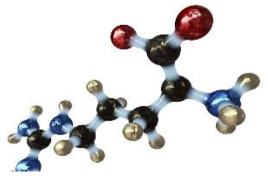
بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ



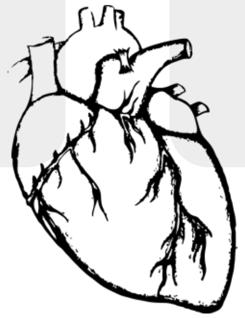
BioChemistry

﴿ وَلَقَدۡ خَلَقۡنَا ٱلۡإِنسَٰنَ وَنَعۡلَمُ مَا تُوَسۡوِسُ بِهِۦ نَفۡسُهُۥۖ وَنَحۡنُ أَقۡرَبُ إِلَيۡهِ مِنۡ حَبۡلِ ٱلۡوَرِيدِ ﴾

MID | Lecture #7

Carbohydrates pt.2

Written by : Ali Alsharaeh
Khaled Abdalla



Reviewed by : Yaman Khalil

Color coding used in the modified:

- *Black: the original slides*
- *Navy Blue: the doctor's explanation/words*
- *Gray: additional information and explanation*
- *Red: important information*

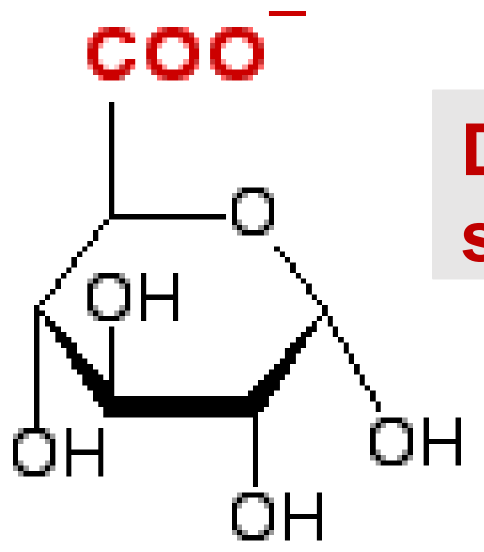
Modified sugars

- When sugars are modified they no longer considered sugars. Modifying sugars is replacing a group with another group, oxidizing and reducing, or removing groups.

Sugar acids (oxidation)

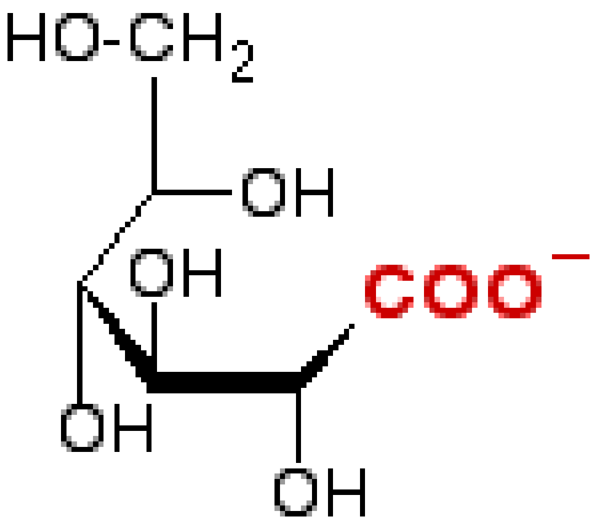
If a sugar is oxidized, it reduces another molecule (reducing sugar)

- Where is it oxidized? What does it form?
  - Hydroxyl group can be oxidized and converted to aldehyde (which can be oxidized and turned into a carboxyl group) or ketone which cannot be oxidized.
  - When you oxidize the 6th carbon on glucose : α-D- gluc<u>ur</u>onic acid.
  - When you oxidize the 1st carbon on glucose : D-gluconic acid



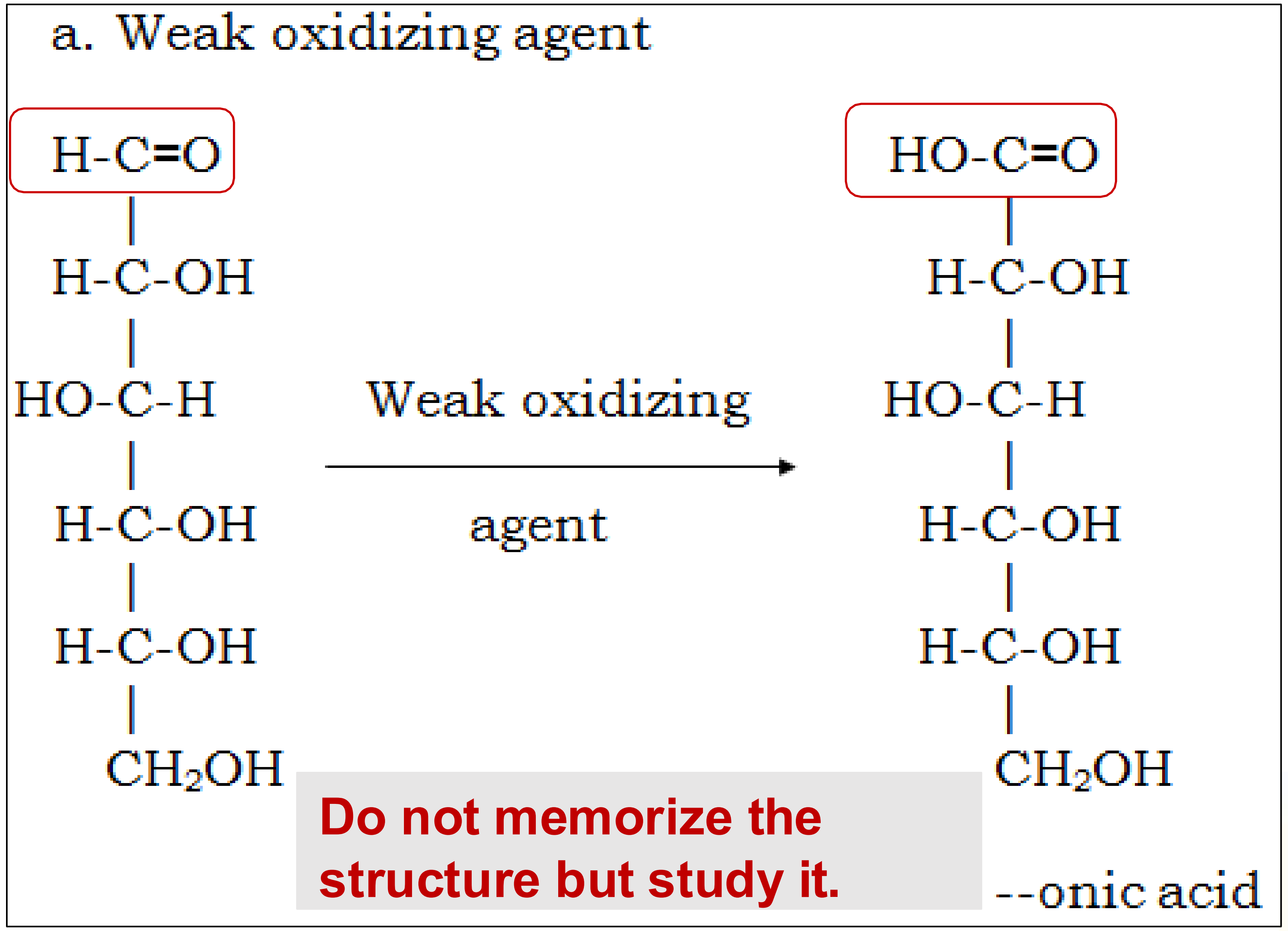
α-D-glucuronate
(D-glucuronic acid, **GlcUA**)
from **oxidation of glucose C6 OH**

Do not memorize the structure but study it.

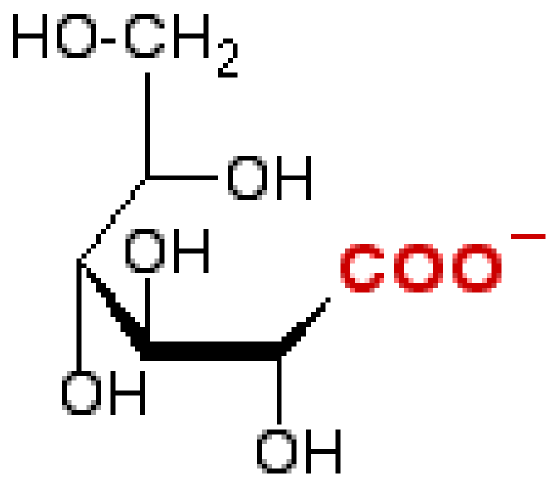


D-gluconate
(D-gluconic acid, **GlcA**)
from **oxidation of glucose C1 aldehyde)**

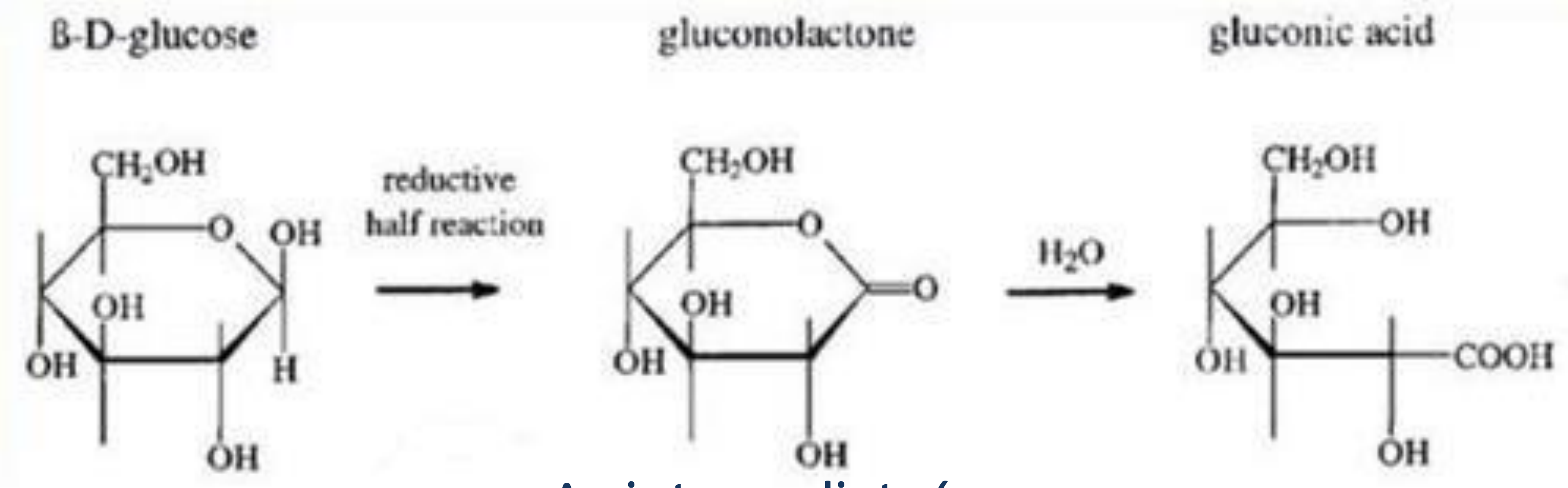
Gluconate



Do not memorize the structure but study it.



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

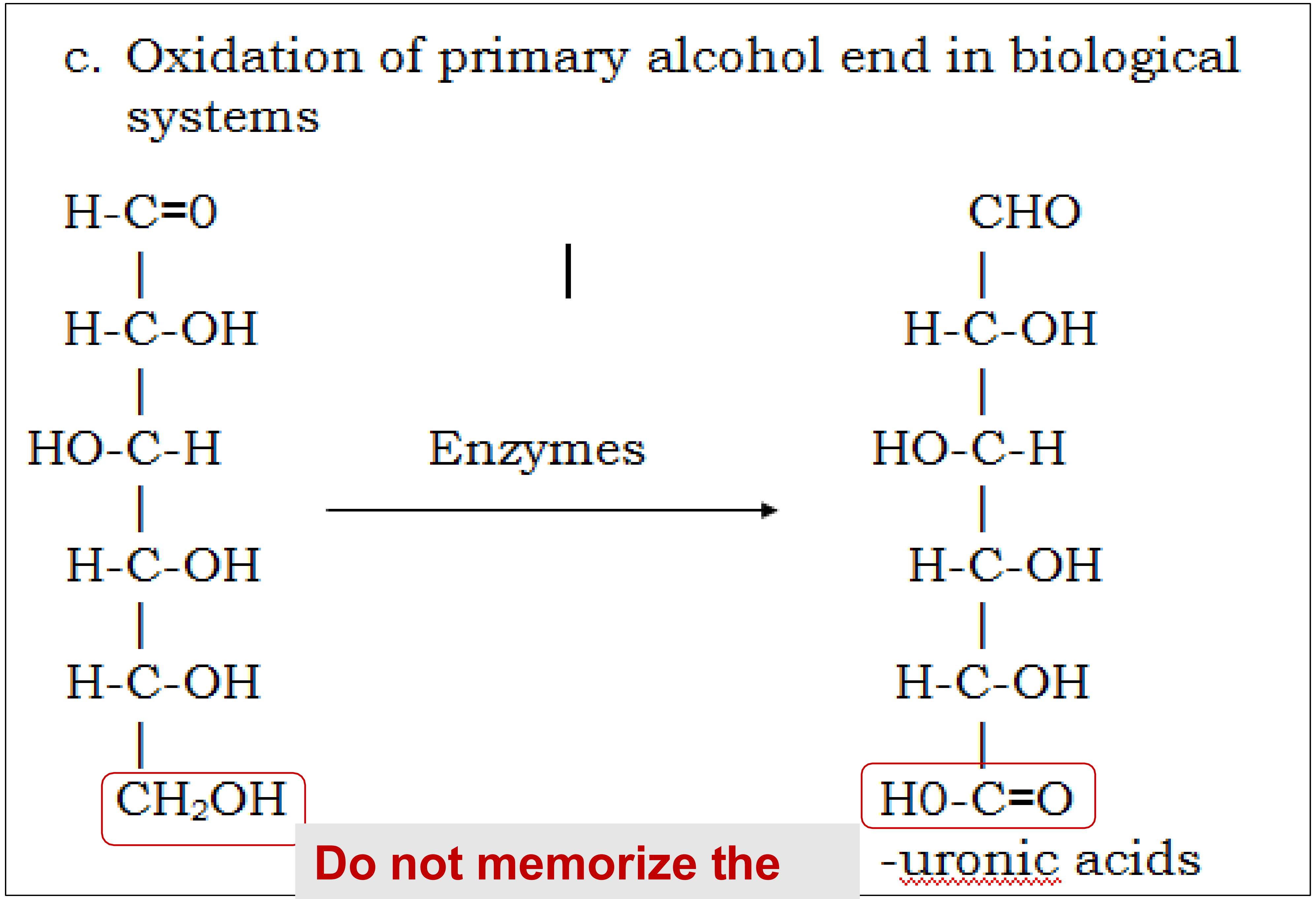


An intermediate (you don't have to know it)

If galactose is oxidized it will be called galactonic acid. You can differentiate between glucose and galactose by looking at carbon number 4

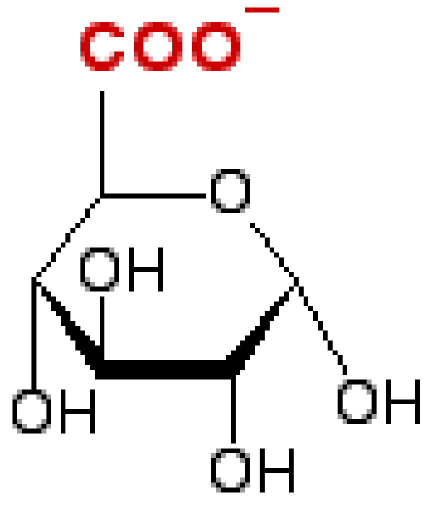
- **Galactonic acid**: The –OH group is on the **left**.
- **Gluconic acid**: The –OH group is on the **right**

Gluc<u>ur</u>onate



Do not memorize the structure but study it.

