# Carbohydrates

Summer semester 2023-2024

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# What are they?

the functional group is carbonyl (C=O) which give the properties of sugar

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

order of naming:
(main)
-COOH > C=O > -OH
acid

- Functions:
  - Source of energy (glycogen and starch)
  - Structure (cellulose and chitin)
  - Building blocks (glycosaminoglycans) → make larger molecules
  - Cellular recognition (glycoproteins)

surface of cells

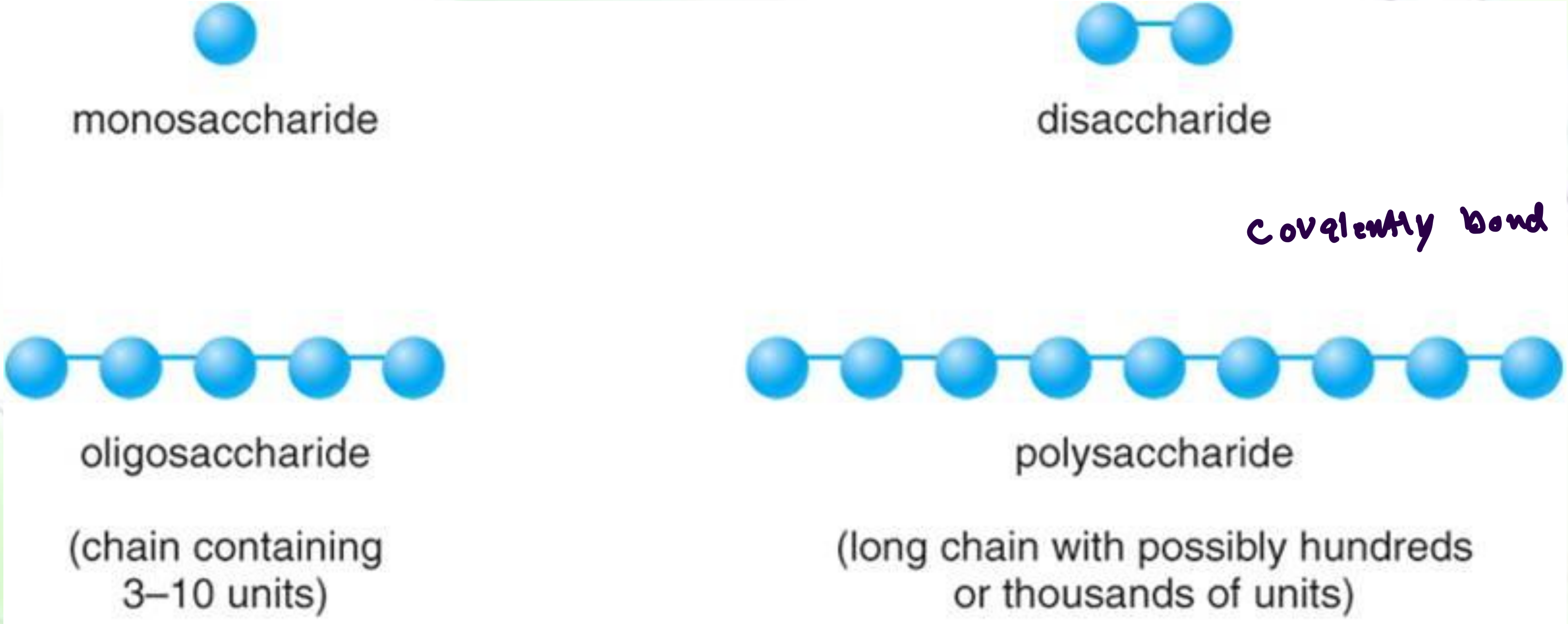
# Carbohydrates – natural forms

- Most carbohydrates are found naturally in bound form rather than as simple sugars.
  - Polysaccharides (starch, cellulose, inulin, gums)
  - have some suger → have some proteins
  - Glycoproteins and proteoglycans (hormones, blood group substances, antibodies)
  - suger
  - lipids that have some suger
  - Glycolipids (cerebrosides, gangliosides)
  - Glycosides suger that rad with alchohol
  - Mucopolysaccharides (hyaluronic acid) → ECM
  - Nucleic acids (DNA, RNA)

# Classification I

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

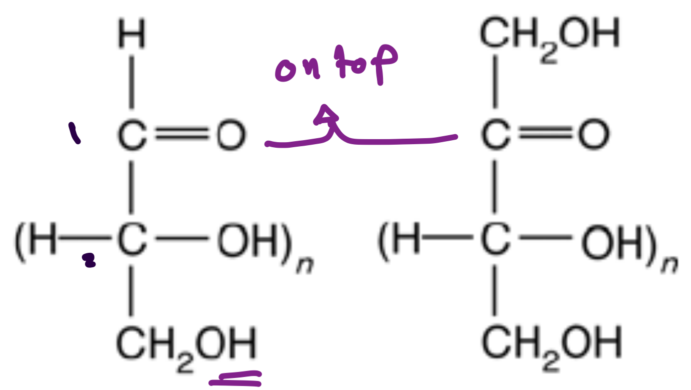
1 2 3-10



# Monosaccharides

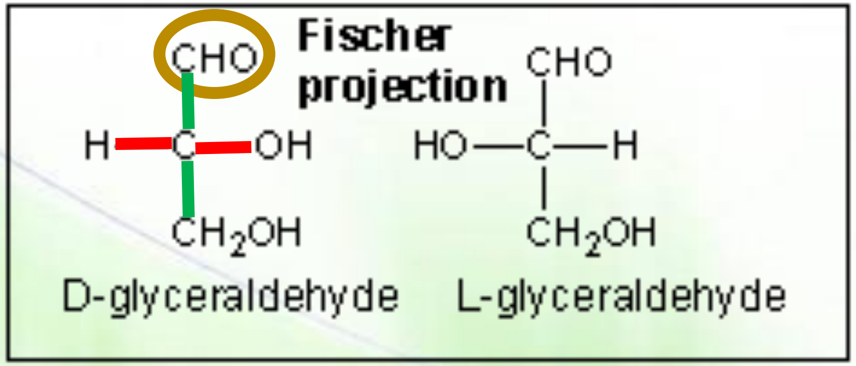
* C H O
1 : 2 : 1 *

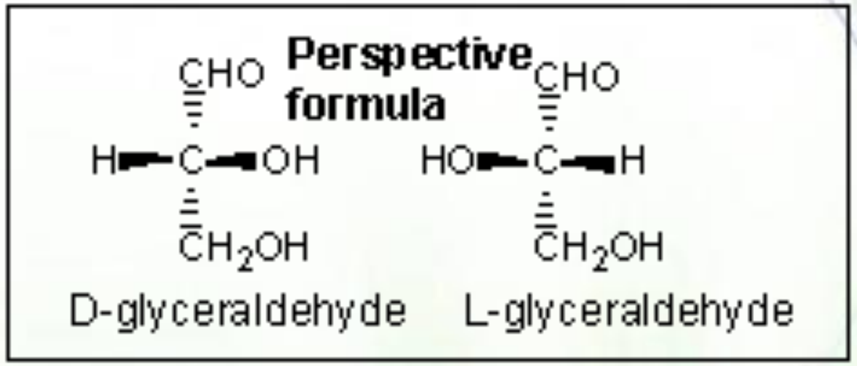
- Basic chemical formula: $(CH_2O)n$
- They contain two or more hydroxyl groups.




An aldose — Aldehyde sugar
A ketose — Ketone sugar

Fisher projections or perspective structural formulas.



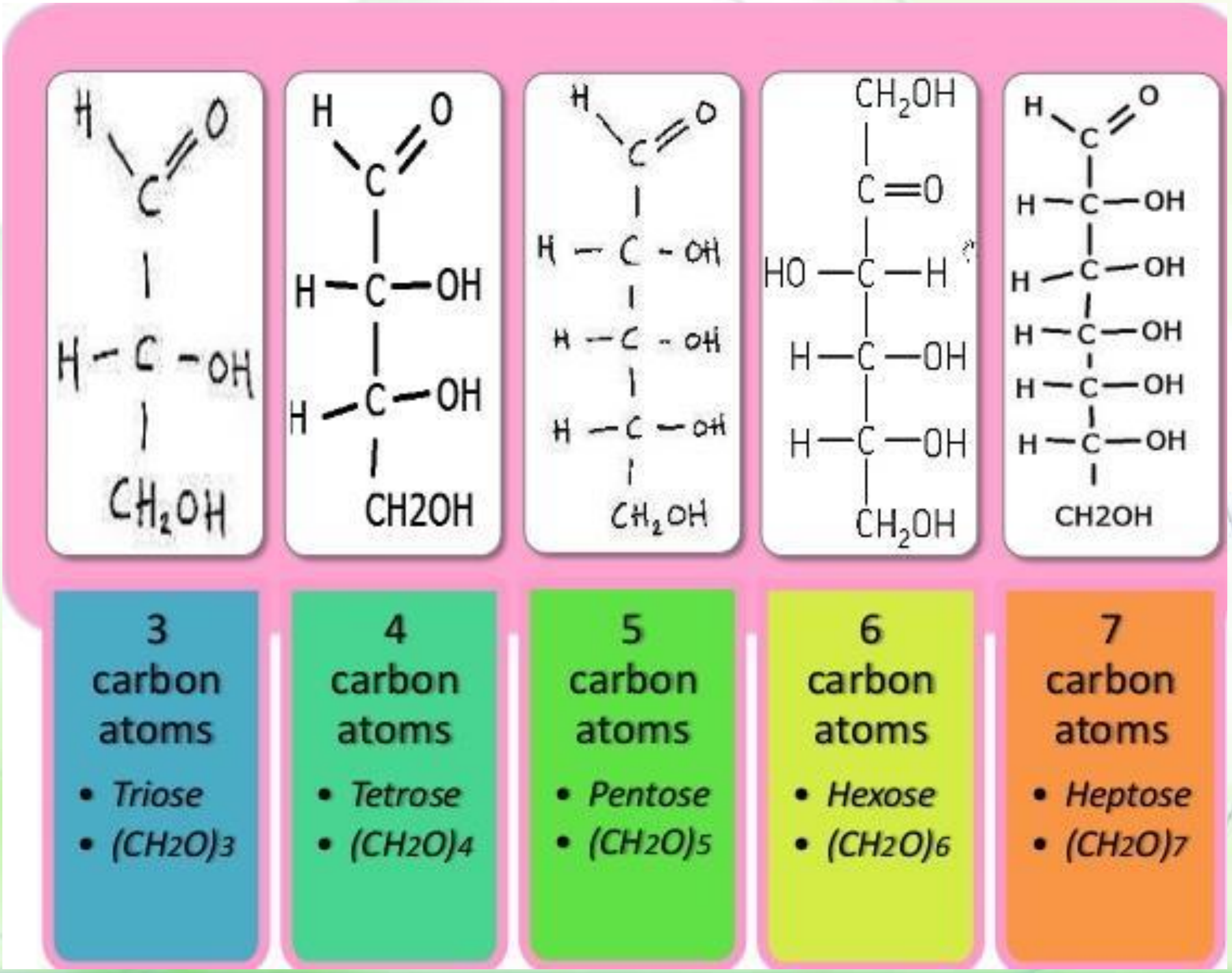




**Forward** **Backward** **Top (C1): Most highly oxidized C**

# Classification 2

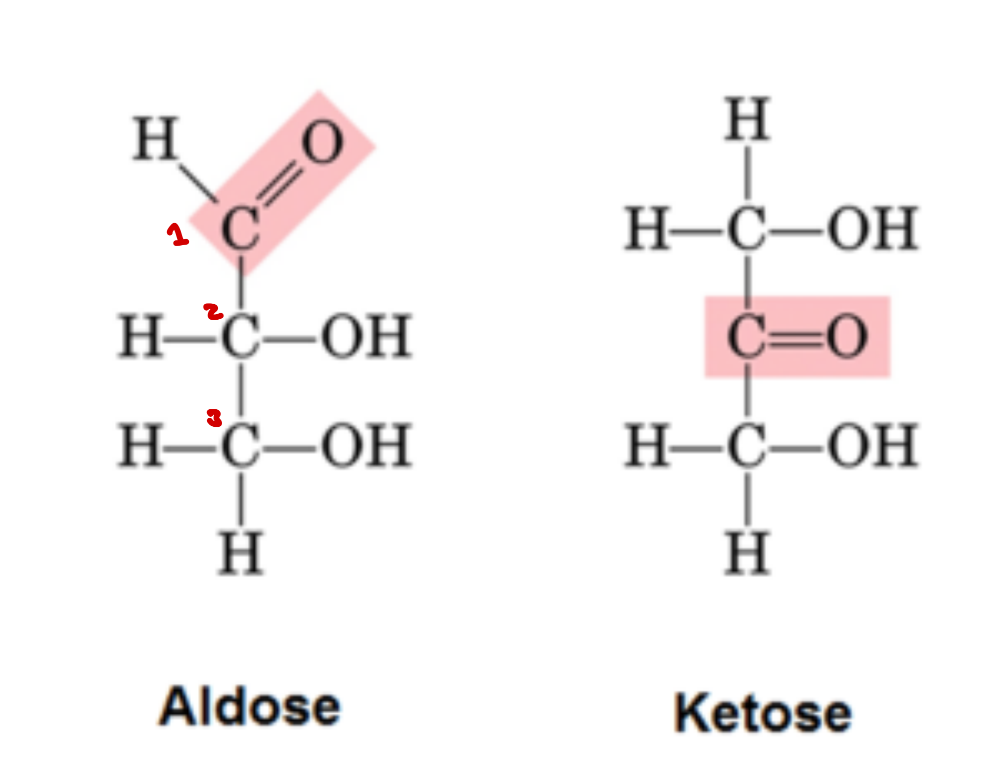
- By the number of carbon atoms they contain.
  - Triose (smallest)
  - Tetrose
  - Pentose
  - Hexose
  - Heptose
  - …

* every C should have OH group except the one with functional group

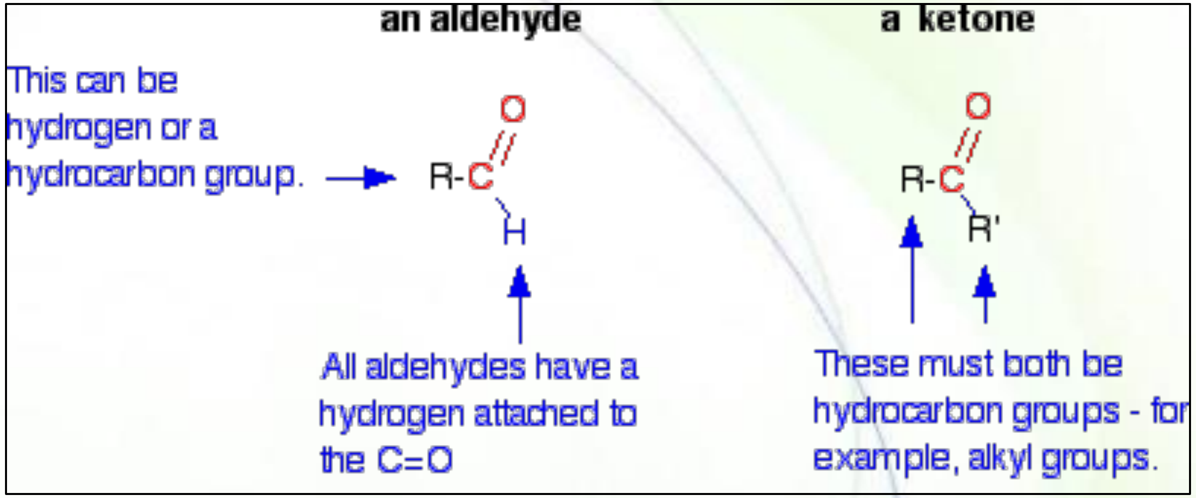


# Classification III

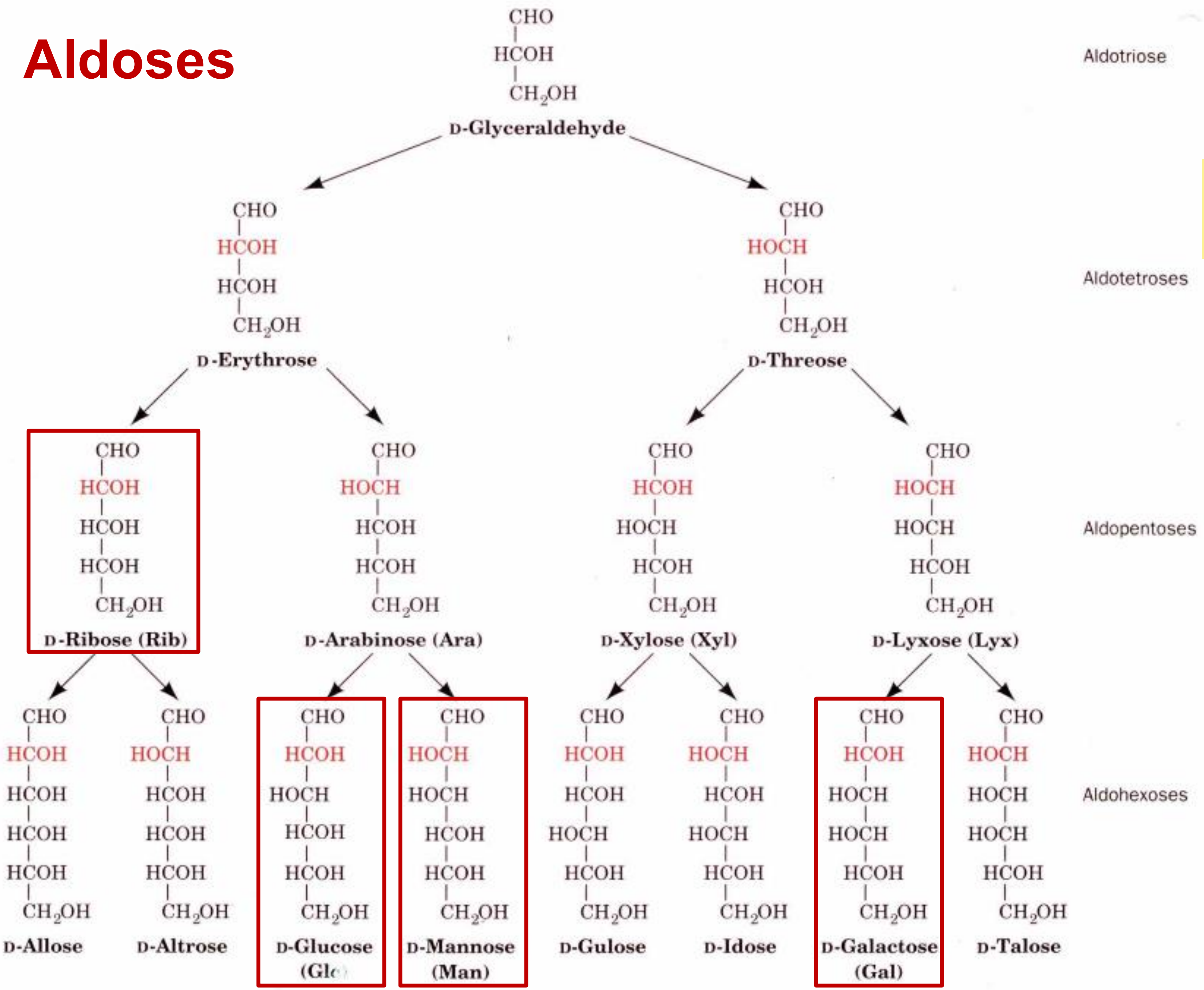
- By the functional group







# Aldoses



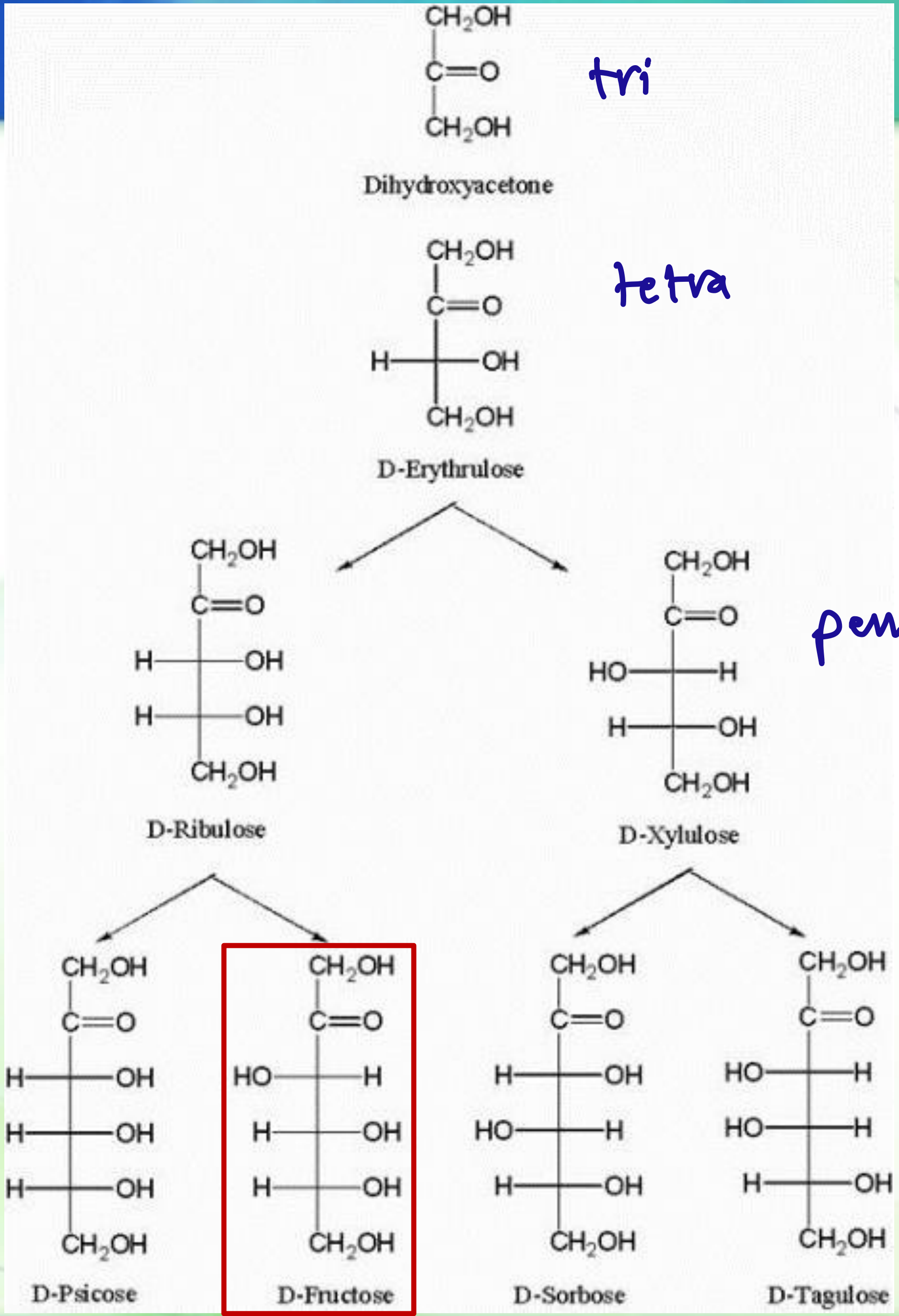

Memorize the ones in boxes.

