

Carbohydrates

CARBOHYDRATE: IMPORTANCE

- **Most Abundant Class of Biomolecules on earth**
- **An Important Macronutrient: sugar & starch.**
- **Oxidation of carbohydrate is the central energy yielding pathway in the most non photosynthetic cells.**
- **Performs important physiological functions in the body: cell recognition & adhesion, cell signaling, glycoconjugates.**
- **Associated with Pathological Conditions (Diabetes Mellitus, Lactose Intolerance).**

DEFINING CARBOHYDRATES

Carbohydrates or Saccharides

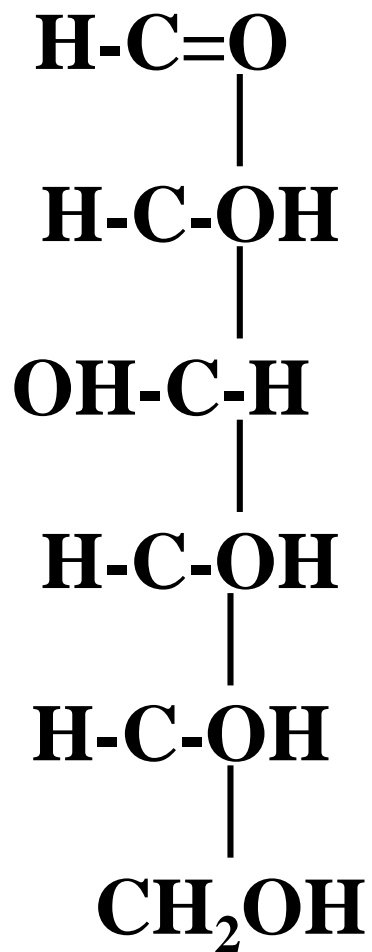
(Greek Sakcharon meaning "Sugar")

- **Organic compounds composed of Carbon, **Hydrogen** and **oxygen**.**
- **Many Carbohydrates also contain Nitrogen and other elements.**

Carbohydrates derive their name from a
Misleading Concept
'Hydrates of Carbon'

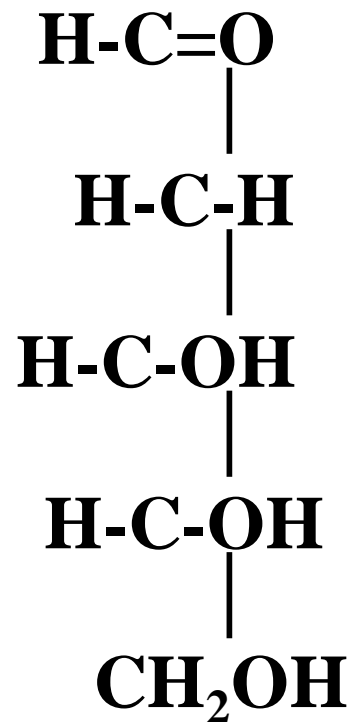
- ❖ Most but not all have a empirical formula $(CH_2O)_n$
- ❖ Hydrogen and Oxygen in Carbohydrates were found to be present in the same proportion as in water (2:1)
(E.g. Glucose $C_6H_{12}O_6$ or $C_6(H_2O)_6$)
- ❖ It is due to this fact that compounds derived their name “Carbon Hydrate”

GLUCOSE



This term is not a perfect derivation as many carbohydrates do not have the same proportion as water.

Example: DEOXYRIBOSE (C₅H₁₀O₄)



CHEMICAL DEFINITION OF **CARBOHYDRATES**

- **Polyhydroxyl: Having more than one hydroxyl group.**

(-OH)

- **Functional Group: It is a specific group of atoms or bonds which are part of a larger hydrocarbon chain.(Provide a specific chemical behaviour).**

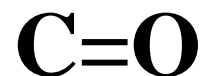
- For carbohydrates, the functional group is the carbonyl group which may be either

Aldehyde Group (H-C=O)

Or

Keto Group (C=O)

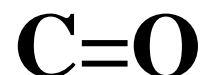
WHAT IS SIMILAR & DIFFERENT IN THESE TWO STRUCTURES?



More than one hydroxyl group in both



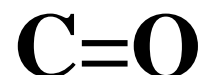
WHAT IS COMMON & DIFFERENT IN THESE TWO STRUCTURES?



Carbonyl Group in both But?



What is common & different
in these two Structures?

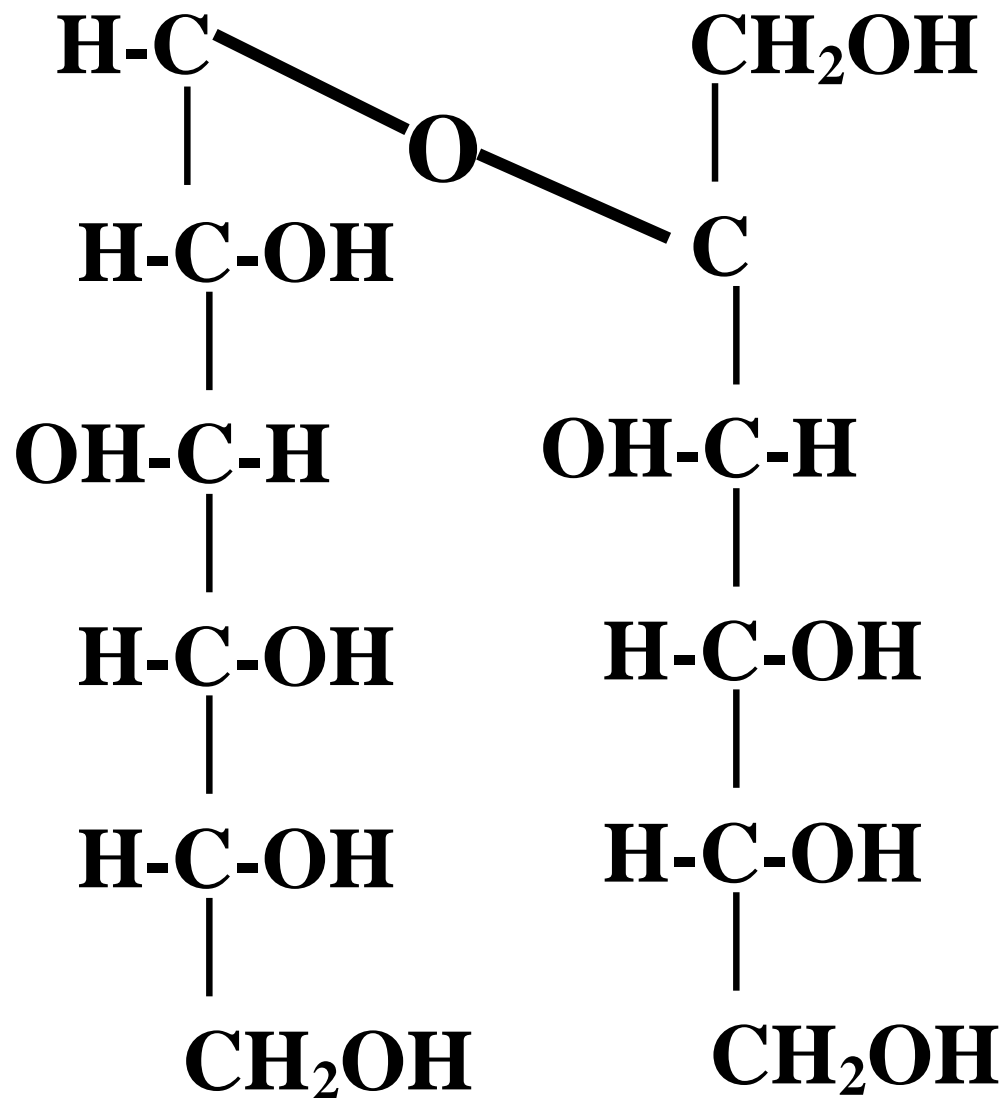


Aldehyde in 1 and Ketone in 2

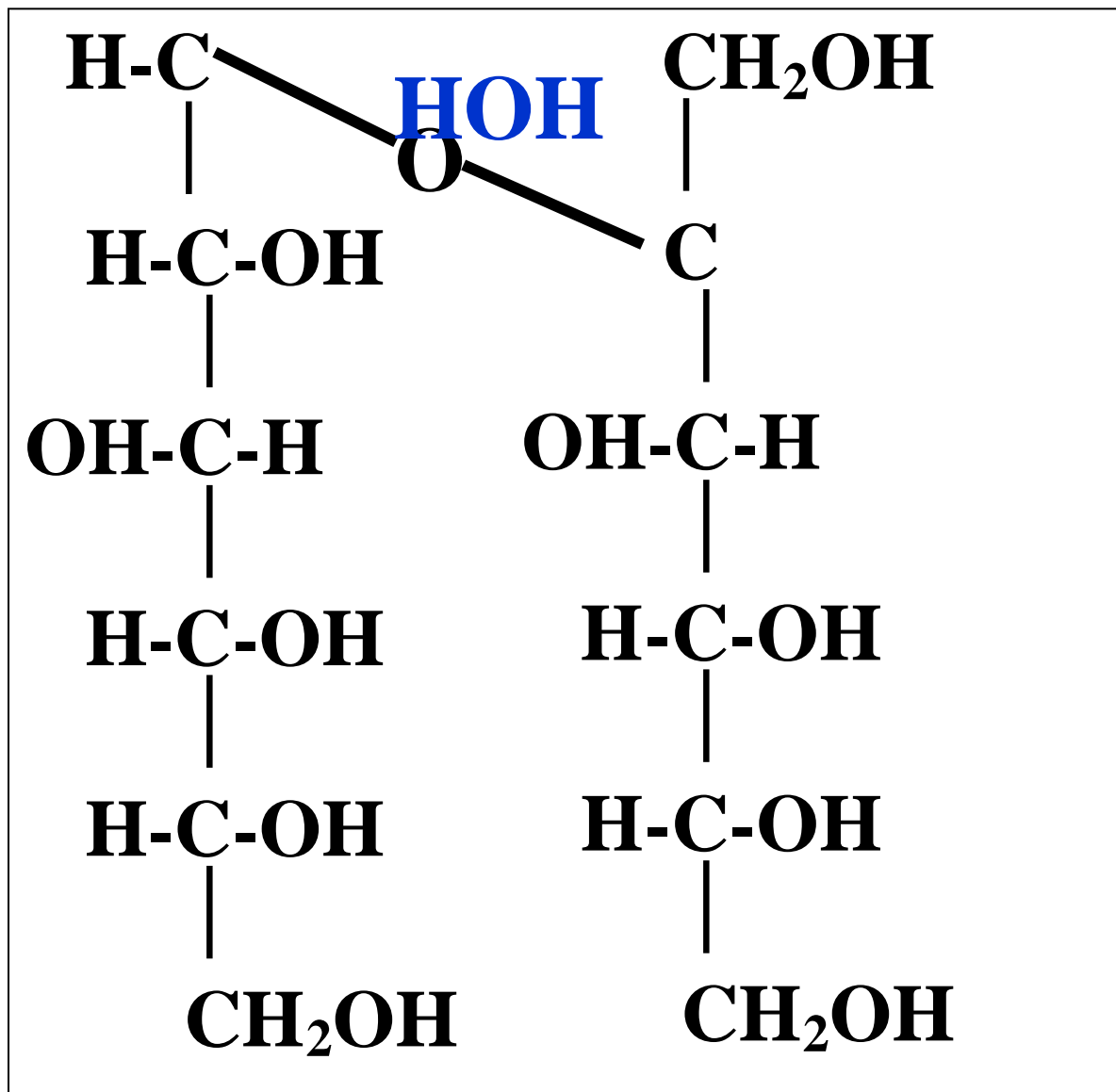


**Carbohydrates are Polyhydroxy
Alcohols with Carbonyl groups
which may either be aldehyde (H-
C=O) or Keto (C=O) Groups**

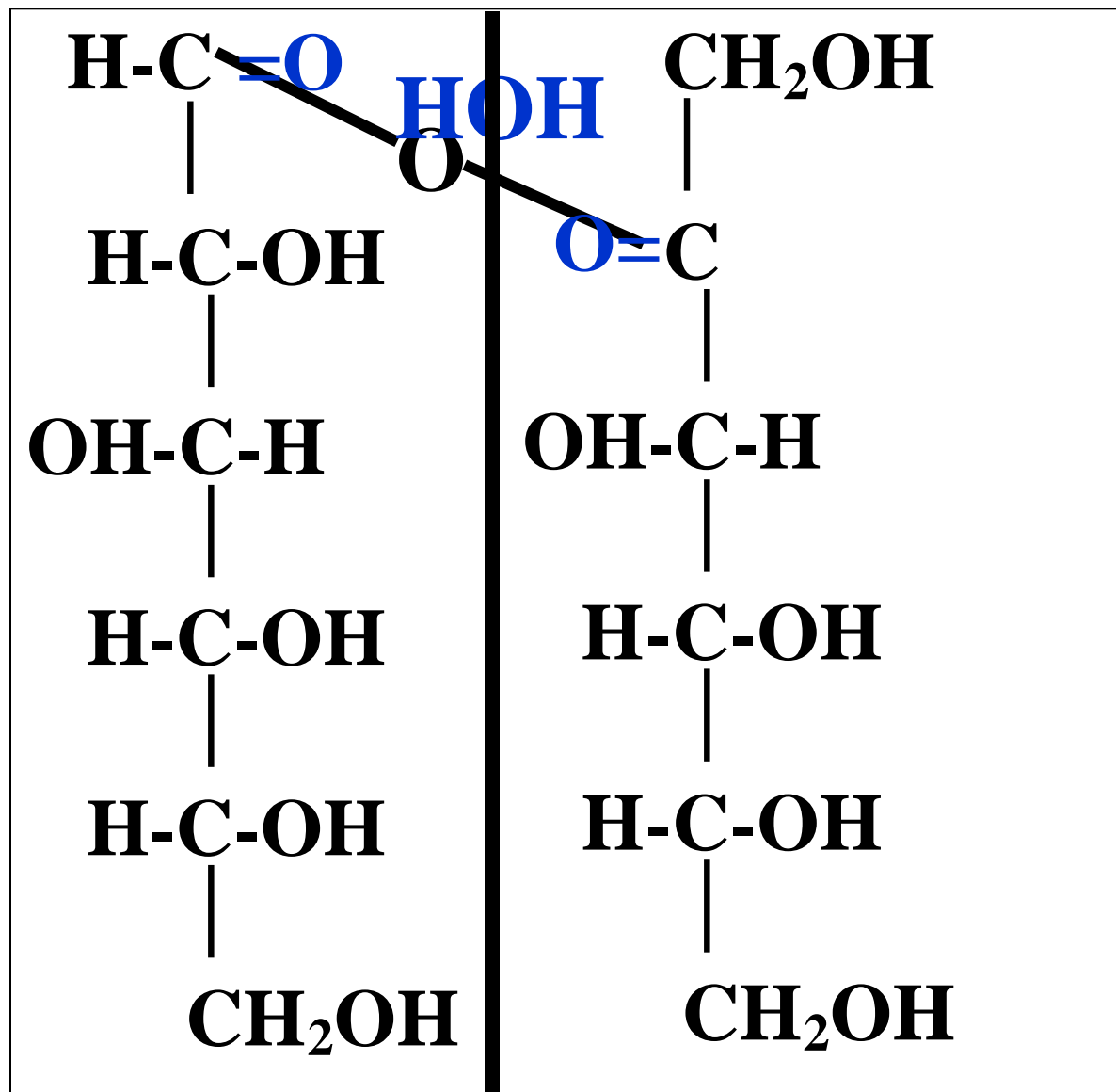
**Can you
Visualize
Either
Aldehyde
Or
Ketone
Group In
This
Polyhydroxy
Alcohol?**