When the 6th carbon is oxidized into a carboxyl group



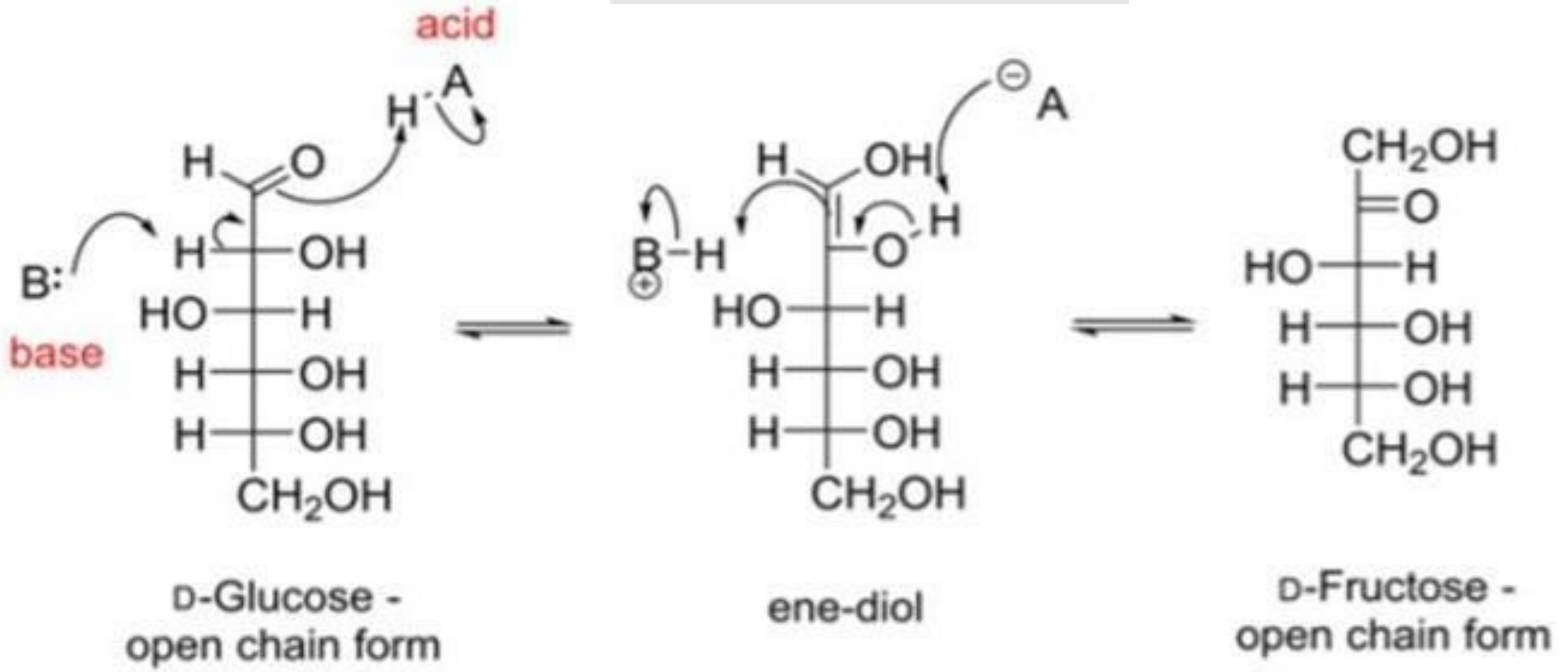
α-D-glucuronate
(D-glucuronic acid, **GlcUA**)
from **oxidation of glucose C6 OH**

Note

- Oxidation of ketoses to carboxylic acids does not occur, but they can be oxidized **indirectly**.

- Ketoses does not oxidize directly. They can get oxidized indirectly, first it converts to an aldose (for example, glucose is oxidized, which is the aldose isomer of fructose)

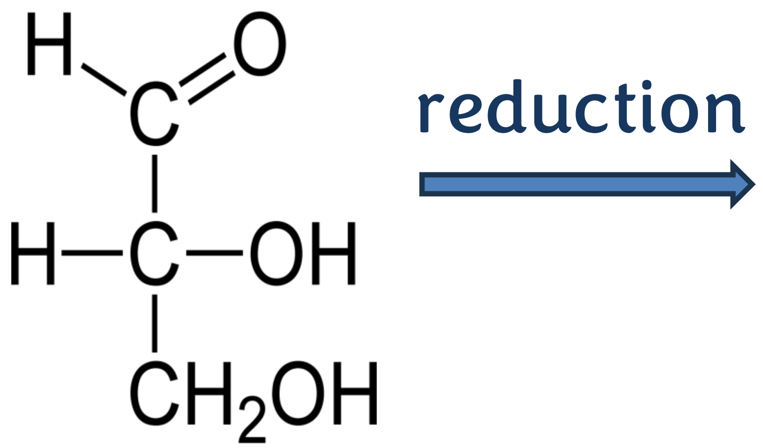
Do not memorize the ene-diol structure but study it.



Note: They both exist in equilibrium

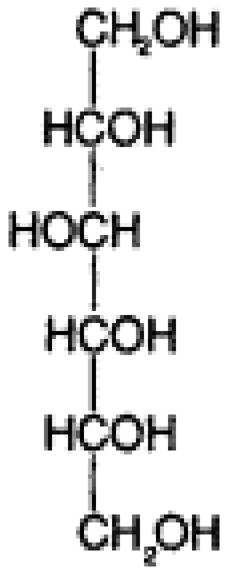
Sugar alcohols (reduction)

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

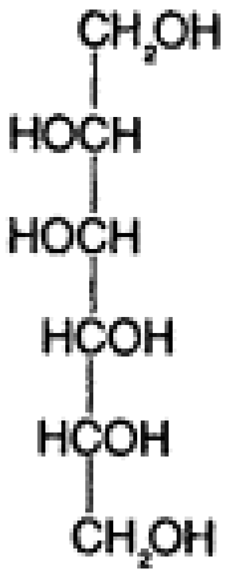


glyceraldehyde

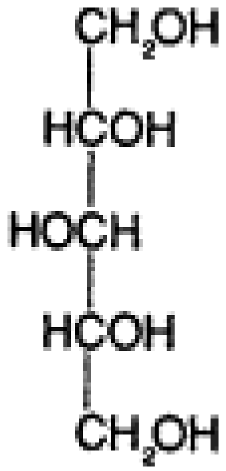
Glycerol
Obtained from the reduction of either D-glyceraldehyde or dihydroxyacetone.



D-Sorbitol
Obtained from the reduction of either the C_1 carbonyl group of glucose or the C_2 carbonyl group of fructose.

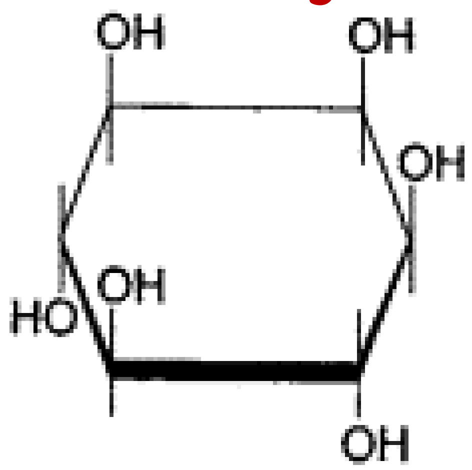


D-Mannitol
Obtained from the reduction of either the C_2 carbonyl group of D-fructose or the C_1 carbonyl group of D-mannose.



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

Note: Memorize the name only here



Myo-inositol

We will get to this sugar in the lipids lecture

- Ketones can be reduced into an alcohol group (secondary)
- Aldehyde groups can be reduced into alcohol group (primary)
- Glyceraldehyde reduces into glycerol

Glycer: 3 carbons   ol: alcohol

- Reducing glucose and fructose gives us sorbitol (common, very sweet, used in gum)
- Reducing mannose and fructose gives us mannitol

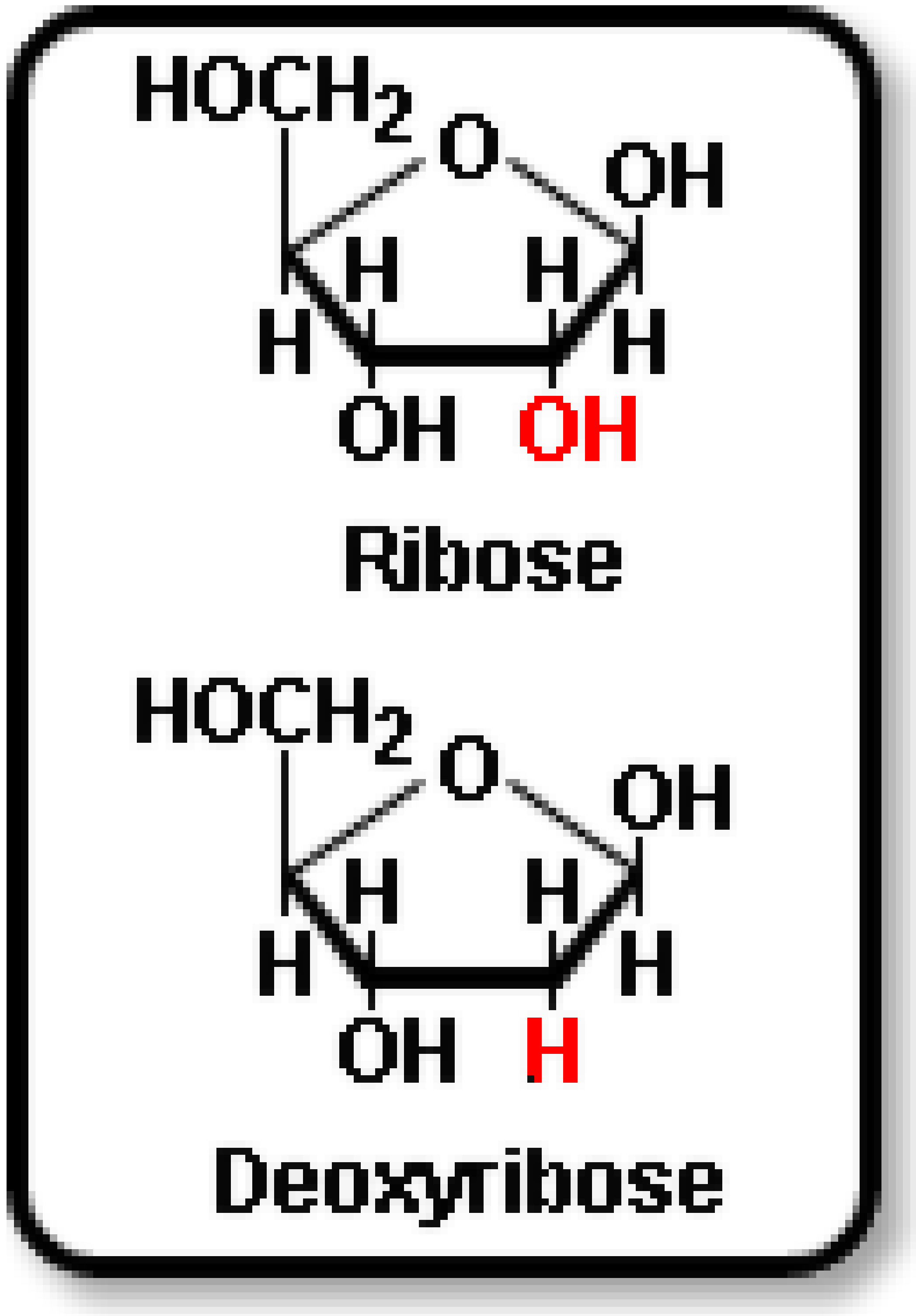
Note: they are both diastereomers, specifically epimers at carbon number 2:

- OH to the right: glucose derived (sorbitol)
- OH to the left: mannose derived (mannitol)

Fructose may be reduced to mannitol or sorbitol (based on the direction of the reduced OH group)

Deoxy sugars (reduced sugars)

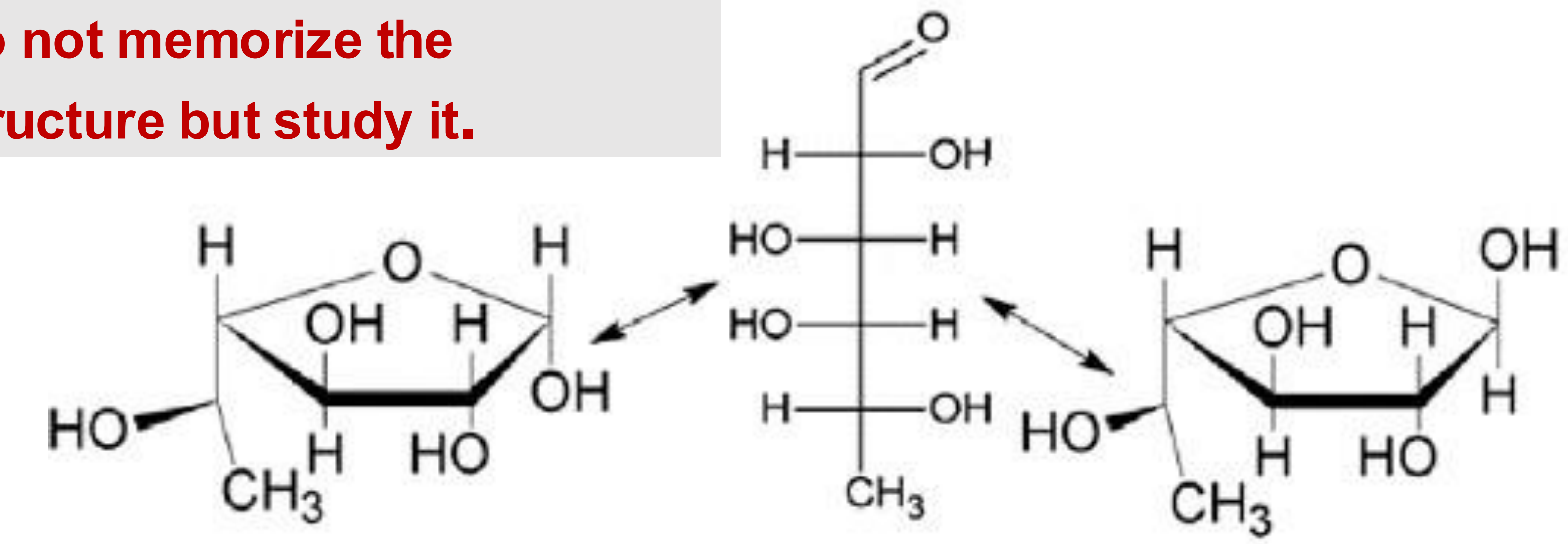
- One or more hydroxyl groups are replaced by hydrogens. (reduction)
- An example is 2-deoxyribose, which is a constituent of DNA.
- By reducing the hydroxyl group from ribose we get deoxyribose which is a main component of DNA
- If we reduce a functional group we will have a sugar alcohol, but if we reduce hydroxy groups we get deoxy sugar.



Another deoxy sugar

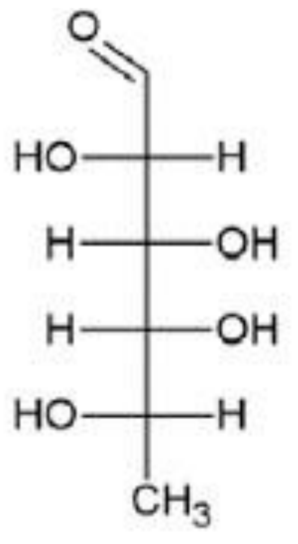
- L-fucose (L-6-deoxygalactose)
  - found in the carbohydrate portions of some glycoproteins

Do not memorize the structure but study it.