اعرف الاسم والتركيب
ومكان OH ورقم الكربون

# of chiral centers : # of C − 2

# Ketoses

# of chiral Centers:
# of C − 3



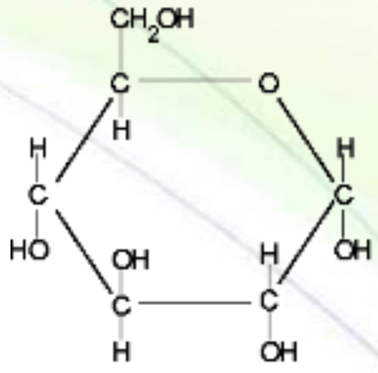

penta

hexa

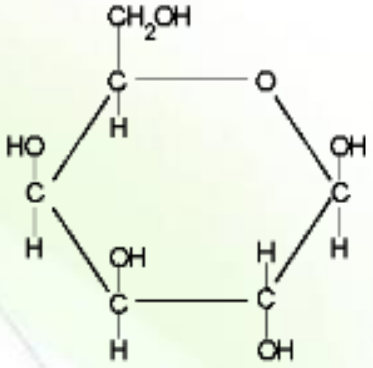
Memorize the ones in boxes.

# Common Monosaccharides

- Glucose:
  - Mild sweet flavor
  - Known as blood sugar
  - Essential energy source (main one)
  - 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

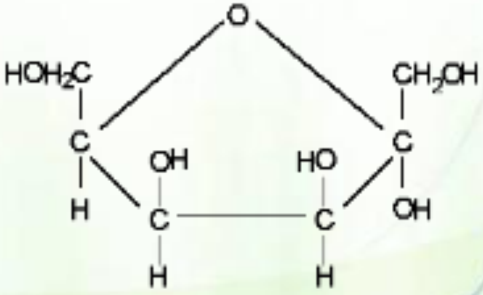


Glucose



Galactose

All may be modified

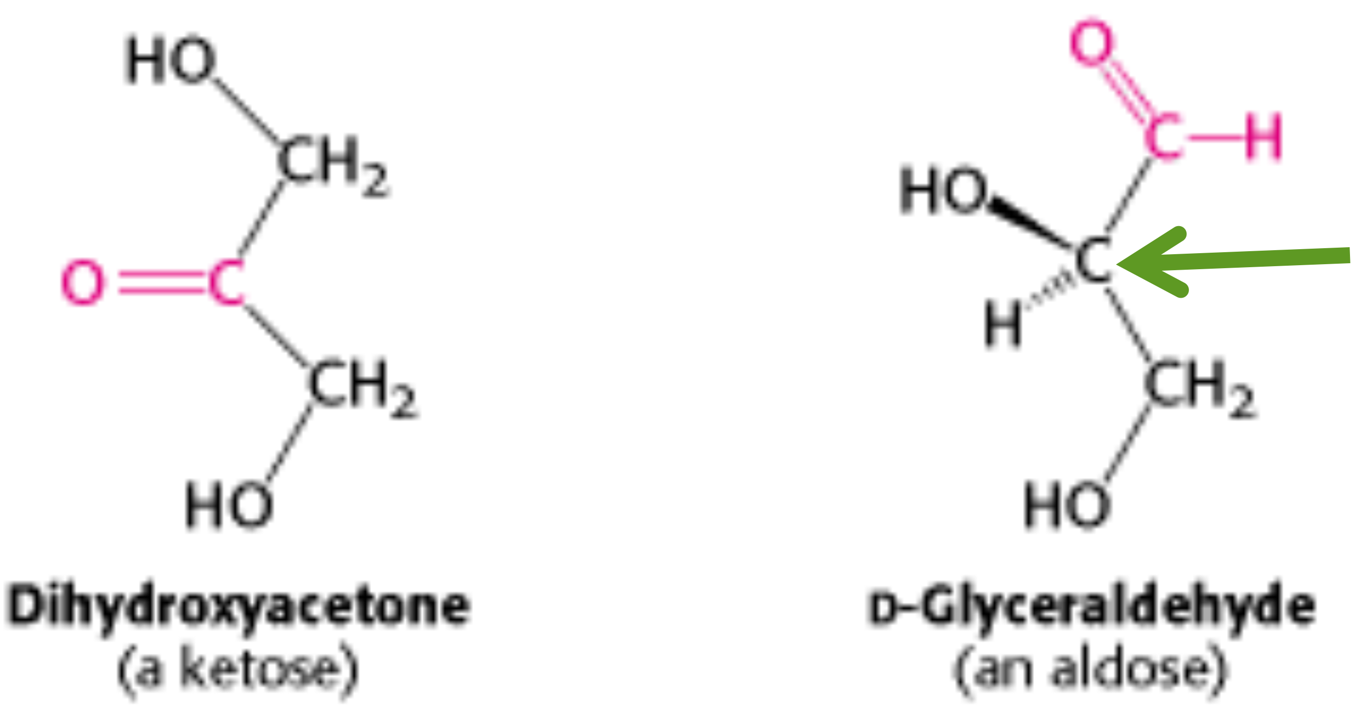


Fructose

# Trioses

**What is a chiral carbon?** ; since enantiomers are not superimposable they can be totally diff

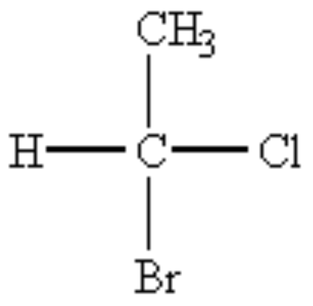
ex: some molecules taste sweet how ever their mirror image tastes bitter!

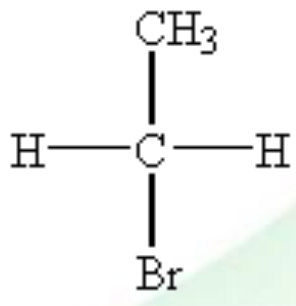


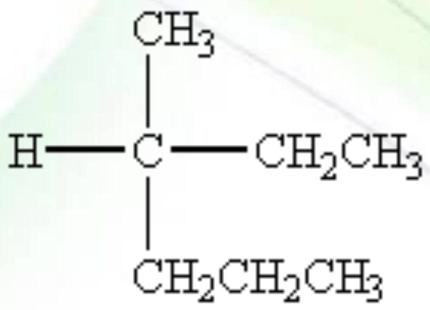

Chiral carbon

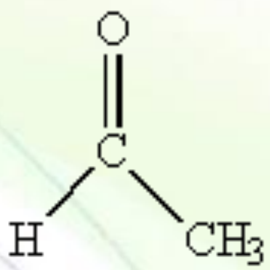
we only have two trioses (the simplest)

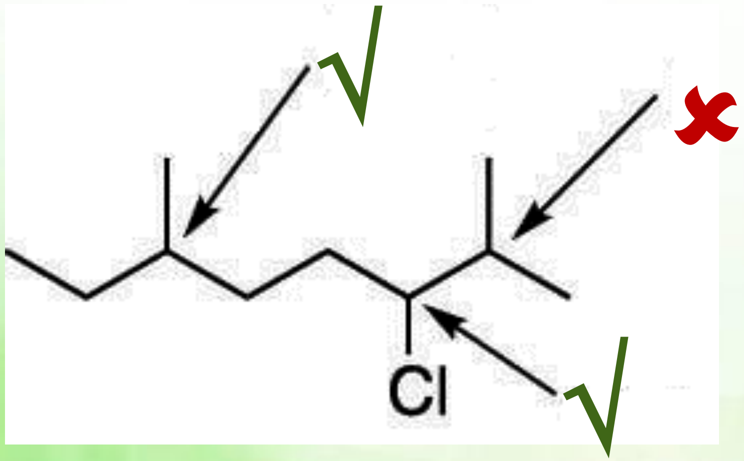
# Note what a chiral carbon is…











# Isomerism

same Molecular formula but diff structural one

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

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

*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.*

Same attachments but diff in arrangment (3D)

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

diff attachments (connected differently)

Epimers → diff in attachment of only one chiral center

# Isomers of glucose

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

# of isomers

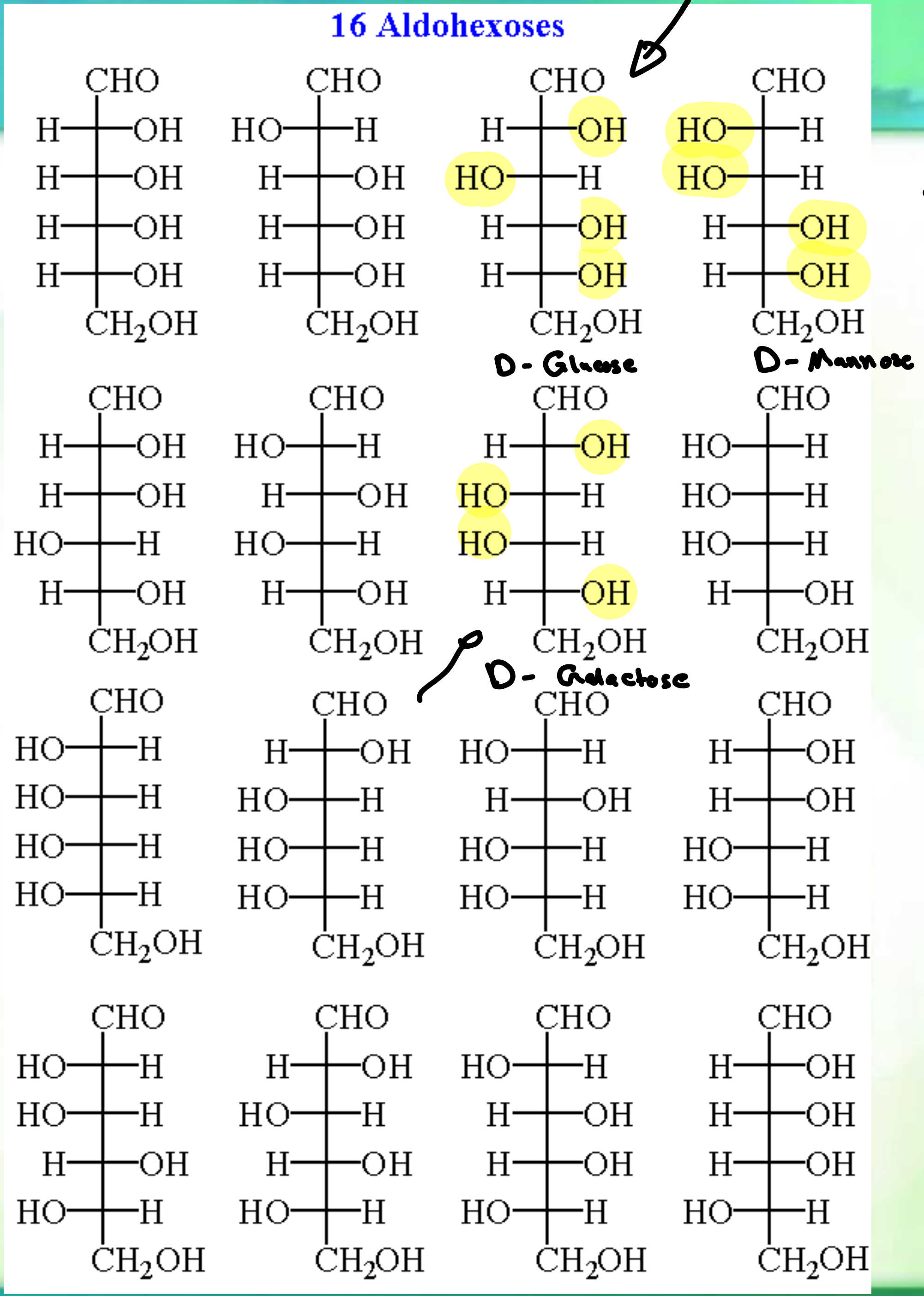
eg: Glucose have 4 => $2^4 = \underline{\underline{16}}$

**Search for:**

**Glucose,**

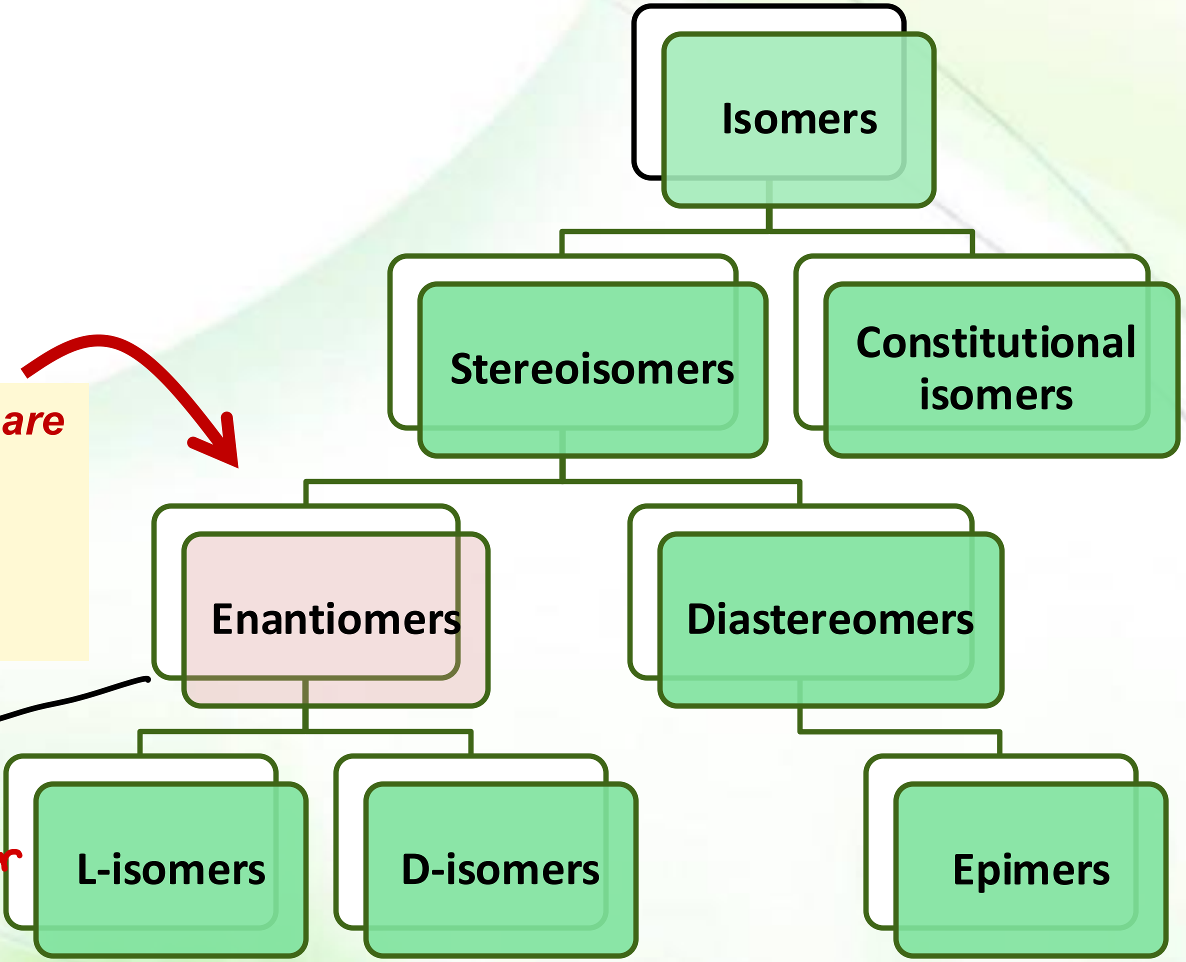
**Galactose**

**Mannose**



# Enantiomers

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



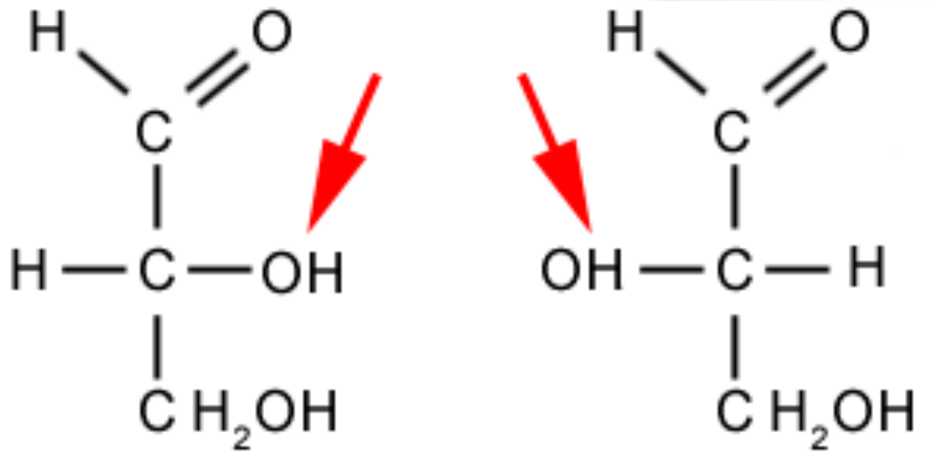

Glucose has only 1 enantiomer which is its mirror image

# Sugar enantiomers (D- vs. L-)

look at the furthest chiral center from the functional group if it is:

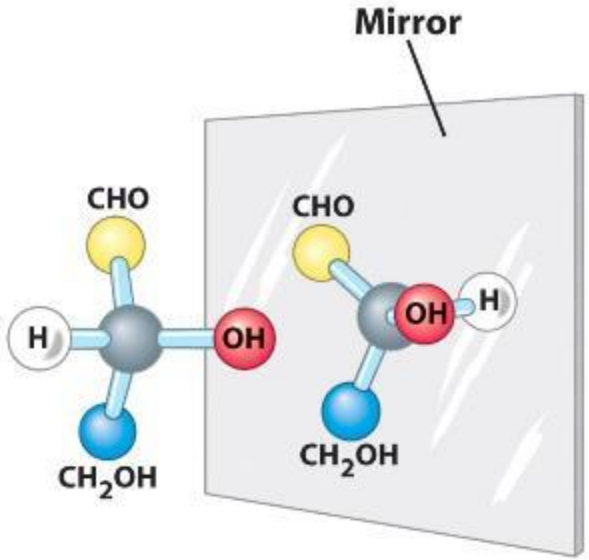
Right → D

left → L



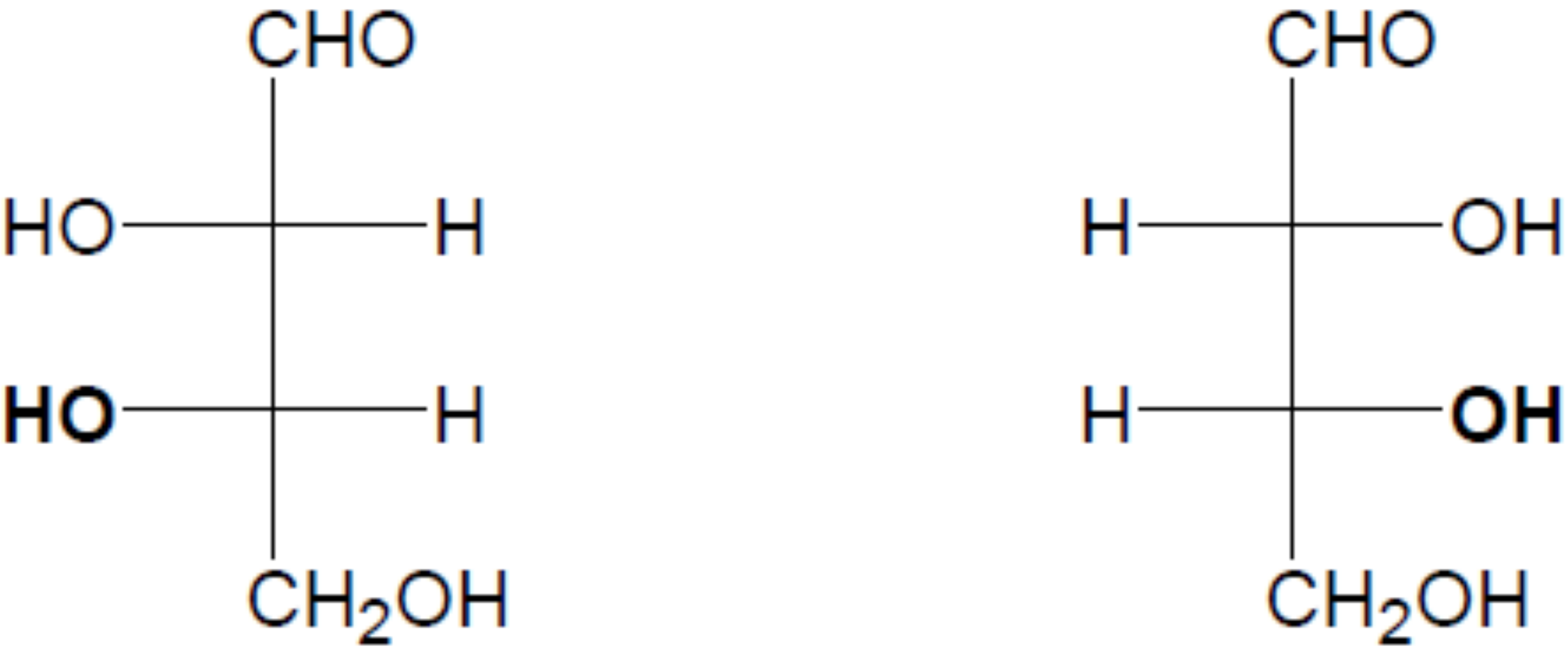
D-Glyceraldehyde L-Glyceraldehyde

it has only 1 enantiomer




Ball-and-stick models

# Which one(s) is a chiral carbon?




L-erythrose D-erythrose

Do not memorize but study them.

