BIOCHEMISTRY OF CARBOHYDRATES

Carbohydrates are the most abundant biomolecules on Earth. Each year, photosynthesis converts more than 100 billion metric tons of CO_2 and H_2O into cellulose and other plant products.

Basic functions of carbohydrates:

1. Certain carbohydrates (sugar and starch) are a principle source of energy
2. Insoluble carbohydrate polymers serve as structural and protective elements in the cell walls of bacteria and plants and in the connective tissues of animals.
3. Some carbohydrate polymers lubricate skeletal joints and
4. Some carbohydrates participate in recognition and adhesion between cells.
5. More complex carbohydrate polymers covalently attached to proteins or lipids act as signals that determine the intracellular location or metabolic fate of these hybrid molecules, called glycoconjugates**.**

There are three major size classes of carbohydrates:

1. Monosaccharides,
2. Diasaccharides,
3. Polysaccharides

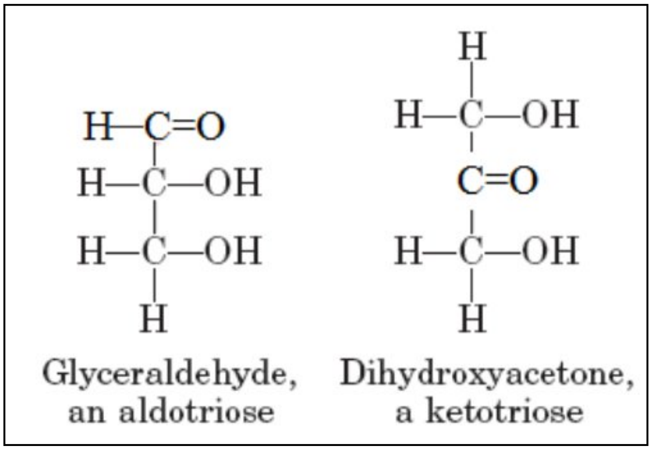
The word “saccharide” is derived from the Greek *sakcharon,* meaning “sugar”. **Monosaccharides,** or simple sugars, consist of a single polyhydroxy aldehyde or ketone unit. The most abundant monosaccharide in nature is the six-carbon sugar D-glucose, sometimes referred to as dextrose. Monosaccharides of more than four carbons tend to have cyclic structures.

When two join together by O-glycosidic bond is called Diasacharide E.g. Lactose, Maltose.

When more than 20 Monosaccharides join together they form Polysaccharide. (Oligosaccharides have more than two and less than 20 Monosaccharides)

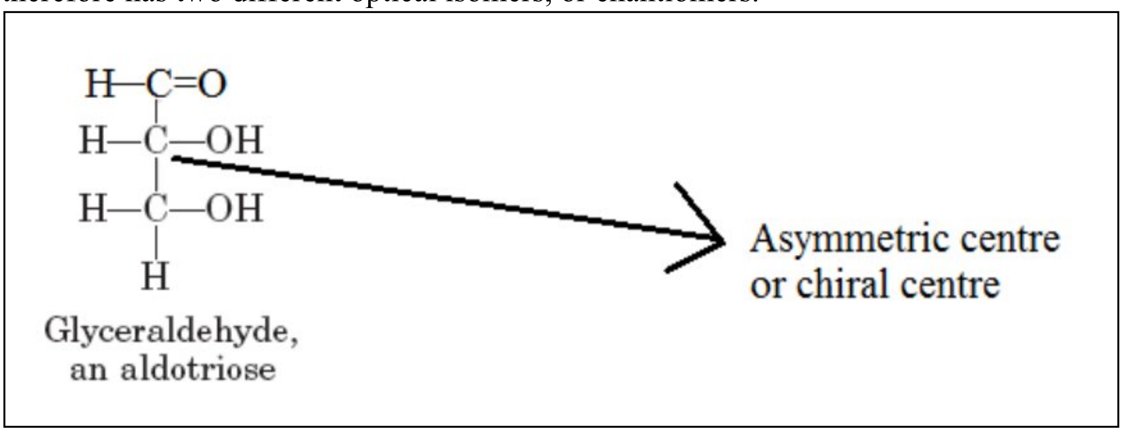
MONOSACCHARIDES AND DISACCHARIDES

There are two families of monosaccharides viz. Aldoses and ketoses. If the carbonyl group is at an end of the carbon chain (that is, in an aldehyde group) the monosaccharide is an **aldose;** if the carbonyl group is at any other position (in a ketone group) the monosaccharide is a **ketose.** The simplest monosaccharides are the two three-carbon trioses: glyceraldehyde, an aldotriose, and dihydroxyacetone, a ketotriose.



