Lecture : 1

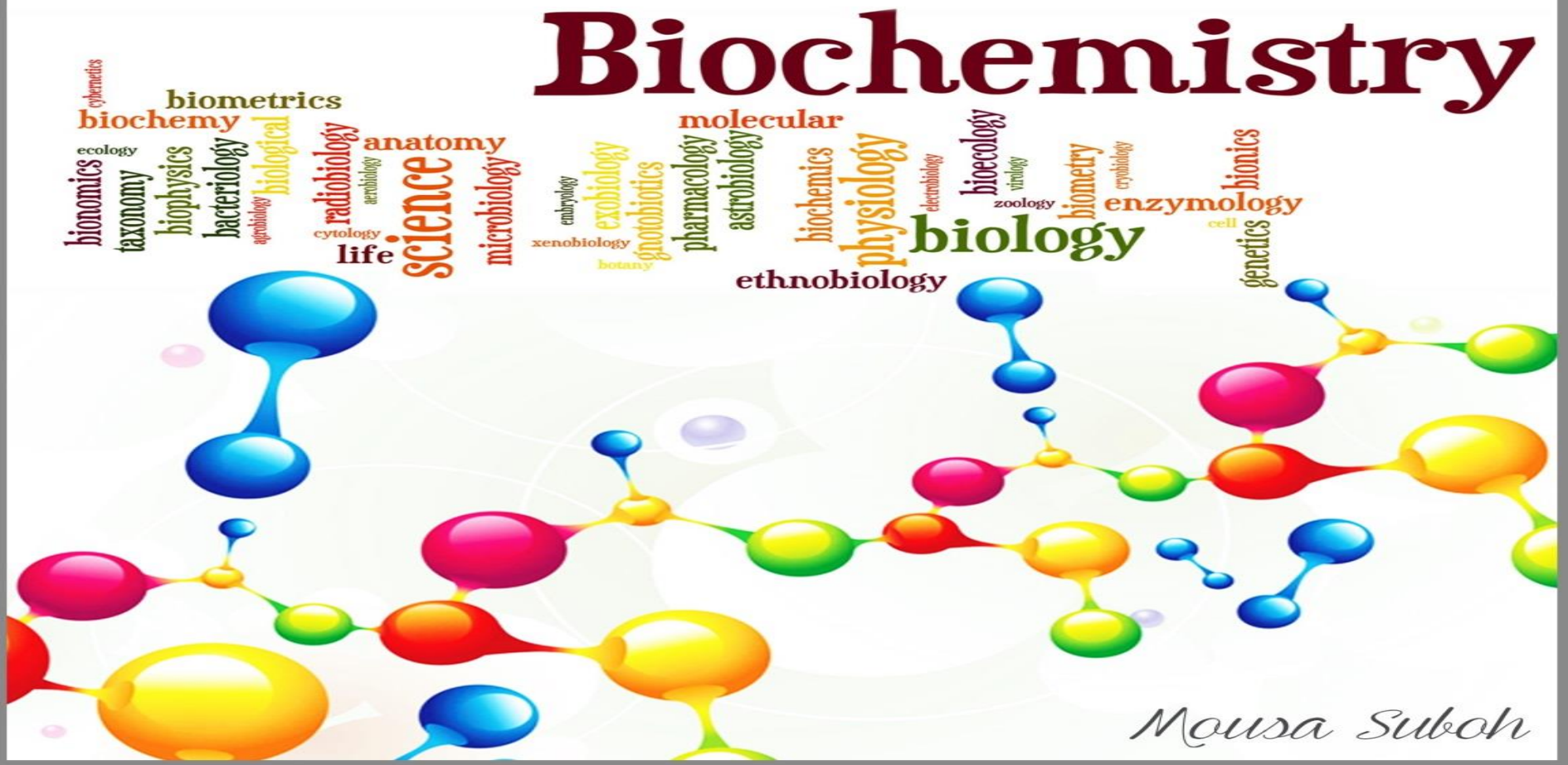
Dr. Name : Dr. Mamoun Ahram

SECTION : 1 , 2 , 3

■ Slide □ Sheet

Medical Committee
The University of Jordan

Biochemistry



Mousa Suboh

Carbohydrates

Lecture 6
Dr. Mamoun Ahram
Summer, 2014

Resource

- This lecture
- 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 recognition

Classification I

- By the number of sugars that constitute the molecule

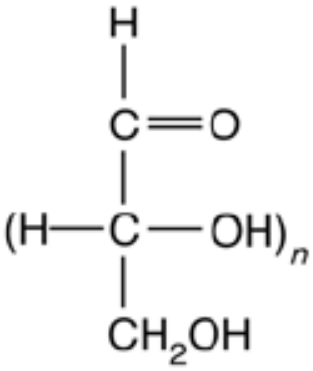
- Monosaccharides
- Disaccharides
- Oligosaccharides
- Polysaccharides

Carbohydrates – natural forms

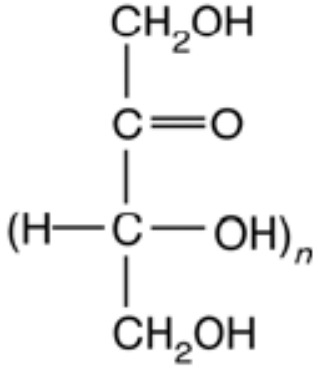
- Most carbohydrates are found naturally in bound form rather than as simple sugars
  - Polysaccharides (starch, cellulose, inulin, gums)
  - Glycoproteins and proteoglycans (hormones, blood group substances, antibodies)
  - Glycolipids (cerebrosides, gangliosides)
  - Glycosides
  - Mucopolysaccharides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

Monosaccharides

- Basic chemical formula: $(CH_2O)n$
- They contain two or more hydroxyl groups

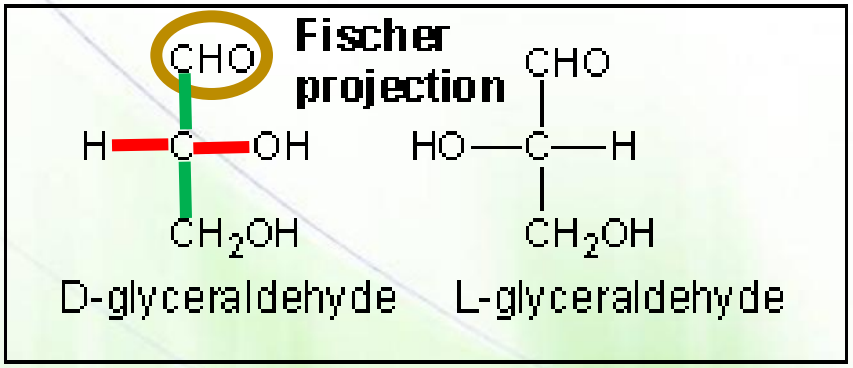


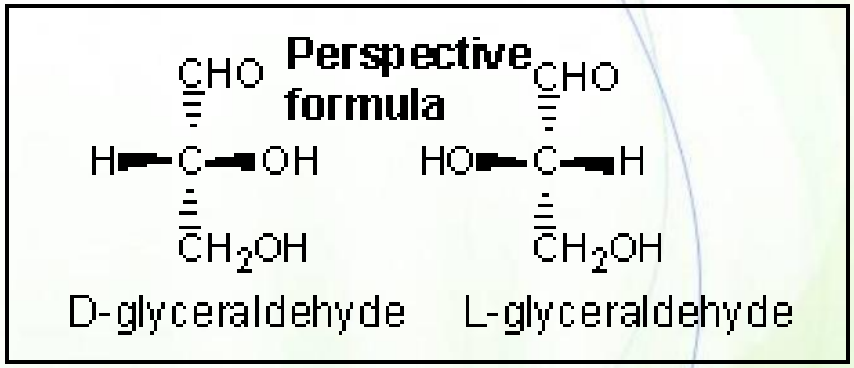
An aldose



A ketose

Fisher projections or perspective structural formulas.

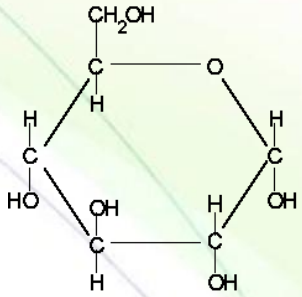




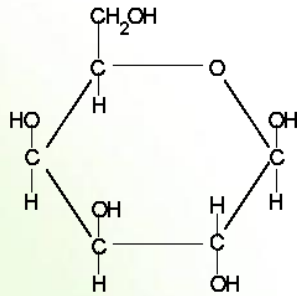
Forward **Backward** **Top (C1): Most highly oxidized C**

Common Monosaccharides

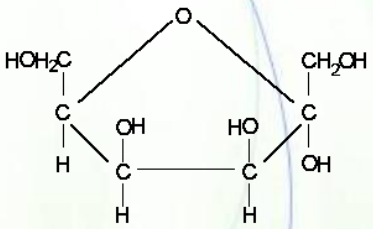
- Glucose:
  - Mild sweet flavor
  - Known as blood sugar
  - Essential energy source
  - Found in every disaccharide and polysaccharide
- Galactose:
  - Hardly tastes sweet & rarely found naturally as a single sugar.
- Fructose:
  - Sweetest sugar, found in fruits and honey
  - Added to soft drinks,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



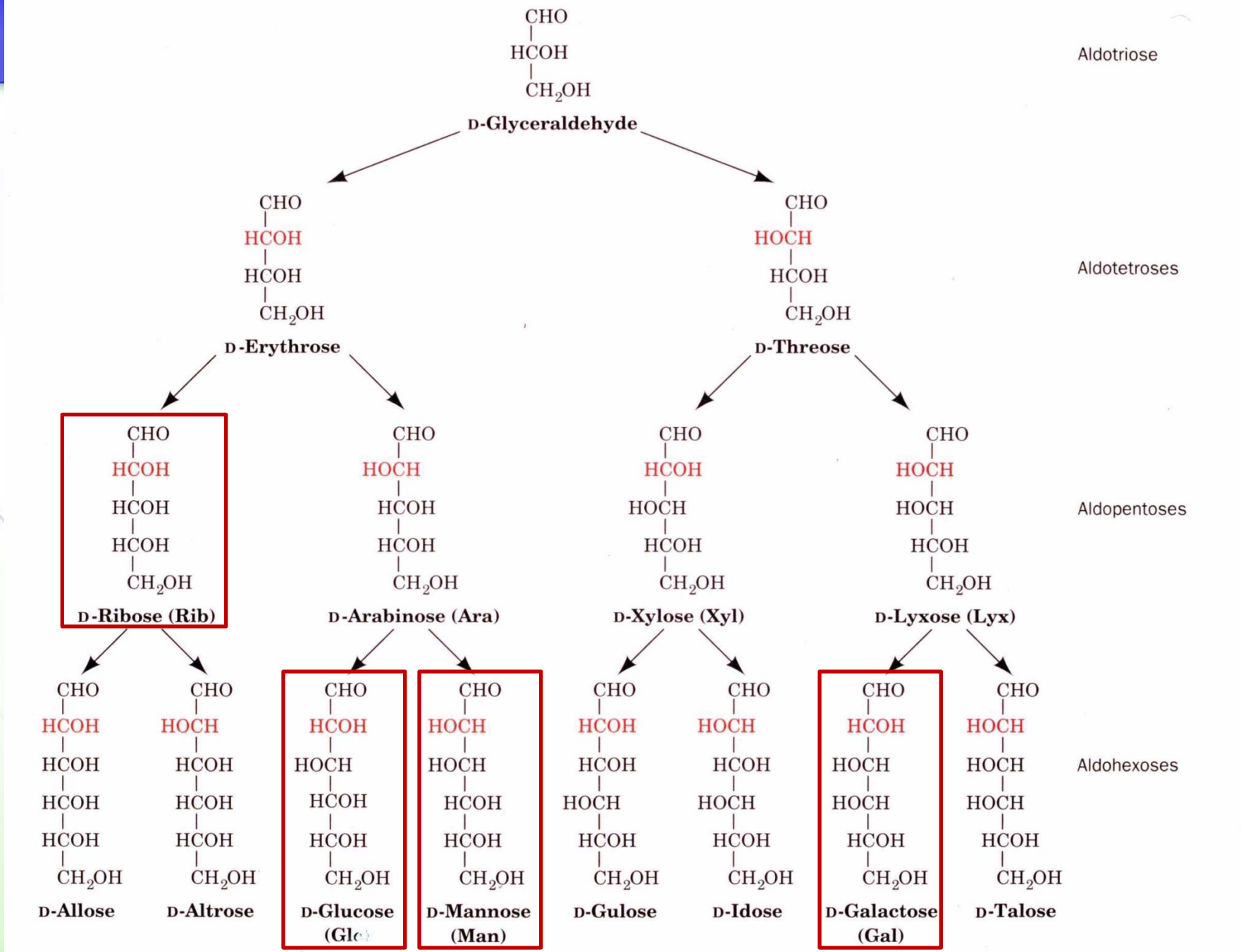
Glucose

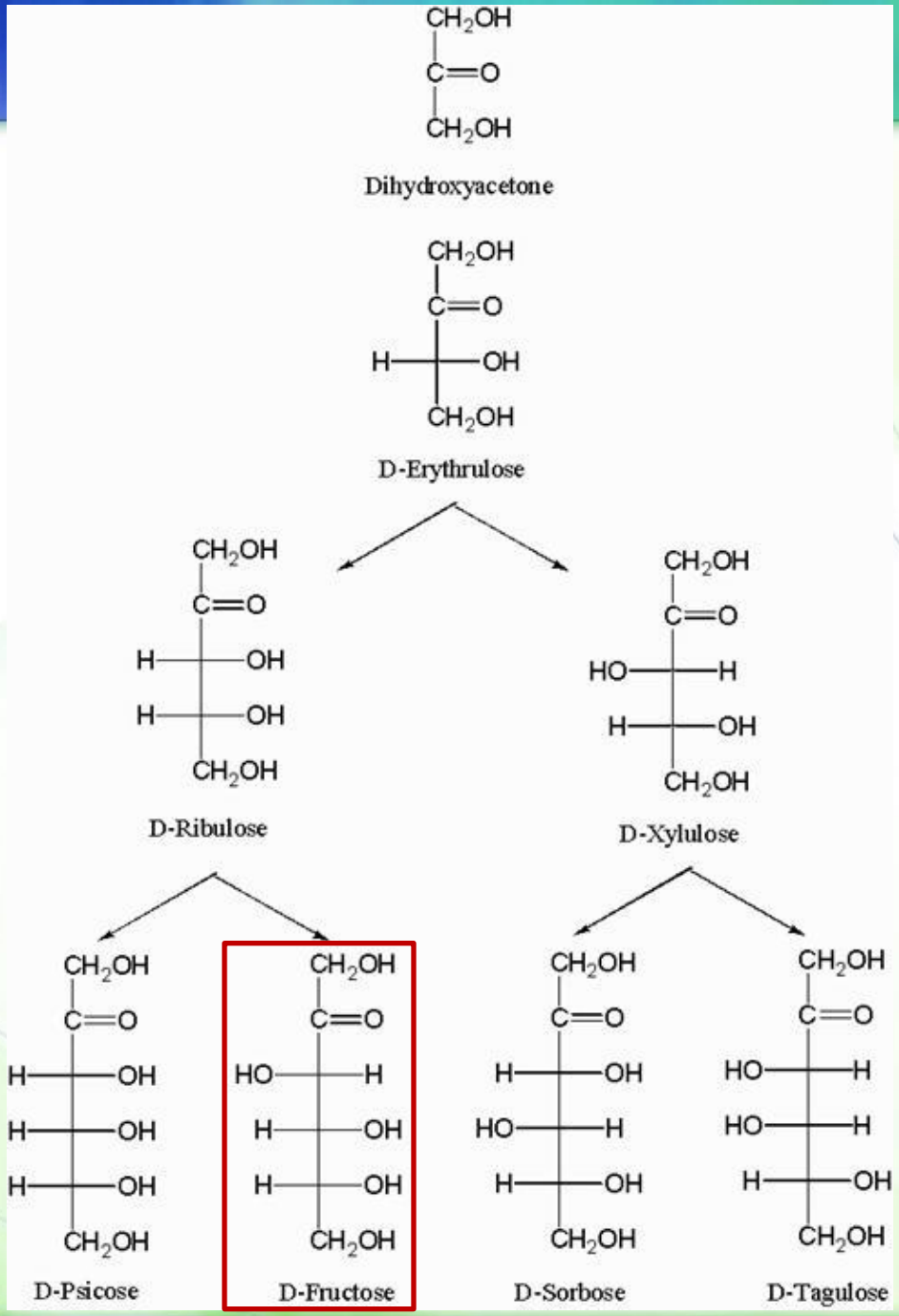


Galactose



Fructose

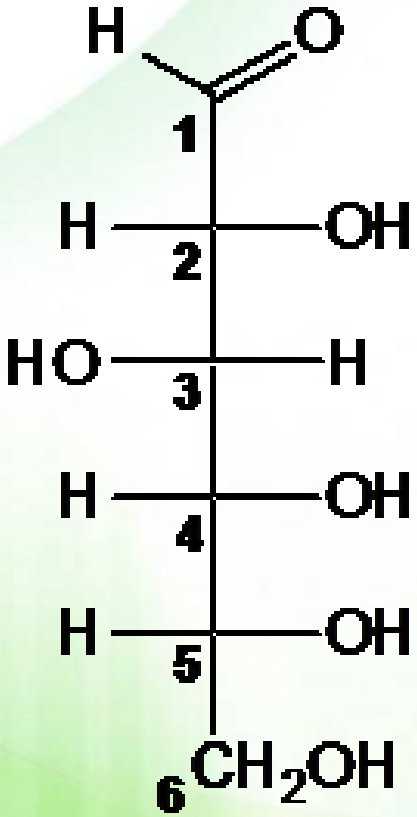

Aldotriose
D-Glyceraldehyde
Aldotetroses
D-Erythrose
D-Threose
Aldopentoses
D-Ribose (Rib)
D-Arabinose (Ara)
D-Xylose (Xyl)
D-Lyxose (Lyx)
Aldohexoses
D-Allose
D-Altrose
D-Glucose (Glc)
D-Mannose (Man)
D-Gulose
D-Idose
D-Galactose (Gal)
D-Talose

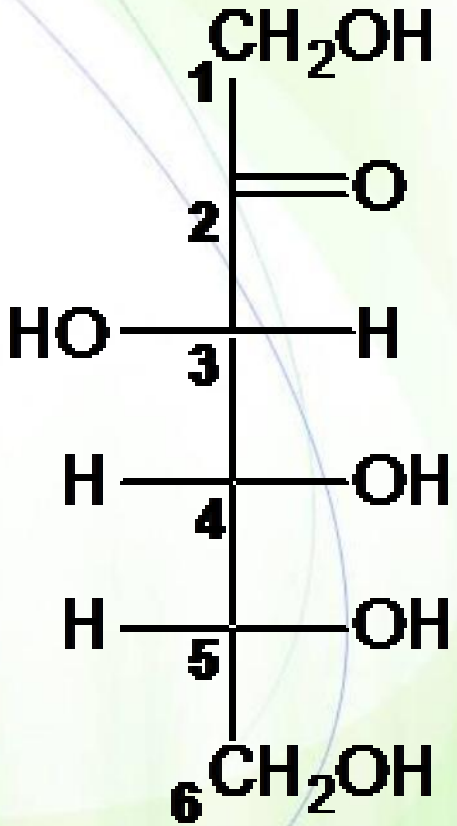

Dihydroxyacetone
D-Erythrulose
D-Ribulose
D-Xylulose
D-Psicose
D-Fructose
D-Sorbose
D-Tagulose

Classification 2

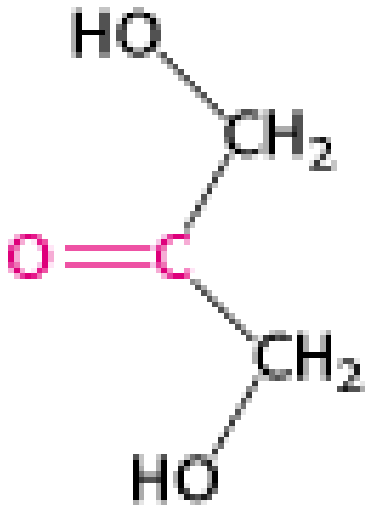
- By the number of carbon atoms they contain

