogen is acted upon in a cell by an enzyme like a **phosphorylase**, the action does not lead to the formation of glucose 1-phosphate.
- It is instead easily converted by enzymes into its isomer, fructose-6-phosphate, which enters directly into the respiratory pathway with minimum energy input.
- Hence the whole process is extremely efficient

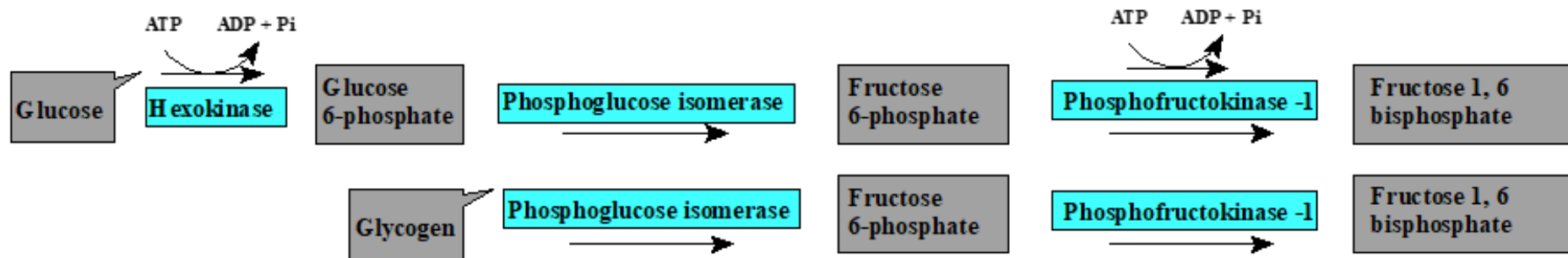
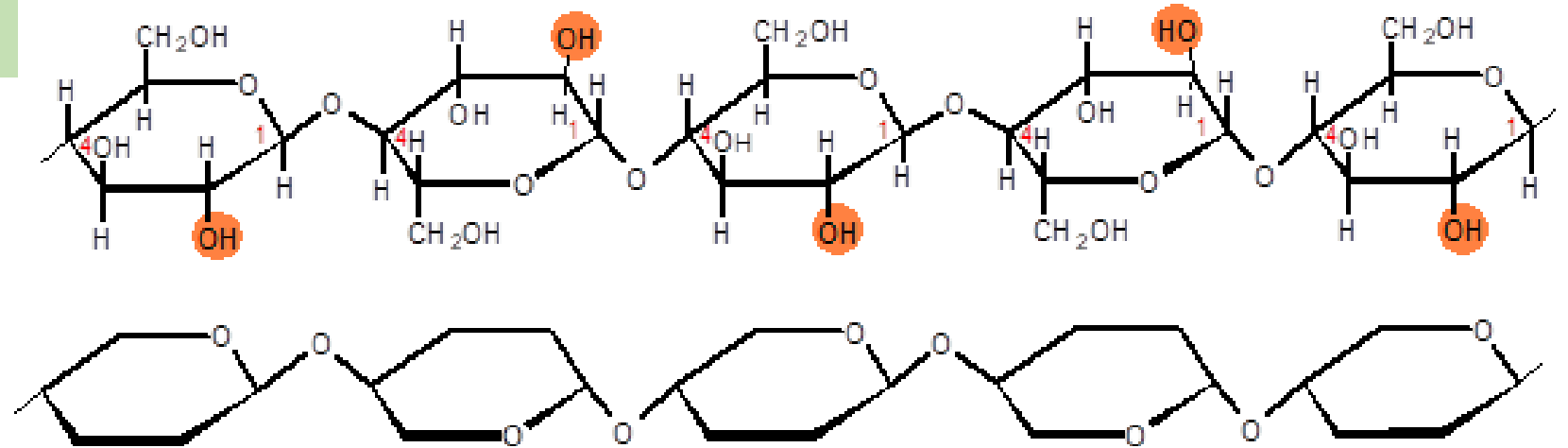


Fig. 34 Glucose is first converted to glucose 6 - phosphate, when glucose is the source of energy. However when glycogen acts as the raw material, fructose 6 -phosphate is the result with less use of energy.

Cellulose



Cellulose Molecule

Fig. 35 Polymer of cellulose showing β -1,4-linkage of glucose units.

- Cellulose is a polymer of a chain of cellobiose molecules. It is another important polysaccharide.
- It is used for structural support in cell walls of plants and many algae.
- More than half of all the carbon in higher plants is cellulose.
- Wood is chiefly cellulose.
- More than 90% of cotton is cellulose.
- The paper on which you write and read from is almost pure cellulose.

- Cellulose from primary plant cell walls is probably of lower molecular weight than from secondary structures. But it is estimated to have a value range of 2 000 to 14 000 glucose units for chains of natural cellulose.
- Cellulose is linear and is made up of only a single species of monosaccharide (glucose).
- It is made up of one type of linkage, the β (1-4) links of cellulose give rise to relatively rigid linear molecules which are able to align closely with their neighbouring molecules and the free hydroxyl groups of carbon 2,3 or 6 probably form hydrogen bonds with neighbouring chains which bind the molecules together.
- In this way the glucan chains are thought to be packed in orientated aggregates, with a definite structure, known as microfibrils.