No! But
Hydrolysis
of This
Compound
Yields Two
Compounds
with
Aldehyde Or
Ketone
Groups



**No! But
Hydrolysis
of This
Compound
Yields Two
Compounds
with
Aldehyde Or
Ketone
Groups**



**Many Polyhydroxy Alcohols may Not
have an active Aldehyde or Ketone
Group But they May Yield
Them On Hydrolysis. They
Are Also Designated as
Carbohydrates.**

**THEREFORE, THE COMPLETE DEFINITION OF
CARBOHYDRATES IS:**

**CARBOHYDRATES ARE POLYHYDROXYL
ALCOHOLS WITH POTENTIALLY ACTIVE CARBONYL
GROUPS WHICH MAY BE EITHER AN ALDEHYDE
OR KETONE GROUP. THEY ALSO CONTAIN THOSE
COMPOUNDS, WHICH YIELD THEM ON
HYDROLYSIS**

Classification of carbohydrates

Carbohydrates are mainly classified into four different groups:

- **Monosachharides**
- **Disaccharides**
- **Oligosaccharides**
- **Polysaccharides**

MONOSACCHARIDES

- **Monosaccharides are those carbohydrates which Cannot be Hydrolyzed further into more simple carbohydrates.**
- **Thus, they are the Simplest form of Carbohydrates.**
- **Familiar examples are:**
Glucose, Fructose, Ribose & Galactose.

Monosaccharides are further classified on the basis of:

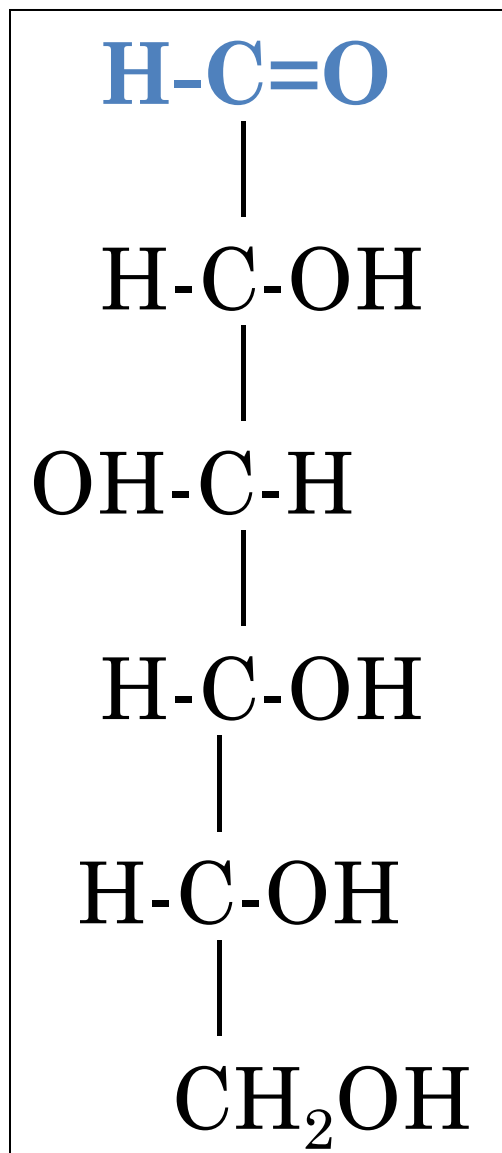
— Aldehyde or Ketone Group:

- Aldomonosaccharides (Aldoses).
- Ketomonosaccharides (Ketoses).

— Carbon Chain Length.

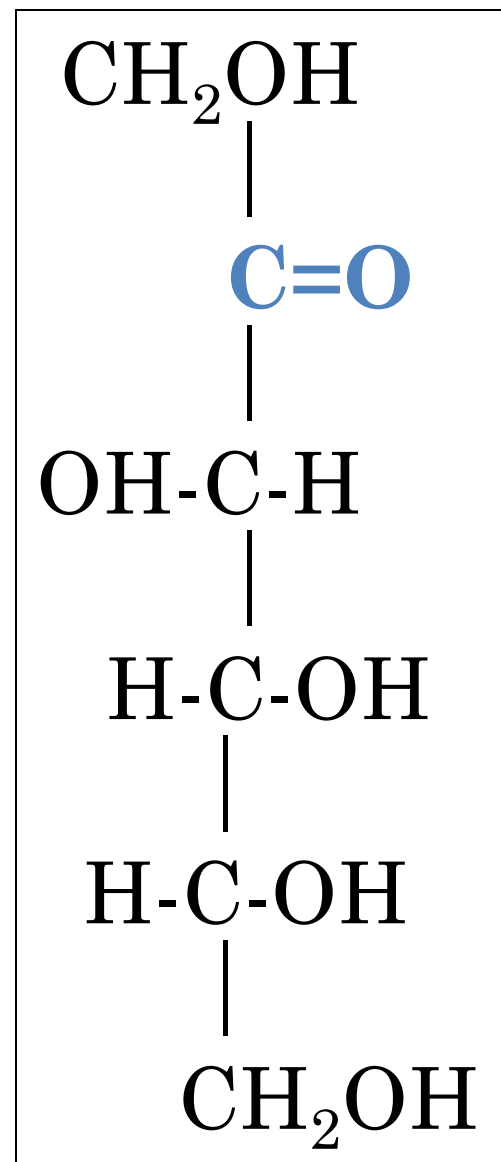
- Trioses.
- Tetroses.
- Pentoses.
- Hexoses.
- Heptoses.

CARBONYL GROUP

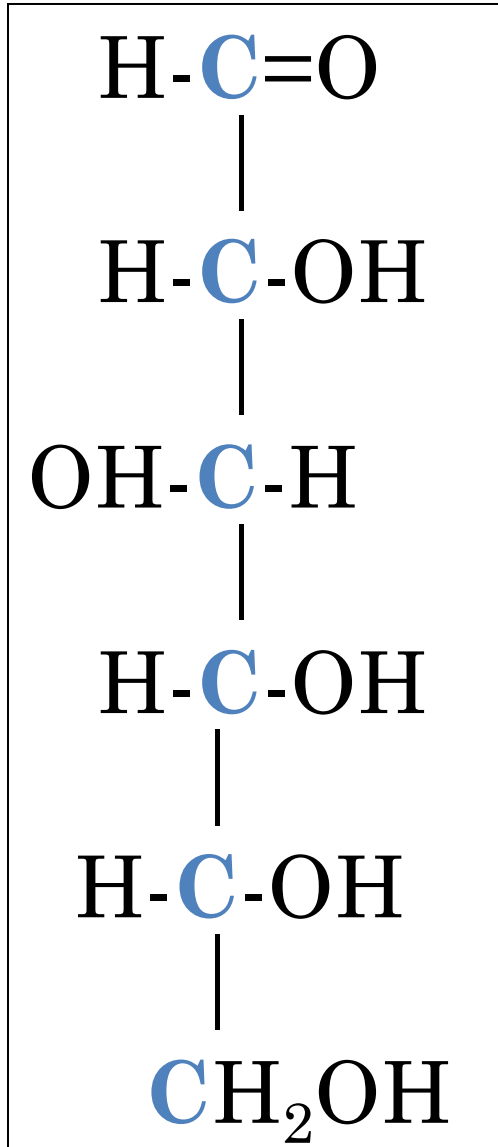


←GLUCOSE

FRUCTOSE-->

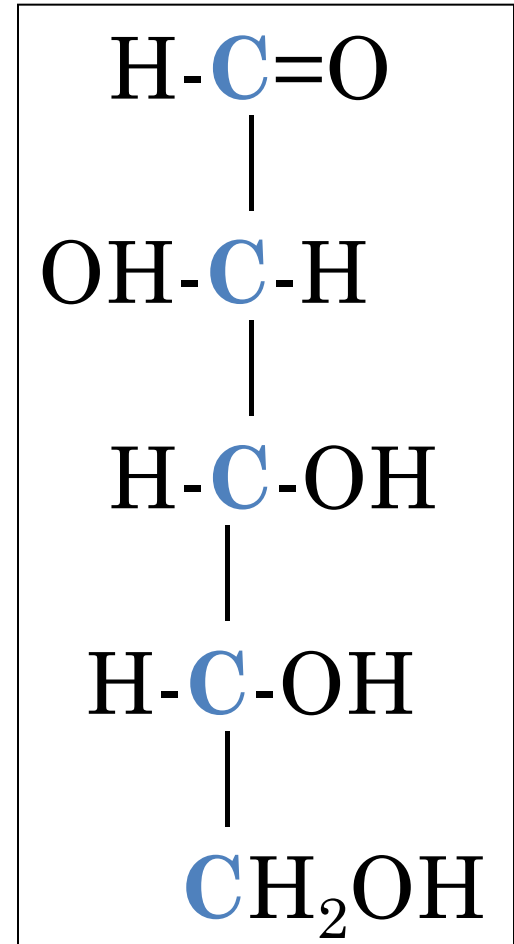


CARBON CHAIN



← GLUCOSE

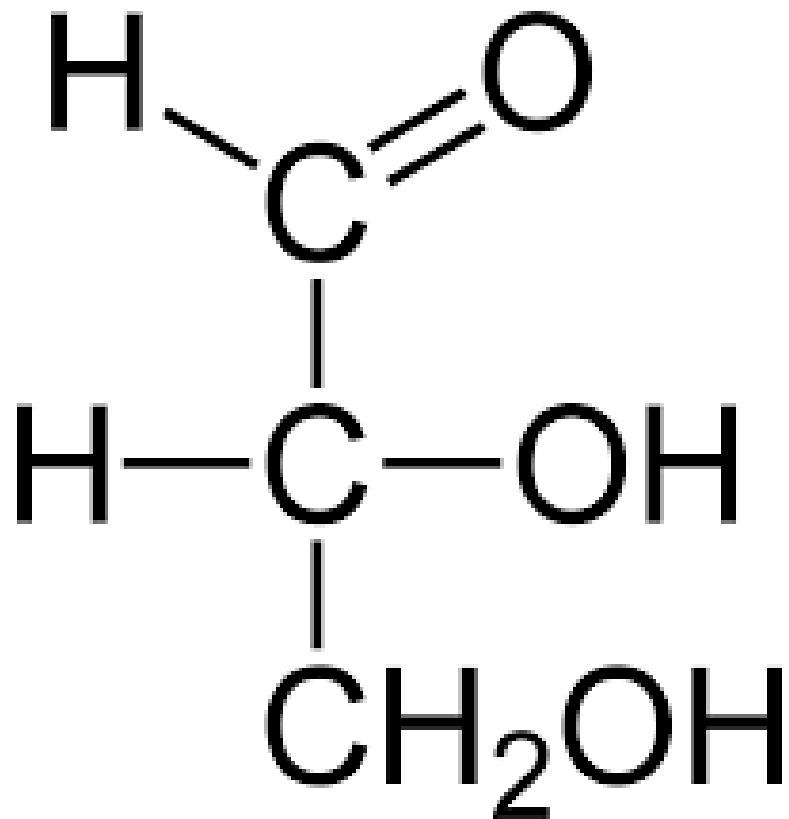
ARABINOSE-->



EXAMPLES OF MONOSACCHARIDES

<u>NO. OF CARBON ATOMS</u>	<u>ALDO</u>	<u>KETO</u>
3C TRIOSE	GLYCERALDEHYDE	DIHYDROXYACETONE
4C TETROSE	ERYTHROSE	ERYTHRULOSE
5C PENTOSE	RIBOSE, XYLOSE	RIBULOSE, XYLULOSE
6C HEXOSE	GLUCOSE, GALACTOSE, MANNOSE	FRUCTOSE

glyceraldehyde

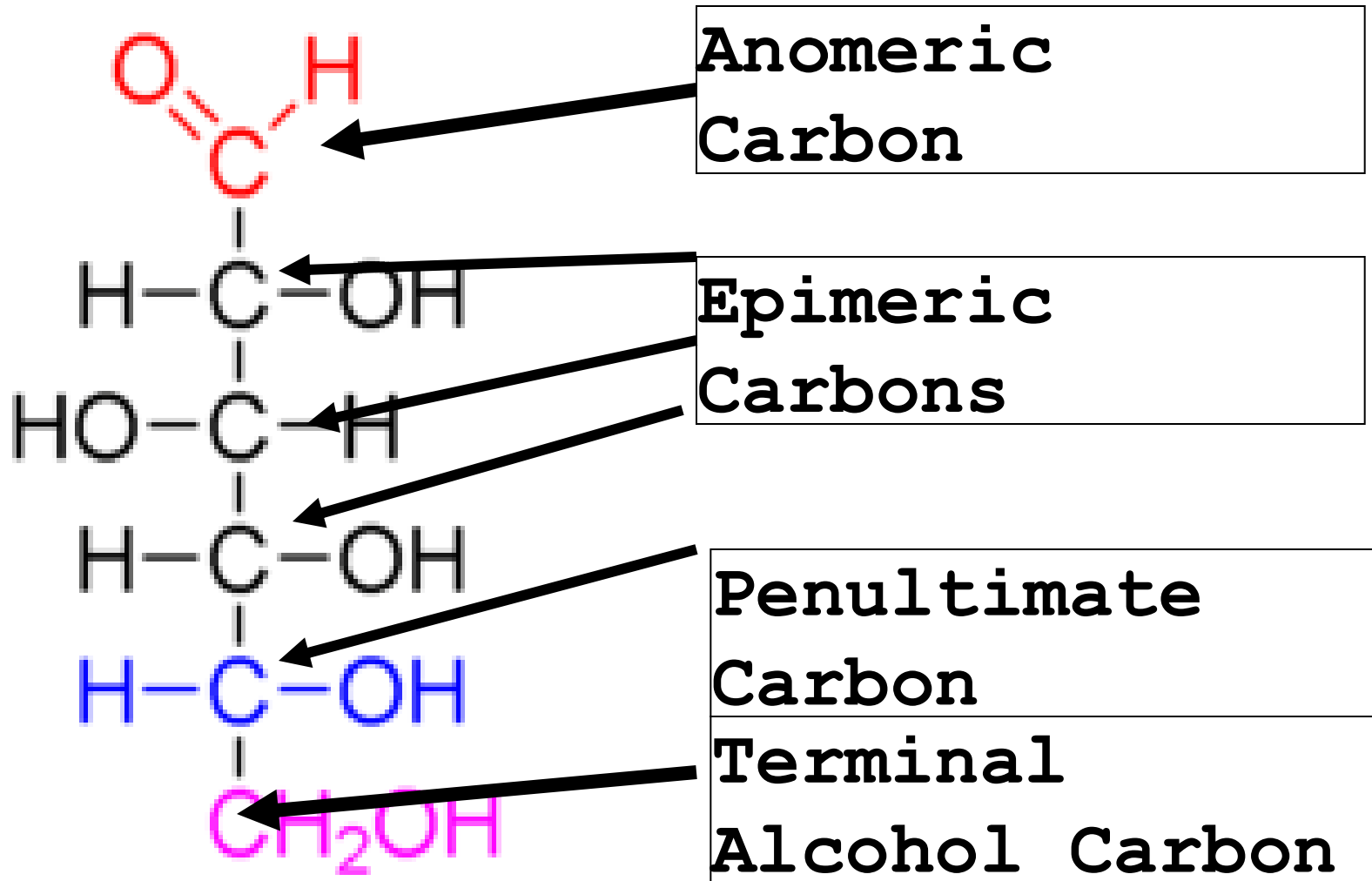


- **GLYCERALDEHYDE IS THE SIMPLEST MONOSACCHARIDE (PARTICULARLY ALDOSES)**
- **IT CANNOT BE HYDROLYZED FURTHER.**
- **IT IS THE SMALLEST POSSIBLE STRUCTURE THAT IS A CARBOHYDRATE CANNOT HAVE LESS THAN 3 CARBON ATOMS.**
- **GENERAL FORMULA OF MONOSACCHARIDE:
(C•H₂O)_N
(WHERE N IS ANY NUMBER OF THREE OR GREATER)**

