Carbohydrates

Campbell and Farrell's Biochemistry, Chapter 16

What are they?

- Carbohydrates are polyhydroxy aldehydes or ketones
- **Saccharide** is another name for a carbohydrate

- Functions:
  - Source of energy
  - Structure (cellulose and chitin)
  - Building blocks
  - Cellular and immune recognition

Classification I

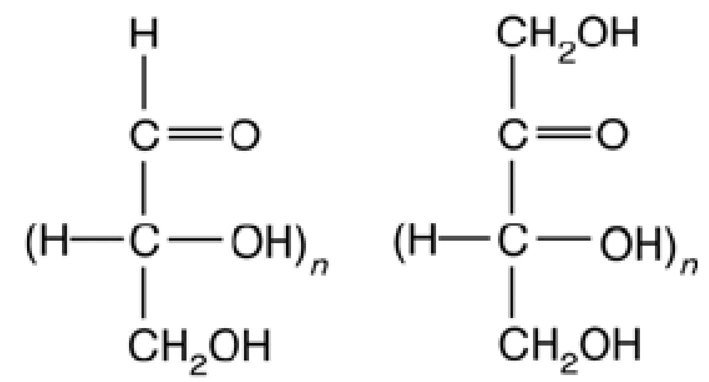
- By the number of sugars that constitute the molecule
  - Monosaccharides
  - Disaccharides
  - Oligosaccharides
  - Polysaccharides

Carbohydrates – natural forms

- Most carbohydrates are found naturally in bound form rather than as simple sugars
  - Polysaccharides (starch, cellulose, inulin, gums)
  - Glycoproteins and proteoglycans (hormones, blood group substances, antibodies)
  - Glycolipids (cerebrosides, gangliosides)
  - Glycosides
  - Mucopolysaccharides (hyaluronic acid)
  - Nucleic acids (DNA, RNA)

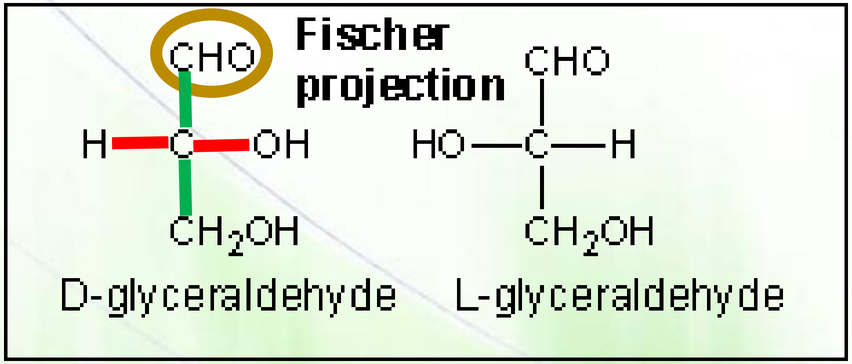
Monosaccharides

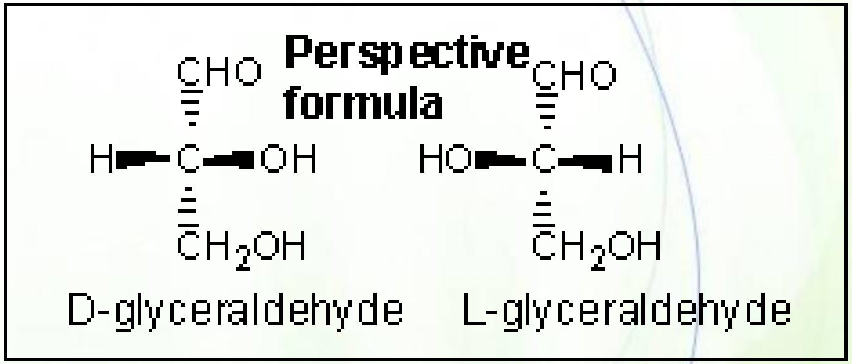
- Basic chemical formula: $C_n(H_2O)_n$
- They contain two or more hydroxyl groups.



An aldose **A ketose**

Fisher projections or perspective structural formulas.

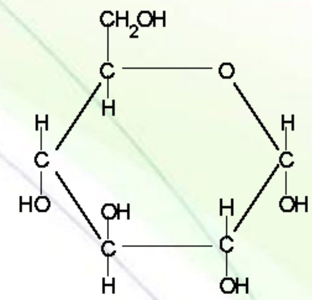




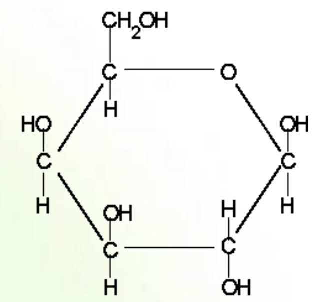
Forward **Backward** **Top (C1): Most highly oxidized C**

Common Monosaccharides

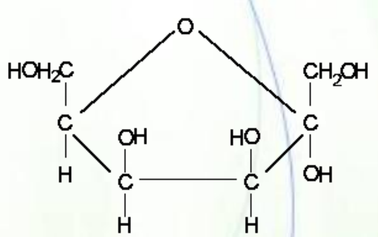
- Glucose:
  - Mild sweet flavor
  - Known as blood sugar
  - Essential energy source
  - Found in every disaccharide and polysaccharide
- Galactose:
  - Hardly tastes sweet & rarely found naturally as a single sugar
- Fructose:
  - Sweetest sugar, found in fruits and honey
  - Added to soft drinks, cereals, desserts



Glucose

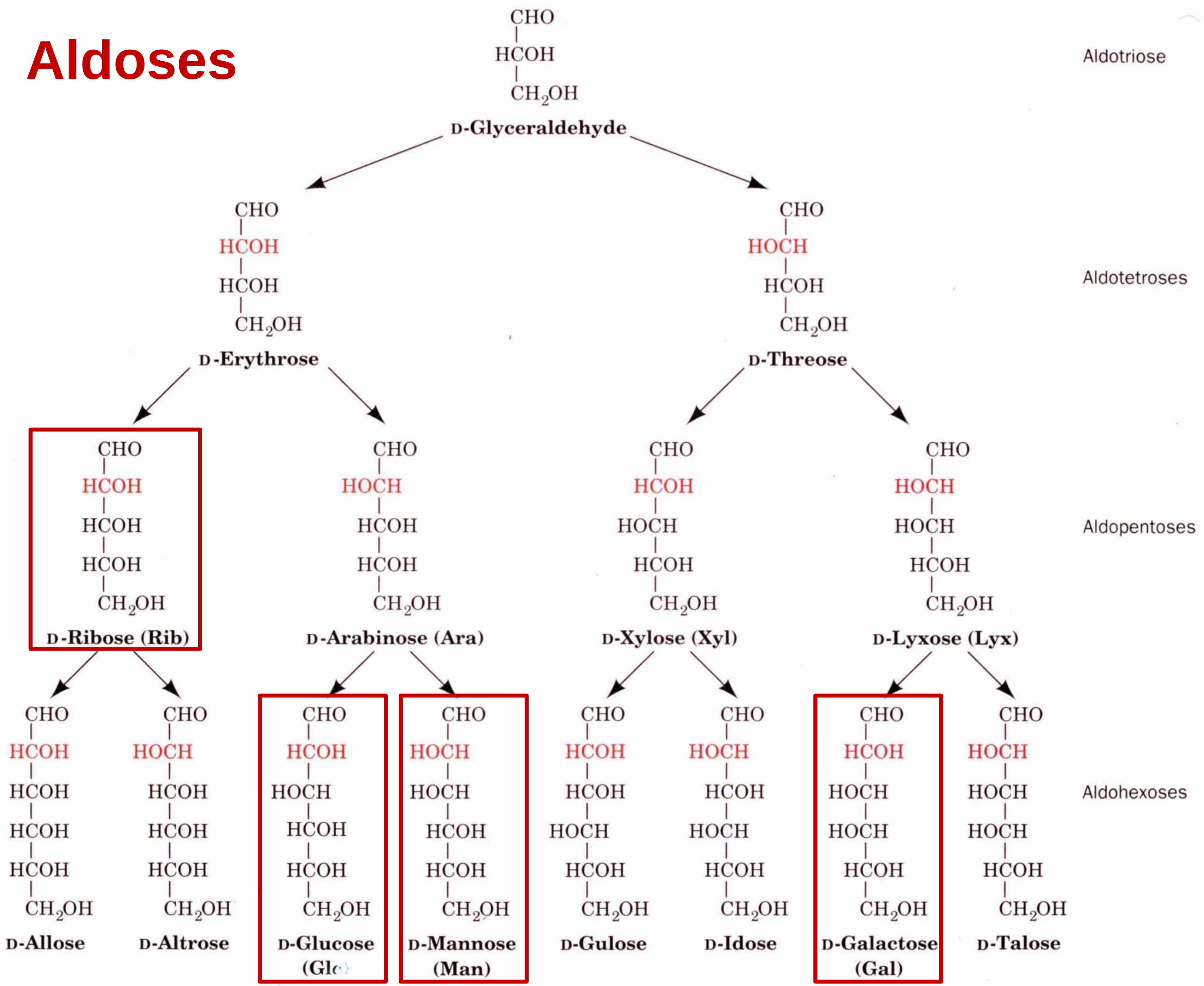


Galactose



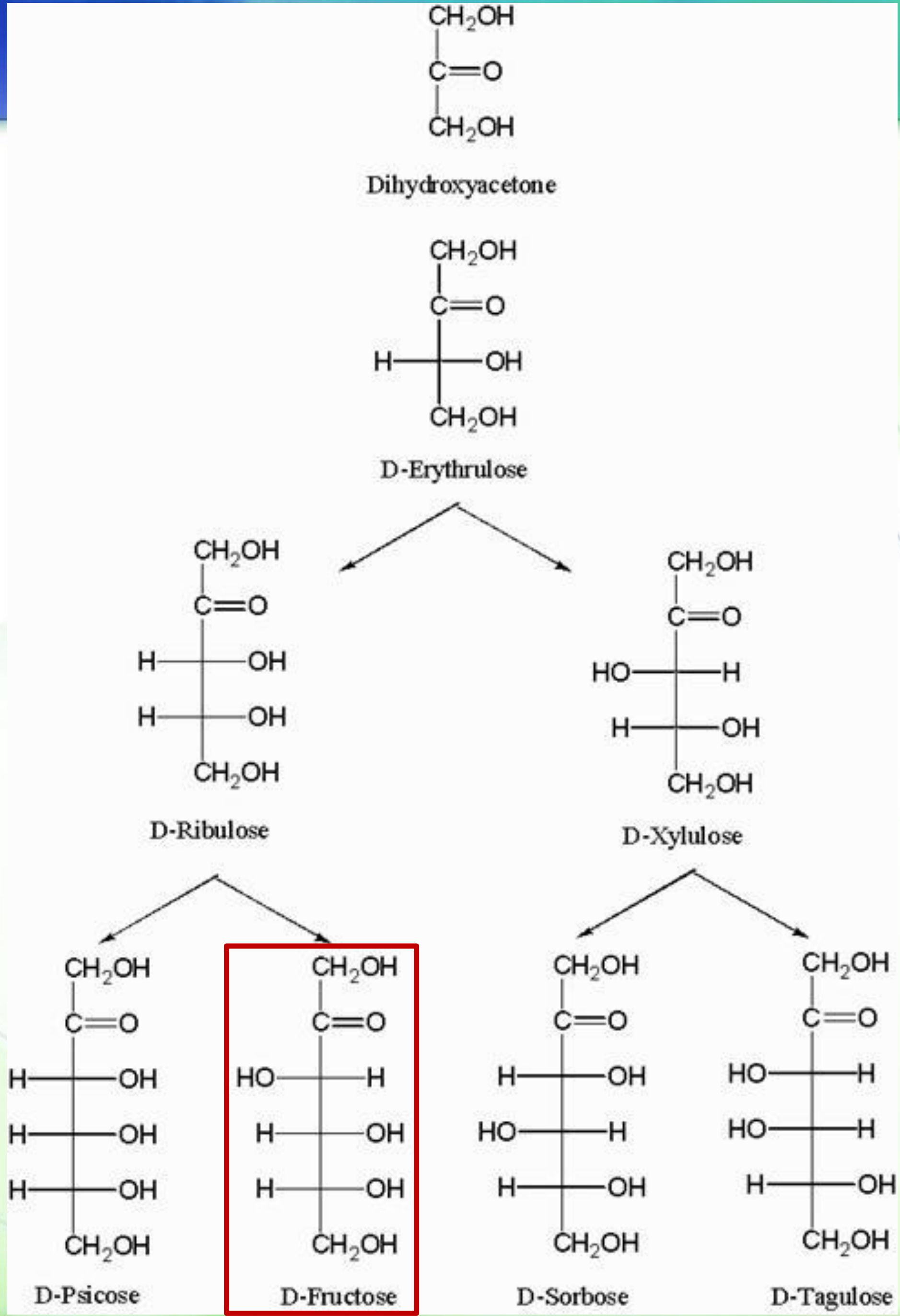
Fructose

Aldoses



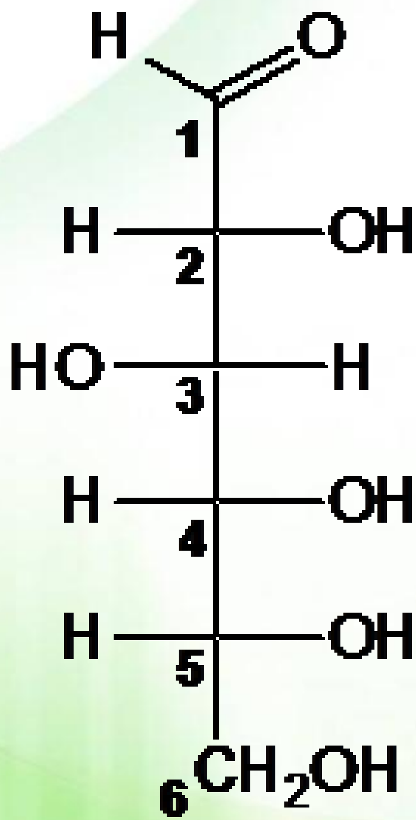
D-Glyceraldehyde
Aldotriose
D-Erythrose
D-Threose
Aldotetroses
D-Ribose (Rib)
D-Arabinose (Ara)
D-Xylose (Xyl)
D-Lyxose (Lyx)
Aldopentoses
D-Allose
D-Altrose
D-Glucose
D-Mannose (Man)
D-Gulose
D-Idose
D-Galactose (Gal)
D-Talose
Aldohexoses

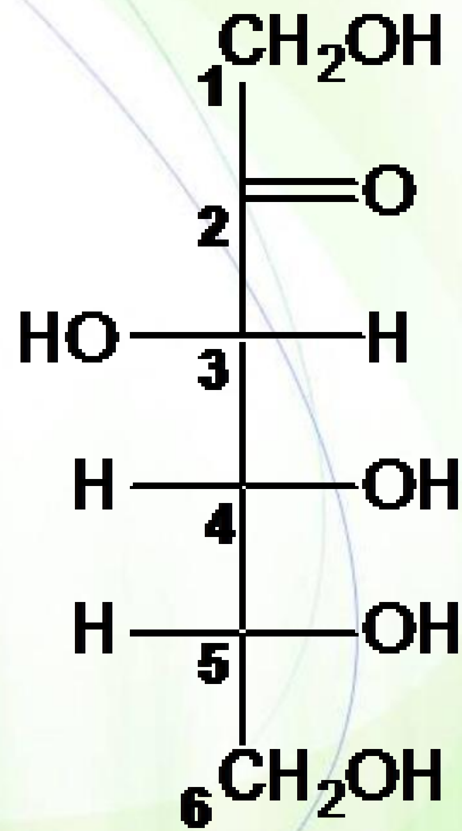
Ketoses


Dihydroxyacetone
D-Erythrulose
D-Ribulose
D-Xylulose
D-Psicose
D-Fructose
D-Sorbose
D-Tagulose

Classification 2

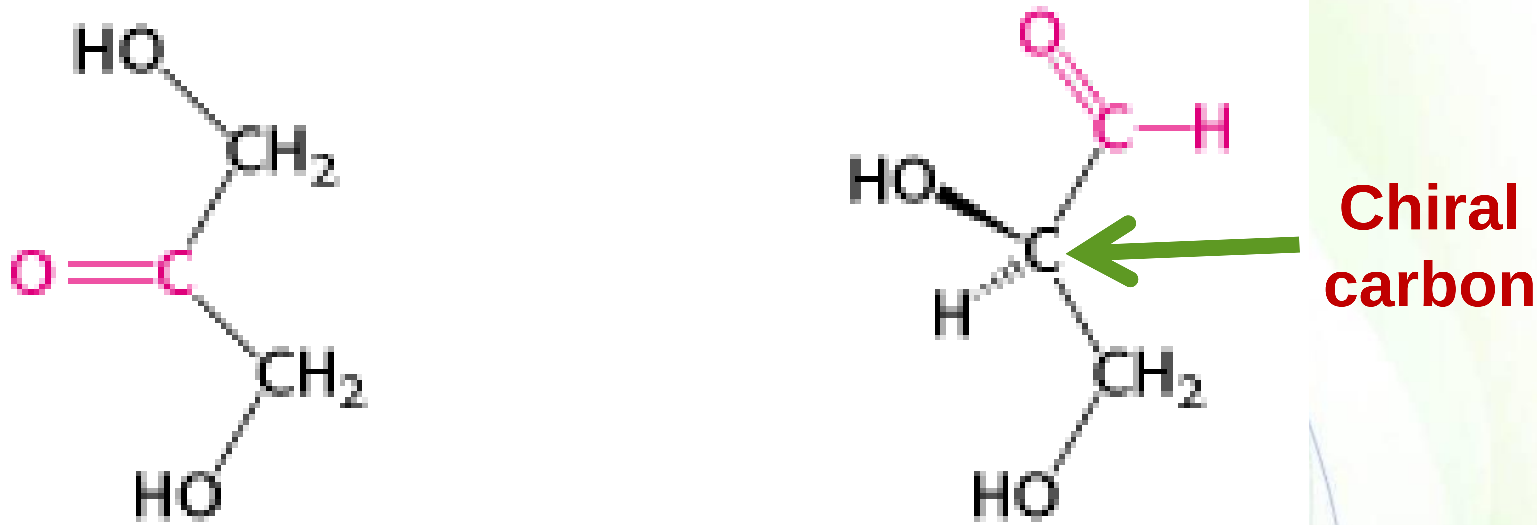
- By the number of carbon atoms they contain
  - Triose
  - Tetrose
  - Pentose
  - Hexose
  - Heptose
  - …





Trioses

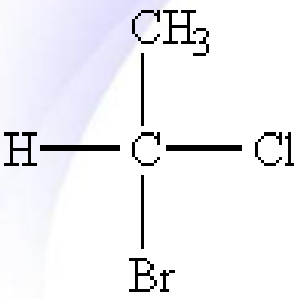
What is a chiral carbon?



Dihydroxyacetone
(a ketose)

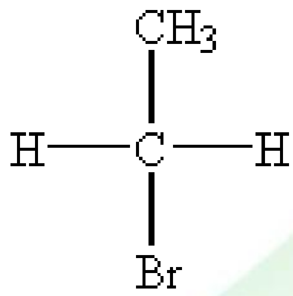
D-Glyceraldehyde
(an aldose)

Note what a chiral carbon is…



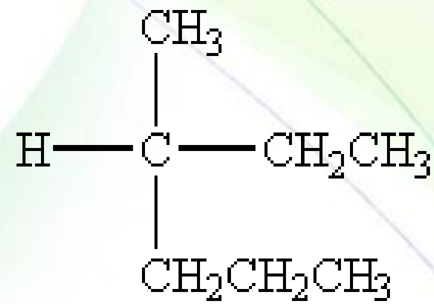
chiral

Has 4 differnt atoms bonded to the carbon



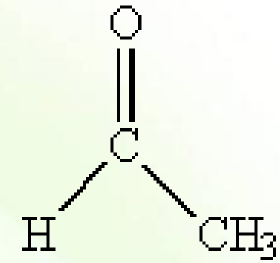
achiral

Does not have 4 different atoms or groups bonded to the carbon (2 hydrogens)



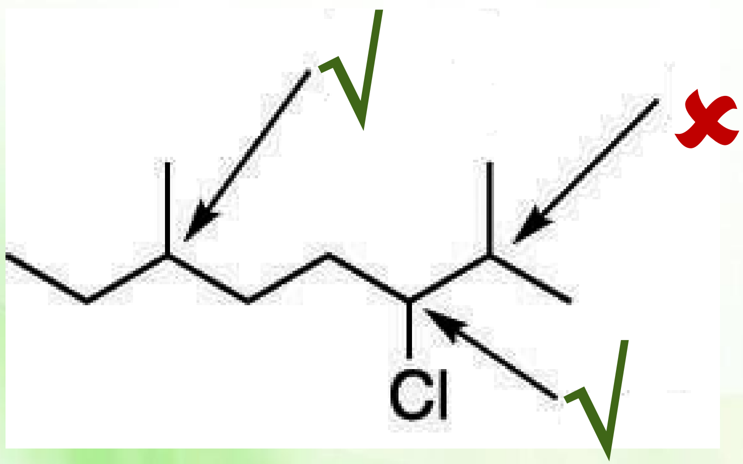
chiral

Has 4 differnt groups bonded to the carbon



achiral

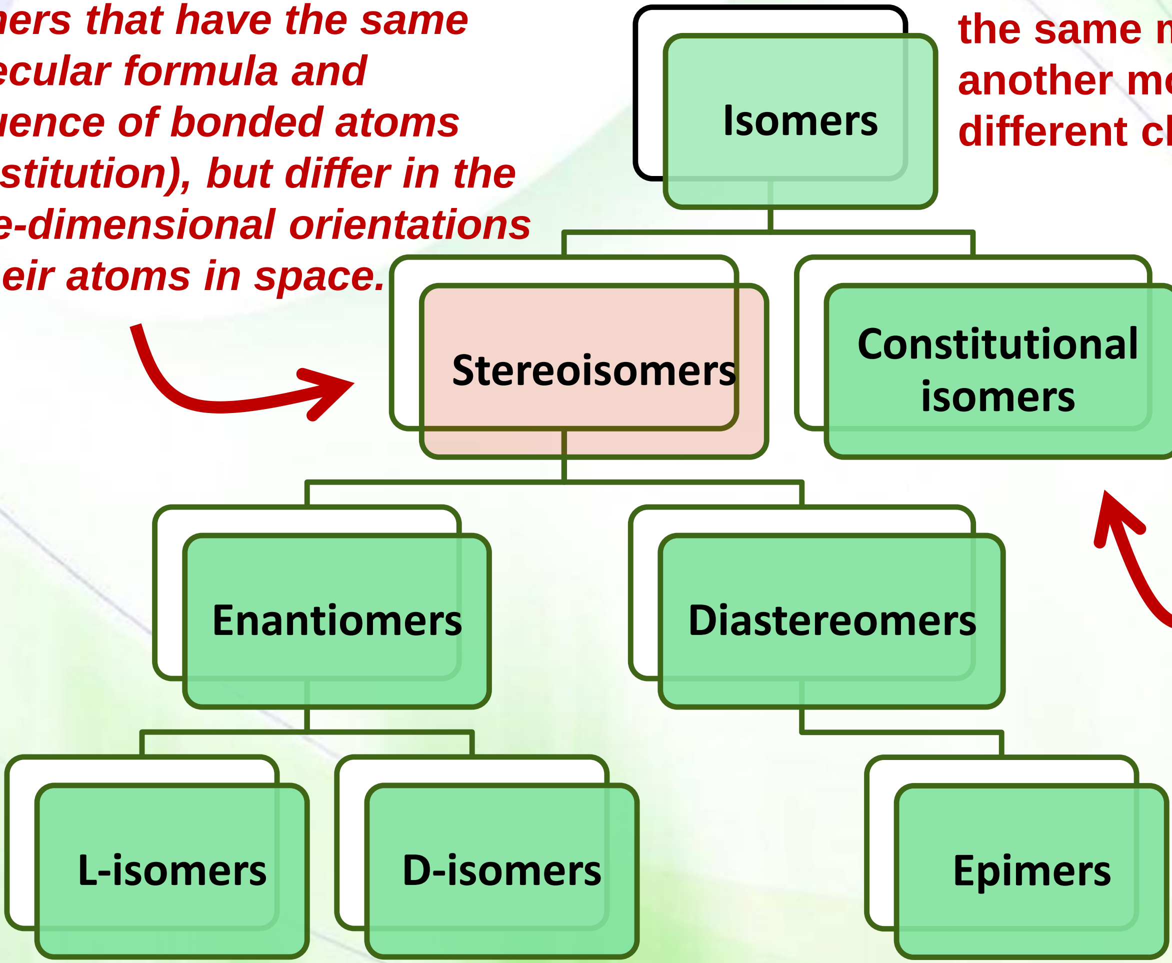
Only has 3 atoms bonded to the carbor.