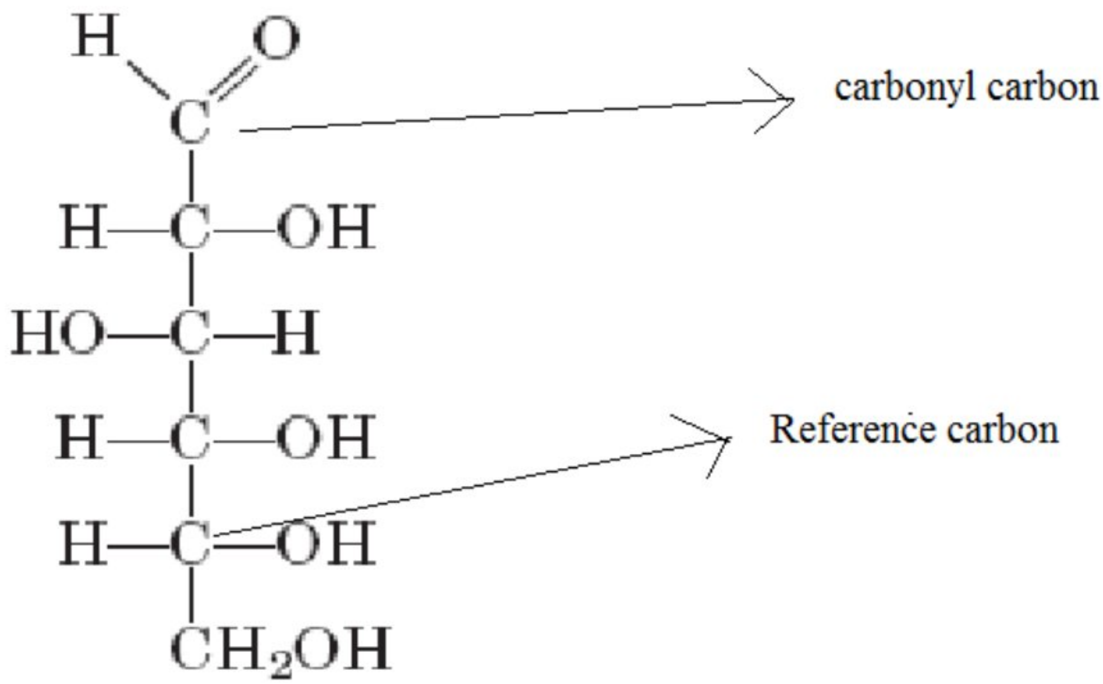
Monosaccharides with four, five, six, and seven carbon atoms are called, respectively, tetroses, pentoses, hexoses, and heptoses.
The D-glucose is called Aldohexose and D-fructose is called Ketohexose.

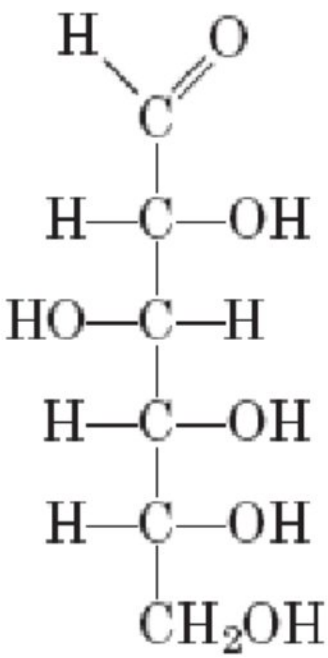
All the monosaccharides except dihydroxyacetone contain one or more asymmetric (chiral) carbon atoms and thus occur in optically active isomeric forms.
The simplest aldose, glyceraldehyde, contains one chiral center (the middle carbon atom) and therefore has two different optical isomers, or enantiomers.



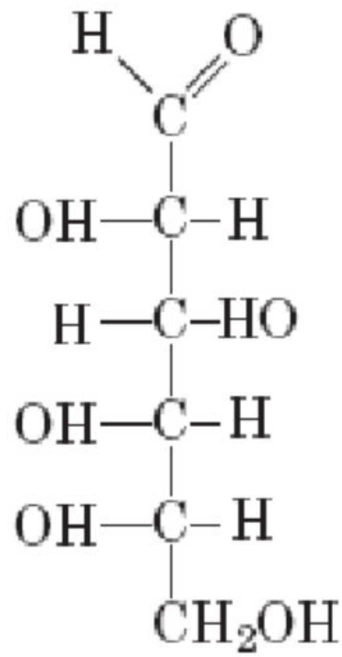
In general, a molecule with *n* chiral centers can have 2^n stereoisomers. Glyceraldehyde has $2^1 = 2$; the aldohexoses, with four chiral centers, have $2^4 = 16$ stereoisomers.

The stereoisomers of monosaccharides of each carbon-chain length can be divided into two groups that differ in the configuration about the chiral center (called reference carbon) *most distant* from the carbonyl carbon. When the OH group in reference carbon is on the left side, it is designated as l-form and when in right hand side is designated as d-form.