Isomerism

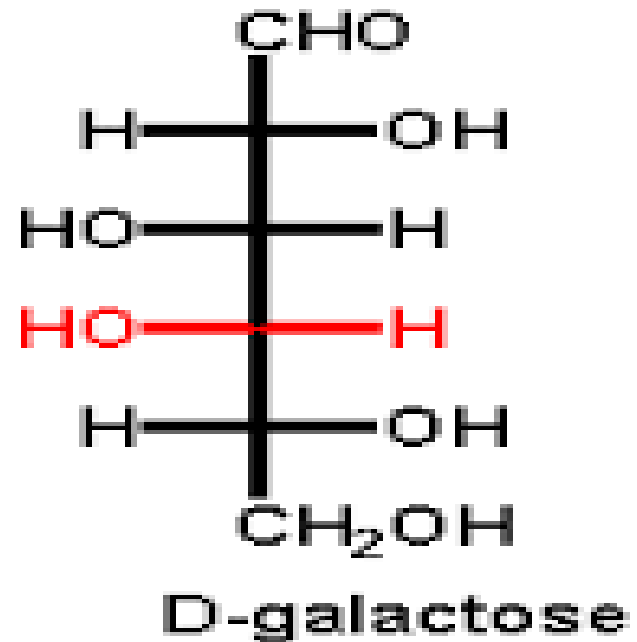
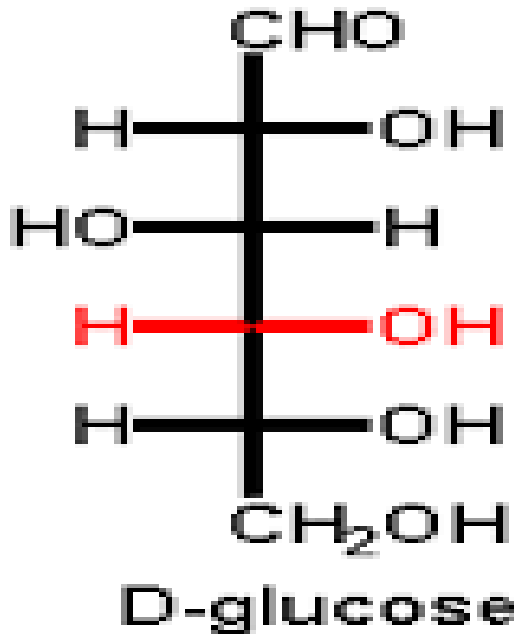
- **Isomers are basically molecules that have the same chemical formula but they differ in their chemical structures.**
- **Asymmetric Carbon is an important determinant of Isomerism.**
- **Asymmetric Carbon is that Carbon which is attached with four different groups.**

Straight Chain Structure of Typical Monosaccharide (Glucose)



Epimerism

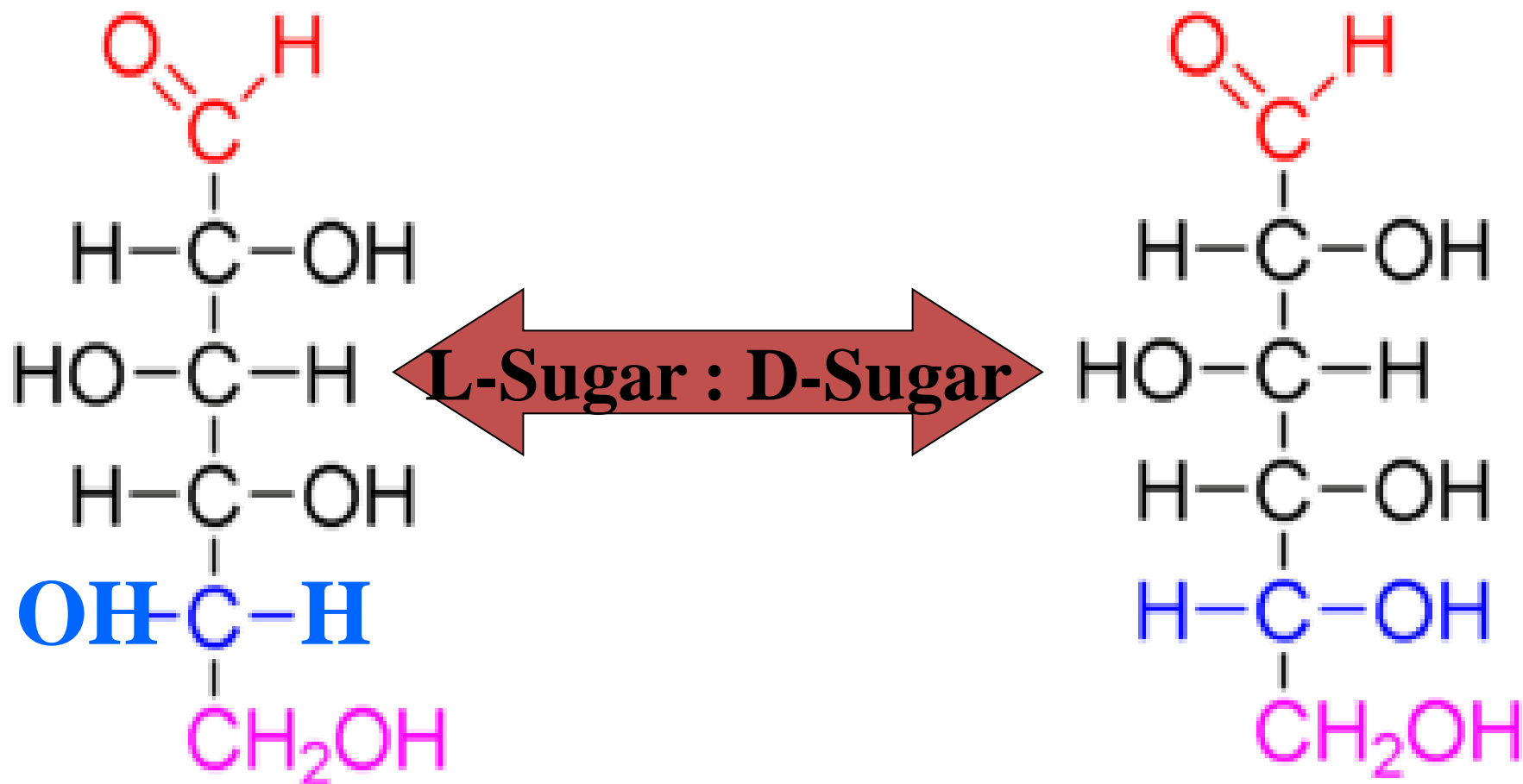
- Isomers which differ from each other only with regard to -OH group on a single asymmetric carbon atom.



Optical isomers/Stereoisomers/Enantiomers

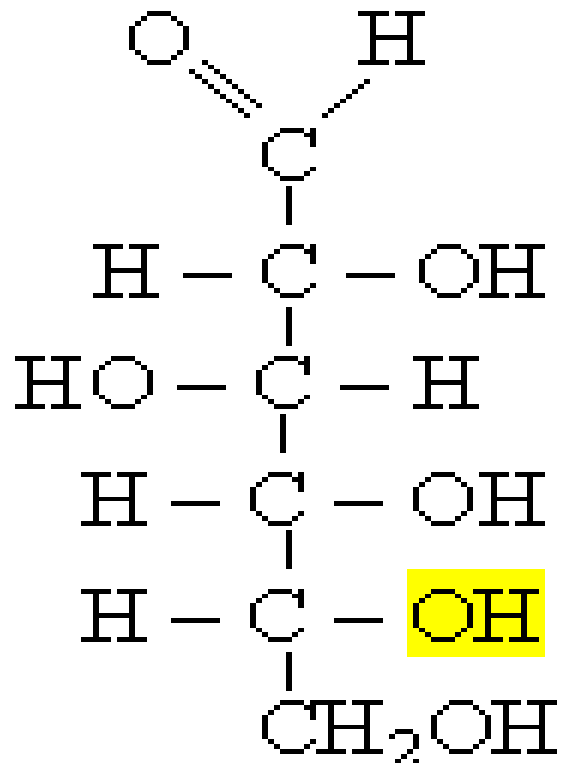
- **When a beam of polarized light is passed through sugars, they will be rotated either towards right or left.**
- **Right Rotation (dextrorotatory) E.g. D-Glucose**
- **Left Rotation (levorotatory) E.g. D-Fructose**

The assignment of D or L is made according to the orientation of the Penultimate Carbon

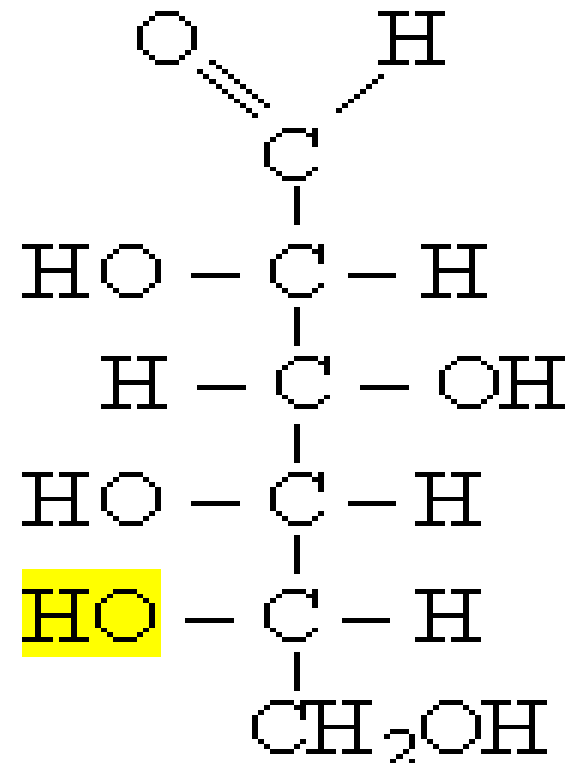


If the Hydroxyl Group is on the right the molecule is a D sugar, Otherwise It is an L sugar

D and L isomerism produce mirror images



D-glucose

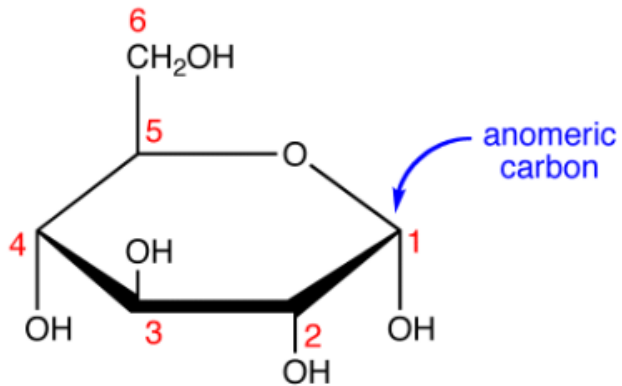


L-glucose

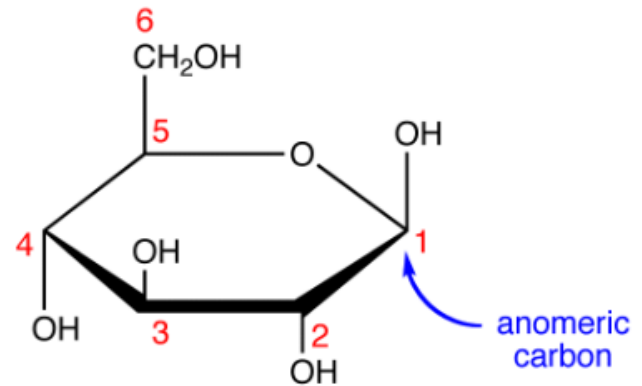
Anomers

- Common monosaccharides have cyclic or ring like structure
- 5 or more carbon atom monosaccharides occurs as cyclic structure in aqueous solution
- **Hemiacetal (OH & CHO)**
- **Hemiketal (OH & C=O)**
- **Anomers** differ only in their configuration about the hemiacetal and hemiketal carbon atom
- α and β anomers
- Six member ring-pyranose
- Five member ring-furanose