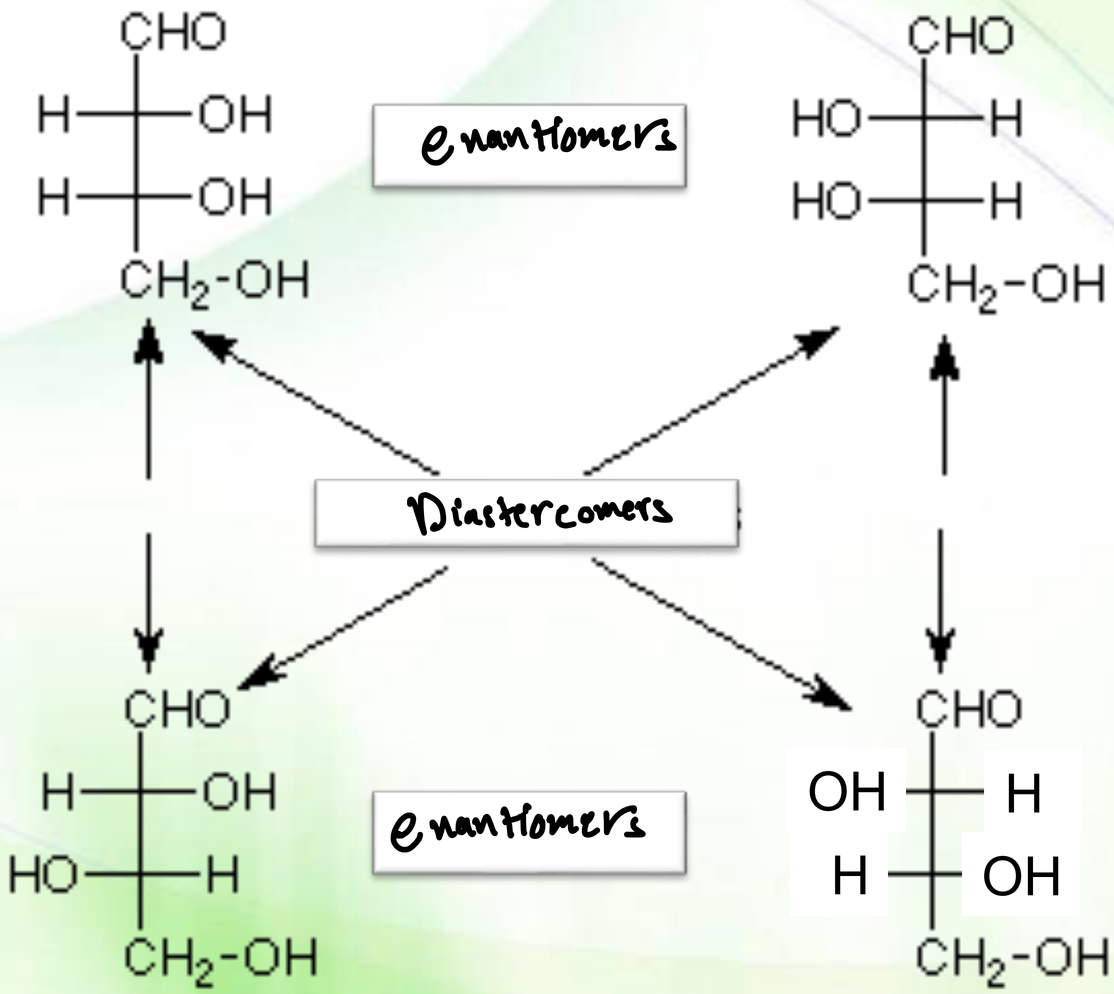
# Isomerism

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

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

Glucose has 14 diastereomers

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



# Isomerism

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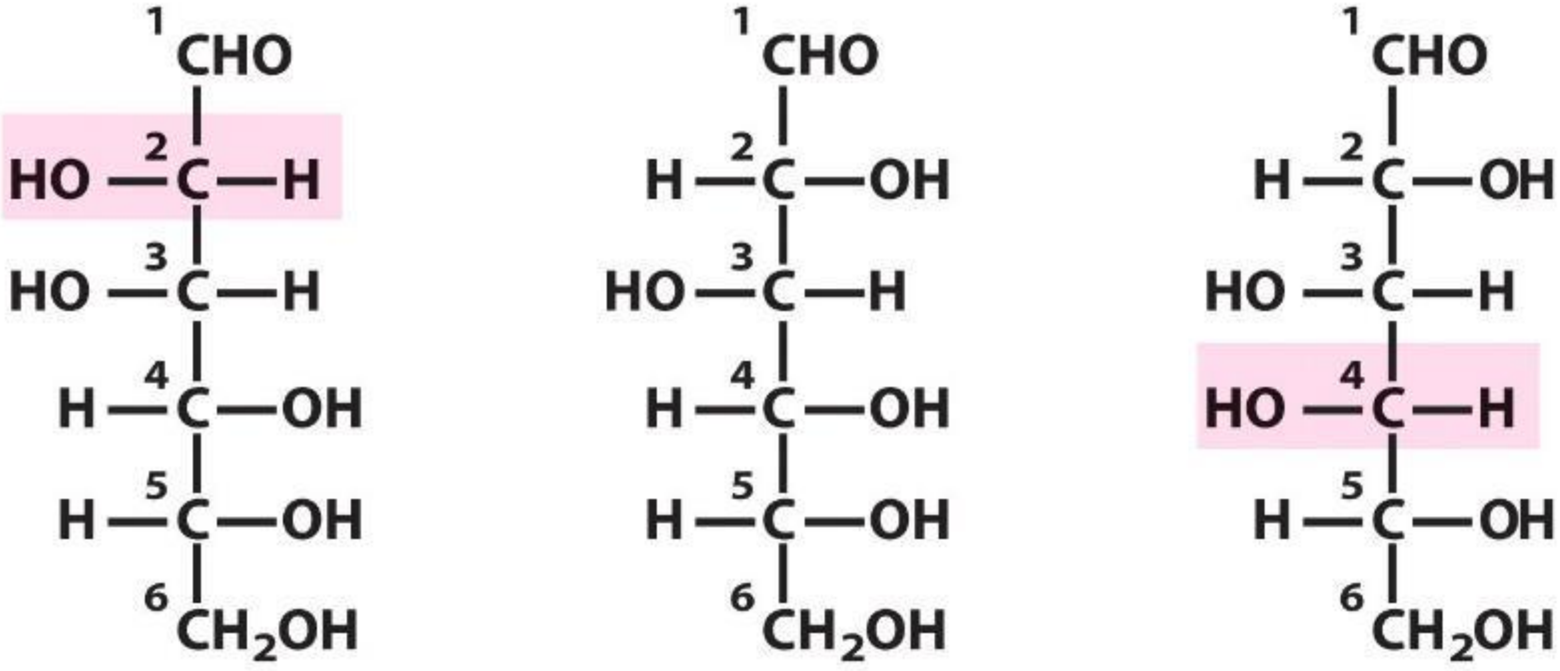
      - D-isomers
    - Diastereomers
      - Epimers
  - Constitutional isomers

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

# Diastereomers with different orientation of one chiral carbonm then... *epimers*

**Memorize and study them.**



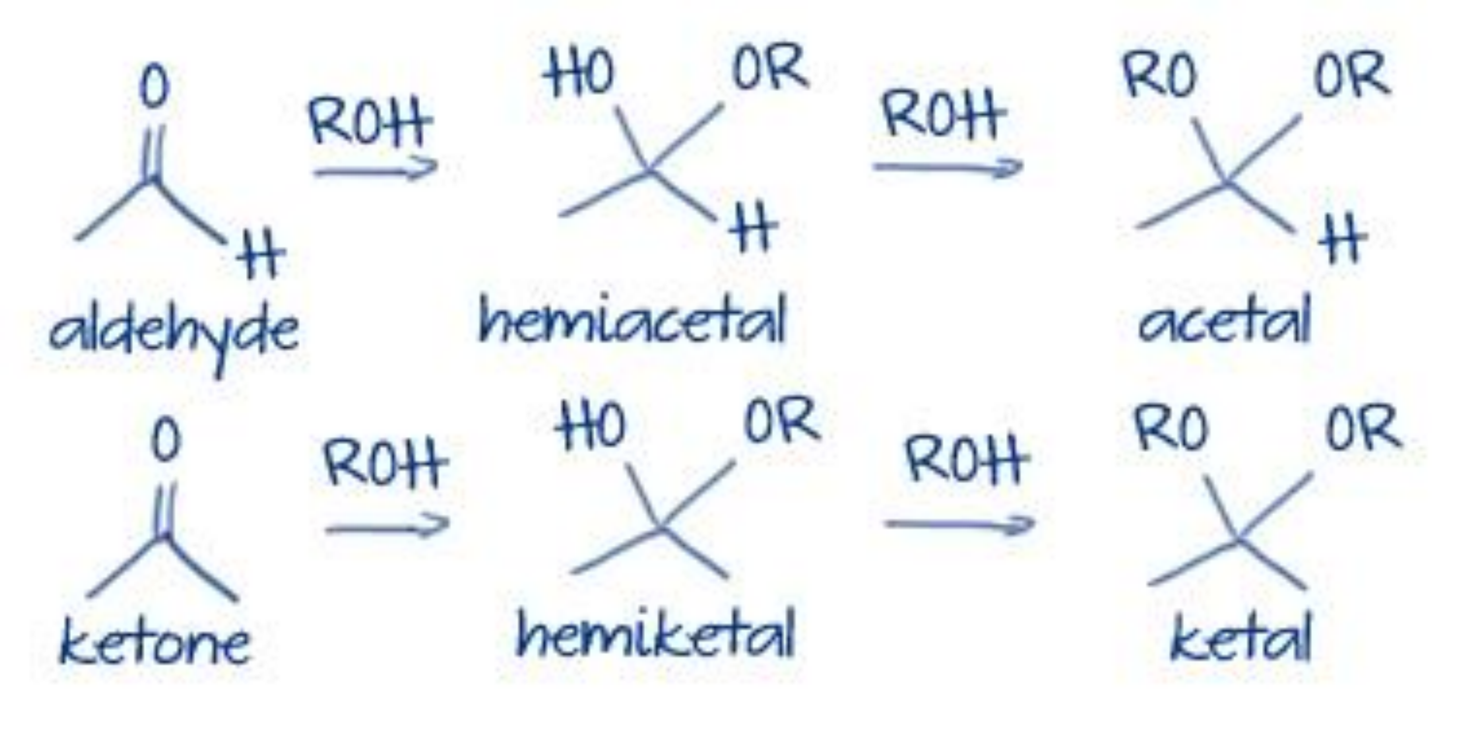
D-Mannose (epimer at C-2) | D-Glucose | D-Galactose (epimer at C-4)

***Is L-glucose an epimer with D-mannose and D-galactose?*** NO, they are diastereomers

# Acetal/ketal vs. hemiacetal/hemiketal

* C=O & OH are reactive

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



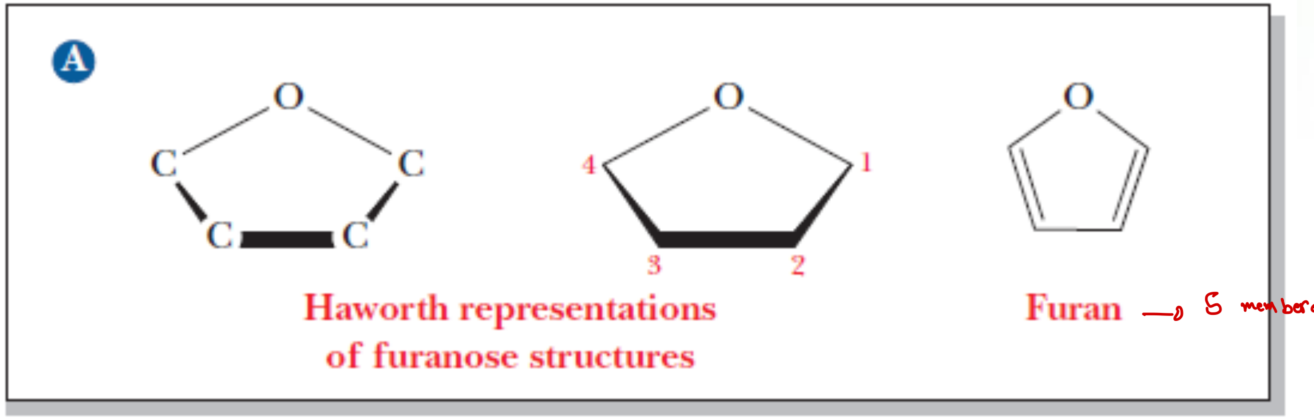

*What is the difference between hemiacetal and hemiketal and the difference between acetal and ketal?*

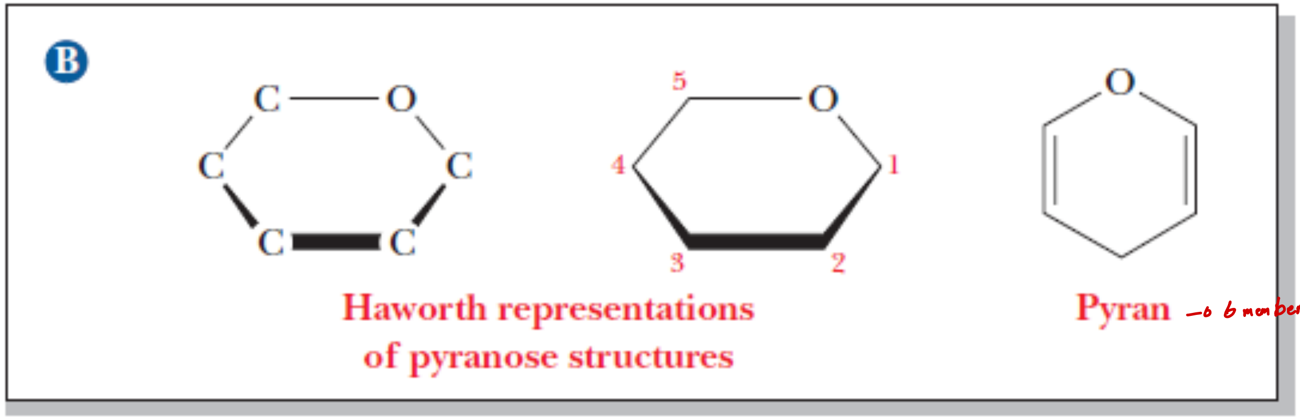
Aldehyde + ROH

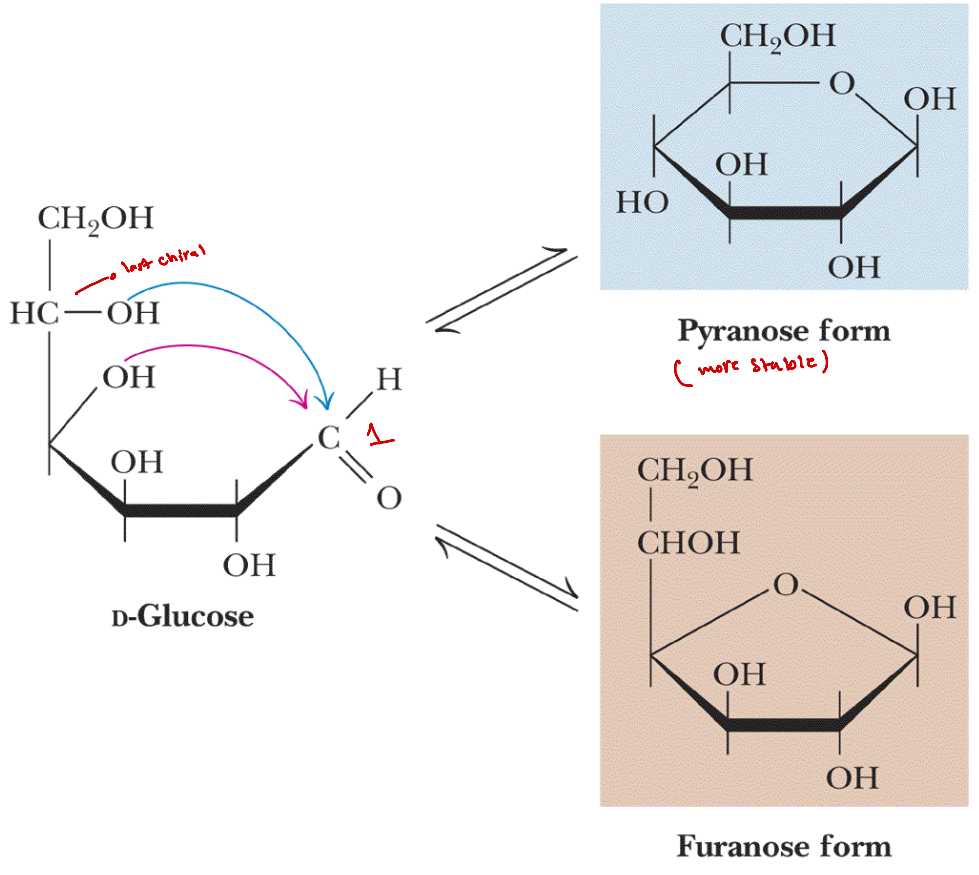
Ketone + ROH

# Formation of a ring structure

→ due to C=O & OH ⇒ it can become a ring which is more stable

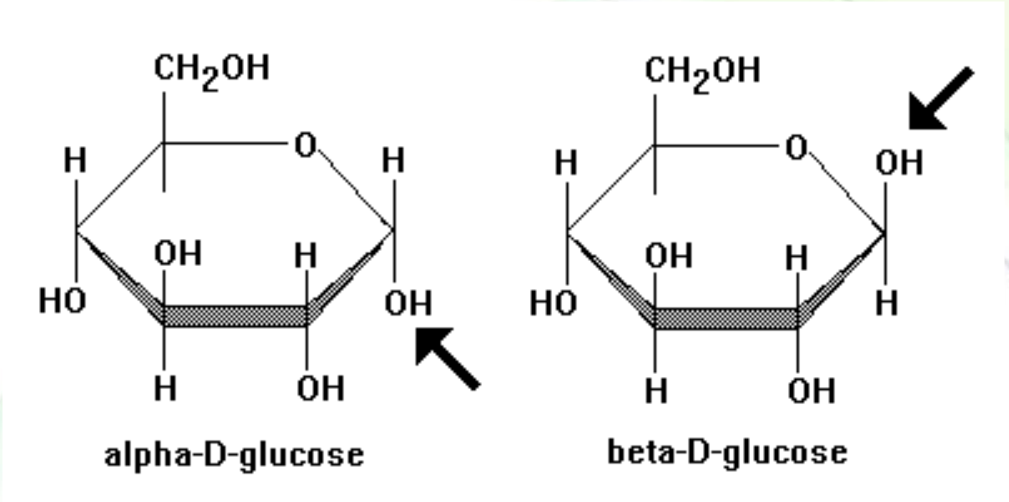


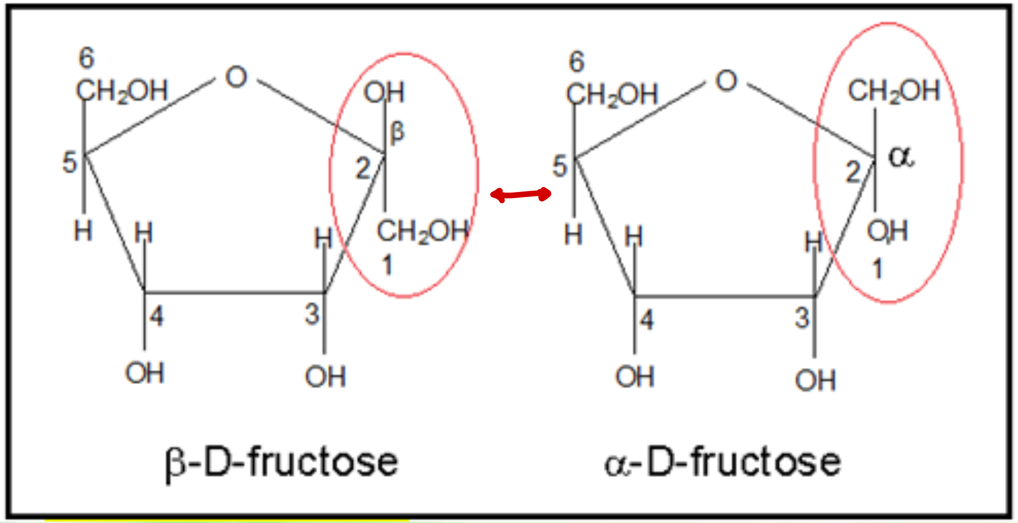



# Anomers

↳ isomers that diff in position of OH on the anomeric carbon



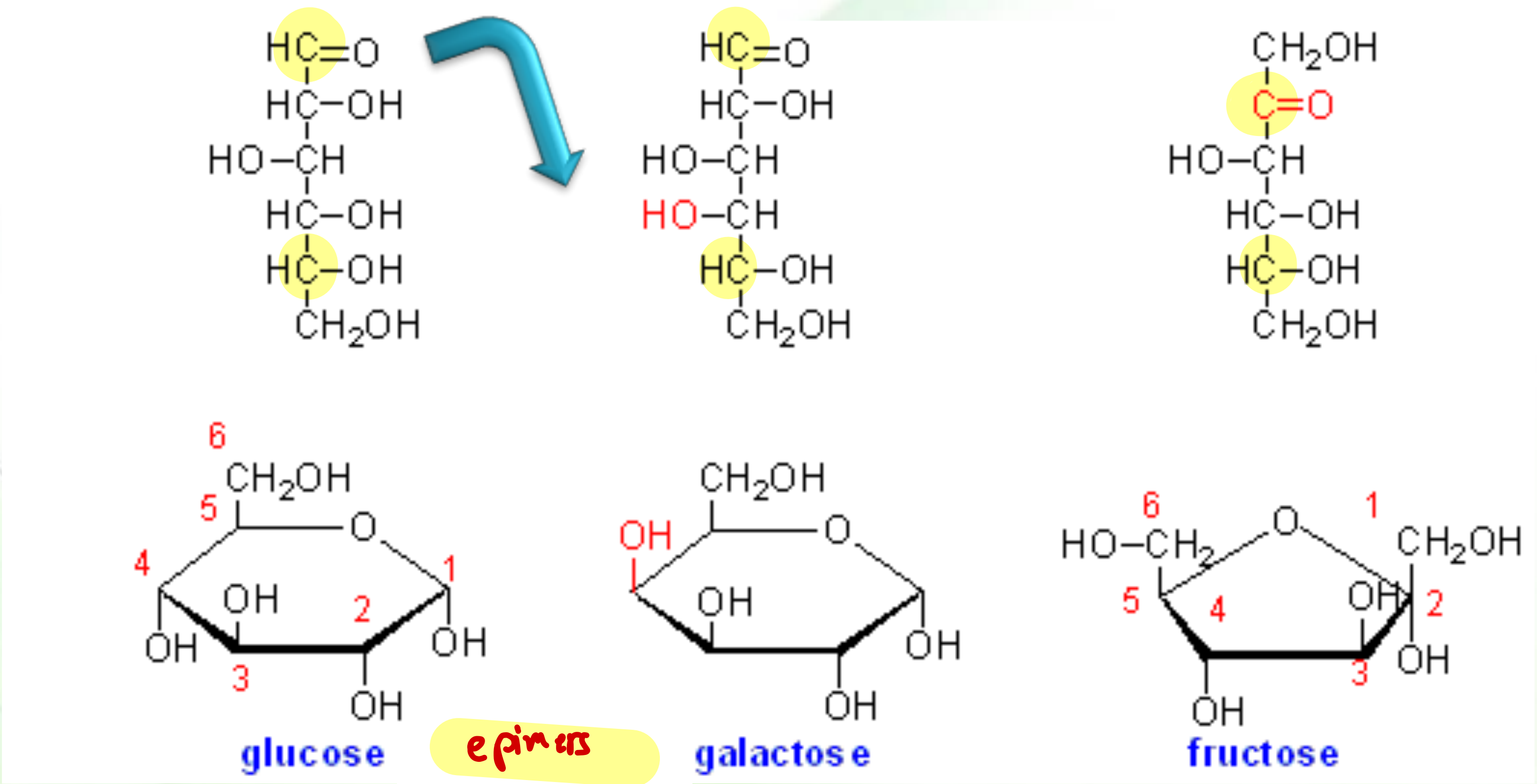

β is more stable ⇒ more rings are in β form



# Chain to ring

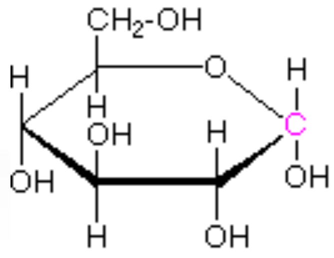
# Left-up, right-down

***Face the sugar and go down to <u>YOUR</u> right***



# Cyclic aldohexoses

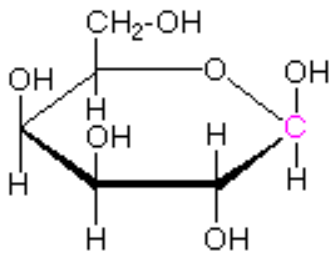
Examples of Some Pyranose Forms of Hexoses