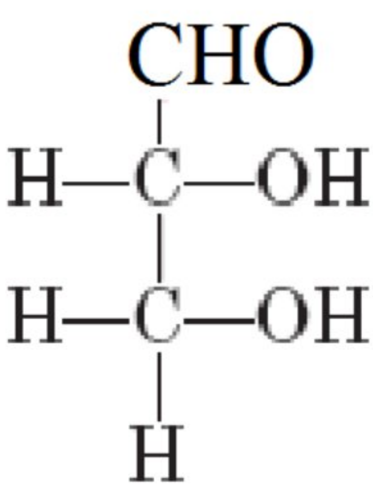

carbonyl carbon
Reference carbon



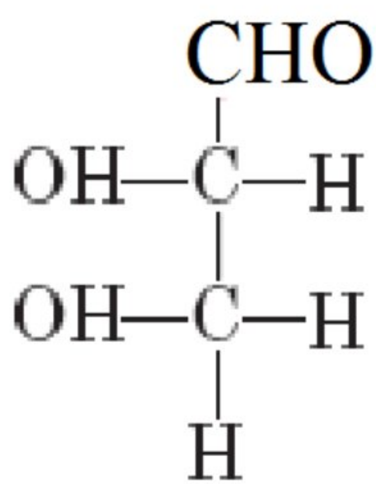
D-form of monosaccharide



L-form of monosaccharide

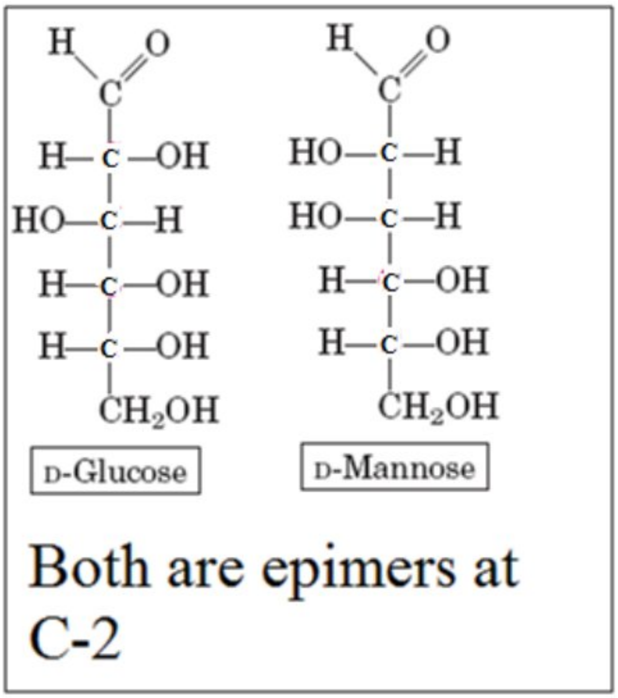


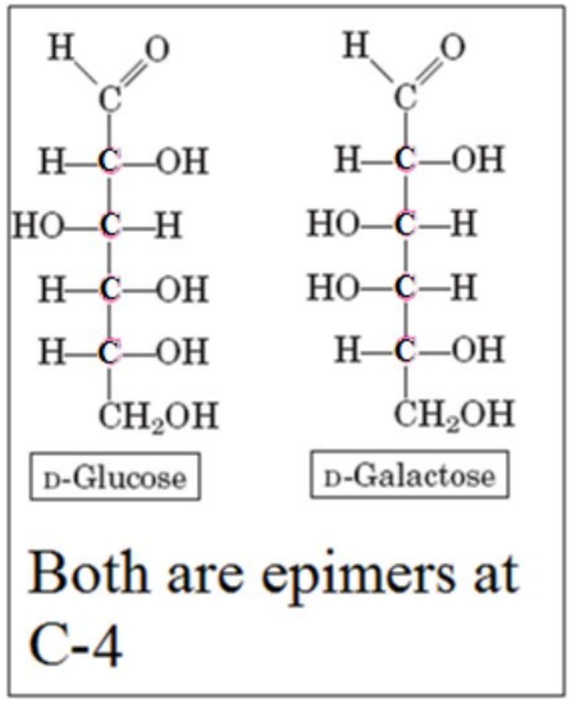
L-glyceraldehyde



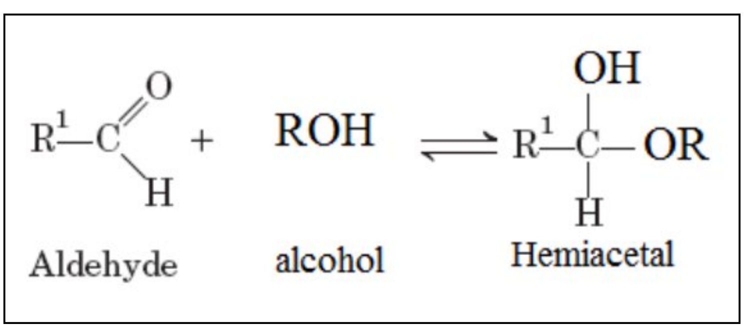
D-glyceraldehyde

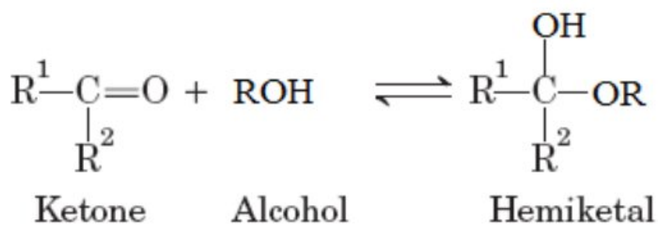
The carbons of a sugar are numbered beginning at the end of the chain nearest the carbonyl group. Each of the eight D-aldohexoses, which differ in the stereochemistry at C-2, C-3, or C-4, has its own name: D-glucose, D-galactose, D-mannose, and so forth.
The four- and five-carbon ketoses are designated by inserting "ul" into the name of a corresponding aldose; for example, D-ribulose is the ketopentose corresponding to the aldopentose D-ribose.
Two sugars that differ only in the configuration around one carbon atom are called **epimers;** D-glucose and D- mannose, which differ only in the stereochemistry at C-2, are epimers, as are D-glucose and D-galactose (which differ at C-4).

