II- CARBOHYDRATES OF BIOLOGICAL IMPORTANCE

ILOs:

By the end of the course, the student should be able to:

1. *Define carbohydrates and list their classification.*
2. *Recognize the structure and functions of monosaccharides.*
3. *Identify the various chemical and physical properties that distinguish monosaccharides.*
4. *List the important monosaccharides and their derivatives and point out their importance.*
5. *List the important disaccharides, recognize their structure and mention their importance.*
6. *Define glycosides and mention biologically important examples.*
7. *State examples of homopolysaccharides and describe their structure and functions.*
8. *Classify glycosaminoglycans, mention their constituents and their biological importance.*
9. *Define proteoglycans and point out their functions.*
10. *Differentiate between glycoproteins and proteoglycans.*

CONTENTS:

CARBOHYDRATES OF BIOLOGICAL IMPORTANCE

Chemical Nature of Carbohydrates

Carbohydrates are polyhydroxyalcohols with an aldehyde or keto group. They are represented with general formulae $\mathbf{C_n(H_2O)_n}$ and hence called hydrates of carbons.

Biomedical importance of Carbohydrates

Carbohydrates are the most abundant organic molecules in nature. They have a wide range of functions, including:

- Providing a significant fraction of the dietary calories for most organisms.
- Acting as a storage form of energy in the body.
- Serving as cell membrane components that mediate some forms of intercellular communication.

Classification of Carbohydrates

Carbohydrates are classified according to the hydrolysis products into four main groups as follows:

I- Monosaccharides: contain one monosaccharide unit.
II- Disaccharides: contain 2 monosaccharide units per molecule.
III- Oligosaccharides: contain from 3 to 10 monosaccharide units per molecule.
IV- Polysaccharides: contain more than 10 monosaccharide units per molecule.

I- MONOSACCHARIDES

Monosaccharides are the simplest group, having the general formula $\mathbf{(CH_2O)_n}$. They are classified according to:-

A) **The number of carbons** in the molecule into trioses (3 carbons), tetroses (4 carbons), pentoses (5 carbons), hexoses (6 carbons) and heptoses (7 carbons).

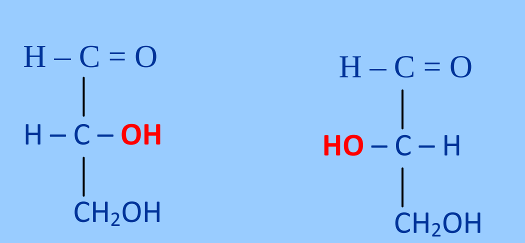
B) **The presence of aldehyde or ketone group** into aldoses and ketoses.

I – Aldoses:

The mother compound of all aldoses is the aldotriose glyceraldehyde. Other aldoses can be formed theoretically; by insertion of secondary alcohol groups (H-C-OH) below the aldehydic group of glyceraldehyde.

All sugars derived from **D-glyceraldehyde** are called **D-sugars**, as indicated by having the hydroxyl group of the penultimate carbon atom (the carbon atom before the last) to the right, while those derived from **L-glyceraldehyde** are called **L- sugars** (contain hydroxyl group on the left side of the penultimate carbon atom). **Most of the naturally occurring monosaccharides are of the D type.**

Aldotrioses



D-Glyceraldehyde L-Glyceraldehyde

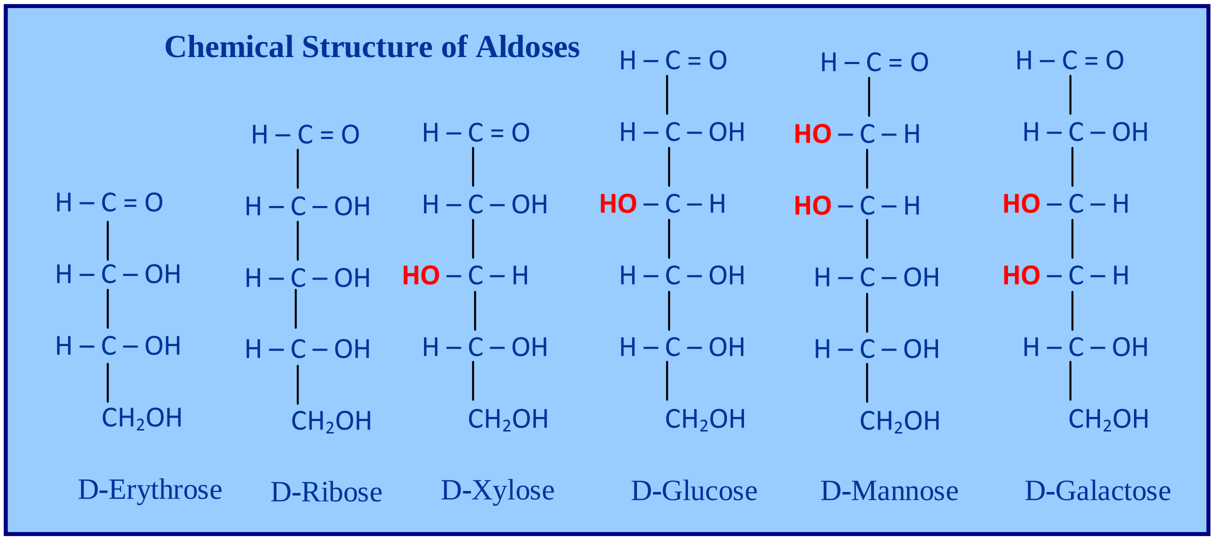
Aldoses are further classified according to the number of carbon atoms present into:

1. Aldotrioses(C3) e.g.D- glyceraldehyde.

2. Aldotetroses (C4) e.g. D-erythrose.

3. Aldopentoses (C5) e.g. D-ribose and D-xylose.

4. Aldohexoses (C6) e.g. D-glucose, D-mannose and D-galactose.



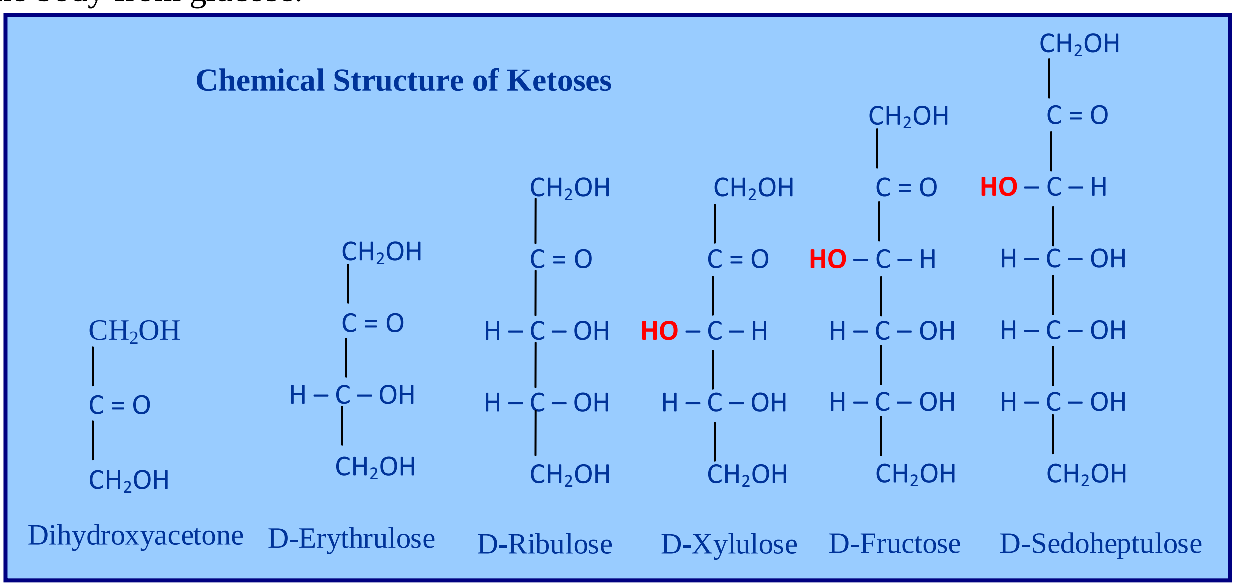
II –Ketoses:

All ketoses have two terminal primary alcohol groups (CH_2OH) and have one ketone group (C=O).The simplest ketose is dihydroxyacetone (C3). Other ketoses are formed, theoretically, by the insertion of secondary alcohol groups below the ketonic group. Ketoses are further classified according to the number of carbon atoms present into:

1.Ketotrioses (C3): dihydroxyacetone. **2.Ketotetroses** (C4) e.g. D-erythrulose.

3.Ketopentoses (C5) e.g. D-ribulose. **4.Ketohexoses** (C6) e.g. D-fructose.

5. D-Sedoheptulose is the only one in human that contains seven carbons; it is formed in the body from glucose.



Forms of Isomerism of Monosaccharides

1. Optical isomers (D and L-sugars) :

Assymetric carbon atoms are those attached to four different atoms or groups. All monosaccharides contain one or more asymmetric carbon atoms except dihydroxyacetone. Stereoisomers are isomeric molecules that have the same molecular formula and sequence of bonded atoms (constitution), but differ in the three-dimensional orientations of their atoms in space.

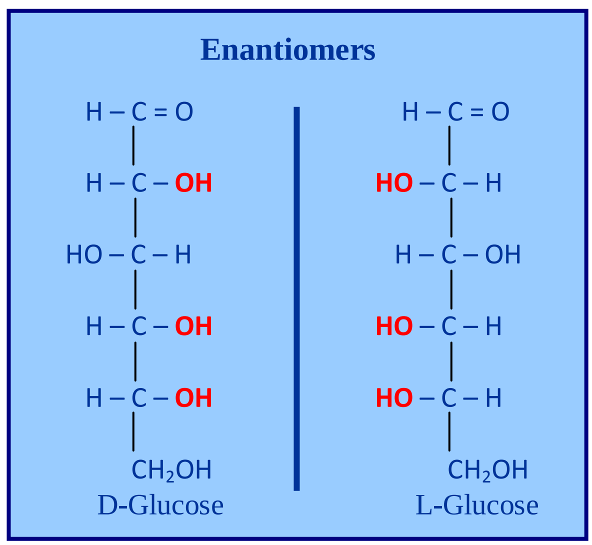
- The number of optical isomers depends on the number of asymmetric carbon atoms. **The number of these isomers = 2^n** (n = the number of asymmetric carbon atoms in the molecule).

-**Aldotrioses** contain one asymmetric carbon atom, so they have 2 isomers (D and L-glyceraldehyde). ***Aldotetrose*** *contain two asymmetric carbon atoms, so they have 4 isomers (2 in the D-form and 2 in the L-form).* ***Aldopentoses*** *contain three asymmetric carbon atoms, so they have 8 isomers (4 in the D-form and 4 in the L-form).* ***Aldohexoses*** *contain four asymmetric carbon atoms, so they have 16 isomers (8 in the D-form and 8 in* ***the L-form).***

- **In case of ketoses**, the number of asymmetric carbon atoms is less by one compared to the corresponding group of aldoses. **Ketotetroses** contain one asymmetric carbon atom, so they have 2 isomers (D and L). ***Ketopentoses*** *contain two asymmetric carbon atoms, so they have 4 isomers.* ***Ketohexoses*** *contain three asymmetric carbon atoms, so they have 8 isomers. Also, half of these isomers is in the D form and the other half in the L-form.*

-**Most of the monosaccharides occurring in mammals are D sugars**, and the enzymes responsible for their metabolism are specific for this configuration**.**

- **Enantiomers:** They are the D- and L- forms of the same compounds (mirror images) eg. D and L-glucose.



-**Optical Activity** is the ability of a substance (containing asymmetric carbon atom) to **rotate the plane polarized light (PPL).**

-If the rotation is to the right, it is termed **dextrorotation**, and designated by the small letter "d" or by the plus sign (+). For example, naturally occurring D-glucose is dextrorotatory is designated as D (+) glucose (+52.5°) and is also called **dextrose**.

-If the rotation is to the left, it is termed **levorotation** and designated by the small letter "**l**" or by the minus sign **(-).** For example, naturally occurring D-fructose which is levorotatory is designated as **D (-) fructose** (-92.3°) and is also called **levulose**.

-All monosaccharides are optically active (each one has its specific and characteristic degree of rotation of PPL) except, dihydroxyacetone (has no asymmetric carbon atoms).

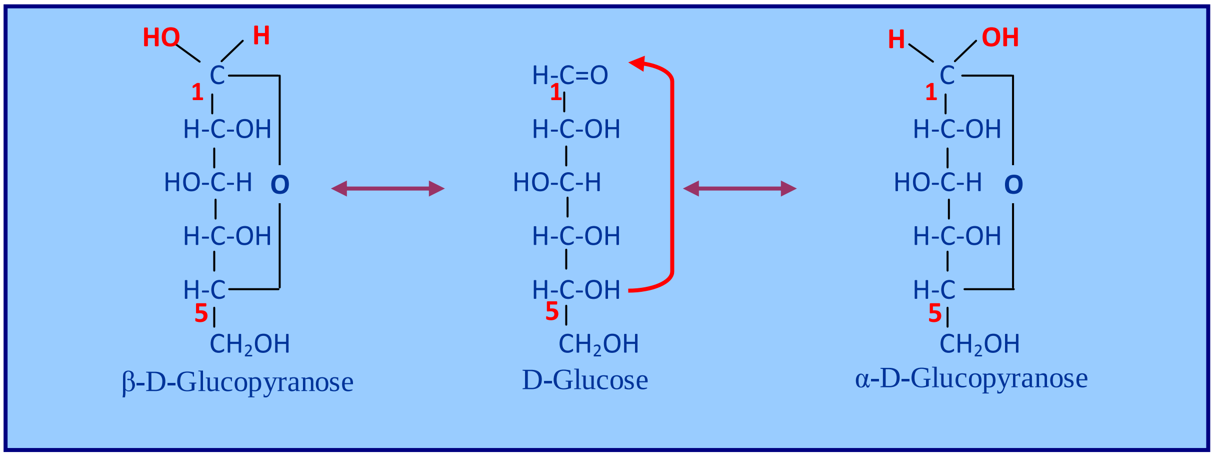
2. Anomers (cyclic structure of monosaccharides):

-**In solution**, the functional **aldehyde** group of glucose combines with **hydroxyl** group of 5^{th} carbon atom. As a result, a 6 membered heterocyclic **pyranose ring** structure containing 5 carbons and one oxygen is formed. The linkage between the aldehyde group and alcohol group is called '**hemiacetal**' linkage.