Difference between Cellulose and Starch

- Cellulose is a major component of primary and secondary cell walls.
- It differs from starch in the way the glucose molecules are attached to one another.
- In starches, the glucose molecules are all oriented in the same way.
- In cellulose, the orientation of the glucose units alternate from one glucose molecule to the next.
- The difference in molecular structure is sufficient to prevent amylases to hydrolyse cellulose.
- It can only be digested by a group of enzymes called cellulases, which are produced by some bacteria, protozoa and a few invertebrates such as terrestrial snails.
- Humans do not produce enzymes that can digest cellulose.

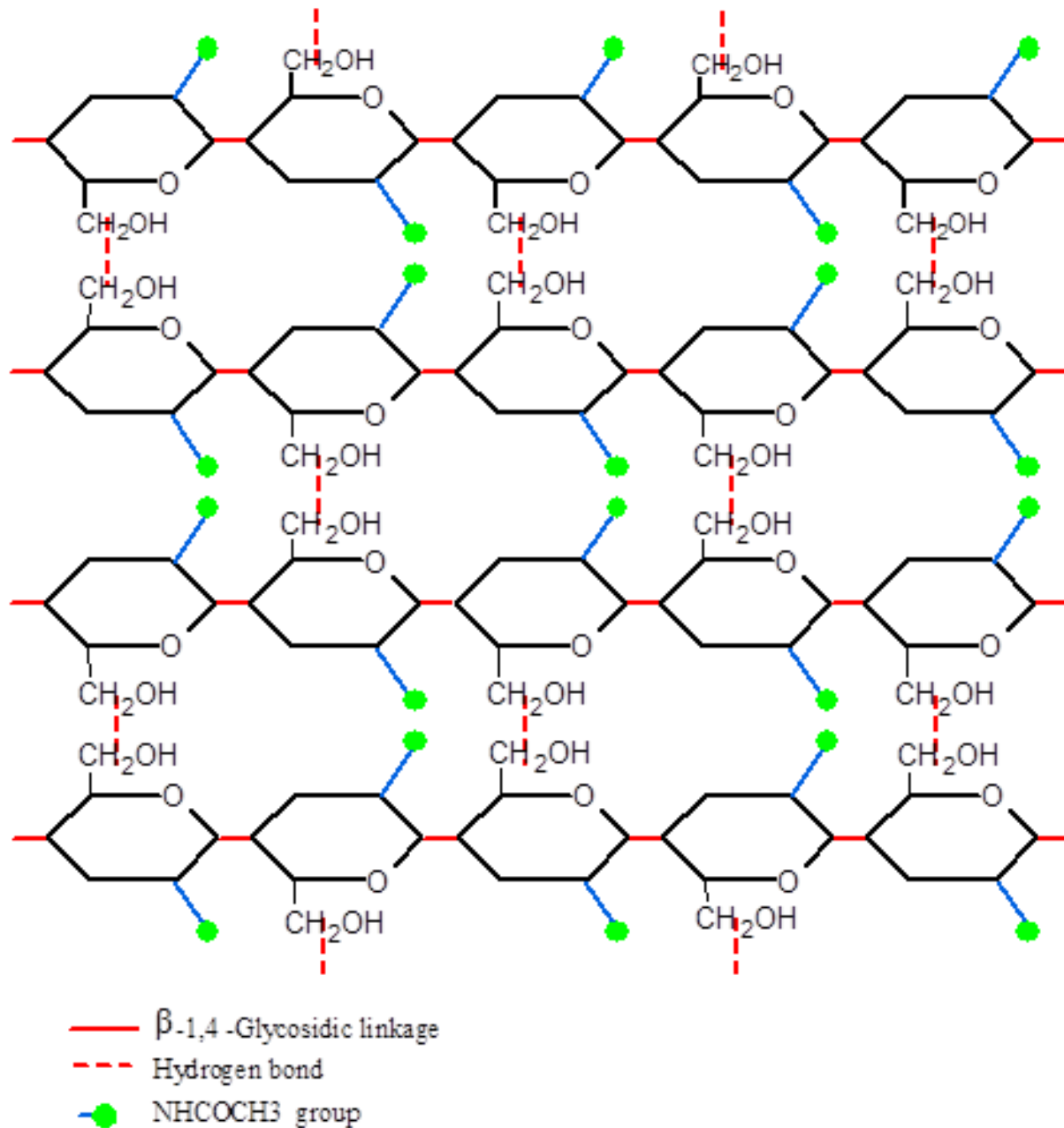


Fig. Chitin chemical structure

- Bacteria and fungi decompose chitin into simple sugars and ammonia.
- It is similar in structure to cellulose, except that the -OH on carbon C-2 is replaced by -NH.CO.CH_3 .

Home work

- Q1. Explain the difference between galactosemia and lactose intolerance.
- Q2. Explain the technique that can be applied to convert a non-reducing sugar such as sucrose into a reducing sugar.
- Q3. Use the word puzzle provided to improve your subject vocabulary.