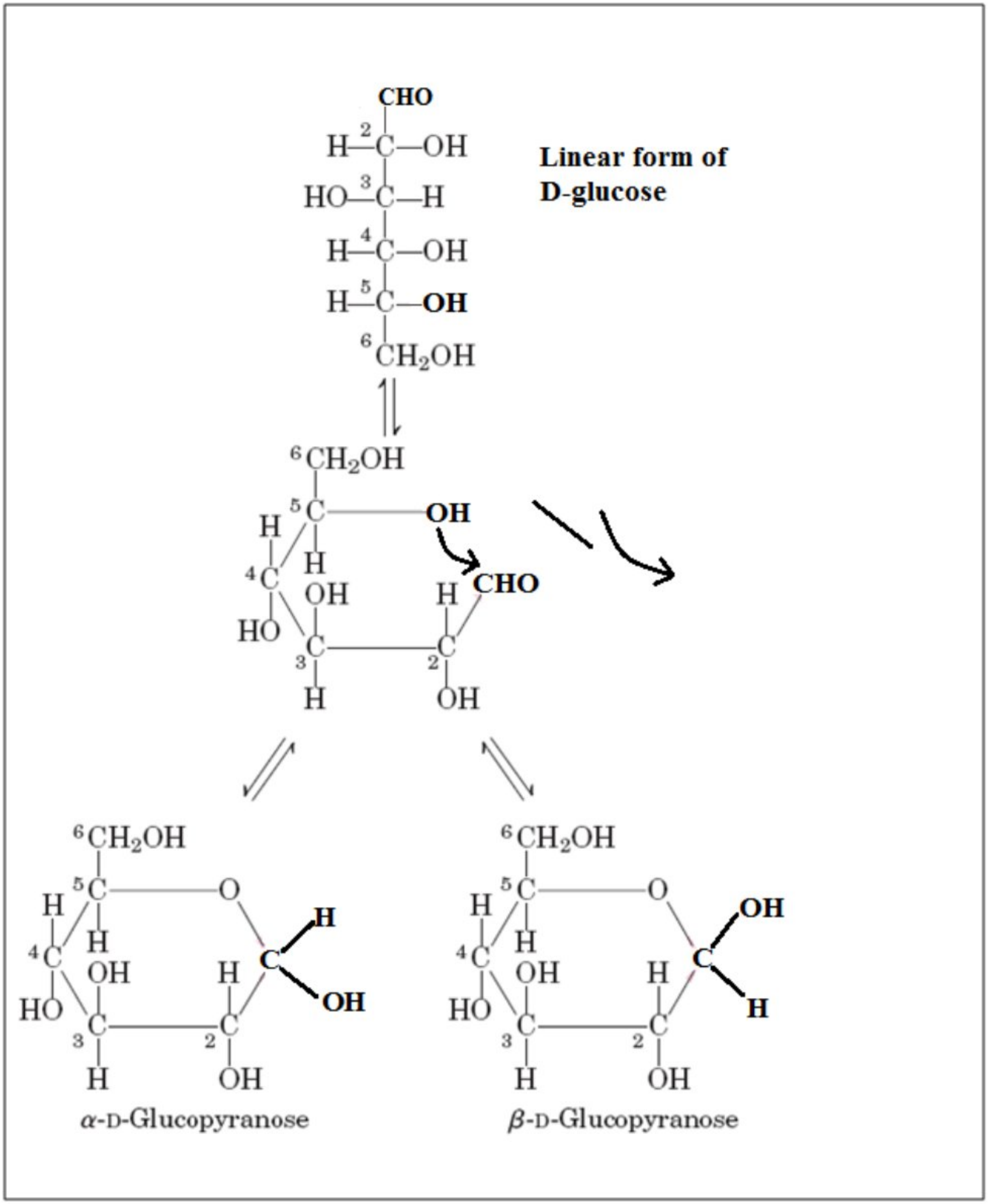




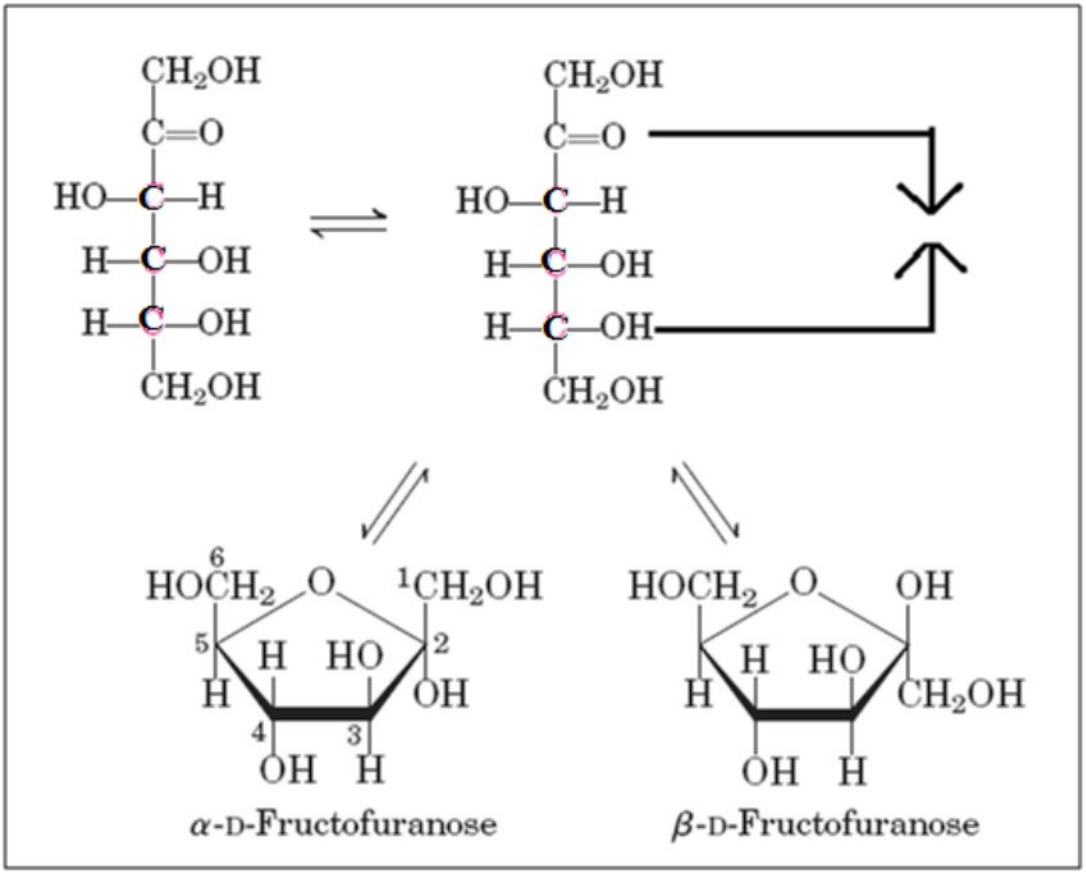
In aqueous solution, most of the monosaccharides having more than 4 or 5 carbon atoms exist in cyclic form. The cyclic structure is formed by formation of covalent bond between carbonyl carbon and oxygen atom of hydroxyl group of another carbon atom within a same molecule. This formation of ring structure is due to a general reaction between aldehyde or ketone and alcohol.