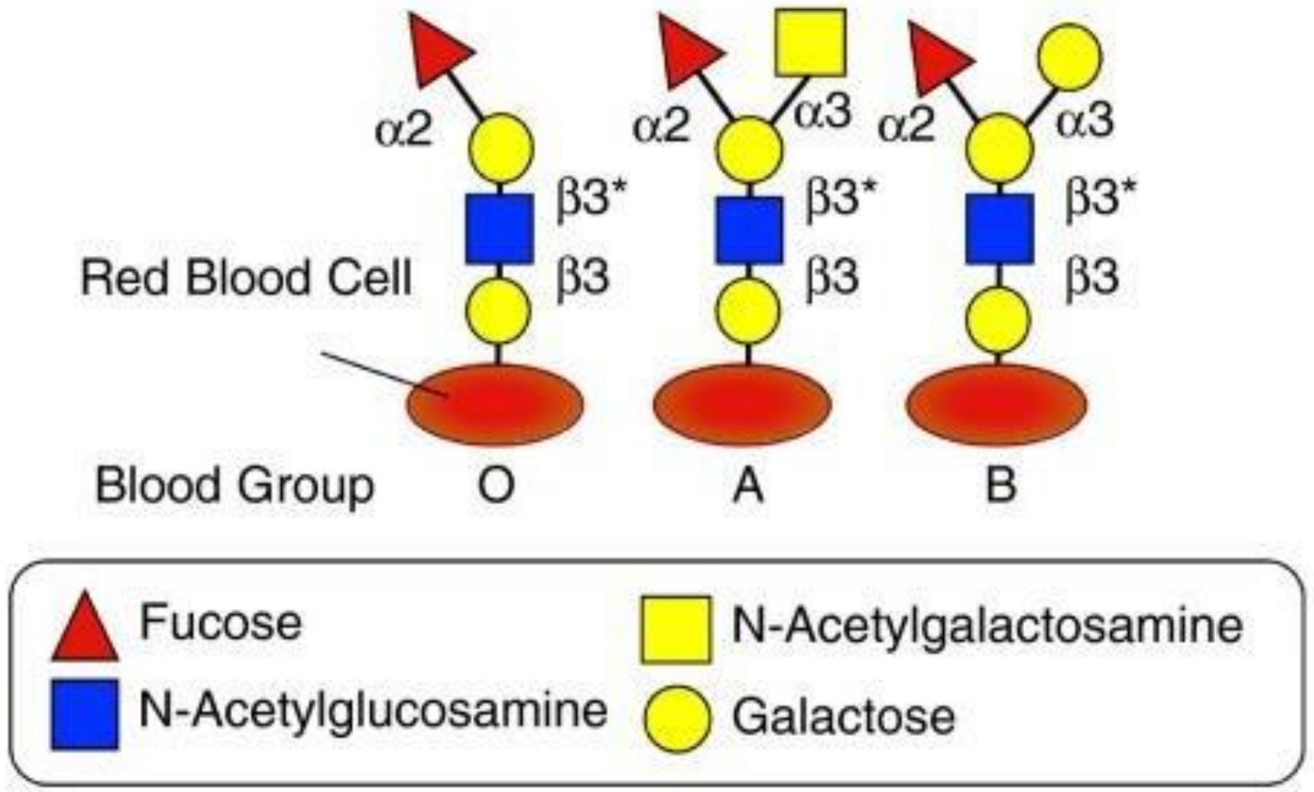


6-deoxy-α-D-galactofuranose 6-deoxy-β-D-galactofuranose

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



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



- Galacto: comes from galactose
- Furanose: 5 member ring, one of them being Oxygen

Do not memorize the components except for fucose.

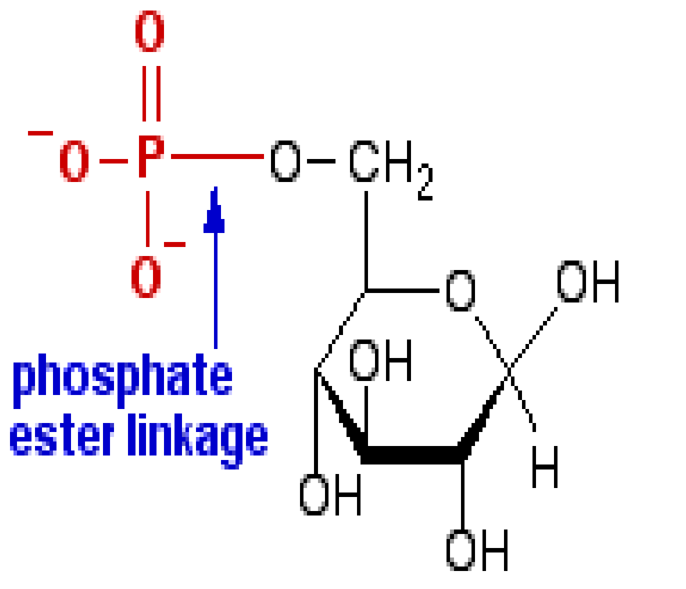
Note: memorize the name of fucose for future purposes in lipids, its used in blood typing where on of the sugars that are on the blood surface of a certain type is fucose

Sugar esters (esterification) : formation of an ester **group** or an ester **bond**

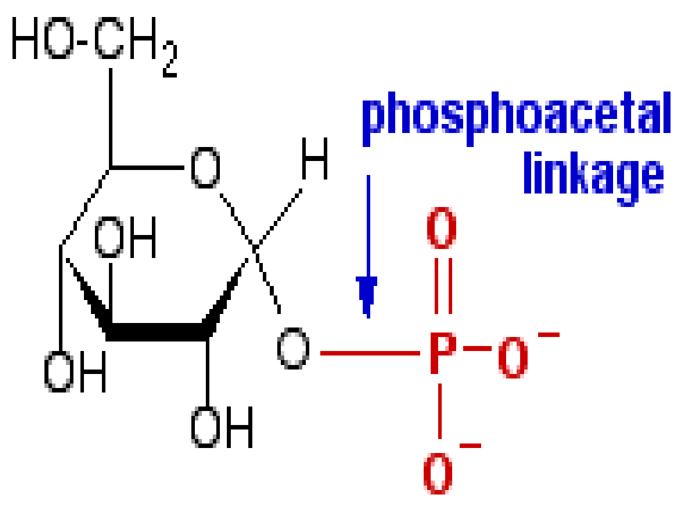
- What is the reacting functional group? Where does it react? What are the end products? Where are they used?

- One of the types of esterification is phosphorylation: Adding a phosphate group to a molecule making it energy rich, by storing energy within the molecule

- **For example**: adding a phosphate group to carbon 6 or 1 on glucose (making it glucose 6 or 1 phosphate) is a key part of generating ATP, by the phosphorylation of glucose to become glucose 6 phosphate



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

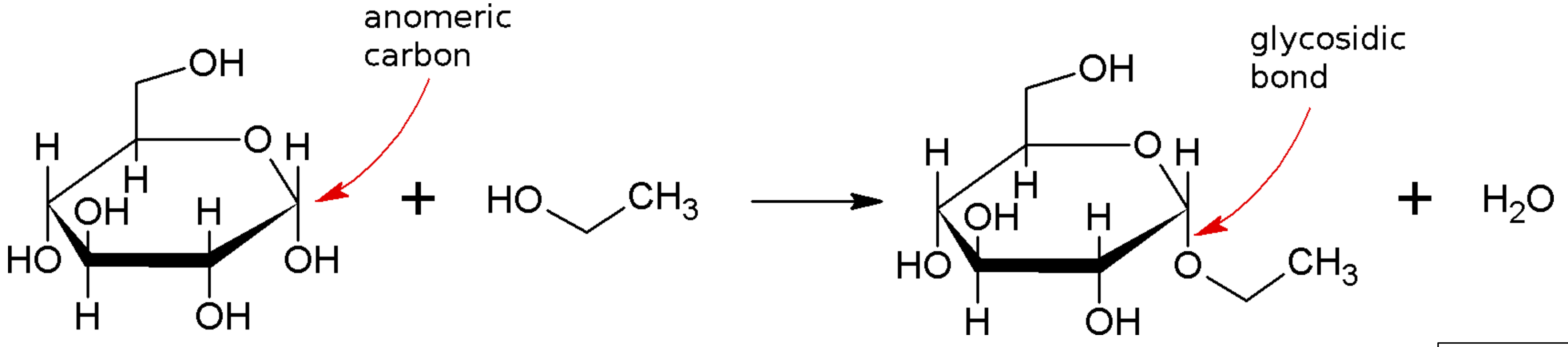


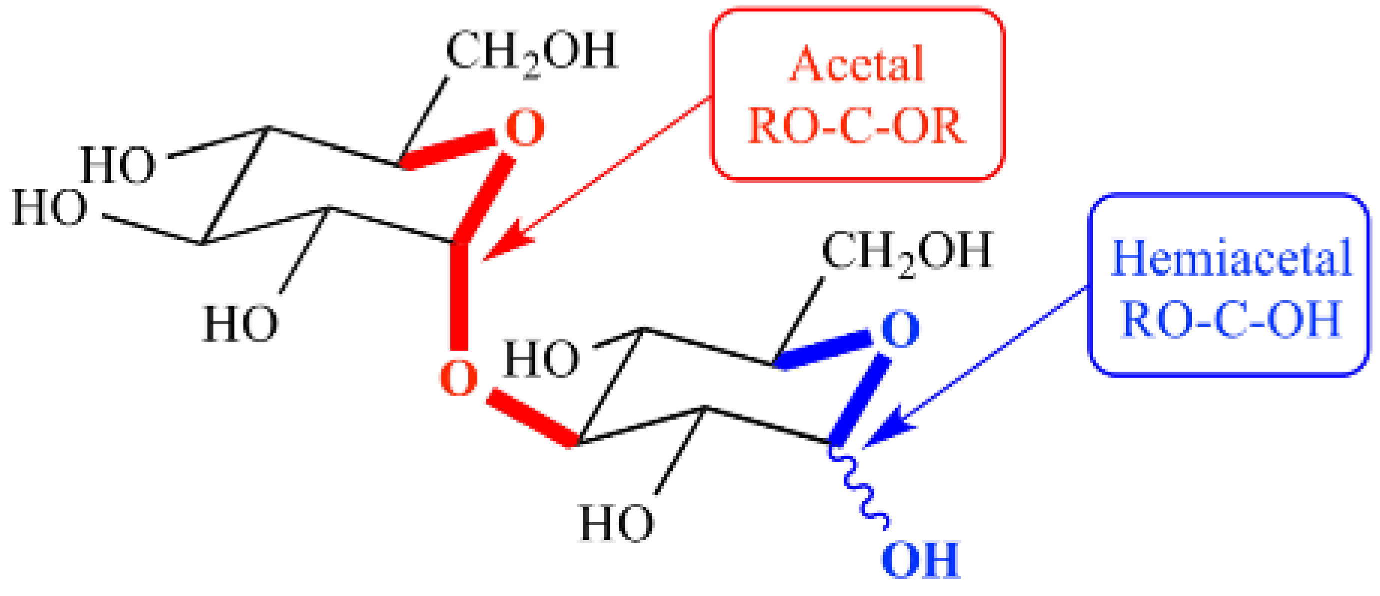
α-D-glucose-1-phosphate
(a phosphoacetal)

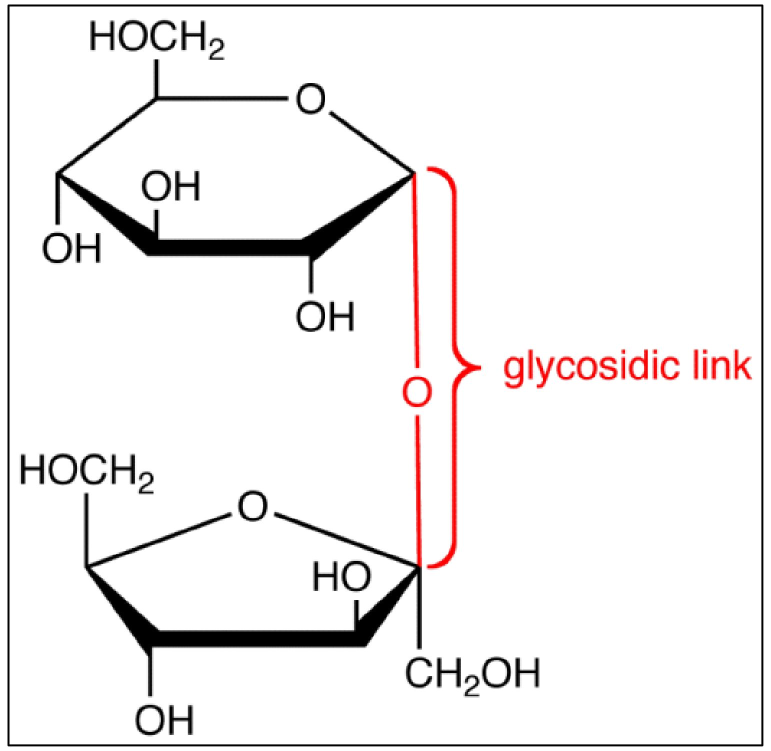
O-Glycosides

The formation of a glycosidic bond involves at least one anomeric carbon

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







Remember

- Sugar anomers: ring structures -pyranose or furanose- the difference between these two molecules is the position of the hydroxyl group on the 1st carbon of aldoses (carbon 1 was the functional group, the anomeric carbon) and the 2nd carbon of ketoses.
- Anomeric carbon: The carbon which determines if the sugar is alpha (below) or beta (on top).

- If the anomeric carbon reacts with another group, it forms a bond called **glycosidic bond (the product is called glycoside).**

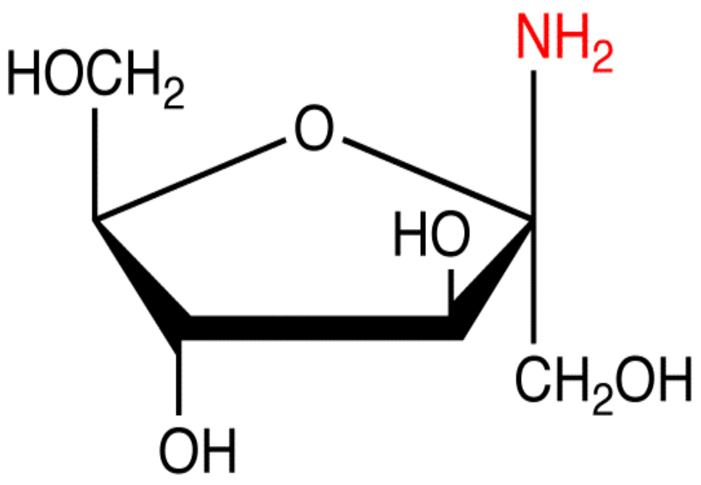
- **Once the bond is formed, the ring shape will not open again.**

- If the glycosidic bond involved an oxygen it becomes an O-glycosidic bond, and the product is called O-glycosides