- Triose
- Tetrose
- Pentose
- Hexose
- Heptose
- …

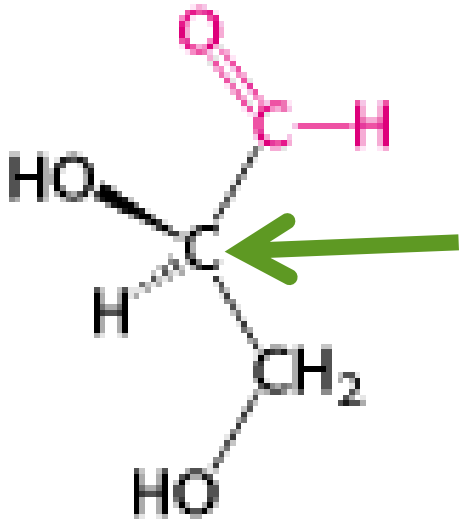




Trioses



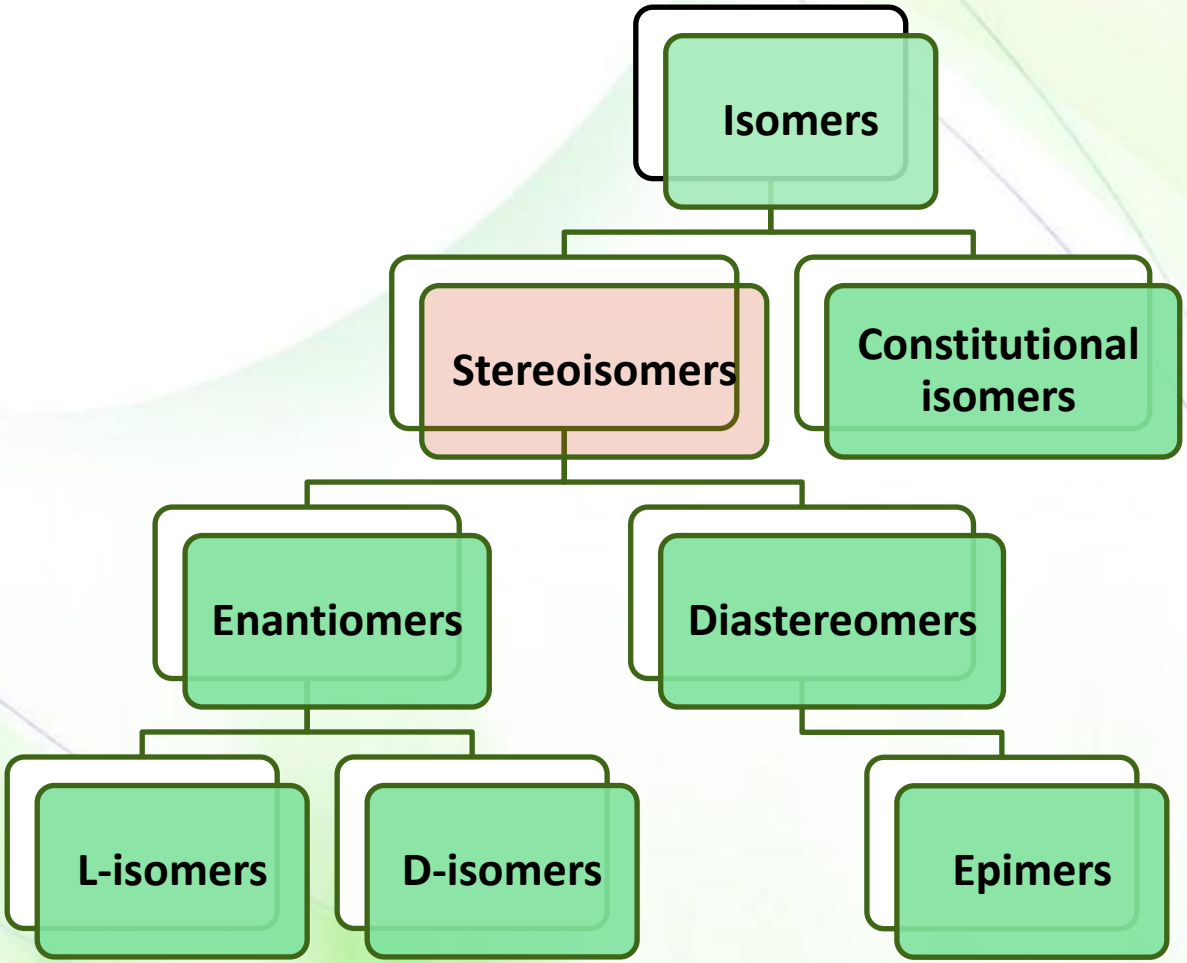
Dihydroxyacetone
(a ketose)



D-Glyceraldehyde
(an aldose)

Chiral carbon

Isomerism

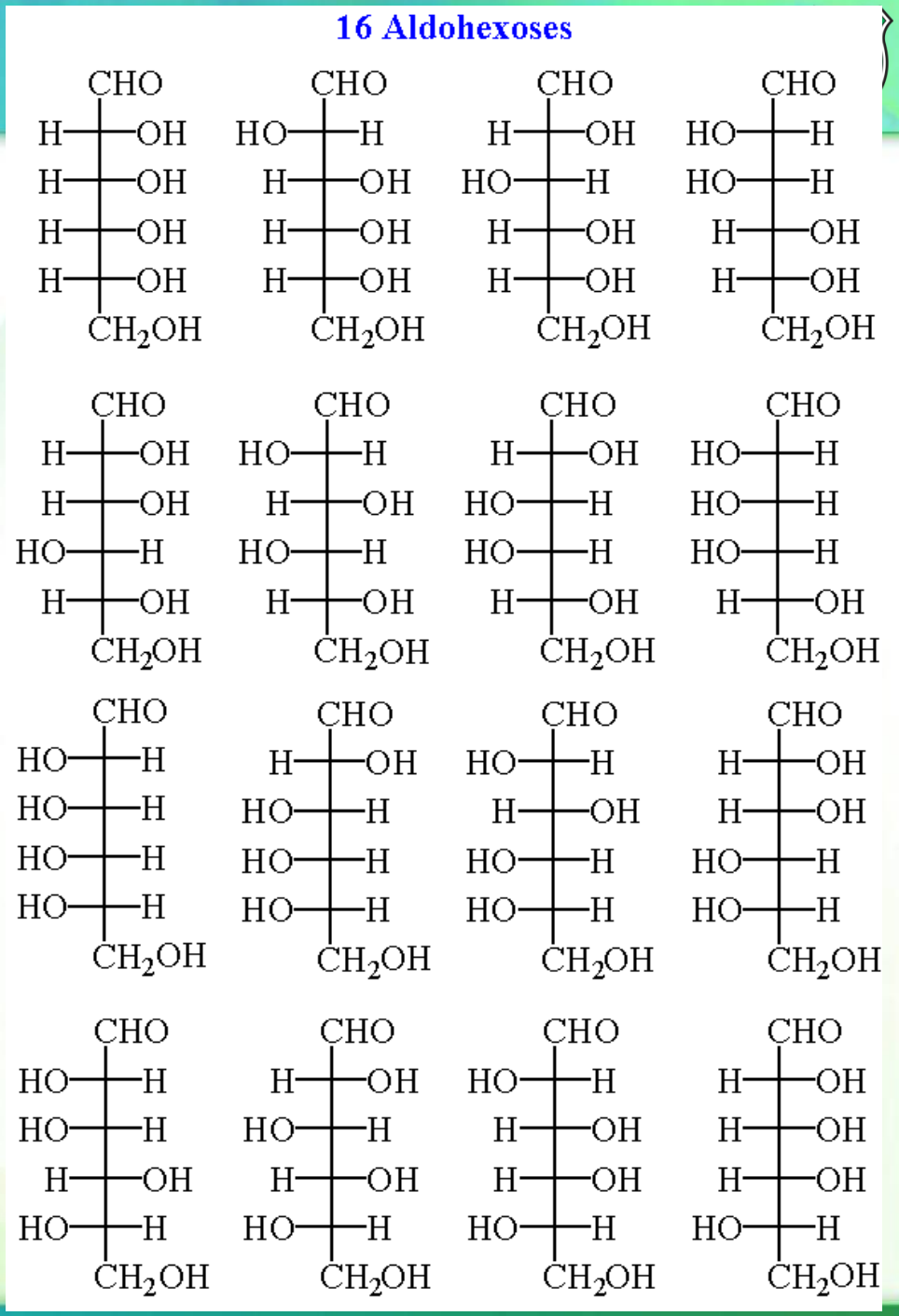

Isomers
Stereoisomers
Constitutional isomers
Enantiomers
Diastereomers
L-isomers
D-isomers
Epimers

Isomers of glucose

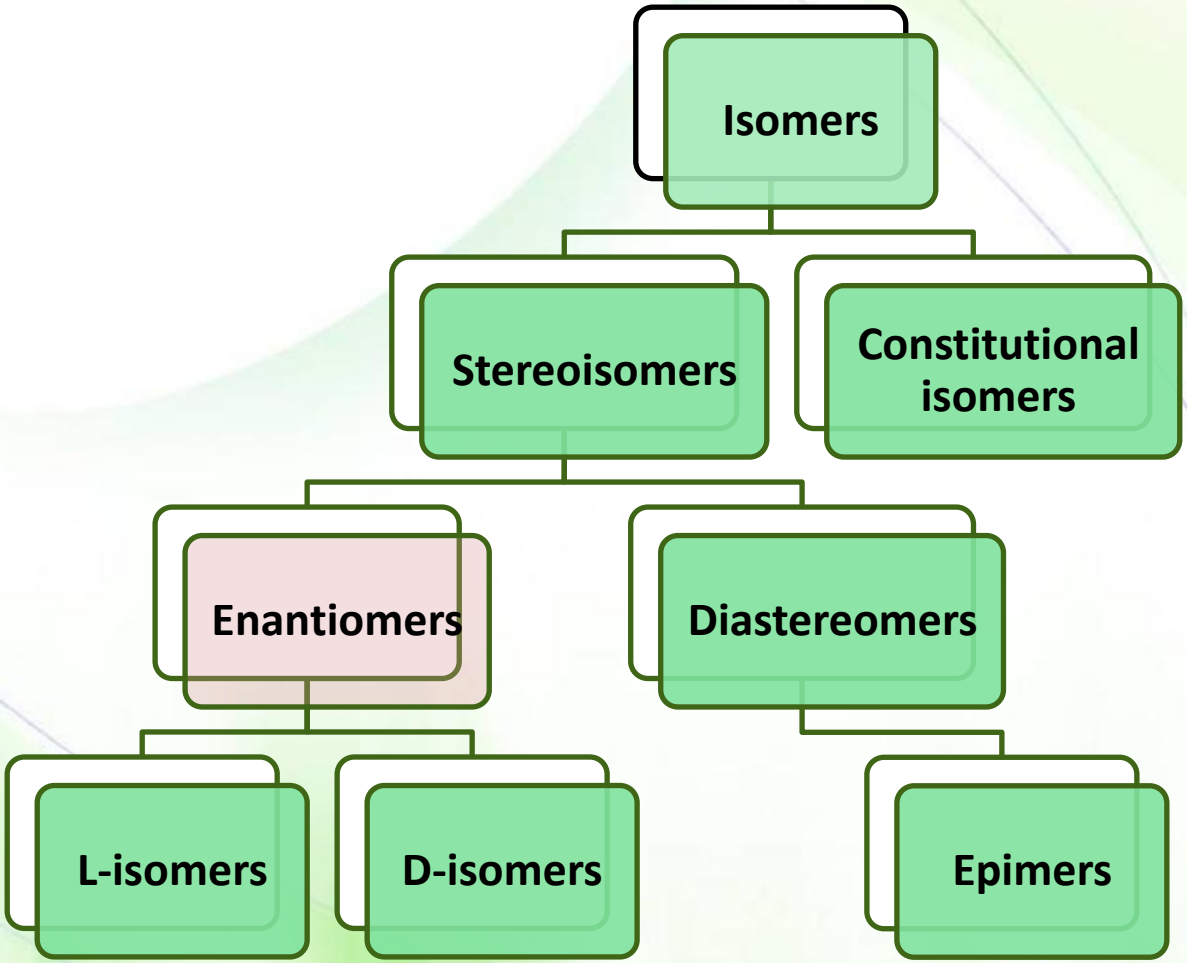
2^n (n is the number of chiral carbons in a sugar molecule)

Search for:

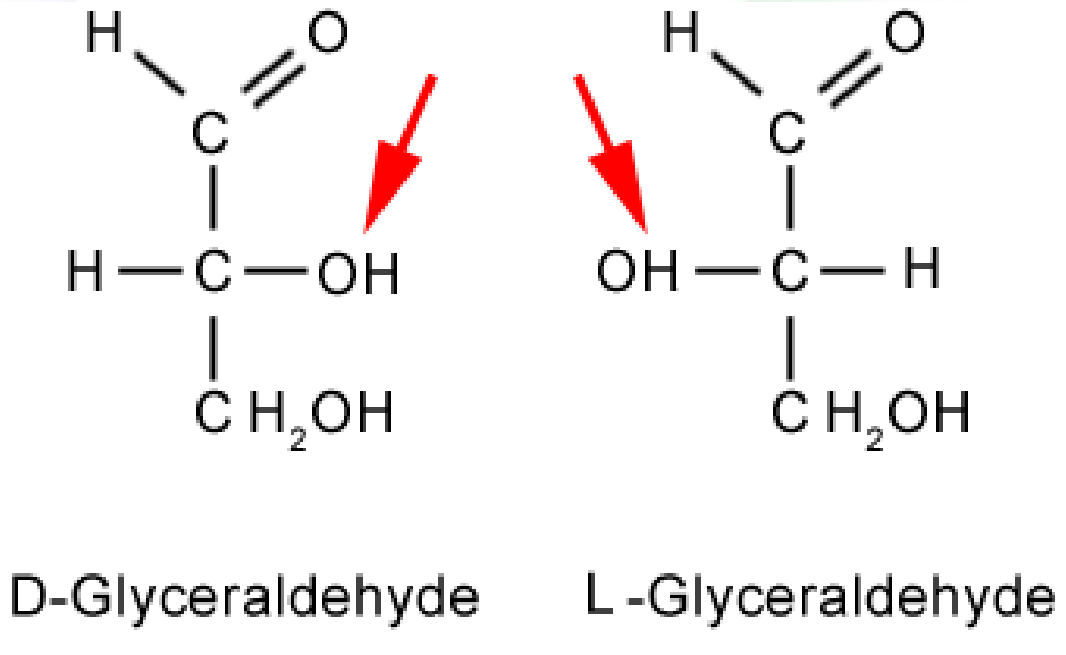
Glucose,
Galactose
Mannose



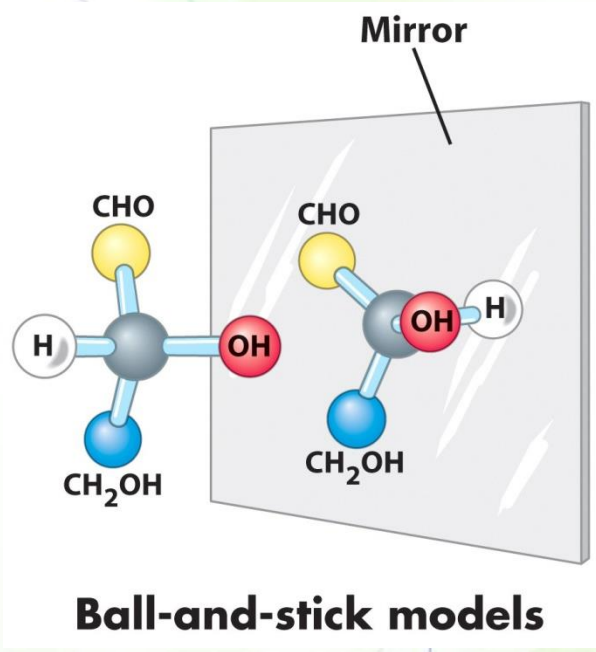
Isomerism


Isomers
Stereoisomers
Constitutional isomers
Enantiomers
Diastereomers
L-isomers
D-isomers
Epimers

Sugar enantiomers (D- vs. L-)

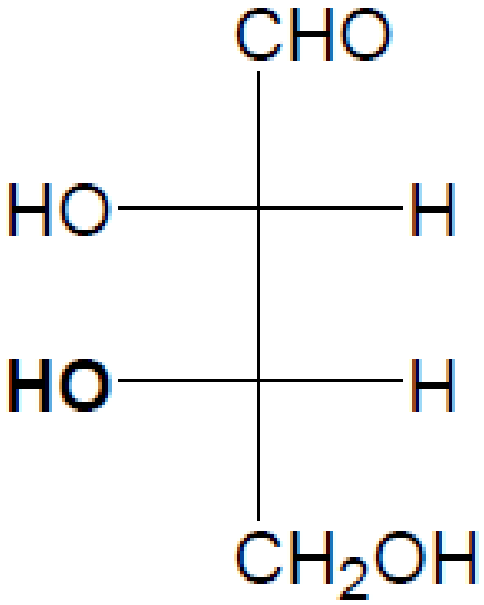


D-Glyceraldehyde L -Glyceraldehyde

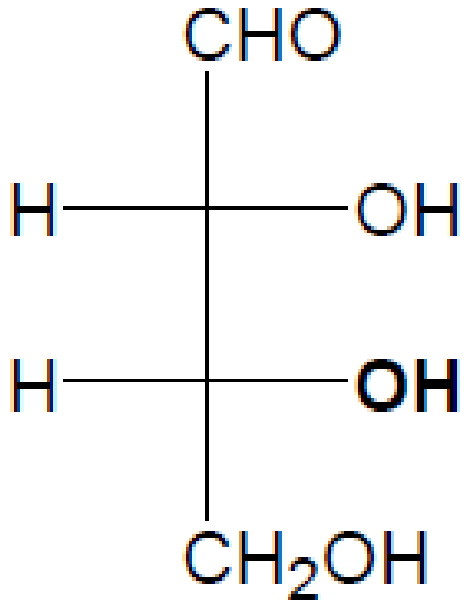


Ball-and-stick models

Which one(s) is a chiral carbon?