- Similarly, a 5 membered **furanose ring** structure is formed from fructose when its keto group combines with hydroxyl group on 5^{th} carbon atom. The linkage between the keto group and alcohol group is called '**hemiketal**' linkage.

-In either case, a new asymmetric carbon is created by the reaction and known as the **anomeric carbon** and the two possible configurations as **anomers**.

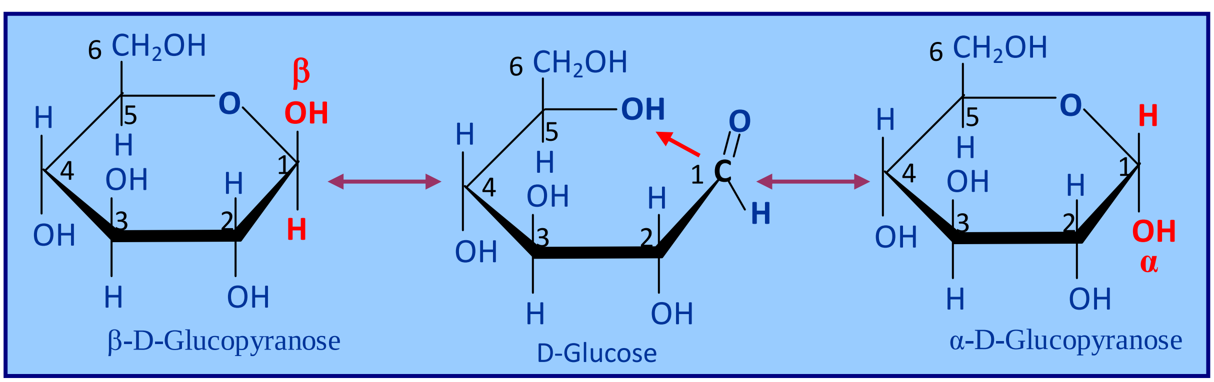
-Cyclization creates a carbon with two possible orientations of the hydroxyl group around it (**α-form and β-form**). In case of D-sugars, the α-form has the OH group to the right of the anomeric carbon and the β- form has the OH group to the left of the anomeric carbon.



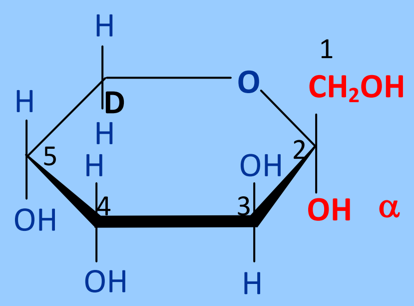
***Haworth** described the furanose or pyranose rings with the edge of the ring nearest to the reader is presented by thick lines, groups which are on the left side of straight structure are projected upwards, and groups on the right side of the straight structure are projected downwards. In case of D-sugars C6 is projecting upwards and in L-sugars C6 is projecting downwards.*

- In case of D-Glucose:

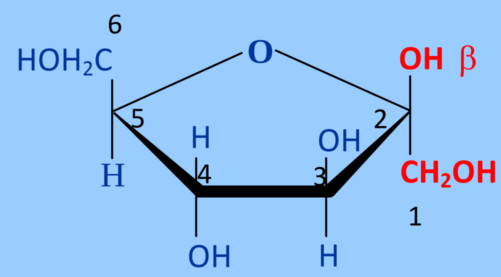
Glucose in solution is present as one third in the α form and two third in the β form at 20°C and traces in the aldehyde form. The latter is formed as intermediate during the conversion between the other two forms.



-In case of D-Fructose:
It is present in two cyclic forms:
a- Furanose is formed due to the cyclization between C5 and C2, and it is present in the disaccharide (sucrose) and polysaccharide (inulin).
b- Pyranose is formed due to the cyclization between C6 and C2, and it is present in this form when it is free in solution.

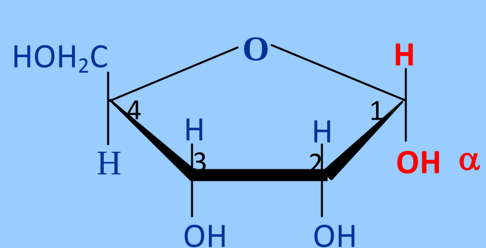


α-D-Fructopyranose

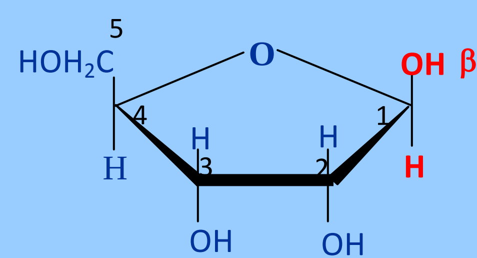


β-D-Fructofuranose

- In case of D- Ribose: cyclization occurs between C4 and C1.



α-D-Ribofuranose



β-D-Ribofuranose

3. Epimers:
-They are compounds which have more than one asymmetric carbon and differ only in the configuration around one carbon.
- Examples: - D-Glucose and D-mannose are epimers at C2.
- D-Glucose and D-galactose are epimers at C4.
-**Anomers** are epimers at C1 of cyclic aldoses and C2 of cyclic ketoses.

4. Aldose-Ketose Isomers (Functional Group Isomerism):
-They have the same molecular formulae but differ in their functional groups.
-For example: Fructose is a functional group isomer of glucose, galactose or mannose.

Important Monosaccharides

1- Trioses: Glyceraldehyde 3-phosphate and dihydroxyacetonephosphate are intermediates during glucose oxidation in living cells.

2- Tetroses : Erythrose 4-phosphate is formed during glucose oxidation in living cells.

3- Pentoses :

- **D-ribose** is a component of many nucleosides and nucleotides and ribonucleic acids (RNA).
- **2-deoxyribose** is a component of deoxyribonucleic acid (DNA).

4- Hexoses :

- **D-glucose (grape sugar)** is the main sugar present in blood and is present in all animal and plant cells, honey and fruits. It enters in the formation of many disaccharides and polysaccharides. It is also termed **dextrose** because it is dextrorotatory.
- **D-fructose (fruit sugar)** is present in honey, fruits and semen. It is a component of sucrose and inulin. It is also termed **levulose** because it is levorotatory.
- **D-galactose** is a component of lactose which is present in milk. It is also found in glycosaminoglycans (GAGS), glycolipids and glycoproteins.