Isomerism

*An **isomer** is a molecule with the same molecular formula as another molecule, but with a different chemical structure.*

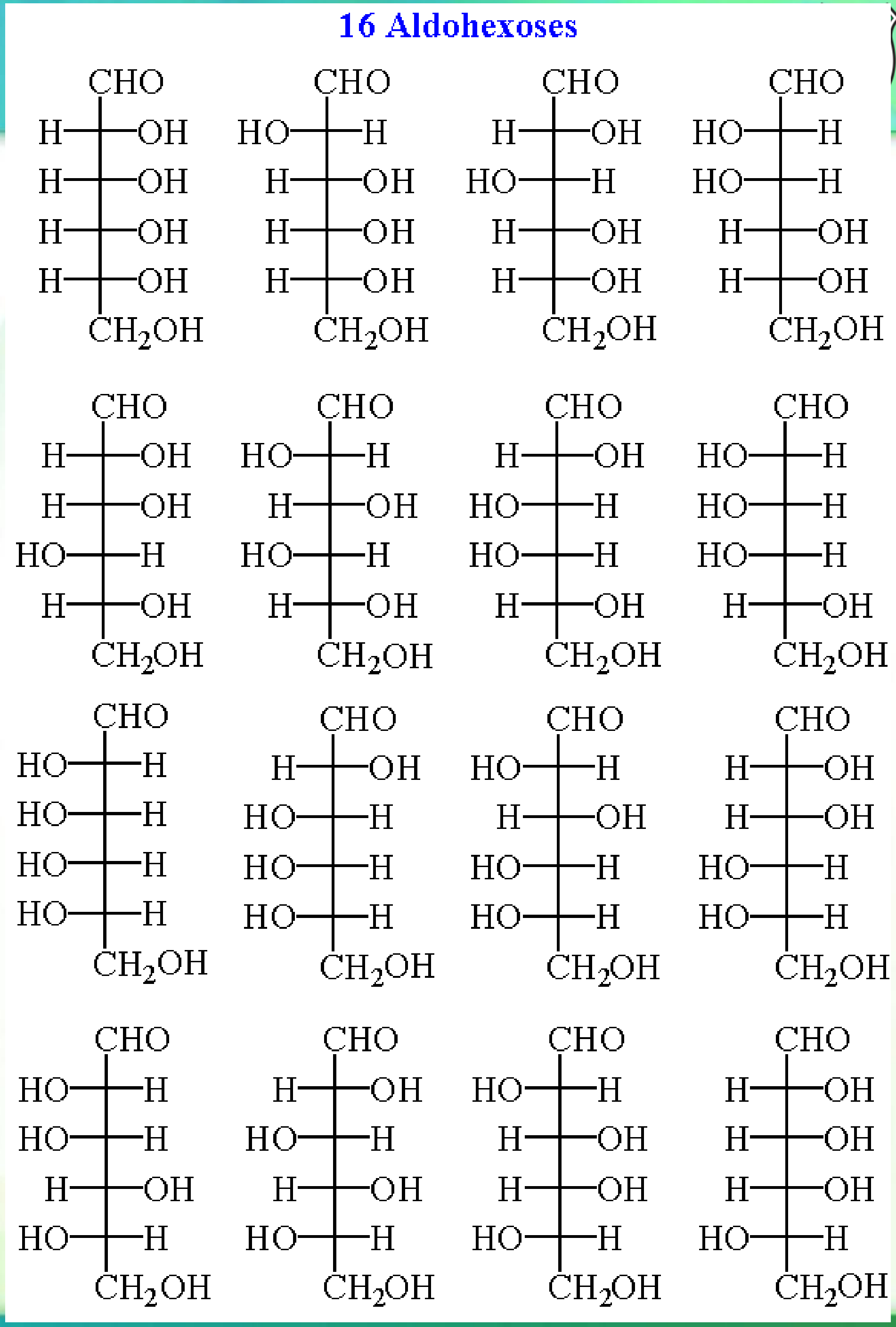
Isomers that have the same molecular formula and sequence of bonded atoms (constitution), but differ in the three-dimensional orientations of their atoms in space.



Molecules with the same molecular formula, but have different bonding patterns and atomic organization.

Isomers of glucose

2^n (n is the number of chiral carbons in a sugar molecule)



Search for:

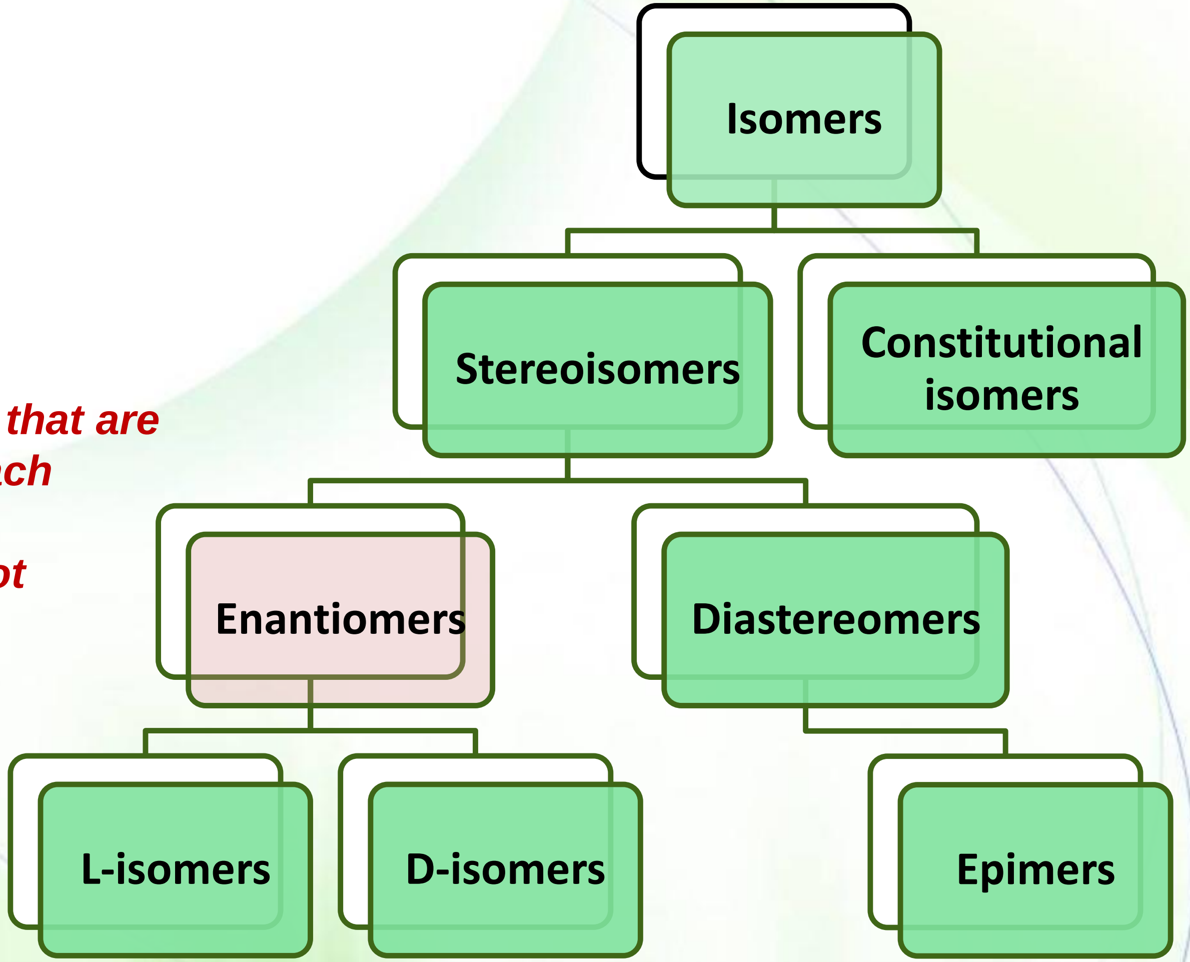
Glucose,

Galactose

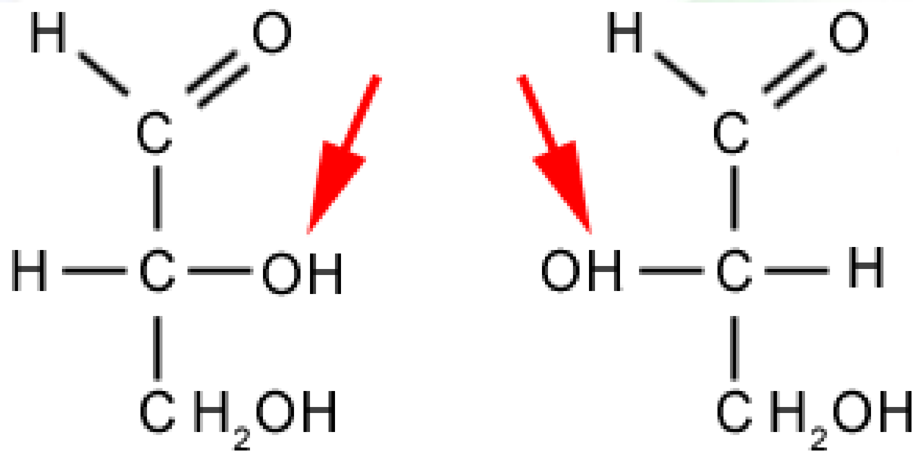
Mannose

Enantiomers

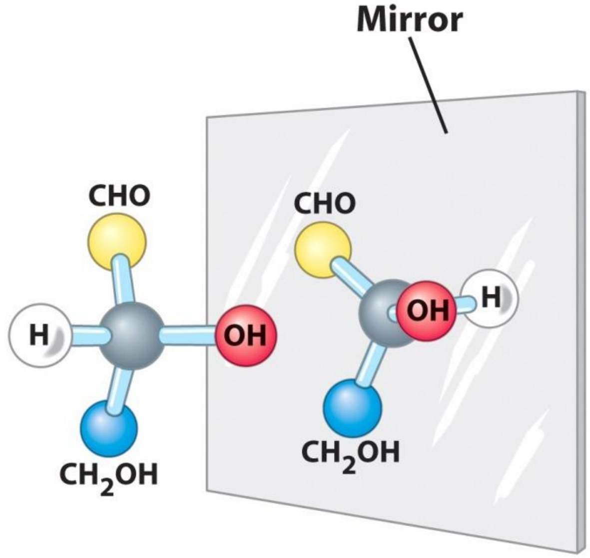
Two stereoisomers that are mirror images of each other and are non-superimposable (not identical)



Sugar enantiomers (D- vs. L-)

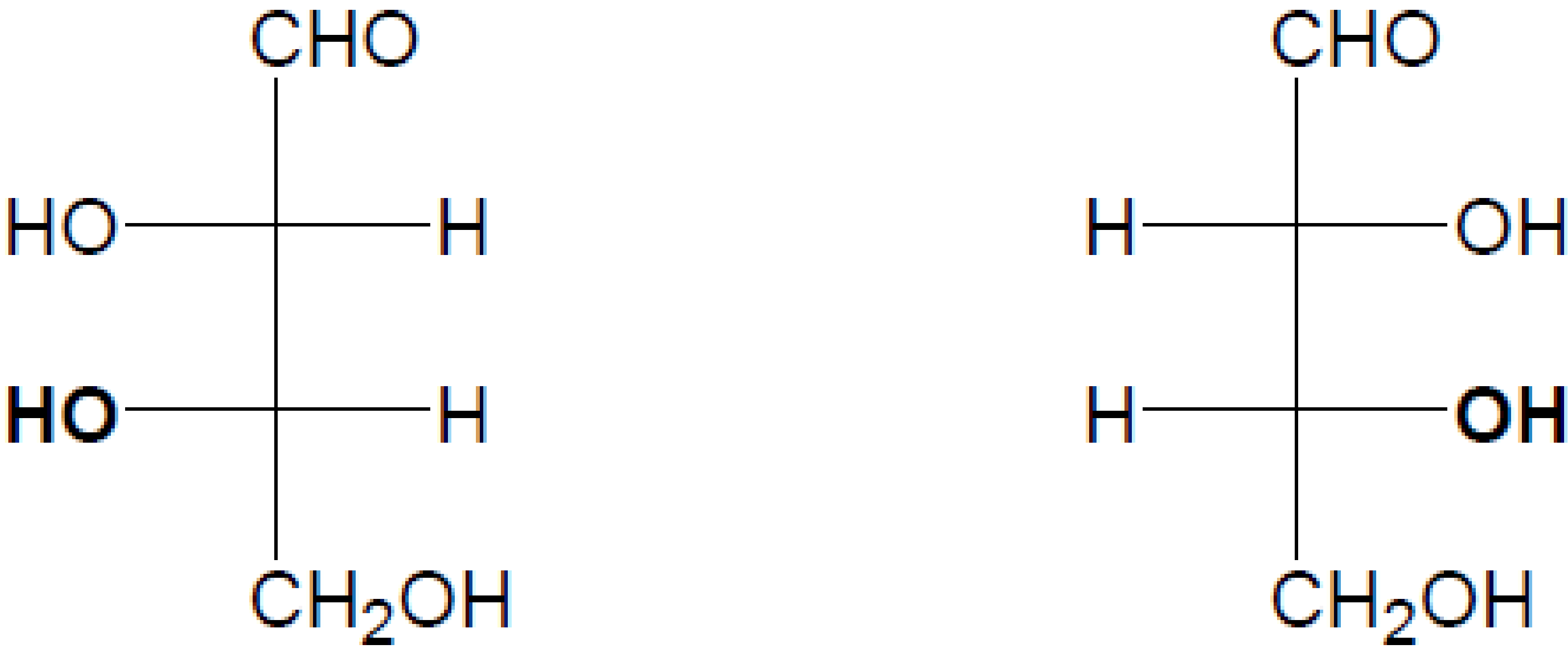


D-Glyceraldehyde L-Glyceraldehyde



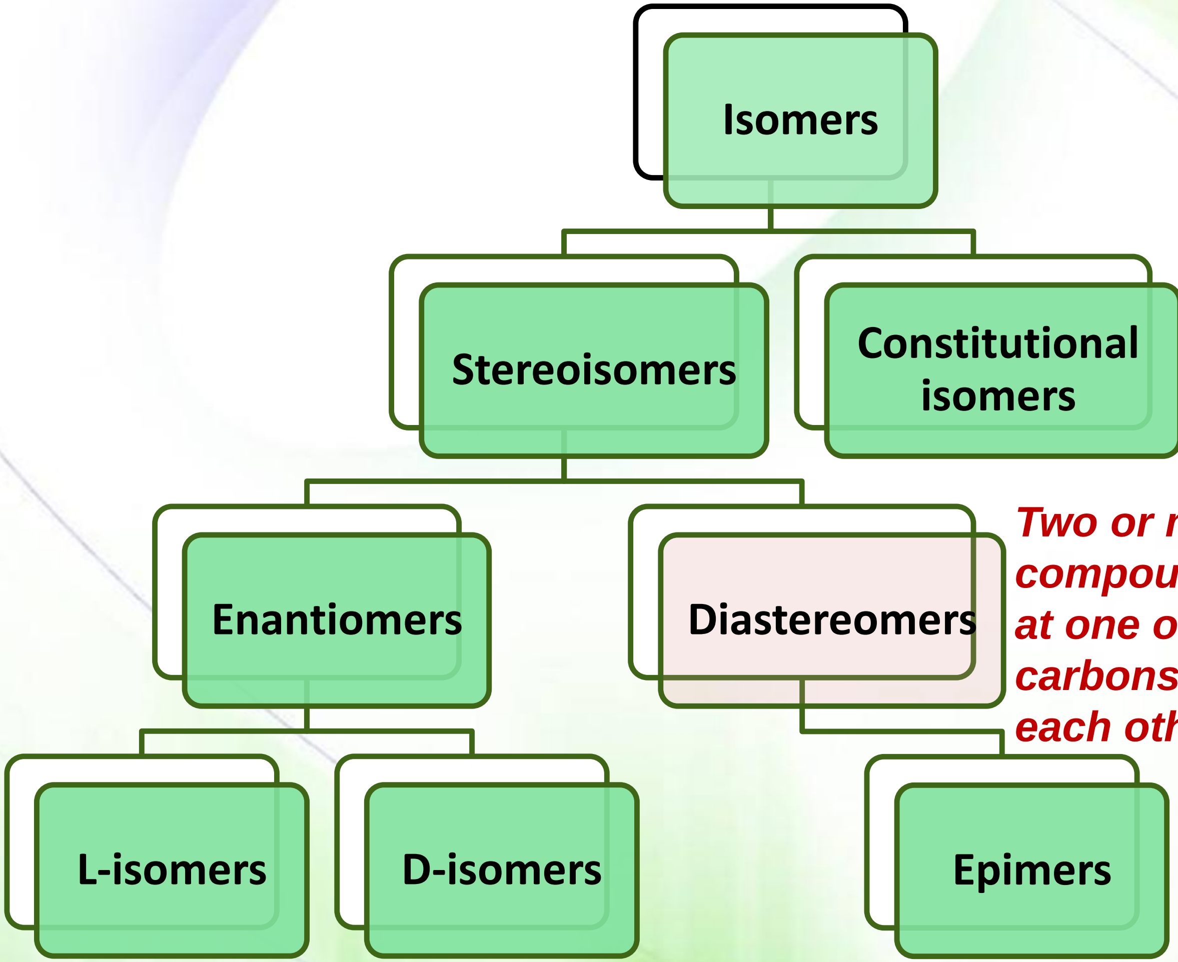
Ball-and-stick models

Which one(s) is a chiral carbon?