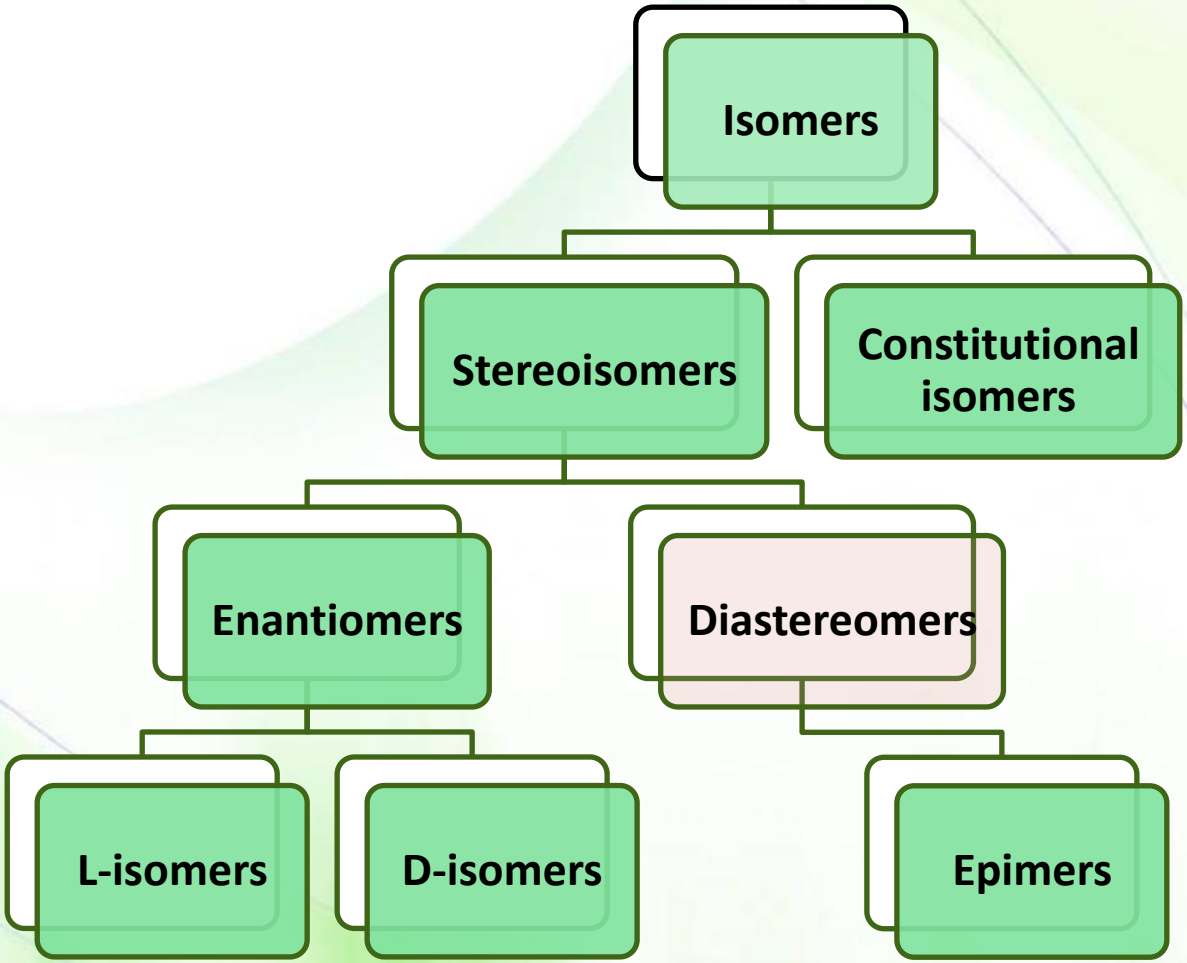


L-erythrose

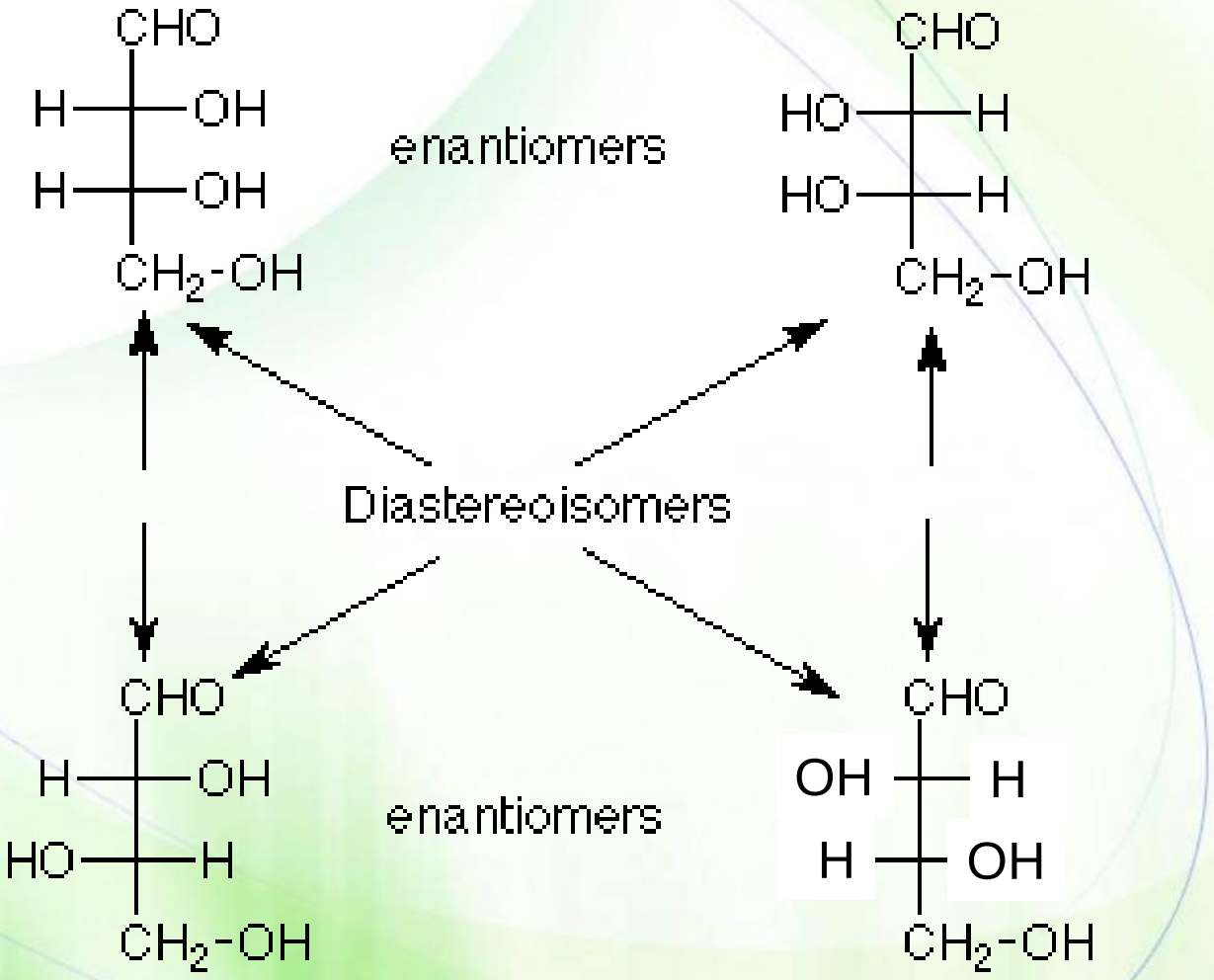


D-erythrose

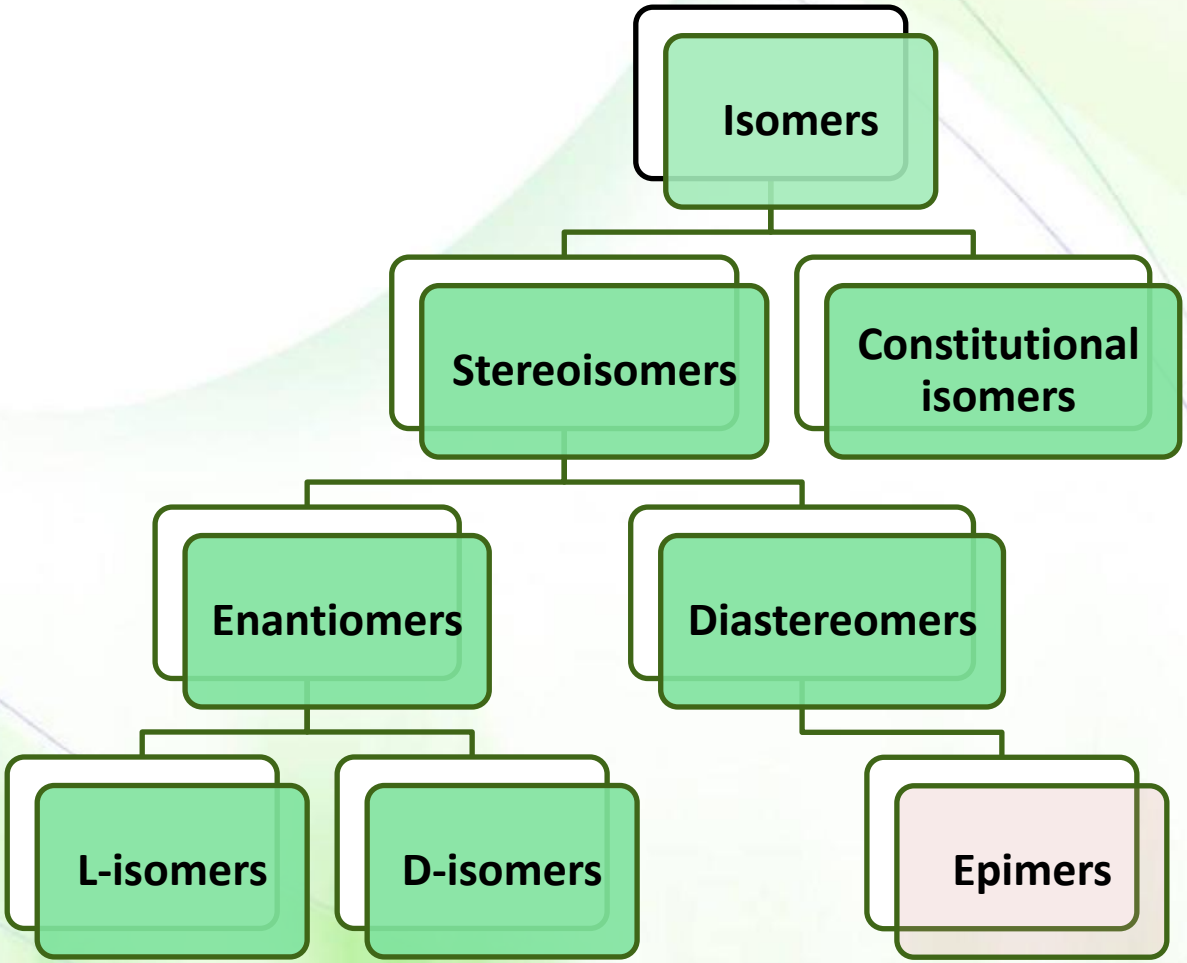
Isomerism


Isomers
Stereoisomers
Constitutional isomers
Enantiomers
Diastereomers
L-isomers
D-isomers
Epimers

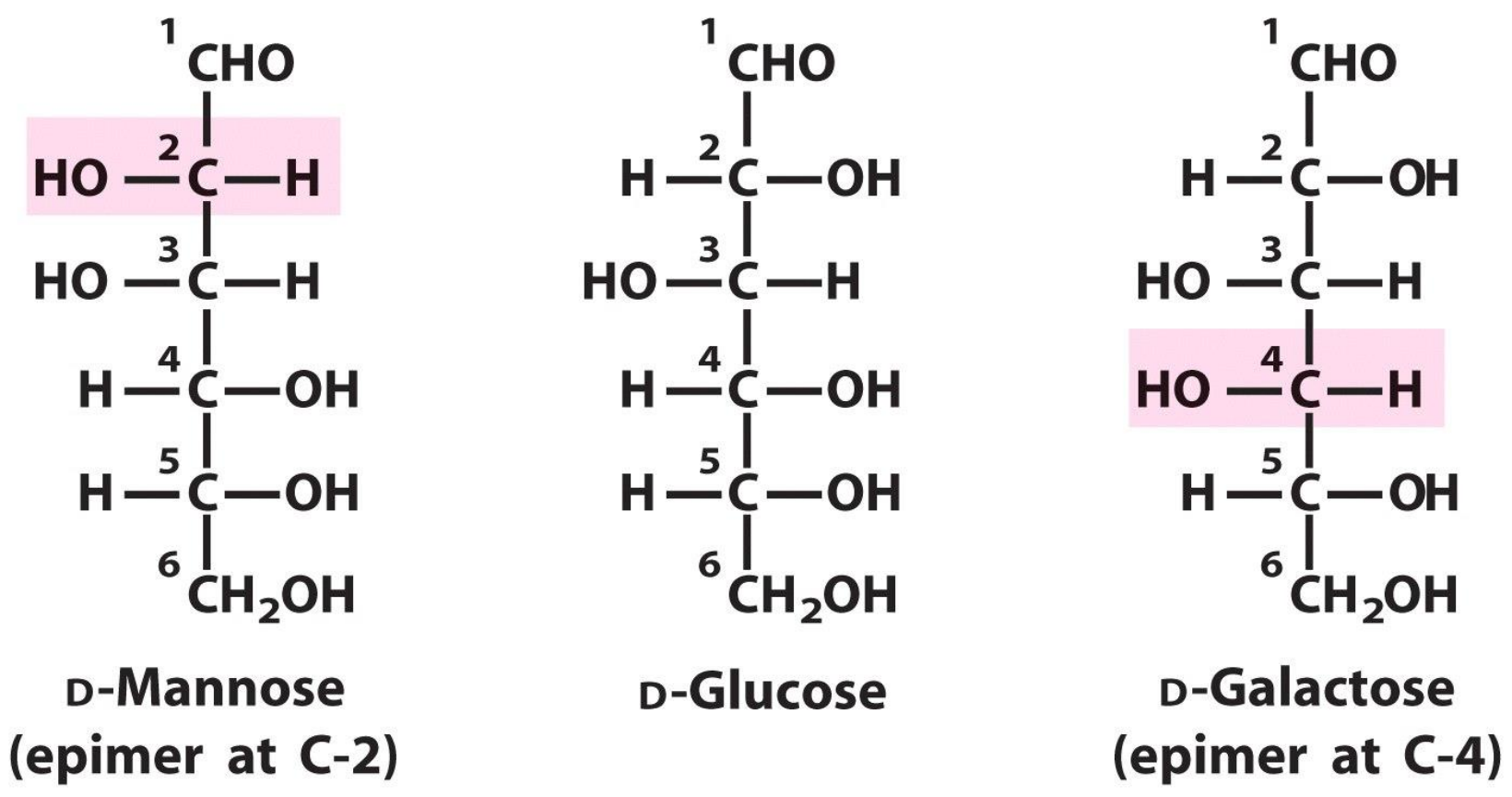
Stereoisomers, but non-mirror images and non-superimposable, then…*diastereomers*



Isomerism

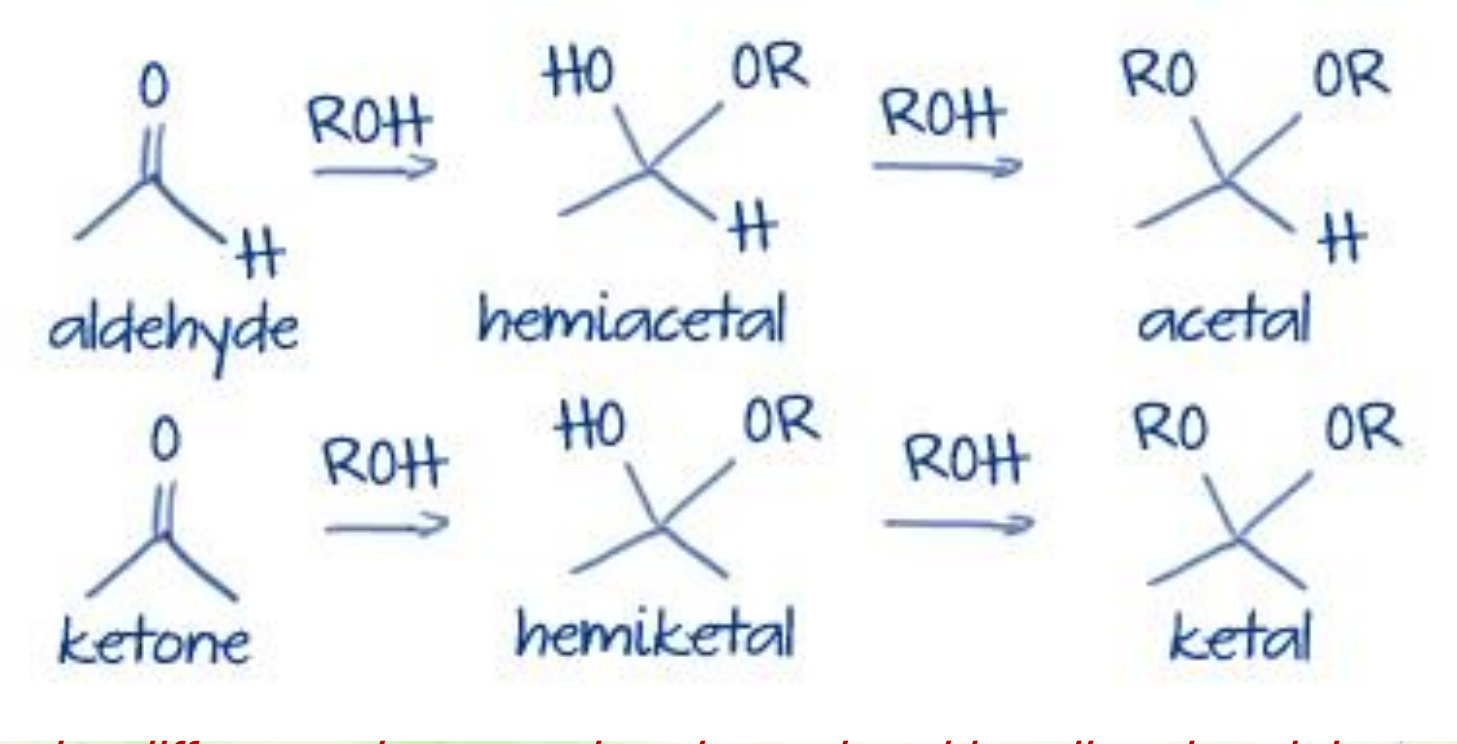

Isomers
Stereoisomers
Constitutional isomers
Enantiomers
Diastereomers
L-isomers
D-isomers
Epimers

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



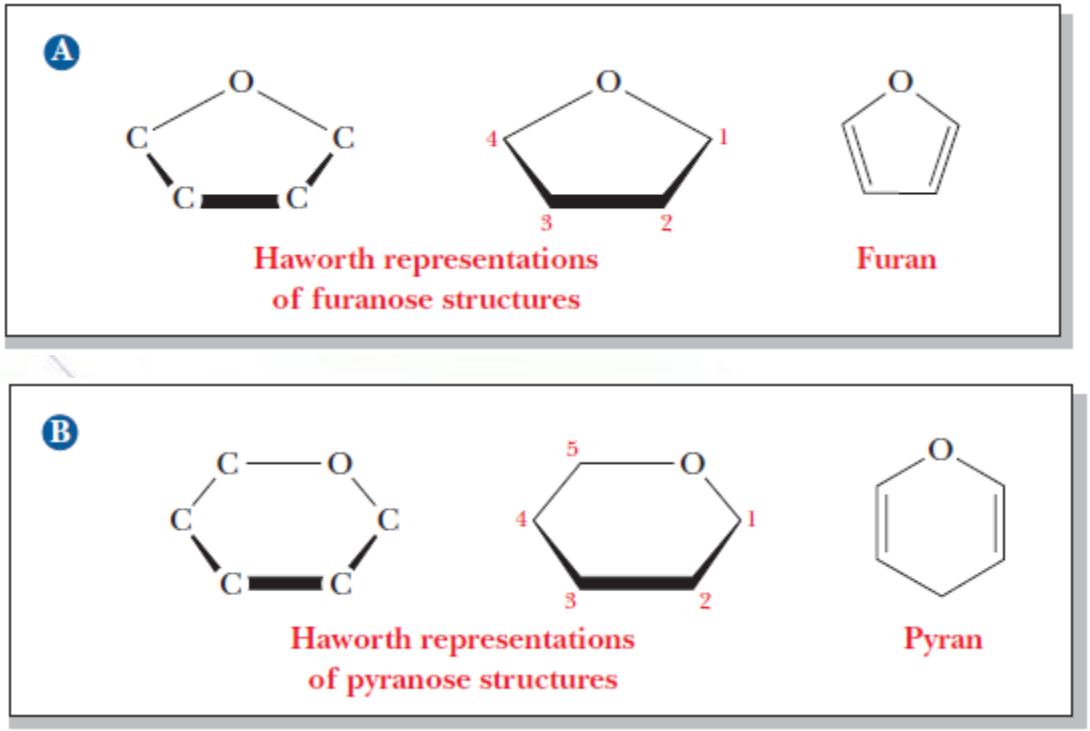
Acetal/ketal vs. hemiacetal/hemiketal

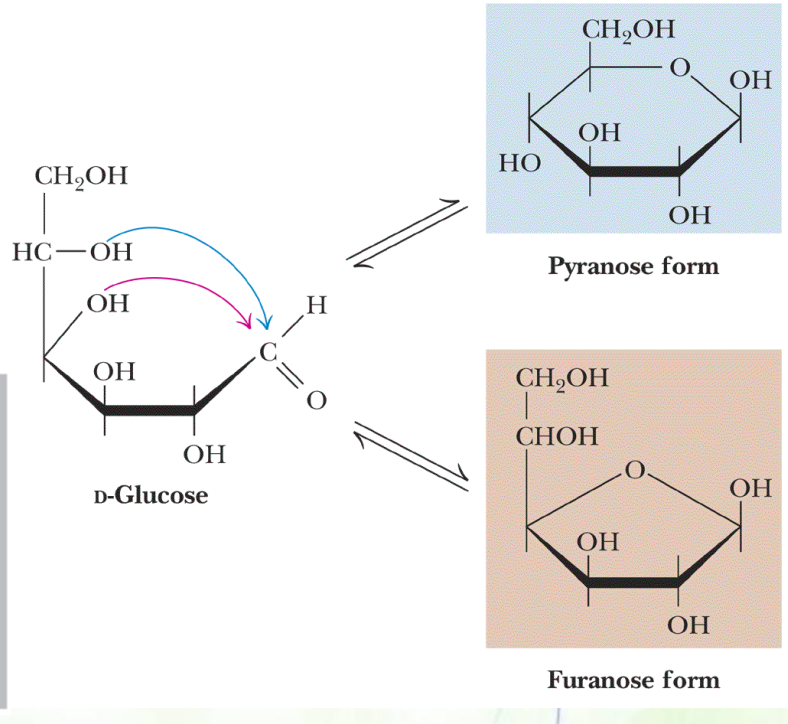
Hemiacetal and hemiketal: ether and alcohol on same carbon
Acetal and ketal: two ethers on same carbon



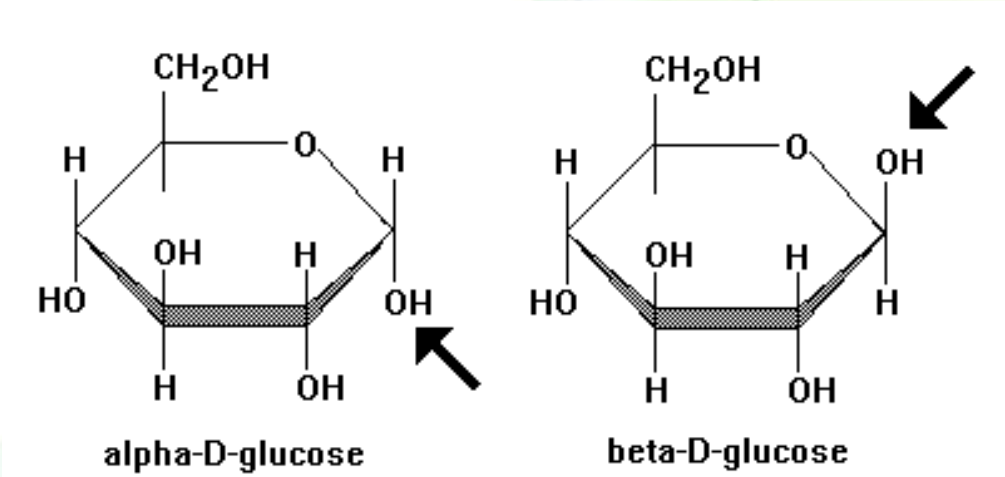
What is the difference between hemiacetal and hemiketal and the difference between acetal and ketal?