Monosaccharide Derivatives

1- Sugar acids:

a- Aldonic acids:

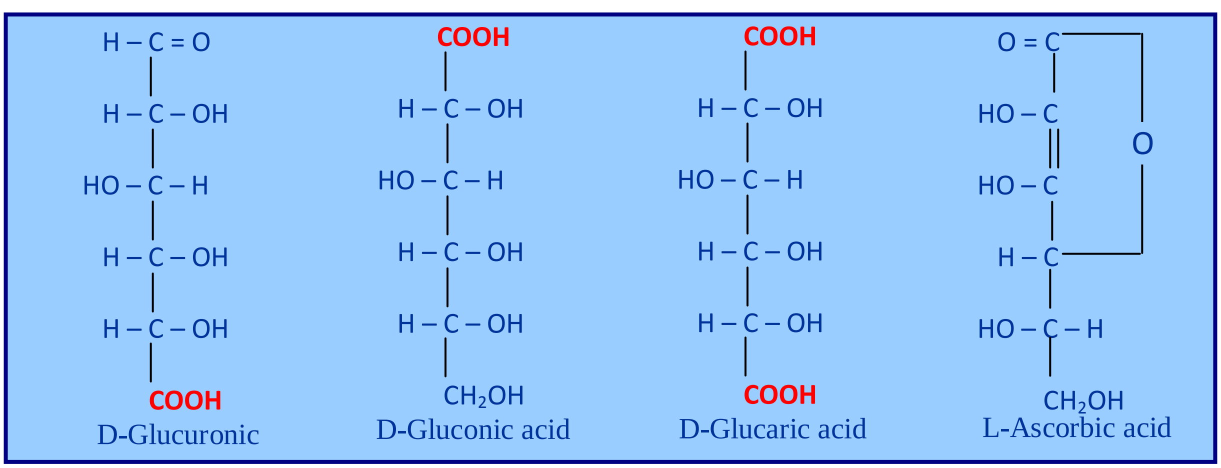
The aldehyde group of aldoses is oxidised to form the corresponding aldonic acid.

- *Glucose is oxidised to form **gluconic acid***
- *Galactose is oxidised to form **galactonic acid**.*

b- Uronic acids :

The primary alcohol group of monosaccharides is oxidised to form the corresponding uronic acid.

- Glucose is oxidised to form **glucuronic acid (GlcUA)**.
- Galactose is oxidised to form **galacturonic acid (GalUA).**



c- Aldaric acids:

These are monosaccharides in which both the aldehyde and primary alcohol groups are oxidised to form the corresponding aldaric acid e.g. glucose gives ***glucaric acid.***

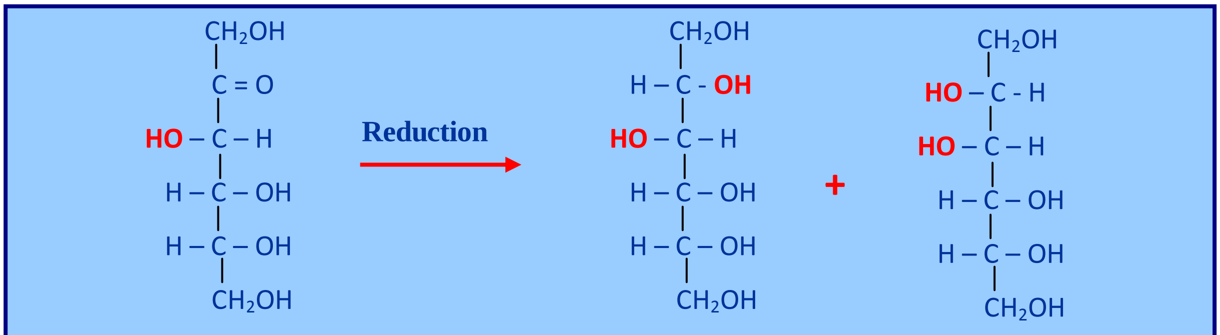
d- L-Ascorbic acid (Vitamin C):

It is formed in some animals (not humans) from glucose. It is considered as a sugar acid.

2- Sugar Alcohols:

-These are sugars in which the carbonyl group is reduced to alcohol group. **Sorbitol** is the alcohol of glucose, **dulcitol** is the alcohol of galactose and **mannitol** is the alcohol of mannose.

-The reduction of ketones produces 2 epimeric alcohols.



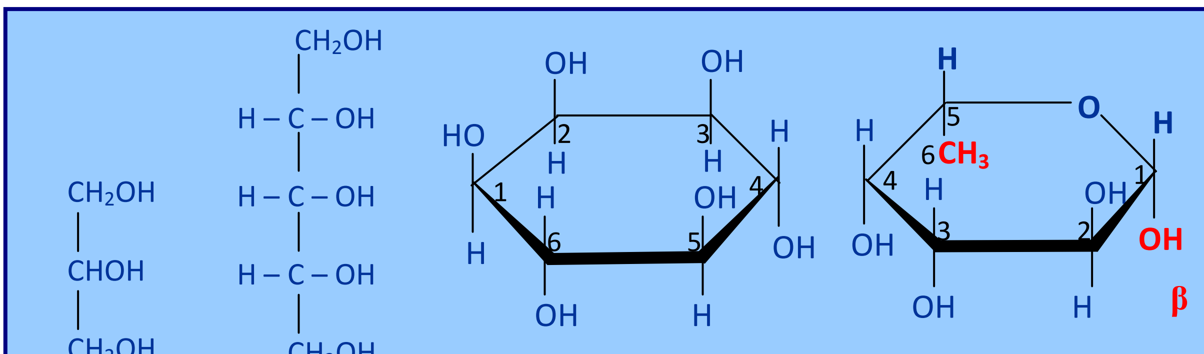
D-Fructose D-Sorbitol D-Mannitol

Important members of sugar alcohols:

a- Glycerol: It is the alcohol of glyceraldehyde or dihydroxyacetone. It is a component of triacylglycerol and most phospholipids.

b- Ribitol: It is the alcohol of ribose. It is a component of riboflavin (vitamin B_2).

c- Myo-inositol: *It is found in animal tissues. It is one of the isomers of inositol which is hydroxylated cyclohexane. It is a component of a phospholipid termed lipositol (phosphatidyl inositol). In plants, it is found as its hexaphosphate derivative known as phytic acid.* ***.*** *Phytic acid inhibits the absorption of* Ca^{2+}*,* Mg^{2+}*,* Cu^{2+} *and* Fe^{2+} *from the intestine due to the formation of insoluble salts.*



Glycerol Ribitol Myo-Inositol β-L-Fucose

3- Deoxysugars :

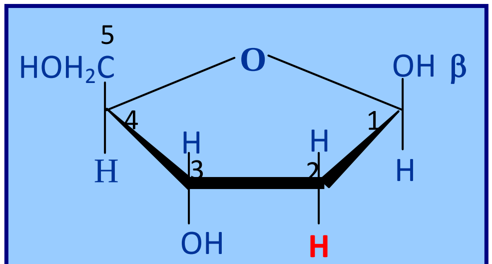
These are sugars in which the hydroxyl group is replaced by a hydrogen atom. The most important examples are:

a- 2-deoxy ribose:

It is present in the structure of DNA.

b- L-Fucose (6-deoxy-L-galactose):

It is present in some cell membrane glycoproteins and blood group antigens.