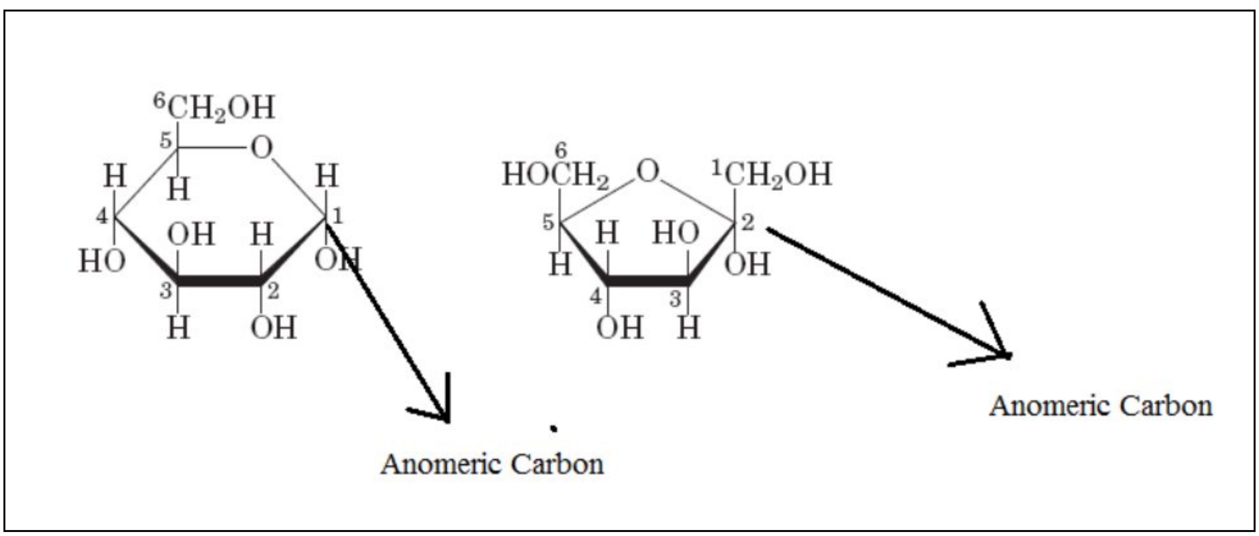

Ketone
Alcohol
Hemiketal



In case of glucose, the first carbon (Carbonyl Carbon) reacts with the oxygen of fifth carbon to form the cyclic ring structure. The cyclic structure is 6 member ring structure.