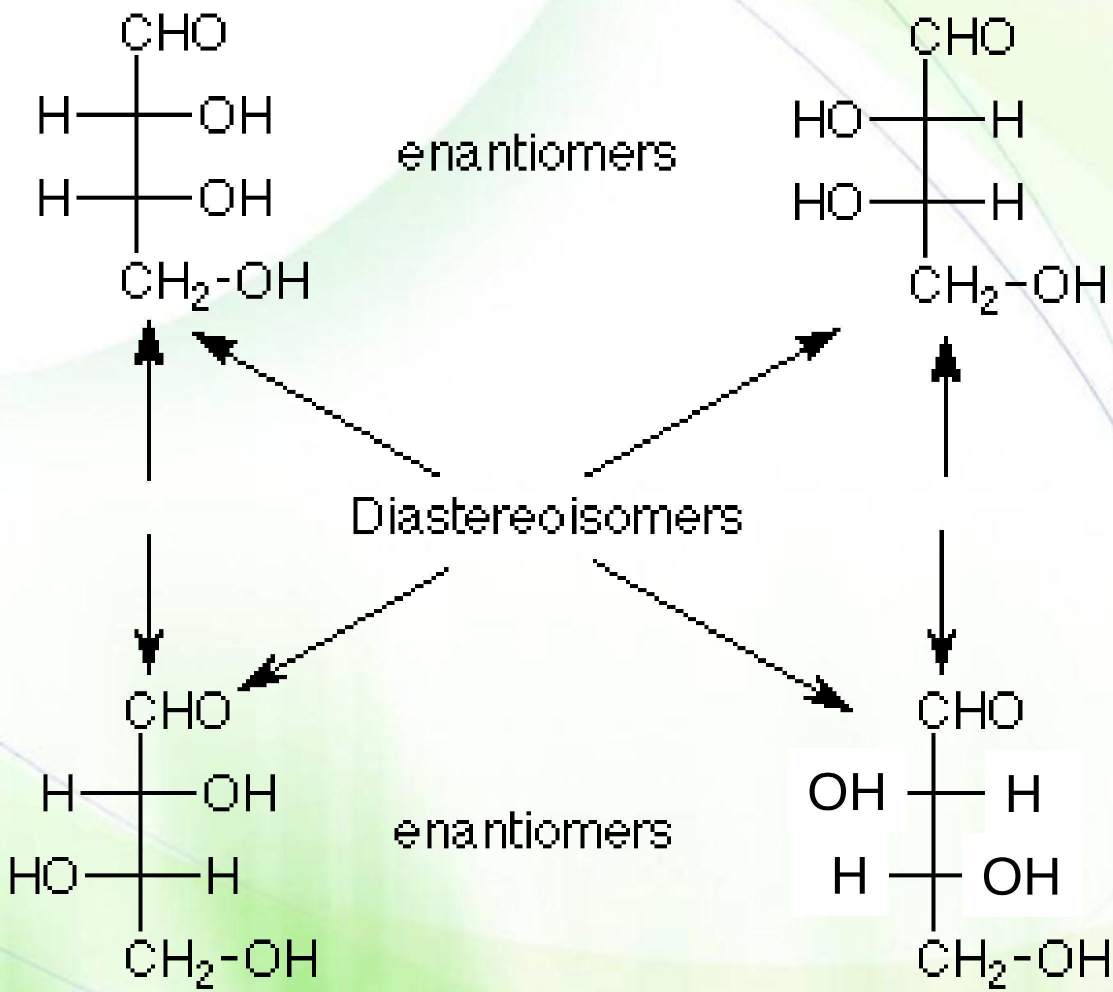
L-erythrose D-erythrose

Isomerism

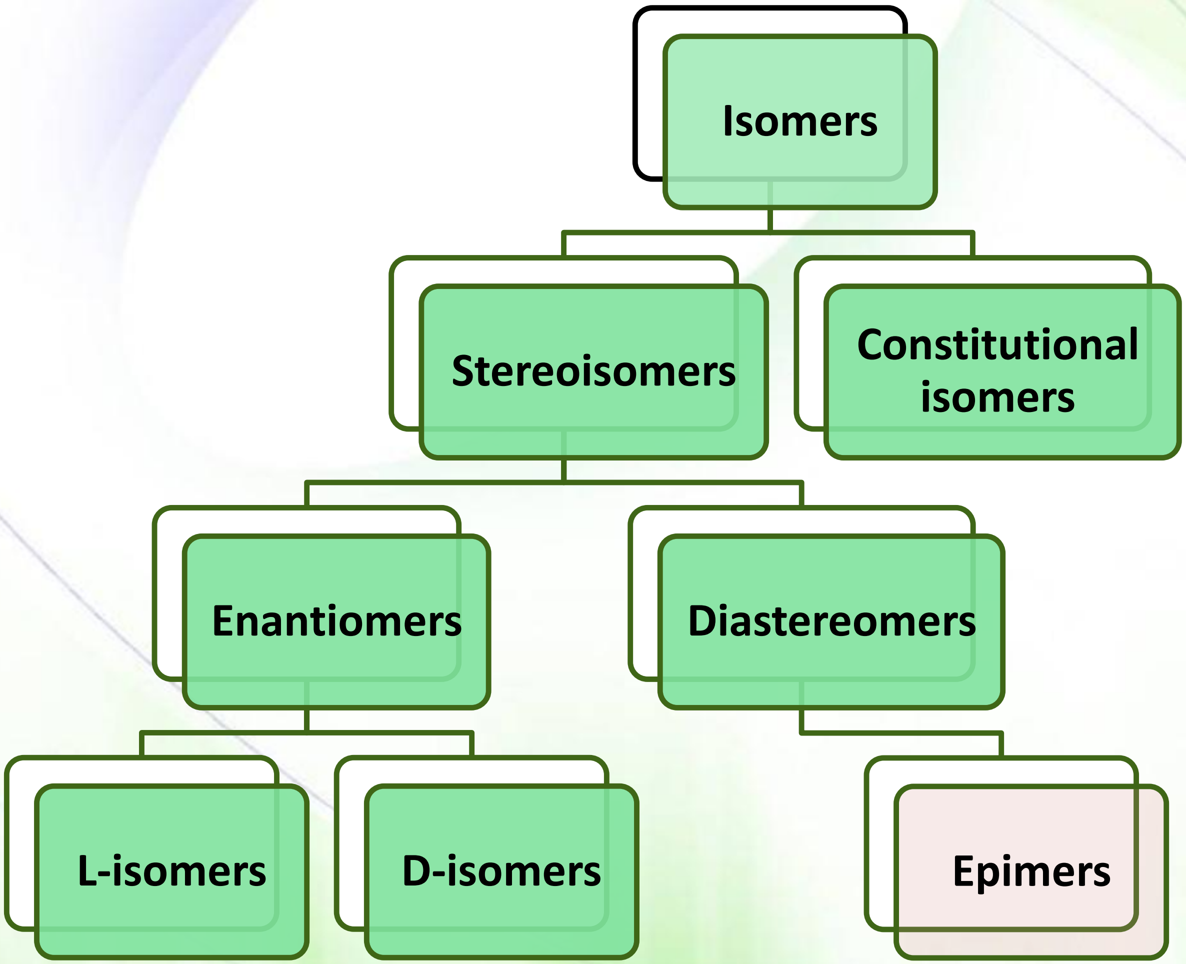


Two or more stereoisomers of a compound having different configurations at one or more (but not all) of the chiral carbons and are not mirror images of each other.

Stereoisomers, but non-mirror images and non-superimposable, then…*diastereomers*

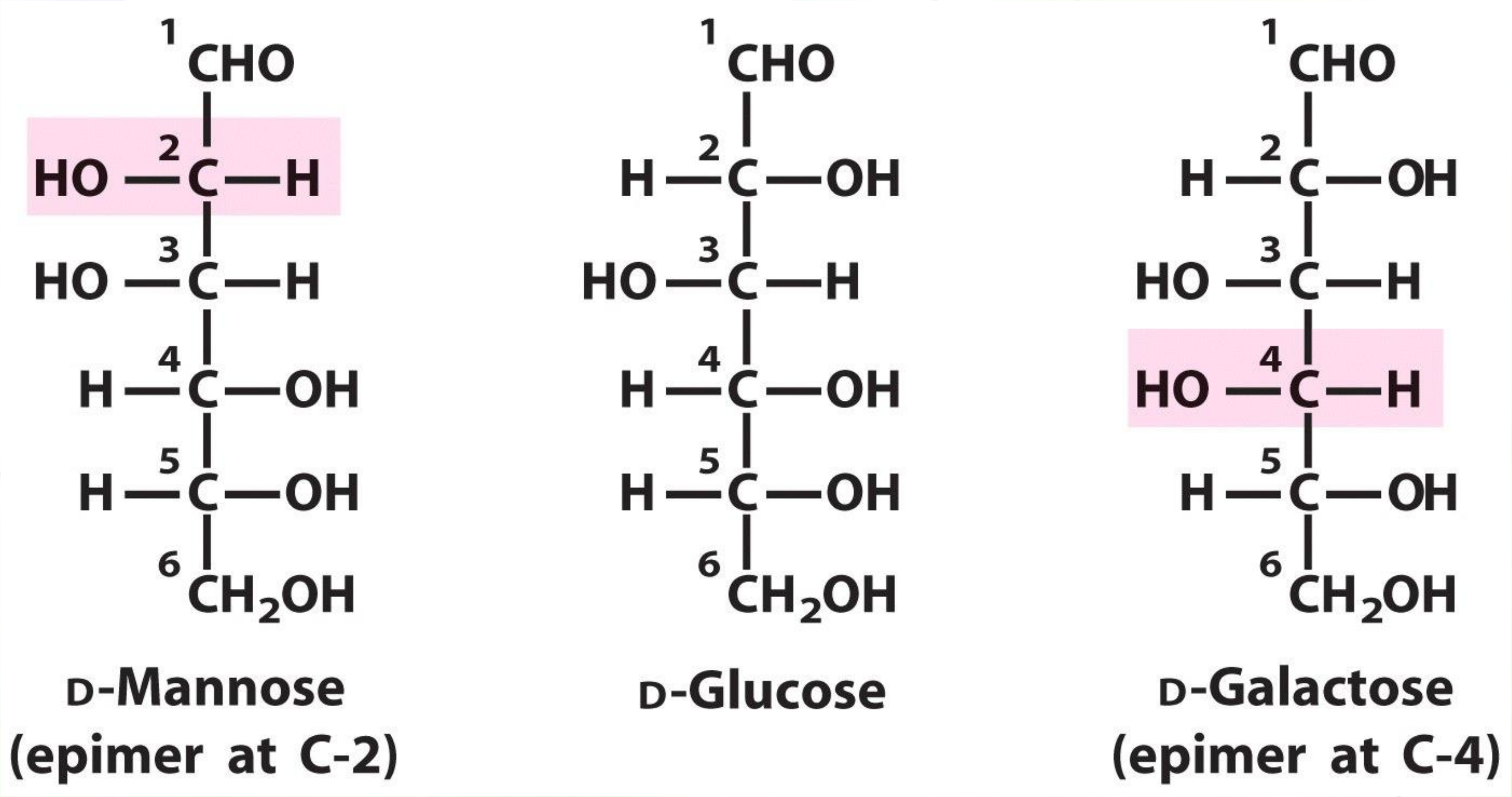


Isomerism



Epimer refers to one of a pair of stereoisomers whereby two isomers differ in configuration at only one chiral carbons.

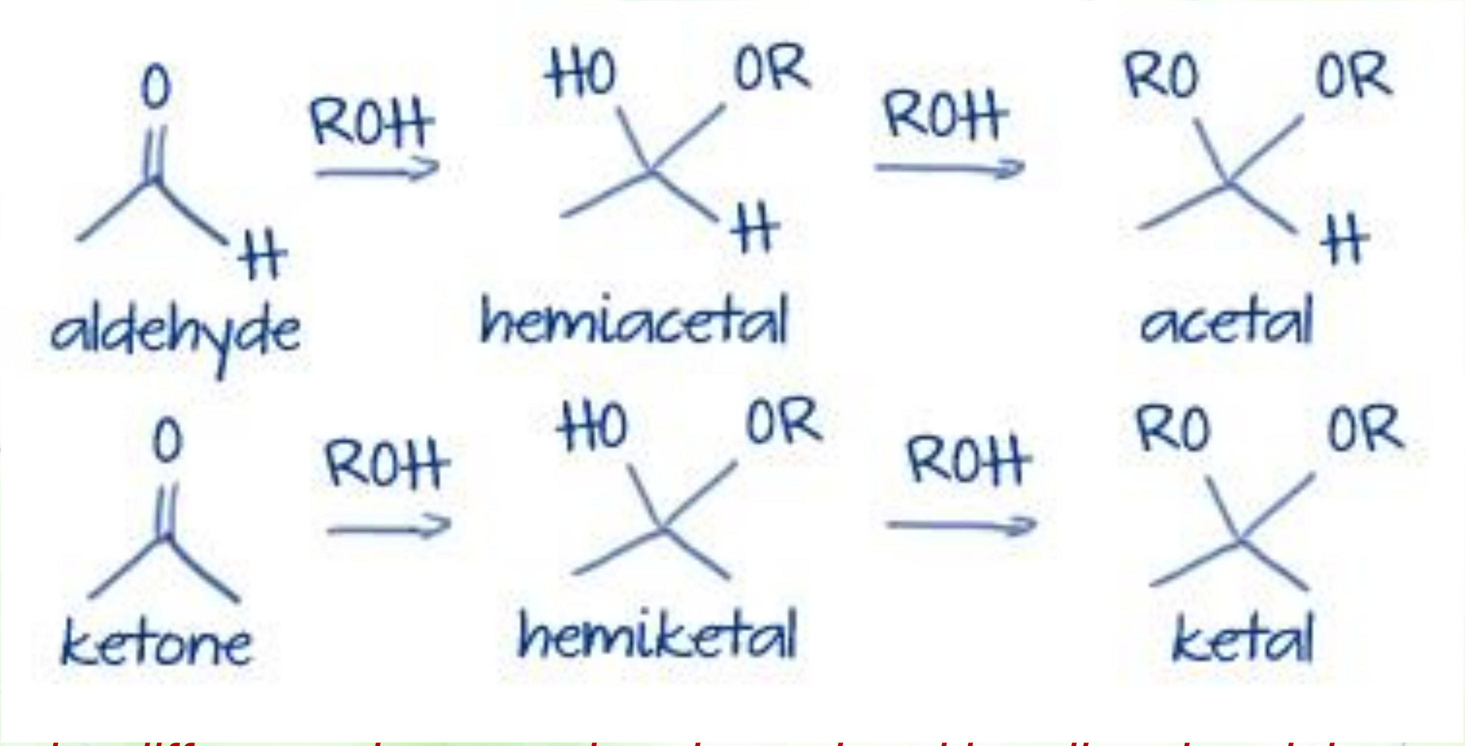
Diastereomers that differ in the orientation of one chiral carbon…*epimers*



Is L-glucose epimer with D-mannose and D-galactose?

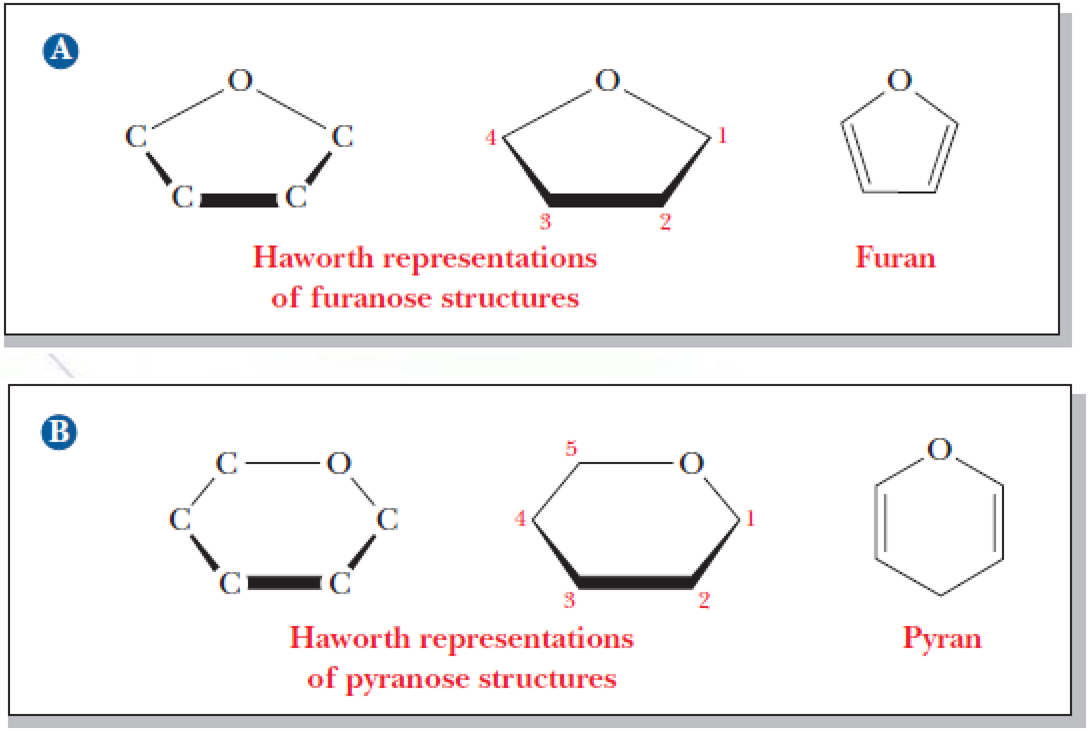
Acetal/ketal vs. hemiacetal/hemiketal

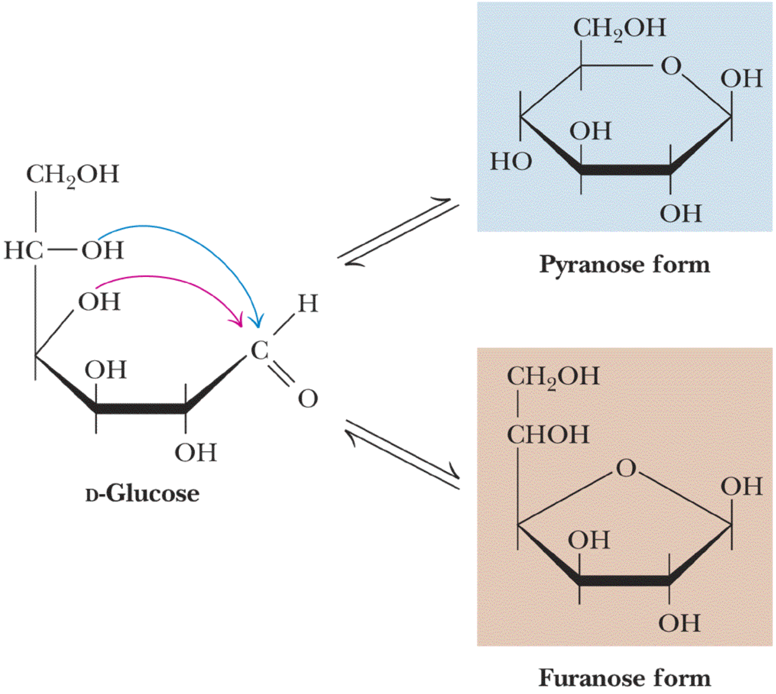
Hemiacetal and hemiketal: ether and alcohol on same carbon
Acetal and ketal: two ethers on same carbon



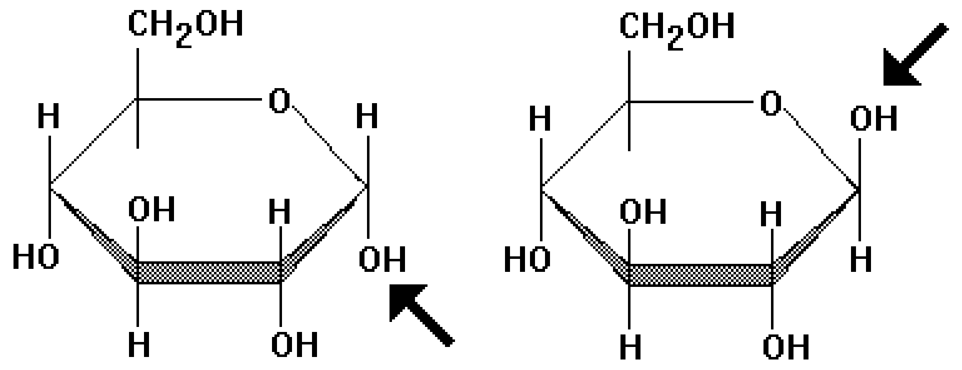
What is the difference between hemiacetal and hemiketal and the difference between acetal and ketal?