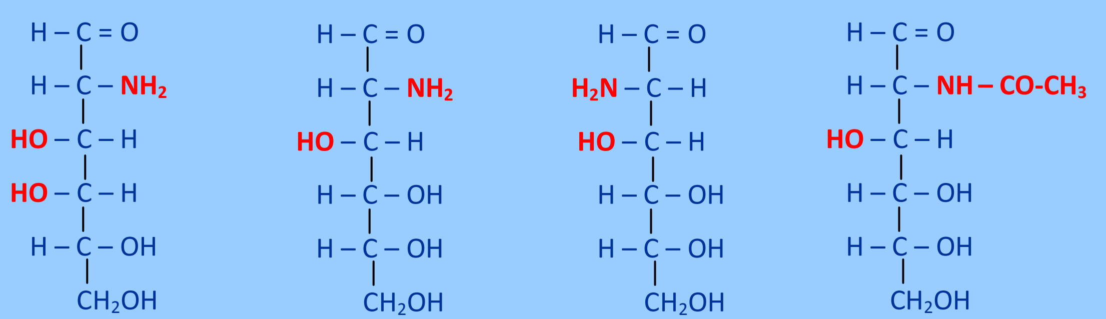
2-Deoxy-Ribose

4- Aminosugars :

-These are sugars in which an amino group (NH_2) replaces the hydroxyl group on the second carbon e.g. glucosamine (GluN), galactosamine (GlaN) and mannosamine (ManN)

-Aminosugars are important constituents of glycosaminoglycans (GAGs) and some types of glycolipids and glycoproteins.

-Several antibiotics contain aminosugars which are important for their antibiotic activity

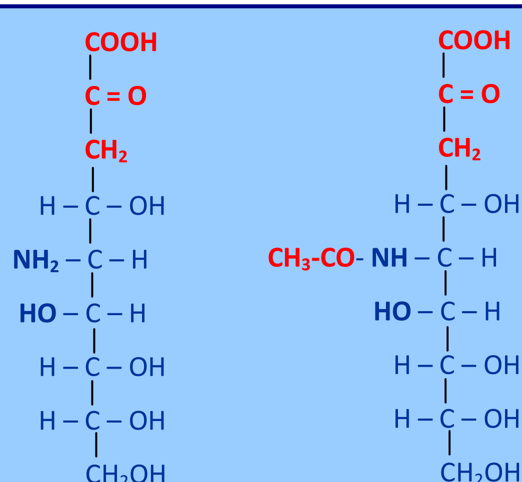


D-Galactosamine D-Glucosamine D-Mannosamine N-acetyl-D-Glucosamine

5- Aminosugar acids :

These are formed by the addition of acids to aminosugars. Addition of pyruvic acid to mannosamine gives neuraminic acid.

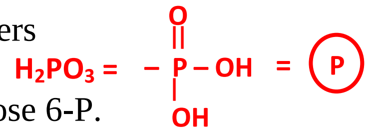
The N-acetyl derivatives of the aminosugar acids are called sialic acids e.g. N-acetyl neuraminic acid (NANA). NANA enters in the structure of glycolipids and glycoproteins.



D-Neuraminic acid N-acetyl-D-Neuraminic acid (NANA)

6- Ester formation:

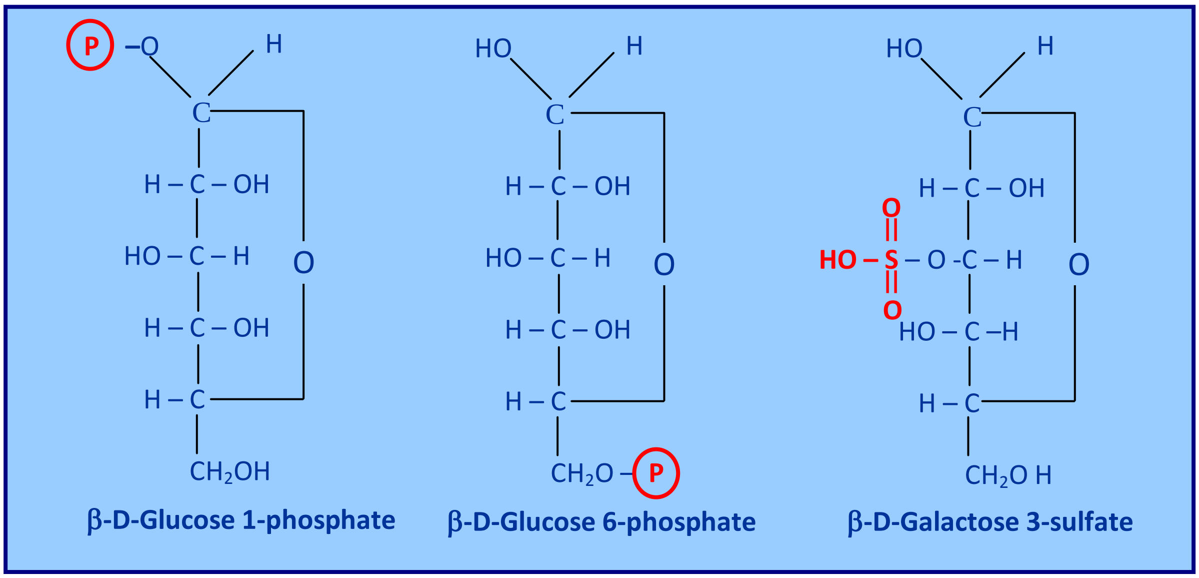
The hydroxyl groups of monosaccharides can form esters with acids



a- Phosphate esters: For example glucose 1-P and glucose 6-P.

b- Sulfate esters :

They are present in certain types of polysaccharides and glycolipids (sulfolipids) e.g. β-D-galactose 3-sulfate.



7- Glycosides:

-Glycosides are **products of condensation of the anomeric carbon** of the sugar **with**:

1) Another sugar **(Glycon):** e.g. formation of disaccharides and polysaccharides. Or

2) Non-Carbohydrate compound **(Aglycon)**: such as alcohols, phenols or nitrogenous bases.

-The glycosidic linkage is named according to the anomeric carbon to which it is attached (α & β) and according to the parent sugar e.g. glucosidic, galactosidic or fructosidic bond.

- Examples of Glycosides

1) Nucleosides are glycosides formed of ribose or deoxyribose and a nitrogenous base found in nucleic acids.

2) Cardiac Glycosides: contain steroids component as aglycone in combination with sugar molecules e.g. digitalis.

II- DISACCHARIDES

Disaccharides consist of two monosaccharides united together by glycosidic linkage. If the glycosidic linkage involves the carbonyl group of both sugars (e.g. sucrose) the resulting disaccharide is non-reducing. On the other hand, if the glycosidic linkage involves the carbonyl group of one of its two sugars (e.g. lactose and maltose) the resulting disaccharide is reducing.