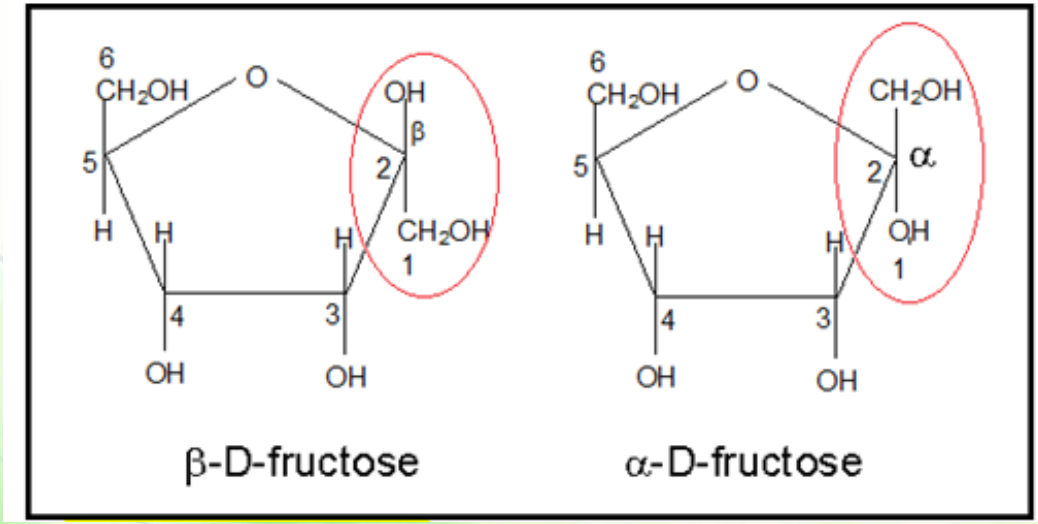
Formation of a ring structure



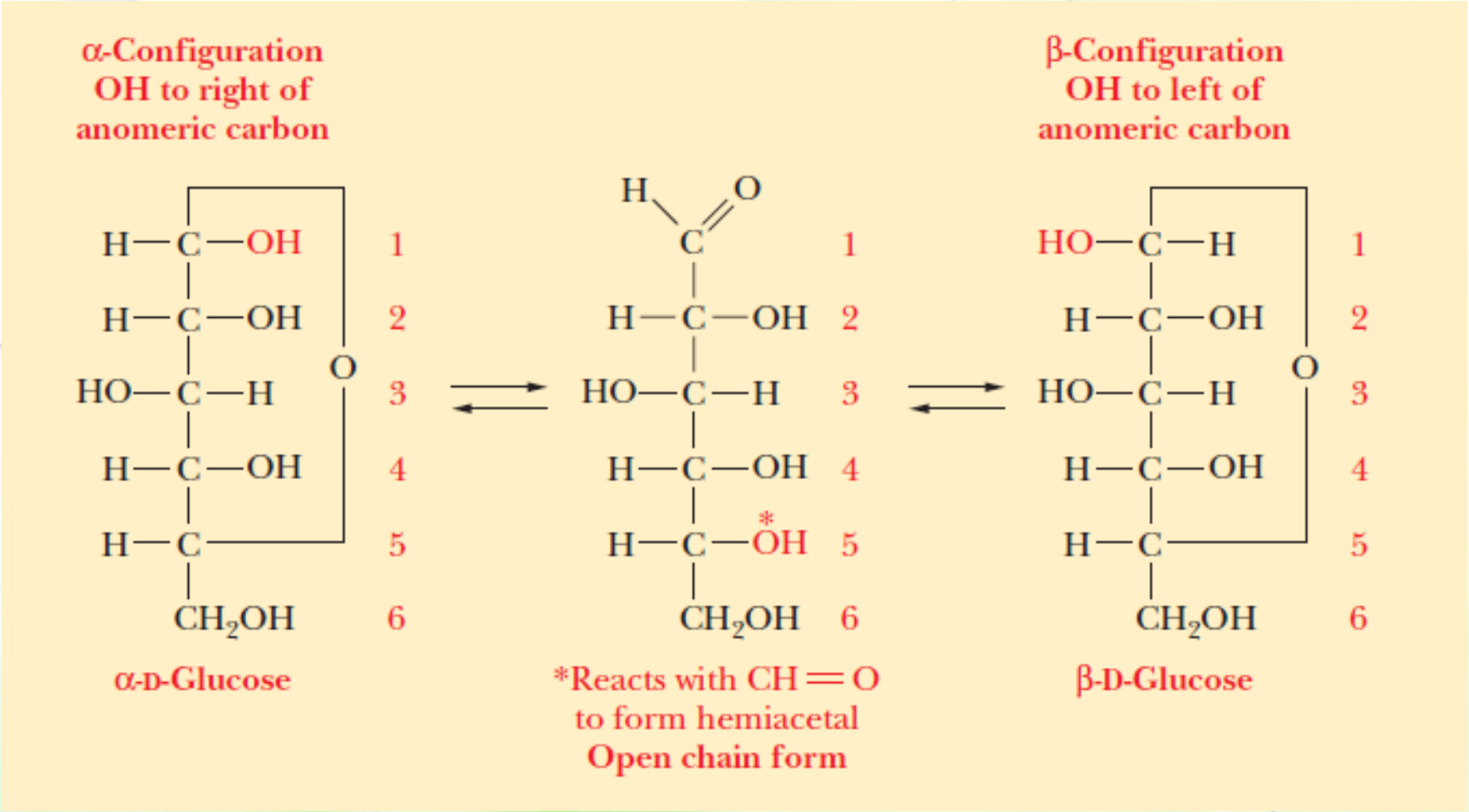


Anomers


CH2OH
O
H
OH
HO
alpha-D-glucose
beta-D-glucose

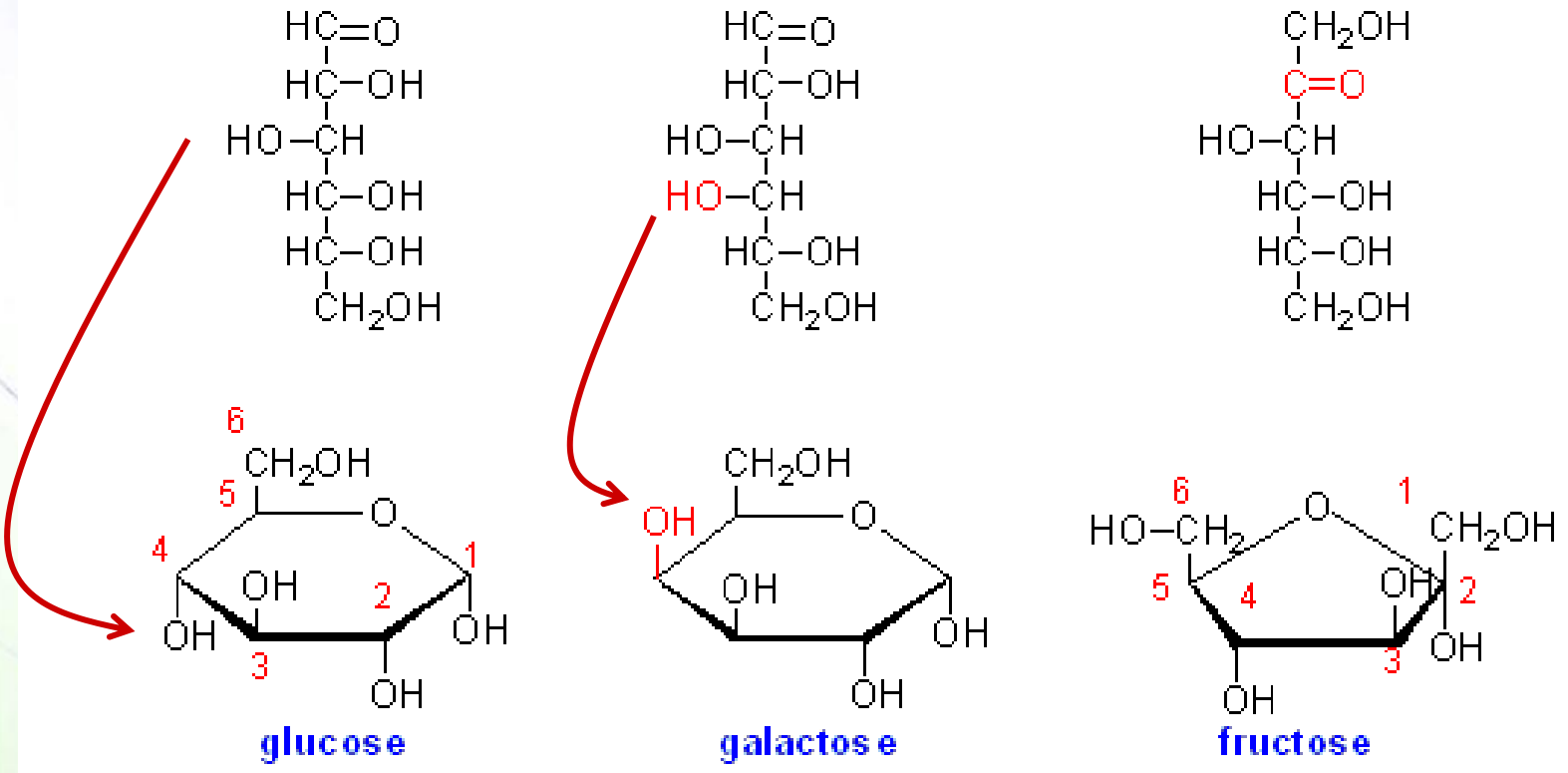

β-D-fructose
α-D-fructose

Anomers as Fischer projection



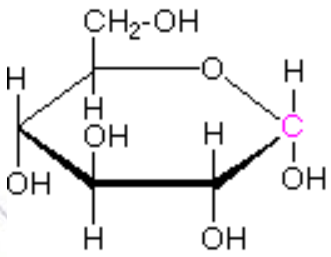
Chain to ring

Left-right vs. up-down

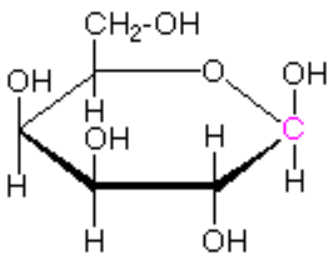


Cyclic aldohexoses

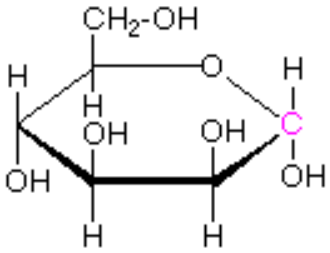
Examples of Some Pyranose Forms of Hexoses



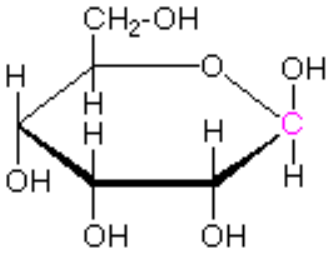
α-D-glucopyranose



β-D-galactopyranose

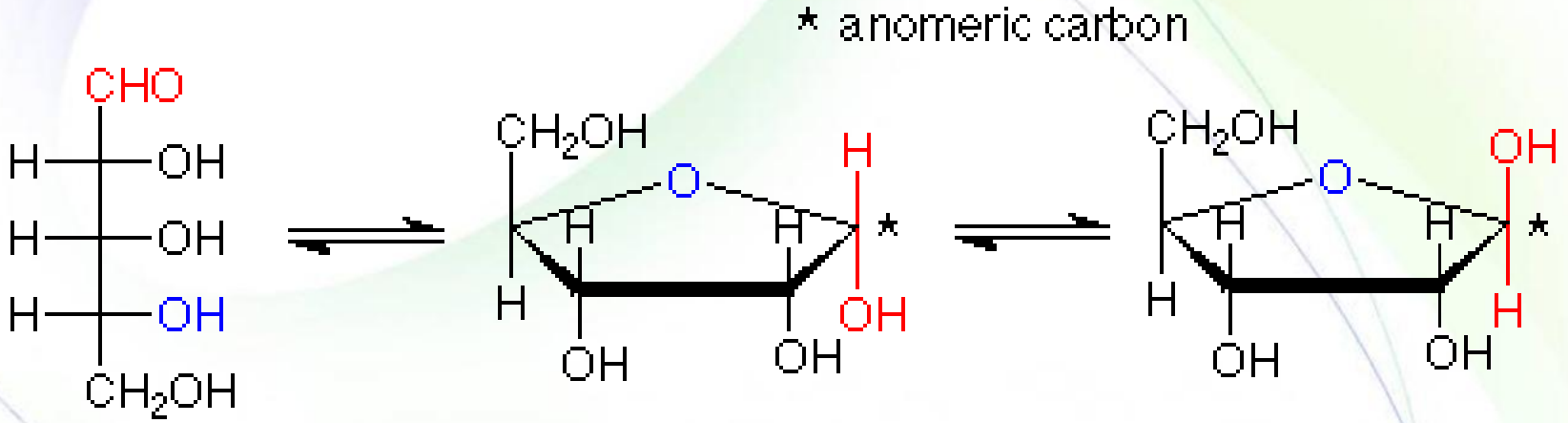


α-D-mannopyranose



β-D-allopyranose

Cyclic ribofuranose



D-ribose

α-D-ribose

OH at anomeric carbon down

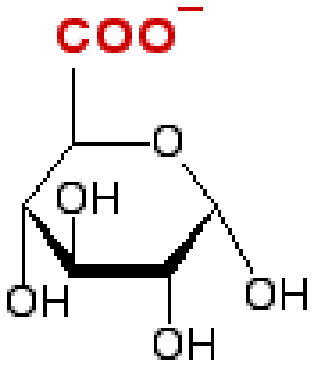
β-D-ribose

OH at anomeric carbon up

Modified sugars

Sugar acids (oxidation)

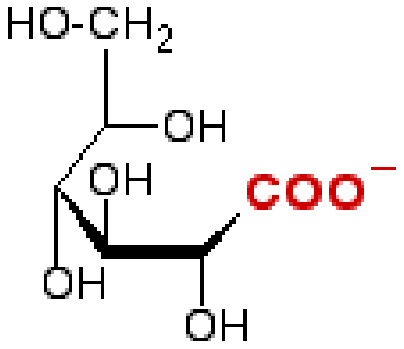
- Where is it oxidized? What does it form?



α-D-glucuronate

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

from **oxidation of glucose C6 OH**



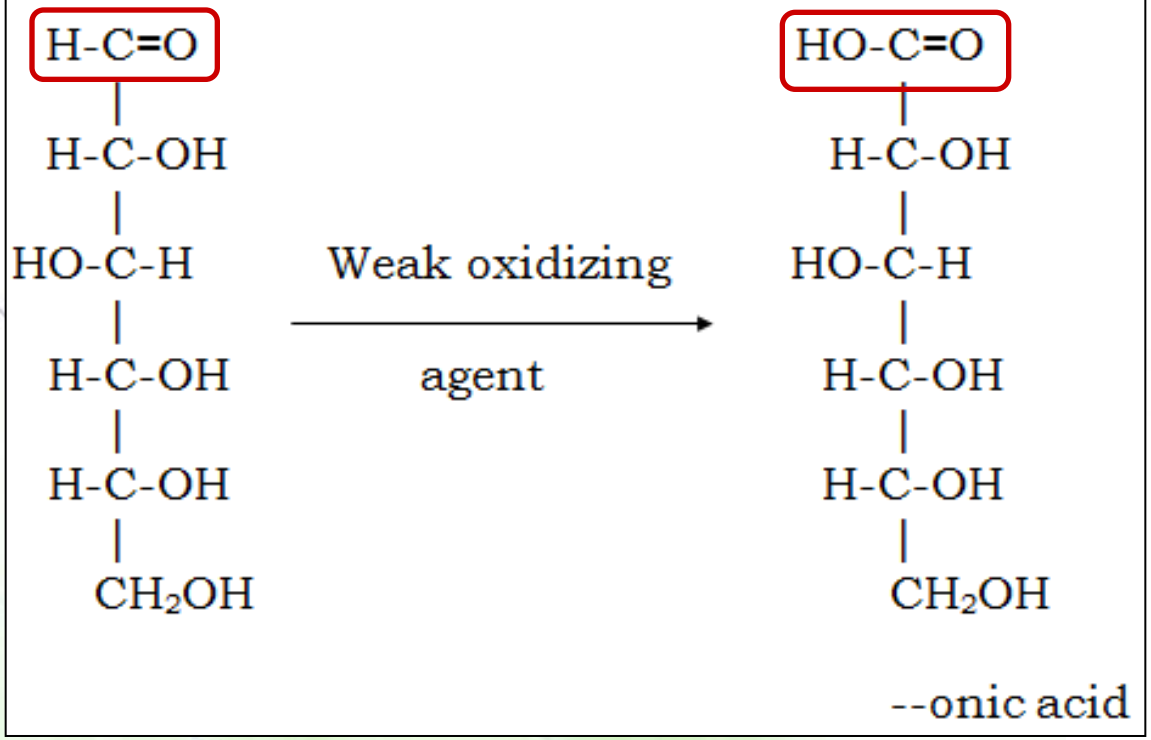
D-gluconate

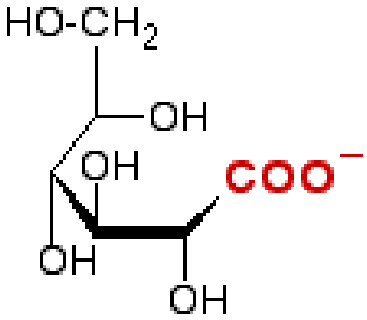
(D-gluconic acid, **GlcA**)

from **oxidation of glucose C1 aldehyde)**

Example 1

a. Weak oxidizing agent





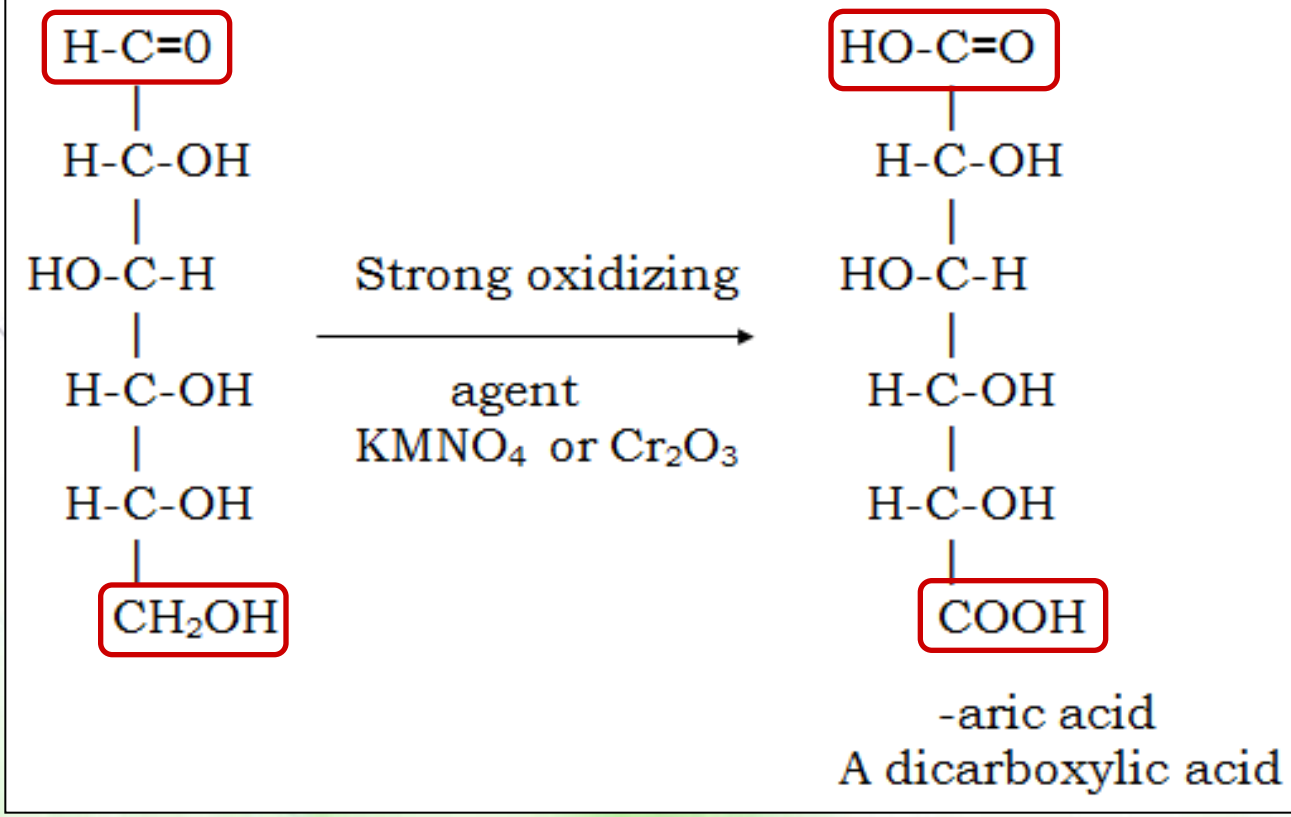
D-gluconate

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

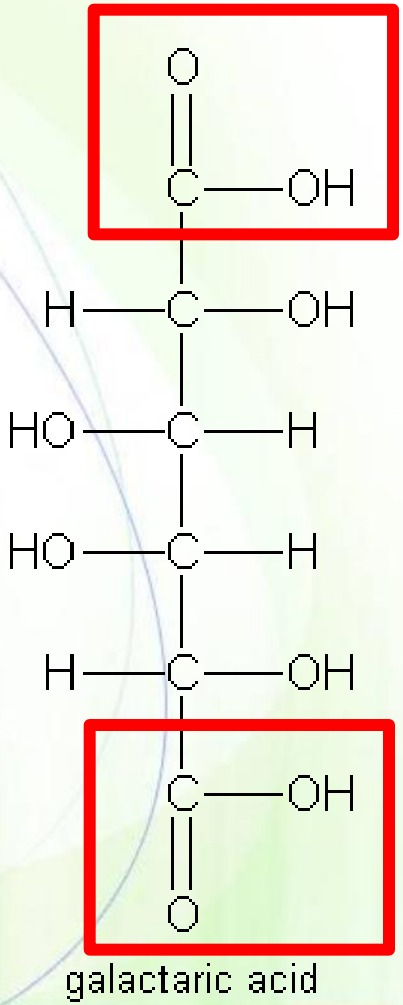
from **oxidation of glucose C1 aldehyde)**