Formation of a ring structure

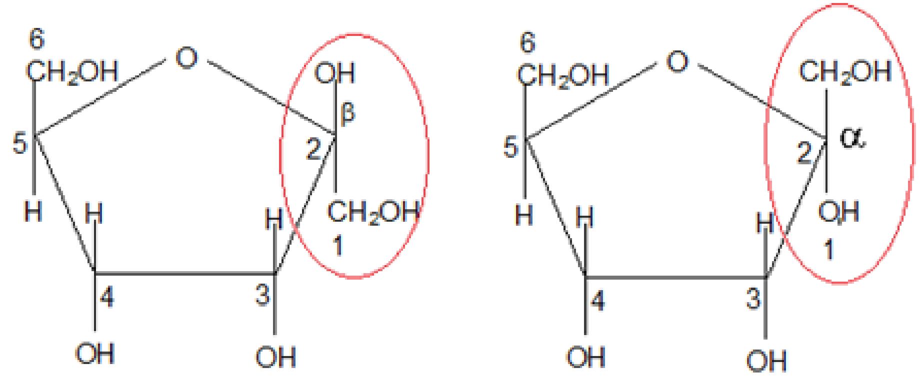




Anomers

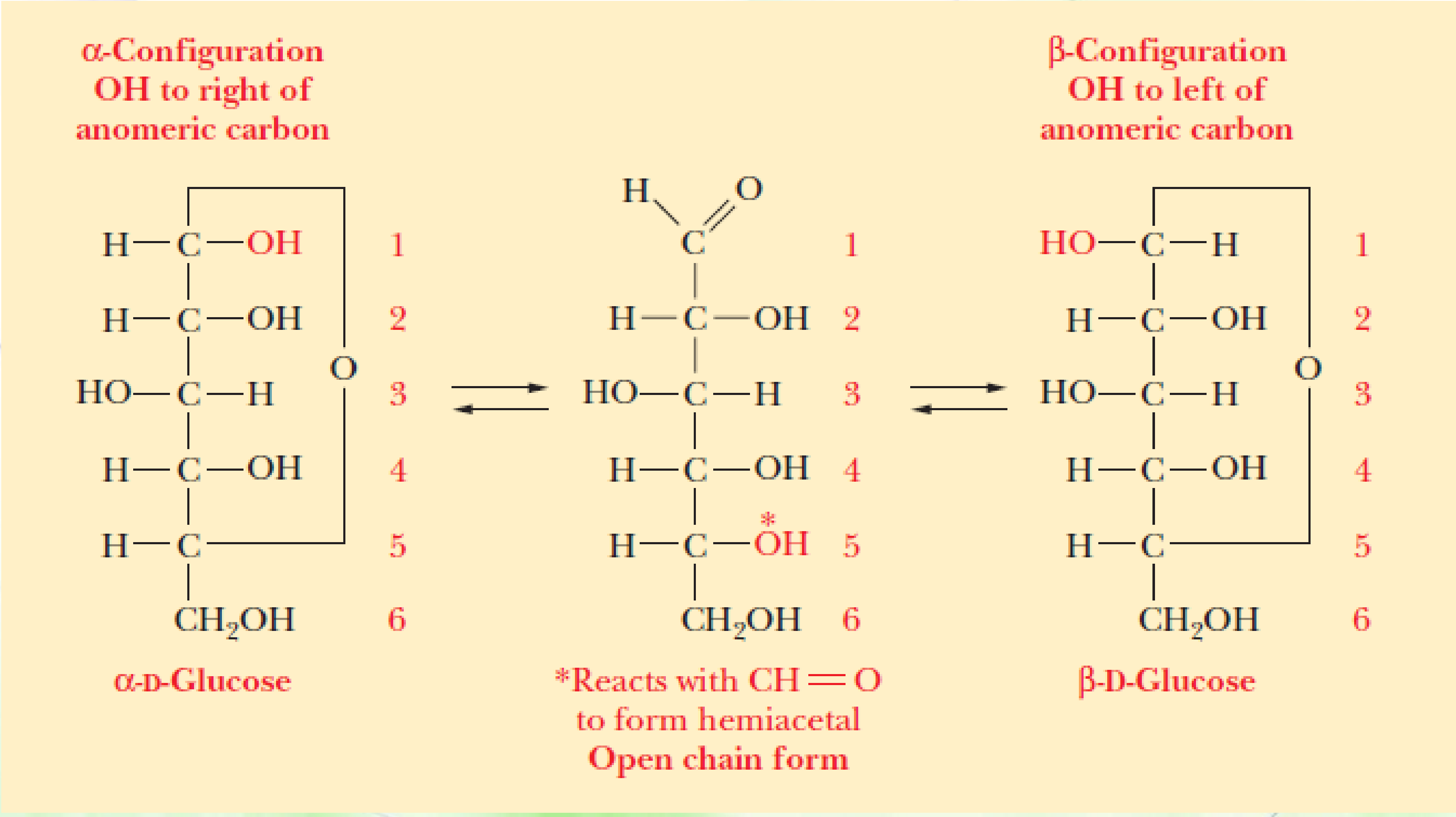


alpha-D-glucose   beta-D-glucose



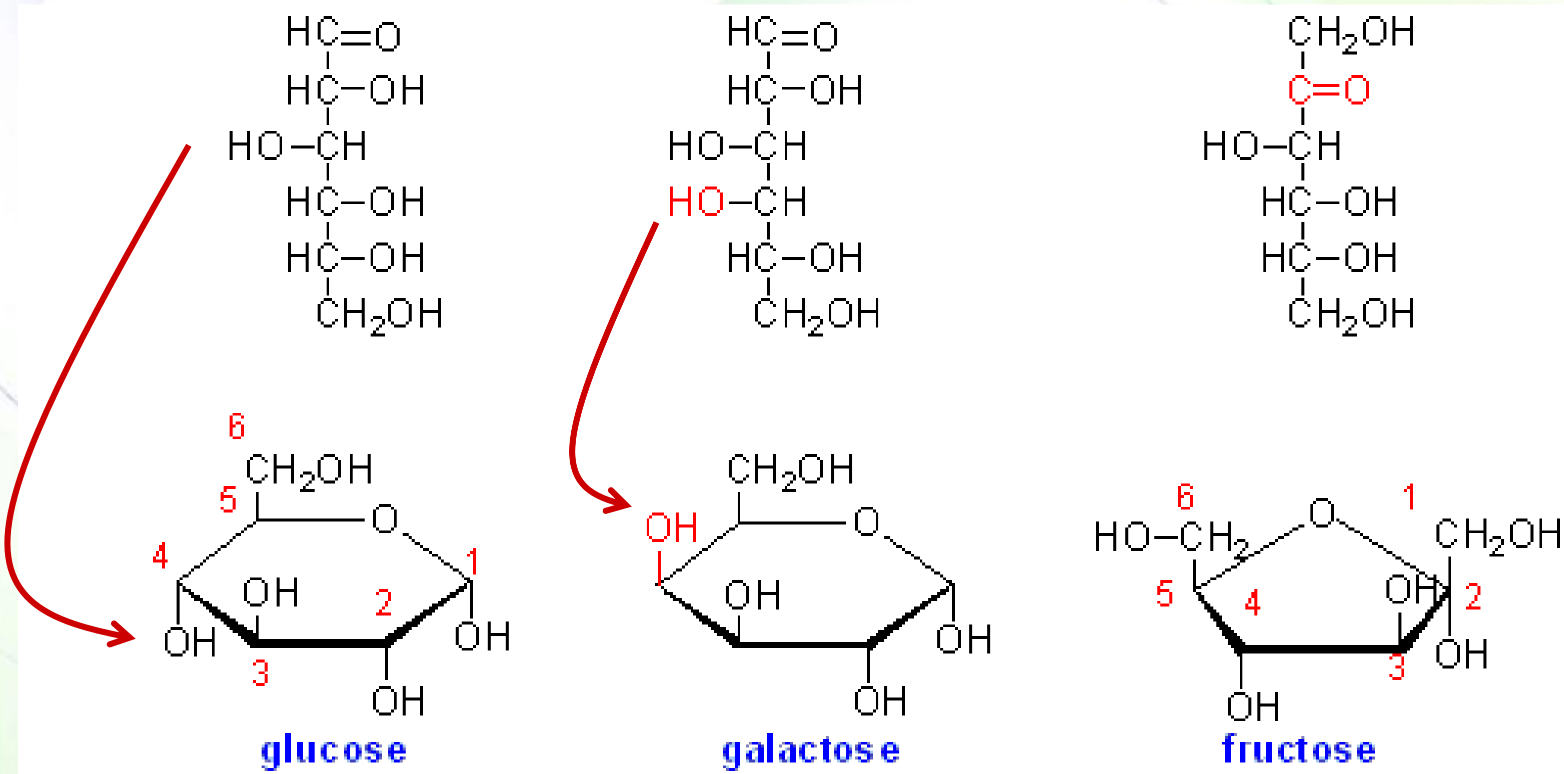
β-D-fructose   α-D-fructose

Anomers as Fischer projection



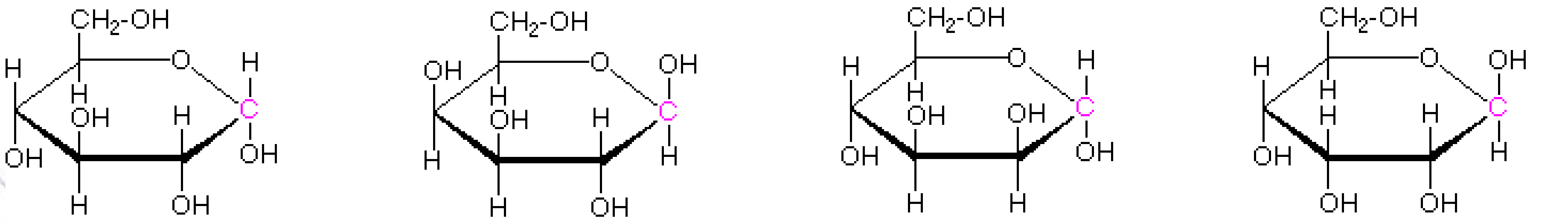
Chain to ring

Left-right vs. up-down



Cyclic aldohexoses

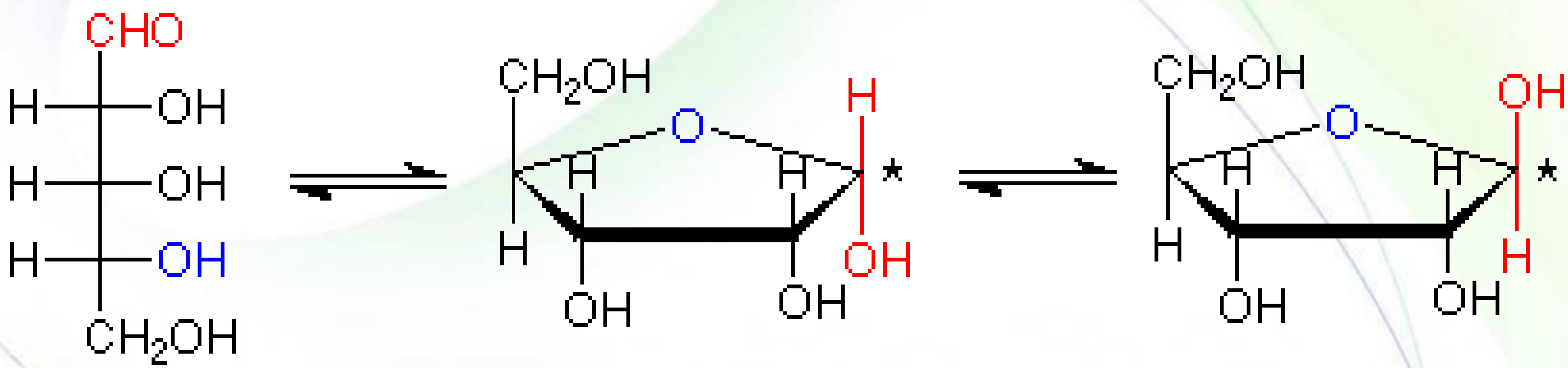
Examples of Some Pyranose Forms of Hexoses



α-D-glucopyranose β-D-galactopyranose α-D-mannopyranose β-D-allopyranose

Cyclic ribofuranose

* anomeric carbon



D-ribose

α-D-ribose

OH at anomeric carbon down

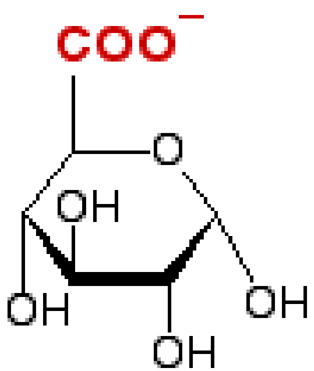
β-D-ribose

OH at anomeric carbon up

Modified Sugars

Sugar acids (oxidation)

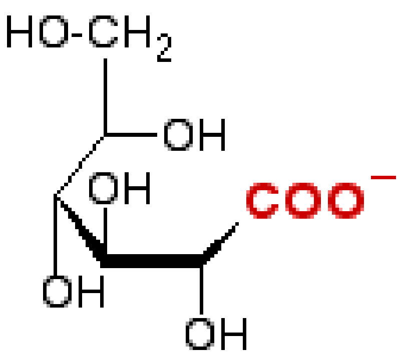
- Where is it oxidized? What does it form?



α-D-glucuronate

(D-glucuronic acid, **GlcUA**)

from **oxidation of glucose C6 OH**

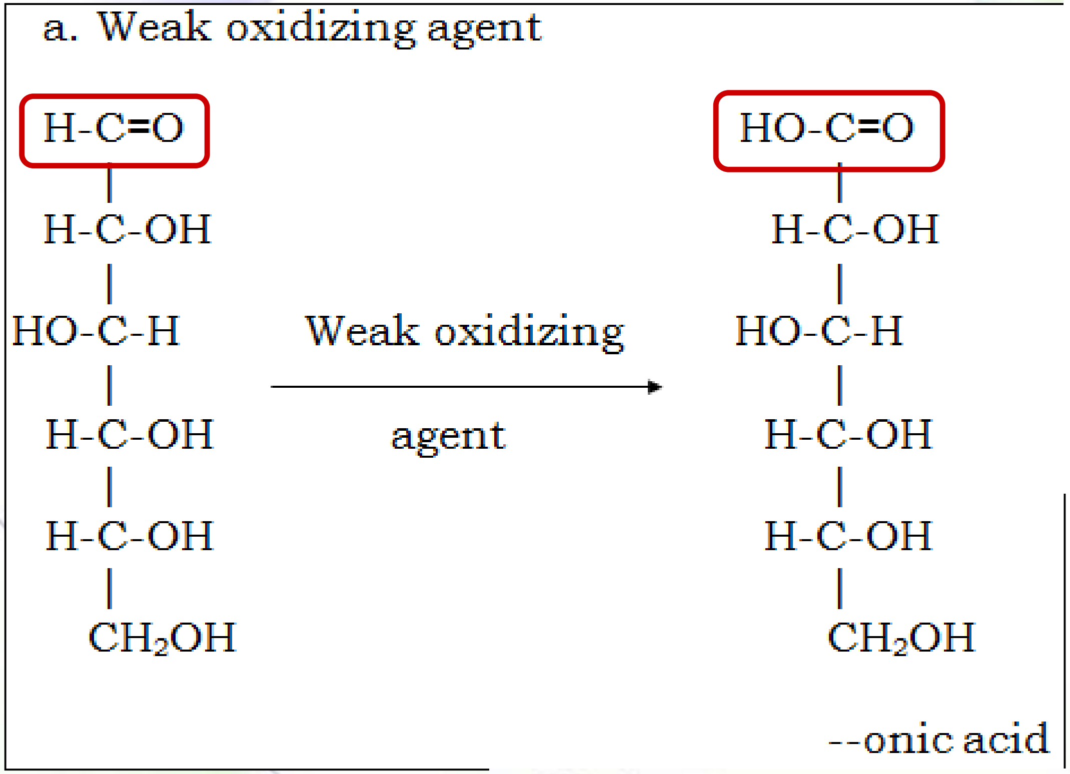


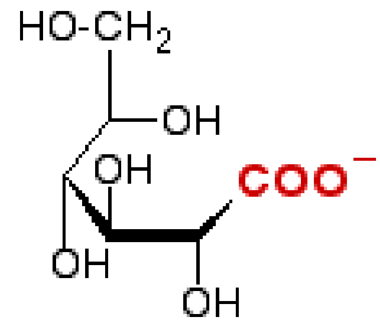
D-gluconate

(D-gluconic acid, **GlcA**)

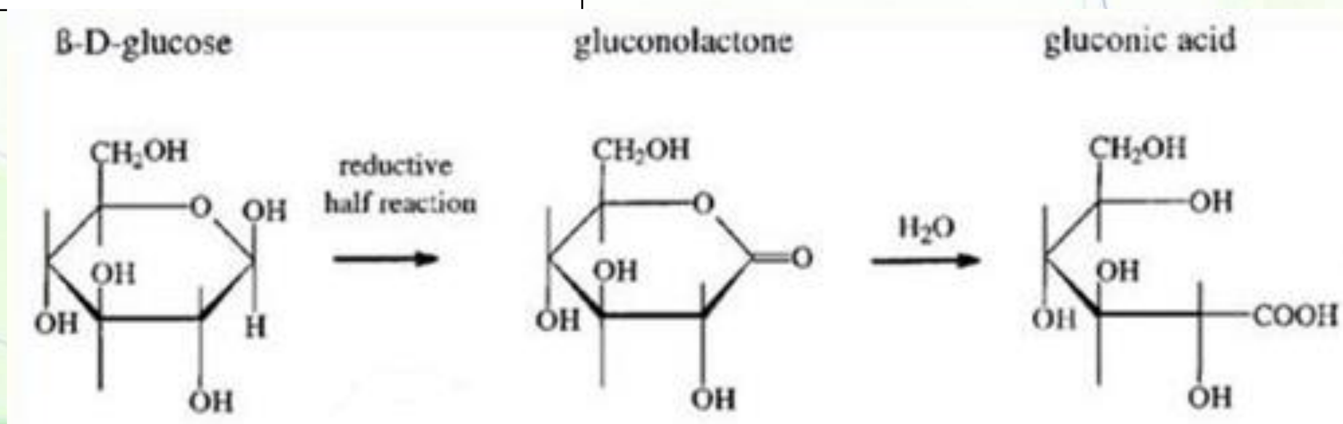
from **oxidation of glucose C1 aldehyde)**

Example 1

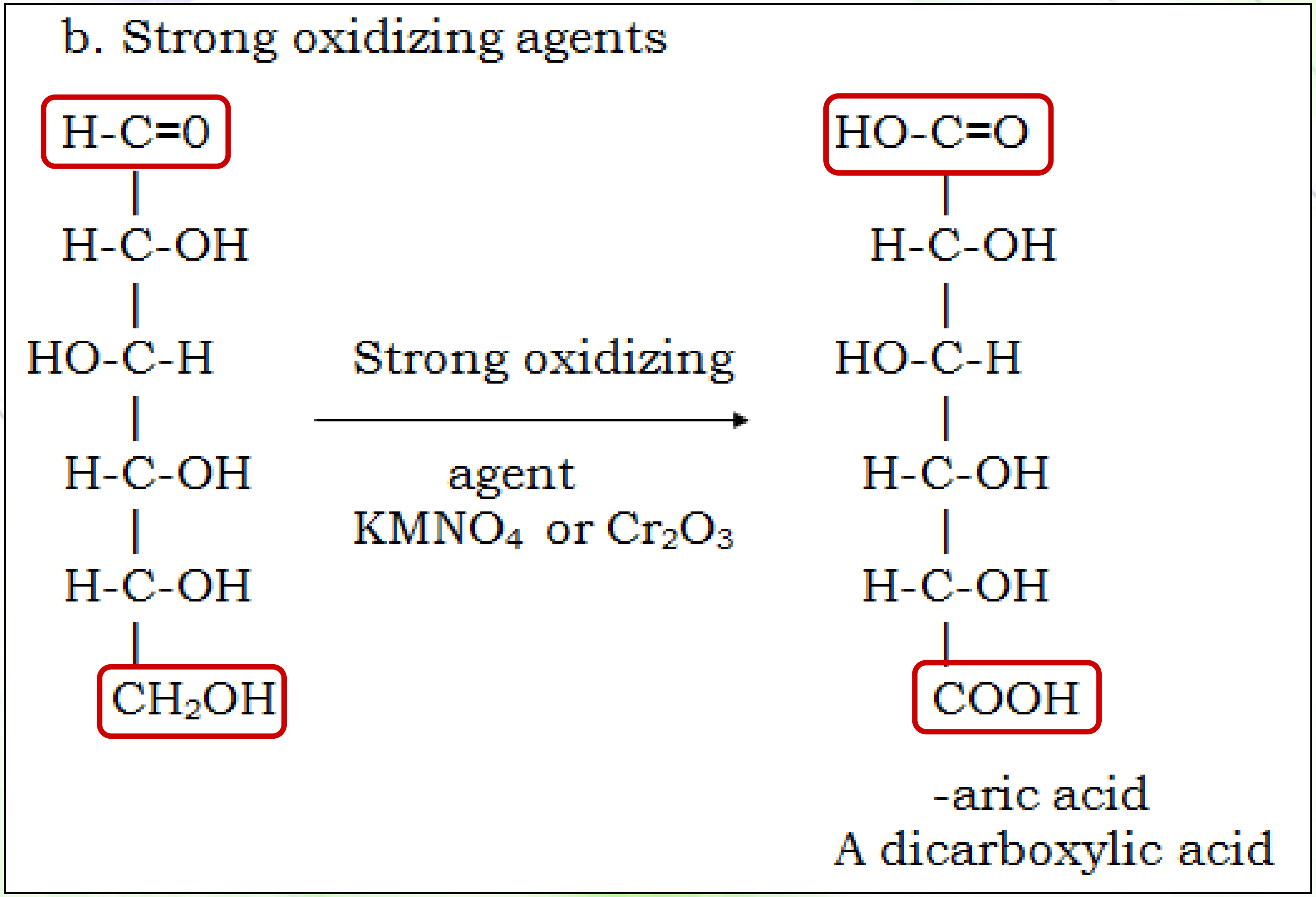


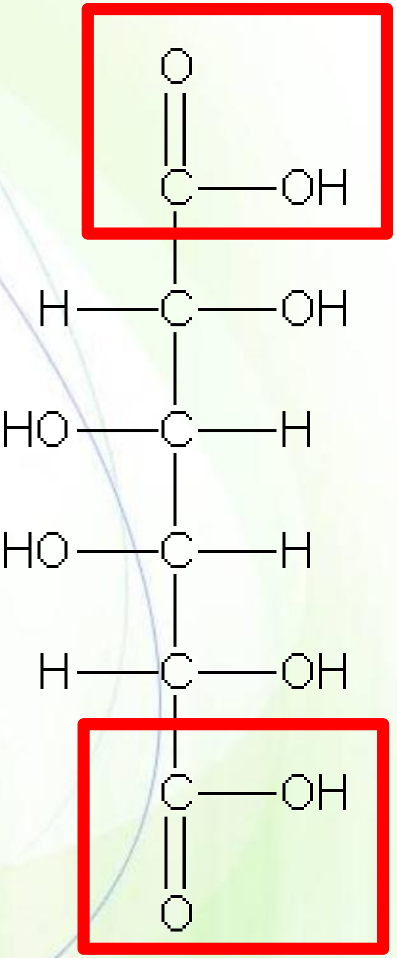


D-gluconate
(D-gluconic acid, **GlcA**)
from **oxidation of glucose C1 aldehyde)**



Example 2

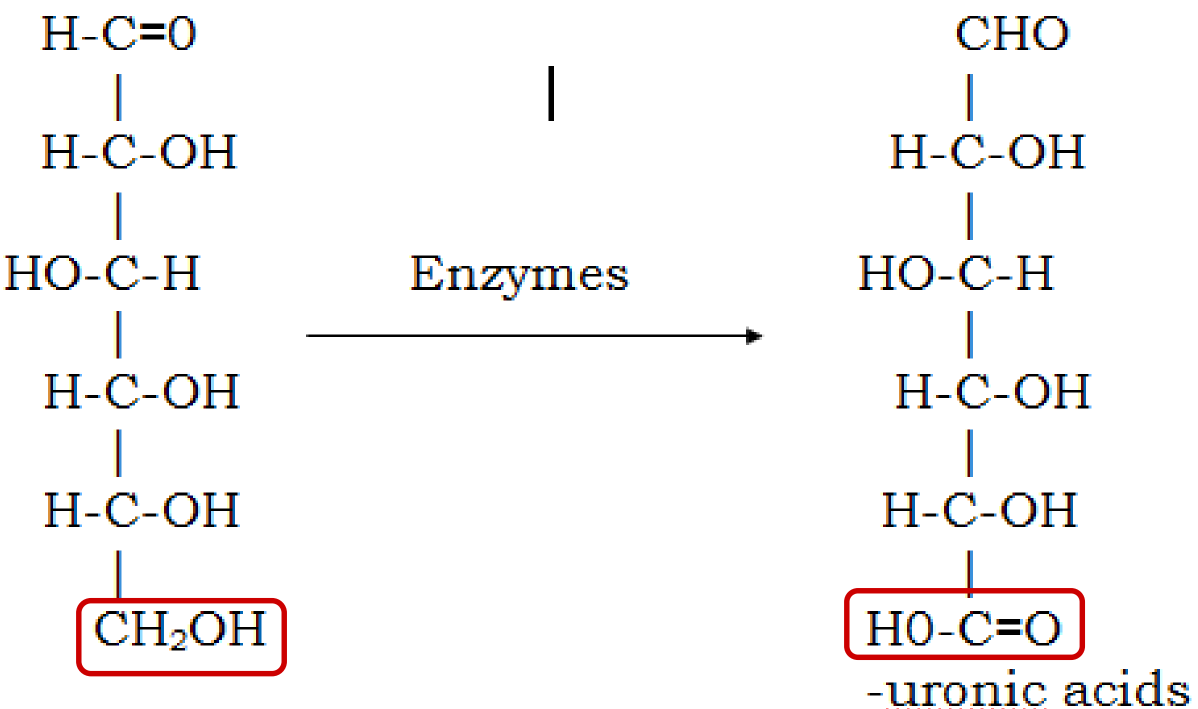


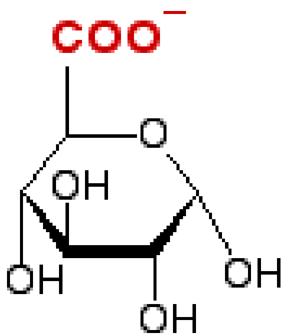


galactaric acid

Example 3

c. Oxidation of primary alcohol end in biological systems





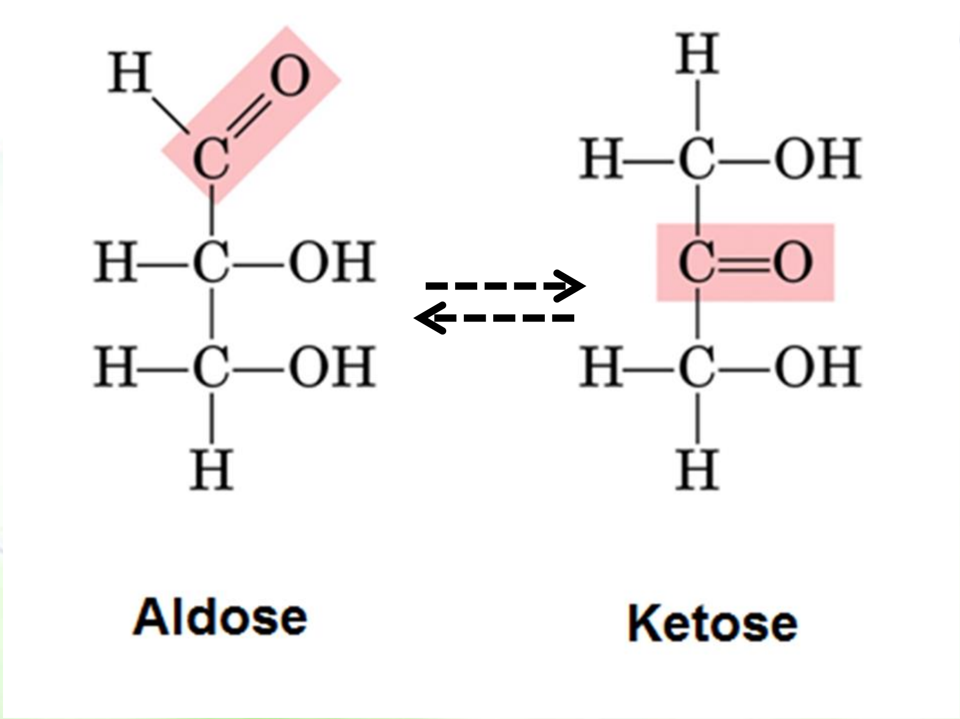
α-D-glucuronate

(D-glucuronic acid, **GlcUA**)