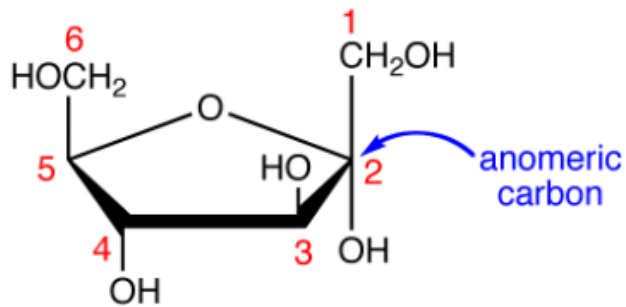
Anomers



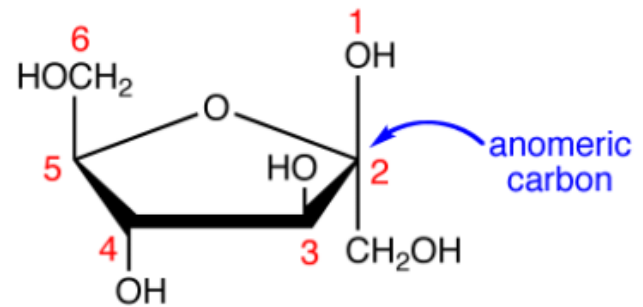
α -D-glucopyranose



β -D-glucopyranose



α -D-fructofuranose



β -D-fructofuranose

Mutarotation

- Mutarotation is the change in the optical rotation because of the change in the equilibrium between two anomers, when the corresponding stereocenters interconvert.
- Cyclic sugars show mutarotation as α and β anomeric forms interconvert
- The α and β anomers are diastereomers of each other and usually have different specific rotations. A solution or liquid sample of a pure α anomer will rotate plane polarised light in the opposite direction than the pure β anomer of that compound. The optical rotation of the solution depends on the optical rotation of each anomer and their ratio in the solution

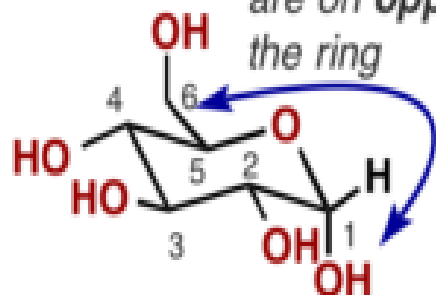
Mutarotation of D-Glucose

Alpha (α) and beta (β) isomers ("anomers") differ in the orientation of the OH at the C-1 hemiacetal carbon

Example: D-glucose

"alpha" (α) isomer:

$C_5\text{-CH}_2\text{OH}$ (up) and $C_1\text{-OH}$ (down) are on **opposite** faces of the ring



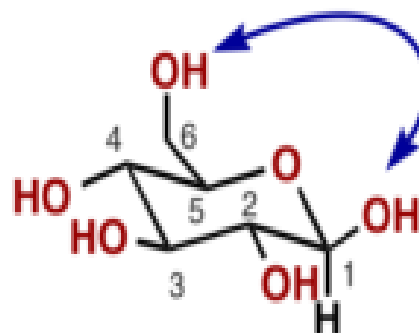
α -D-Glucose

drawn as "chair"

Specific rotation: $[\alpha]_D^{20} + 112^\circ$

"beta" (β) isomer:

$C_5\text{-CH}_2\text{OH}$ (up) and $C_1\text{-OH}$ (up) are on the **same** face of the ring



β -D-Glucose

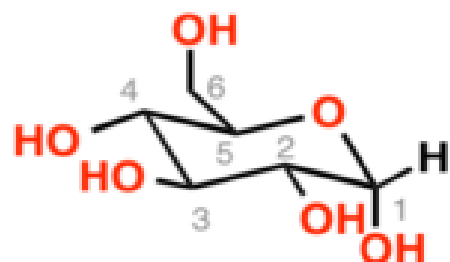
drawn as "chair"

Specific rotation: $[\alpha]_D^{20} + 18.7^\circ$

Note different specific rotations!

Mutarotation

When 100% pure α -D-glucopyranose is dissolved in water, the specific rotation slowly changes from $+112^\circ$ to $+52.5^\circ$ over a few hours.



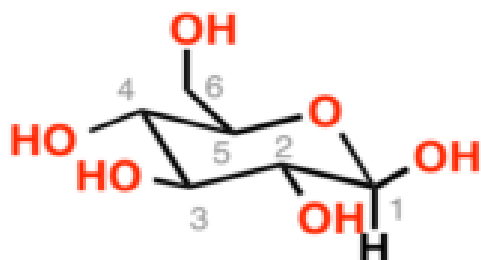
α -D-Glucose (pyranose form)

Specific rotation: $[\alpha]_D^{20} + 112^\circ$

Dissolve in water

*specific rotation decreases
over several hours, until
reaching stable value of $+52.5^\circ$*

Similarly, when 100% pure β -D-glucopyranose is dissolved in water, the specific rotation slowly changes from $+18.7^\circ$ to $+52.5^\circ$.



β -D-Glucose (pyranose form)

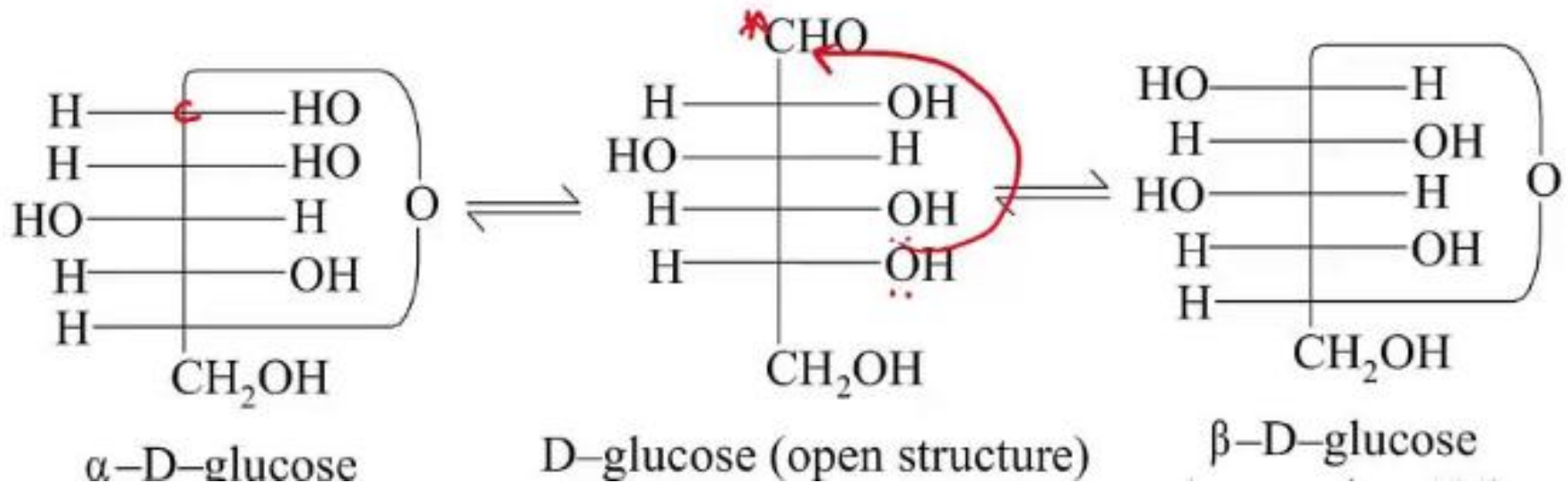
Specific rotation: $[\alpha]_D^{20} + 18.7^\circ$

Dissolve in water

*specific rotation increases
over several hours, until
reaching stable value of $+52.5^\circ$*

This is called "mutarotation" ("*muta*" = change, so "change of rotation")

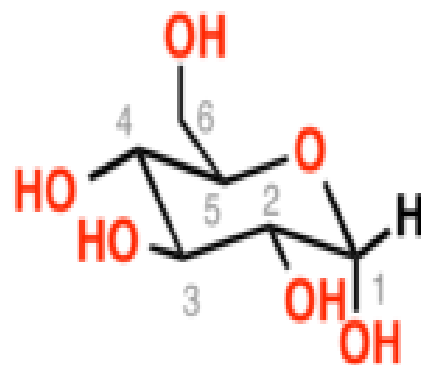
Why change in specific rotation ?



Why the change in specific rotation?

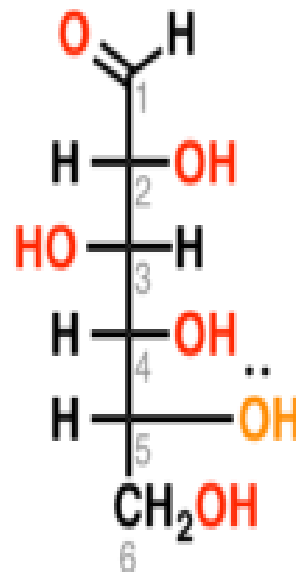
The alpha and beta anomers are each in equilibrium with the "linear" form, and therefore with each other.

"alpha" (α) isomer:



α -D-Glucose

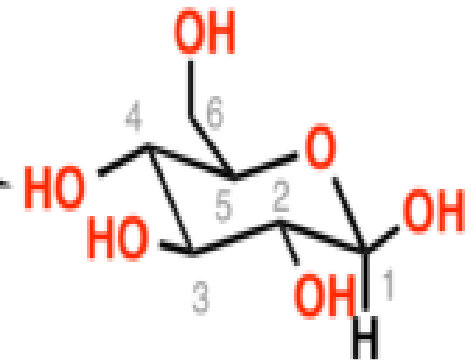
36%
(at equilibrium)



D-Glucose

("linear" form)

"beta" (β) isomer:



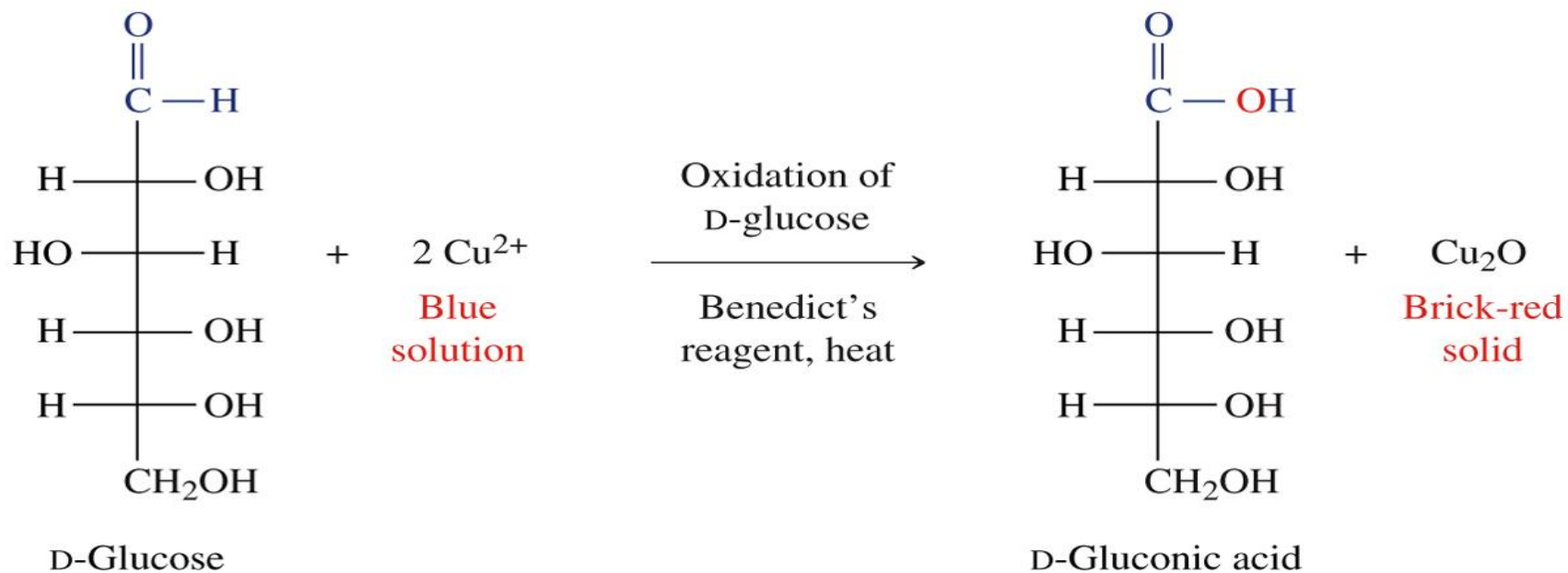
β -D-Glucose

64%
(at equilibrium)

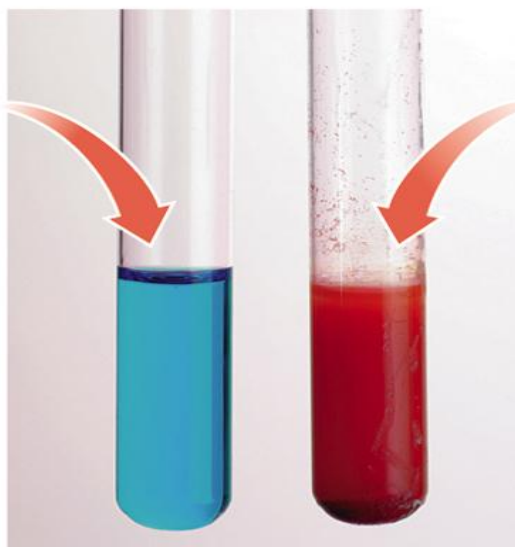
At equilibrium the mixture consists of 36% α -D-Glucose, 64% β -D-Glucose, and traces of the linear and furanose forms.

Reducing Sugars

- Monosaccharides can be oxidized by relatively mild oxidizing agents such as ferric (Fe^{3+}) or cupric (Cu^{2+}) ion.
- The carbonyl carbon is oxidized to a carboxyl group. Glucose and other sugars capable of reducing ferric or cupric ion are called **reducing sugars**.
- This property is the basis of Fehling's reaction, a qualitative test for the presence of reducing sugar.
- By measuring the amount of oxidizing agent reduced by a solution of a sugar, it is also possible to estimate the concentration of that sugar.