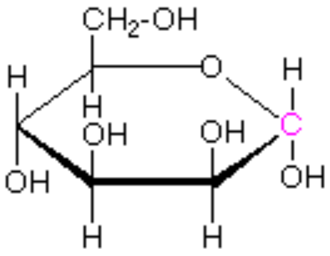

α

α-D-glucopyranose

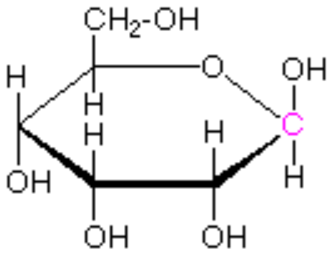
last chiral center (C5)
OH is down




β-D-galactopyranose

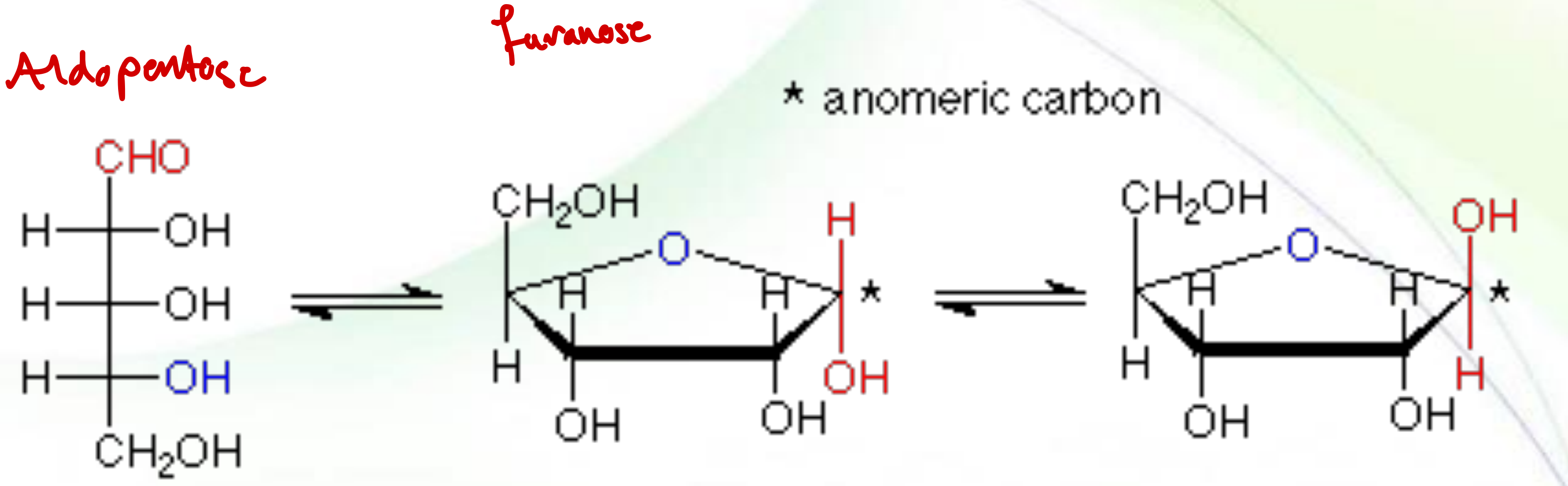



α-D-mannopyranose




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

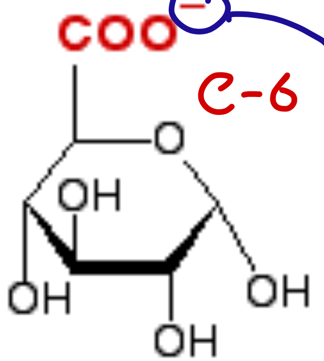
# Sugar acids (oxidation)

- Where is it oxidized? What does it form?

@ C-1, C-6

Alchohol → Carboxyl

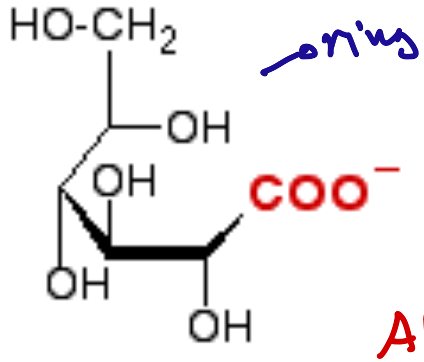
C-6




**α-D-glucuronate**
(D-glucuronic acid, **GlcUA**)
from **oxidation of glucose C6 OH**

ring opens

C-1

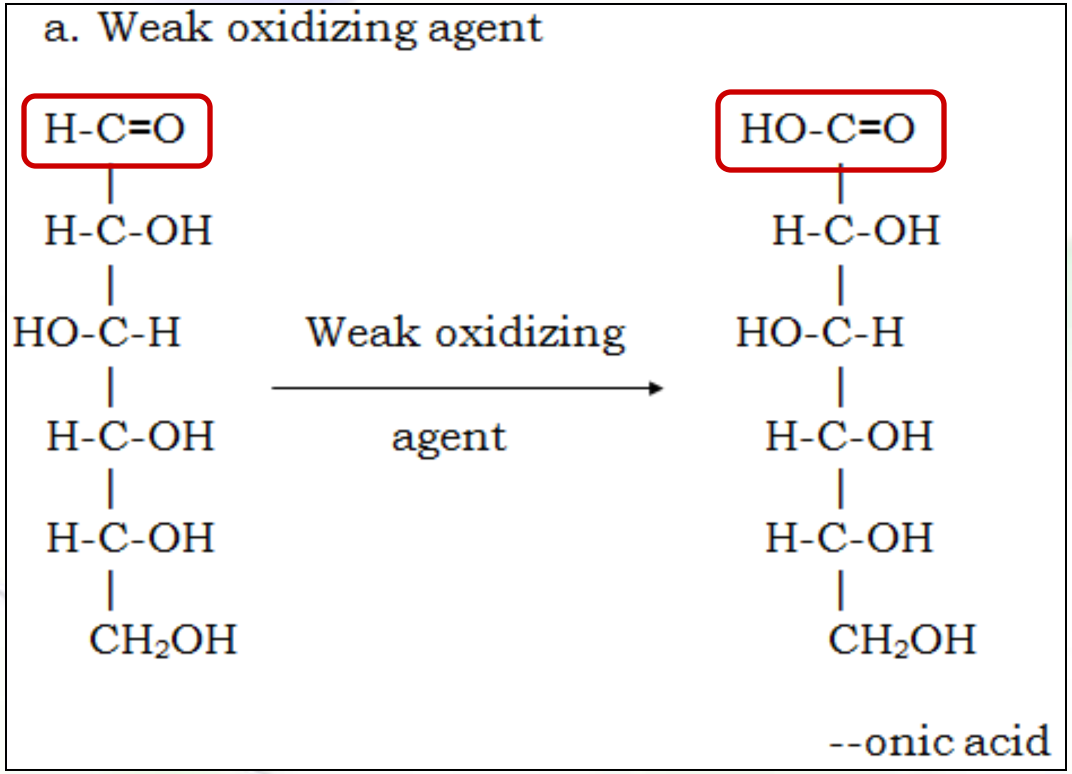


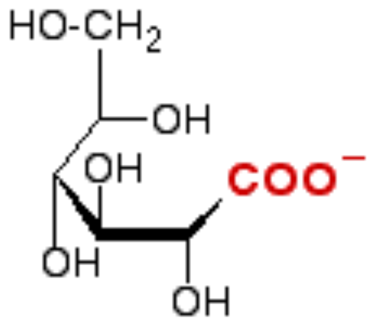

Aldehyde → Carboxyl

**D-gluconate** → conjugate base ( carboxyl is ionized)
+ Acid only when (COOH)
(D-gluconic acid, **GlcA**)
from **oxidation of glucose C1 aldehyde)**

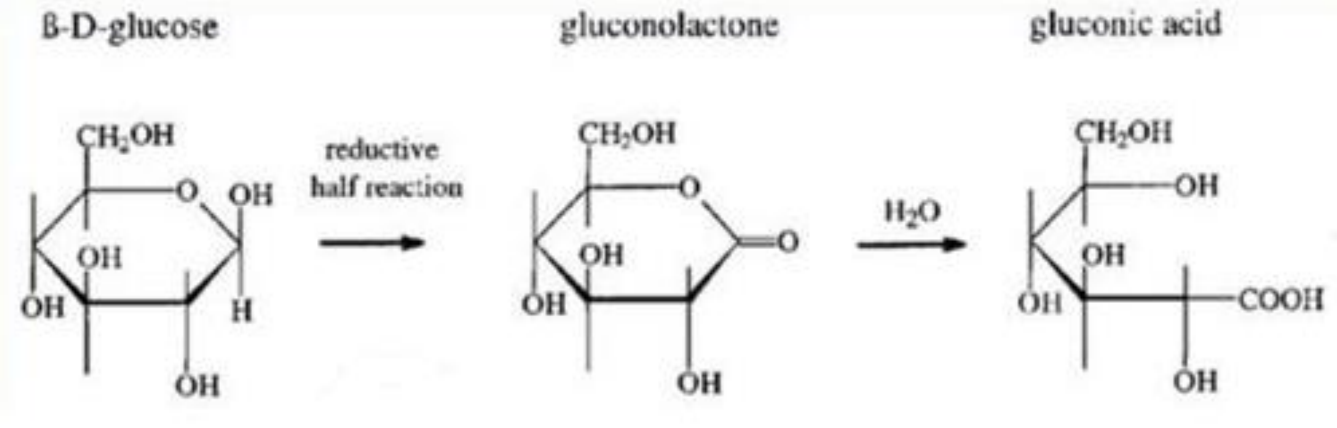
**Do not memorize the structure but study it.**

# Gluconate




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




**Do not memorize the structure but study it.**

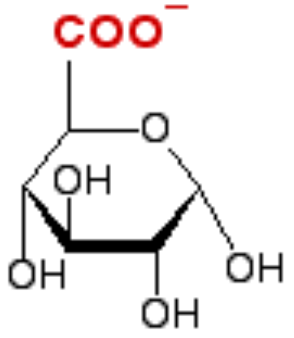
# Glucoronate

c. Oxidation of primary alcohol end in biological systems

$$
\begin{array}{ccc}
\text{H-C=0} & & \text{CHO} \\
| & & | \\
\text{H-C-OH} & & \text{H-C-OH} \\
| & & | \\
\text{HO-C-H} & \xrightarrow{\text{Enzymes}} & \text{HO-C-H} \\
| & & | \\
\text{H-C-OH} & & \text{H-C-OH} \\
| & & | \\
\text{H-C-OH} & & \text{H-C-OH} \\
| & & | \\
\boxed{CH_2OH} & & \boxed{\text{H0-C=O}}
\end{array}
$$

-uronic acids

**Do not memorize the structure but study it.**



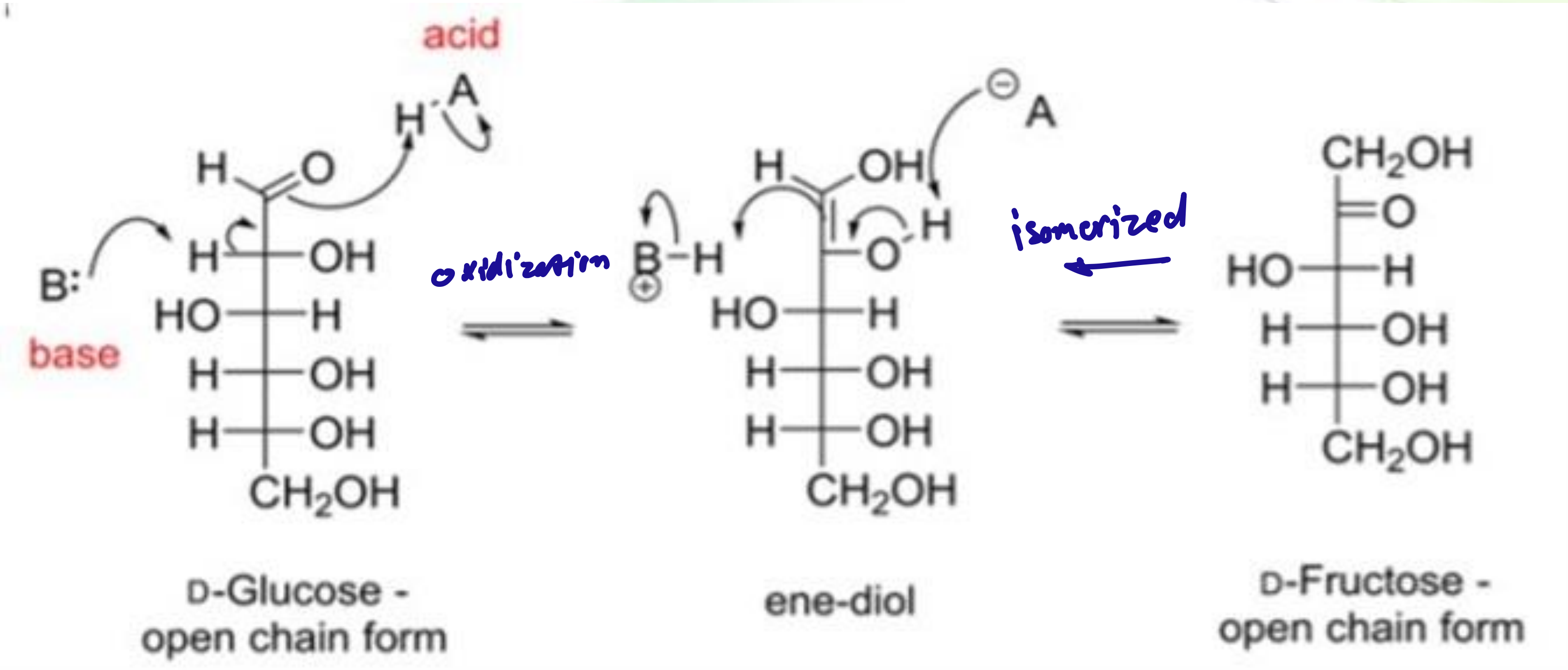

**α-D-glucuronate**

(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 indirectly.

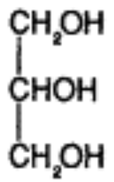



**Do not memorize the ene-diol structure but study it.**

# Sugar alcohols (reduction)

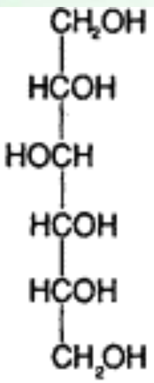
- What does it form? Alchohol
- Examples include sorbitol, mannitol, and xylitol, which are used to sweeten food products

+ glycerol



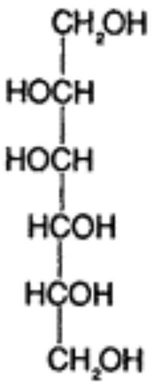
Glycerol

Obtained from the reduction of either D-glyceraldehyde or dihydroxyacetone.



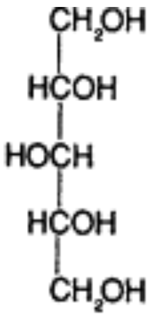
D-Sorbitol in food

Obtained from the reduction of either the $C_1$ carbonyl group of glucose or the $C_2$ carbonyl group of fructose.



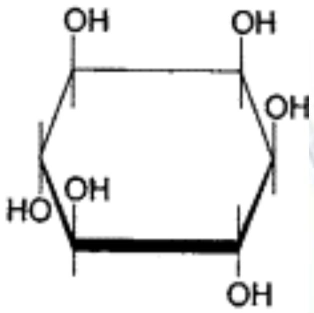
D-Mannitol

Obtained from the reduction of either the $C_2$ carbonyl group of D-fructose or the $C_1$ carbonyl group of D-mannose.



~~Xylitol~~

~~Obtained from the reduction of either the $C_1$ carbonyl group of D-xylose or the $C_2$ carbonyl group of D-xylulose.~~



Myo-inositol

**We will get to this sugar in the lipids lecture**

JUST READ

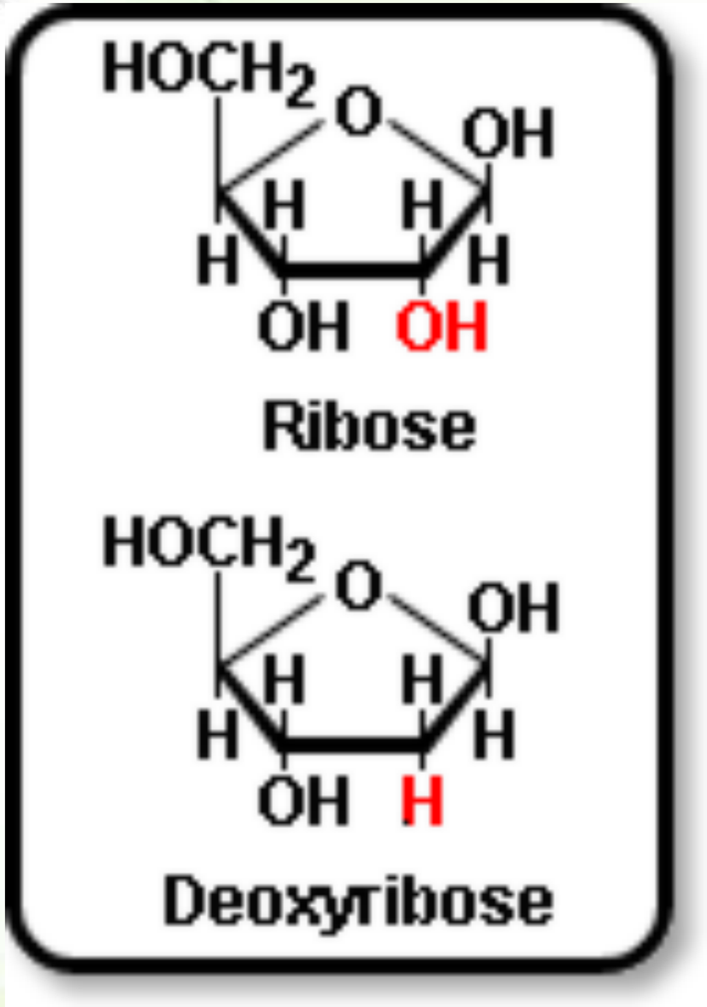
-ol: alchohol

⇒ they are made from Alchohol

# Deoxy sugars (reduced sugars)

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

C-2 OH will be removed



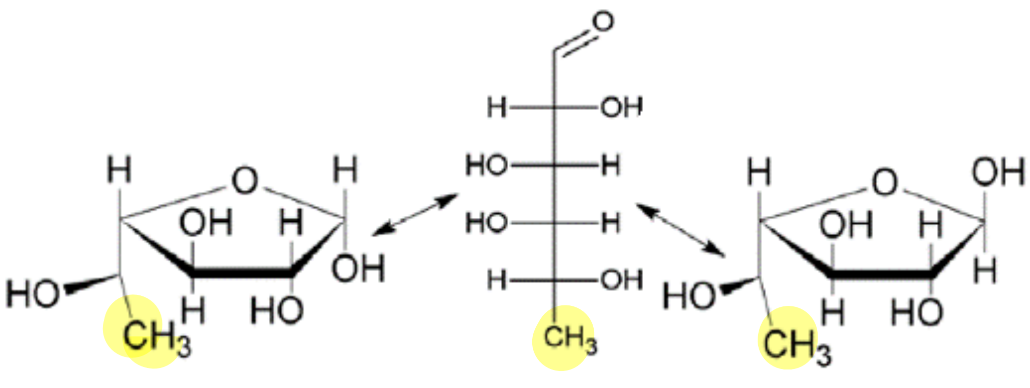

suger

reduced suger

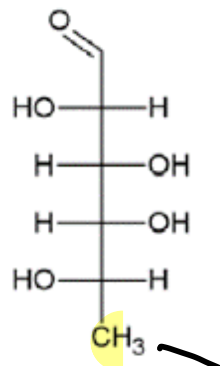
# Another deoxy sugar

- L-fucose (L-6-deoxygalactose)
  - found in the carbohydrate portions of some glycoproteins

↳ Antigens on RBCs

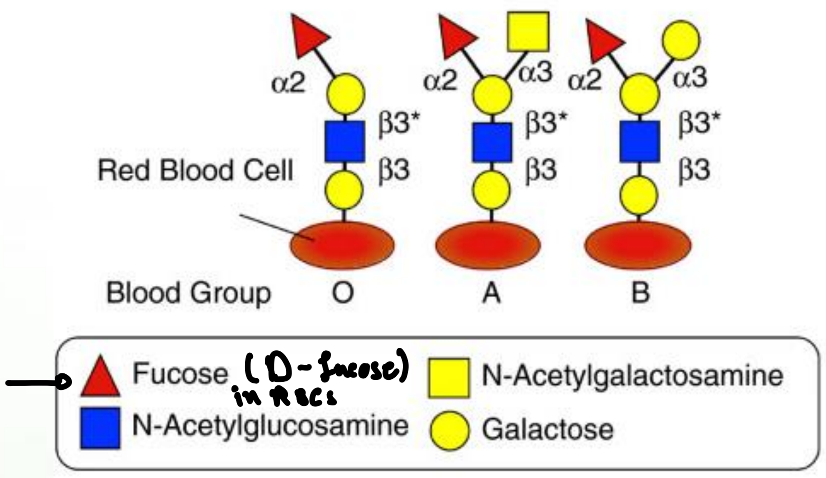



D-fucose (6-deoxy-D-galactose)