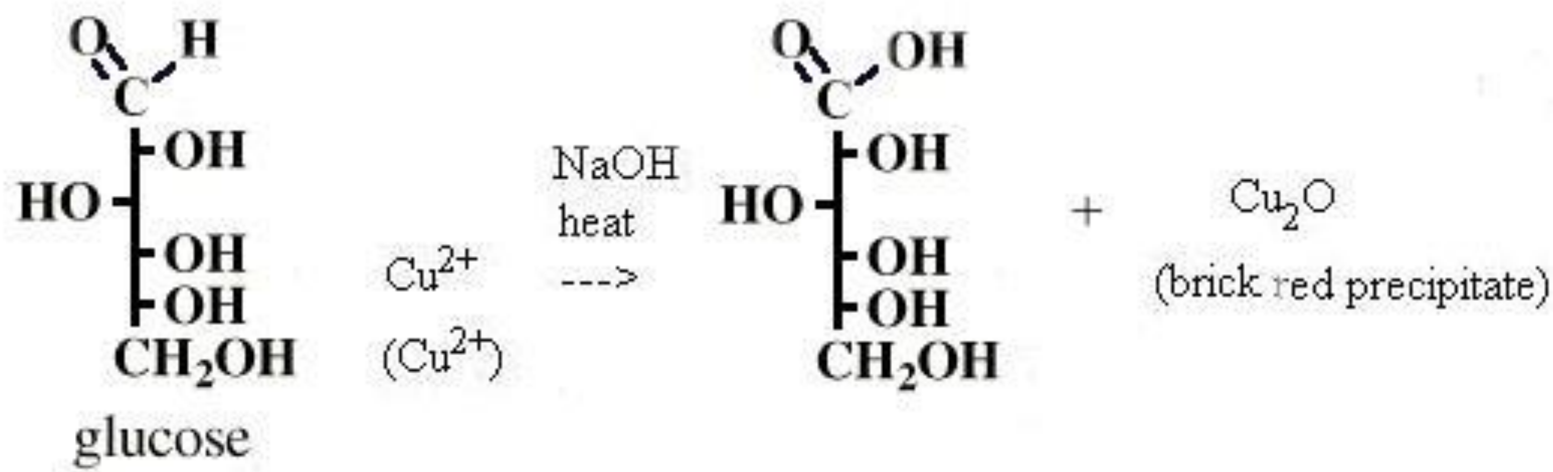
from **oxidation of glucose C6 OH**

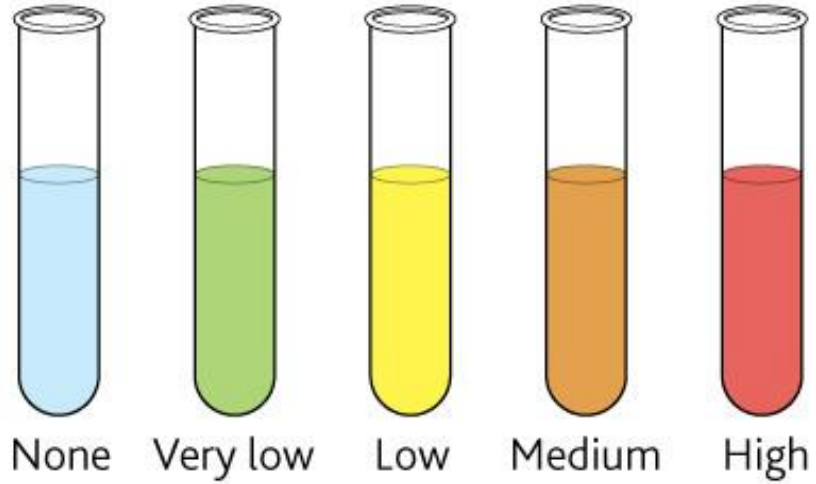
Note

- Oxidation of ketoses to carboxylic acids does not occur, but they can be oxidized because of formation of enediol form

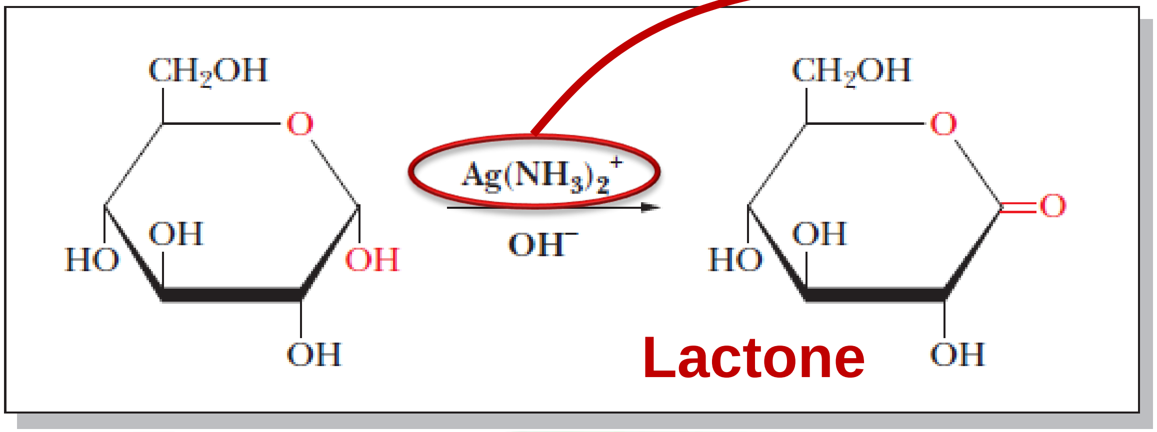


Benedict's test





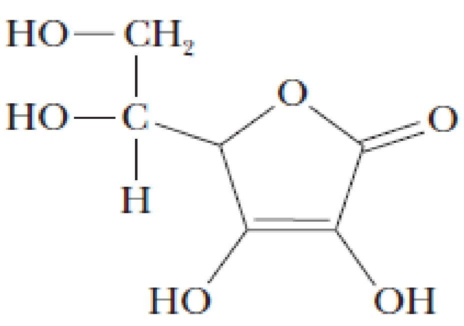
Oxidation of cyclic sugars (lactone)



Tollen's test

A more recent method for the detection of glucose, but not other reducing sugars, is based on the use of the enzyme glucose oxidase.

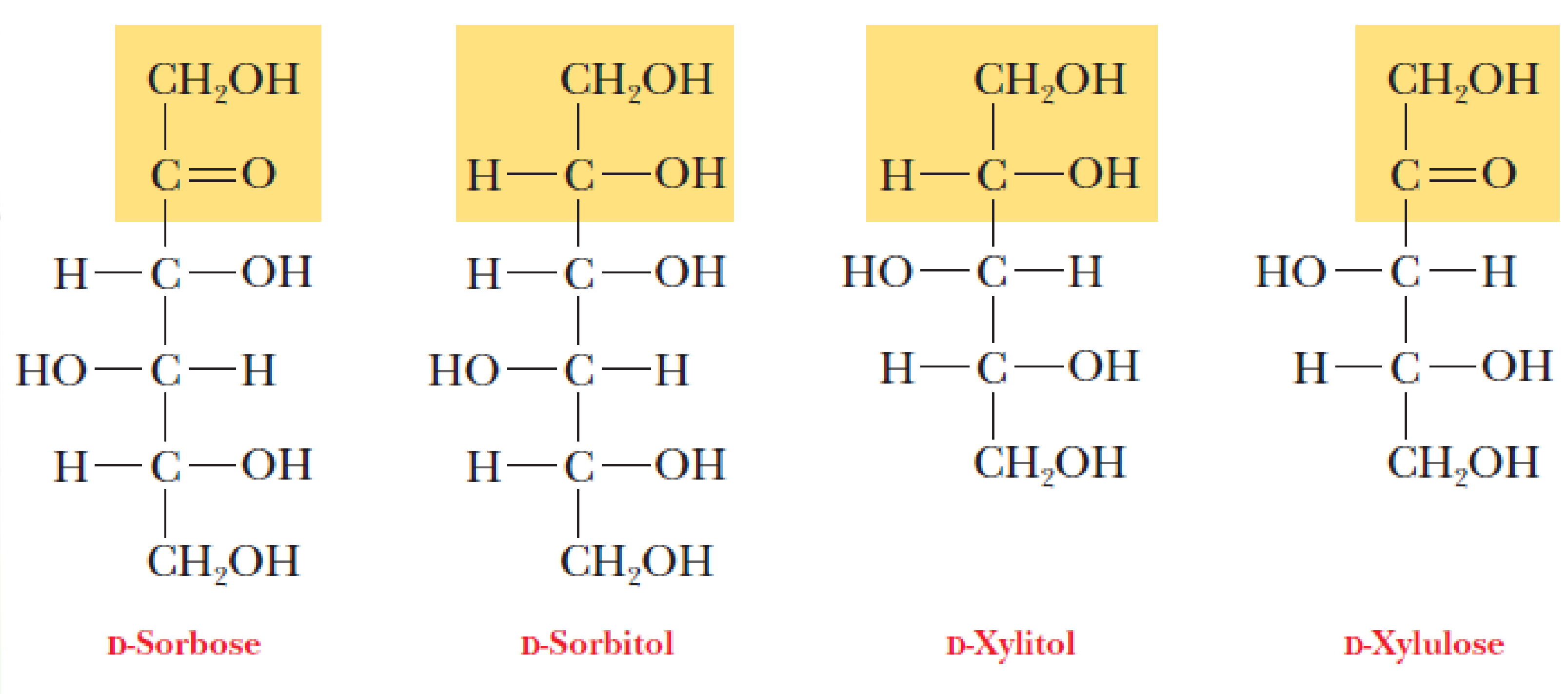
- **Vitamin C (ascorbic acid) is an unsaturated lactone.**
- **Air oxidation of ascorbic acid, followed by hydrolysis of the ester bond, leads to loss of activity as a vitamin.**
- **A lack of fresh food can cause vitamin C deficiencies, which, in turn, can lead to scurvy.**



Ascorbic acid (Vitamin C)

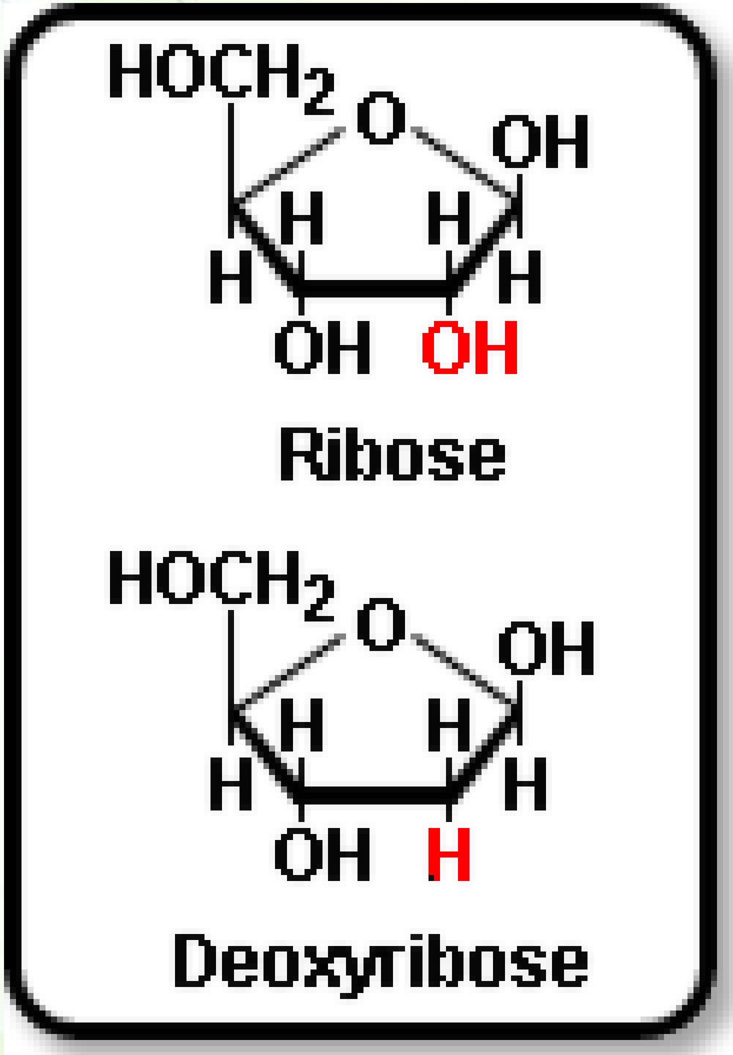
Sugar alcohols (reduction)

- What does it form?
- Examples include sorbitol, mannitol, and xylitol, which are used to sweeten food products



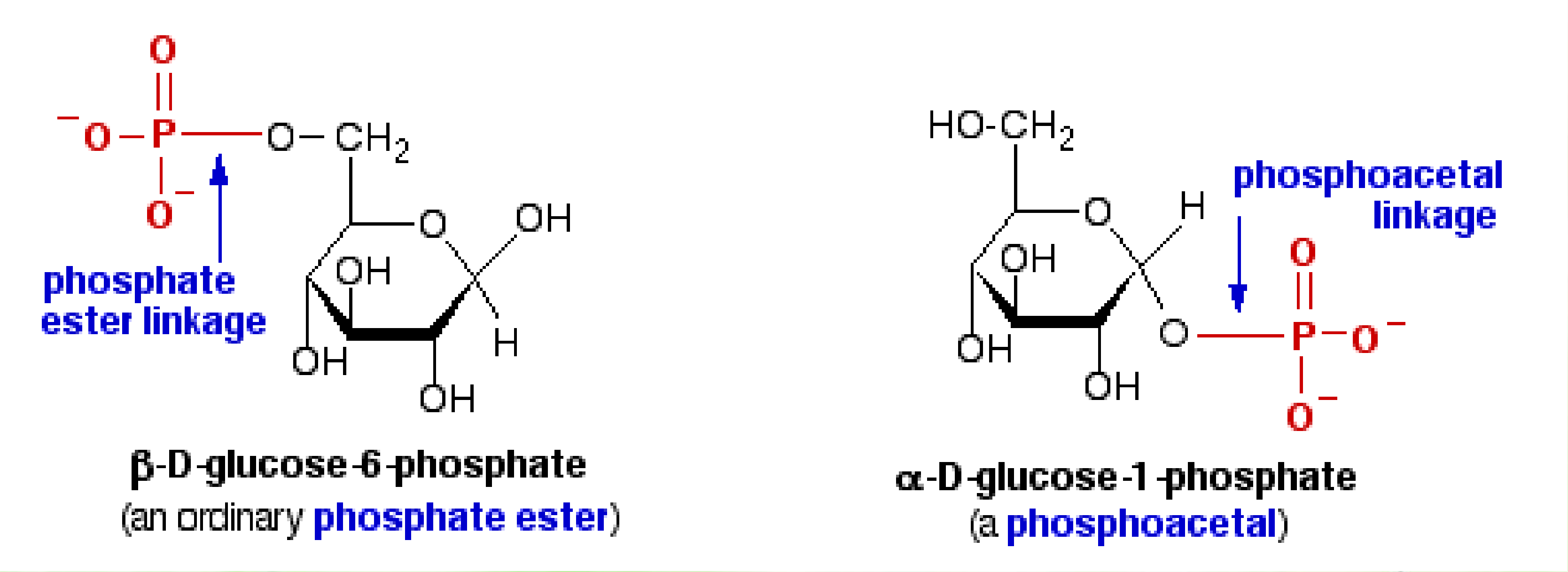
Deoxy-sugars (reduced sugars)

- One or more hydroxyl groups are replaced by hydrogens.
- An example is 2-deoxyribose, which is a constituent of DNA.



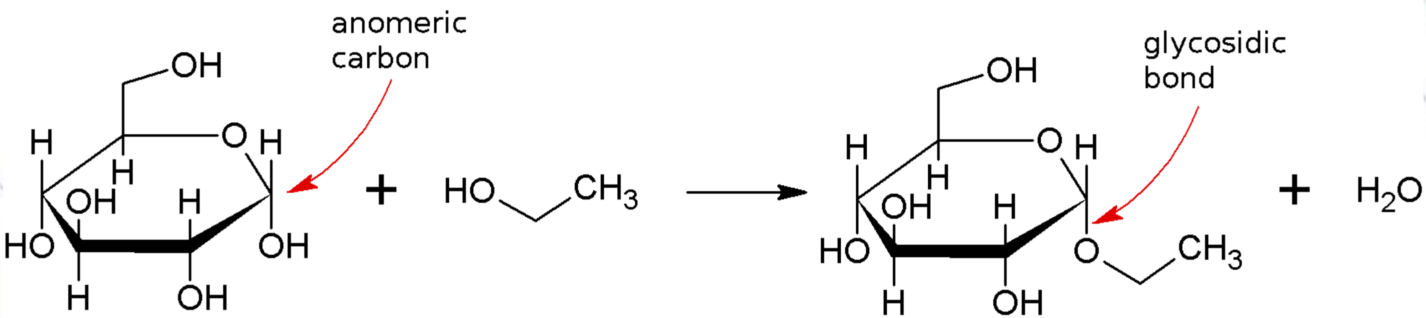
Sugar esters (esterification)

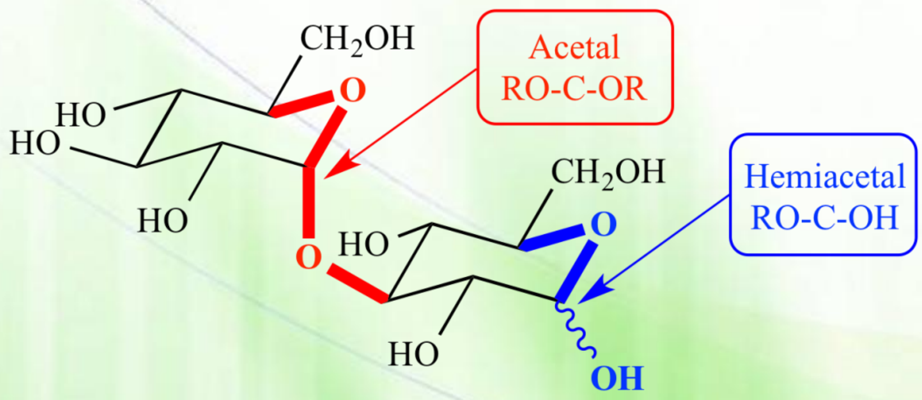
- What is the reacting functional group? Where does it react? What are the end products? Where are they used?

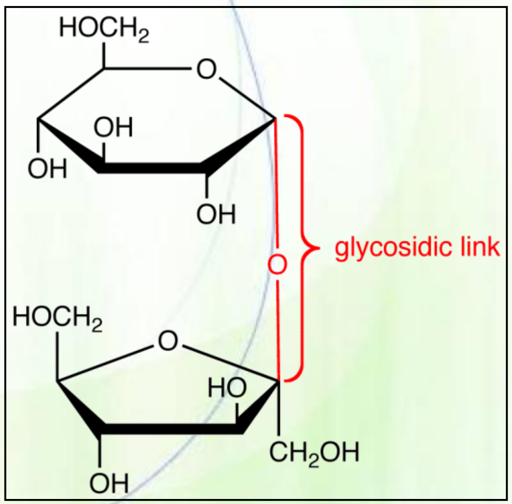


O-Glycosides

- What is the reacting functional group? Where does it react? What are the end products? Where are they used?

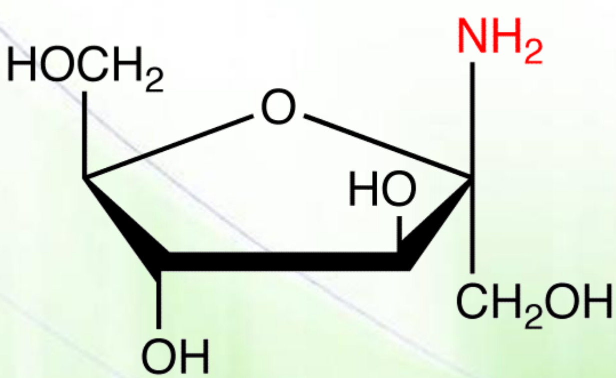




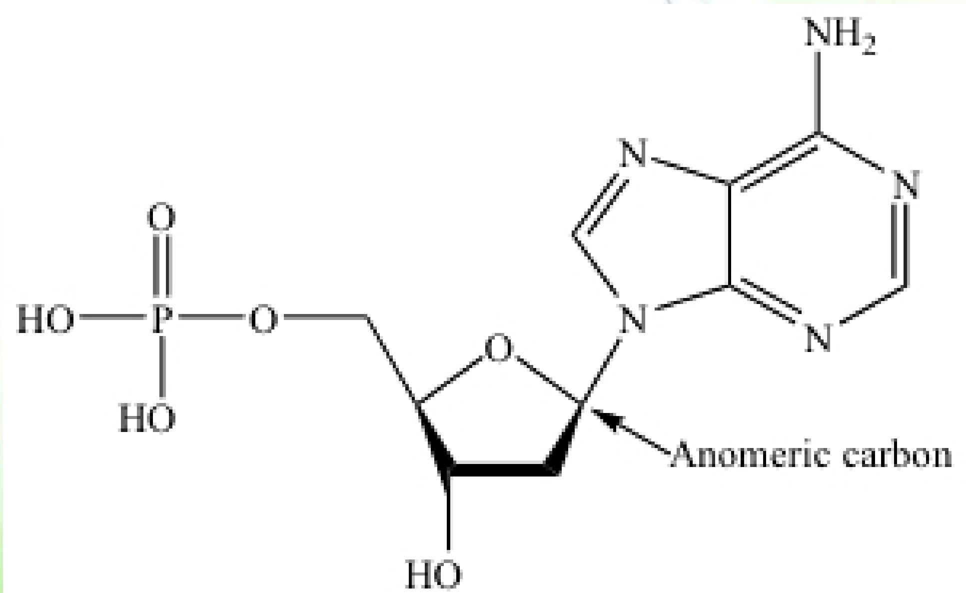


N-glycosides

- What is the reacting functional group? Where does it react? What are the end products? Where are they used?
- Examples: nucleotides (DNA and RNA)

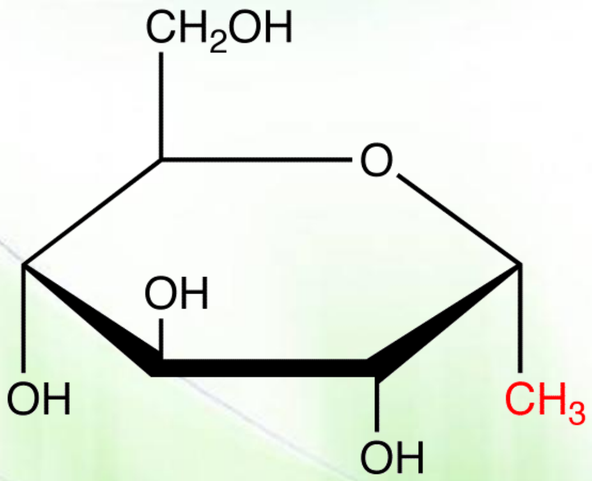


N-glycoside

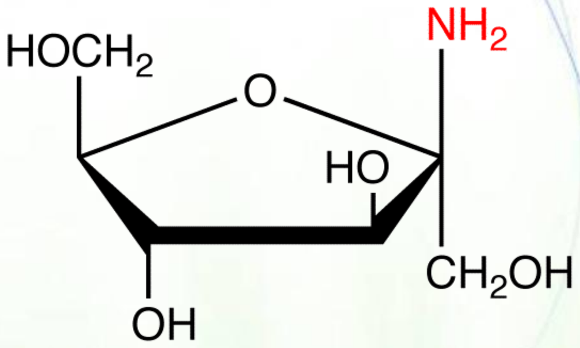


Note

- Glycosides derived from furanoses are called **furanosides**, and those derived from pyranoses are called **pyranosides,** regardless if they are N- or O-linkded.