Example 2

b. Strong oxidizing agents



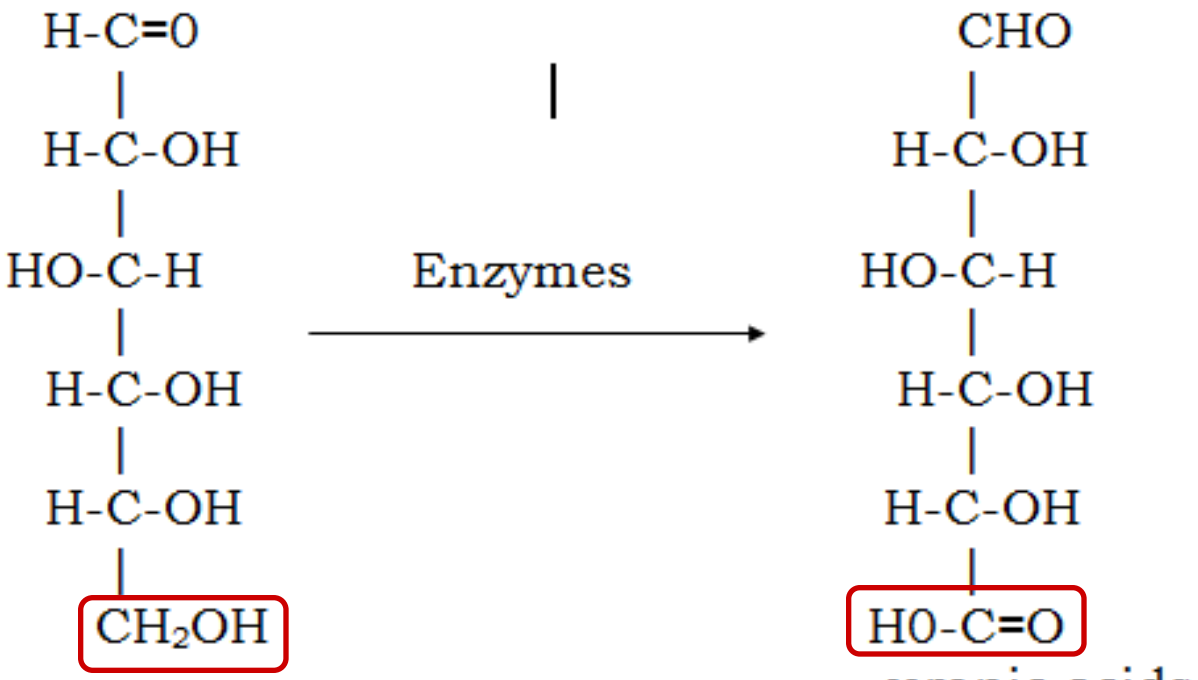
-aric acid
A dicarboxylic acid

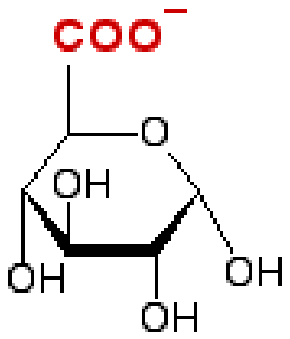


galactaric acid

Example 3

c. Oxidation of primary alcohol end in biological systems





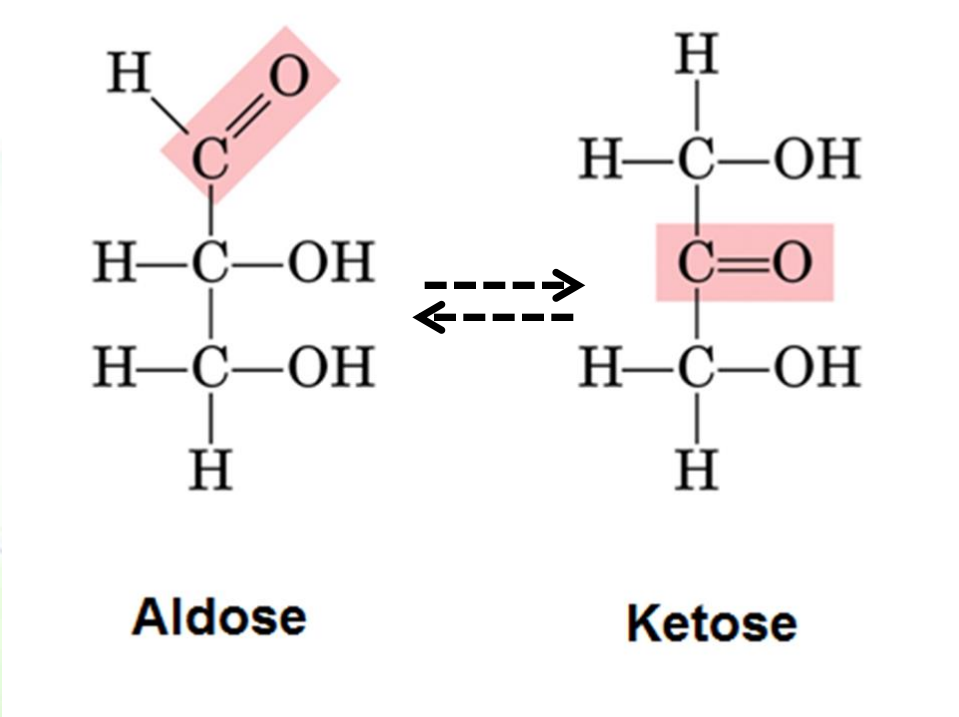
α-D-glucuronate

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

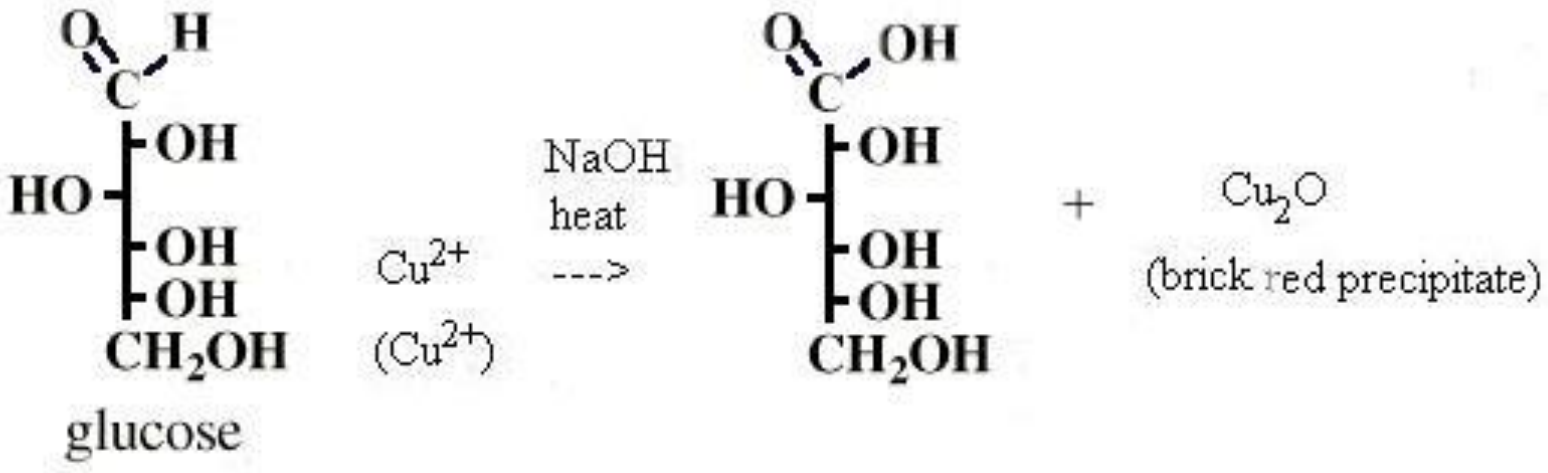
from **oxidation of glucose C6 OH**

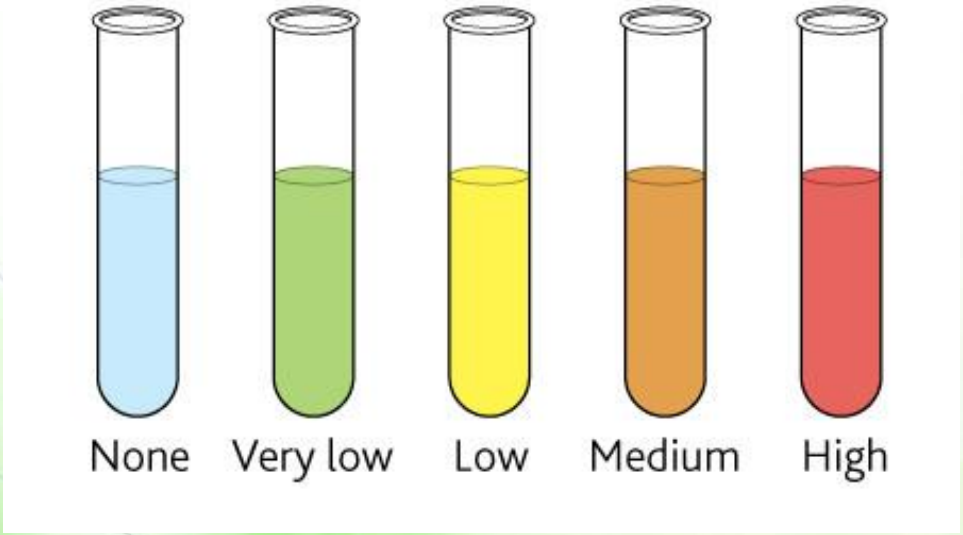
Note

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

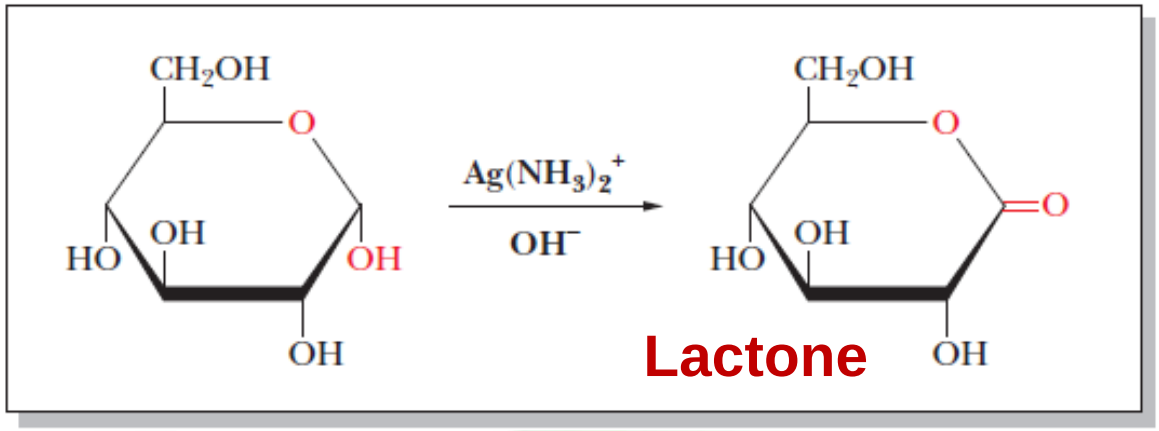


Benedict's test





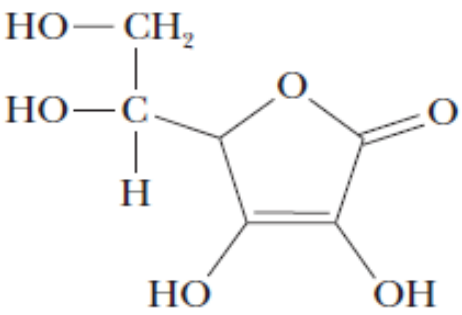
Oxidation of cyclic sugars (lactone)



Tollen's test

detection of glucose, but not other reducing sugars, is based on the use of the enzyme glucose oxidase

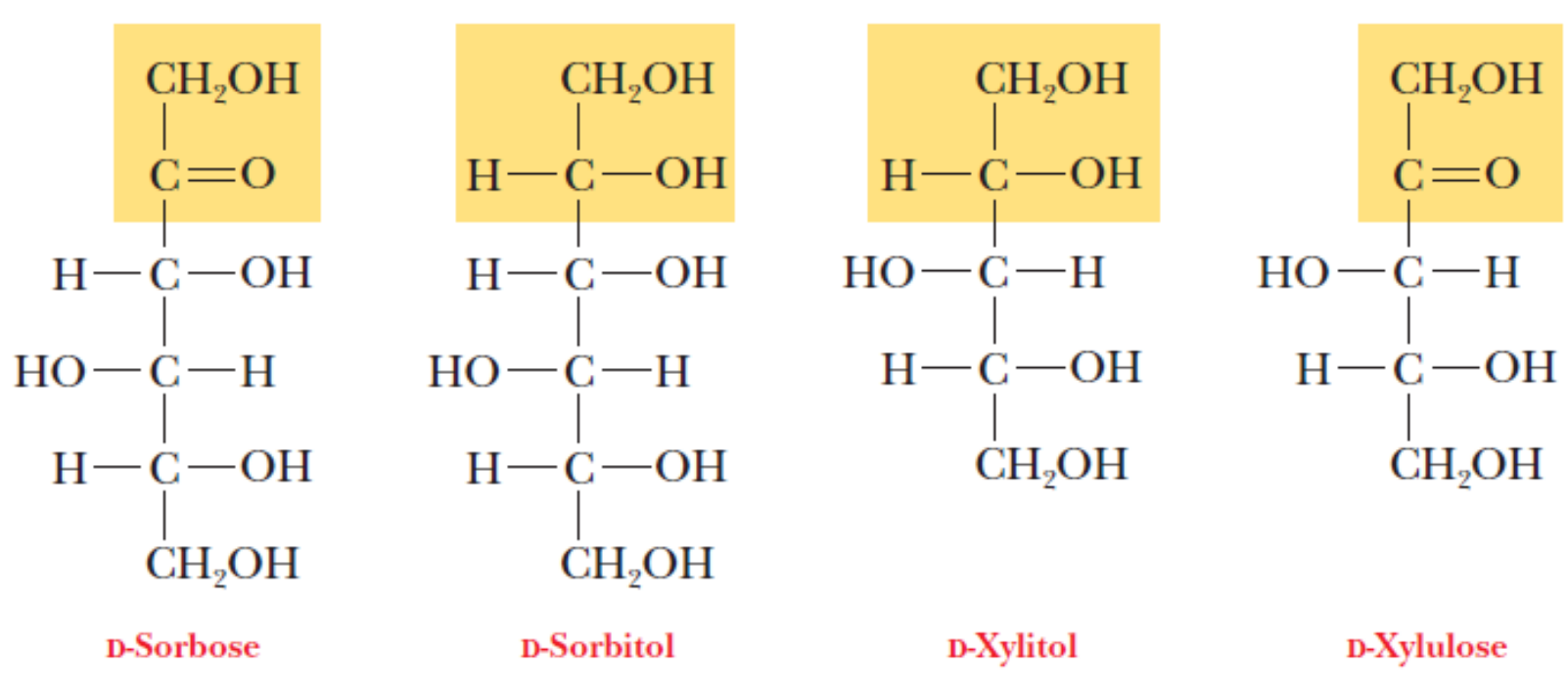
- **Vitamin C (ascorbic acid) is an unsaturated lactone.**
- **Air oxidation of ascorbic acid, followed by hydrolysis of the ester bond, leads to loss of activity as a vitamin.**
- **a lack of fresh food can cause vitamin C defi ciencies, which, in turn, can lead to the disease scurvy.**



Ascorbic acid
(Vitamin C)

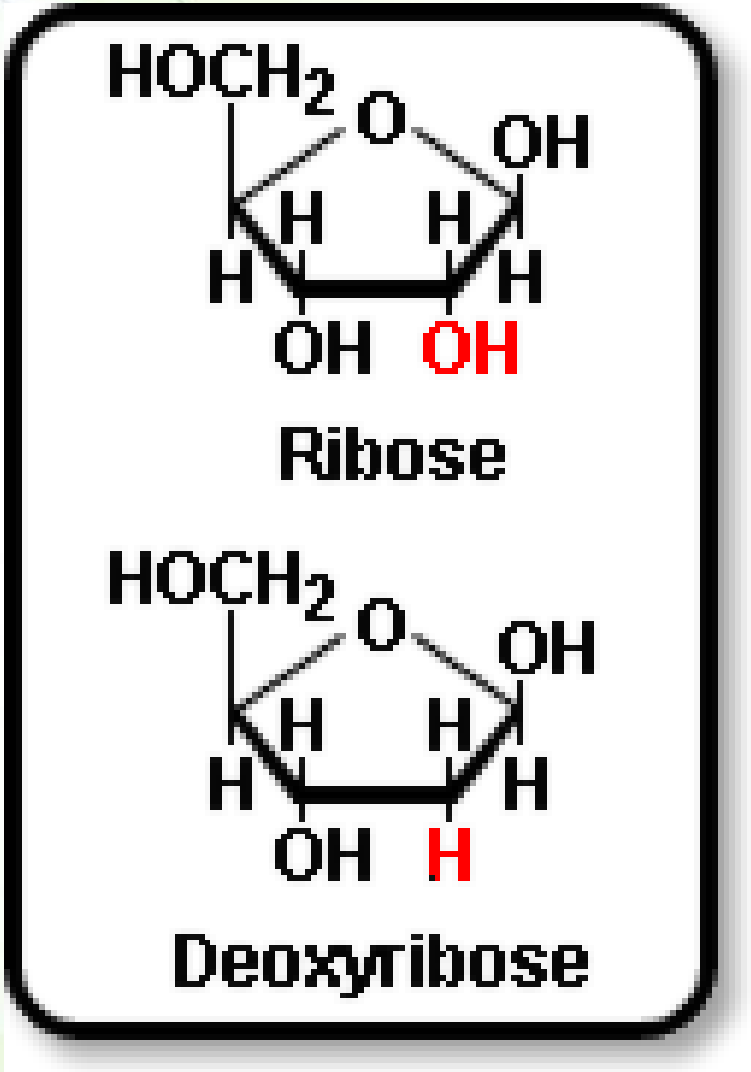
Sugar alcohols (reduction)

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



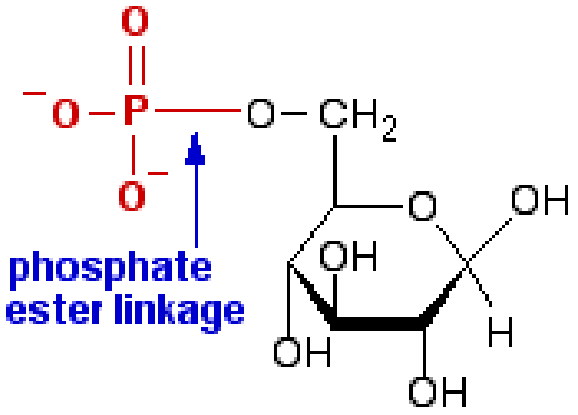
Deoxy sugars (reduced sugars)

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

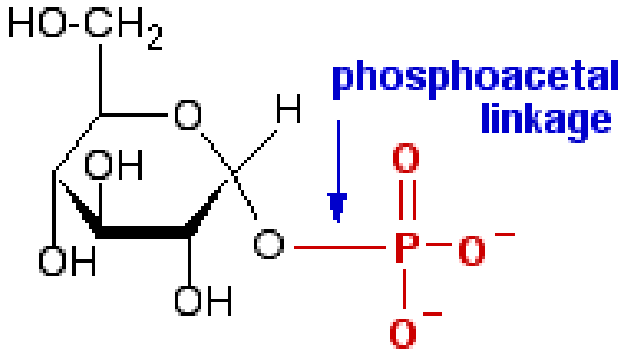


Sugar esters (esterification)

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



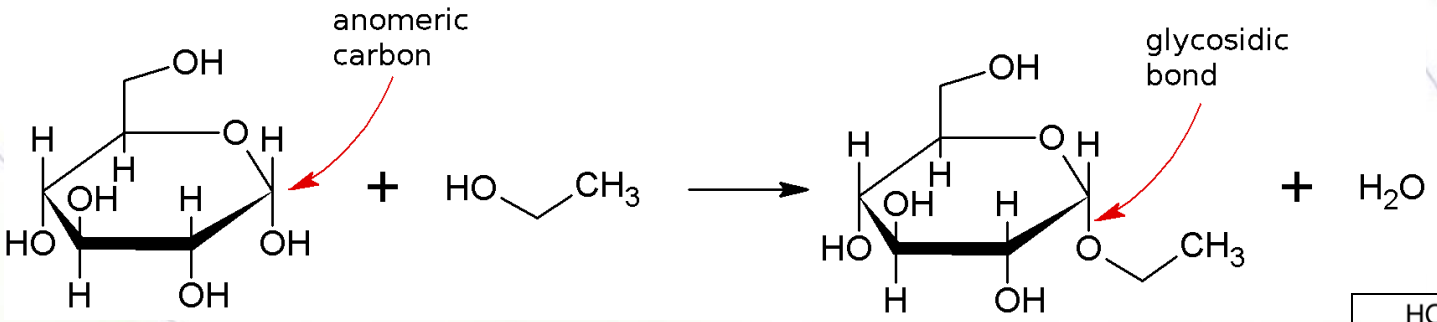
β-D-glucose-6-phosphate
(an ordinary **phosphate ester**)

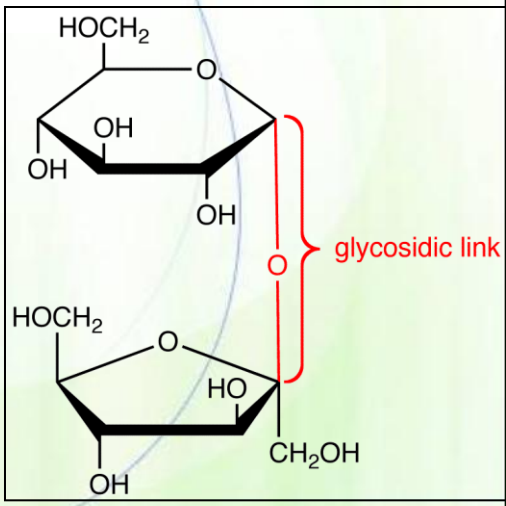


α-D-glucose-1-phosphate
(a **phosphoacetal**)

O-Glycosides

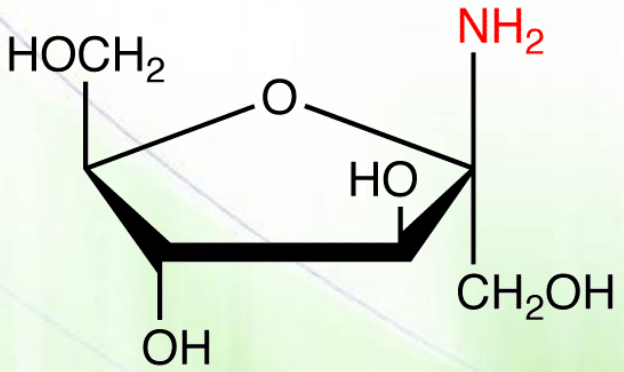
- What is the reacting functional group? Where does it react? What are the end products? Where are they used?