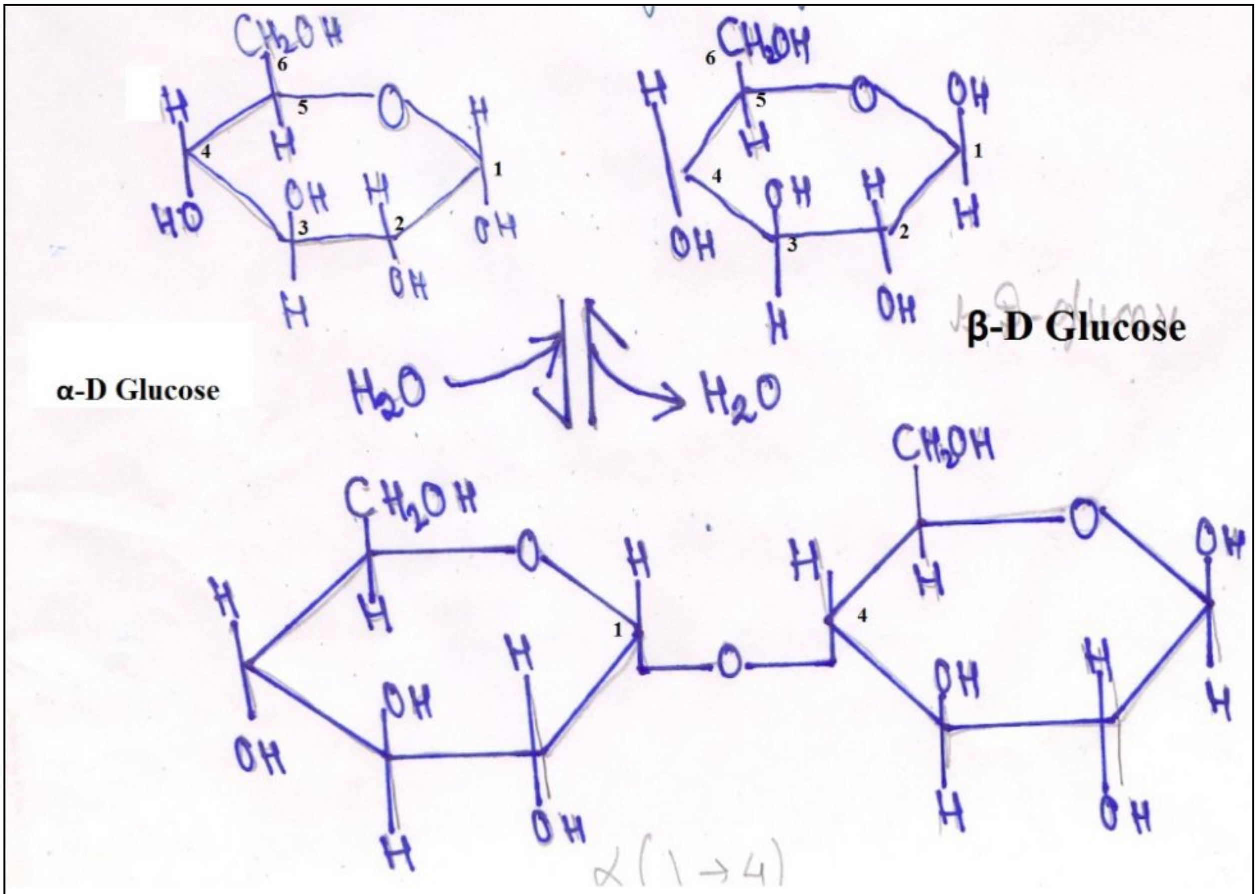


Isomeric forms of monosaccharides that differ only in their configuration about the hemiacetal or hemiketal carbon atom are called **anomers.** The hemiacetal (or carbonyl) carbon atom is called the **anomeric carbon.** In case of monosaccharides the anomeric carbon is the carbonyl carbon.



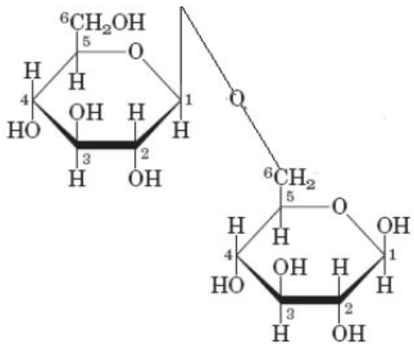
DIASACCHARIDES

When two monosaccharides are joined together through a covalent bond called O-glycosidic bond, they form diasaccharide. The O-glycosidic bond is formed when a hydroxyl group of one sugar reacts with the anomeric carbon of the other. When an anomeric carbon participates in a glycosidic bond, the sugar cannot assume the linear form. The end of diasaccharide or polysaccharide that has the free anomeric carbon atom is called reducing end. The glycosidic bonds are readily cleaved by acid but resists cleavage by alkalis.



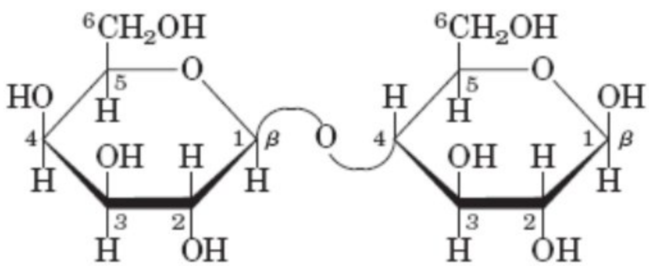
Maltose

α-D-glucopyranosyl-(1→4)-D-glucopyranose



α-D-glucopyranosyl-(1→6)-D-glucopyranose

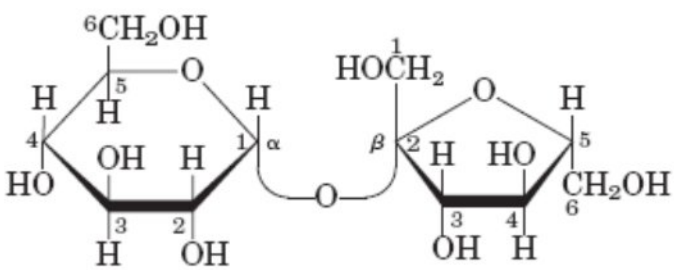
Isomaltose



Lactose (β form)

β-D-galactopyranosyl-(1→4)-β-D-glucopyranose

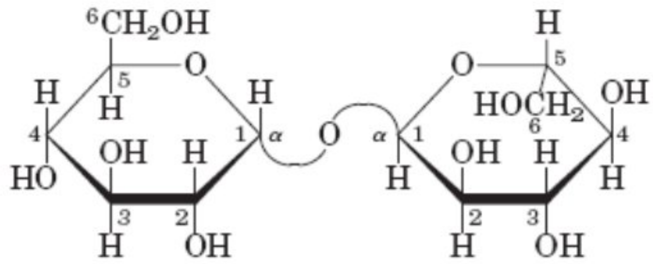
Gal(β1→4)Glc



Sucrose

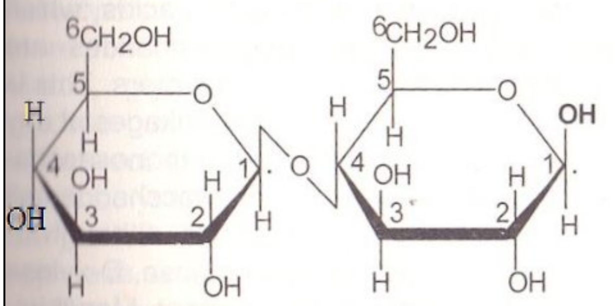
α-D-glucopyranosyl β-D-fructofuranoside

Glc(α1↔2β)Fru



Trehalose
α-D-glucopyranosyl α-D-glucopyranoside
Glc(α1↔1α)Glc

Cellobiose



β-D-Glucopyronosyl-(1→4)- β-D-Glucopyronoside

POLYSACCHARIDES

Polysaccharides also called glycans. The two types of polysaccharides are Homo-polysaccharides and Hetero-polysaccharides. Homo polysaccharides act as storage fuels such as starch, glycogen and as structural polysaccharides such as cellulose, chitin. The Hetero polysaccharides function as extra-cellular support. E.g. Bacterial cell wall.