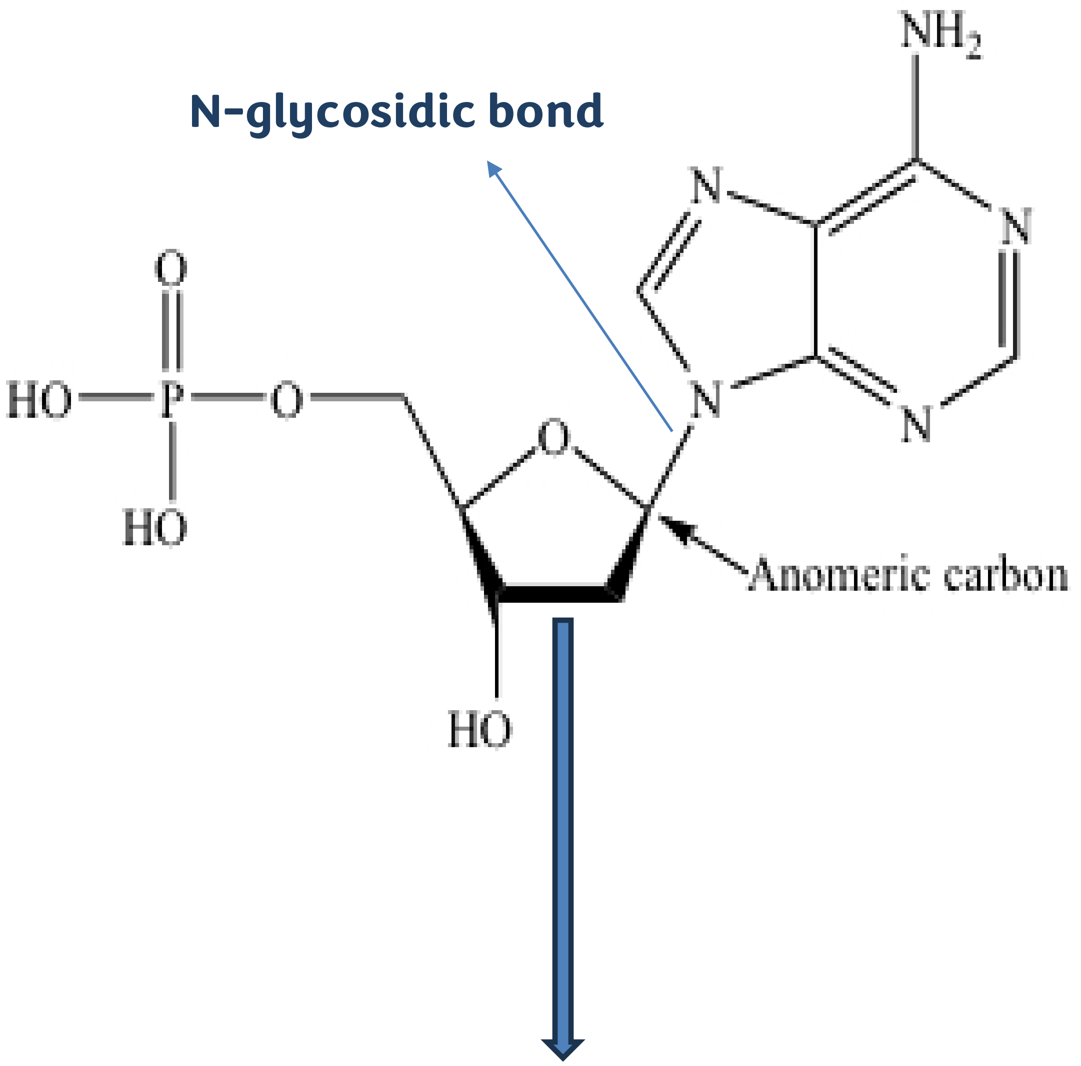
N-Glycosides

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

- If the glycosidic bond involved a amino group, it becomes a N-glycosidic bond, and the product is called N-glycosides



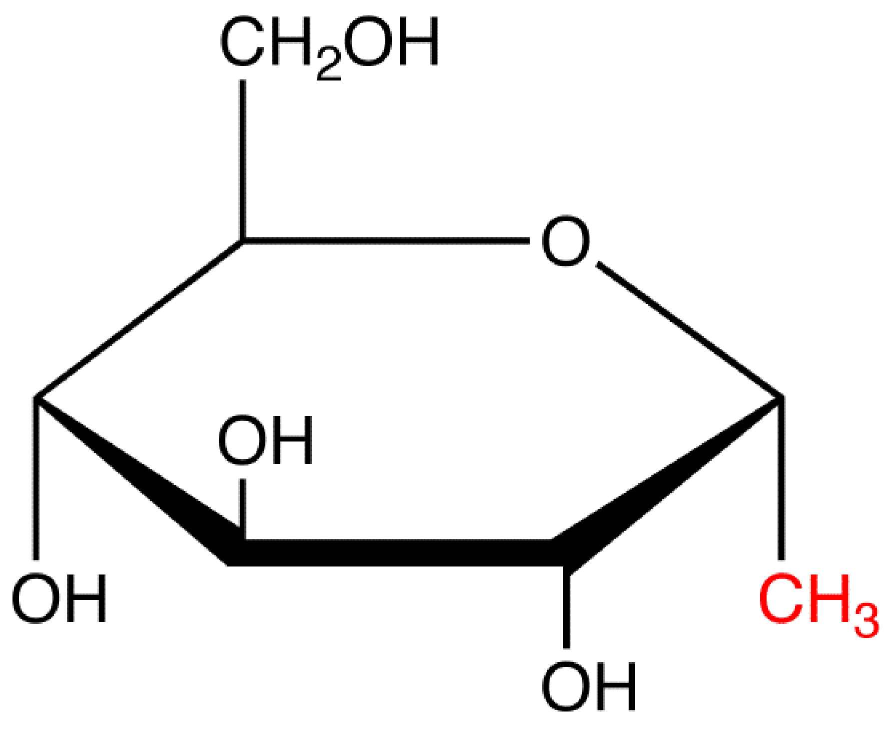
N-glycoside



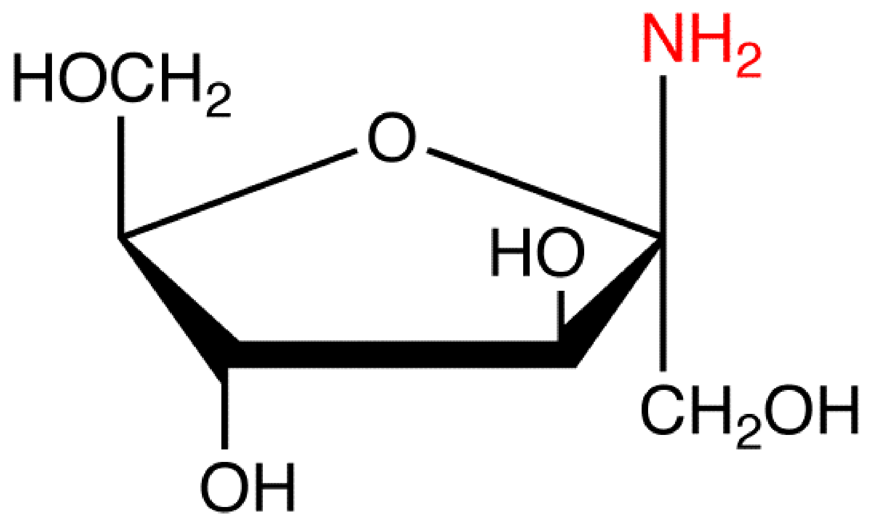
This is DNA, because there is no hydroxyl group making it 2-deoxy ribose

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



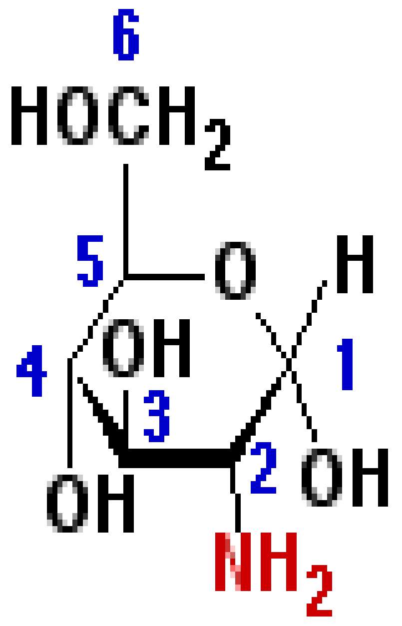
N-glycoside

Amino sugars

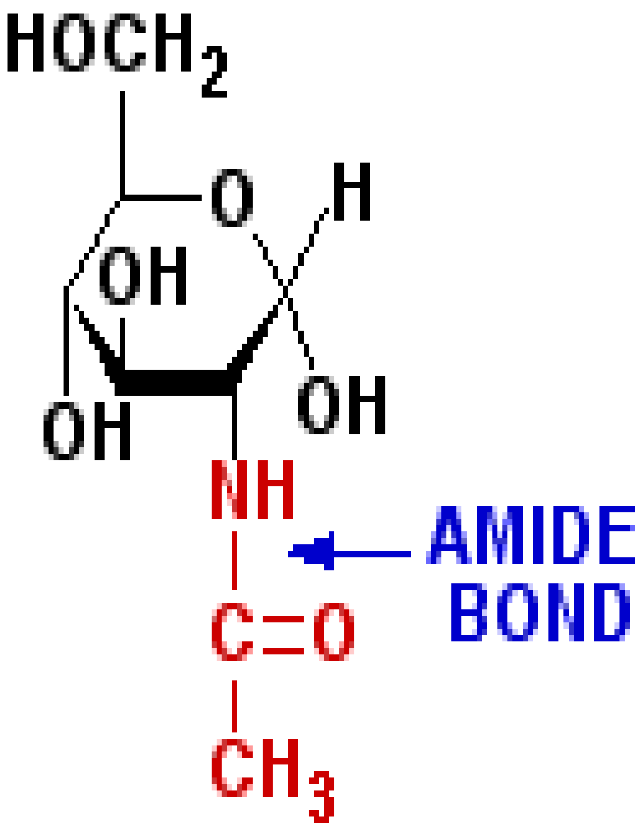
- What is the reacting functional group? Where does it react? What are the end products? Where are they used?
- Further modification by acetylation

- We can replace any hydroxyl group with amine, making it amino sugar.

- Note: the difference between N-glycosides and amino sugars is that in N-glycosides the nitrogen is linked to the **anomeric** carbon (**otherwise,** it is an amino sugar).



α-D-2-glucosamine
(GlcN)



N-acetyl-α-D-2-glucosamine
(GlcNAc)

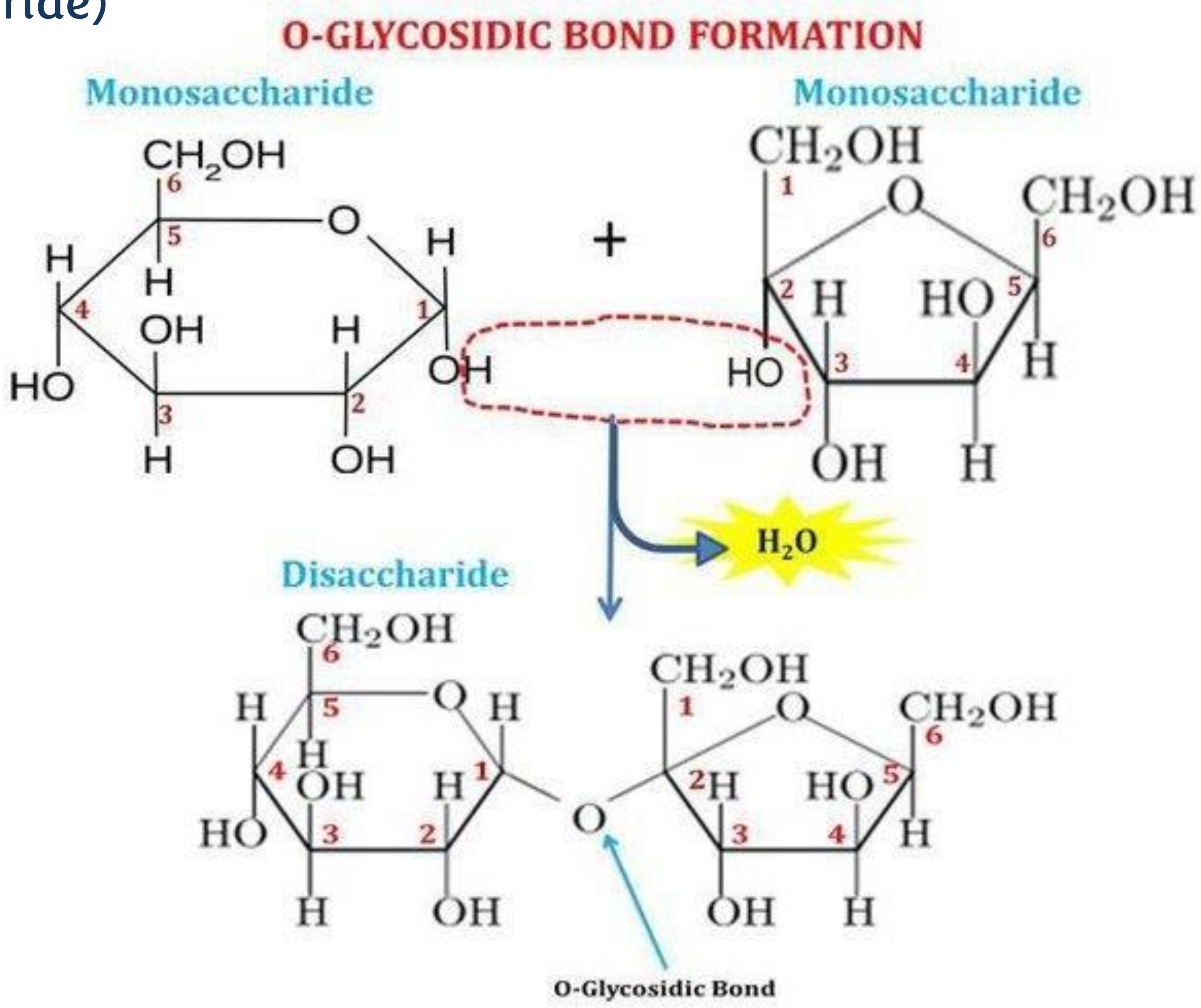
Disaccharides

2 monosaccharides that form a glycosidic bond

3-10 subunits

Hetero = 2 different sugar molecules that form a disaccharide (lactose & sucrose)
Homo = 2 of the same sugar molecules (maltose)

- What are disaccharide? Oligosaccharides? Hetero- vs. homo-?
- What is the type of reaction? Condensation reaction (loss of water)
- What is a residue? A residue is a small molecule (monosaccharide) **that's a part** of a larger molecule
- Synthesizing enzymes are glycosyltransferases.
- Do they undergo mutarotation?
- Are products stable?



Glycosyltransferase are enzymes that form glycosidic bond

Mutarotation (changing the position of the OH molecule to be above or below the carbon (alpha & beta):
happens only when we have a free anomeric carbon (ex: maltose & lactose)
However a disaccharide like sucrose cannot mutarotate because both anomeric carbons are occupied

Products are very stable because of the glycosidic bond

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)

From left to right

- 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

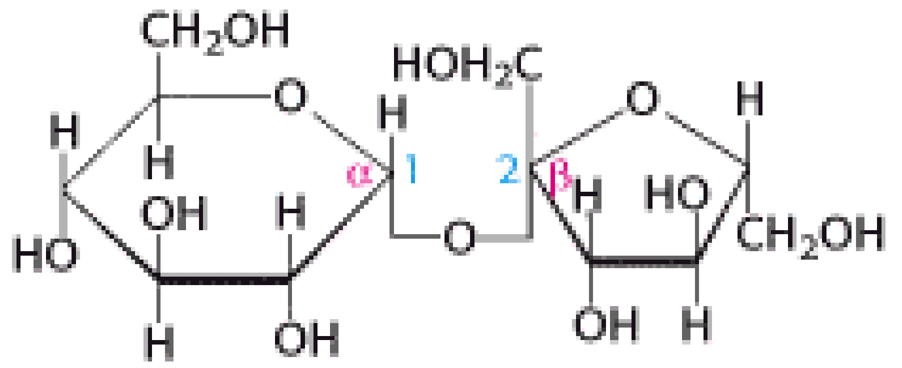
All monosaccharides are reducing sugars because they have free anomeric carbon

Both lactose and maltose are reducing sugars as both glucose molecules on the right side have free anomeric carbon as shown by the blue circle

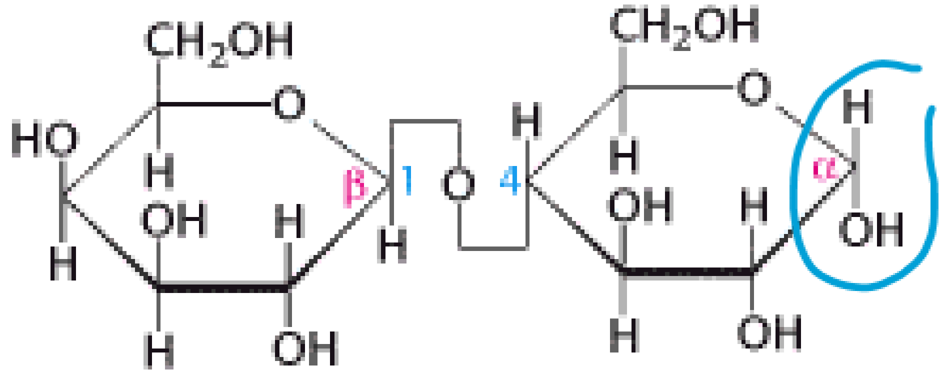
Do not memorize the structures but study them.

