Introduction to Biochemistry and Molecular Biology

Lecture {6}

Carbohydrates Pt.2

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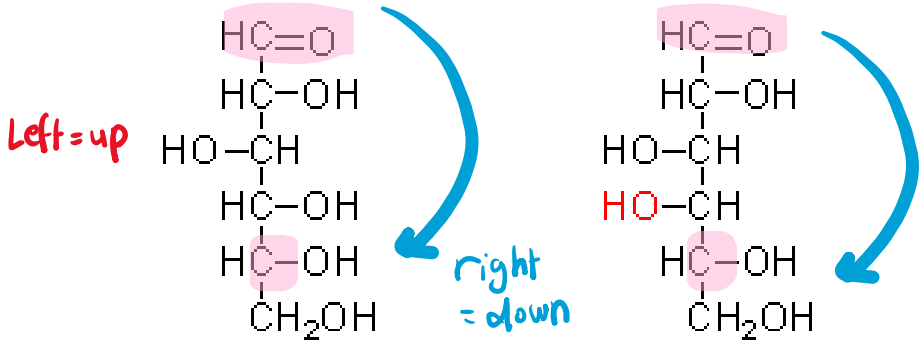
Chain to ring

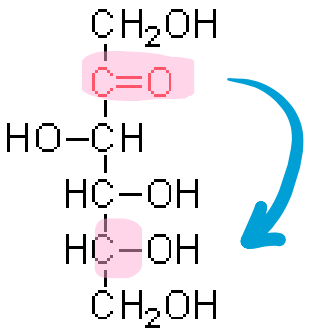
Left-up, right-down

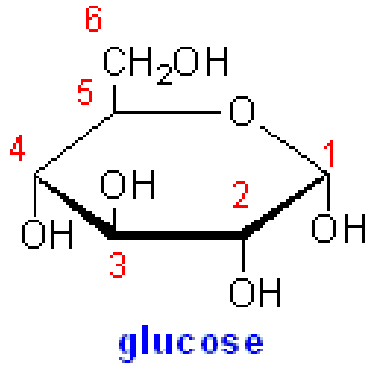
Face the sugar and go down to YOUR right

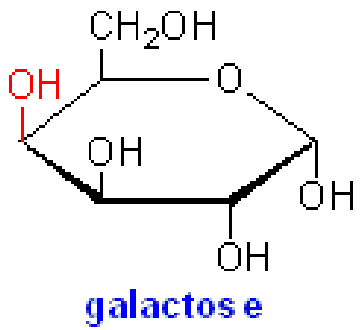
To get the ring form of a chain sugar molecule:

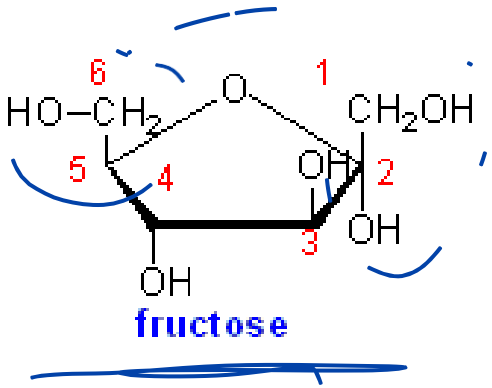
- **Tilt the carbonyl group towards the last chiral center (to the right)**
- **All the H\OH groups that were on the right side of the chain will go downwards.**
- **All the H\OH groups that were on the left side of the chain will go upwards.**