Negative test
for reducing
sugar



Positive test
for reducing
sugar

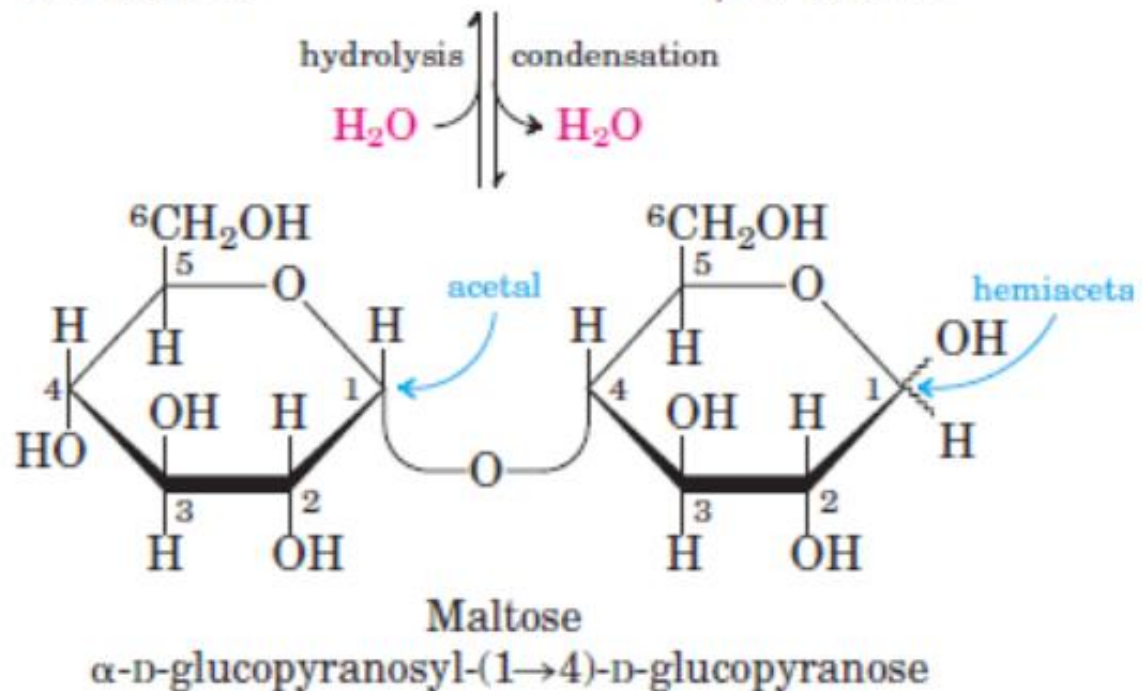
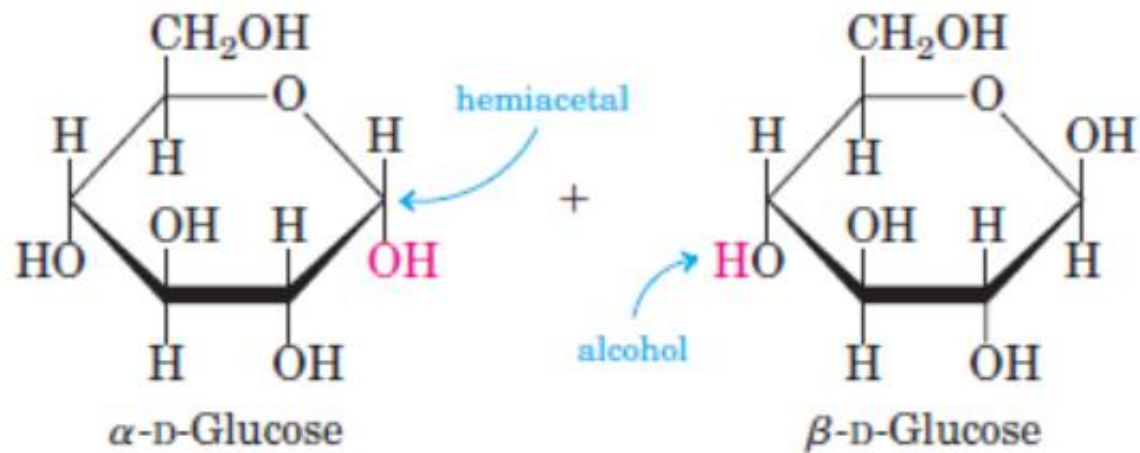
Brick-red precipitate

Cu²⁺

Cu₂O(s)

Disaccharides

Disaccharides (such as maltose, lactose, and sucrose) consist of two monosaccharides joined covalently by an **O-glycosidic bond**, **which is formed when a hydroxyl** group of one sugar reacts with the anomeric carbon of the other

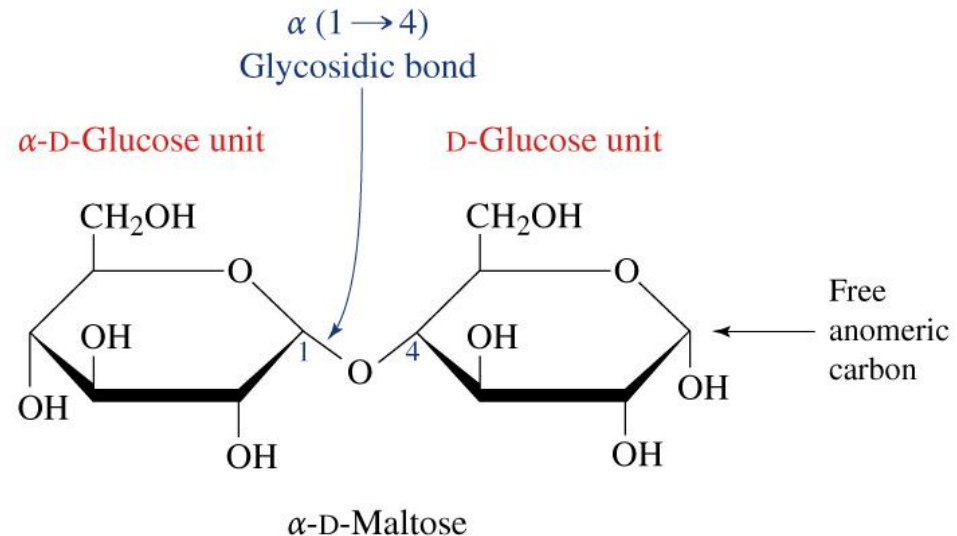


1. Maltose

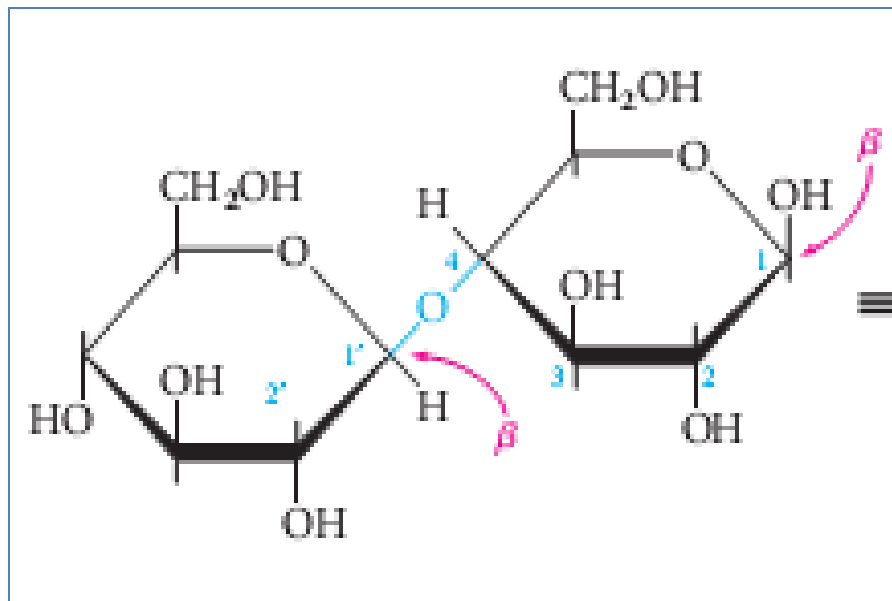
- Maltose comes from the hydrolysis of large polymeric oligosaccharides such as starch and glycogen and is in turn hydrolyzed to glucose by **maltase**.
- Sucrase, lactase, and maltase are located on the outer surfaces of epithelial cells lining the small intestine



Grain

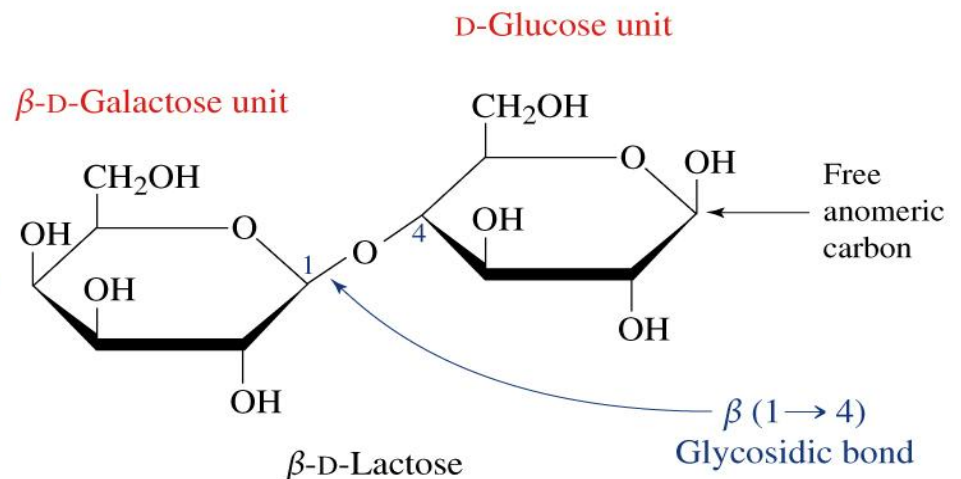


- **Cellobiose** is an isomer of maltose.
- It differs from maltose only in having the β configuration at C-1 of the left glucose unit. Otherwise, all other structural features are identical, including a link from C-1 of the left unit to the hydroxyl group at C-4 in the right unit.



2. Lactose

- Lactose, the disaccharide of milk, consists of galactose joined to glucose by β -1,4-glycosidic linkage.
- Lactose is hydrolyzed to these monosaccharides by **lactase** in human beings and by **β -galactosidase** in bacteria.
- Lactose is formed in the urine of pregnant women, and it gives a positive test with Cu^{2+} containing reagents since it is a reducing sugar



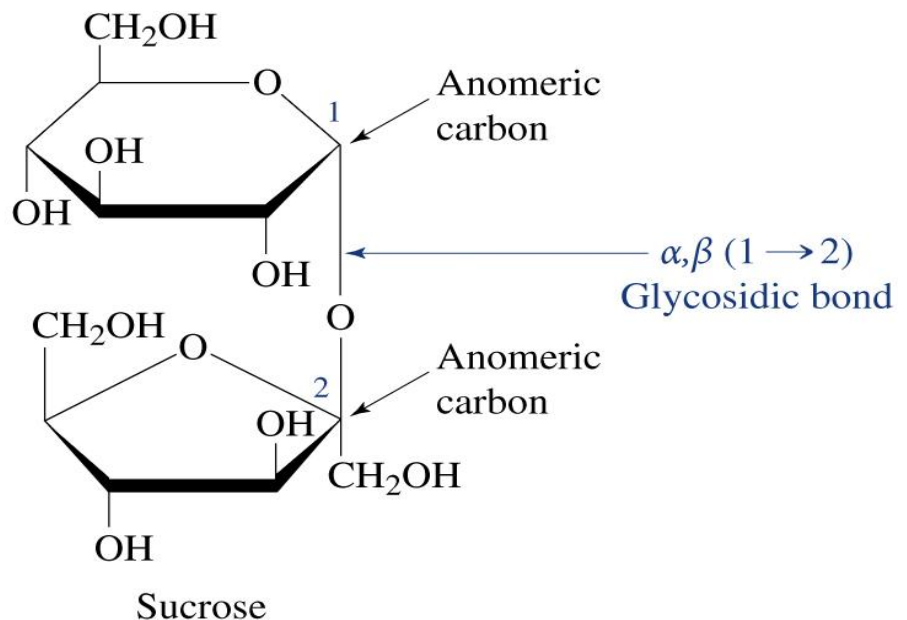
3. Sucrose

- Sucrose is the common table sugar
- Is obtained commercially from sugar cane or sugar beets.
- The anomeric carbon atoms of a glucose unit and a fructose unit are joined in this disaccharide;
- The configuration of this glycosidic linkage is α for glucose and β for fructose.
- Sucrose can be cleaved into its component monosaccharides by the enzyme **sucrase**.



α -D-Glucose unit

β -D-Fructose unit



Reducing & Non Reducing Properties

- Disaccharides with 1,4 linkage are reducing because they have a free aldehyde group in one of the two monosaccharides.
- Lactose & maltose are reducing sugars.
- Sucrose with 1,2 linkage, no aldehyde or ketone group is free, therefore sucrose is a non reducing sugar

Sweetness and Sweeteners (Sugar Substitutes)

- Sweetness is literally a matter of taste.
- Although individuals vary greatly in their sensory perceptions, it is possible to make some quantitative comparisons of sweetness.
- For example, we can take some standard sugar solution (say 10% sucrose in water) and compare its sweetness with that of solutions containing other sugars or sweetening agents.
- If a 1% solution of some compound tastes as sweet as the 10% sucrose solution, we can say that the compound is 10 times sweeter than sucrose.

- D-Fructose is the sweetest of the simple sugars—almost twice as sweet as sucrose.
- D-Glucose is almost as sweet as sucrose.
- On the other hand, sugars like lactose and galactose have less than 1% of the sweetness of sucrose.

Many synthetic sweeteners are known

- The most common sugar substitutes (non-saccharides) are:
 1. **Saccharin** is made commercially from toluene.
 2. **Cyclamates**: they are not used anymore because they might cause cancer.
 3. **Aspartame**: methyl ester of the aspartic acid/phenylalanine dipeptide.

Polysaccharides

Polysaccharides

•Most carbohydrates found in nature occur as polysaccharides, polymers of medium to high molecular weight. Polysaccharides, also called **glycans**, differ from each other in the identity of their:

- recurring monosaccharide units**
- in the length of their chains**
- in the types of bonds linking the units**
- in the degree of branching**

Homopolysaccharides:

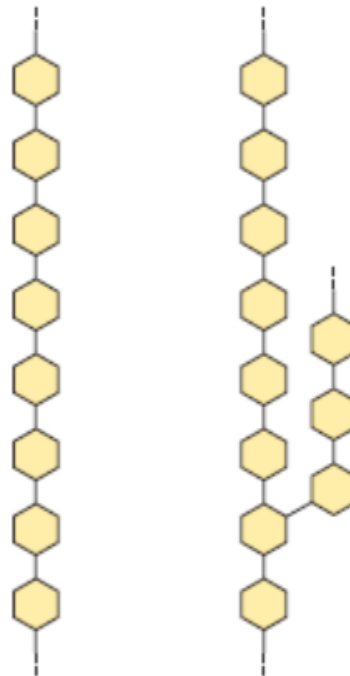
contain only a single type of monomer

Heteropolysaccharides:

contain two or more different kinds

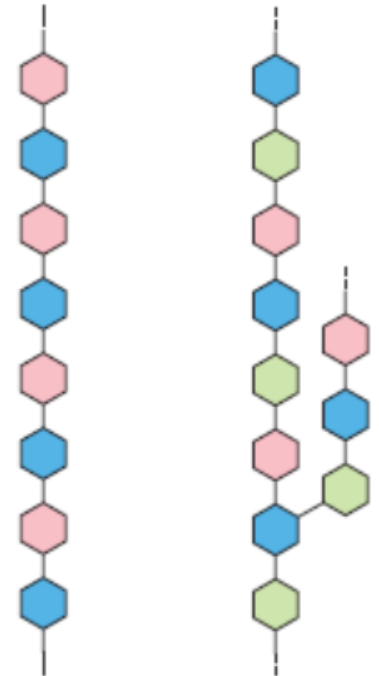
Homopolysaccharides

Unbranched Branched



Heteropolysaccharides

Two monomer types, unbranched Multiple monomer types, branched



Storage Polysaccharides

- Starch is a glucose storage polysaccharide that accumulates in small granules in plant cells.
- Starch is a mixture of amylose and amylopectin.
 - **Amylose**, which makes up about 20% of starch, is made up of 250 to 4000 D-glucose units $\alpha(1\rightarrow4)$ bonded in a continuous chain. Long chains of amylose tend to coil.
 - **Amylopectin** makes up about 80% of plant starch. It also contains D-glucose units connected by $\alpha(1\rightarrow4)$ glycosidic bonds. About every 25 glucose units along a linear glucose chain, a second glucose chain branches off through an $\alpha(1\rightarrow6)$ glycosidic bond.
- When we eat starch, our digestive system breaks it down into glucose units for use by our bodies.