Disaccharides are classified into reducing disaccharides and non reducing disaccharides.

A- Reducing Disaccharides

These are disaccharides which have a free anomeric carbon in the second sugar unit, so they exist in both α and β forms and mutarotate.

Examples: Maltose, isomaltose and lactose.

1. Maltose (Malt sugar):

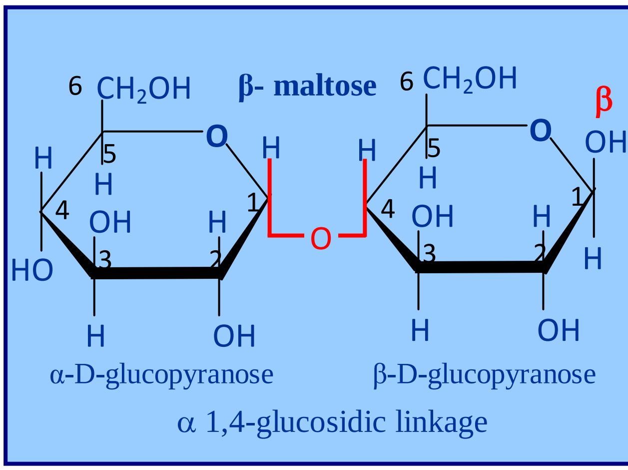
It is formed of two molecules of **D-glucopyranose united by α1, 4-glucosidic linkage**. It is present in both α and β forms. Maltose is the main product of digestion of starch by amylase. It is hydrolyzed by maltase enzyme or by acids into two molecules of D-glucose.

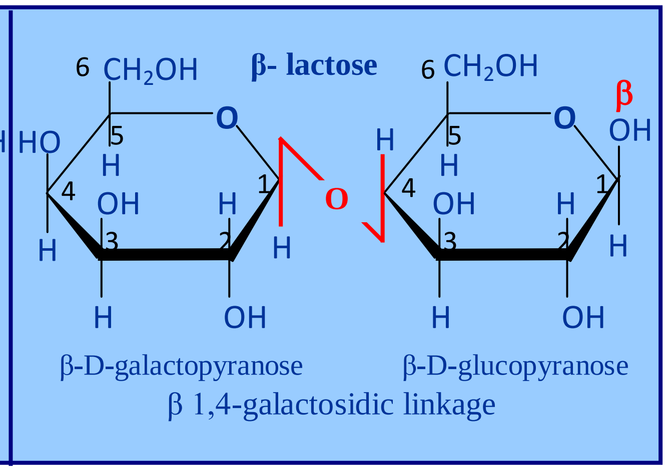
2. Isomaltose:

It is formed of two molecules of **D-glucopyranose united by α1, 6-glucosidic linkage**. Isomaltose is one of the hydrolysis products of starch and glycogen by amylase, as it represents the branching point of the molecule.

3. Lactose (Milk sugar):

It is formed of **β-D-galactopyranose and D-glucopyranose united by β1,4-galactosidic** linkage. It is hydrolyzed by lactase enzyme or by acids into D-glucose and D-galactose.

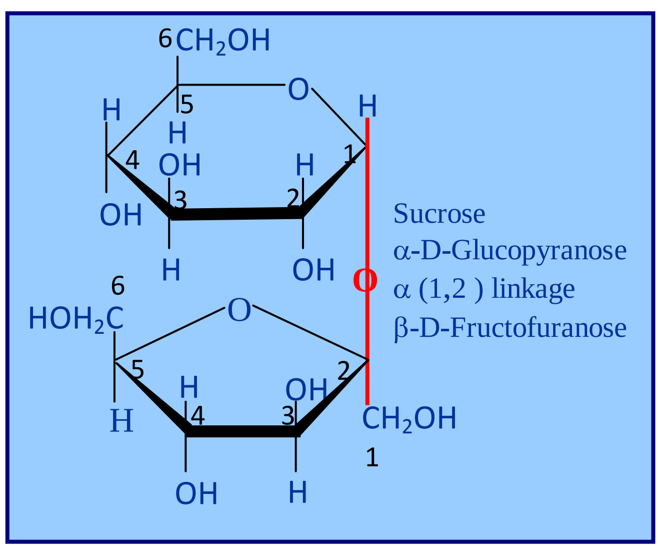




B- Non –Reducing Disaccharides

Sucrose (Cane sugar) (Table sugar):

- It is present in plants as sugar cane and beets. It is formed of **β-D-fructofuranose** and **α-D-glucopyranose** united by **α1,2-glucosidic linkage or β2,1-fructosidic linkage**.
- Both anomeric carbons are involved in the linkage, so sucrose is non-reducing.



III- OLIGOSACCHARIDES

These are polymers of **3-10 monosaccharide units**. They are not an important source of carbohydrates in diet for humans as most of them are nondigestible. They are present as a constituent of many types of glycolipids and glycoproteins e.g. oligosaccharides which are constituent of ABO blood group substance, immunoglobulins, and glycolipids and glycoproteins of cell membranes.

IV- POLYSACCHARIDES

Polysaccharides are composed of **more than 10 monosaccharide units** linked by glycosidic bonds. Since the condensation of the monosaccharide units involves the carbonyl groups of the sugars, leaving only one free carbonyl group at the end of a big molecule, polysaccharides are nonreducing.
Polysaccharides include homopolysaccharides and heteropolysaccharides.

A- Homopolysaccharides

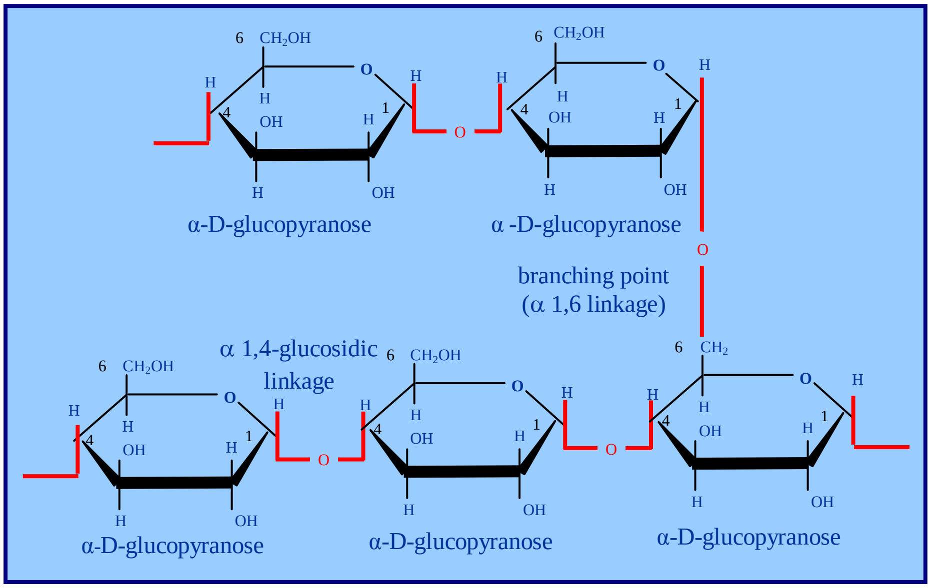
These are polysaccharides which are entirely made up of only one type of monosaccharide units. They are given names according to the nature of their building units as follows:
1. Glucans: formed of D-glucose units and include starch, dextrins, glycogen and cellulose.
2. Fructans: formed of D-fructose units e.g. inulin present in plants.