L-fucose
(6-deoxy-L-galactose)

was $CH_2OH$




**Do not memorize the structure but study it.**

**Do not memorize the components except for fucose.**

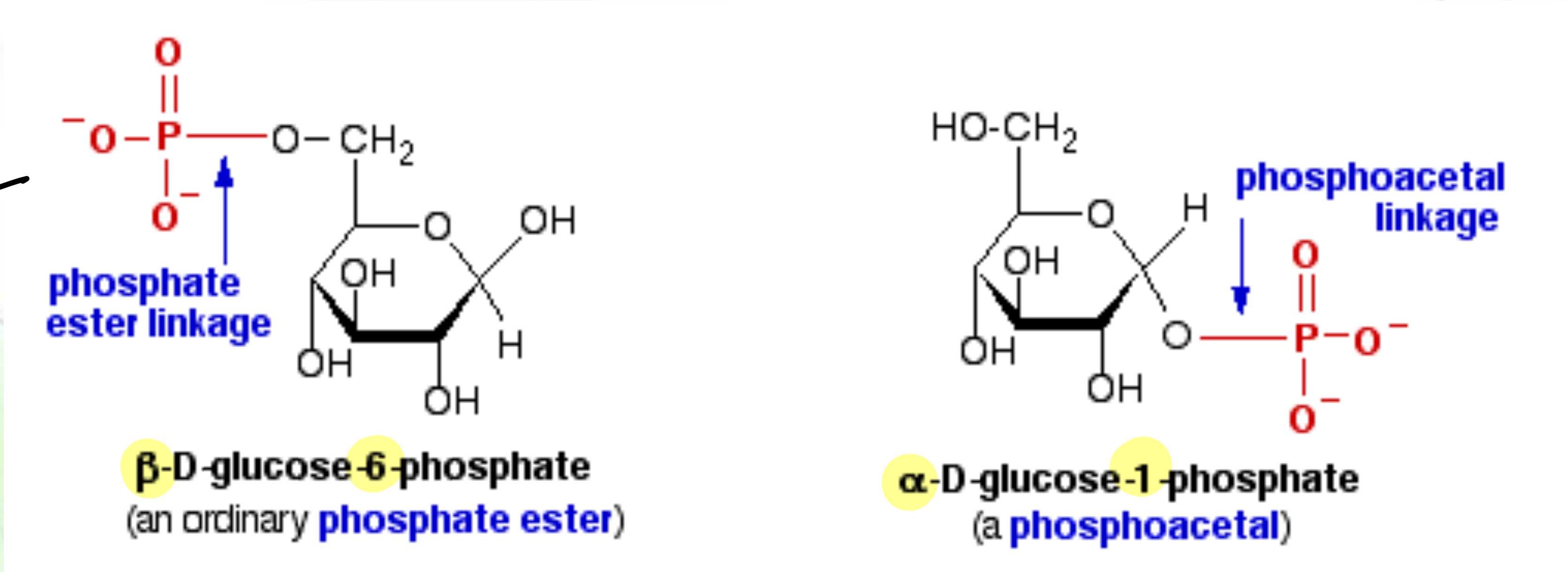
# Sugar esters (esterification)

↳ formation of ester

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

phosphorylation either at C-1 or C-6 → phosphoester

high energy molecule that helps in metabolism



# O-Glycosides

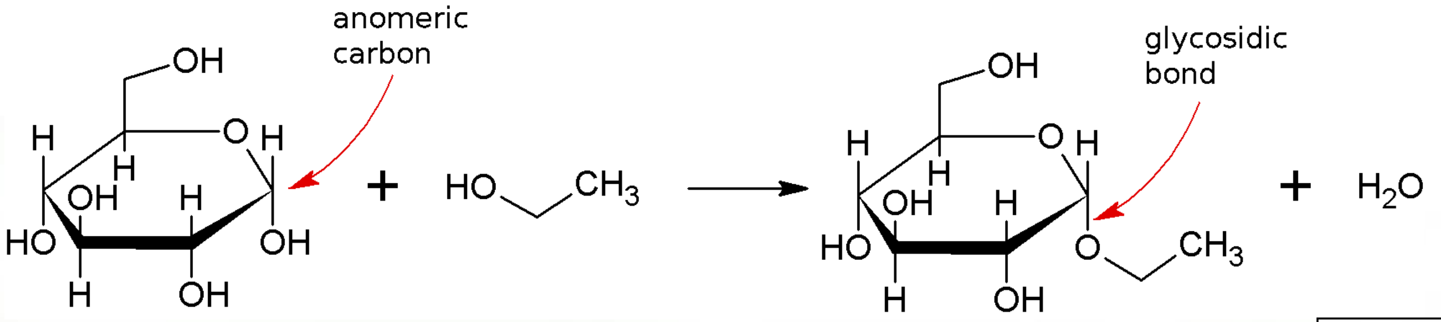
RxN of C-1 + OH

anomeric → glycosidic

↳ O from OH

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

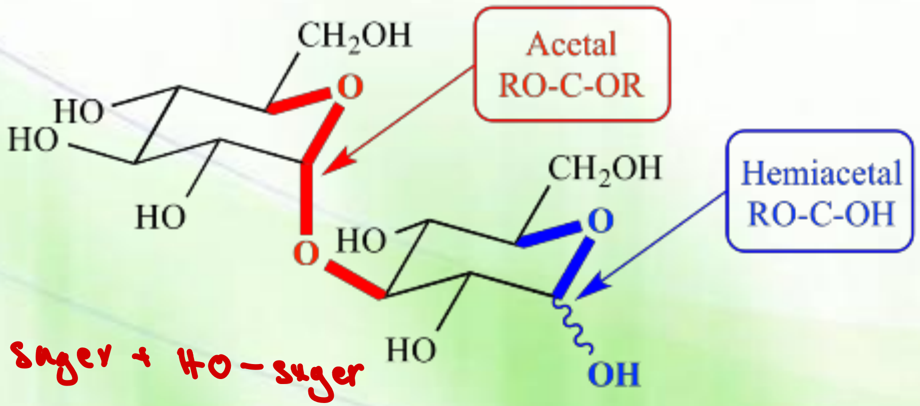
1-

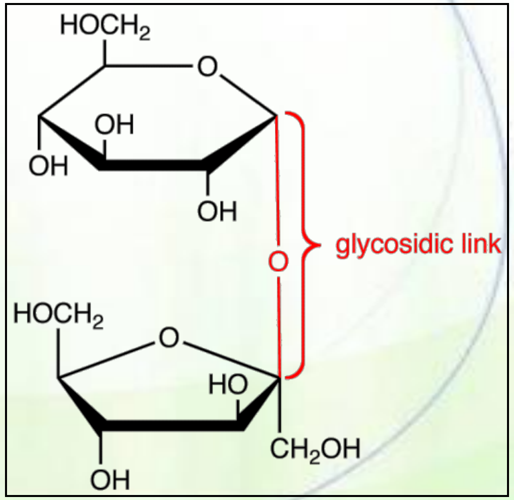



the bond can be α or β

depending on the position of C-1

→ once the rxn is formed no mutarotation (fixed) (importance)



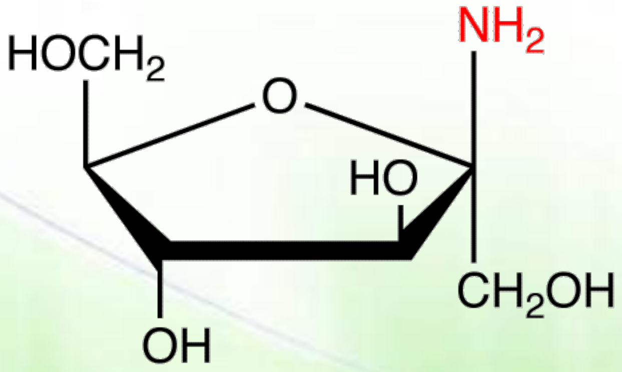

another way: sugar + HO-sugar

# N-Glycosides

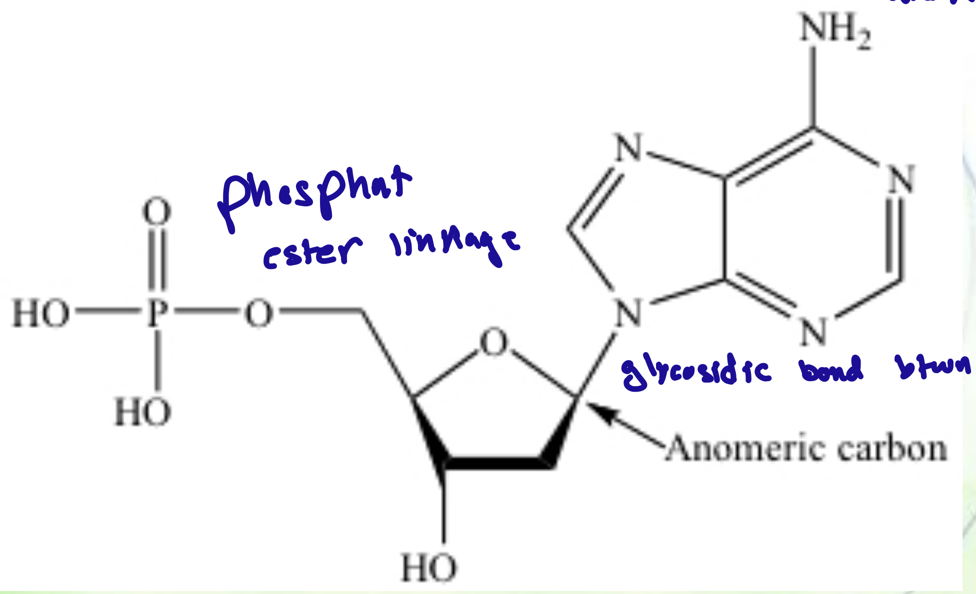
monosach + amine → glycosidic bond

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

the glycosidic can be btwn both anomeric carbons




*N*-glycoside

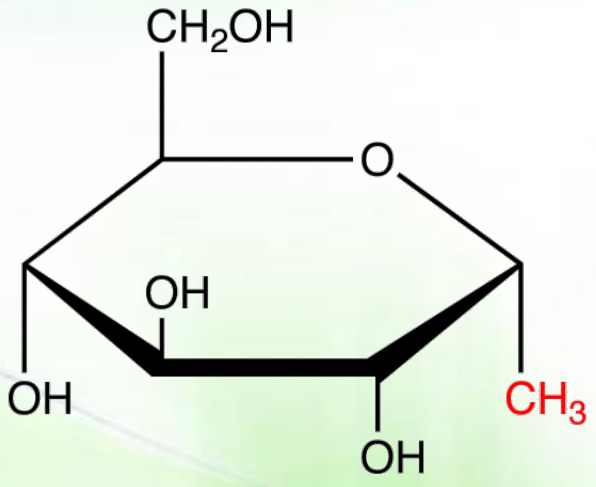



phosphat ester linkage

glycosidic bond btwn C & N

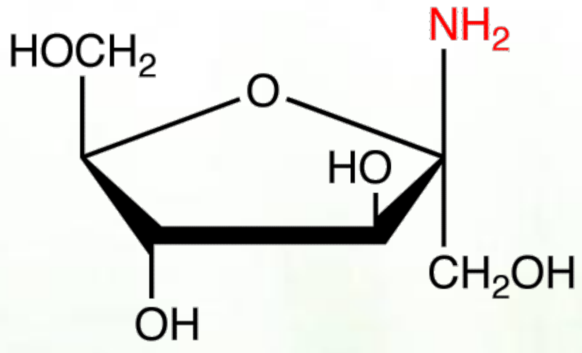
# Note

- 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

↳ methyl




*N*-glycoside

# Amino sugars

* addition of an amine group

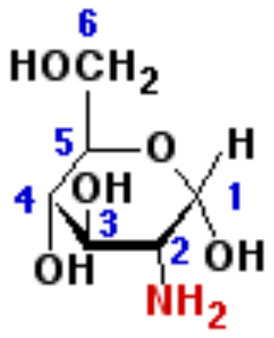
- What is the reacting functional group? Where does it react? What are the end products? Where are they used?
- Further modification by acetylation

differ from N-glycosidic

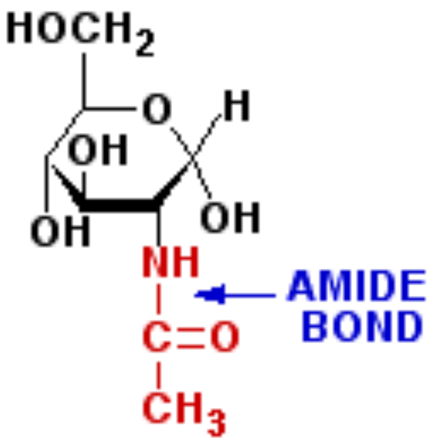
N replaces OH of C other than the anomeric (C)

usually # 2

* the bond is amine bond




α-D-2-glucosamine
(GlcN)

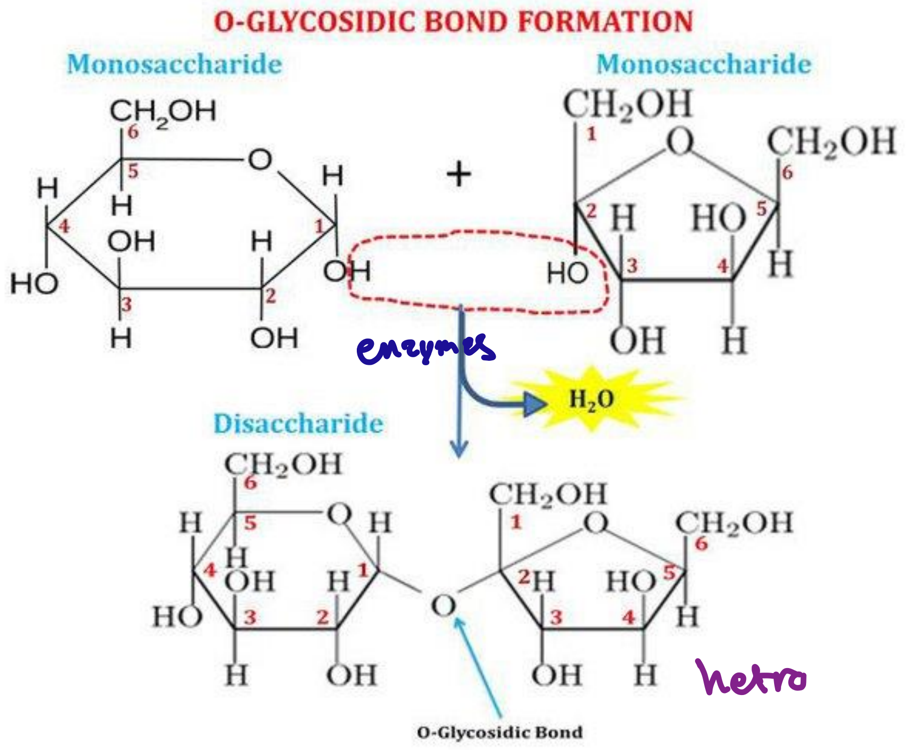



N-acetyl-α-D-2-glucosamine
(GlcNAc)

# Disaccharides

2 sugers 3~10

- What are disaccharide? Oligosaccharides? Hetero- vs. homo-?
  diff suger — same suger
- What is the type of reaction? condensation: release of $H_2O$ (involves the C-1)
- What is a residue? each subunit
- Synthesizing enzymes are glycosyltransferases. (transfer suger)
- Do they undergo mutarotation? no
- Are products stable? yes



# Distinctions of disaccharides

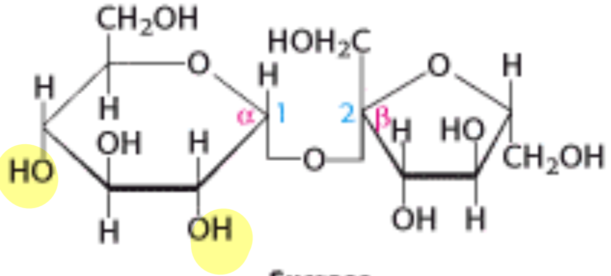
- The 2 specific sugar monomers involved and their stereoconfigurations (D- or L-)
- The carbons involved in the linkage (C-1, C-2, C-4, or C-6)
- The order of the two monomer units, if different (example: galactose followed by glucose) Identity of the sugar
- The anomeric configuration of the OH group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

All sugars in the body are D & for the exam purposes

# Abundant disaccharides

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

non-reducing

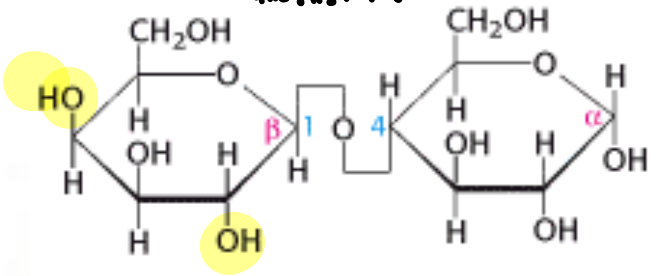


table

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

the first residue of the disaccharides

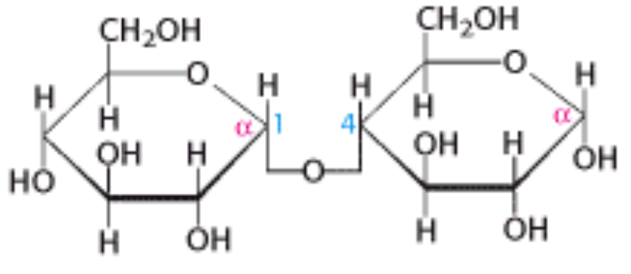
reducing



Milk

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

reducing



Malt

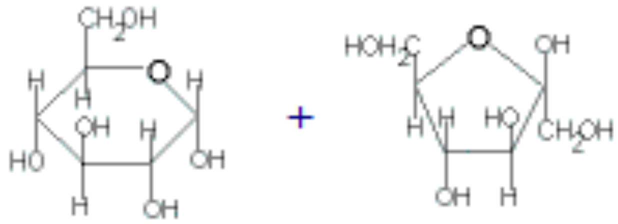
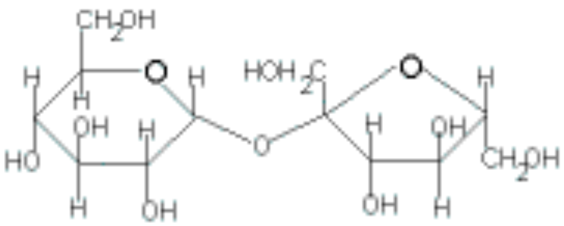
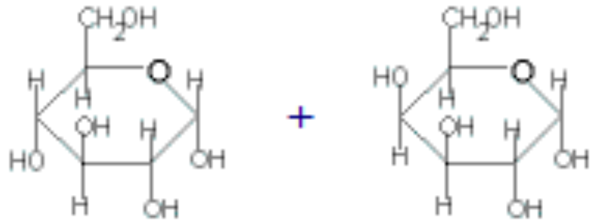
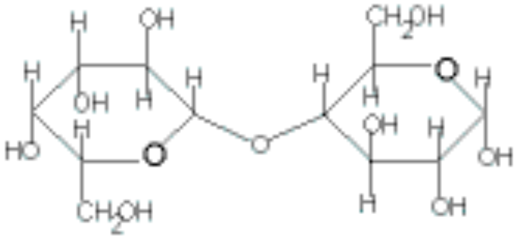
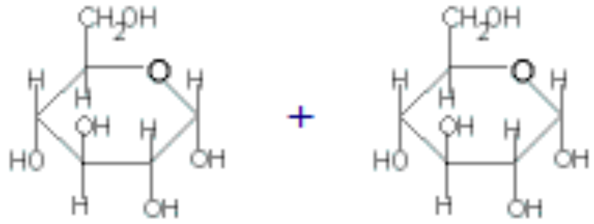
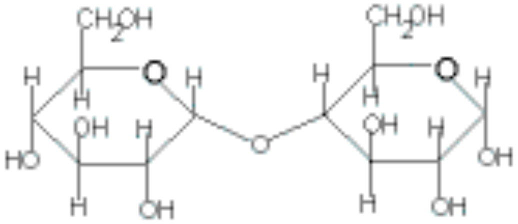
Maltose
(α-D-Glucopyranosyl-(1→4)-α-D-glucopyranose

*steps to identify the sugar
- pyran or furan
- OH on C2
- OH on C4

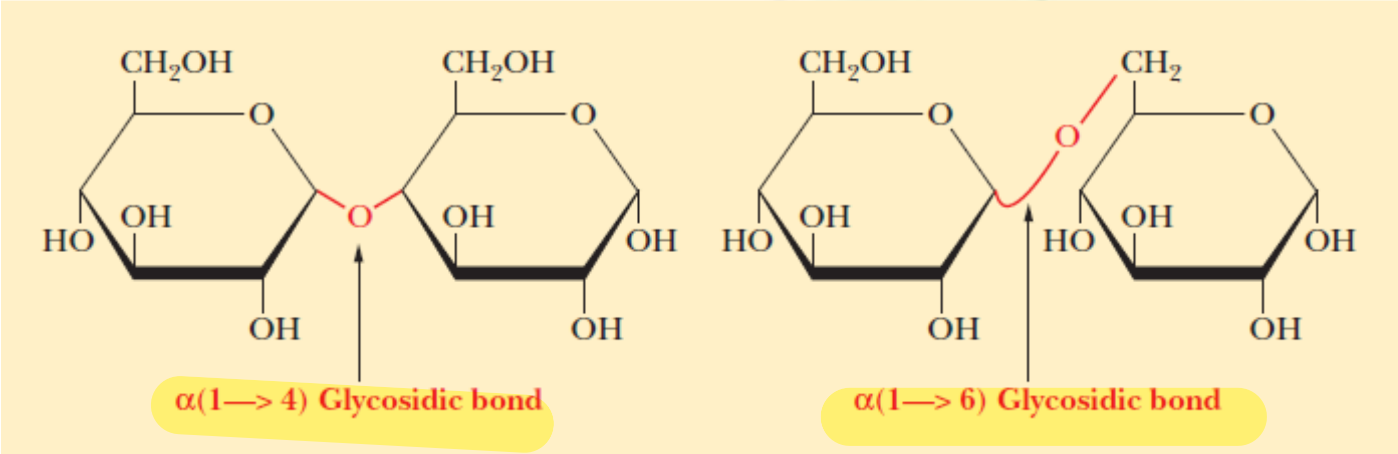
eg: pyran - OH on C2 below - OH on C4 below → Glucose