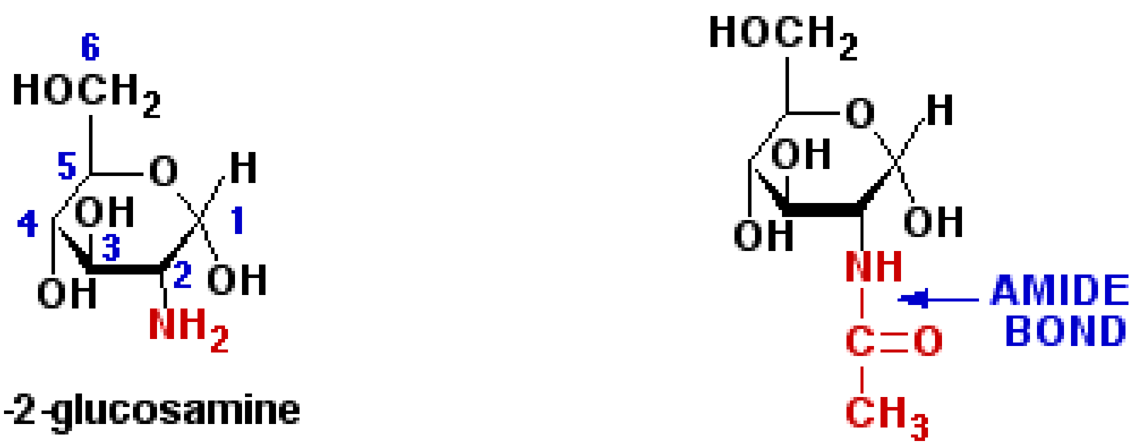
C-glycoside



N-glycoside

Amino sugars

- What is the reacting functional group? Where does it react? What are the end products? Where are they used?
- Further modification by acetylation

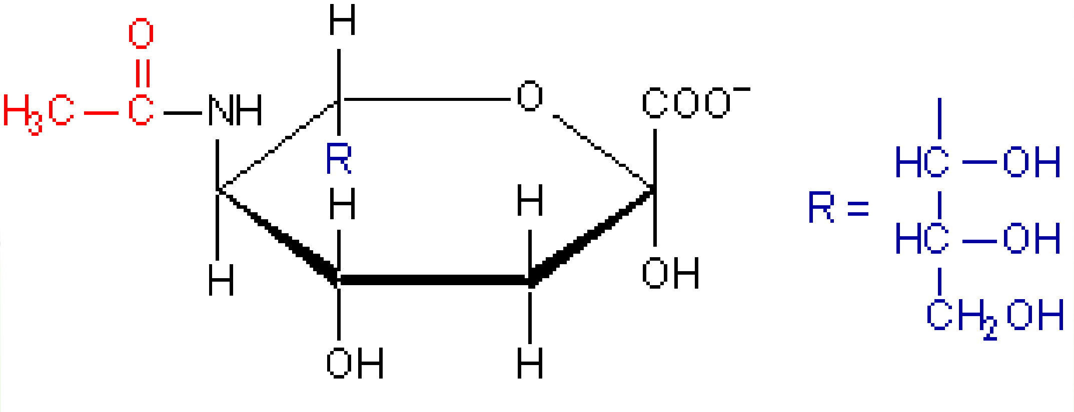


α-D-2-glucosamine (GlcN)

N-acetyl-α-D-2-glucosamine (GlcNAc)

Sialic acid

- *N*-acetylneuraminate
- Precursor: the amino sugar, neuraminic acid
- Location: a terminal residue of oligosaccharide chains of glycoproteins and glycolipids.



N-acetylneuraminate (sialic acid)

Disaccharides

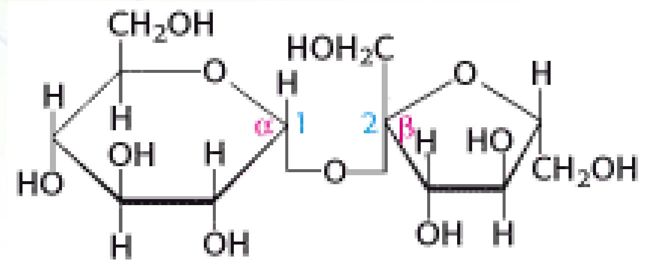
- What are disaccharide? Oligosaccharides? Hetero- vs. homo-?
- What is the type of reaction?
- What is a residue?
- Synthesizing enzymes are glycosyltransferases
- Do they undergo mutarotation?
- Are products stable?

Distinctions of disaccharides

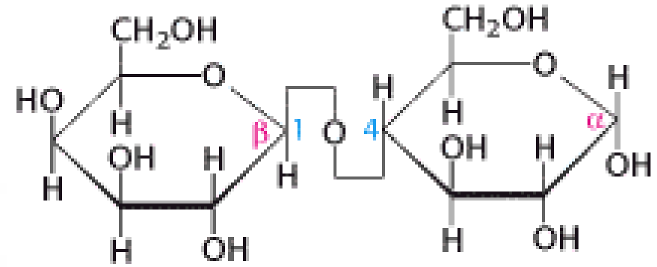
- The 2 specific sugar monomers involved and their stereoconfigurations (D- or L-)
- The carbons involved in the linkage (C-1, C-2, C-4, or C-6)
- The order of the two monomer units, if different (example: galactose followed by glucose)
- The anomeric configuration of the OH group on carbon 1 of each residue (α or β)

Abundant disaccharides

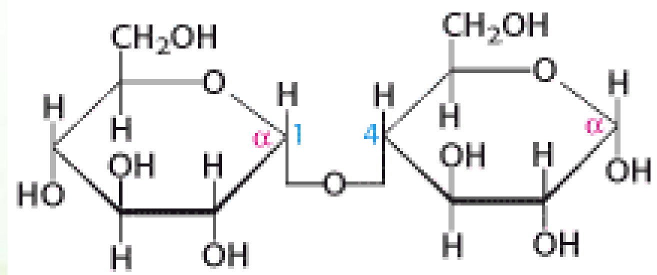
- Configuration
- Designation
- Naming (common vs. systematic)
- Reducing vs. non-reducing



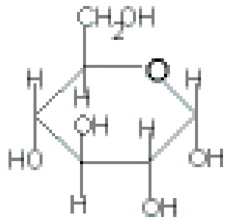
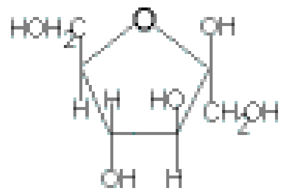
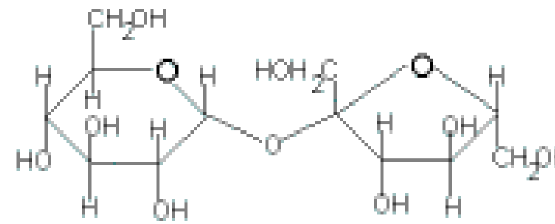
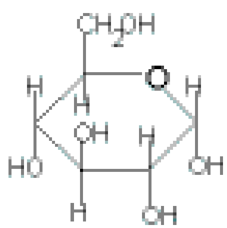
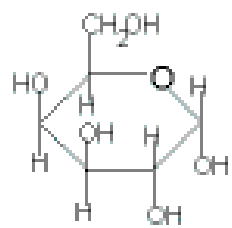
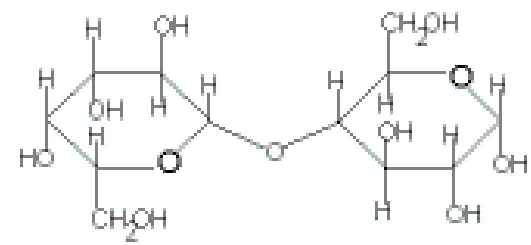
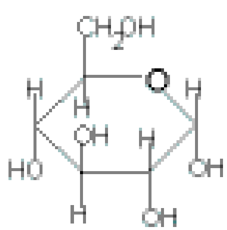
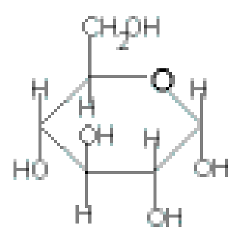
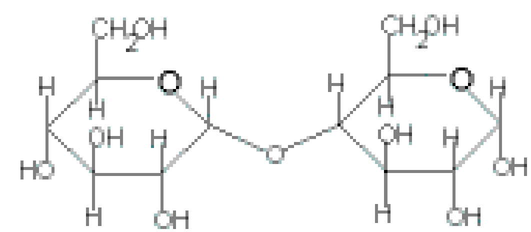
Sucrose
(α-D-Glucopyranosyl-(1 → 2)-β-D-fructofuranose



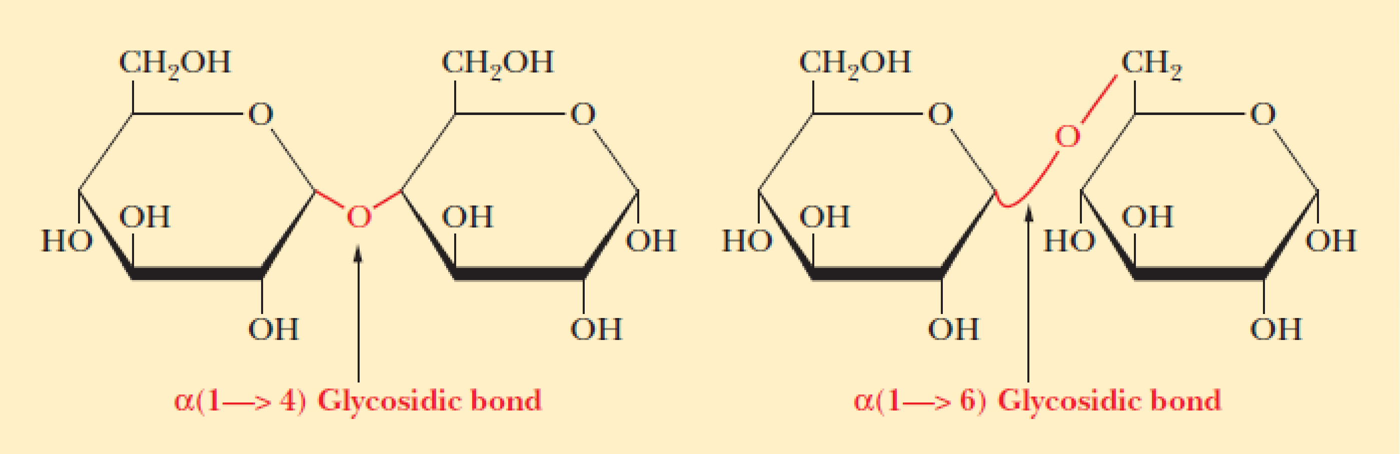
Lactose
(β-D-Galactopyranosyl-(1 → 4)-α-D-glucopyranose

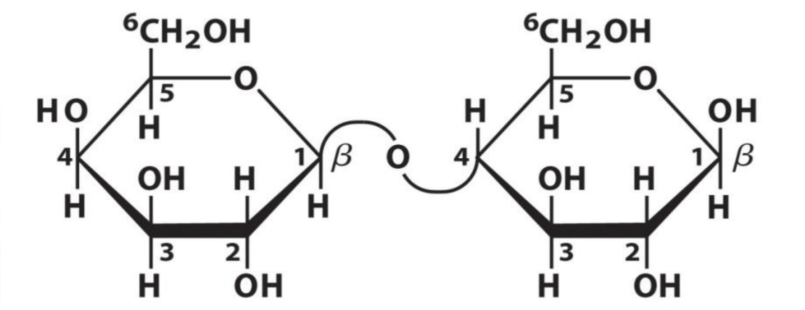


Maltose
(α-D-Glucopyranosyl-(1 → 4)-α-D-glucopyranose

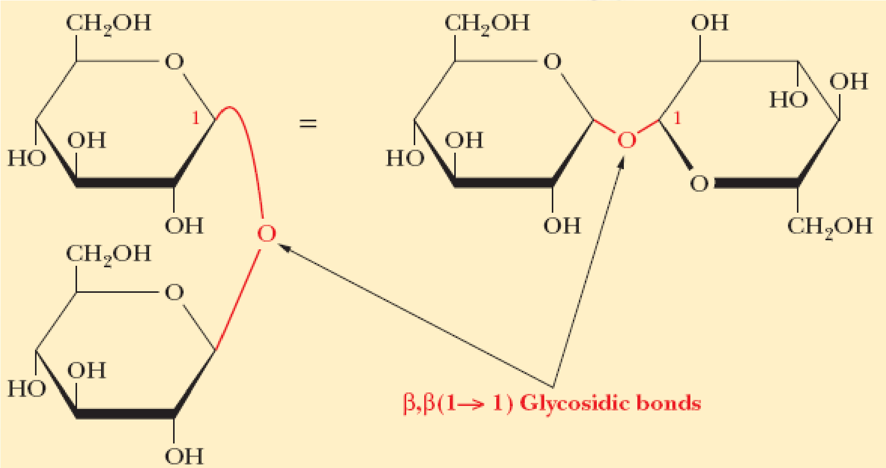
Name	Formula	Formed from	Structure
sucrose	$C_{12}H_{22}O_{11}$	glucose + fructose  + 	---> sucrose + H_2O 
lactose	$C_{12}H_{22}O_{11}$	glucose + galactose  + 	---> lactose + H_2O 
maltose	$C_{12}H_{22}O_{11}$	glucose + glucose  + 	---> maltose + H_2O 

Different forms of disaccharides



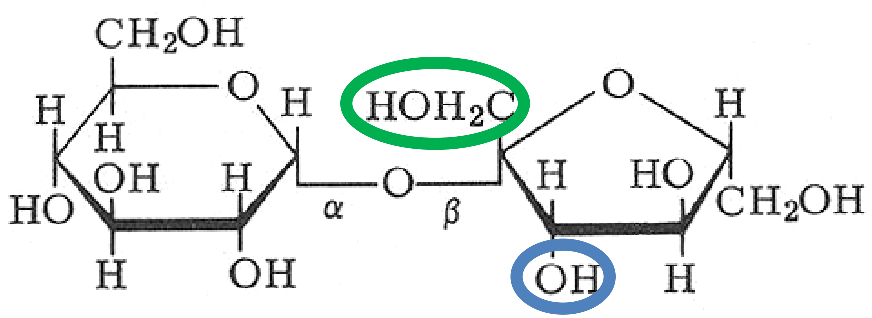


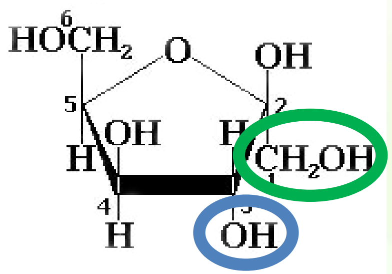
Lactose (β form)
β-D-galactopyranosyl-(1→4)-β-D-glucopyranose
Gal(β1→4)Glc

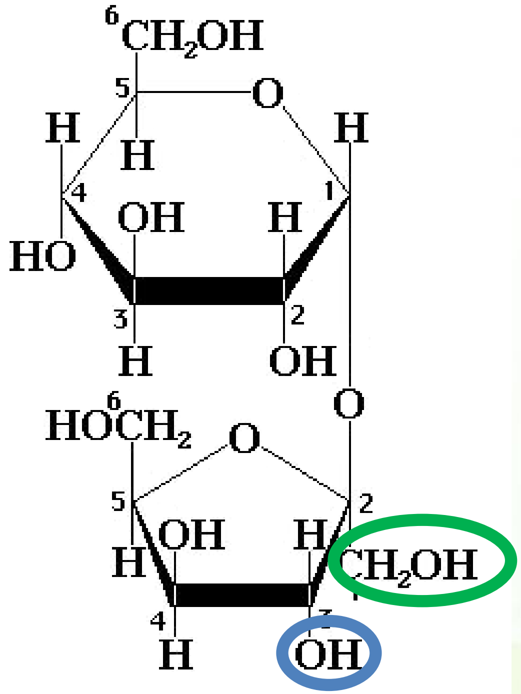


A disaccharide of β-D-glucose.

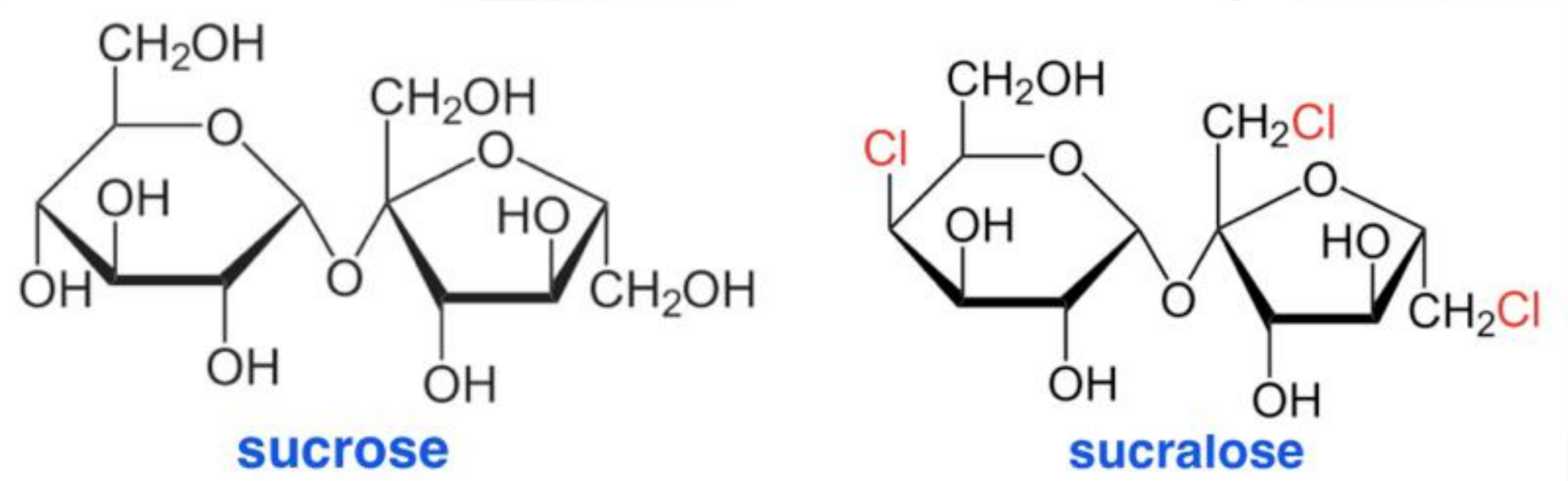
Sucrose







Sucralose (artificial sweetener)

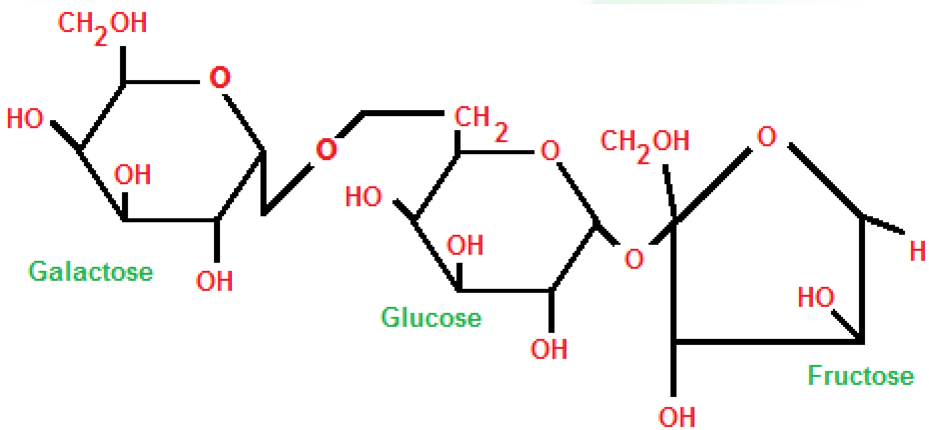


Milk problems

- Lactose Intolerance: A deficiency of the enzme lactase in the intestinal villi allows lactase of intestinal bacteria to digest it producing hydrogen gas, carbon dioxide, and organic acids and leading to digestive problems (bloating and diarrhea).
- Galactosemia: Missing a galactose-metabolizing enzyme can result in galactosemia where nonmetabolized galactose accumulates within cells and is converted to the hydroxy sugar galactitol, which cannot escape cells. Water is drawn into cells and the swelling causes cell damage, particularly in the brain, resulting in severe and irreversible retardation. It also causes cataract.

Raffinose

- What are oligosaccharide?
- Example: raffinose
- It is found in Found in beans and vegetables like cabbage, brussel, sprouts, broccoli, asparagus.



"You want that double-order of our world-famous baked beans for here... or, we sincerely hope... to go?"

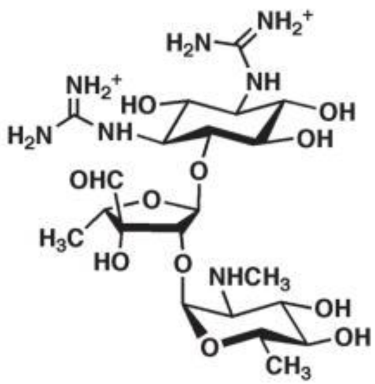
Humans lack the alpha-galactosidase enzyme that is needed to break down raffinose, but intestinal bacteria can ferment it into hydrogen, methane, and other gases.

Homework

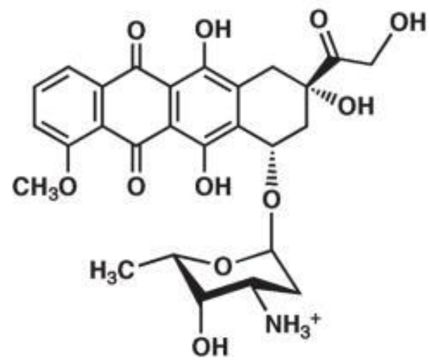
1. Recognize the monosaccharides that make up raffinose.
2. What is the monosaccharide that is attached to *what* disaccharide?