Non-reducing (sucrose) because there are no free anomeric carbon

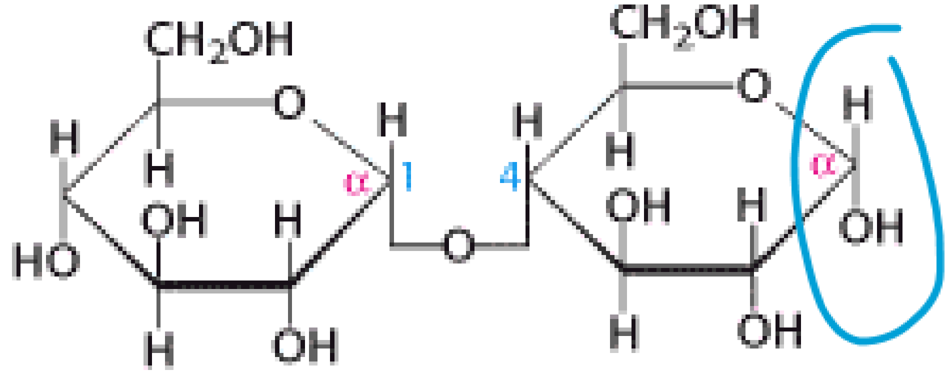
Study the structures well



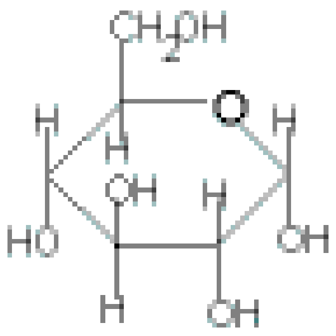
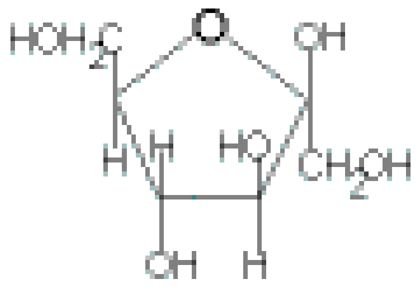
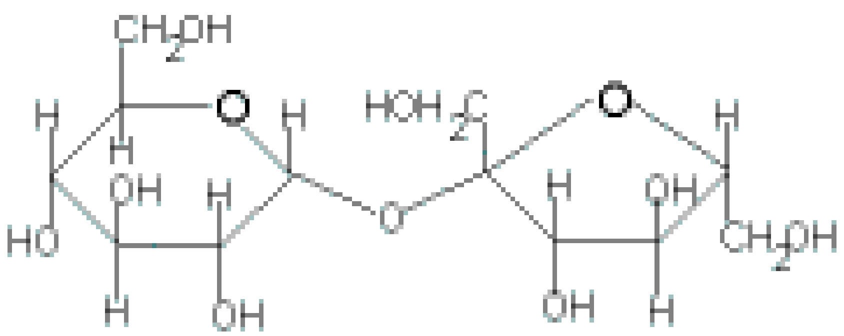
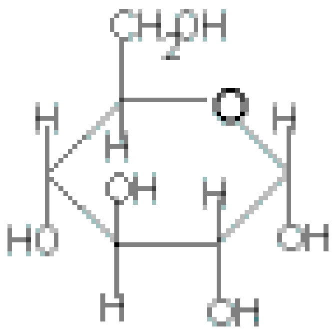
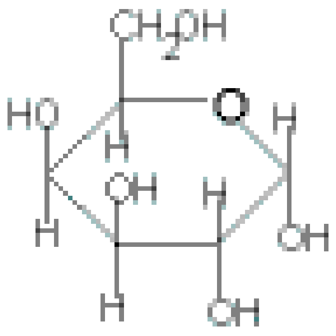
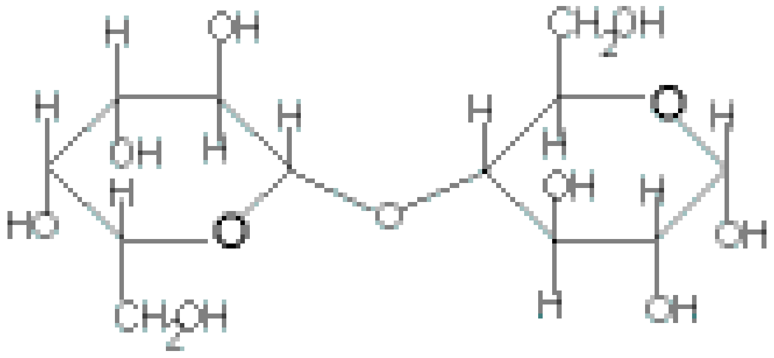
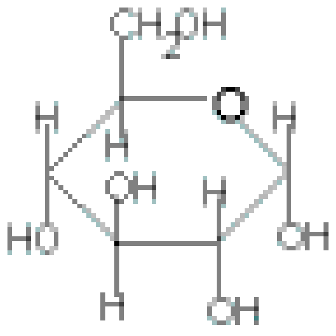
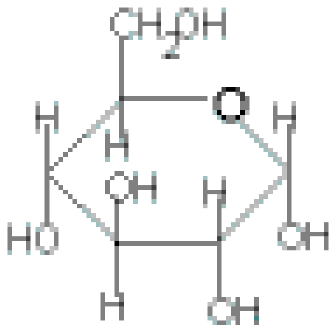
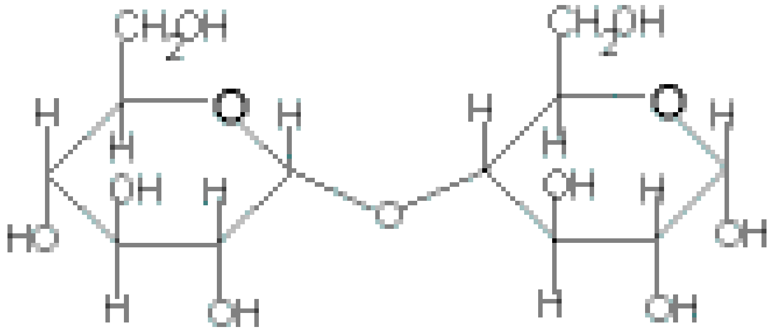
Sucrose
(α-D-Glucopyranosyl-(1→2)-β-D-fructofuranose



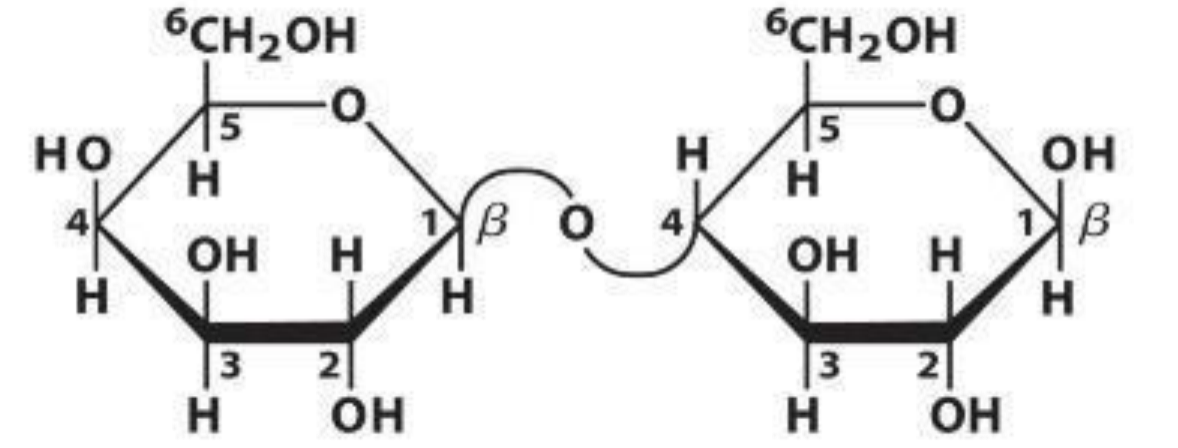
Lactose
(β-D-Galactopyranosyl-(1→4)-α-D-glucopyranose



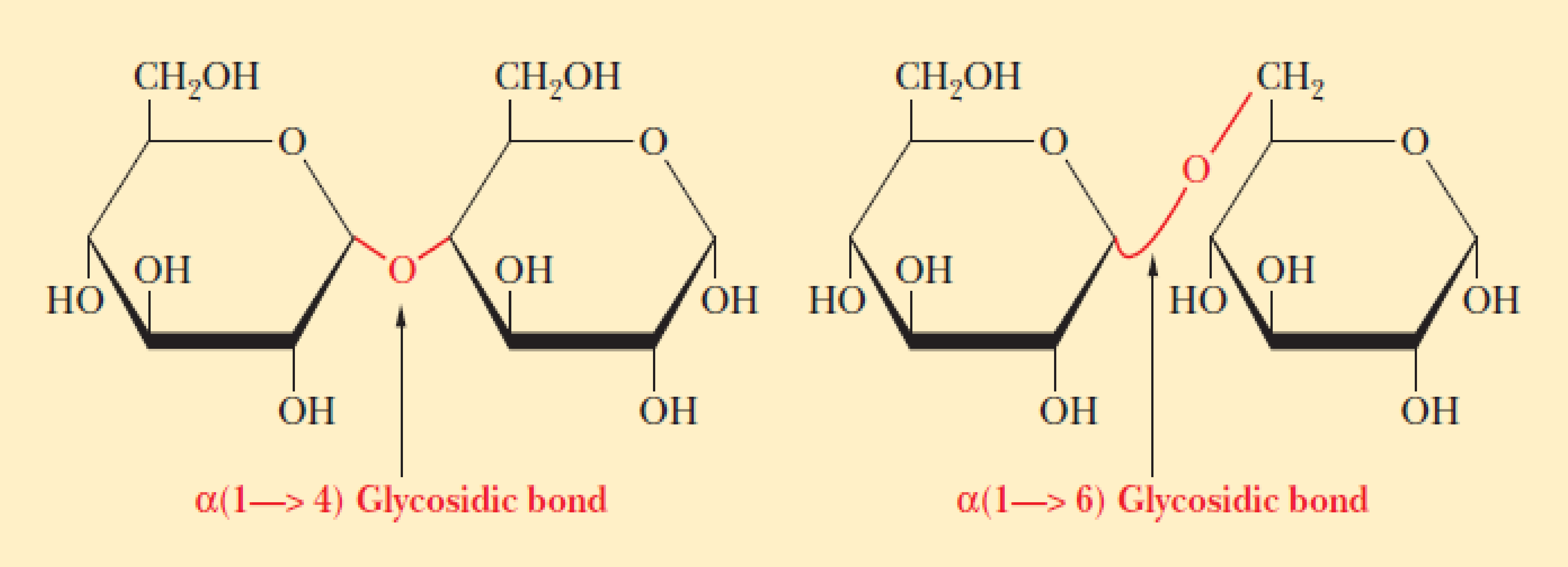
Maltose
(α-D-Glucopyranosyl-(1→4)-α-D-glucopyranose

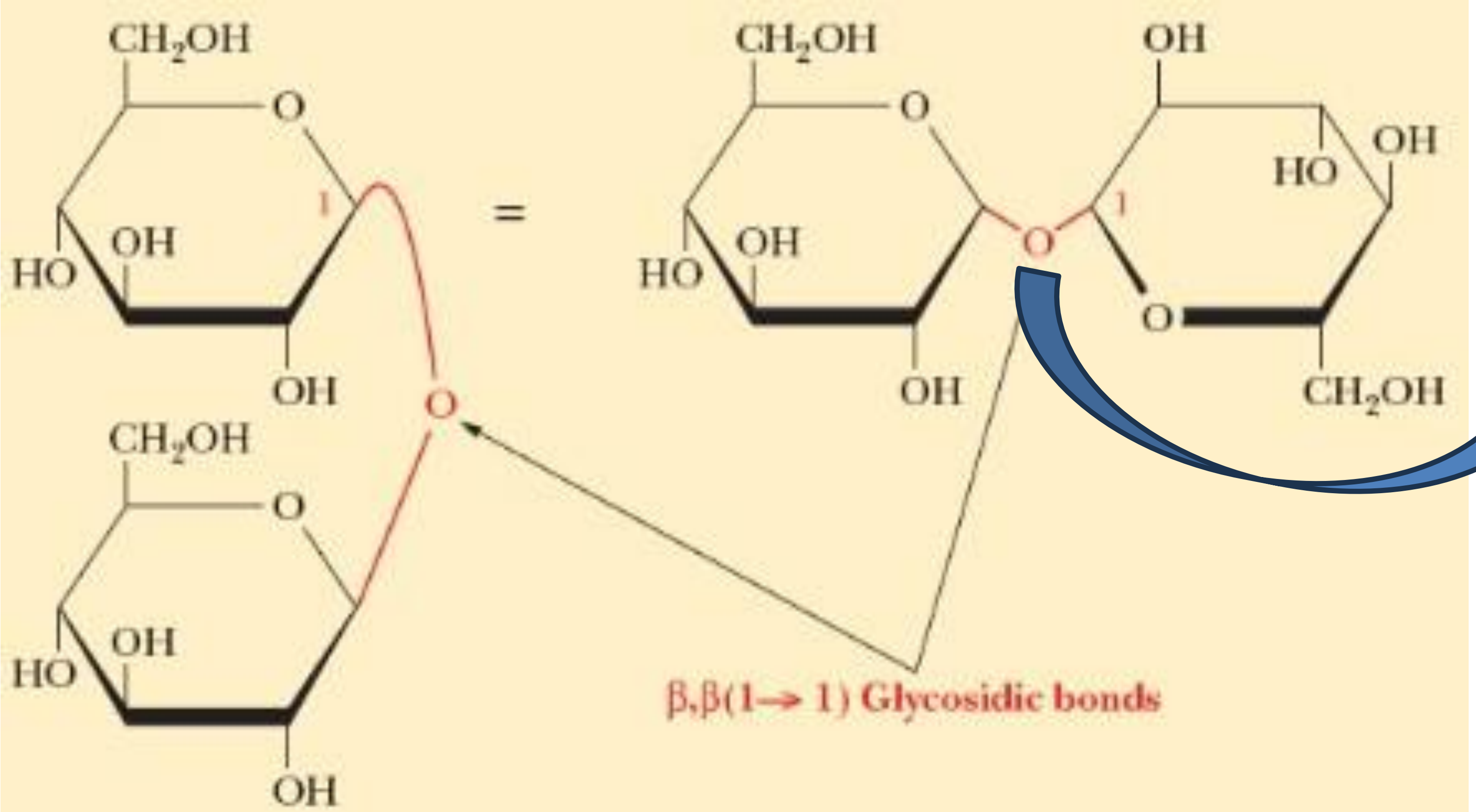
Name	Formula	Formed from	Structure
sucrose **The usually used sugar**	$C_{12}H_{22}O_{11}$	glucose + fructose  + 	---> sucrose + H_2O 
lactose **Milk sugar**	$C_{12}H_{22}O_{11}$	glucose + galactose  + 	---> lactose + H_2O 
maltose **Malt sugar**	$C_{12}H_{22}O_{11}$	glucose + glucose  + 	---> maltose + H_2O 