HOMO-POLYSACCHARIDES

- Starch: polymer of α-D glucose linked by α(1→4) glycosidic linkage. It is comprised of two types of components viz. Amylase and amylopectin. The amylase is an unbranched chain. And amylopectin is highly branched. The frequency of branching is 24 to 30 residues. The branching involves at α(1→6) glycosidic linkage.
- Glycogen: polymer of α-D glucose linked by α(1→4) glycosidic linkage. It is storage polysaccharide of animals. It is highly branched (one branch per 8-12 residues). It is more compact than starch. It is present mainly in liver and skeletal muscles. Each branch of glycogen ends with a non-reducing monosaccharide (one without a free anomeric carbon). the polymers are tightly coiled helical structure.
- Cellulose: Structural polysaccharide.
    - Made of β-D glucose, linked by β (1→4) glycosidic linkage
    - Straight chains (not helical structure like that of polymers of α-D glucose)
    - *Most abundant polymer*

- Chitin:
    - Structural polysaccharide.
    - Made of β-D-N-Acetly-Glucosamine, linked by β (1→4) glycosidic linkage.
    - Principal component of exoskeleton of arthropods.
    - *Second Most abundant polymer after cellulose.*

HETERO-POLYSACCHARIDES

1. Bacterial cell wall is made of N-acetyl Glucosamine and N-acetyl muramic acid having β(1→4) linkage. The β chains are linked by pentaglycine in Gram Positive bacteria. In Gram negative bacteria, the β chains are linked by D-Alanine. The enzyme lysozyme present in tears breaks the having β(1→4) linkage for disrupting the bacterial cell wall to kill the bacteria. The antibiotics kills bacteria by preventing the synthesis of cross linkers.