Storage Polysaccharides

- **Glycogen is the storage homopolysaccharide found in animals.** Most glycogen stores are located in the liver and in muscles.
- Glycogen is identical in structure to amylopectin except that $\alpha(1\rightarrow6)$ branching occurs about every 12 glucose units.
- Glycogen is in the liver to maintain constant glucose levels in the blood when sugars are not being consumed.
- The large amount of branching in this molecule allows for quick hydrolysis when glucose is needed.

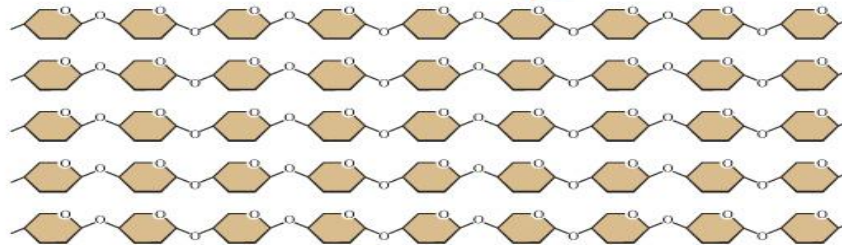
Structural Homopolysaccharides: Cellulose

- **Cellulose** contains glucose units bonded $\beta(1 \rightarrow 4)$.
- This glycosidic bond configuration changes the three-dimensional shape of cellulose compared with that of amylose.
- The chain of glucose units is straight (unbranched homopolysaccharides). This allows chains to align next to each other to form a strong rigid structure.

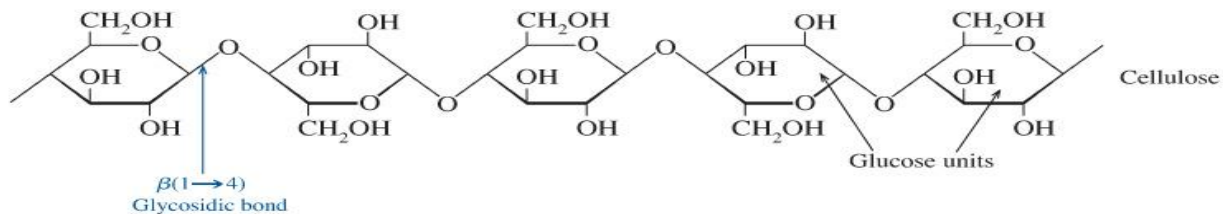
Structural Homopolysaccharides



Fibers formed
from aligned
cellulose



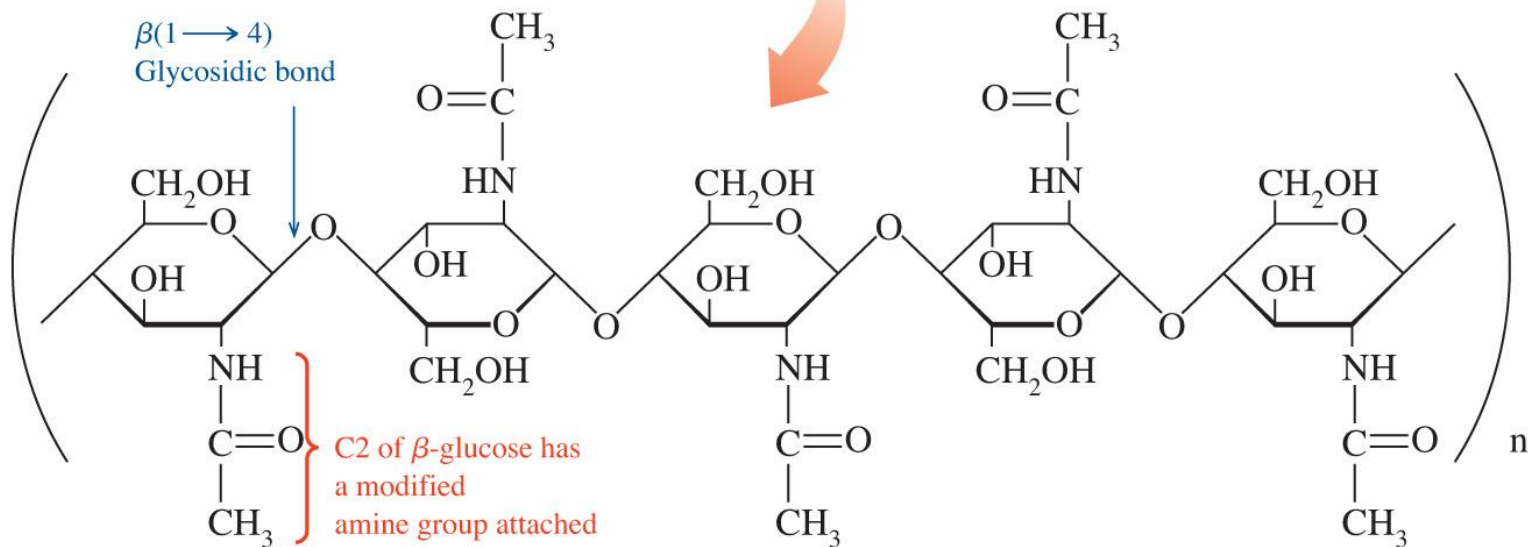
Cellulose
aligns to
form rigid
structures



Cellulose

- Cellulose is an insoluble fiber in our diet because we lack the enzyme cellulase to hydrolyze the $\beta(1\rightarrow4)$ glycosidic bond.
- Some animals and insects can digest cellulose because they contain bacteria that produce cellulase.

Structural Homopolysaccharides: Chitin



Structural Homopolysaccharides: Chitin

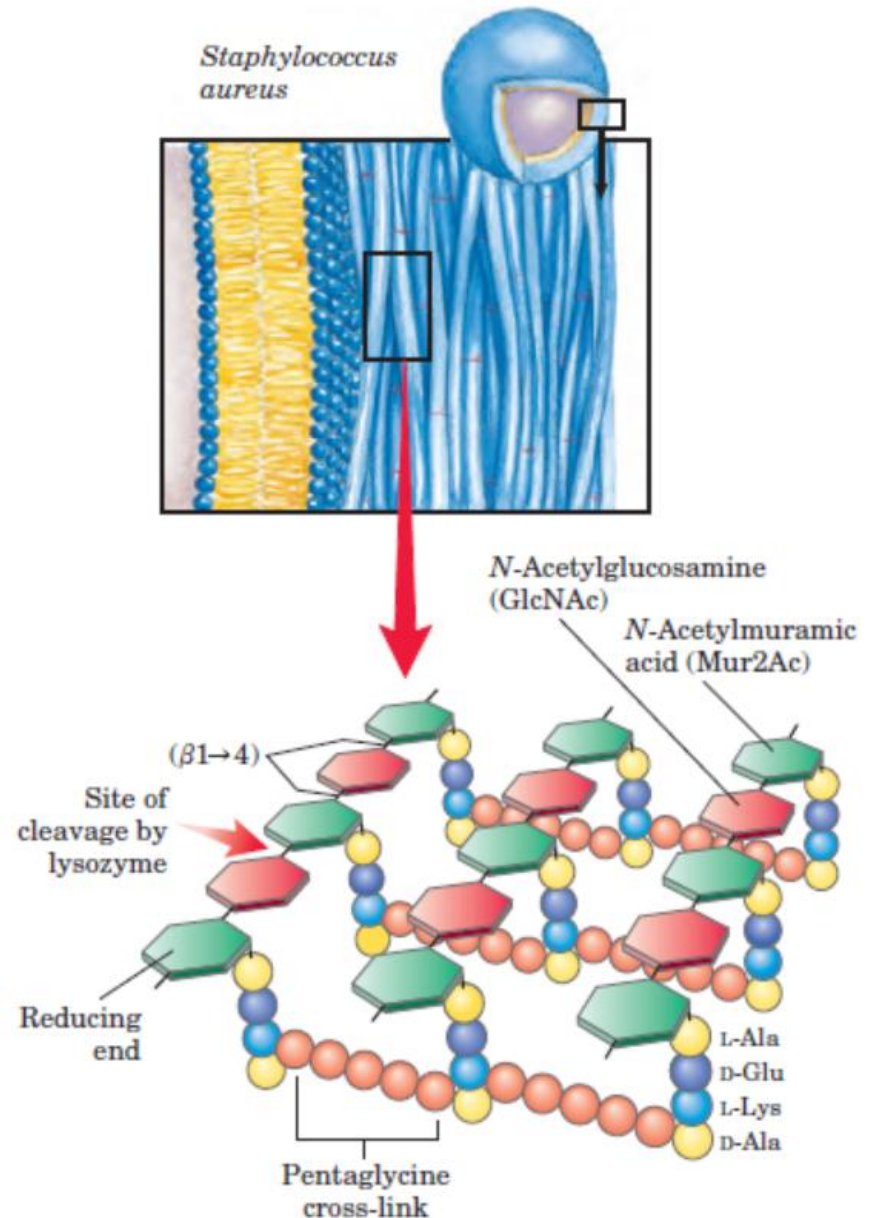
- **Chitin** makes up the exoskeleton of insects and crustaceans and cell walls of some fungi.
- It is made up of *N*-acetylglucosamine containing $\beta(1\rightarrow4)$ glycosidic bonds.
- It is structurally strong homopolysaccharides.
- The second most abundant polysaccharide, next to cellulose, in nature.

Structural Heteropolysaccharides

- Bacterial and Algal Cell Walls Contain Structural Heteropolysaccharides

- Peptidoglycan:

The rigid component of bacterial cell walls is a heteropolymer of alternating (β 1-4)-linked *N*-acetylglucosamine and *N*-acetylmuramic acid residues



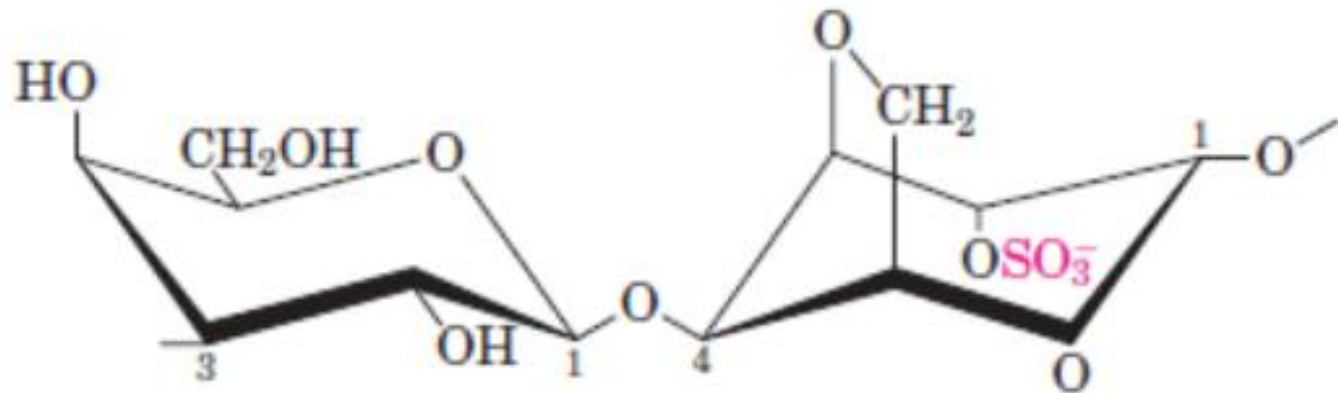
Structural Heteropolysaccharides: Agar



- Certain marine red algae, including some of the sea weeds, have cell walls that contain **agar**, a mixture of sulfated heteropolysaccharides made up of D-galactose and an L-galactose derivative ether-linked between C-3 and C-6.
- The two major components of agar are the unbranched polymer **agarose** ($Mr \sim 120,000$) and a branched component **agaropectin**.

Structure of Agarose

- The repeating unit consists of D-galactose (β 1-4)-linked to 3,6-anhydro-L-galactose (in which an ether ring connects C-3 and C-6)
- These units are joined by (α 1-3) glycosidic links to form a polymer 600 to 700 residues long. A small fraction of the 3,6-anhydrogalactose residues have a sulfate ester at C-2



Agarose

3)D-Gal(β 1 \rightarrow 4)3,6-anhydro-L-Gal2S(α 1 repeats

Heteropolysaccharides of Extracellular Matrix:

Glycosaminoglycans

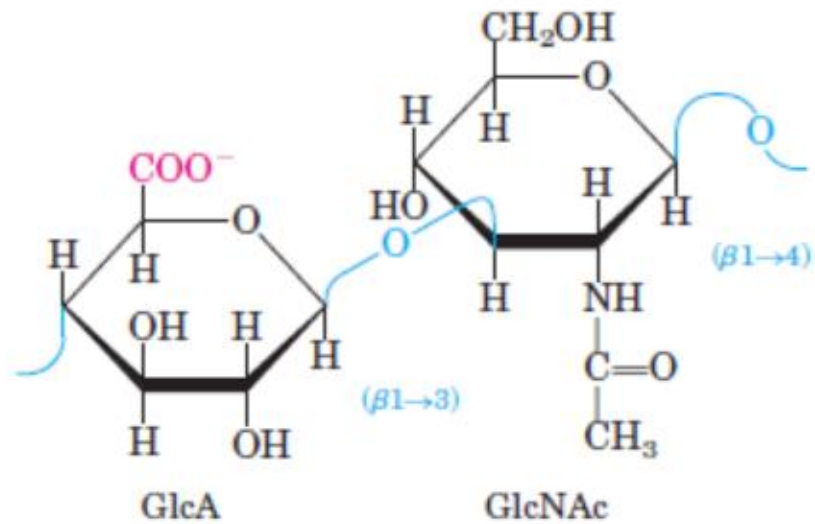
- The extracellular space in the tissues of multicellular animals is filled with a gel-like material, the **extracellular matrix, also called ground substance**, which holds the cells together and provides a porous pathway for the diffusion of nutrients and oxygen to individual cells. The extracellular matrix is composed of an interlocking meshwork of heteropolysaccharides and fibrous proteins such as collagen, elastin, fibronectin, and laminin.
- The heteropolysaccharides, the **glycosaminoglycans**, are a family of linear polymers composed of repeating disaccharide units (Fig. 7–24). One of the two monosaccharides is always either *N-acetylglucosamine* or *N-acetylgalactosamine*; the other is in most cases a uronic acid, usually D-glucuronic or L-iduronic acid.
- In some glycosaminoglycans, one or more of the hydroxyls of the amino sugar are esterified with sulfate.