Different forms of disaccharides



Lactose (β form)
β-D-galactopyranosyl-(1$\rightarrow$4)-β-D-glucopyranose
Gal(β1$\rightarrow$4)Glc

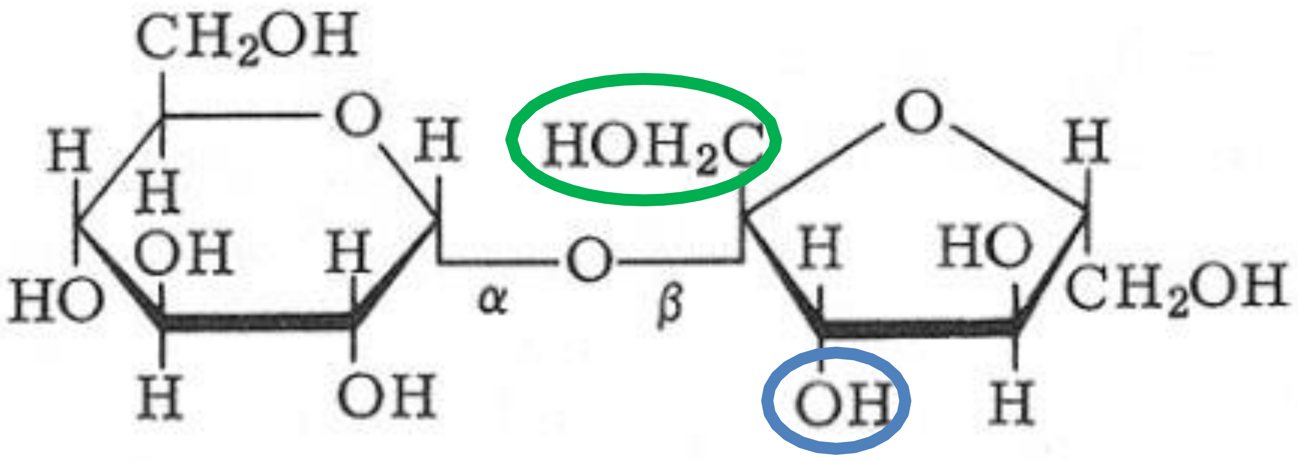


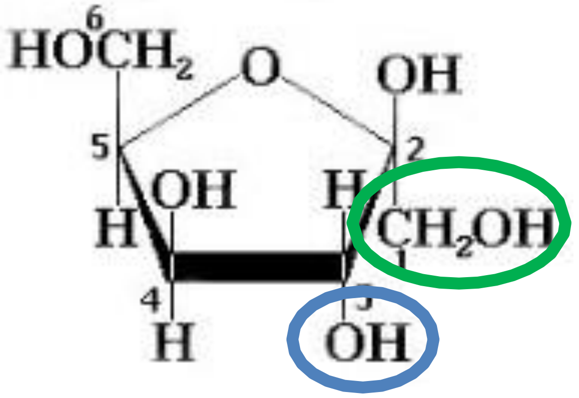


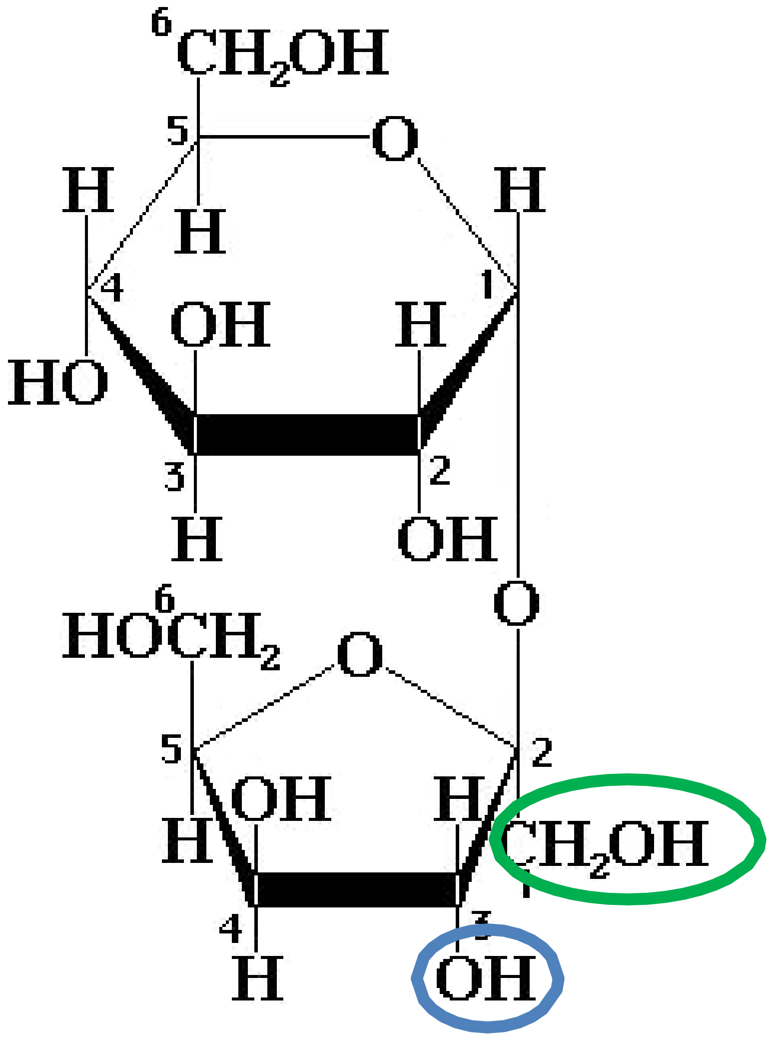
- This one should be α,β (1 --> 1) glycosidic bond.
- The doctor said that the questions about this topic will not be complex.

A disaccharide of β-D-glucose.

Sucrose







Do not study it. This is extra to fulfil your curiosity.

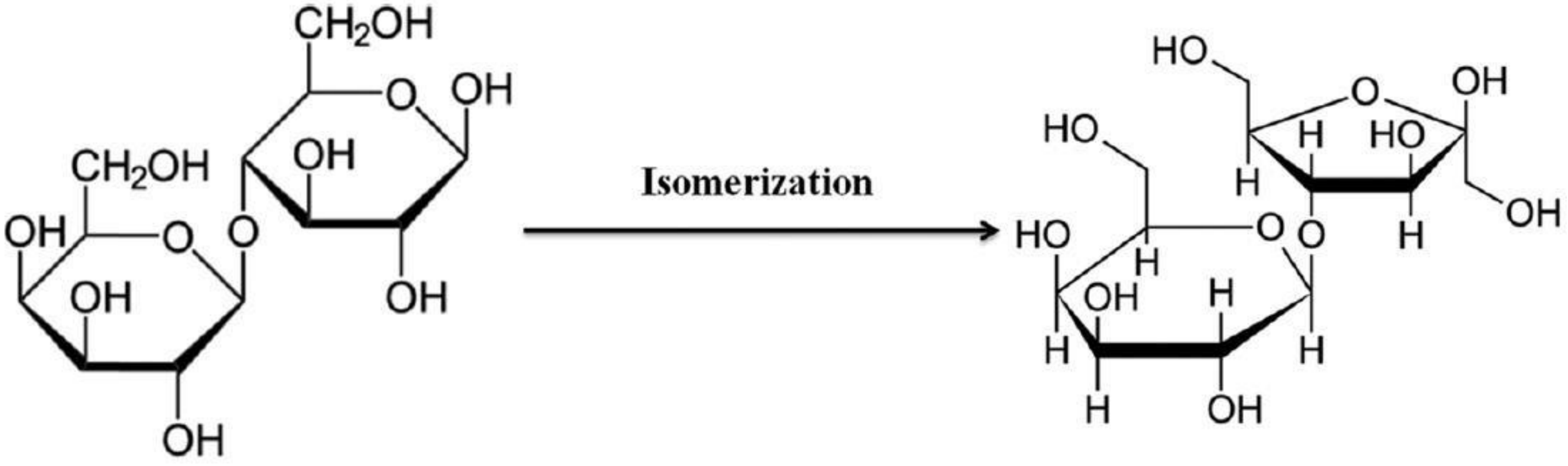
Lactulose

The commercial name is "duphalac"

A microbiome is a bacteria inside the intestine which controls the following:
1) GI System (Digestion)
2) Mood
3) Cancer treatment success
4) Treats Colon issues that happen due to the lack of health-promoting bacteria

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

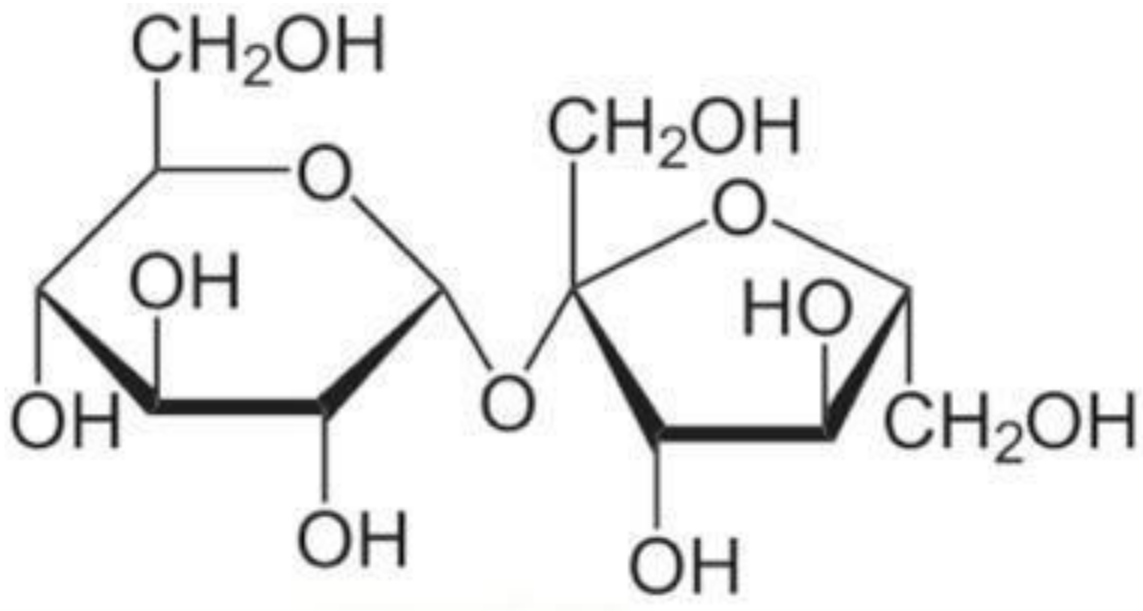
Do not memorize the structure but study it.



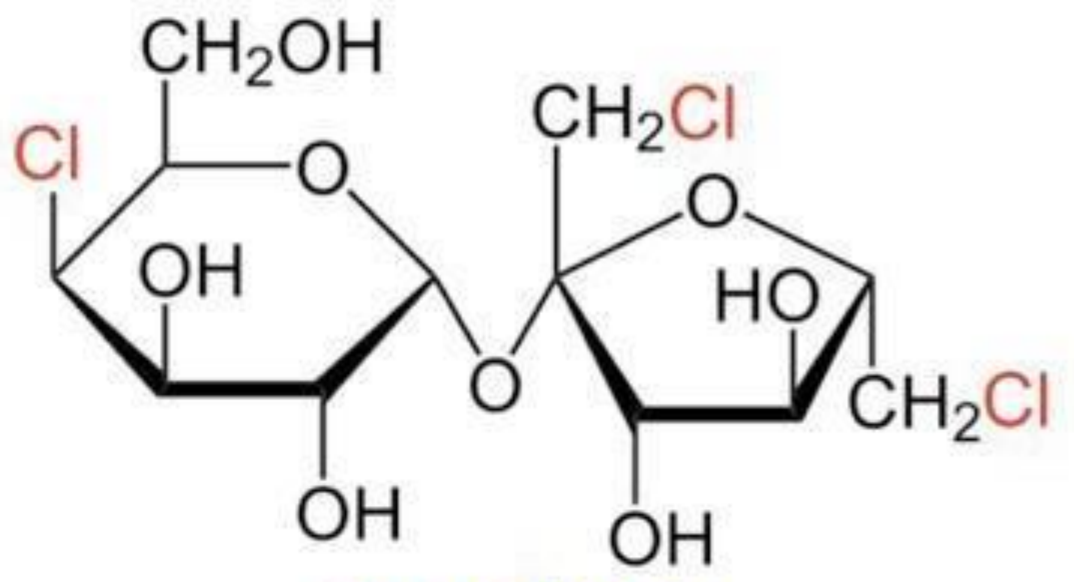
Lactose

Lactulose

Sucralose (artificial sweetener)



sucrose



sucralose

News > WebMD Health News

Sucralose Damages DNA, Linked to Leaky Gut: Study

Lisa O'Mary
June 01, 2023

Sucralose, a Common Artificial Sweetener, May Increase Cancer Risk

WebMD

It may occur because of genetics or due to aging (the activity of lactase is decreased)

Milk problems

- 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, resulting in severe and irreversible retardation. It also causes **cataract (if it accumulates in retina cells).**

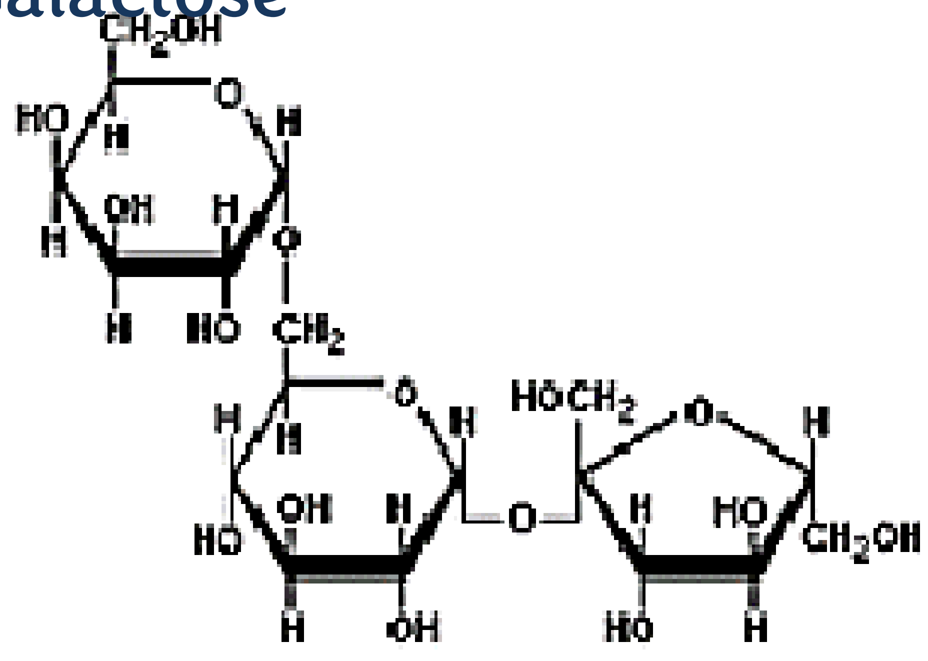
Galactosemia can also cause loss of vision

Raffinose

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

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

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

Homework

1) Galactose + Glucose + Fructose

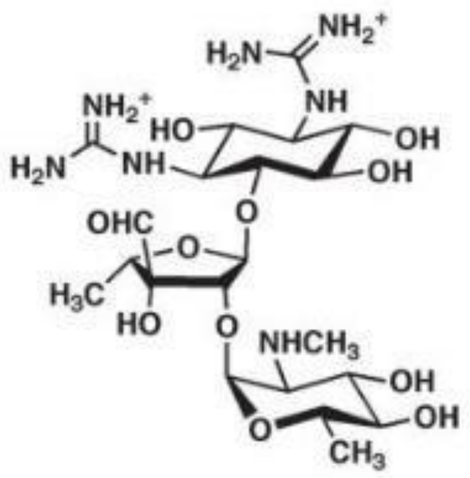
1. Recognize the monosaccharides that make up raffinose.