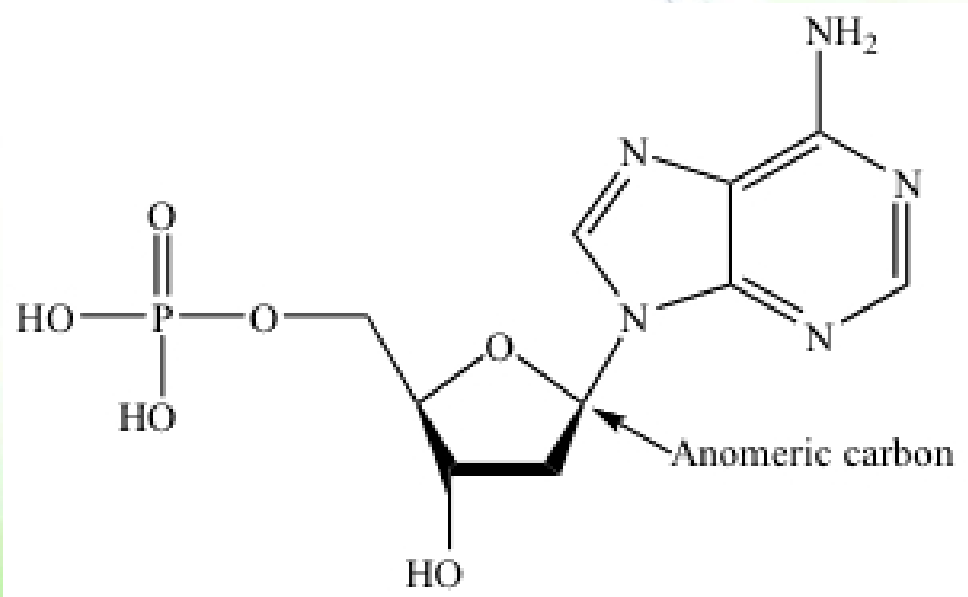


N-glycosides

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

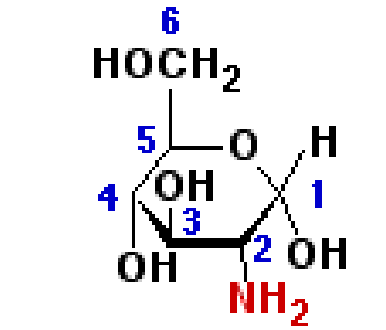


N-glycoside

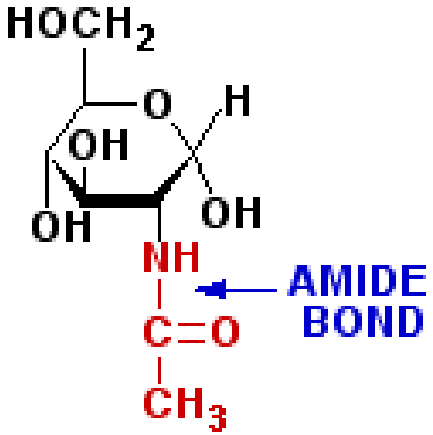


Amino sugars

- 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)

Disaccharides

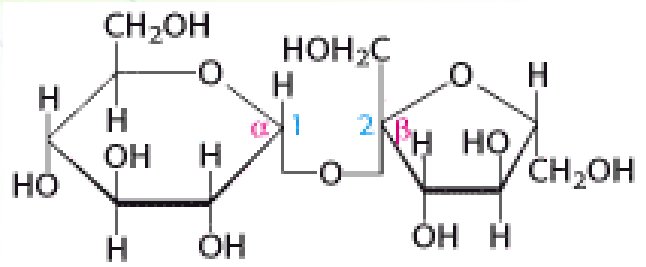
- What are disaccharide? Oligosaccharides? Hetero- vs. homo-?
- What is the type of reaction?
- What is a residue?
- Synthesizing enzymes are glycosyltransferases
- Do they undergo mutarotation?
- Are products stable?

Distinctions of disaccharides

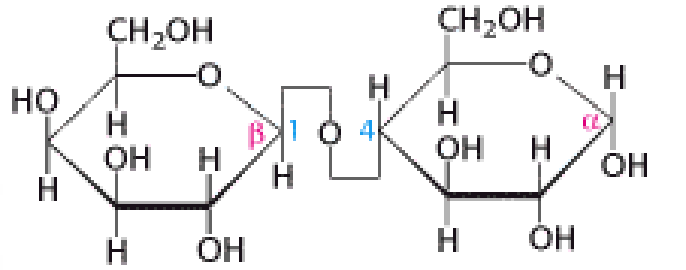
- The 2 specific sugar monomers involved and their stereoconfigurations (D- or L-)
- The carbons involved in the linkage (C-1, C-2, C-4, or C-6)
- The order of the two monomer units, if different (example: galactose followed by glucose)
- The anomeric configuration of the OH group on carbon 1 of each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

Abundant disaccharides

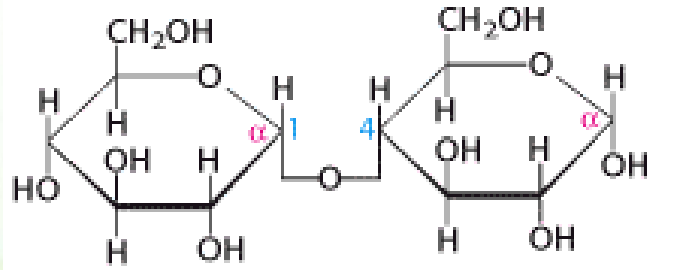
- Configuration
- Designation
- Naming (common vs. systematic)
- Reducing vs. non-reducing



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

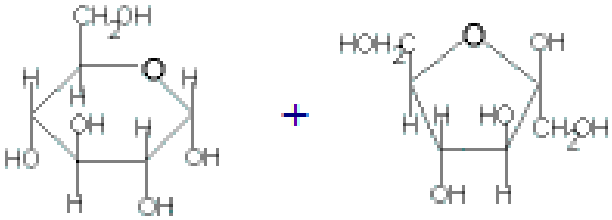


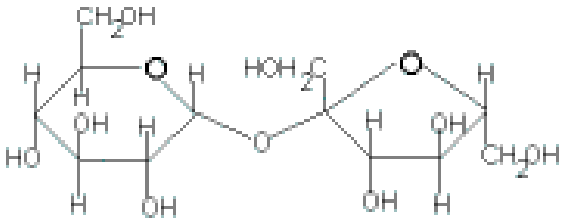
Lactose
(β-D-Galactopyranosyl-(1→4)-α-D-glucopyranose

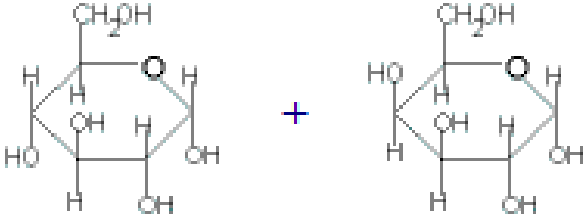


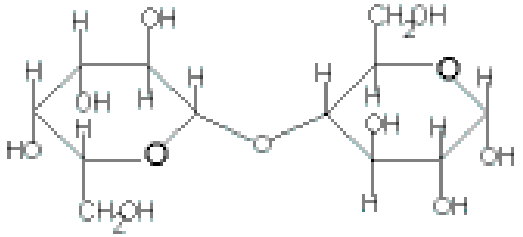
Maltose
(α-D-Glucopyranosyl-(1→4)-α-D-glucopyranose

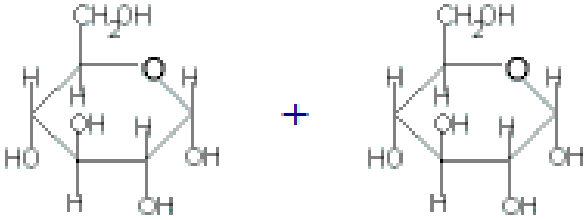
Name	Formula	Formed from	Structure
sucrose	$C_{12}H_{22}O_{11}$	glucose + fructose	---> sucrose + H_2O
lactose	$C_{12}H_{22}O_{11}$	glucose + galactose	---> lactose + H_2O
maltose	$C_{12}H_{22}O_{11}$	glucose + glucose	---> maltose + H_2O

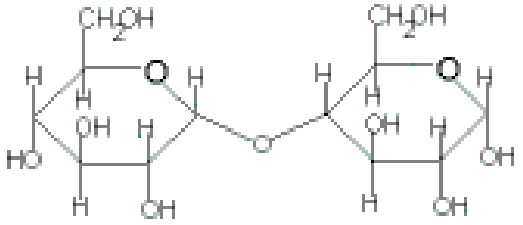




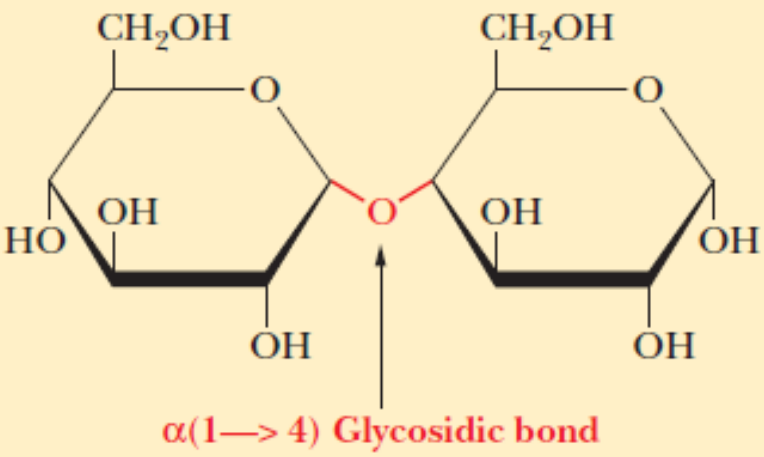




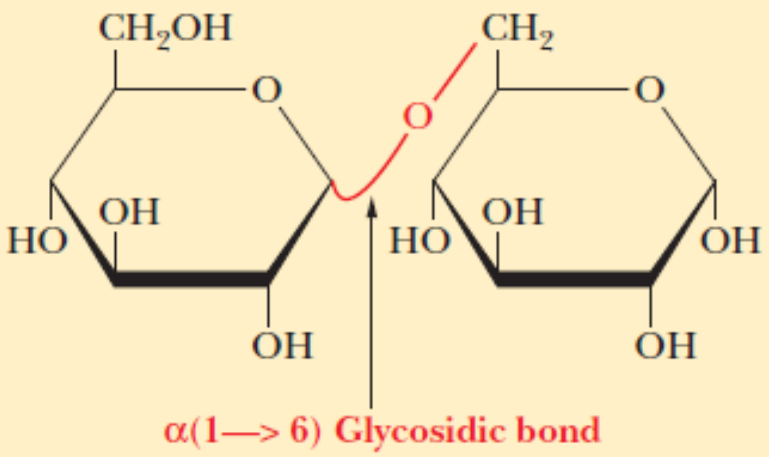




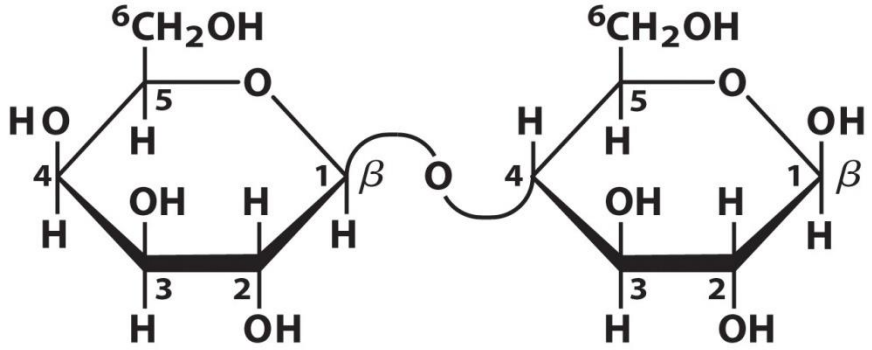
Different forms of disaccharides



α(1—> 4) Glycosidic bond

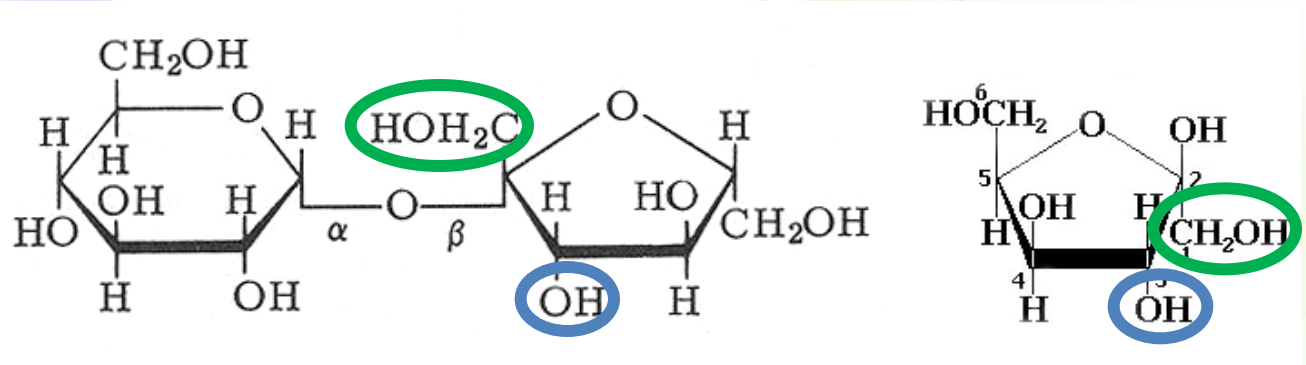


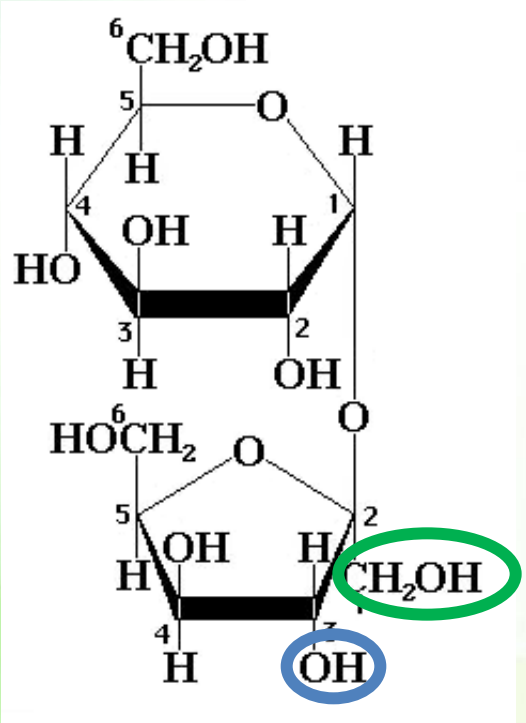
α(1—> 6) Glycosidic bond



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

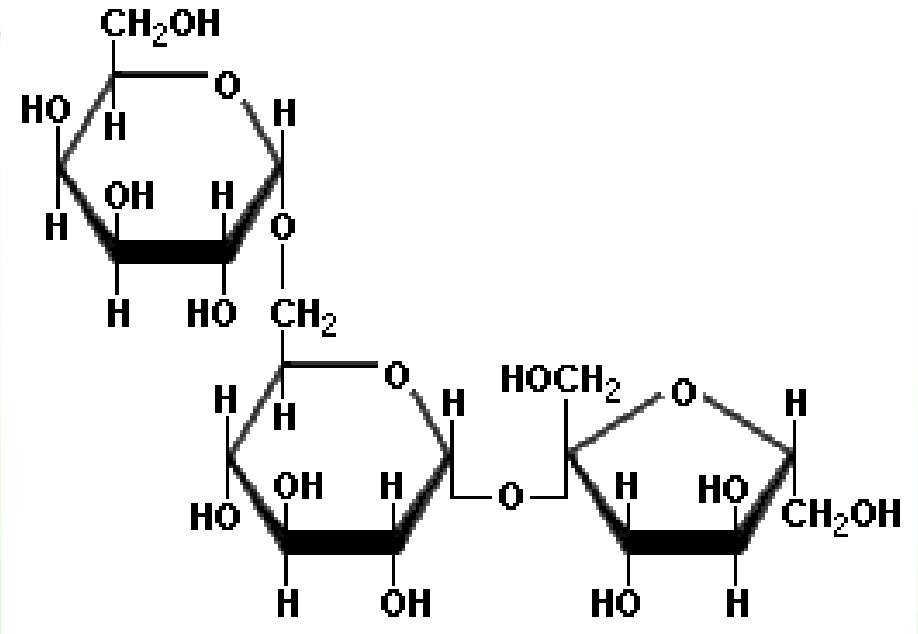
Sucrose


CH2OH
HOH2C
HO
OH
α
β
CH2OH
HO6CH2
OH
CH2OH


6CH2OH
HO
OH
HO6CH2
OH
CH2OH

Raffinose

- What are oligosaccharide?
- Example: raffinose
- It is found in peas and beans

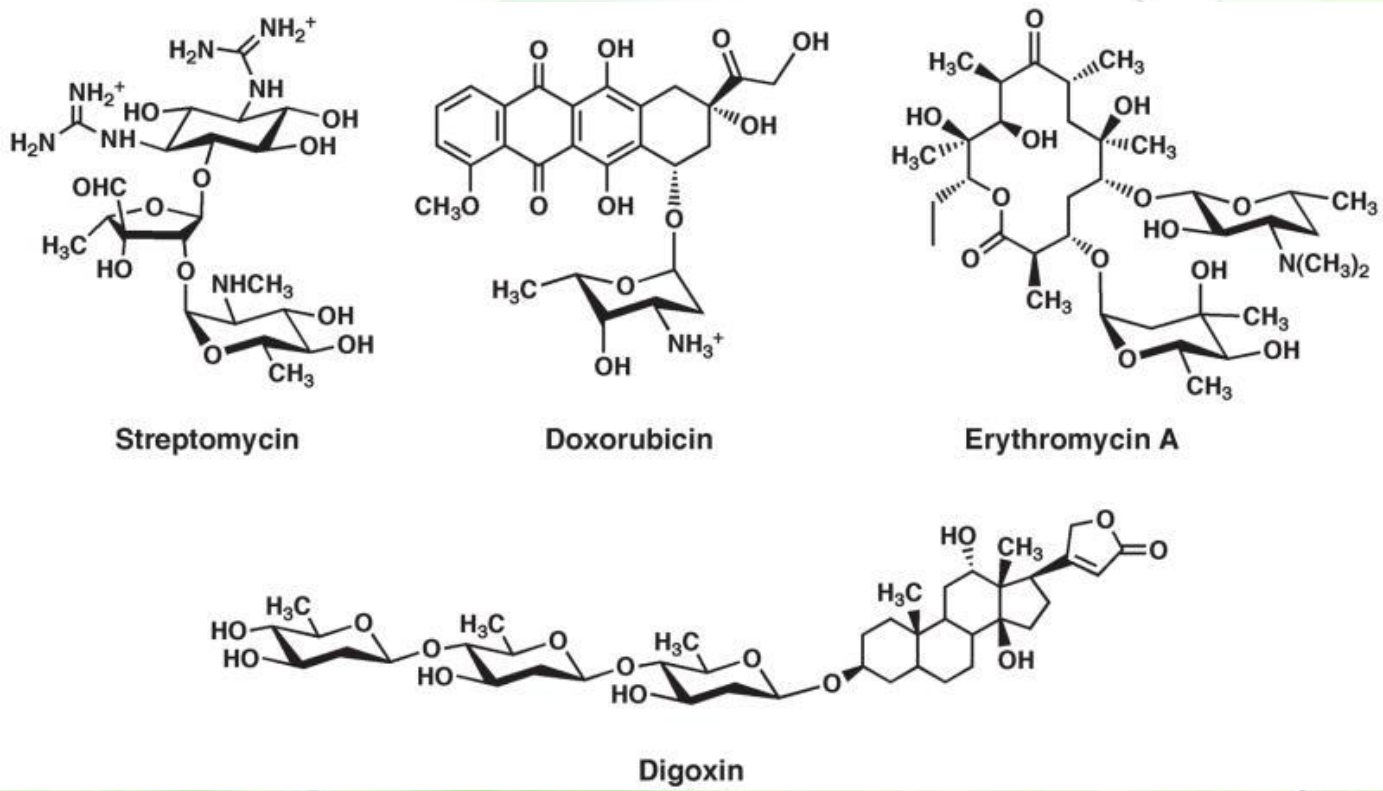


Homework

1. What are the names of 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)



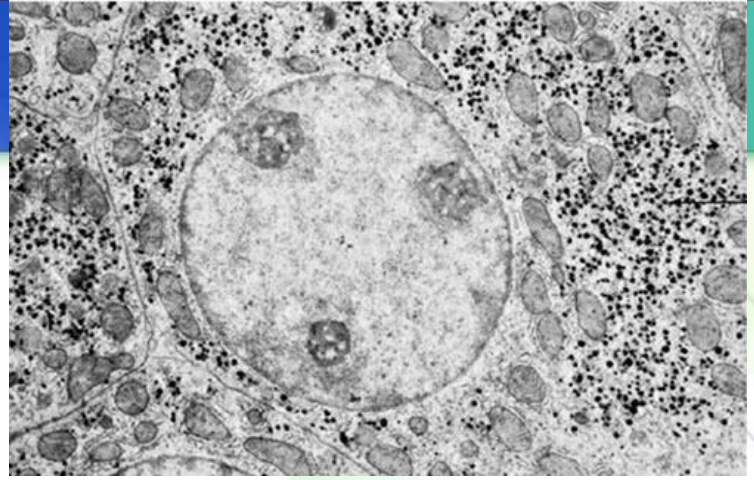
Polysaccharides

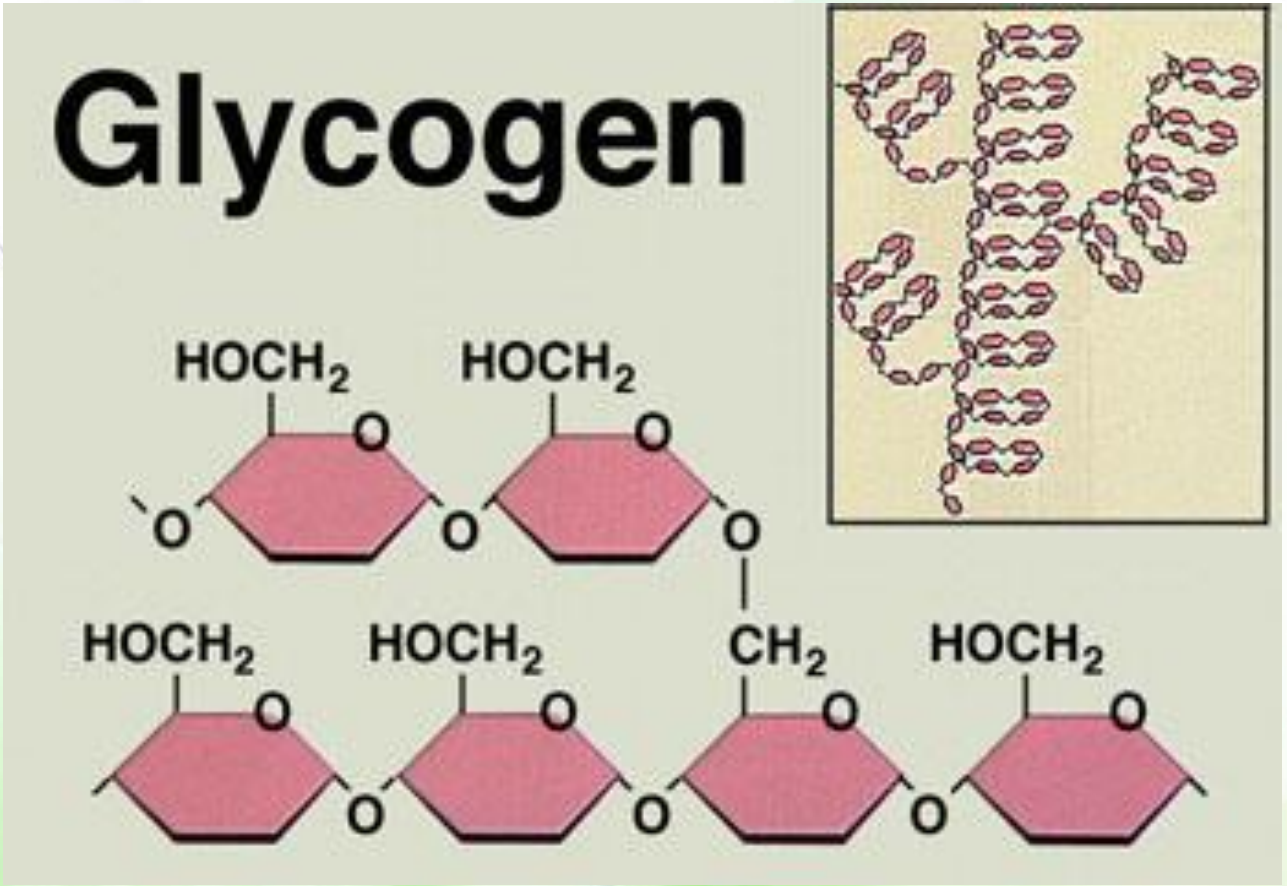
- What are polysaccharides?
- Homopolysaccharide (homoglycan) vs. heteropolysaccharides