Glycosaminoglycan

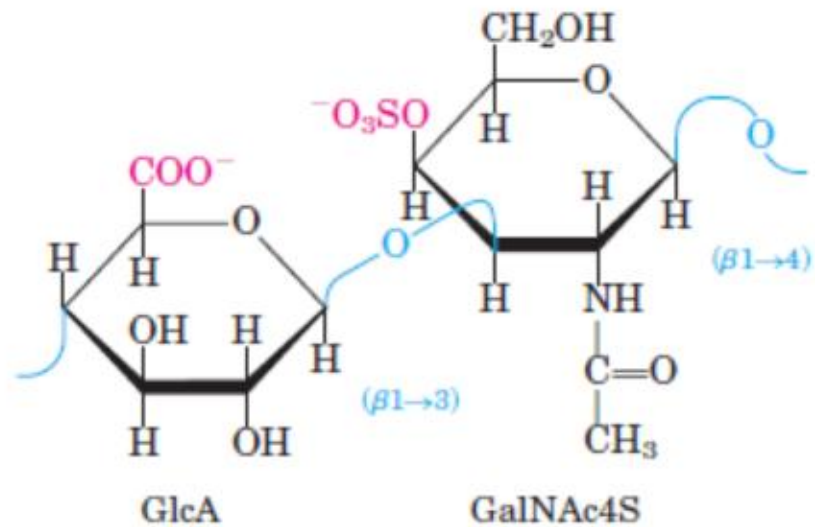
Repeating disaccharide

Number of
disaccharides
per chain

Hyaluronate
~50,000



Chondroitin
4-sulfate
20-60

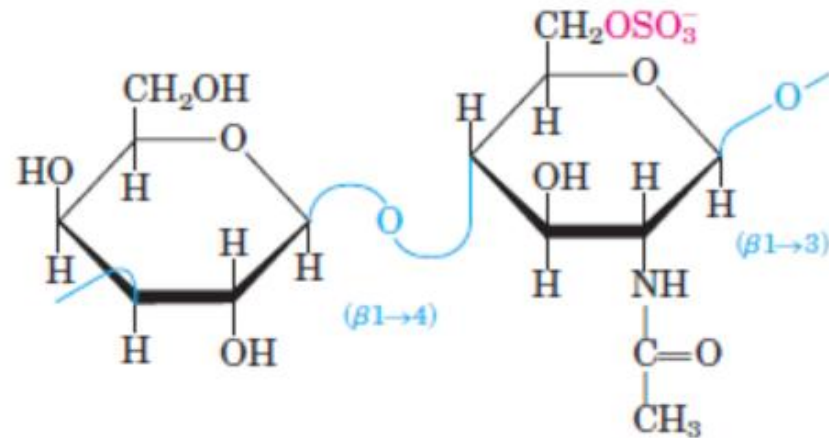


Glycosaminoglycan

Repeating disaccharide

Number of
disaccharides

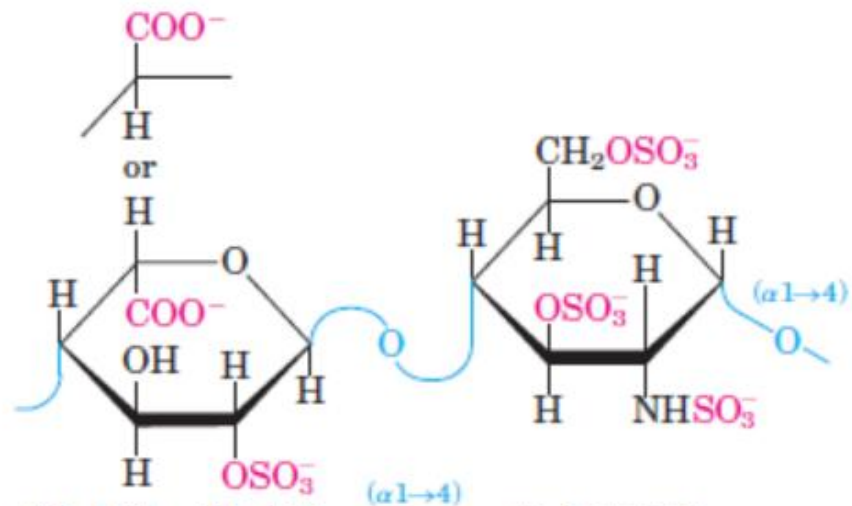
Keratan
sulfate
~25



Gal

GlcNAc6S

Heparin
15-90

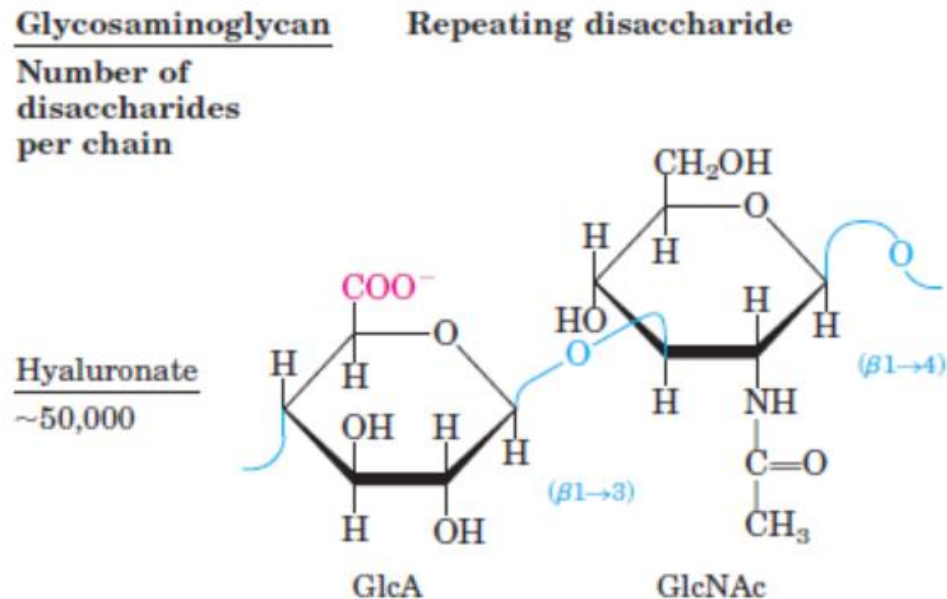


GlcA2S or IdA2S

GlcNS3S6S

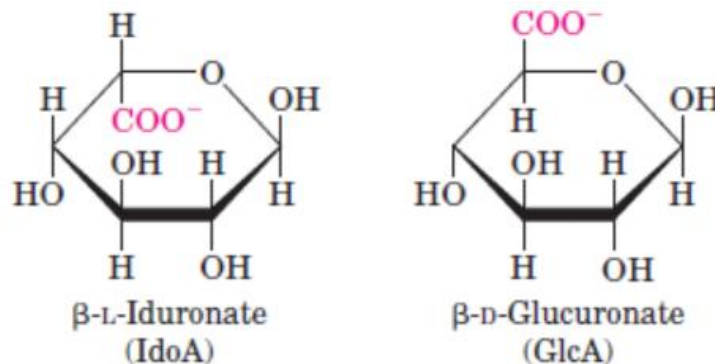
Hyaluronic acid

The glycosaminoglycan **hyaluronic acid** (hyaluronate at physiological pH) contains alternating residues of D-glucuronic acid and *N-acetylglucosamine* with up to 50,000 repeats of the basic disaccharide unit, hyaluronates have molecular weights greater than 1 million; they form clear, highly viscous solutions that serve as lubricants in the synovial fluid of joints and give the vitreous humor of the vertebrate eye its jellylike consistency. Hyaluronate is also an essential component of the extracellular matrix of cartilage and tendons, to which it contributes tensile strength and elasticity as a result of its strong interactions with other components of the matrix.



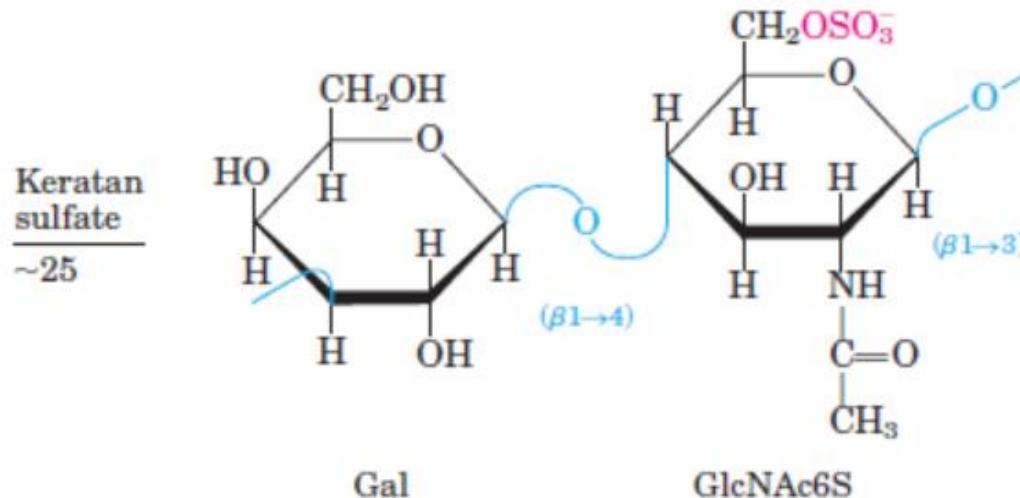
Chondrotin Sulphate & Dermatan Sulphate

- Other glycosaminoglycans differ from hyaluronate in two respects: they are generally much shorter polymers and they are covalently linked to specific proteins (proteoglycans).
- **Chondroitin sulfate** (Greek *chondros*, “cartilage” contributes to the tensile strength of cartilage, tendons, ligaments, and the walls of the aorta.
- **Dermatan sulfate** (Greek *derma*, “skin”) contributes to the pliability of skin and is also present in blood vessels and heart valves. In this polymer, many of the glucuronate (GlcA) residues present in chondroitin sulfate are replaced by their epimer, iduronate (IdoA).



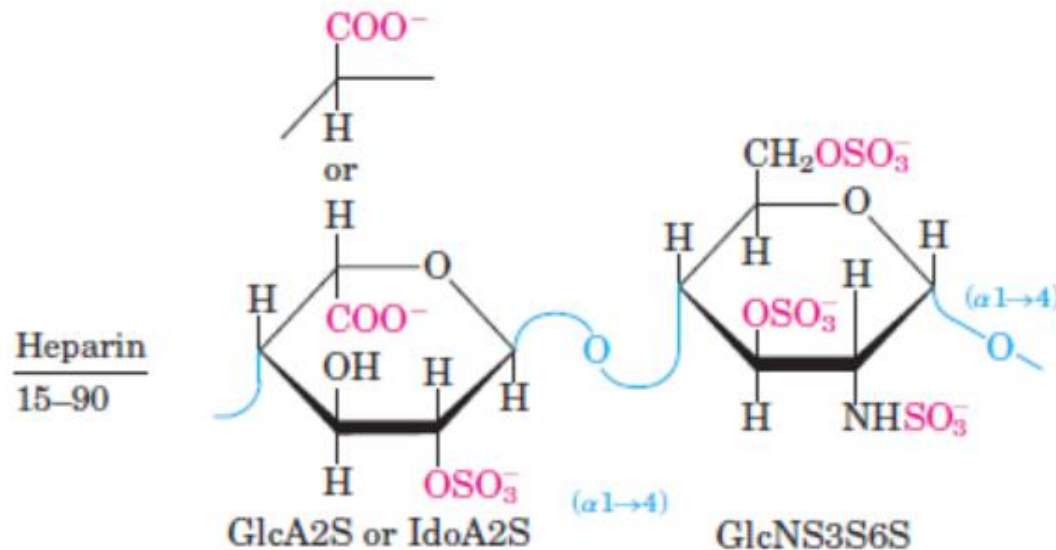
Keratan Sulphate

- Keratan sulfates (Greek *keras*, “horn”) have no uronic acid and their sulfate content is variable.
- They are present in cornea, cartilage, bone, and a variety of horny structures formed of dead cells: horn, hair, nails, and claws.



Heparin: Anticoagulant

- Heparin (Greek *he-par*, “liver”) is a natural anticoagulant made in mast cells (a type of leukocyte) and released into the blood, where it inhibits blood coagulation by binding to the protein antithrombin. Heparin binding causes antithrombin to bind to and inhibit thrombin, a protease essential to blood clotting.
- 2-O-sulphated iduronic acid and 2, 6-O-sulphated, N-sulphated glucosamine



Glycoconjugates: Proteoglycans, Glycoproteins, and Glycolipids

- In addition to their important roles as stored fuels and as structural materials **polysaccharides and oligosaccharides are information carriers**: they serve as destination labels for some proteins and as mediators of specific cell-cell interactions and interactions between cells and the extracellular matrix.
- In most of these cases, the informational carbohydrate is covalently joined to a protein or a lipid to form a **glycoconjugate**, which is the biologically active molecule.

Proteoglycans

- **Proteoglycans** are macromolecules of the cell surface or extracellular matrix in which one or more glycosaminoglycan chains are joined covalently to a membrane protein or a secreted protein. The glycosaminoglycan moiety commonly forms the greater fraction (by mass) of the proteoglycan molecule, dominates the structure, and is often the main site of biological activity
- Proteoglycans are major components of connective tissue such as cartilage, in which their many noncovalent interactions with other proteoglycans, proteins, and glycosaminoglycans provide strength and resilience.