2) Galactose is attached to sucrose

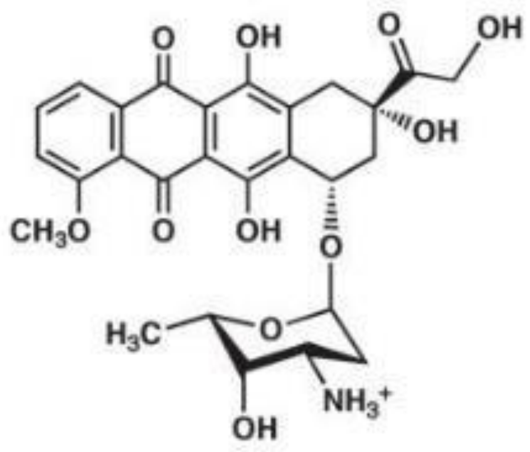
2. What is the monosaccharide that is attached to *what* disaccharide?

Oligosaccharides as drugs

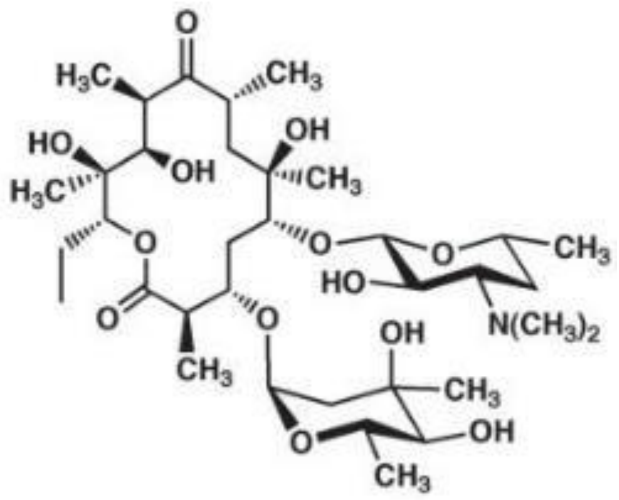
- Streptomycin and erythromycin (antibiotics)
- Doxorubicin (cancer chemotherapy)
- Digoxin (cardiovascular disease)



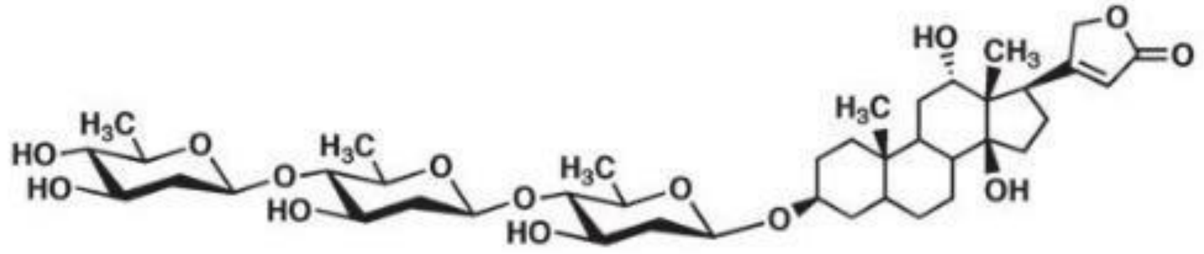
Streptomycin



Doxorubicin



Erythromycin A



Digoxin

Do not memorize or study the structures.

Polysaccharides

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

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

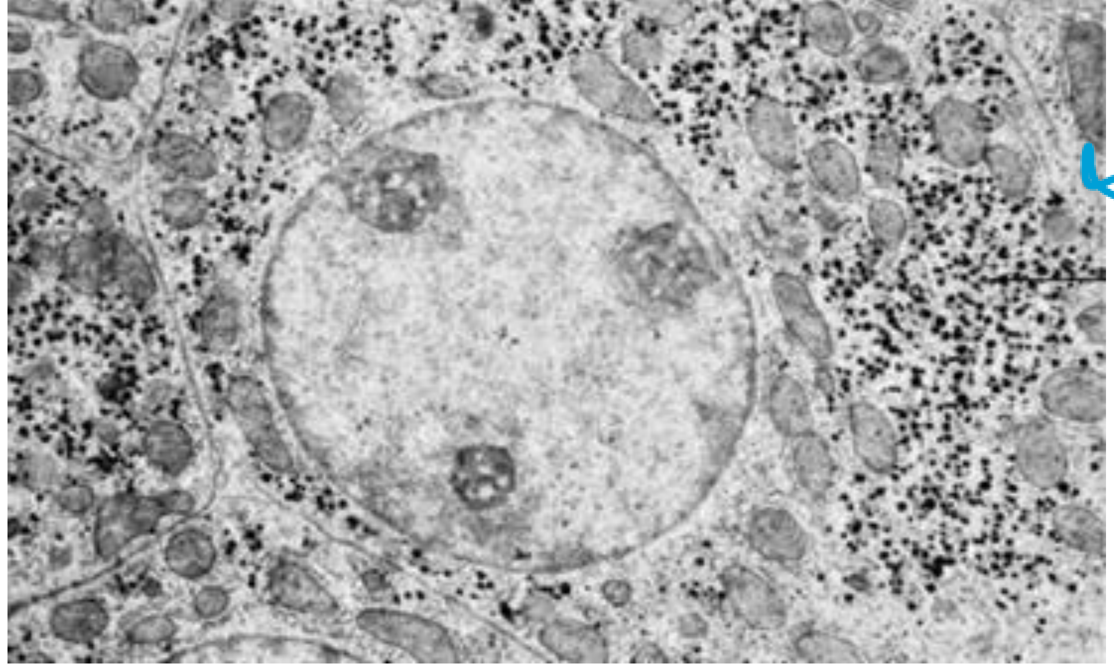
Glycogen

Glycogen stores polysaccharides in humans and mammals

glycogen is a homopolysaccharide

90% of glycogen is stored in the liver while 10% is stored in skeletal muscles

The liver supports other organs -such as brain- with glucose

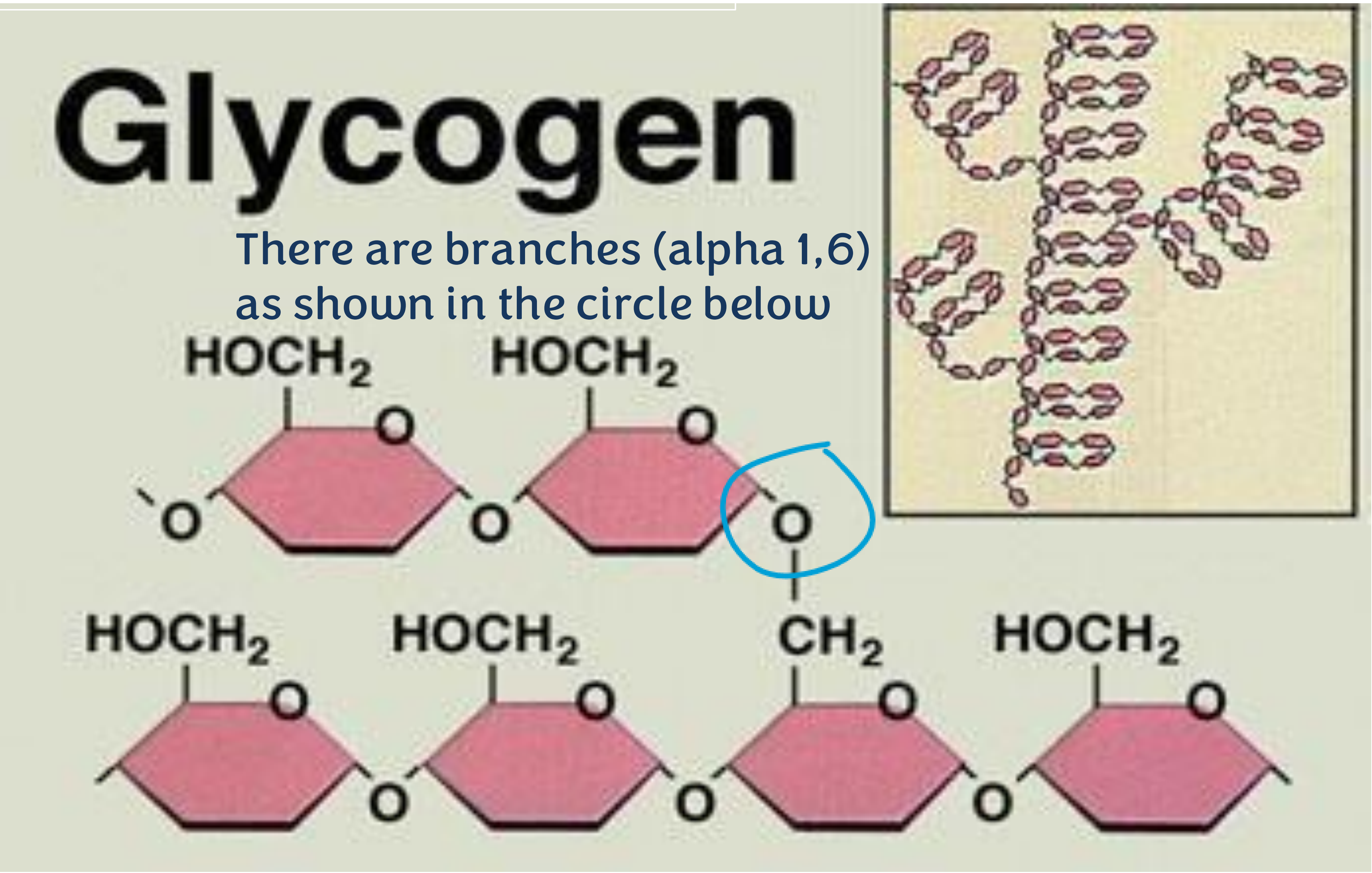


Every dot represents Glycogen

Every dot represents a glucose residue

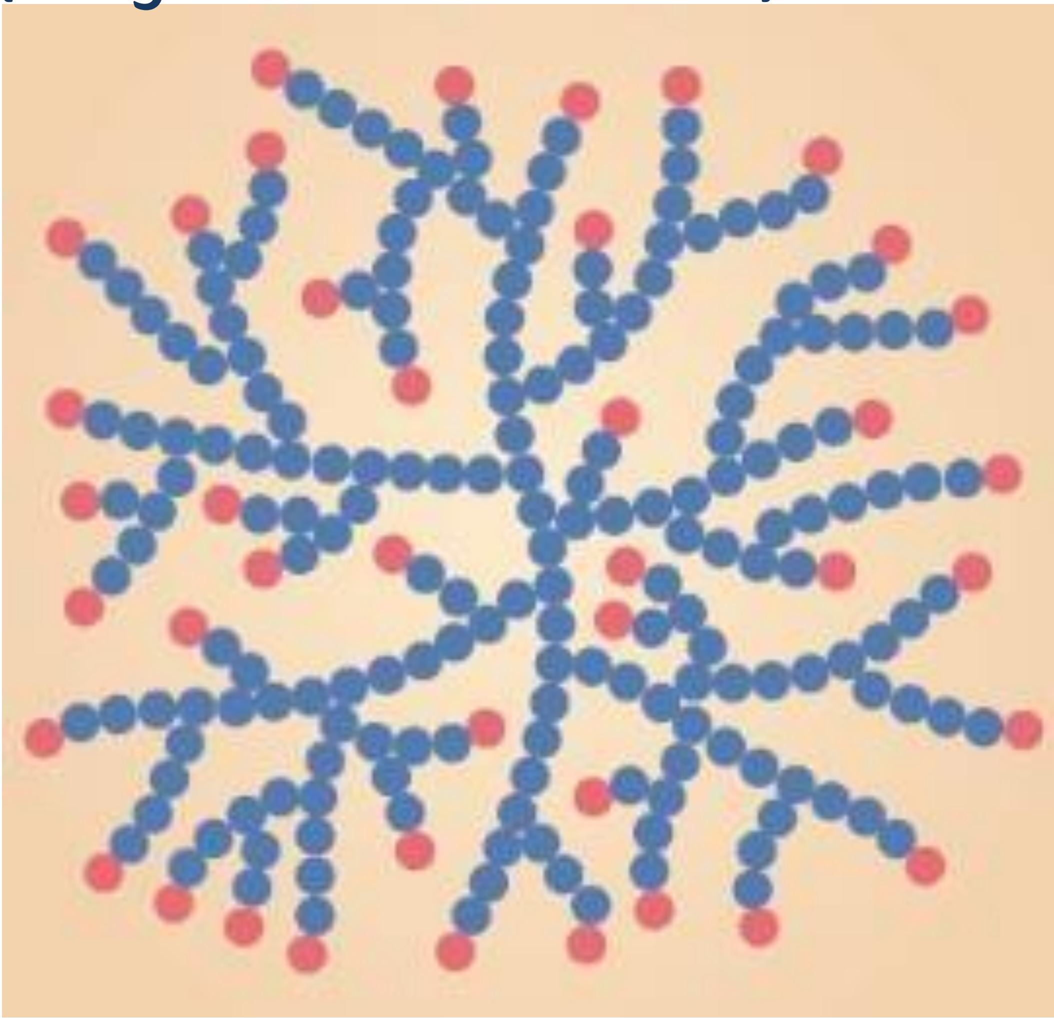
Memorize

Liver takes each dot gradually (they take the red dots)



There are branches (alpha 1,6) as shown in the circle below

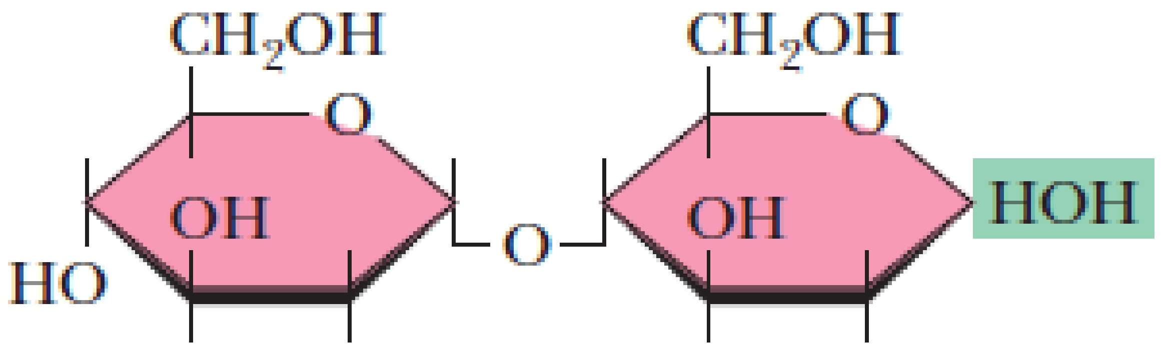
Most of it are chains connected by alpha 1,4 glycosidic bond



Advantage of Alpha bond:

It makes the molecule flexible, increasing the capacity of storing glucose.