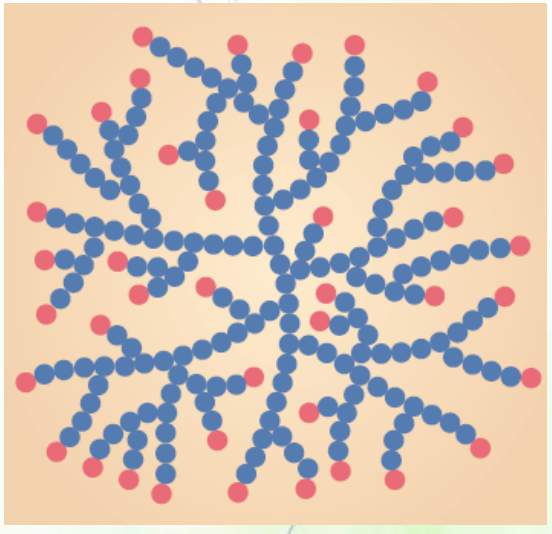
Features of polysaccharides

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

Glycogen

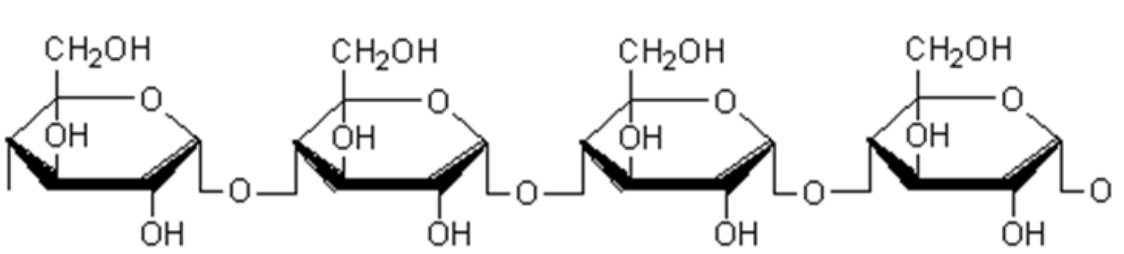




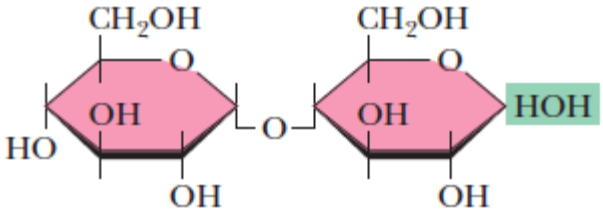


Starch

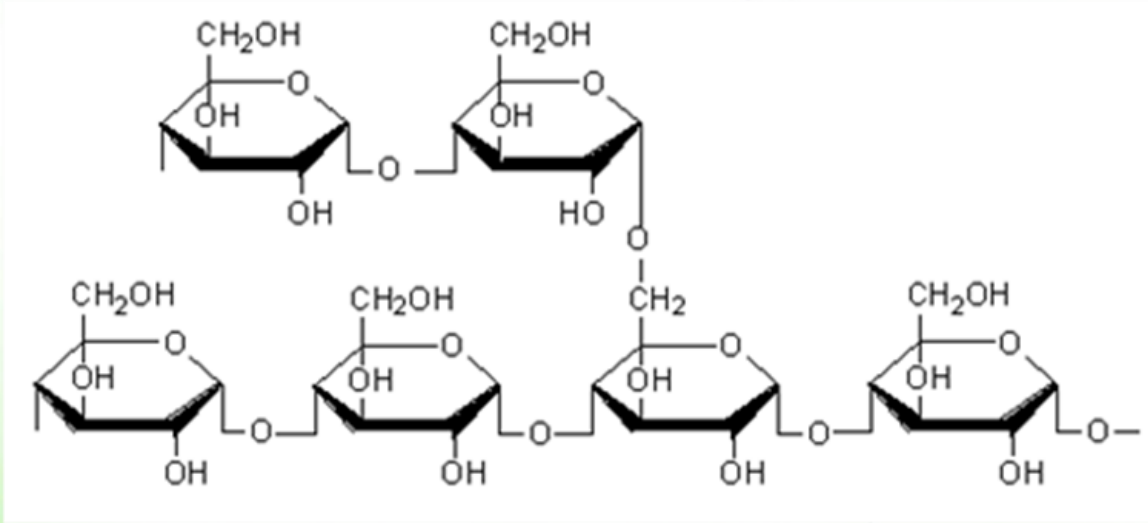
- Which organisms?
- Forms:
  - amylose (10-20%)
  - amylopectin (80-90%)



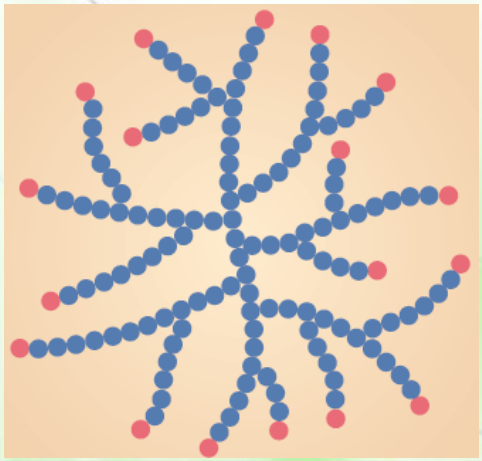
Amylose Structure



Maltose (glucose-α-1,4-glucose)

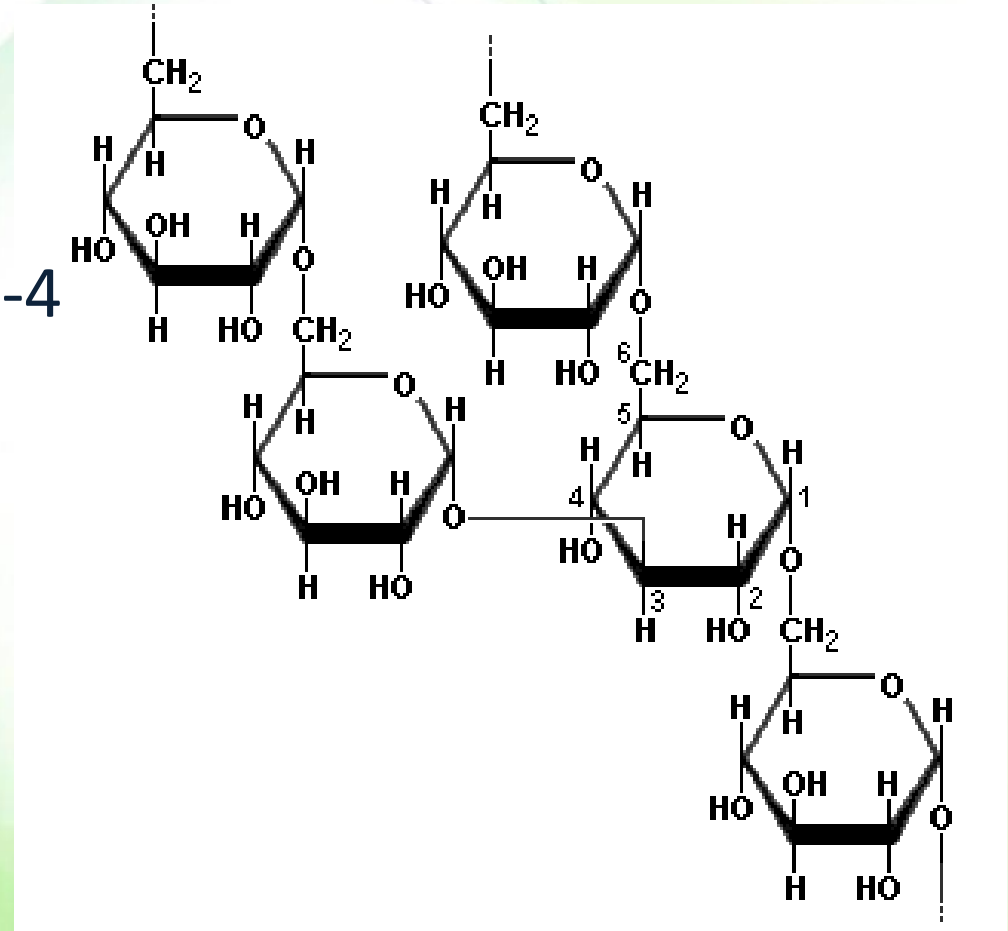


Amylopection Structure

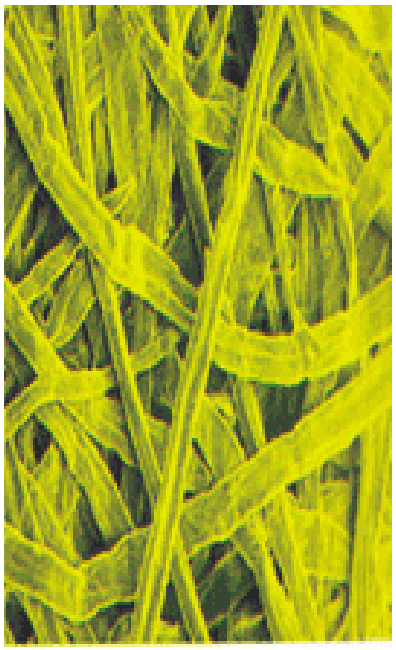


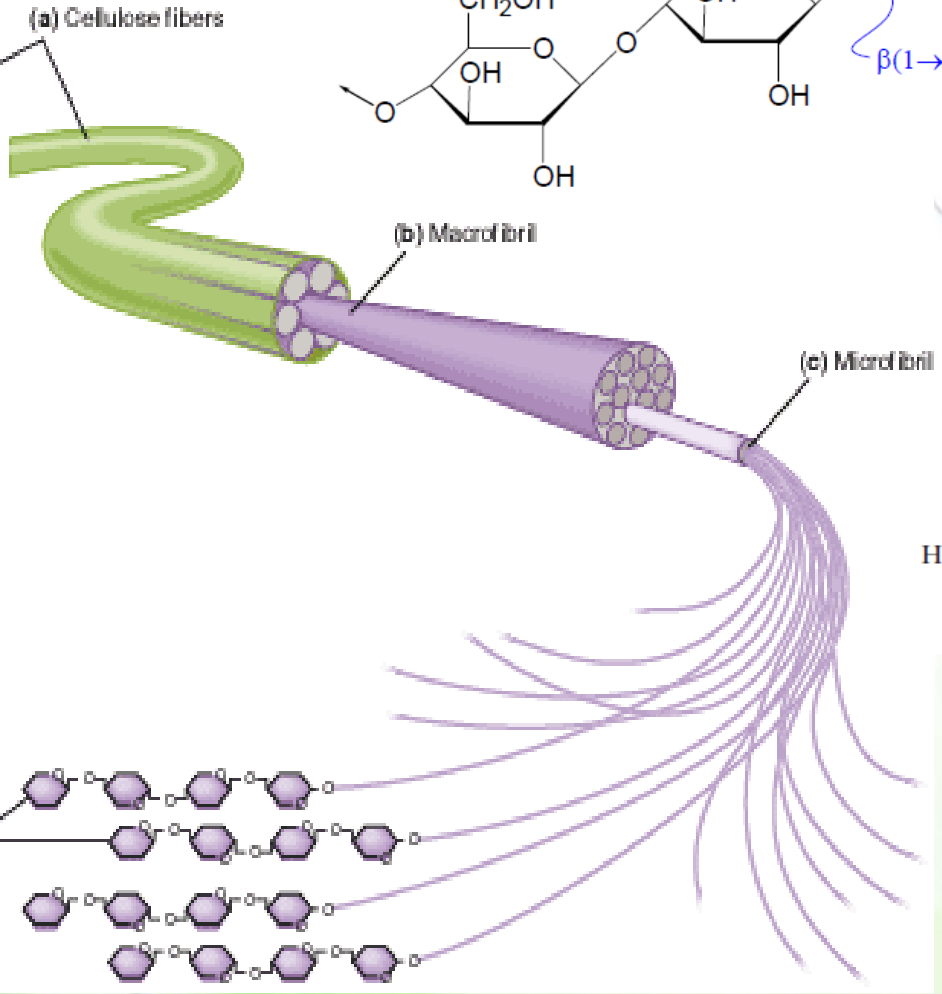
Dextran

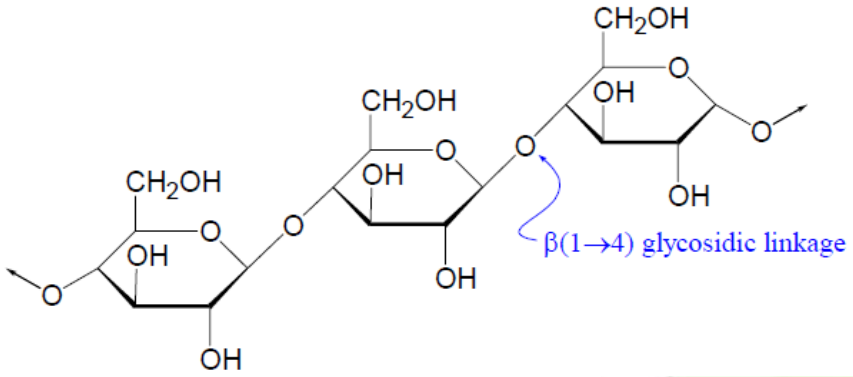
- A storage polysaccharide
- Yeast and bacteria
- α-(1-6)-D-glucose with branched chains
- Branches: 1-2, 1-3, or 1-4

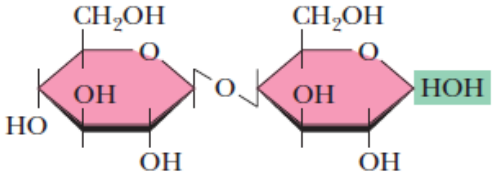


Cellulose





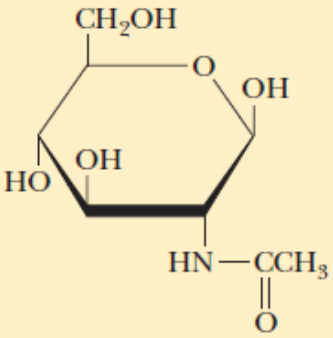




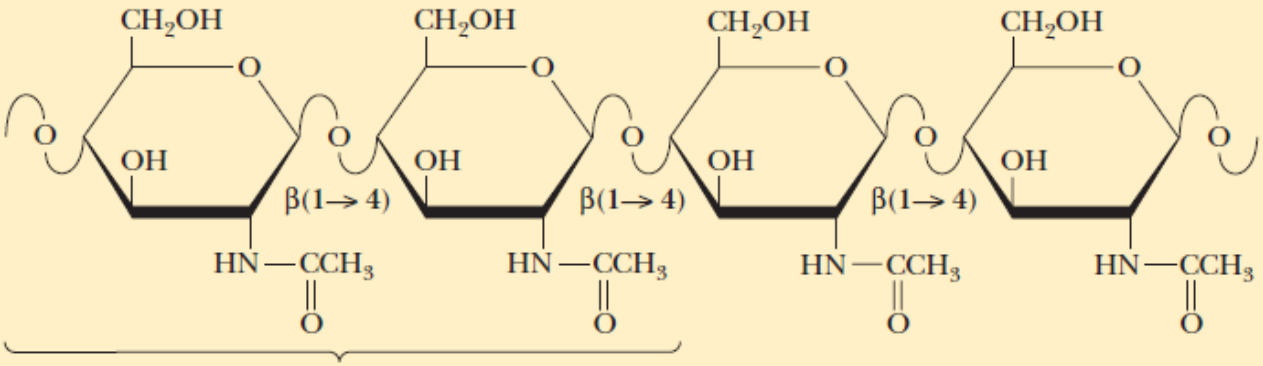
Cellobiose (glucose-β-1,4-glucose)

Chitin

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



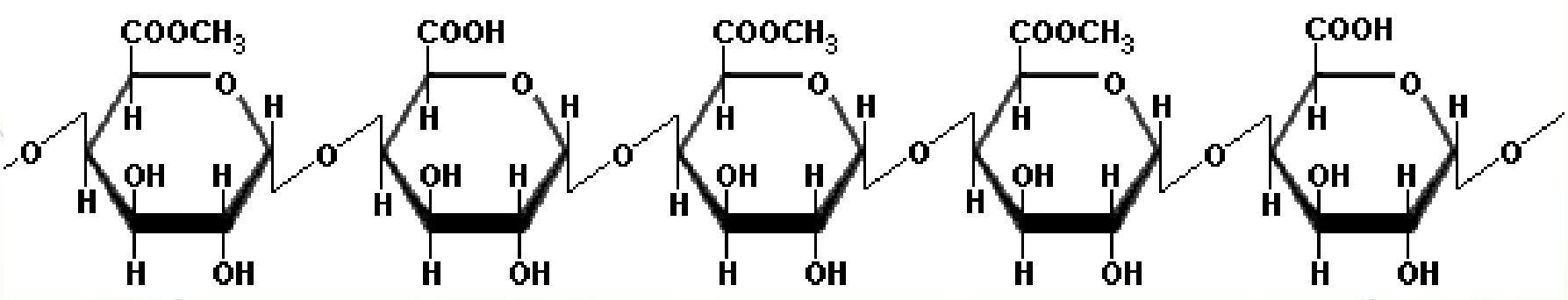
N-Acetyl-β-D-glucosamine



Repeating disaccharide in chitin

Pectin

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

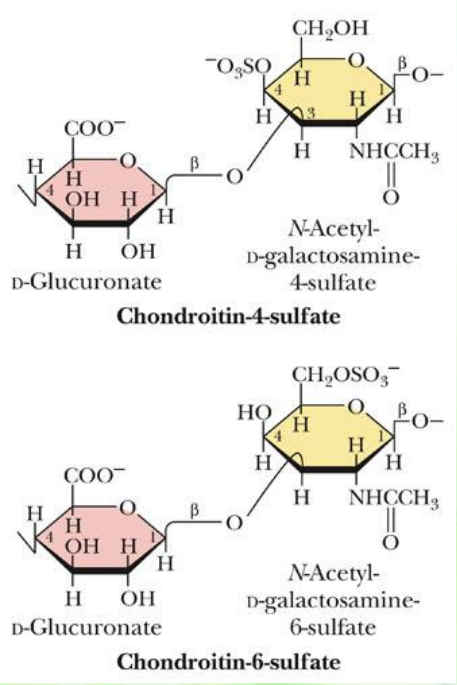


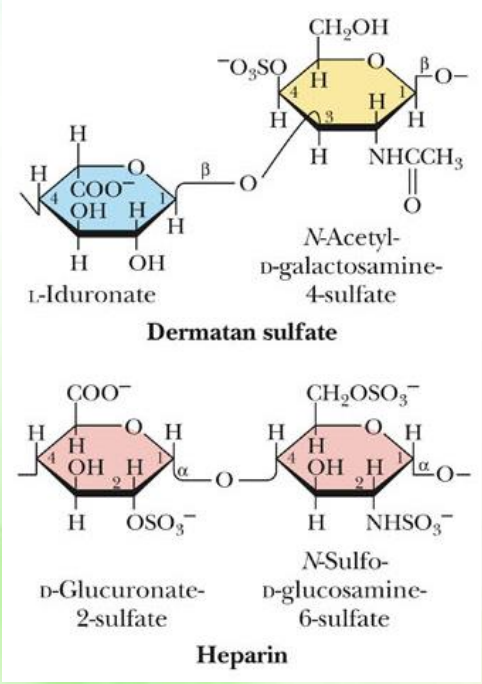
Are polysaccharides reducing?

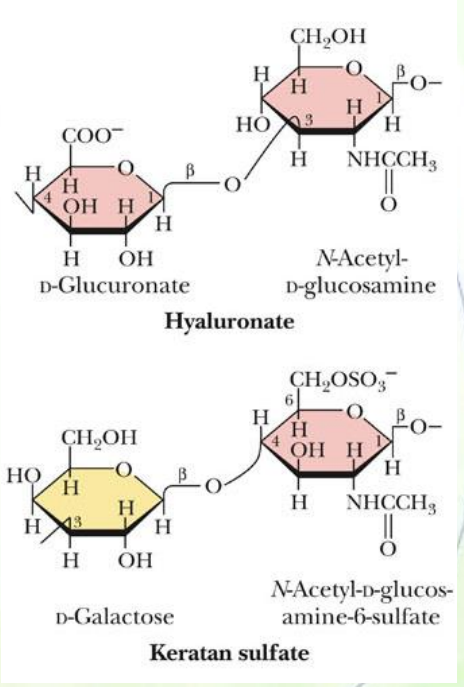
- A sample that contains only a few molecules of a large polysaccharide, each molecule with a single reducing end, might well produce a negative test because there are not enough reducing ends to detect.