Glucans

1- Starch :
Starch is the chief storage form of carbohydrates in chlorophyll-containing plants. It is present in large amounts in cereals (rice and wheat), tubers (potatoes and sweet potatoes) and legumes (beans). Starch granules contain two forms, amylose (15- 20%) in the inner part and amylopectin (80-85%) in the outer part.

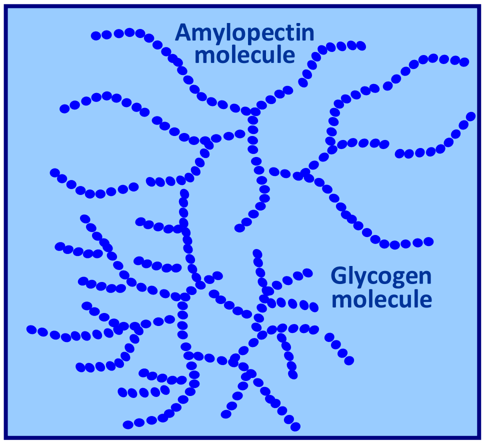
a. Amylose: The amylose molecule is composed of about 300-400 (up to 1000) of **α-D-glucopyranose molecules** connected by **α1,4-glucosidic linkage** forming an **unbranched chain**.

b. Amylopectin: It is a **branched polysaccharide**; each branch is formed of **24-30 α-D-glucopyranose units**. The amylopectin glucose units are connected by **α1,4-glucosidic linkage** within the branches and by **α1,6-glucosidic linkage** at the branching points.



2- Dextrins:

They are produced during the hydrolysis of starch by salivary or pancreatic amylase.

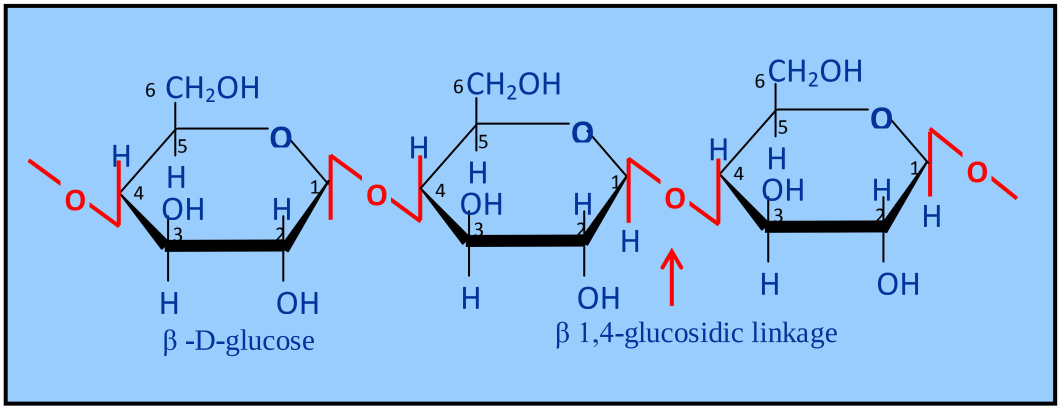


3- Glycogen:

Glycogen is the storage form of carbohydrates in animals (animal starch). It is mainly present in **skeletal muscles and liver**.

4- Cellulose:

Cellulose forms the principal part of the cell wall of plants. It is formed of a **long non-branched chain of β-D-glucopyranose units** connected together by **β1,4-glucosidic linkage**. Cellulose is insoluble in water and gives no color with iodine. It is non-hydrolysable by amylase because it contains a β1,4-glucosidic linkage. It can be hydrolyzed by strong acids or by **cellulase** (present in some bacteria). The presence of cellulose in diet is important as it increases the bulk of food, which stimulates intestinal contractions and prevents constipation.



B – Heteropolysaccharides

These are polysaccharides which are formed of more than one type of monosaccharide unit. They include glycosaminoglycans (GAGs) formly called mucopolysaccharides.

Glycosaminoglycans (GAGs)

Glycosaminoglycans are:
- Unbranched
-Long chains (usually >50 sugar units) heteropolysaccharides
- Composed of **repeating disaccharide units,** *usually* made up of **an amino sugar** and a **uronic acid.**

Glycosaminoglycans are **classified into**:
I- Sulfate free glycosaminoglycans: e.g. hyaluronic Acid
II- Sulfate containing glycosaminoglycans: e.g. chondroitin sulphate, keratan sulphate, dermatan sulphate, heparin and heparan sulphate

Type of GAGs	Constituents	Localization
Hyaluronic acid (HA)	glucuronic acid +N-acetyl-glucosamine	Synovial fluid, skin, ground substance of connective tissue, umbilical cord, vitreous body of the eye, embryonic tissues.
Chondroitin sulfate (CS)	glucuronic acid +N-acetyl-galactosamine sulfate	- Most abundant GAG - Prominent component of cartilage, tendons, ligaments, bone, aorta.
Dermatan sulfate (DS)	L-iduronic acid +N-acetyl-galactosamine sulfate	Skin, blood vessels, heart valves.
Keratan sulfate (KS)	galactose +N-acetyl-glucosamine sulfate (No uronic acid)	Cornea, cartilage, bone
Heparin	L-iduronic (D-glucuronic) acid--sulfate + glucosamine bisulfate	Abundant in granules of mast cells that line blood vessels of liver, lung, skin.
Heparan sulfate	More glucuronic acid and its glucosamine residue contains less sulfate than heparin.	Basement membrane, component of cell surface

GAGs and proteoglycans

Most of the **GAGs** are covalently conjugated to a **protein core,** the product of which is termed **proteoglycans.** They are formed mainly of carbohydrates (95%) and only (5%) proteins.
GAGs are present mainly in the extracellular matrix (ECM) or ground substance in association with other extracellular proteins (explained in chapter of proteins of ECM).

Functions of GAGs and proteoglycans

1- They are important constituents of extracellular matrix.

2- The **negatively charged** carboxylate and sulfate groups on the proteoglycan bind **positively charged** ions and form hydrogen bonds with trapped water molecules, thereby creating a **hydrated gel**. This gel:

- Provides flexible **mechanical support** for the ECM.
- Acts as a filter that allows the **diffusion of ions** (e.g., Ca^{2+}), H_2O, and other small molecules but **slows diffusion of proteins and movement of cells.**
- Acts as a **lubricant** in synovial fluid.
- Is compressible: when a GAG solution is compressed, water is squeezed out and GAGs occupy a smaller volume. When the compression is released, their molecules regain their original hydrated size. This gives GAGs solutions the **shock absorbing** properties and explains their role as shock absorbents in joints and making the eyeball **resilient**.