Starch

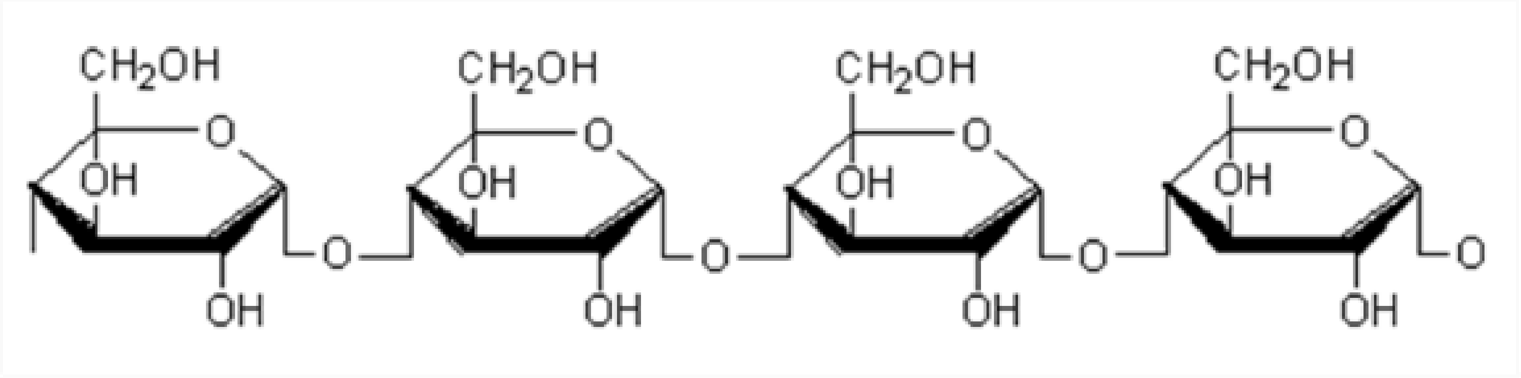


Maltose (glucose-α-1,4-glucose)

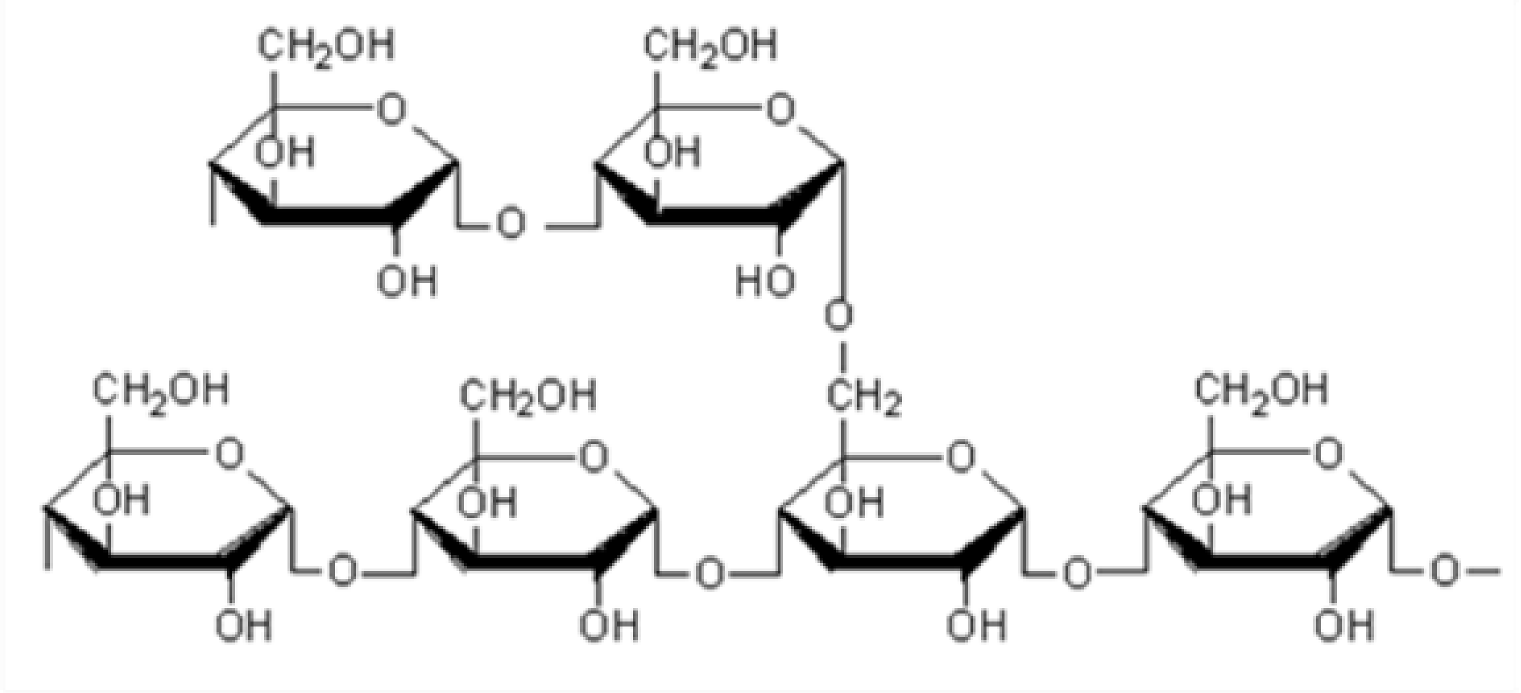
Starch is also a homopolysaccharide
Starch stores glucose for plants

Memorize

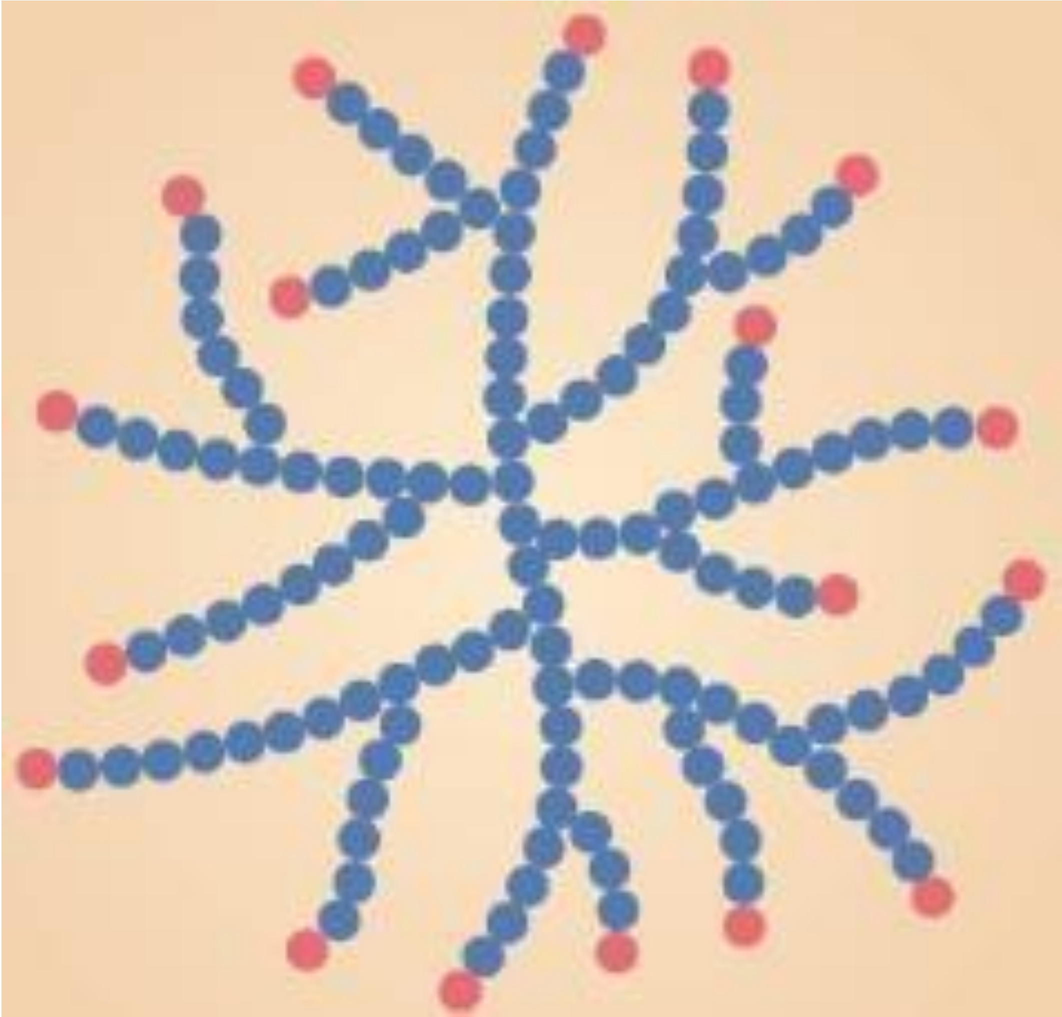
- Which organisms?
- Forms:
  - amylose (10-20%) Unbranched
  - amylopectin (80-90%) Branched (glycogen is more branched than amylopectin)



Amylose Structure

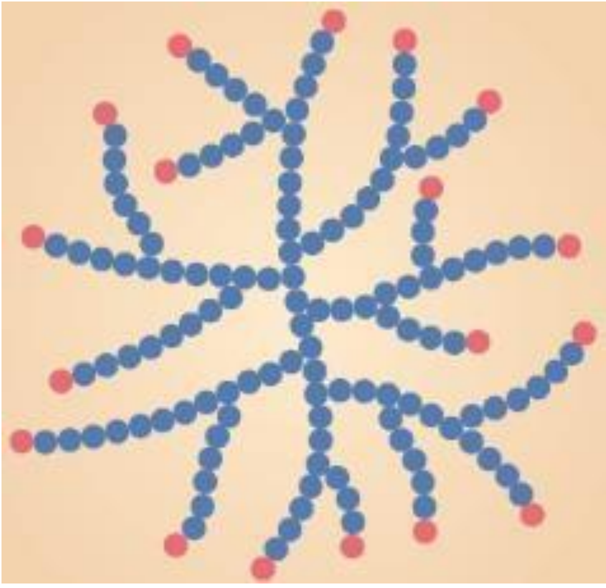


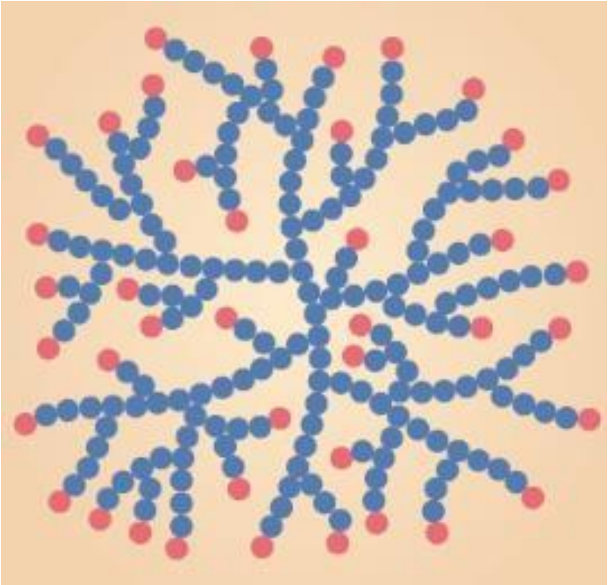
Amylopection Structure



Glycogen vs. amylopectin

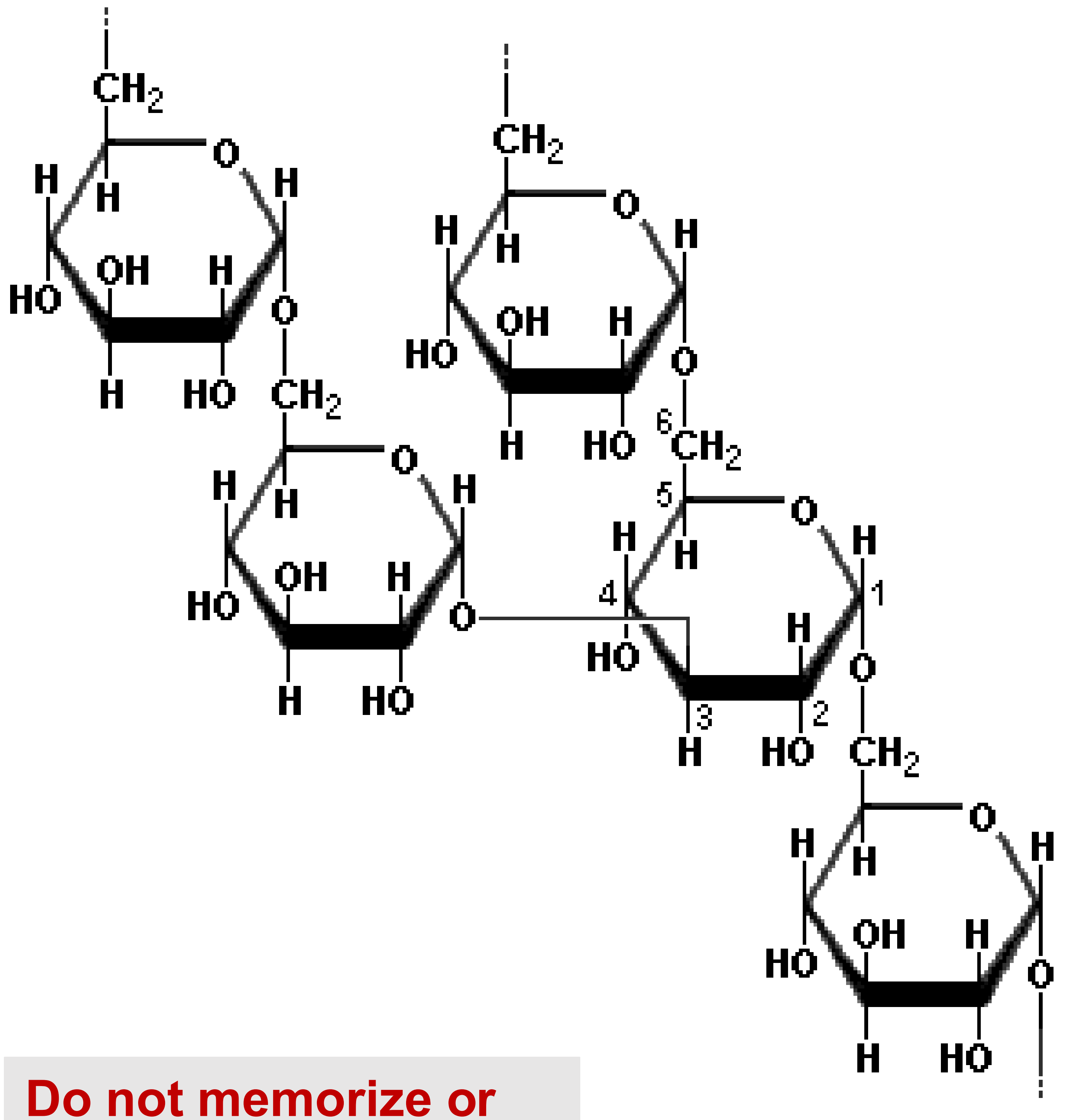
- Both are made from the same monomer and both are branched.
- Glycogen exists in animals and amylopectin in plants.
- Glycogen is more highly branched.
  - Branch points occur about every 10 residues in glycogen and about every 25 residues in amylopectin.
- **Why is branching important?**
  - It makes 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**



Do not memorize or study the structures.

Click to test your studying

For any feedback, scan the code or click on it.

Corrections from previous versions:

Versions	Slide # and Place of Error	Before Correction	After Correction
V0 → V1			
V1 → V2			

Additional Resources: رسالة من الفريق العلمي:

Reference Used:

Prof. Mamoun Ahram recorded lecture

https://youtu.be/aV5Wzx3V2uI?list=PLTt9vDX28ItI

Extra References for the Reader to Use:

Marks’ Basic Medical Biochemistry (6th edition)

سُورَةُ فُصِّلَتْ

إِنَّ ٱلَّذِينَ قَالُوا۟ رَبُّنَا ٱللَّهُ ثُمَّ ٱسْتَقَٰمُوا۟ تَتَنَزَّلُ عَلَيْهِمُ
ٱلْمَلَٰٓئِكَةُ أَلَّا تَخَافُوا۟ وَلَا تَحْزَنُوا۟ وَأَبْشِرُوا۟ بِٱلْجَنَّةِ
ٱلَّتِى كُنتُمْ تُوعَدُونَ ٣٠ نَحْنُ أَوْلِيَآؤُكُمْ فِى ٱلْحَيَوٰةِ ٱلدُّنْيَا
وَفِى ٱلْءَاخِرَةِ وَلَكُمْ فِيهَا مَا تَشْتَهِىٓ أَنفُسُكُمْ وَلَكُمْ
فِيهَا مَا تَدَّعُونَ ٣١