Oligosaccharides as drugs

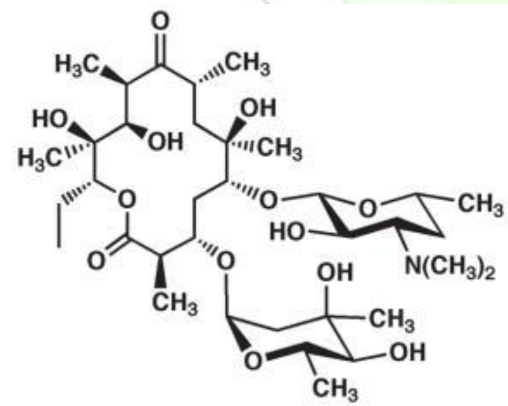
- Streptomycin and erythromycin (antibiotics)
- Doxorubicin (cancer chemotherapy)
- Digoxin (cardiovascular disease)



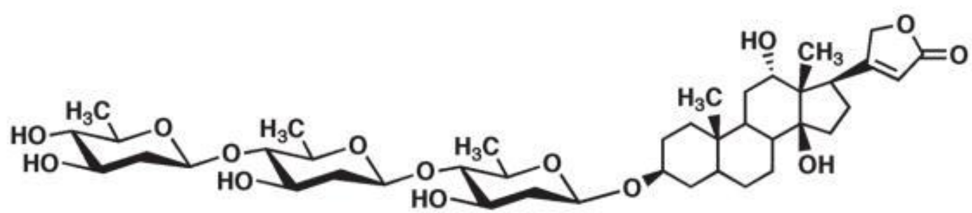
Streptomycin



Doxorubicin



Erythromycin A



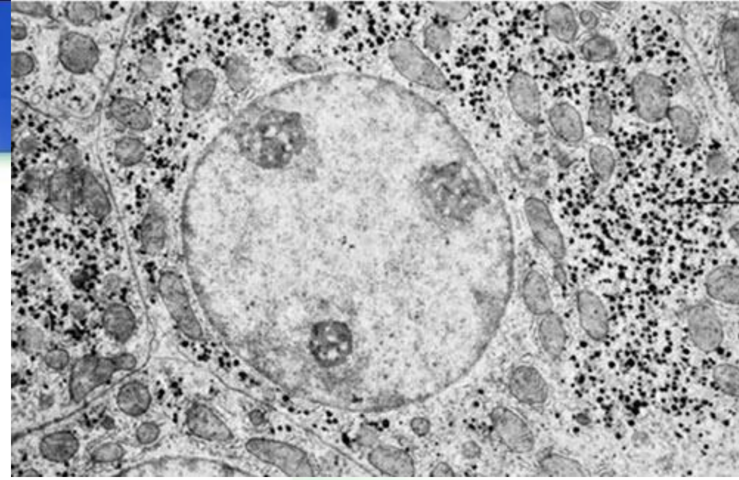
Digoxin

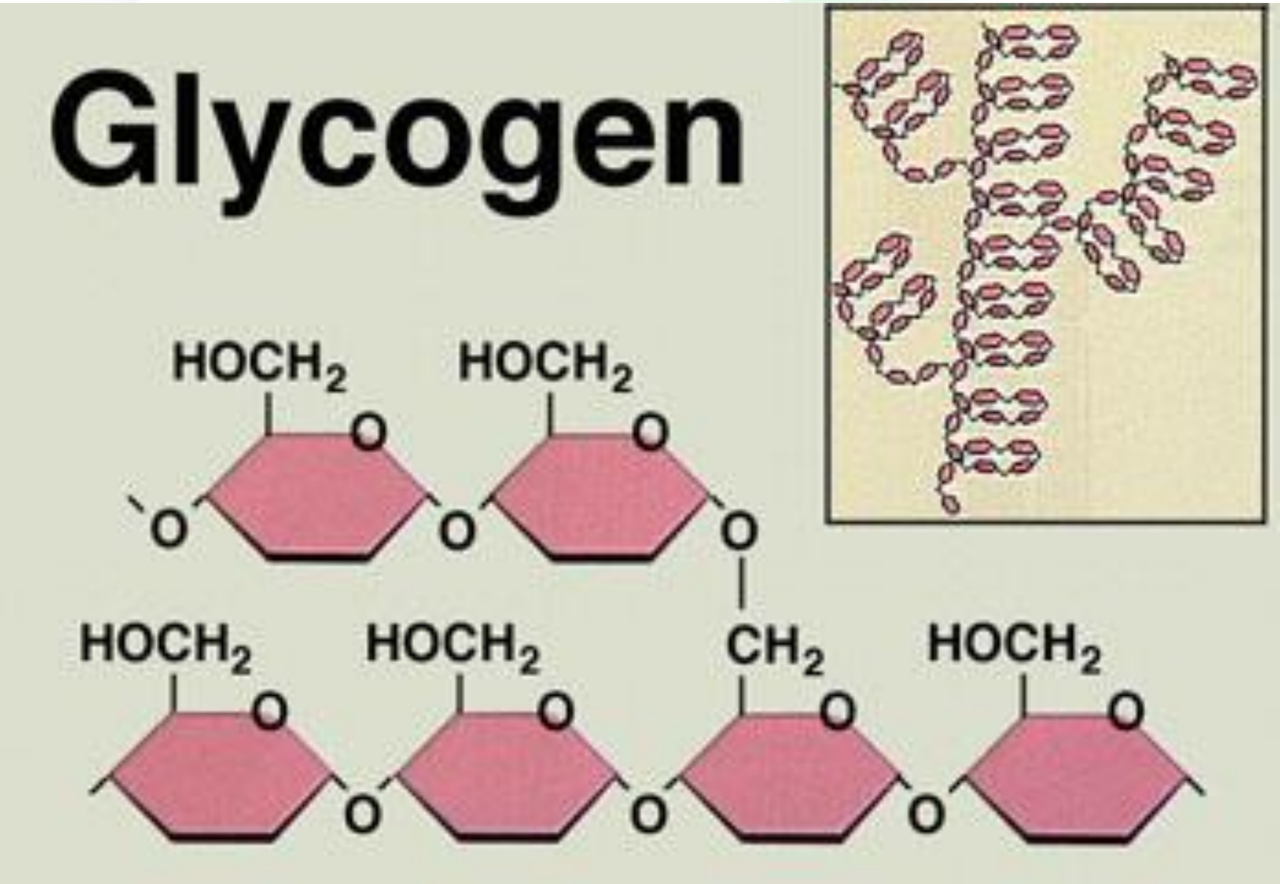
Polysaccharides

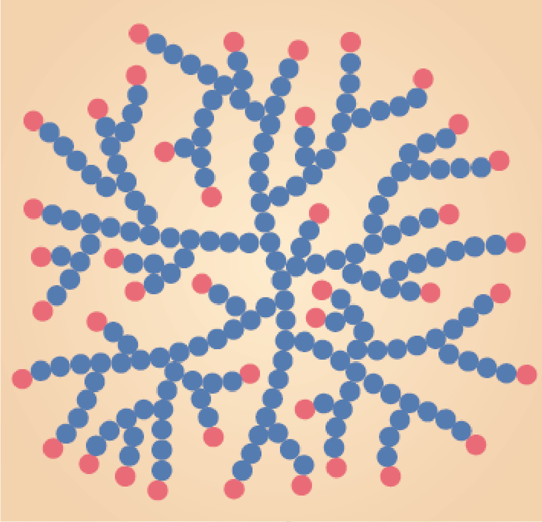
- What are polysaccharides?
- Homopolysaccharide (homoglycan) vs. heteropolysaccharides

- Features of polysaccharides:
  - Monosaccharides
  - Length
  - Branching
  - Purpose:
    - Storage (glycogen, starch, dextran)
    - Structural (cellulose, pectin, chitin)

Glycogen

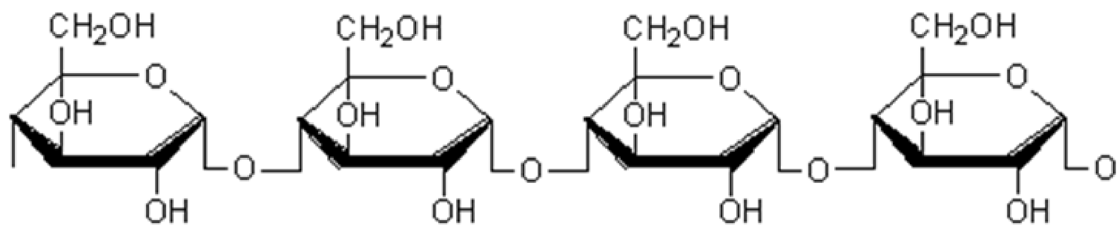




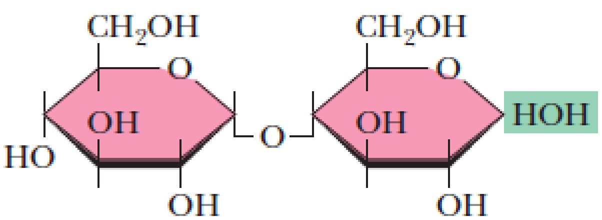


Starch

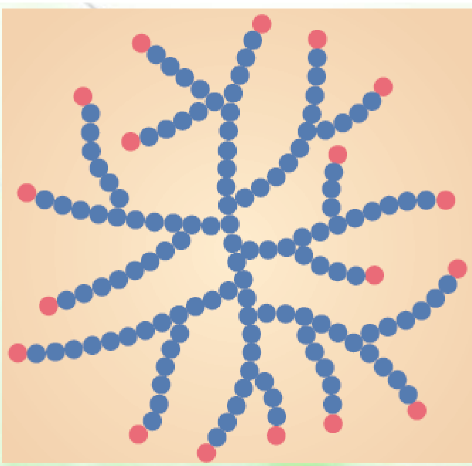
- Which organisms?
- Forms:
  - amylose (10-20%)
  - amylopectin (80-90%)

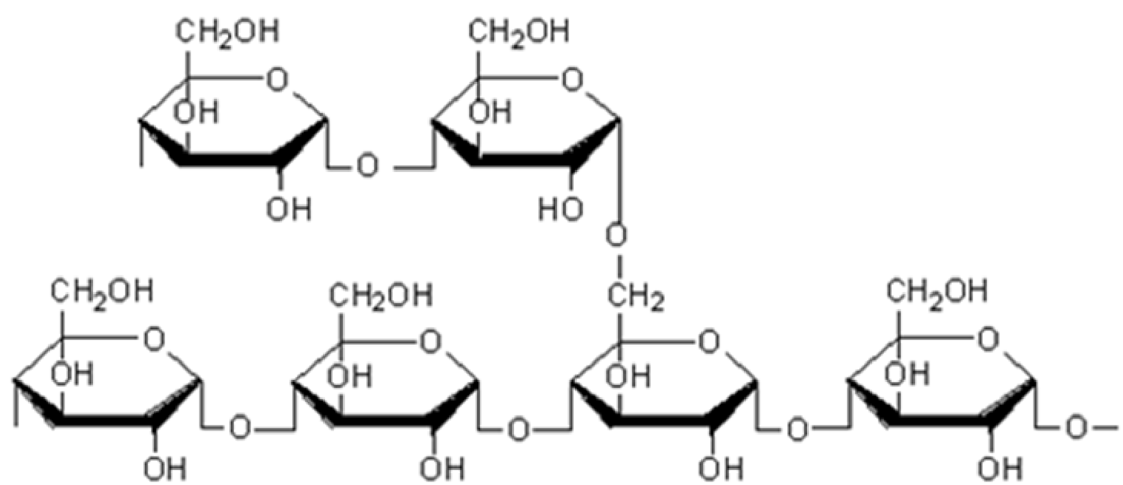


Amylose Structure



Maltose (glucose-α-1,4-glucose)





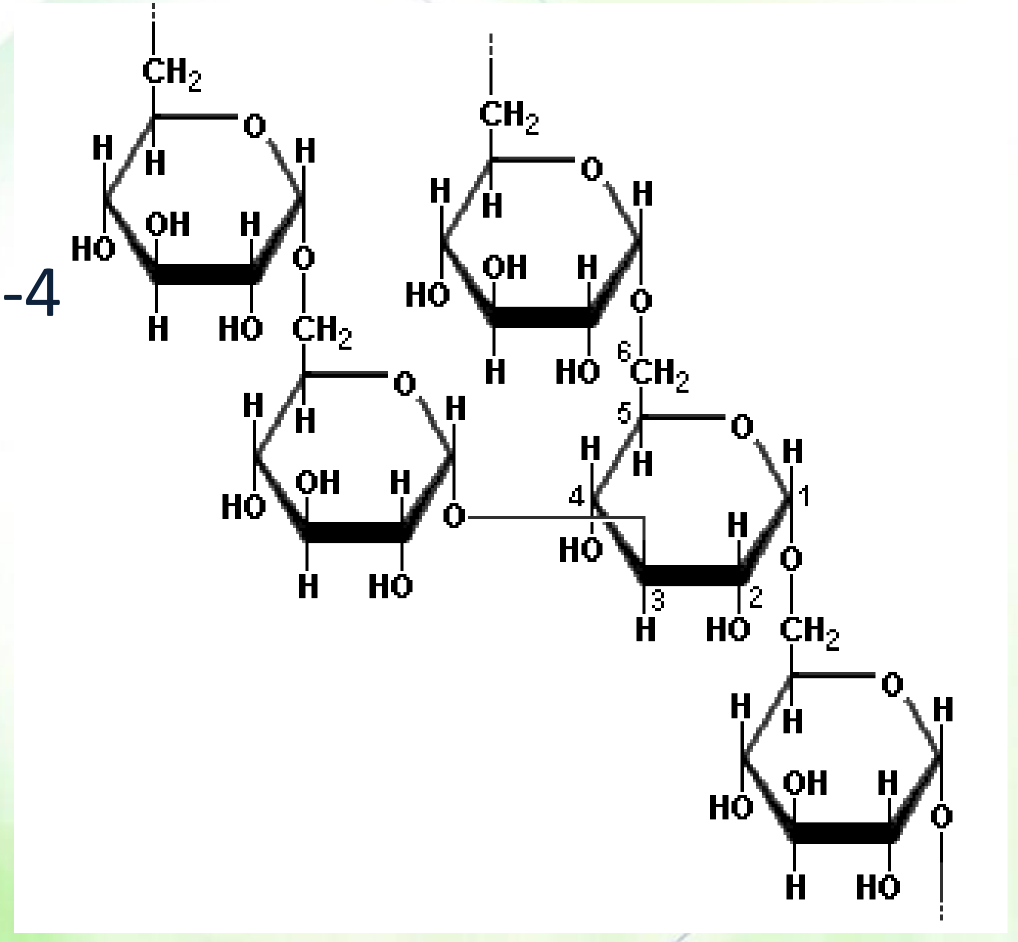
Amylopection Structure

Glycogen vs. amylopectin

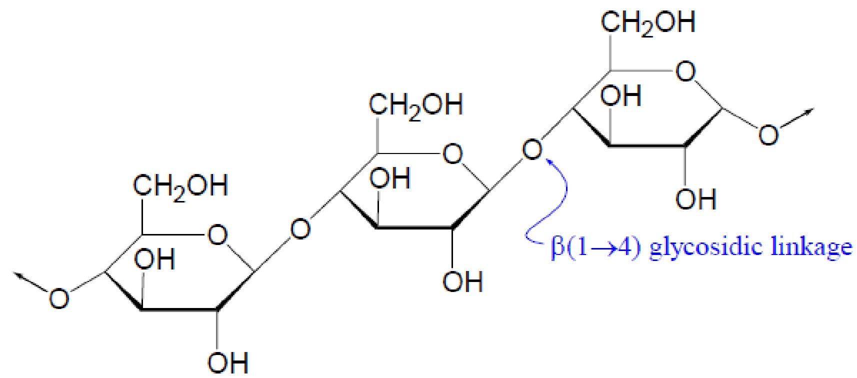
- Both are made from the same monomer and both are branched.
- Glycogen exists in animals and amylopectin in plants.
- Glycogen is more highly branched.
  - Branch points occur about every 10 residues in glycogen and about every 25 residues in amylopectin.
- Why is branching important?
  - It makes it more water-soluble and does not crystallize.
  - Easy access to glucose residues.

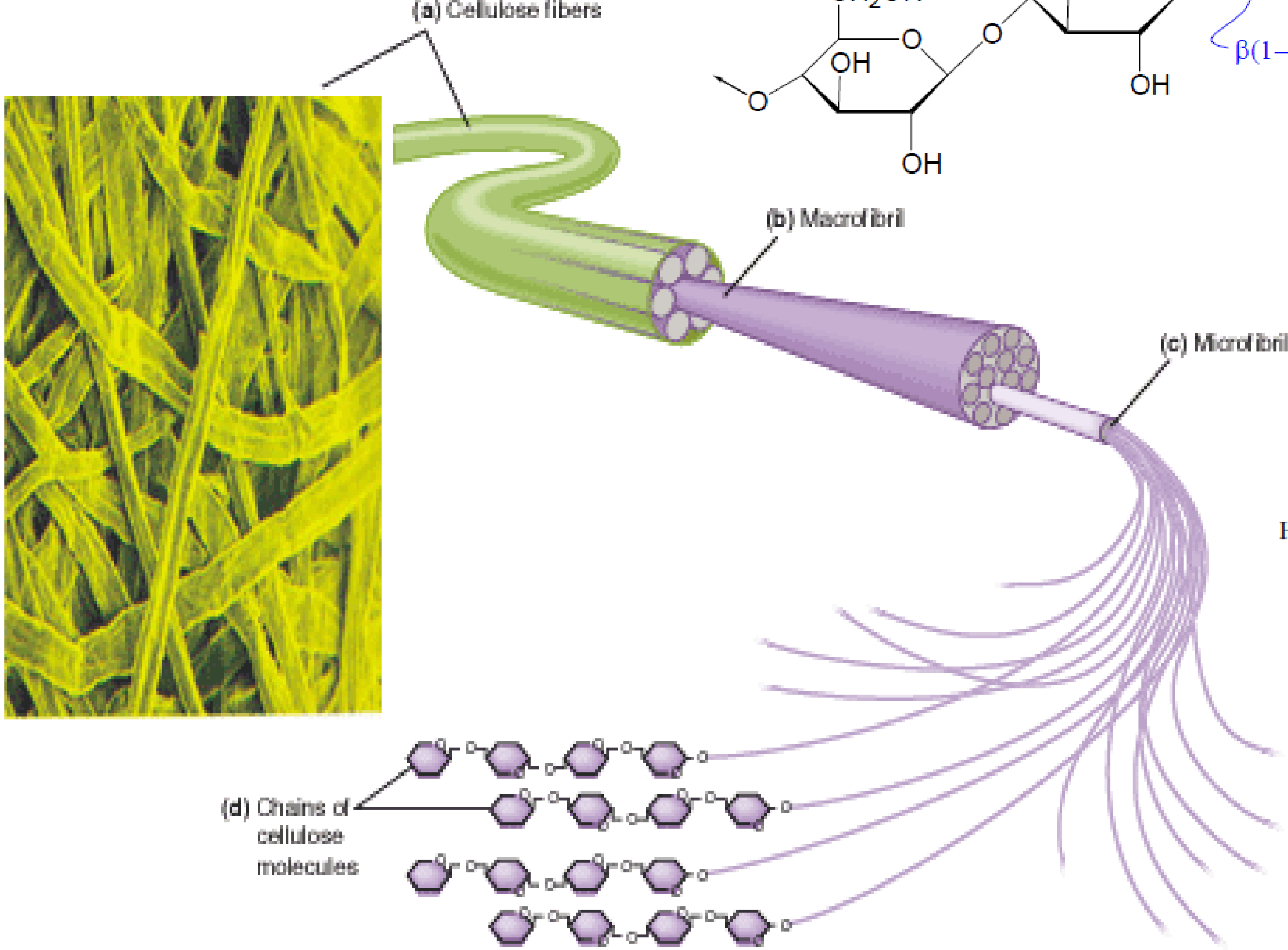
Dextran

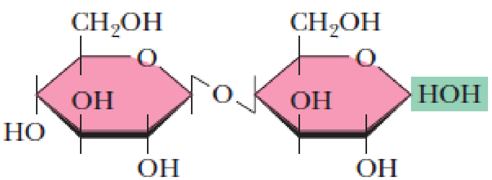
- A storage polysaccharide
- Yeast and bacteria
- α-(1-6)-D-glucose with branched chains
- Branches: 1-2, 1-3, or 1-4



Cellulose





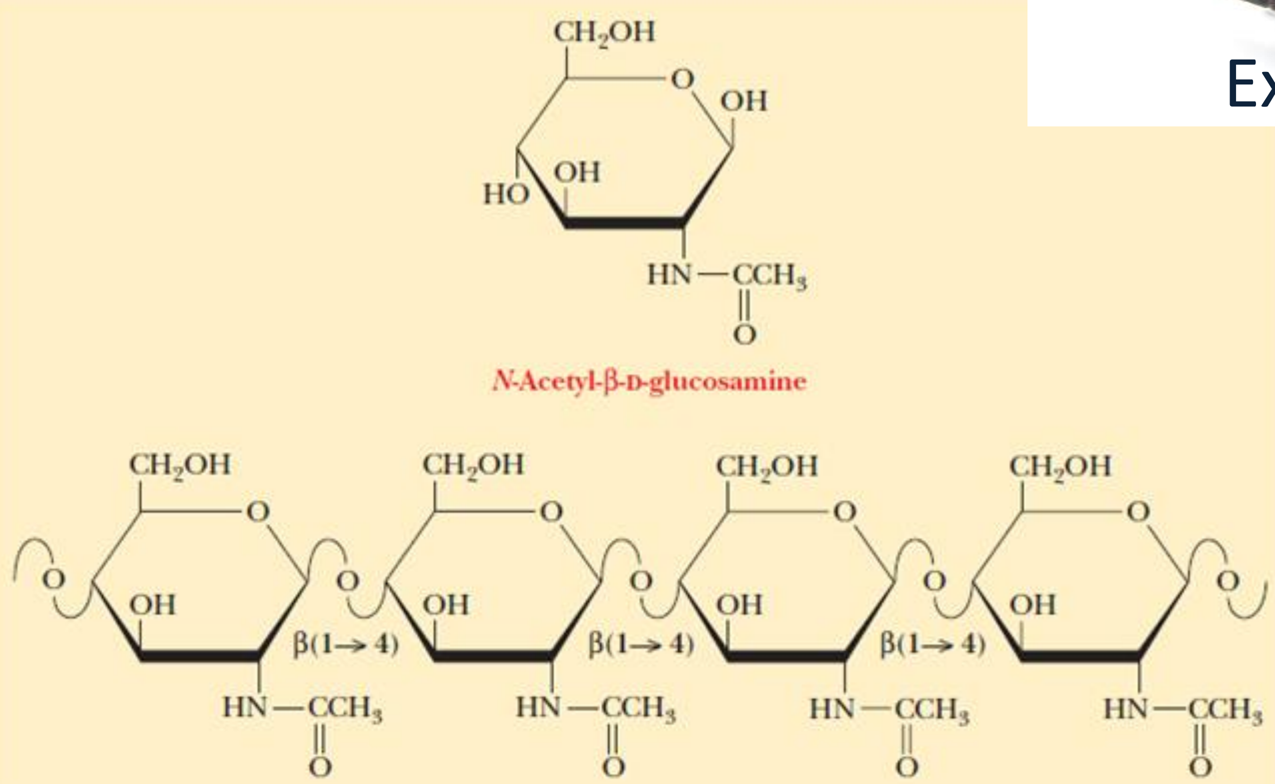


Cellobiose (glucose-β-1,4-glucose)

Chitin

- What is the precursor?
- Where does it exist?