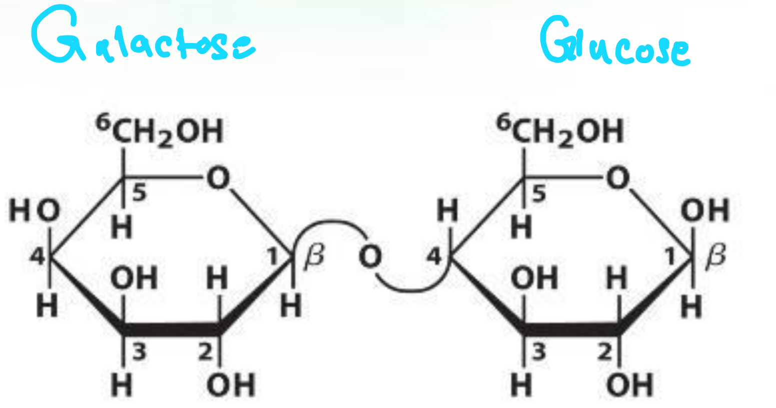
* at least one free anomeric carbon (then all monosacch- are reducing

* non-reducing = no-free C-1

| 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

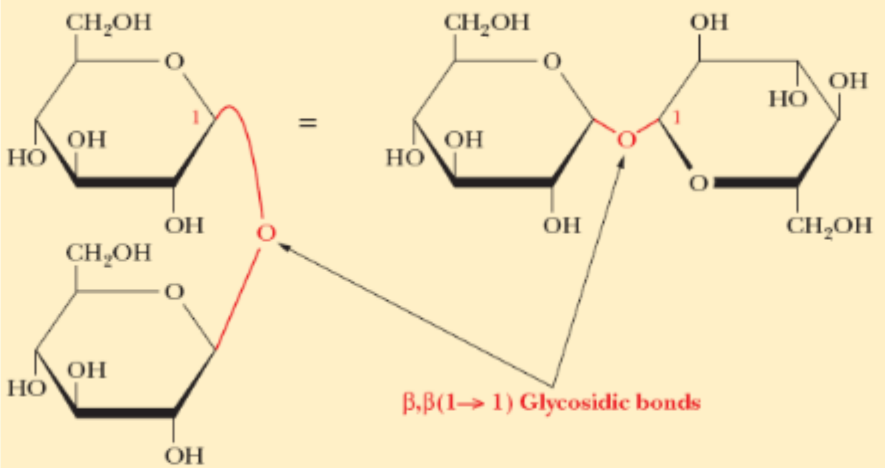



Lactose ($\beta$ form)

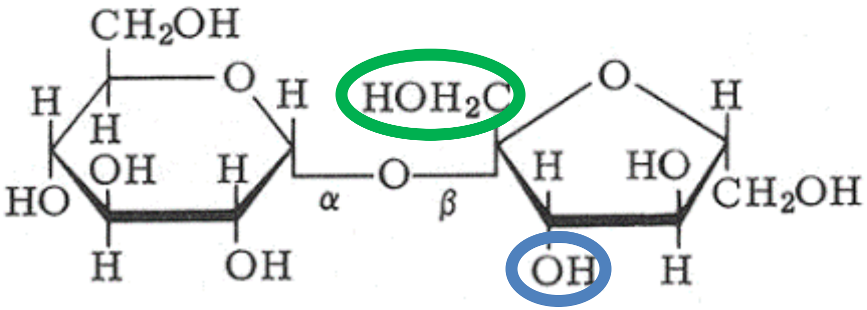
$\beta$-D-galactopyranosyl-(1→4)-$\beta$-D-glucopyranose

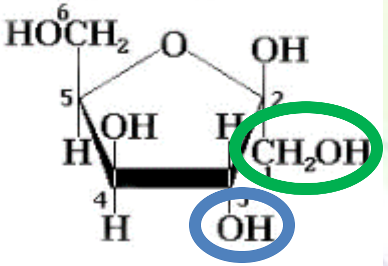
Gal($\beta$1→4)Glc

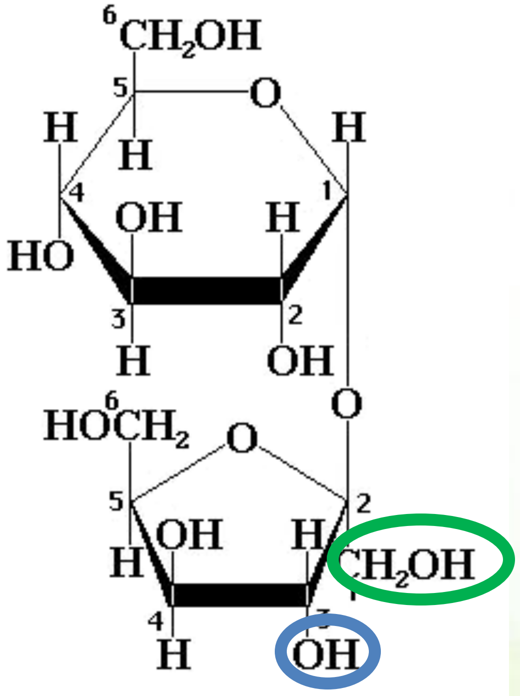



**A disaccharide of β-D-glucose.**

# Sucrose



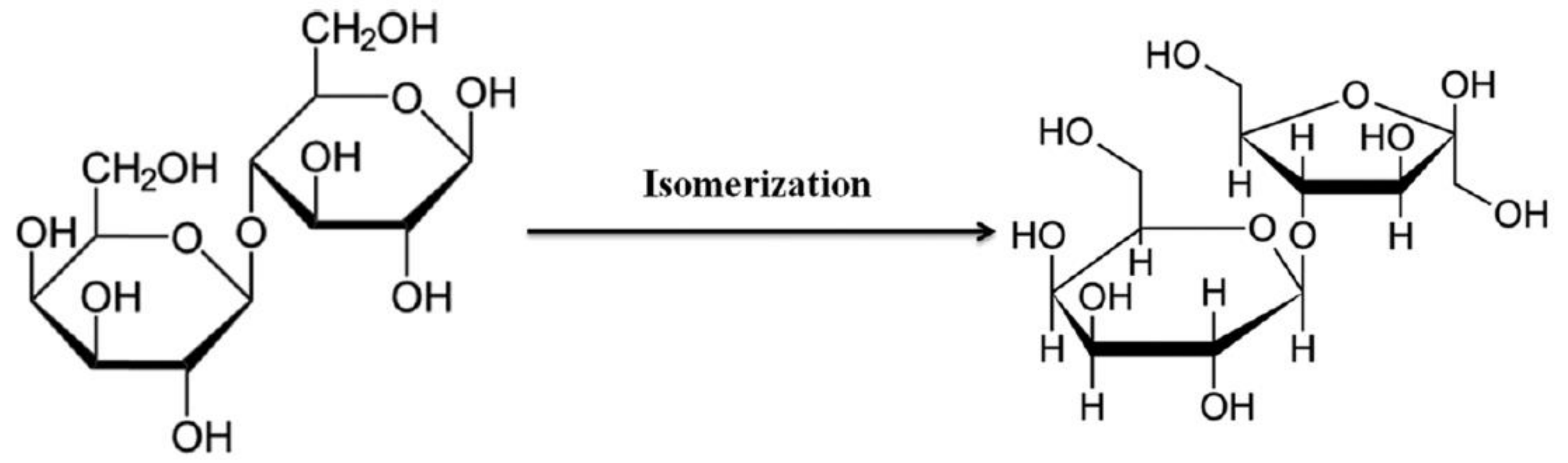

This is extra

# Lactulose

ريان بني سلامة

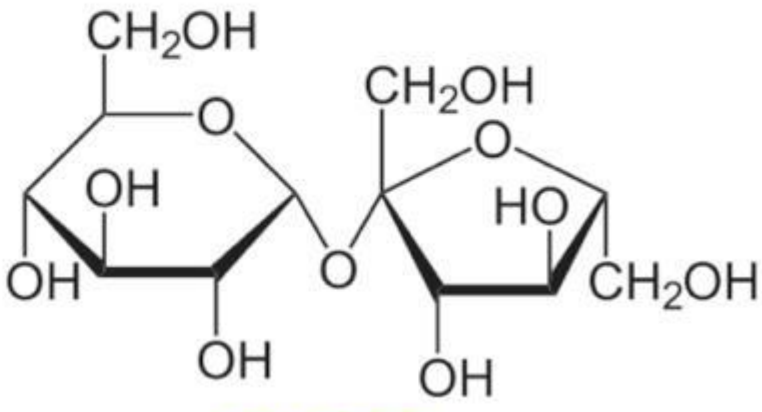
**Do not memorize the structure but study it.**

- It is formed by the isomerization of lactose.
- It has health benefits:
  - It is used in treating constipation.
  - It promotes the growth of health-promoting gut bacteria.
  - It modulates the immune system.

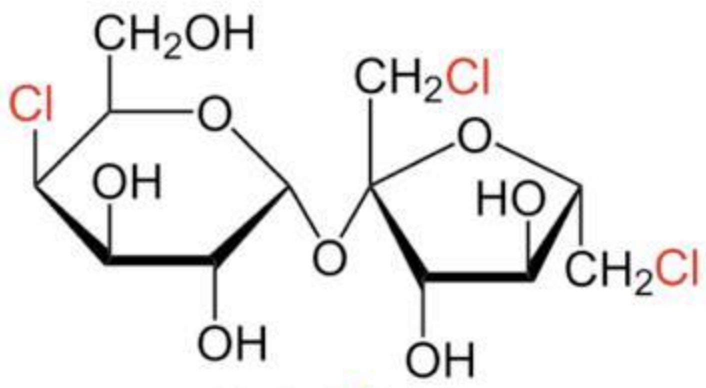




Lactose Lactulose

# Sucralose (artificial sweetener)




sucrose




sucralose


can be damiging

News > WebMD Health News

## Sucralose Damages DNA, Linked to Leaky Gut: Study

Lisa O'Mary
June 01, 2023

WebMD

## Sucralose, a Common Artificial Sweetener, May Increase Cancer Risk

# Milk problems

gases
pain, sounds → due to bacteria

- Lactose Intolerance: A deficiency of the enzyme 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, → (nerve damage) resulting in severe and irreversible retardation. mental retardation It also causes cataract. → eventually blindness

# Raffinose

بسبب نفخة

3 -10

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


زهرة

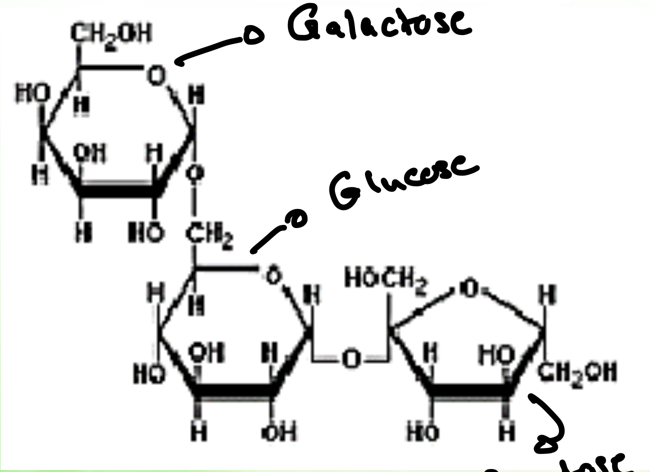
+ حمض

"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.**

Galactose

Glucose



fructose

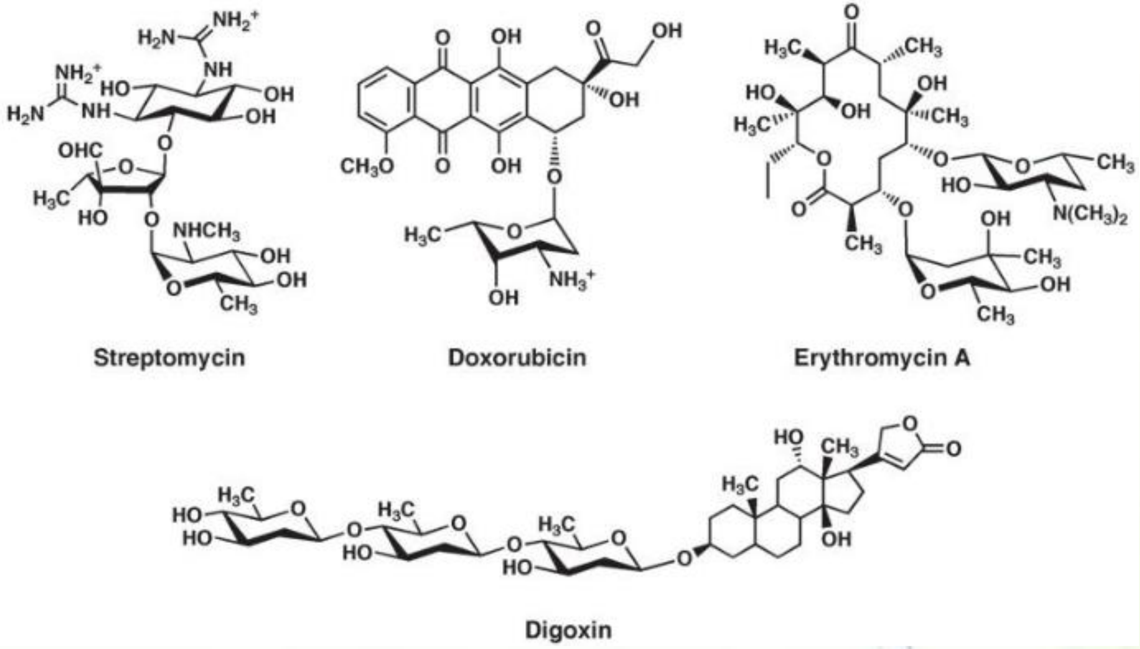
## Homework

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)

they are modified sugars




Do not memorize or study the structures.

# Polysaccharides

o large sugers

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

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

# Glycogen

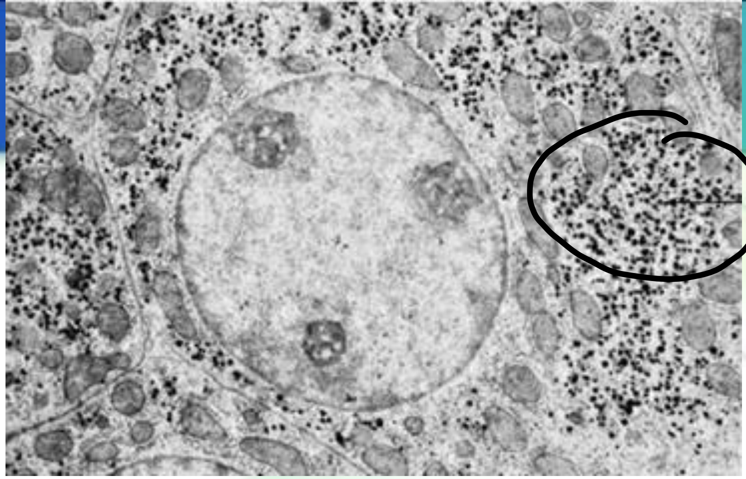
→ humans
↳ animals

Storage

Glocuse stored in Cell

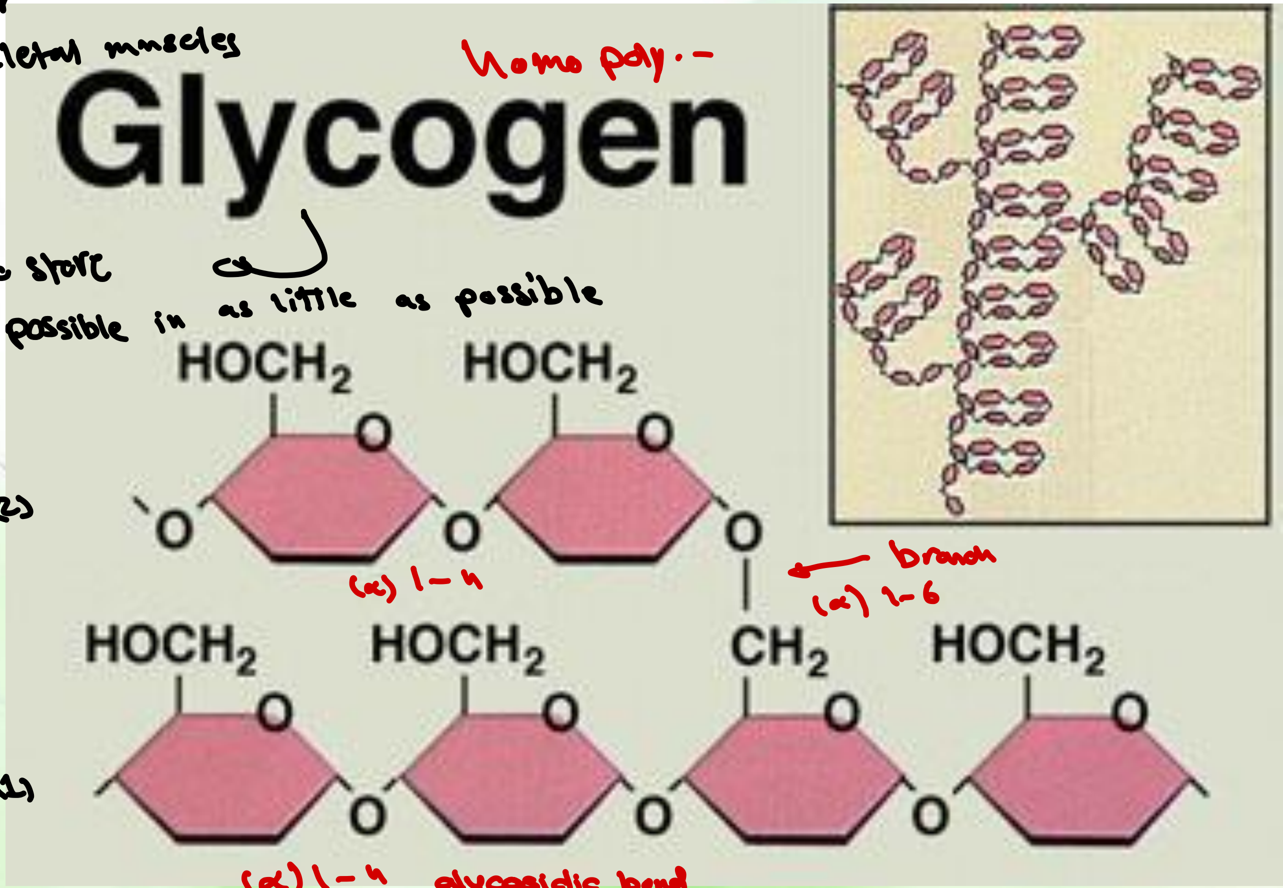
90% → liver

10% → skeletal muscles



→ every black dot is a glycogen

homo poly.-




flexiable to store as many as possible in as little as possible

chain(2)

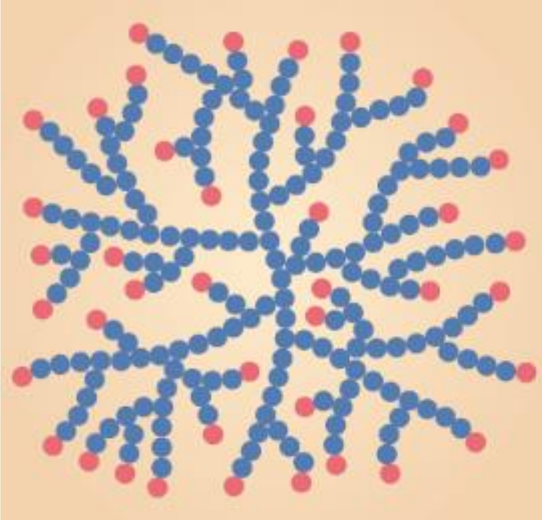
(α) 1-4

← branch (α) 1-6

chain(1)

(α) 1-4 glycosidic bond

Memorize



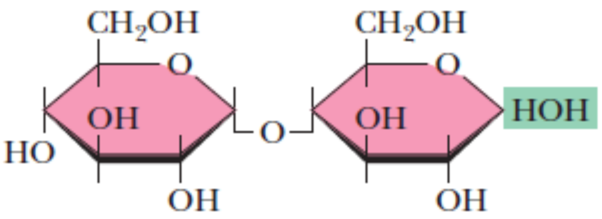
α glycosidic is flexible so it can rotate

# Starch → plants

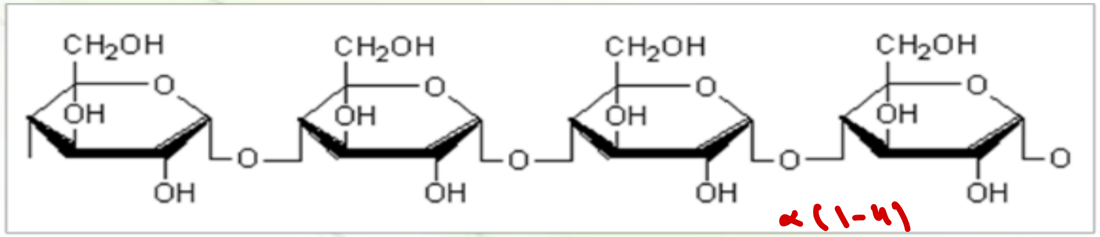
→ homo poly . . .