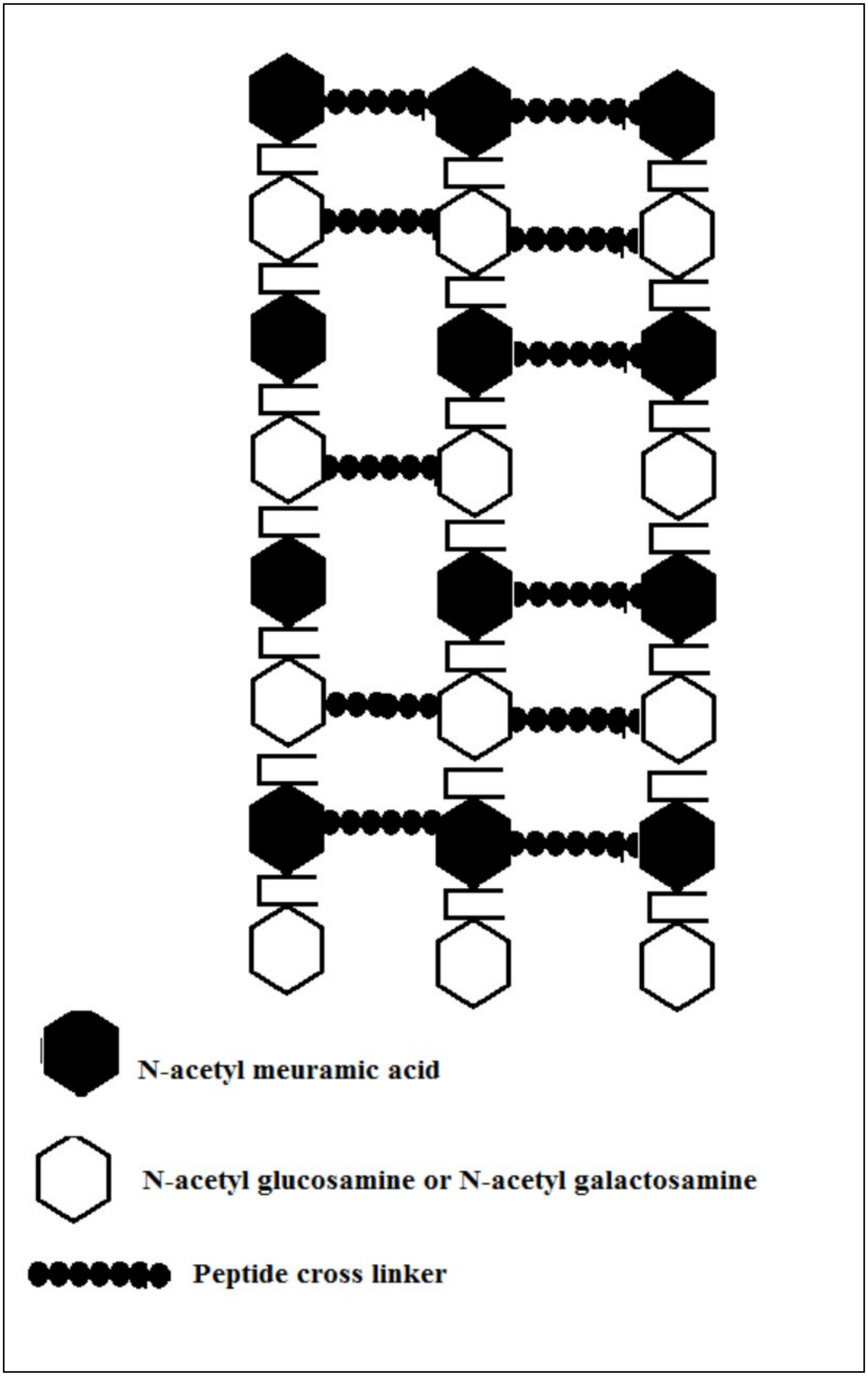
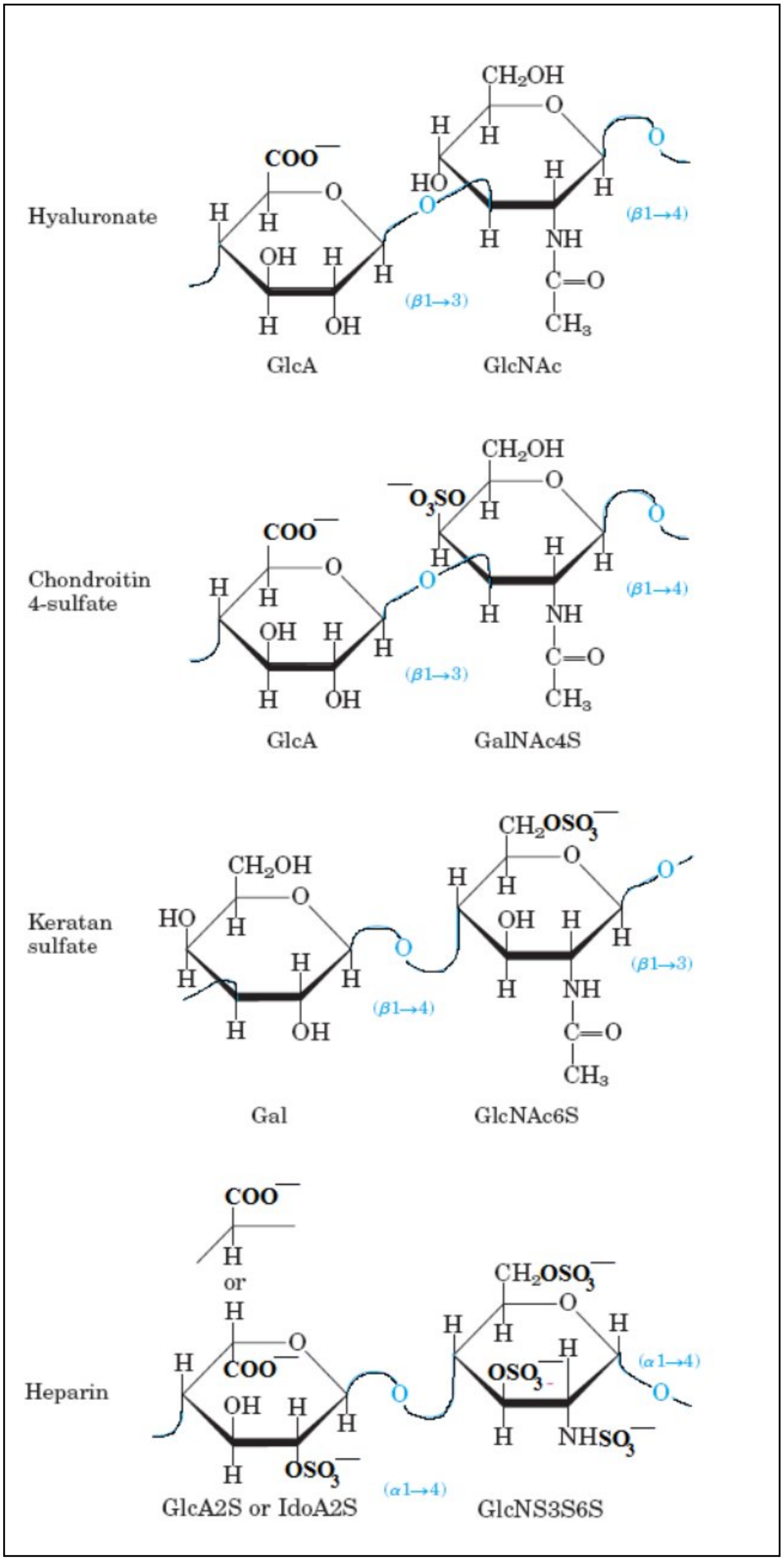


Fig: Peptidoglycan layer of bacterial cell wall.

2. Glycosaminoglycans or the mucopolysaccharides:
    - Repeating diasaccharides.
    - Gel like consistency that fills the space between cells (Extracellular matrix).
    - Commonly made of N-acetyl-glucosamine or N-acetyl galactosamine and glucuronic acid. E.g. Hyaluronate, Chondroitin Sulphate, Keratine Sulphate.
    - Some of the glycosaminoglycans have sulphate groups. The combination of sulphate and carboxylate groups give them negative charge. In order to minimize the repulsive forces of negatively charges, they form extended helical structure so that the negatively charged carboxylate groups or the sulphate groups form helical structures.


Hyaluronate
GlcA
GlcNAc
(β1→3)
(β1→4)
Chondroitin 4-sulfate
GlcA
GalNAc4S
(β1→3)
(β1→4)
Keratan sulfate
Gal
GlcNAc6S
(β1→4)
(β1→3)
Heparin
GlcA2S or IdoA2S
GlcNS3S6S
(α1→4)
(α1→4)

GLYCONJUGATES

The carbohydrates are covalently joined to a protein or lipid to form a glycoconjugate.

a) Proteoglycans: the glycosamino-glycans are covalently linked to a membrane protein or secreted protein. It is the main component of connective tissues.
b) Glycoproteins: one or several oligosaccharides joined covalently to a protein. They generally act as a signalling molecules. They are present in on outer surface of plasma membrane, extracellular matrix, blood etc.
c) Glycolipids:
    - These are membrane lipids.
    - The oligosaccharides are covalently attached to lipid as polar head group.
    - They act as specific sites for recognition by carbohydrate-binding proteins.