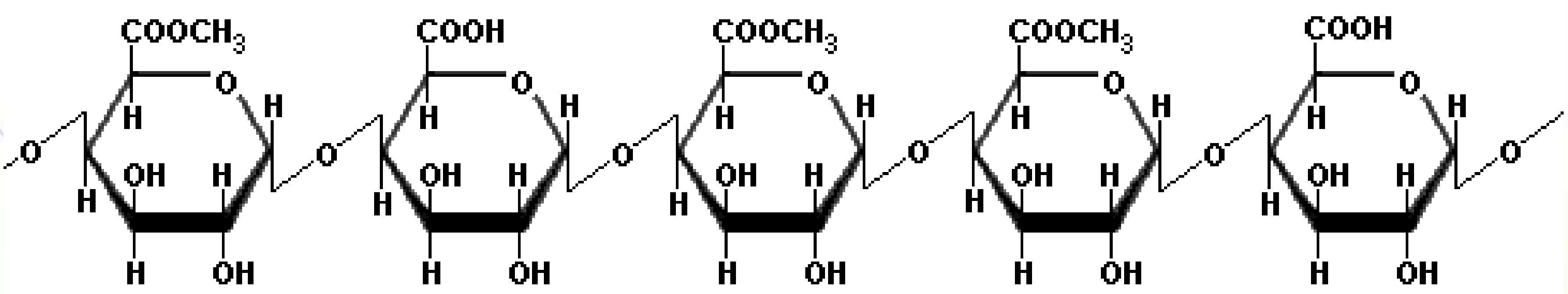
Exoskeleton



Credit: Getty Images/iStockphoto

Pectin

- What is the precursor?
- Where does it exist?

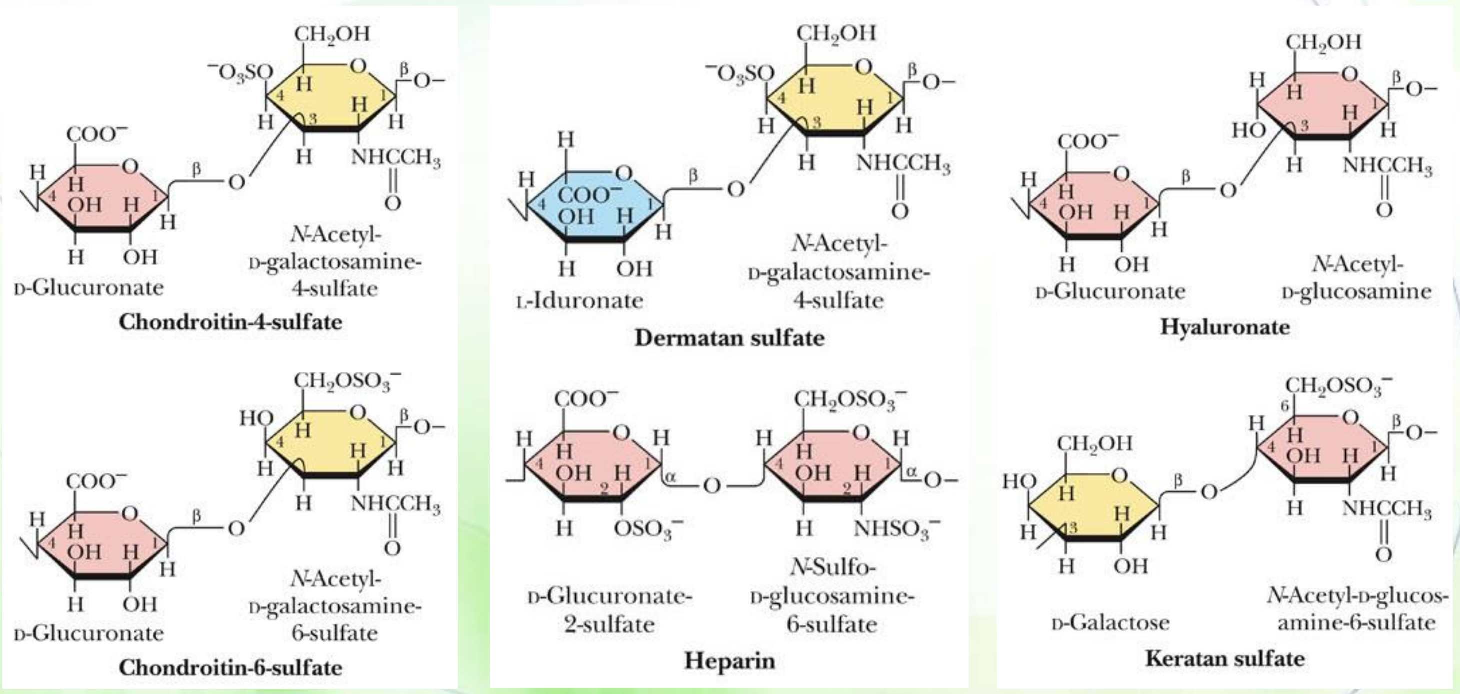


Are polysaccharides reducing?

- A sample that contains only a few molecules of a large polysaccharide, each molecule with a single reducing end, might well produce a negative test because there are not enough reducing ends to detect.

Glycosaminoglycans

- What are they? Where are they located?
- Derivatives of an amino sugar, either glucosamine or galactosamine
- At least one of the sugars in the repeating unit has a negatively charged carboxylate or sulfate group

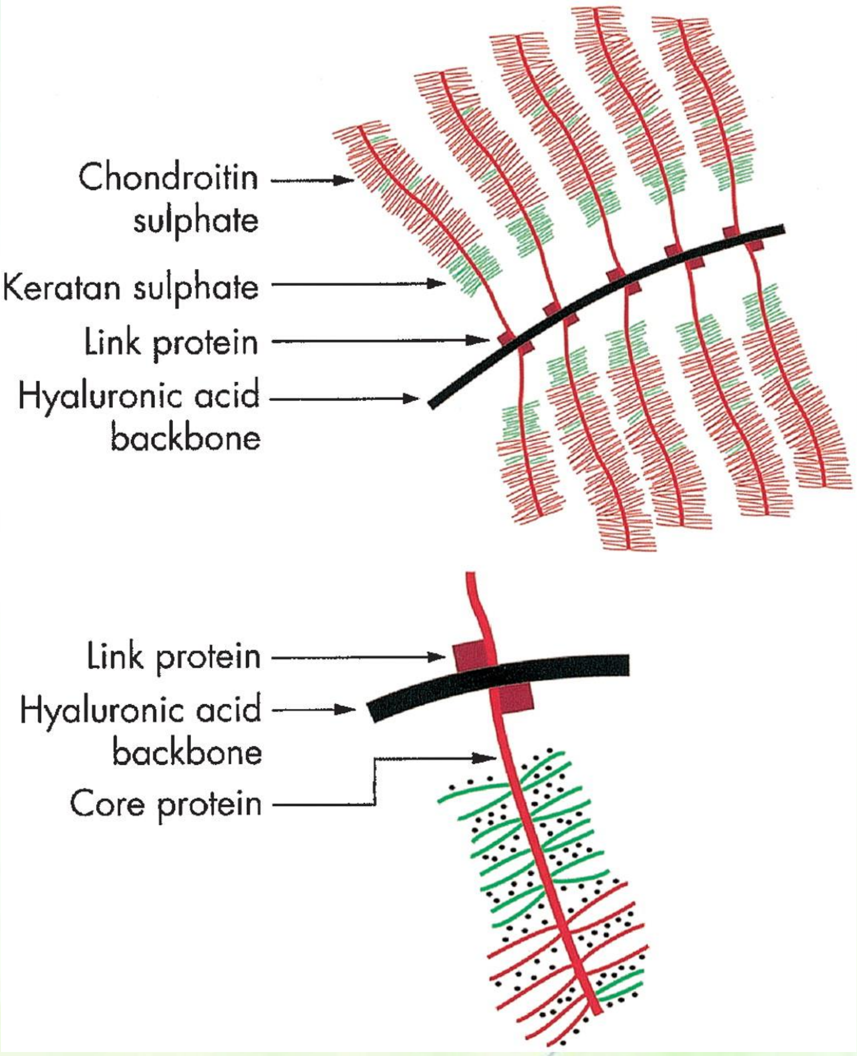


Localization and function of GAG

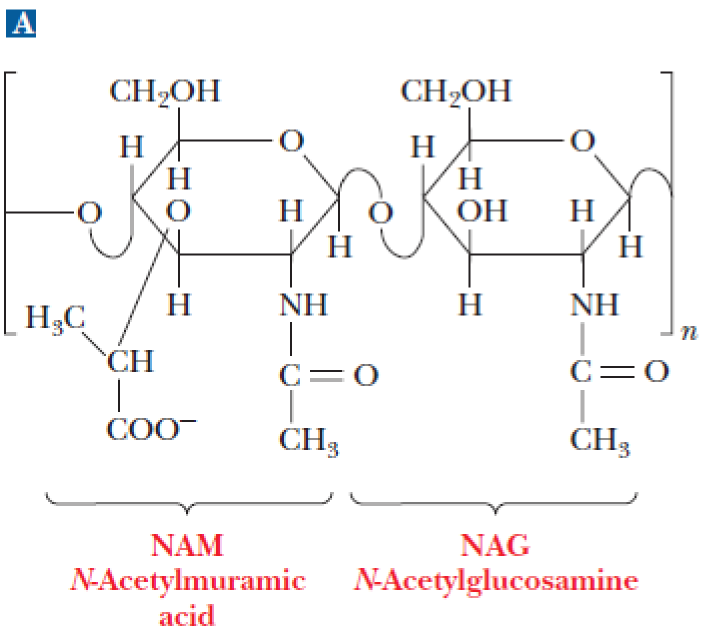
GAG	Localization	Comments
Hyaluronate	synovial fluid, **vitreous humor, ECM of loose connective tissue**	**the lubricant fluid , shock absorbing** As many as 25,000 disaccharide units
Chondroitin sulfate	**cartilage**, bone, heart valves	**most abundant GAG**
Heparan sulfate	basement membranes, components of cell surfaces	contains higher acetylated glucosamine than heparin
Heparin	component of intracellular granules of mast cells lining the arteries of the lungs, liver and skin	**A natural anticoagulant**
Dermatan sulfate	skin, blood vessels, heart valves	
Keratan sulfate	cornea, bone, cartilage aggregated with chondroitin sulfates	Only one not having uronic acid

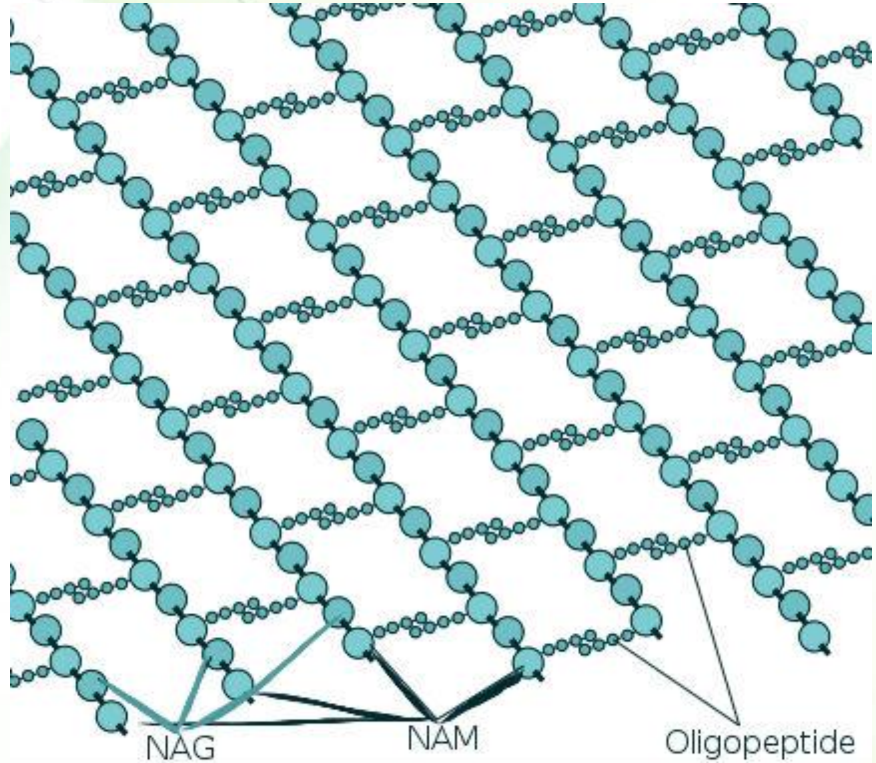
Proteoglycans

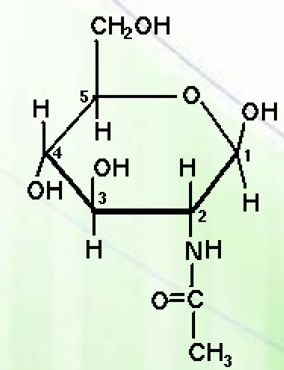
- Lubricants
- Structural components in connective tissue
- Mediate adhesion of cells to the extracellular matrix
- Bind factors that stimulate cell proliferation



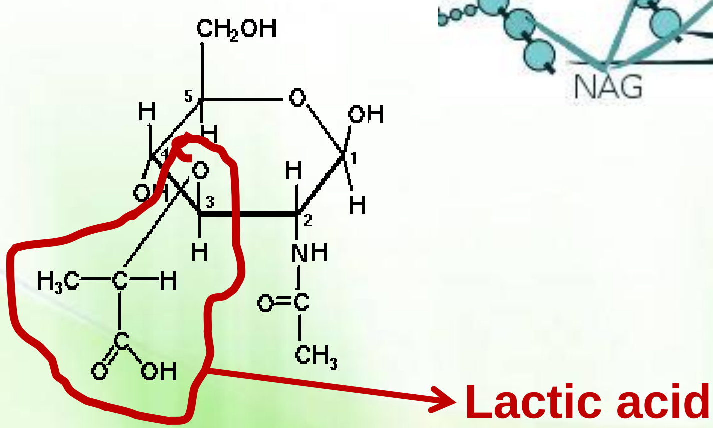
Bacterial cell wall





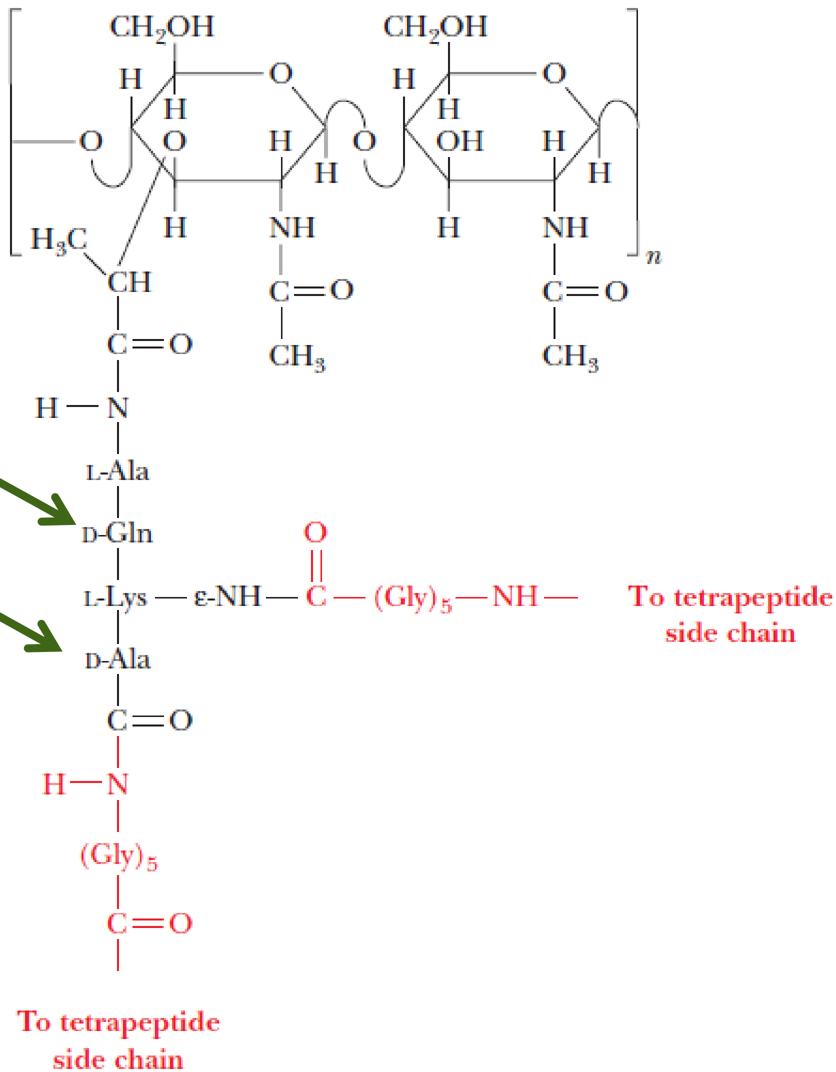


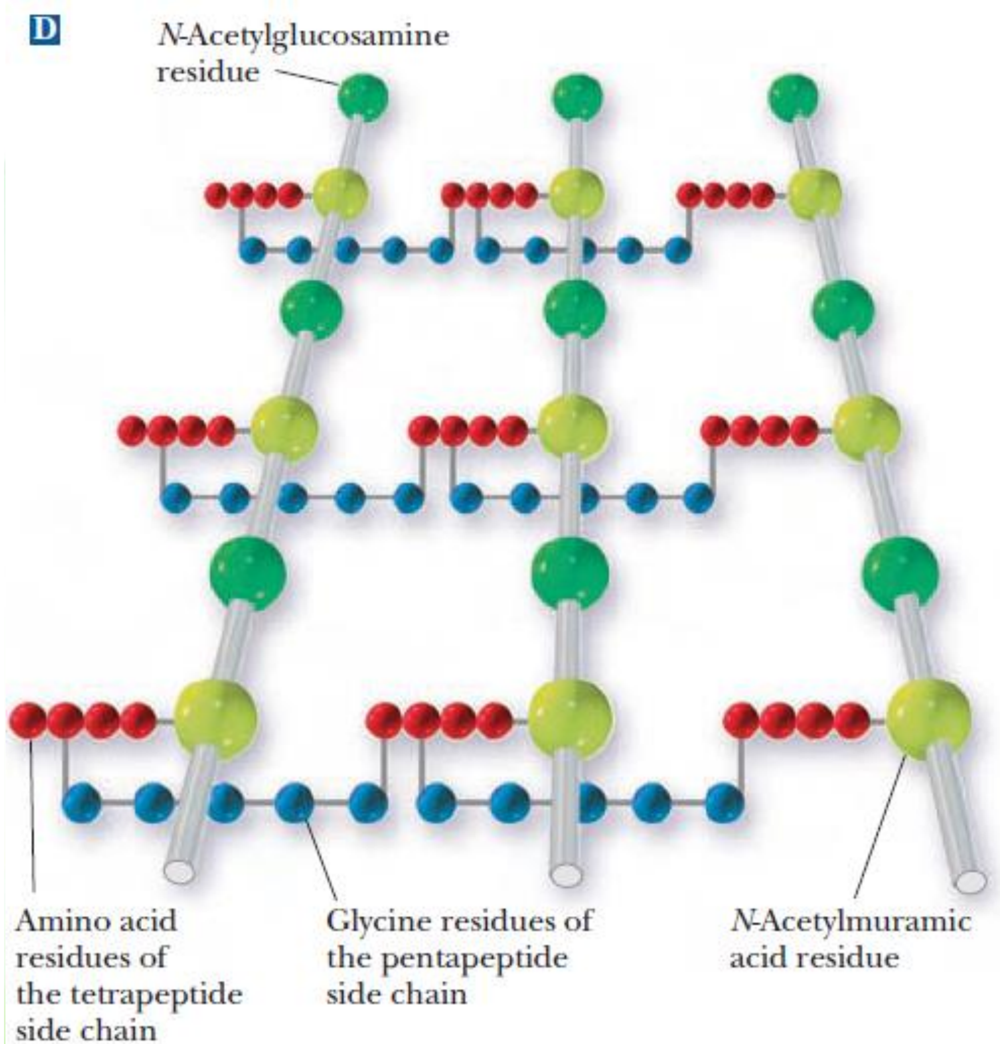
N-acetylglucosamine (NAG)



N-acetylmuramic acid (NAM)

Peptidoglycan





Glycoproteins

- The carbohydrates of glycoproteins are linked to the protein component through either *O*-glycosidic or *N*-glycosidic bonds
  - The *N*-glycosidic linkage is through the amide group of asparagine (Asn, N)
  - The *O*-glycosidic linkage is to the hydroxyl of serine (Ser, S), threonine (Thr, T) or hydroxylysine (hLys)

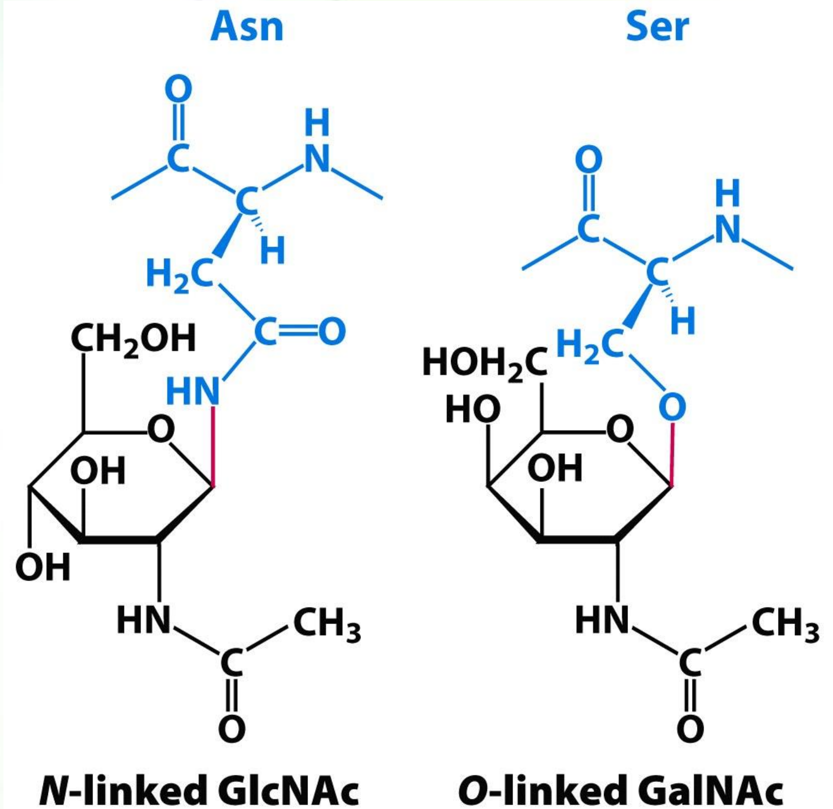


Figure 11.15
Biochemistry, Seventh Edition

Significance of protein-linked sugars

- Soluble proteins as well as membrane proteins
- Purpose:
  - Protein folding
  - Protein targeting
  - prolonging protein half-life
  - Cell-cell communication
  - Signaling

Blood typing

- Three different structures:
  - A, B, and O
- The difference:
  - *N*-acetylgalactosamine (for A)
  - Galactose (for B)
  - None (for O)