→ storage

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

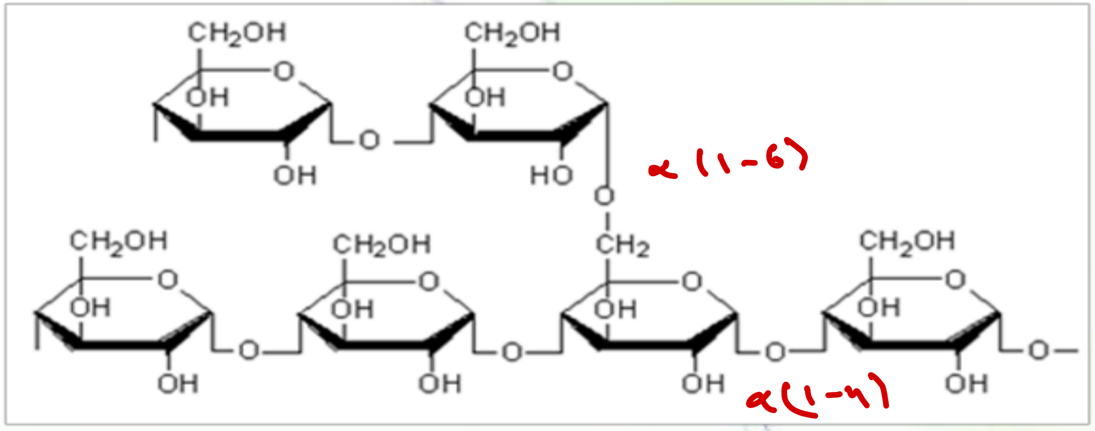



Maltose (glucose-α-1,4-glucose)




α(1-4)

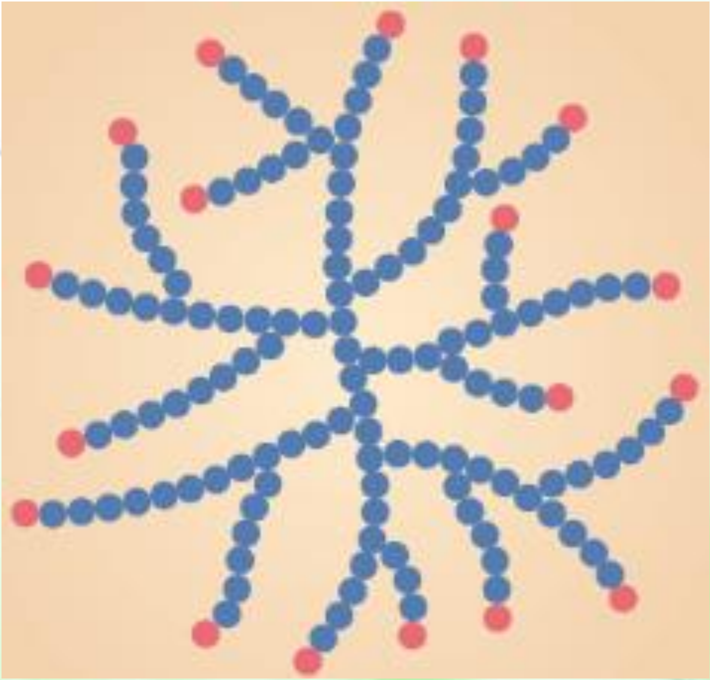
Amylose Structure




α(1-6)

α(1-4)

(branch ) Amylopection Structure

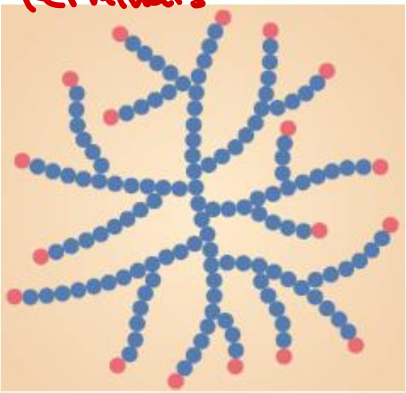


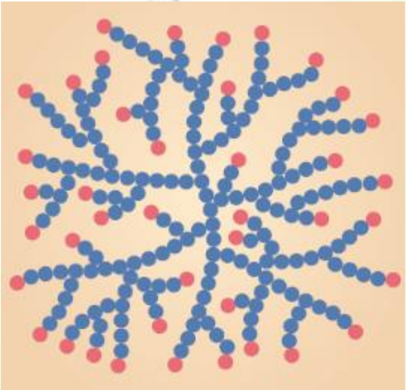
**Memorize**

# 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. → cuz in plants they have more water
  - Easy access to glucose residues. → due to many terminals

* more glucose can be stored

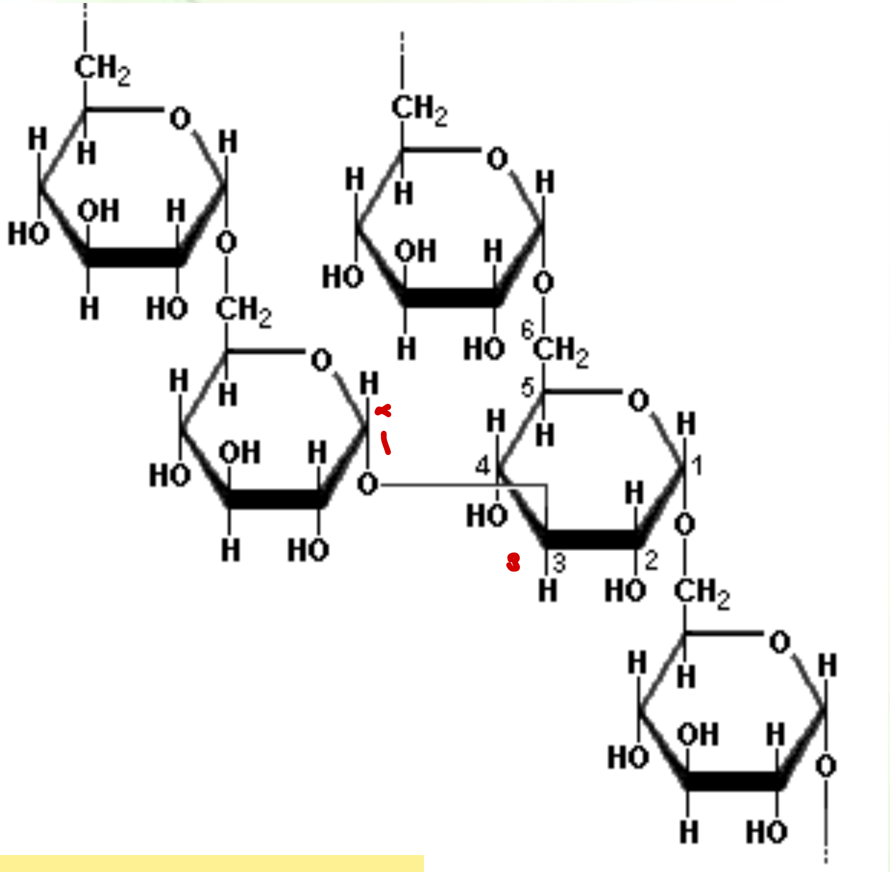




# Dextran ( homo poly.. )

↳ Storage

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



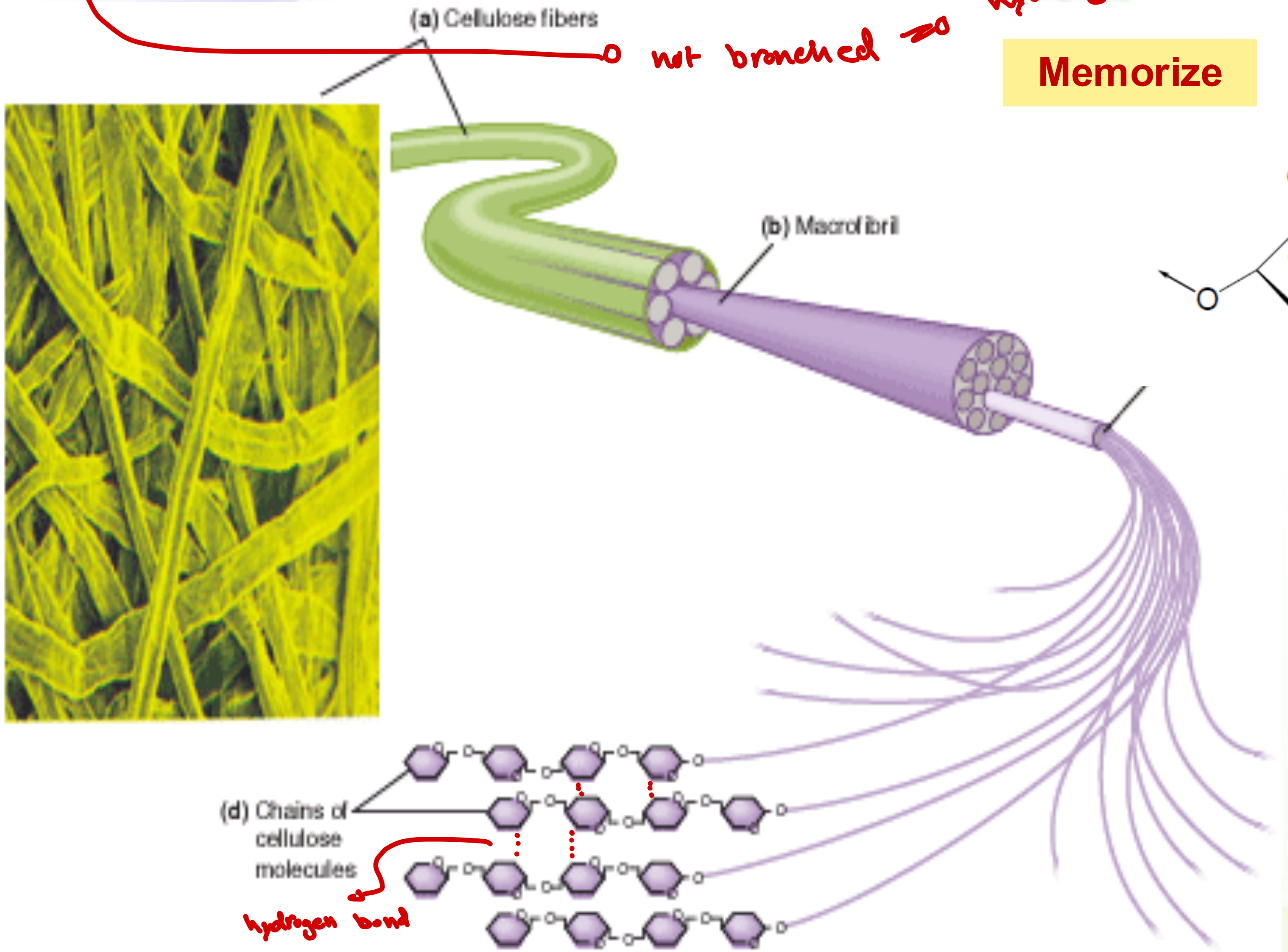

**Do not memorize or study the structures.**

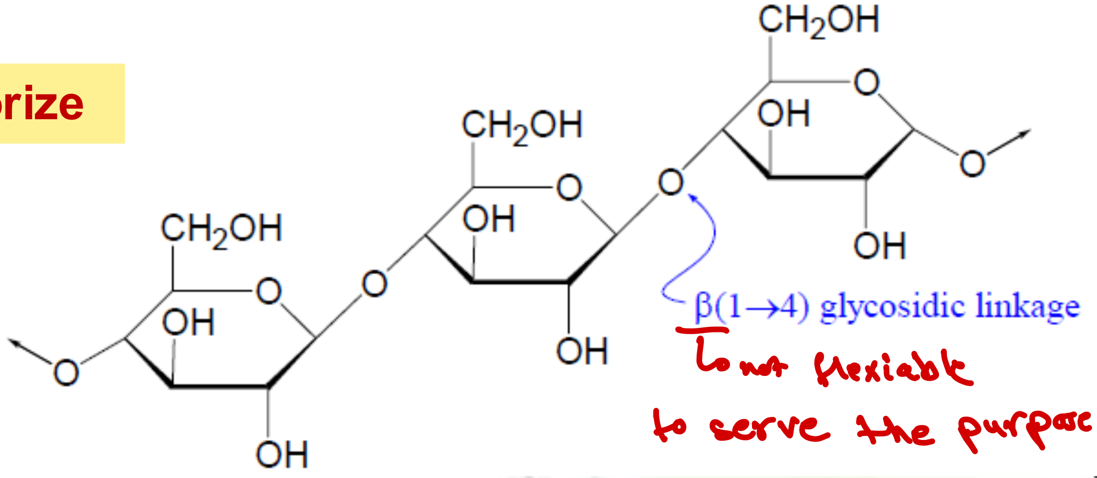
# Cellulose

↳ structural homo poly

→ not branched ⇒ hydrogen bondes ⇒ stronger

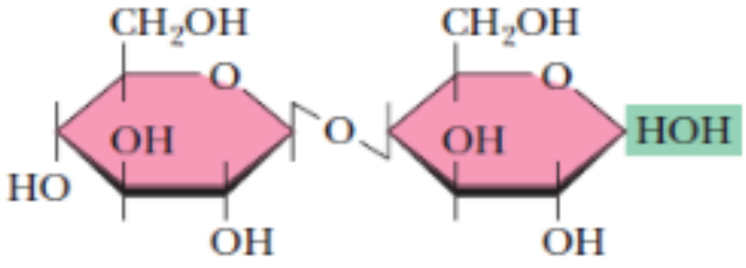
**Memorize**




↳ not flexiable

to serve the purpose




Cellobiose (glucose-β-1,4-glucose)

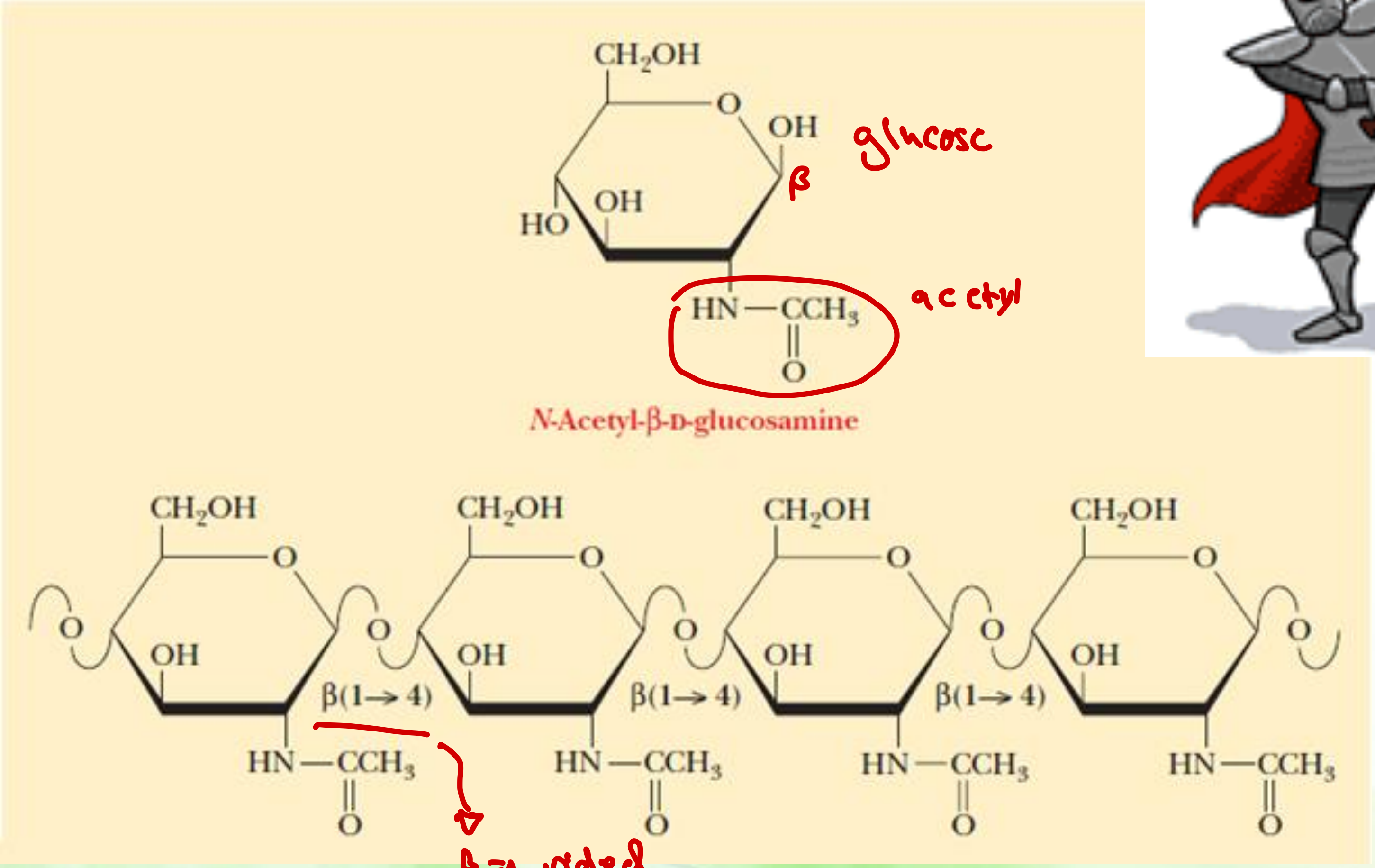
* its healthy → bully ⇒ more water

making stool moies (براز) (رطب)

# Chitin

↳ homo poly

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





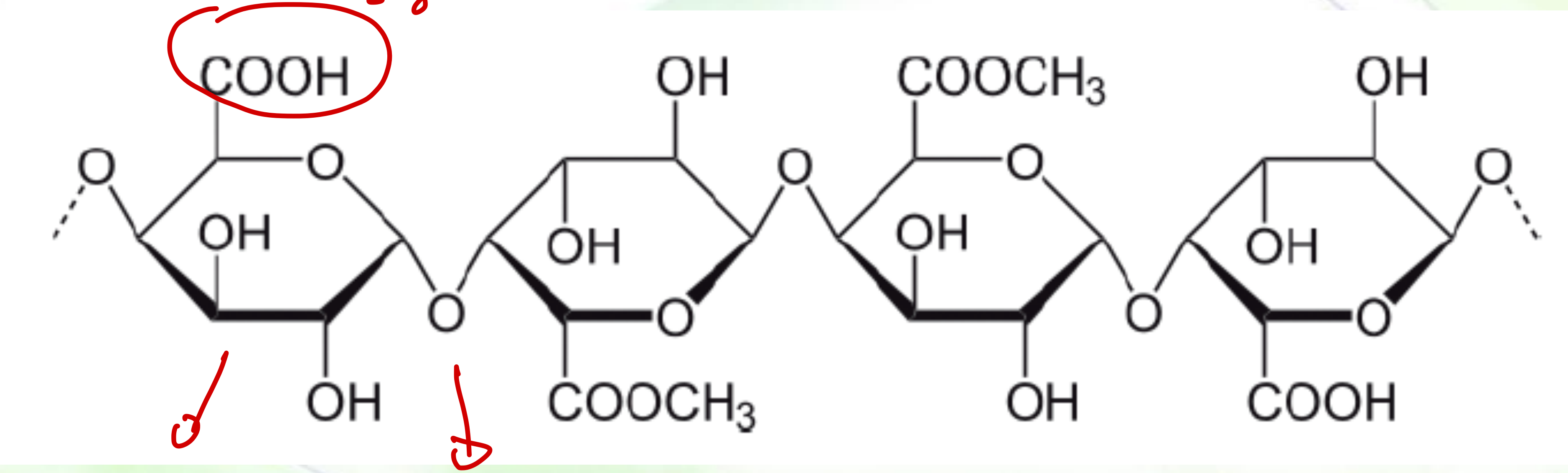
~~Do not memorize or study the structures.~~

memorize & study

# Pectin → plants

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

suger acid




galactose

β (1-4) glycosidic

~~Do not memorize or study the structures.~~

# Are polysaccharides reducing?

↳ it excist in termni but over all
they are not

- 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 → hetro poly...

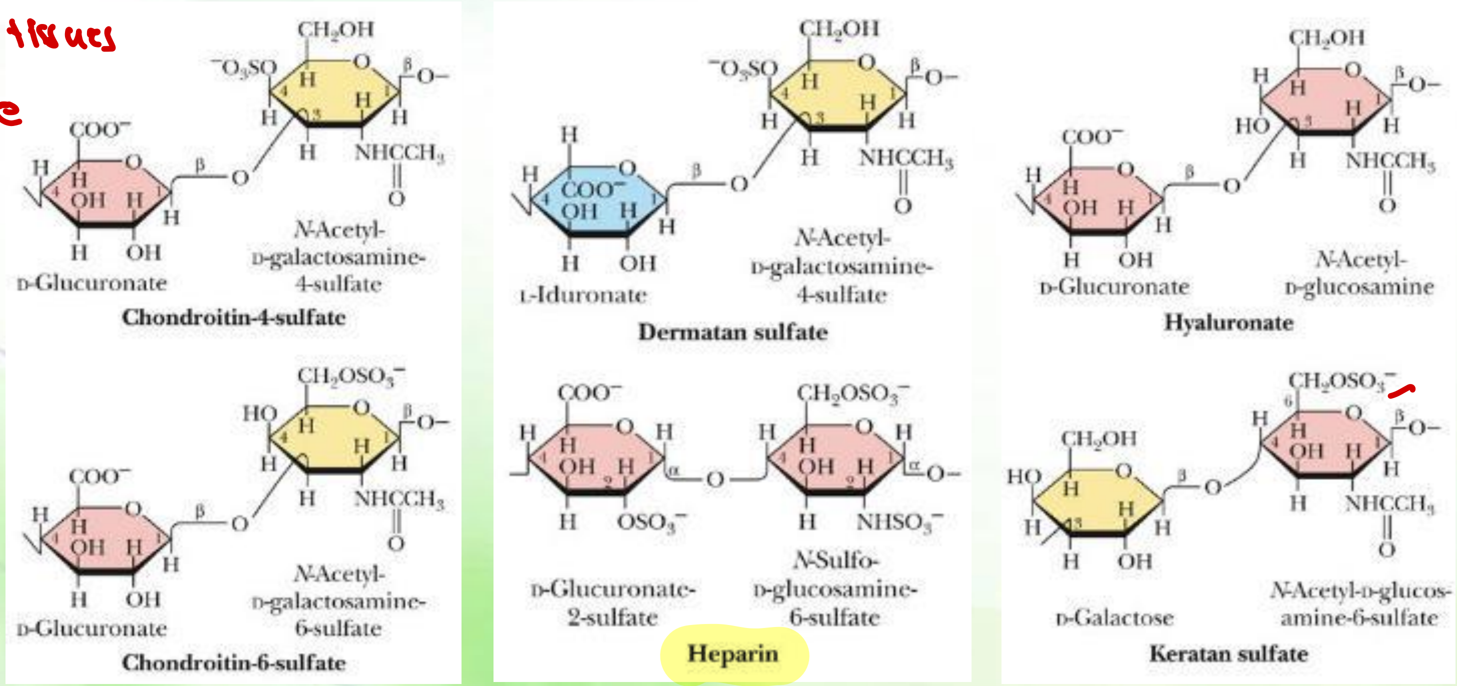
→ repeated disaccharides
at least one is an amino sugar

→ in ECM
makes CT

- 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

→ makes repulsion to cushion

* they exist in tissues like cartilage




**Do not memorize or study the structures.**

Questions would be identify the structure

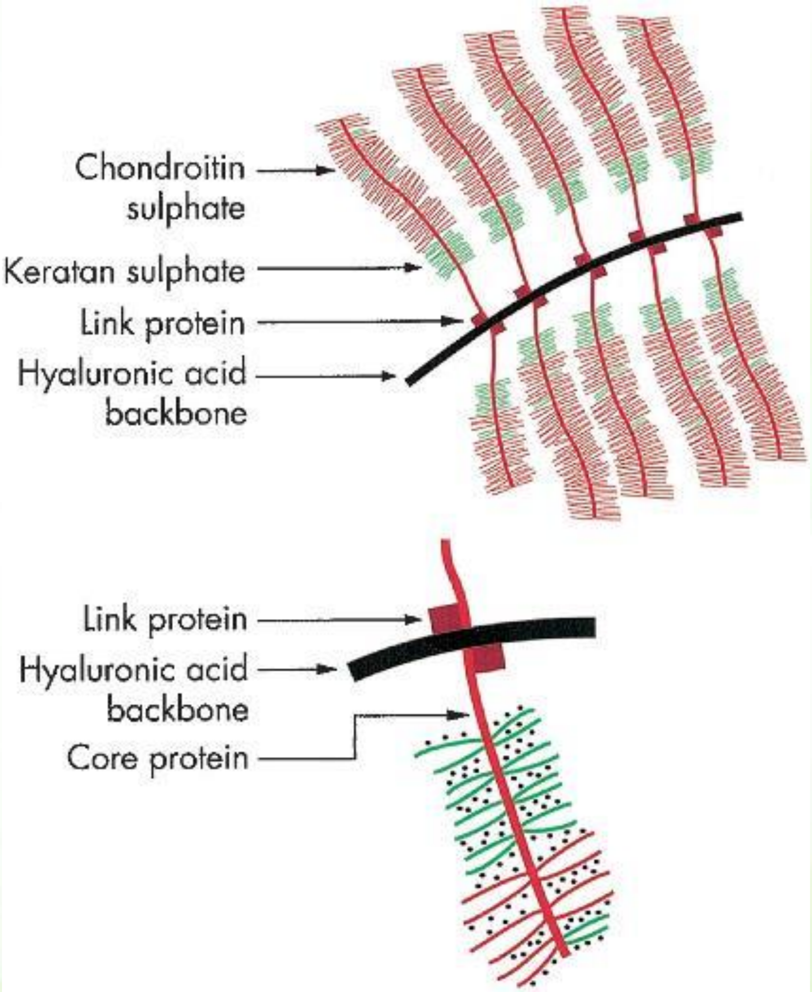
# Localization and function of GAG

| GAG | Localization | Comments |
|---|---|---|
| Hyaluronate | synovial fluid, **vitreous humor, ECM of loose connective tissue** | **the lubricant fluid , shock absorbing**<br>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<br>lining the arteries of the lungs, liver and skin | يمنع التخثر<br>**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