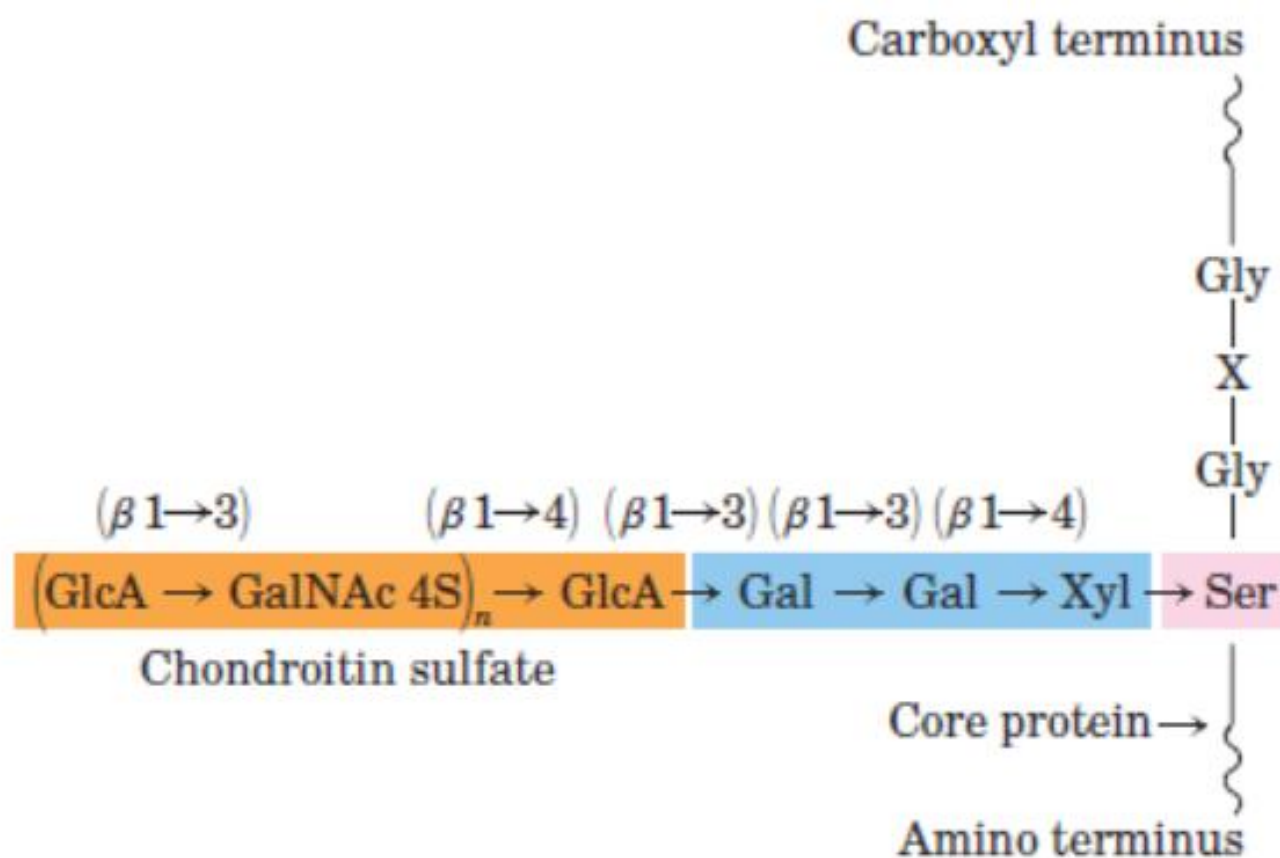
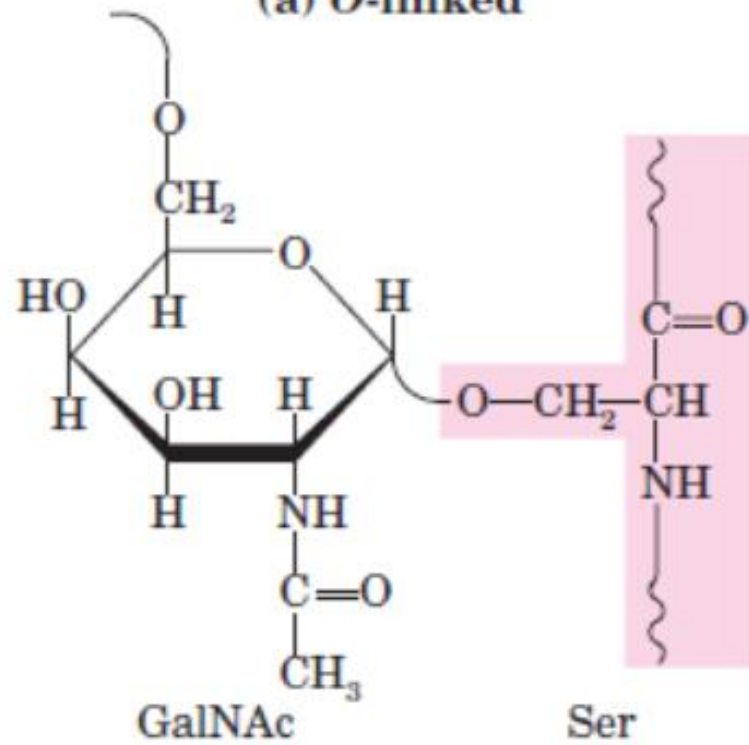


FIGURE 7-26 Proteoglycan structure, showing the trisaccharide bridge. A typical trisaccharide linker (blue) connects a glycosaminoglycan—in this case chondroitin sulfate (orange)—to a Ser residue (red) in the core protein. The xylose residue at the reducing end of the linker is joined by its anomeric carbon to the hydroxyl of the Ser residue.

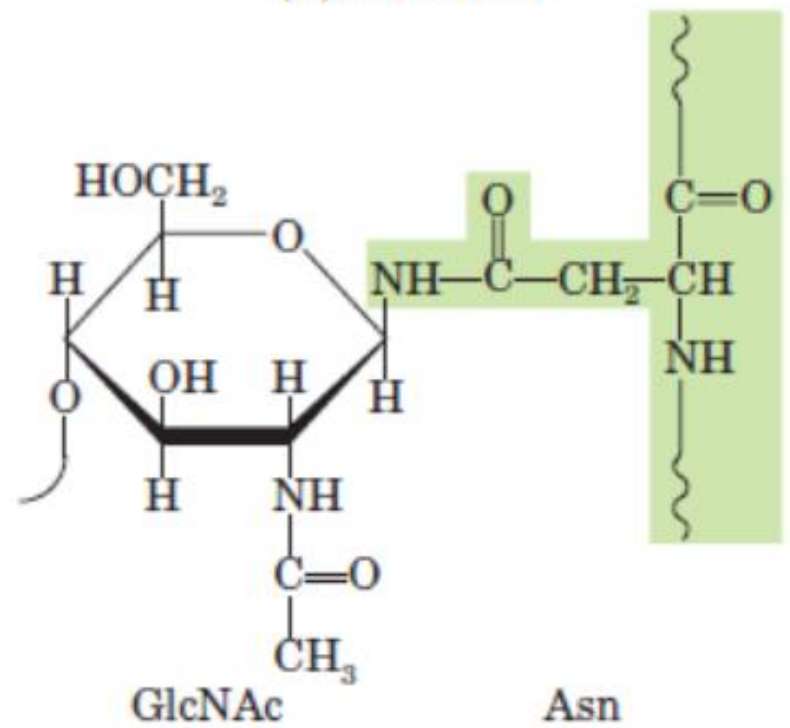
Glycoproteins

- **Glycoproteins** have one or several oligosaccharides of varying complexity joined covalently to a protein.
- They are found on the outer face of the plasma membrane, in the extracellular matrix, and in the blood.
- The carbohydrate is attached at its anomeric carbon through a glycosidic link to the -OH of a Ser or Thr residue (*O-linked*), or through an *N-glycosyl link* to the amide nitrogen of an Asn residue (*N-linked*).
- Many of the proteins secreted by eukaryotic cells are glycoproteins, including most of the proteins of blood. For example, immunoglobulins (antibodies) and certain hormones, such as follicle-stimulating hormone, luteinizing hormone, and thyroid-stimulating hormone, are glycoproteins. Many milk proteins, including lactalbumin, and some of the proteins secreted by the pancreas (such as ribonuclease) are glycosylated, as are most of the proteins contained in lysosomes.

(a) *O*-linked

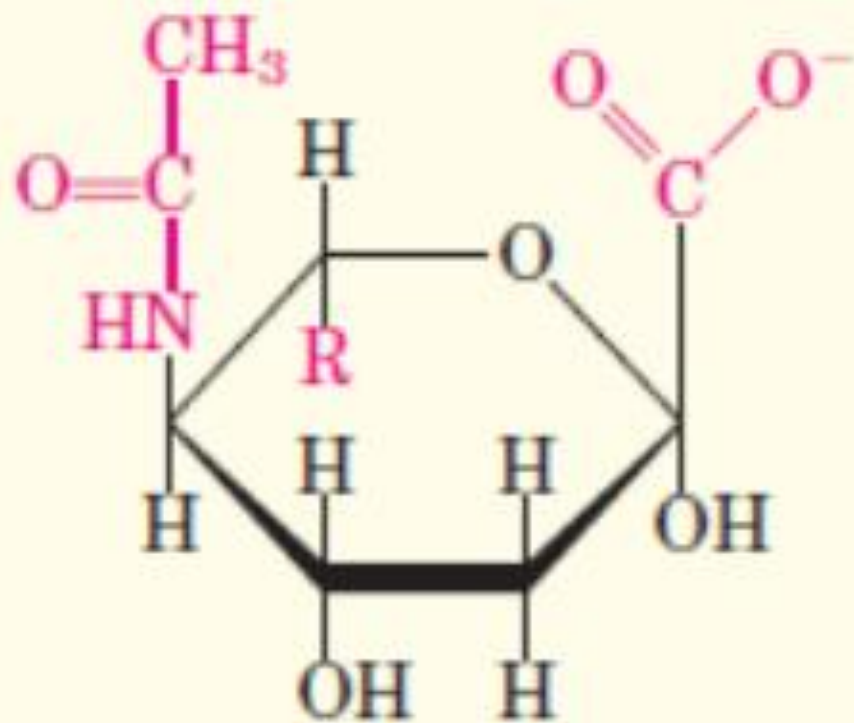


(b) *N*-linked

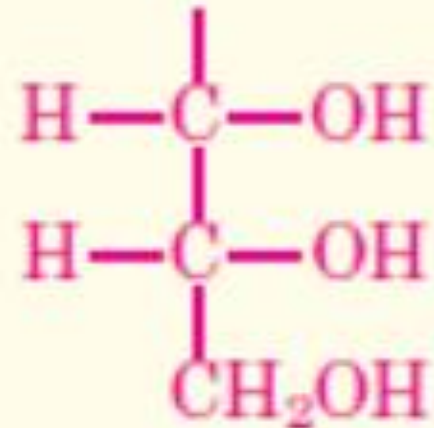


Glycolipids and Lipopolysaccharides

- Glycolipids and lipopolysaccharides are lipids of plasma membrane with covalently attached oligosaccharide chains exposed on the cell's outer surface.
- **Gangliosides** are membrane lipids of eukaryotic cells in which the polar head group, the part of the lipid that forms the outer surface of the membrane, is a complex oligosaccharide containing sialic acid



R=

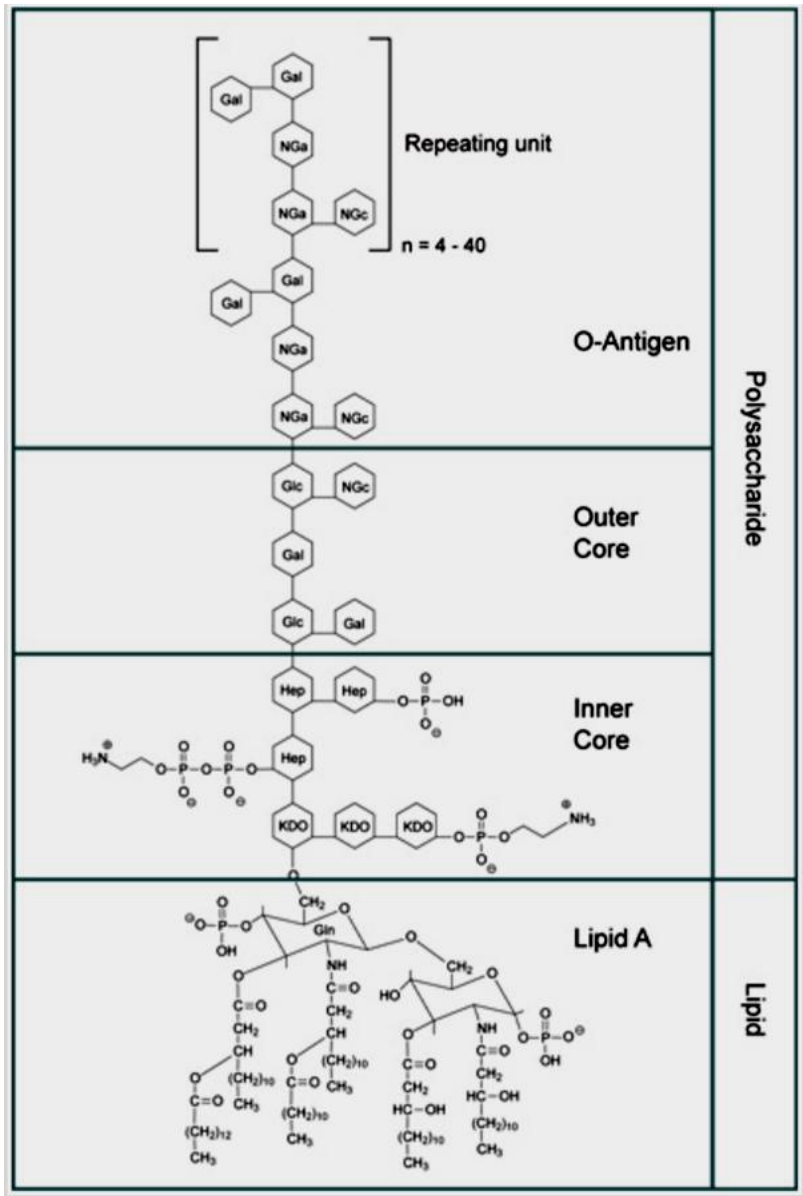


N-Acetylneuraminic acid
(a sialic acid)

Sugars as information code

- Oligosaccharides are far more information-dense than nucleic acids or proteins.
- **Lectins, proteins with highly specific carbohydrate-binding domains**, are commonly found on the outer surface of cells, where they initiate interaction with other cells.
- In vertebrates, oligosaccharide tags “read” by lectins govern the rate of degradation of certain peptide hormones, circulating proteins, and blood cells.
- Lectins are also present inside cells, where they mediate intracellular protein targeting.
- **Selectins** are plasma membrane lectins that bind carbohydrate chains in the extracellular matrix or on the surfaces of other cells, thereby mediating the flow of information between cell and matrix or between cells

Lipopolysaccharides



Lipopolysaccharides (LPS), also known as lipoglycans and **endotoxins**, are large molecules consisting of a **lipid** and a **polysaccharide** composed of **O-antigen**, **outer core** and **inner core** joined by a covalent bond; they are found in the outer membrane of Gram-negative bacteria.