3- The proteoglycans **interact** with a variety of **proteins in the matrix**, such as collagen and elastin, and theses interactions are important in determining the **structural organization of the matrix.**

4-**Hyaluronic acid proteoglycans**
In addition to the above functions, hyaluronic acid is:

- Present in high concentration in **embryonic tissues** and play an important role in cell migration and morphogenesis.
- Involved in **wound healing (repair).** In the initial phase of wound healing, hyaluronic acid concentration increases many folds at the wound site.

Hyaluronidase enzyme (spreading factor):
- This enzyme can hydrolyze hyaluronic acid present in the ground substance of connective tissue.
-Hyaluronidase secreted by some bacteria helps the spread of bacteria through subcutaneous tissues. It is also present in sperms (head) and helps the process of ovum fertilization.

5-**Heparin** proteoglycan is an important **anticoagulant** (prevents thrombus formation), it acts by binding with factor IX and XI. Also, it produces activation of **antithrombin**. It binds specifically to **lipoprotein lipase enzyme** and increases its release form the capillary wall to the plasma. This enzyme helps in removal and clearance of blood lipids.

6- **Keratan sulfate proteoglycan** is important for transparency of the **cornea**.

7- **Heparan sulfate proteoglycans** are associated mainly with **plasma membrane** of cells and play an important role in cell membrane receptors and cell-cell interactions.

8- **Aggrecan:**
It is the major proteoglycan present in cartilage. It has a very complex structure containing several types of GAGs (hyaluronic acid, chondroitin sulfate and keratan sulfate) attached to a protein core and a link protein. GAGs side chains bind electrostatically to collagen fibrils. GAGs side chains are acidic and therefore negatively charged, they repel each other. Hence, they attract water in between causing the molecule to form a gel. It plays an important role in compressibility of cartilage.

GAGs and aging:

Structure of aggrecan changes with age:

- The amount of CS in cartilage diminishes with age, whereas the amount of KS and hyaluronic acid increase.
- The average monomer size is decreased.
- The chondroitin sulfate content is decreased and chains become shorter.

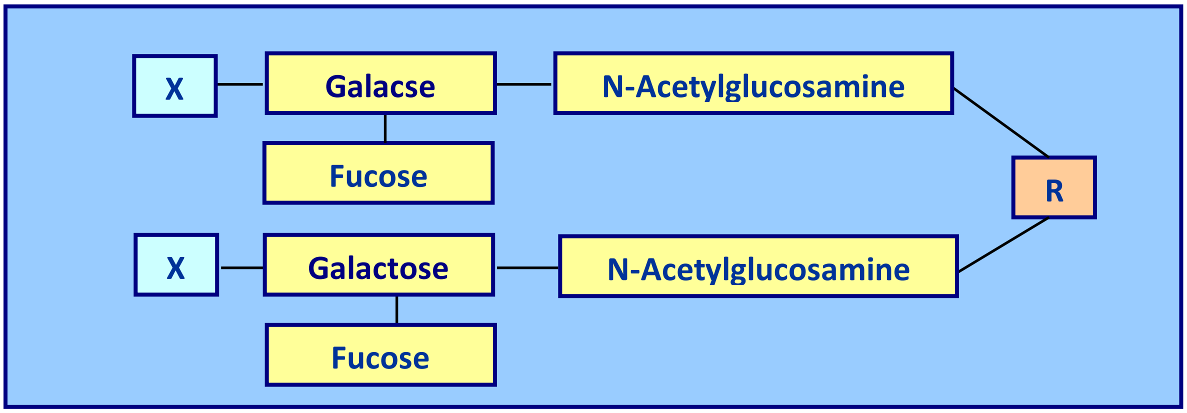
These changes may contribute to the development of **osteoarthritis**.
Also changes in the amounts of certain GAGs in the **skin** occur with aging and help to account for the characteristic changes in this organ in the elderly

Glycoproteins

They are proteins to which oligosaccharide chains are covalently bound. The carbohydrate contents of glycoproteins are less relative to proteoglycans and deficient of uronic acids and the repeating disaccharide units of proteoglycans.
Eight monosaccharides are commonly present in the oligosaccharide chain of glycoproteins i.e. **galactose, glucose, mannose, xylose, fucose, N-acetylglucosamine, N-acetylgalactosamine and N-acetylneuraminic acid**. They are found in mucous fluids, tissues, blood and in cell membrane. The carbohydrate content of glycoproteins is quite variable, it is 1% in collagen, 4% in IgG, 50 % in mucins and 85% in the ABO blood group antigens. (Refer also to the chapter: Protein Chemistry)

ABO Blood Group Antigens

The human blood groups A, B, AB, and O depend on the oligosaccharide part of the **glycoprotein or a glycolipid** on the surface of erythrocytic cells.



R group is an oligosaccharide joined to either a protein molecule (to form a glycoprotein) or lipid molecule (to form a glycolipid). Two oligosaccharide chains (or arms) are bound to R as shown in the above figure.
X is variable and it indicates the blood group type as follows:
In type O: X is absent.
In type A: X in both arms is **N-acetylgalactosamine**.
In type B: X in both arms is **galactose**.

Comparison between Proteoglycans and Glycoproteins

	Proteoglycans	**Glycoproteins**
Protein content	Up to 5%	More than 5%
Carbohydrate content	95 %	1- 85 %
Type of Carbohydrate Present	GAGs	Oligosaccharide chain: - No uronic acids -No repeating disaccharide units

FORMATIVE ASSESSMENT

I. M.C.Q

1. When two carbohydrates are epimers:
   a) One is a pyranose, the other a furanose
   b) One is an aldose, the other a ketose
   c) They differ in length by one carbon
   d) They differ only in the configuration around one carbon atom
2. Which of following is an anomeric pair?
   a) D-glucose and L-glucose
   b) D-glucose and D-fructose
   c) α-D-glucose and β-D-glucose
   d) α-D-glucose and β-L-glucose

II. Problem solving

A 54 –year- old woman who was bed ridden in a nursing home began to develop swelling of her left leg. She was evaluated with venous Doppler ultrasound and was found to have deep vein thrombosis. She was immediately started on heparin.

1. What is the chemical nature of heparin?
2. Explain on biochemical basis why is it used in this case?

III. Give the hydrolytic products for each of the following:

1. Inulin
2. Starch
3. Milk sugar

Key Answers

I. M.C.Q

1	2
d	c

II. Problem solving

- Sulfate containing glycosaminoglycan.
- To prevent further thrombus formation. Heparin is an **anticoagulant**. It activates an antithrombin and inactivates coagulation factors IX and XI by binding to them.

III. Give the hydrolytic products

1. Fructose
2. By amylase: a mixture of dextrins and maltose. By acid hydrolysis gives glucose.
3. Glucose and galactose.

REFERENCES

❖ *Harper's Illustrated Biochemistry*
❖ *Lippincott's Illustrated Reviews: Biochemistry*