↳ large sugar w/ peptides

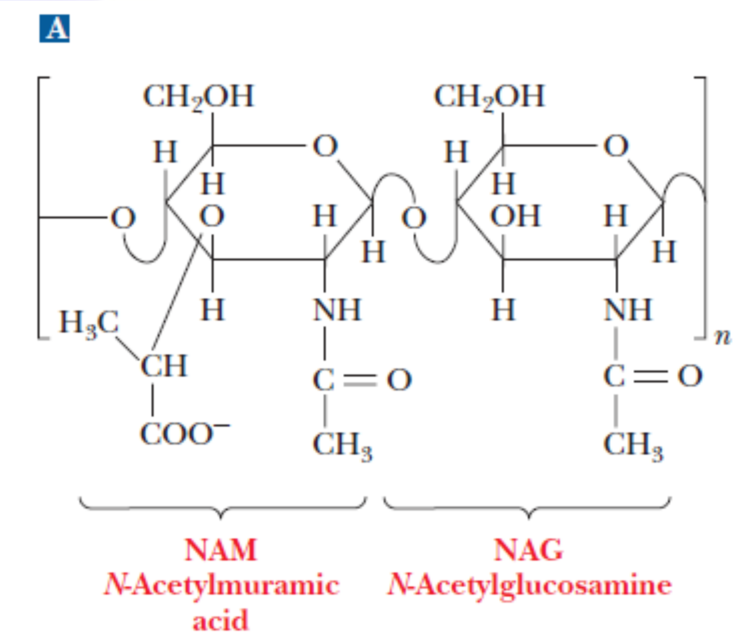
- Lubricants
- Structural components in connective tissue
- Mediate adhesion of cells to the extracellular matrix
- Bind factors that stimulate cell proliferation

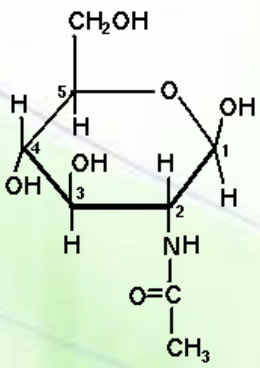



* they connect cells so they communicate

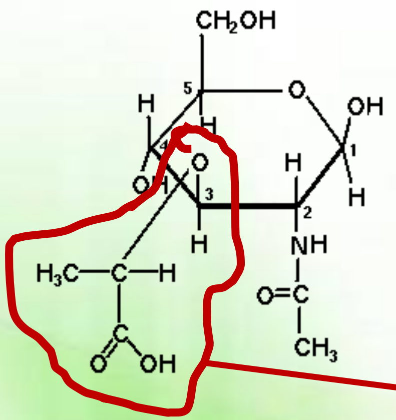
* nutrients are stored in them

# Bacterial cell wall



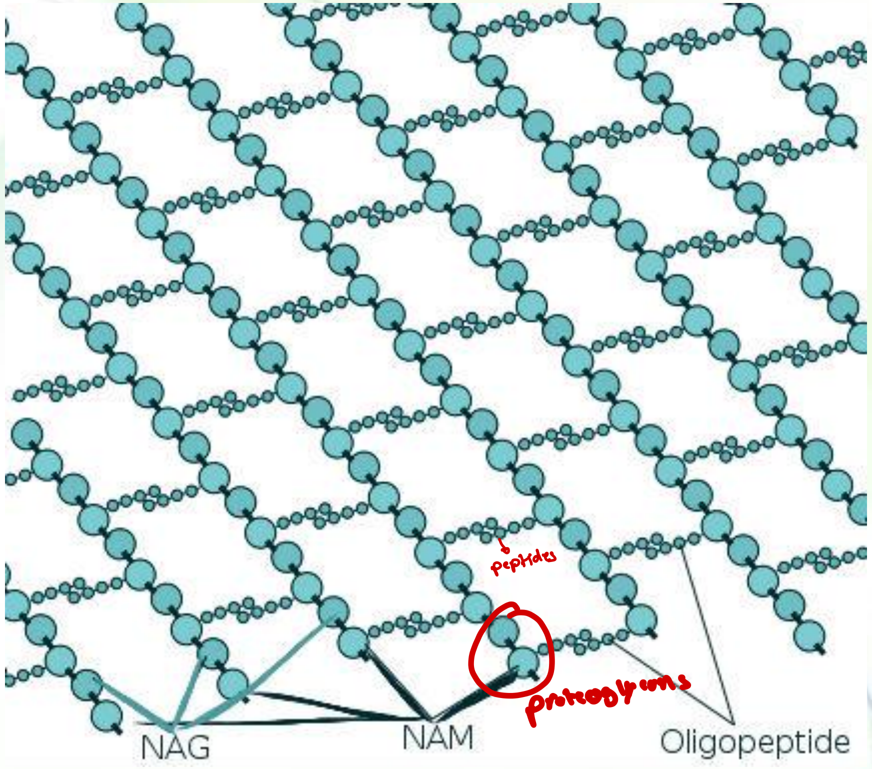




N-acetylglucosamine (NAG)




N-acetylmuramic acid (NAM)

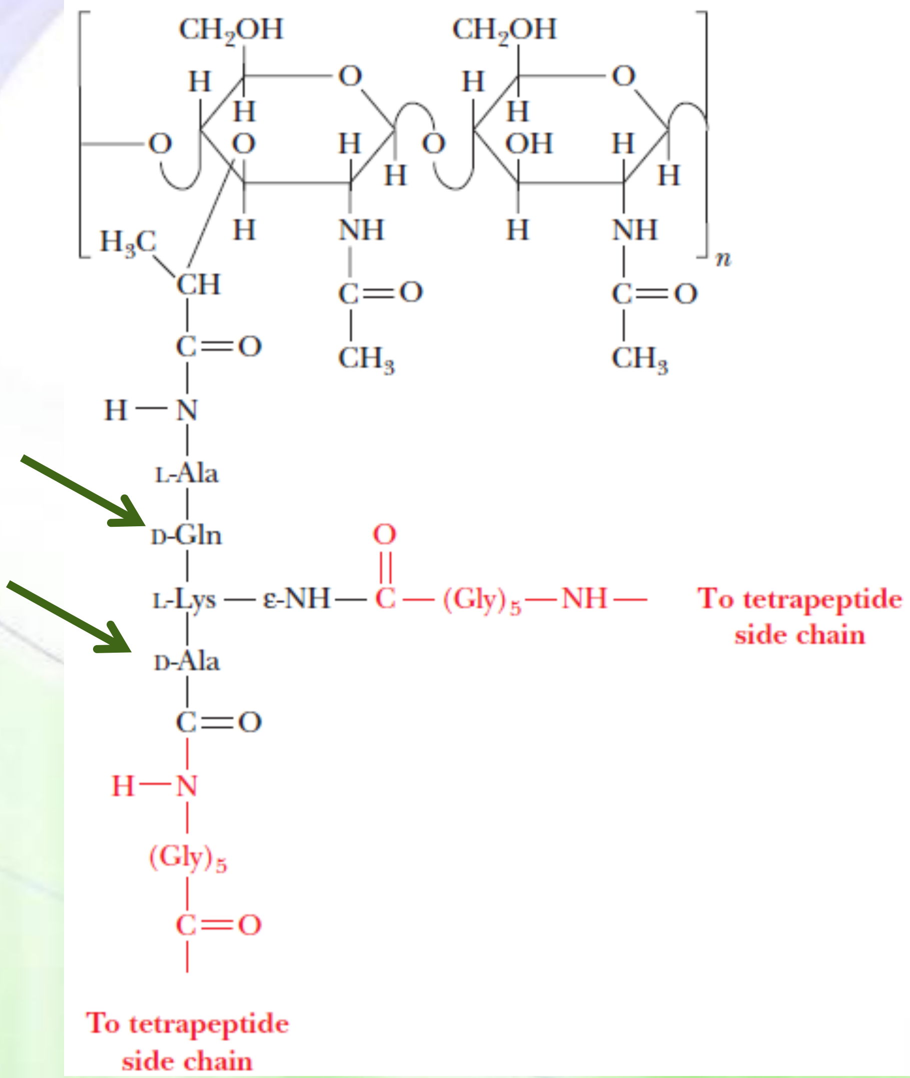
Lactic acid

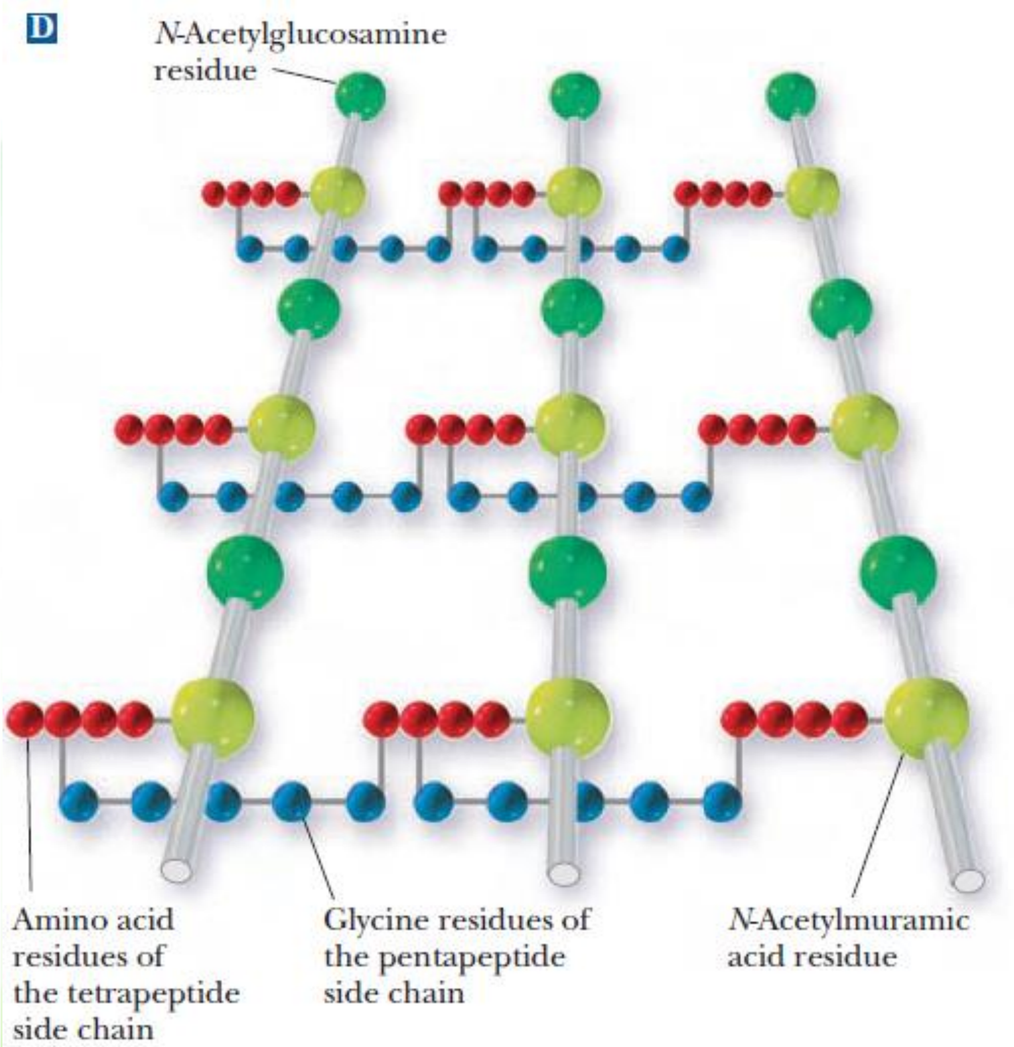



Chains that are not branched

**Do not memorize or study the structures.**

# Peptidoglycan



# Glycoproteins

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

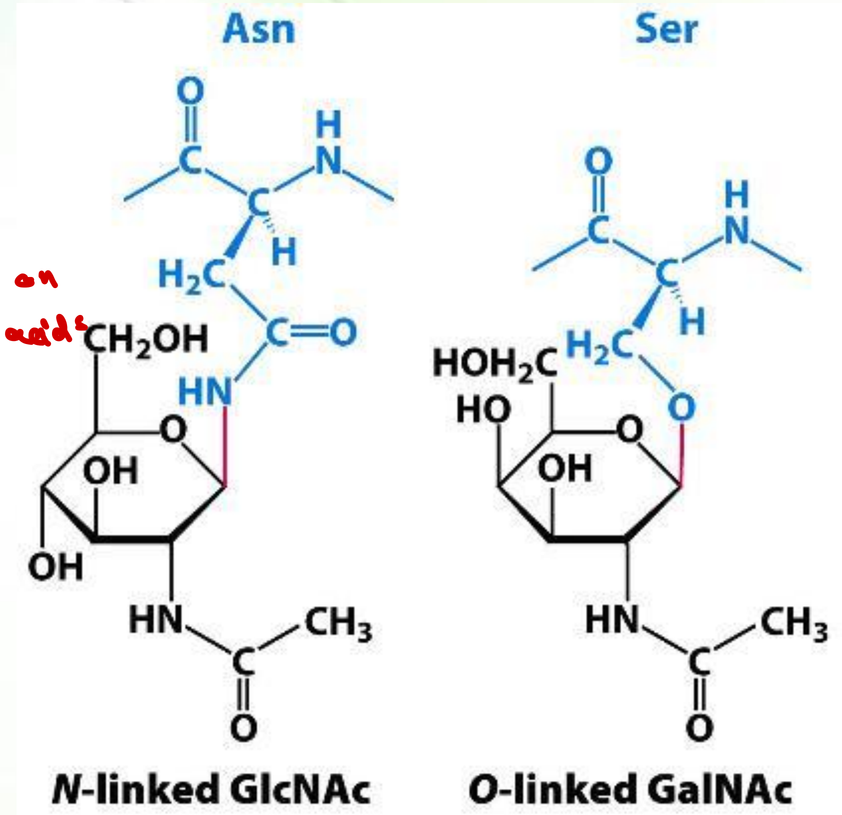



Figure 11.15
*Biochemistry*, Seventh Edition

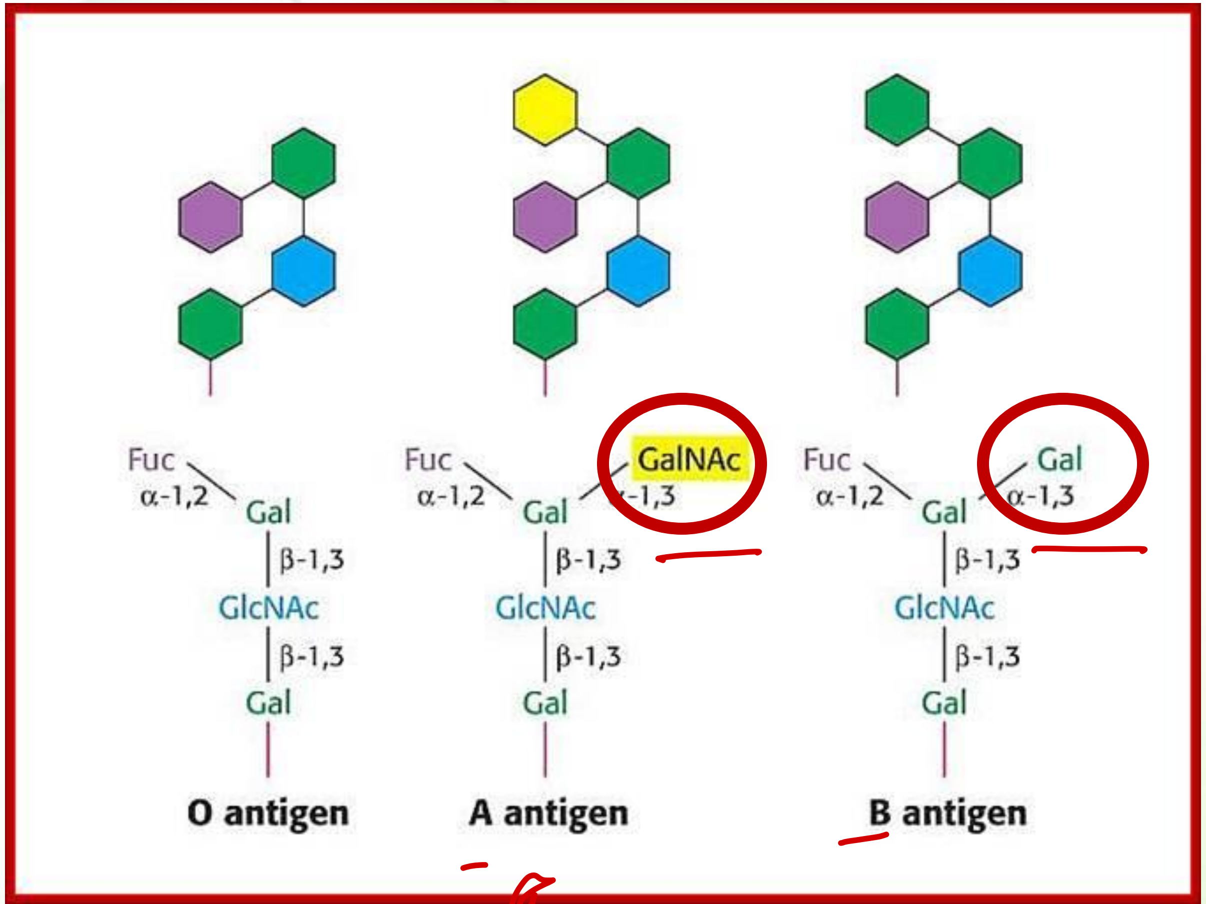

**Do not memorize or study the structures.**

# Significance of protein-linked sugars

- Soluble proteins as well as membrane proteins
- Purpose:
  - Protein folding
  - Protein targeting → where to send the protein
  - prolonging protein half-life (stability)     glycocilated → it has sugars
  - Cell-cell communication
  - Signaling

# Blood typing and glycoproteins

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

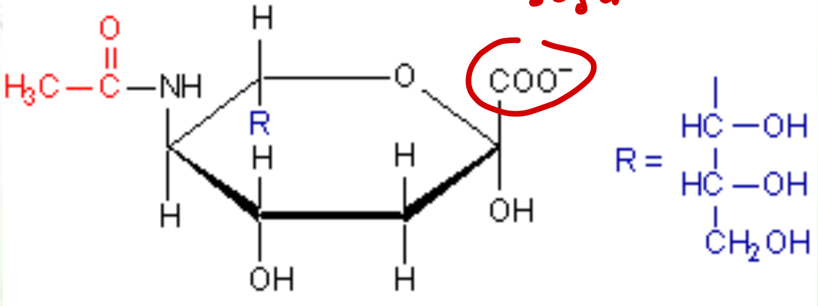


# Sialic acid

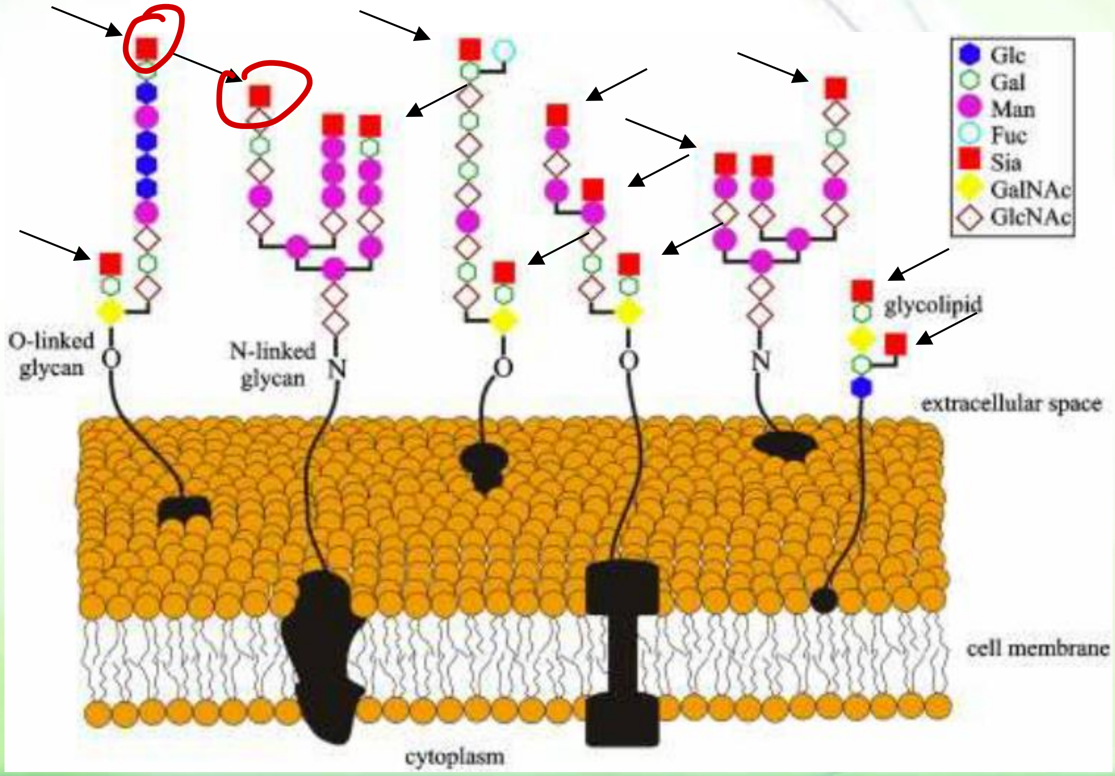
ريان بني سلامة

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

sugar acid




*N*-acetylneuraminate (sialic acid)




**Do not memorize or study the structures.**

من يفعل خيراً لا يعدم جوازيه

لا يذهب العرف بين الله والناس

ريان بني سلامه Ray