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





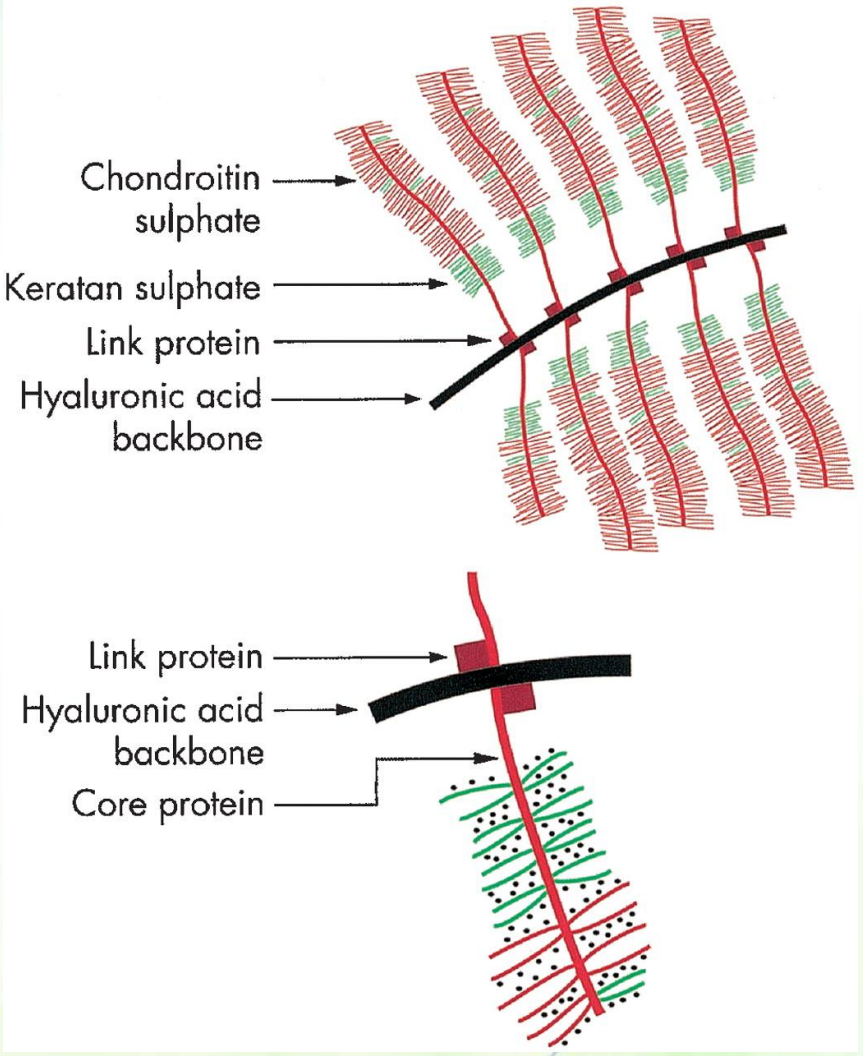


Localization and function of GAG

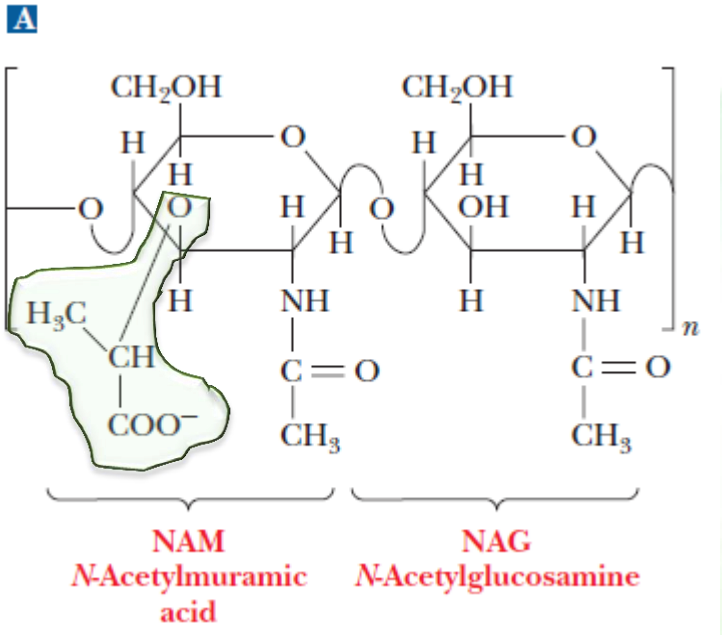
GAG	Localization	Comments
Hyaluronate	synovial fluid, vitreous humor, ECM of loose connective tissue	the lubricant fluid , shock absorbing As many as 25,000 disaccharide units
Chondroitin sulfate	cartilage, bone, heart valves	most abundant GAG
Heparan sulfate	basement membranes, components of cell surfaces	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

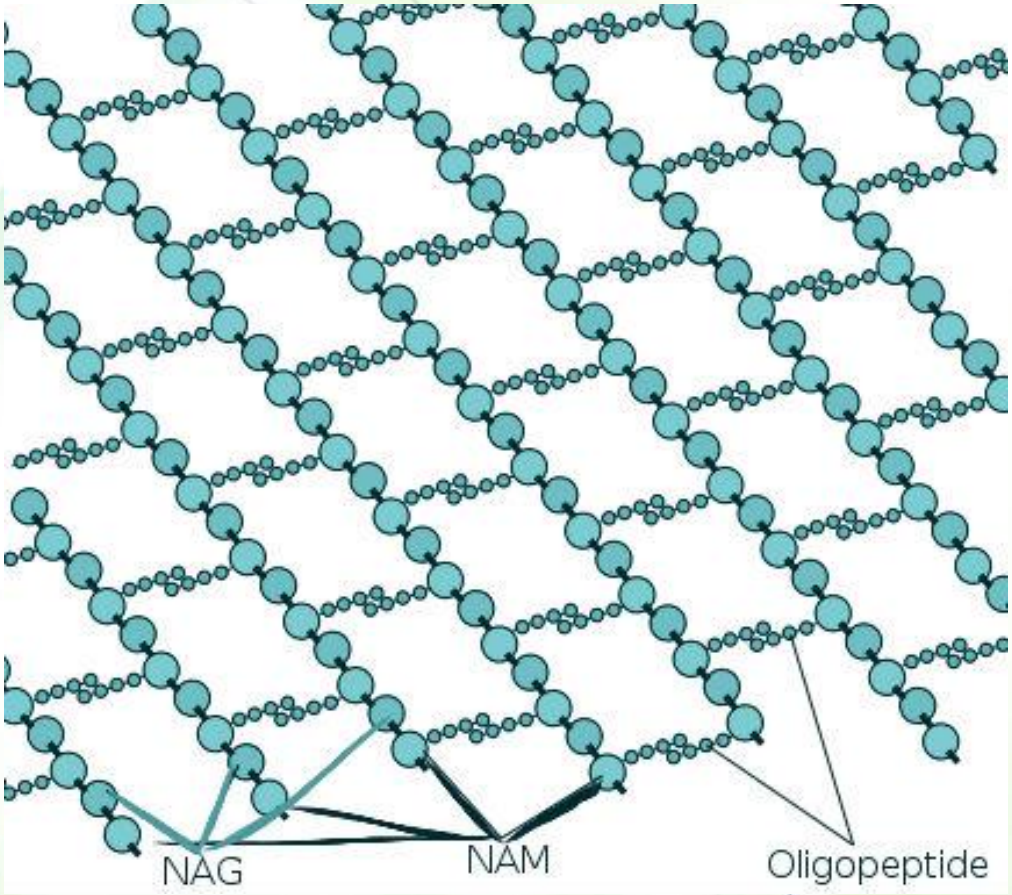
Proteoglycans

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

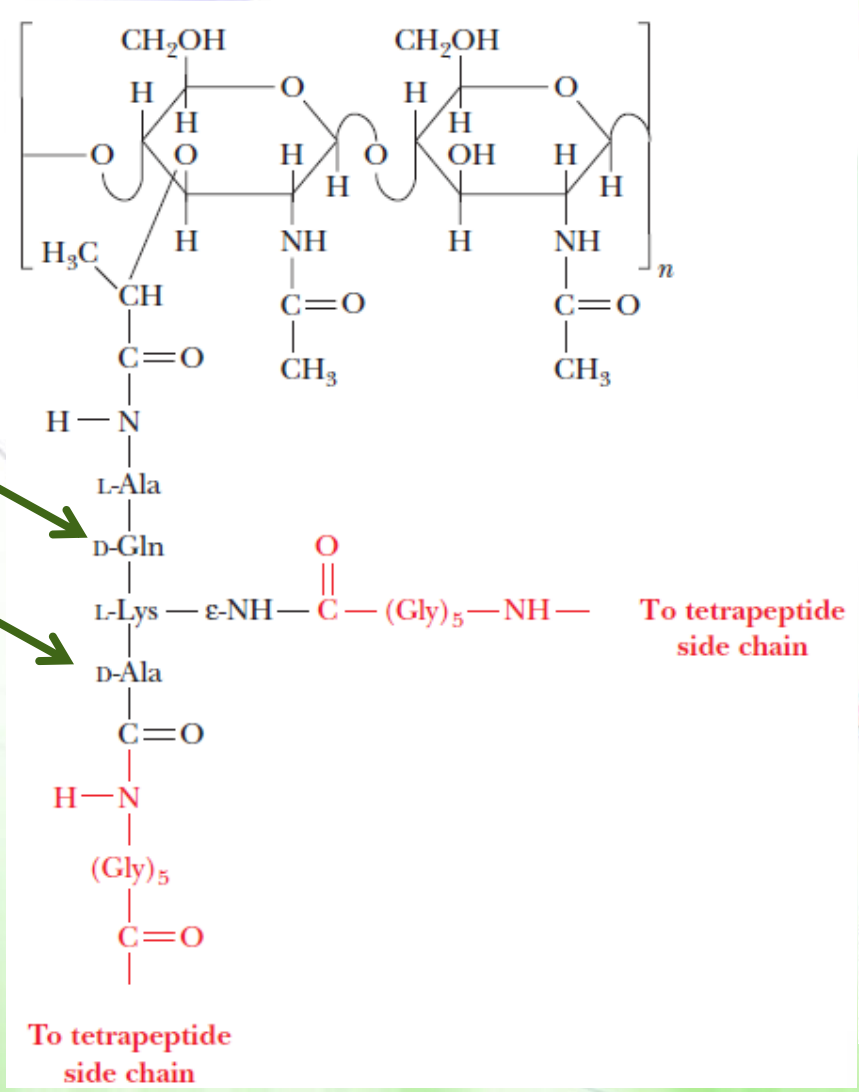


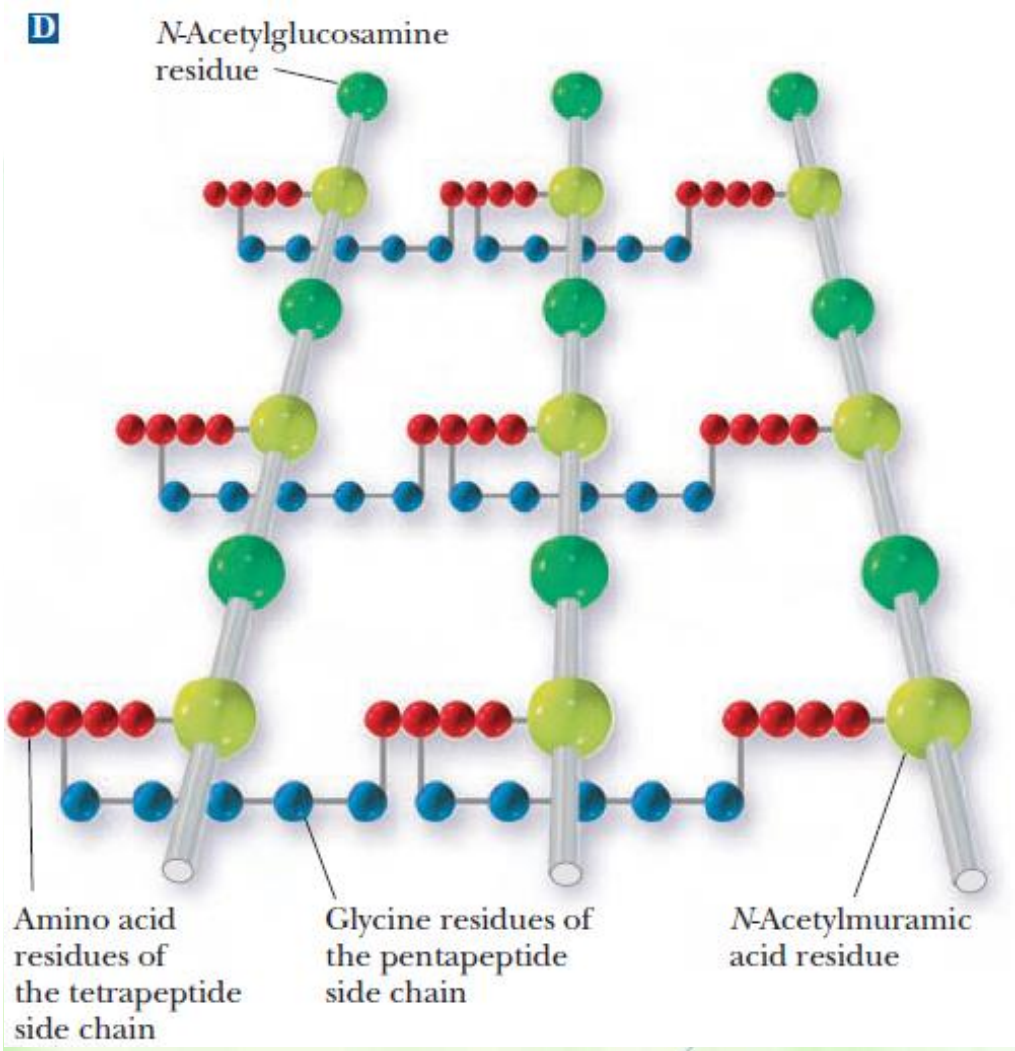
Bacterial cell wall





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)

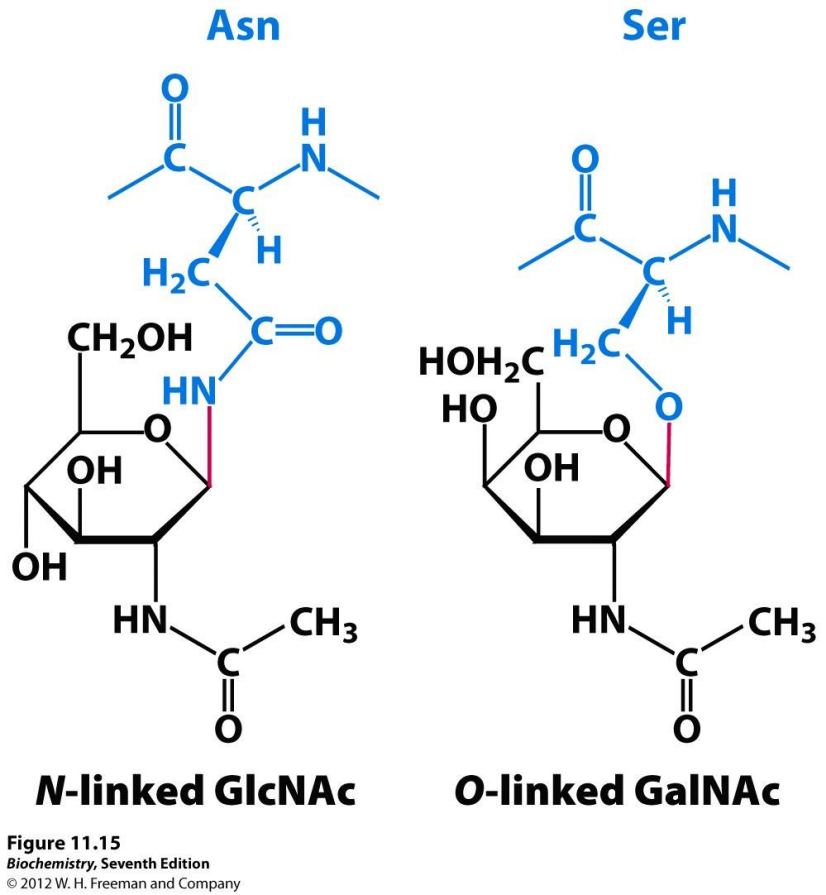


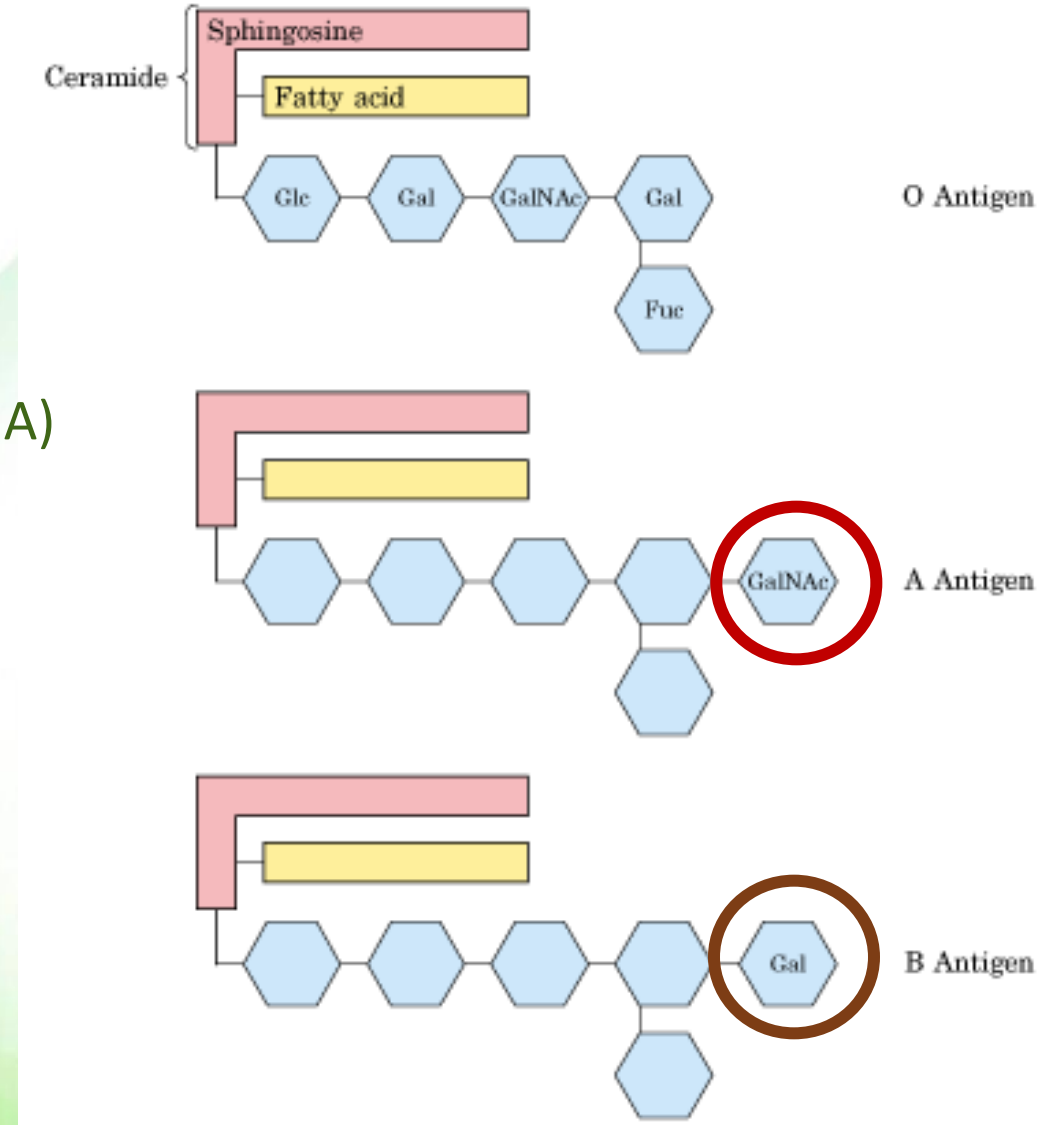
Figure 11.15
Biochemistry, Seventh Edition

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

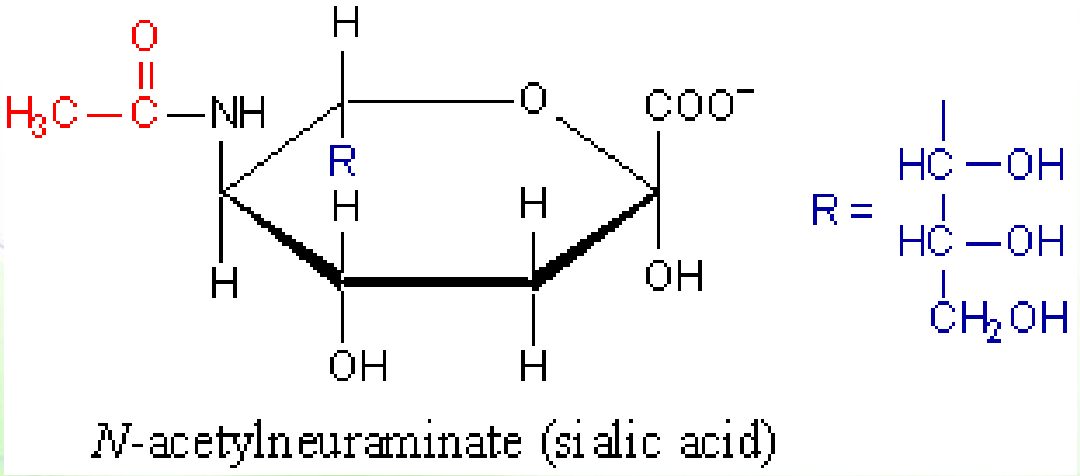
Blood typing

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



Sialic acid

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



N-acetylneuraminate (sialic acid)