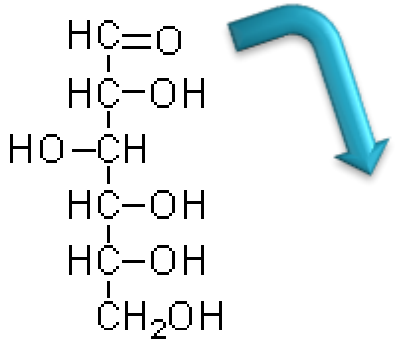


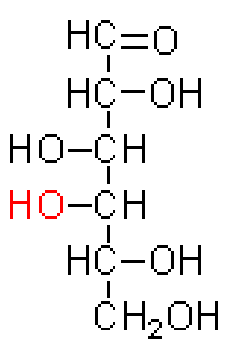


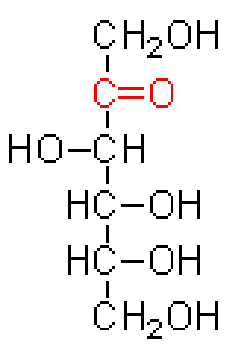


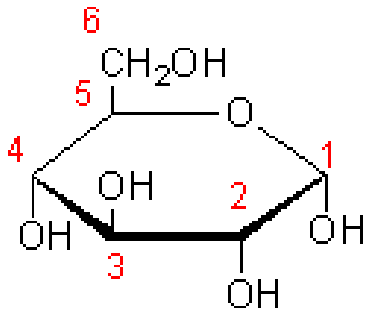


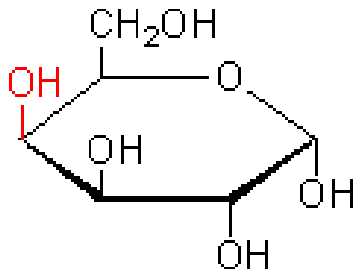
Chain to ring

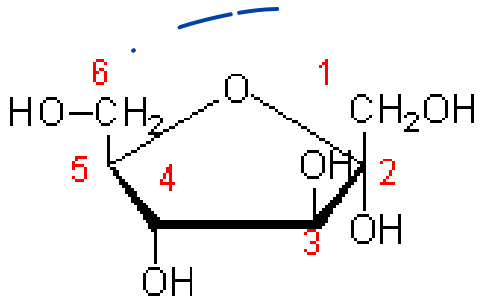












(**this was mentioned in the last lecture**)
NOTICE THIS:
We said that **galactose and glucose** were **diastereomers** (bcz they're stereoisomers that are not mirror images of each others) more specifically, they're **epimers** (at C-4)

Why? Bcz at this carbon the placement of OH differs **>> So,** the configuration has differed only at this singular chiral center ***(you can examine this closely using the ring form, where OH at C-4 is UP is galactose & DOWN in glucose)***
What about **Mannose** with **Glucose**? They're also **epimers** at **C-2** (same reason)

****all of this is only applicable on a D- molecules together or L-molecules together only, hence you cant call a D-Glucose and an L-Mannose epimers**

Notice the names***

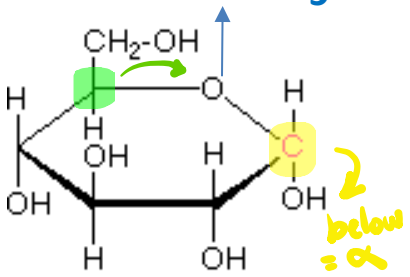
Cyclic aldohexoses

All of these are pyranose >> 6-membered ring, 5-C atoms inside

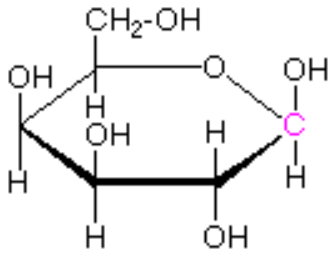
**Remember: we look at the Anomeric Carbon (C-1) to determine α & β types and at the last chiral center to determine D- or L- types (in chain form)

In the chain form, this linkage was an OH molecule bound to the last chiral center to the right

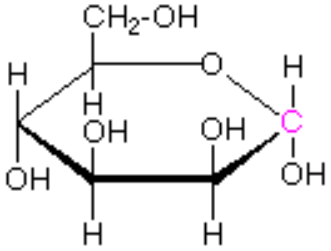
Examples of Some Pyranose Forms of Hexoses



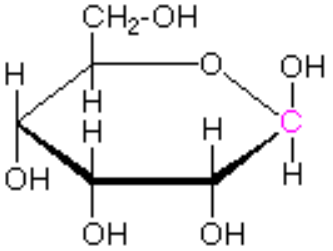
α-D-glucopyranose



β-D-galactopyranose



α-D-mannopyranose



β-D-allopyranose

α > OH below the ring at C-1 (Anomeric)
D> CH2OH above the ring
Gluco> glucose derivative
Pyranose> 6-membered ring with 5-carbons inside

β > OH above the ring at C-1 (Anomeric)
D> CH2OH above the ring
Galacto> Galactose derivative
Pyranose> 6-membered ring with 5-carbons inside

**you don't need to know how to determine D- or L- types in a ring form (extra)

**Glucofunarose is a 5- membered ring with 4- carbons inside

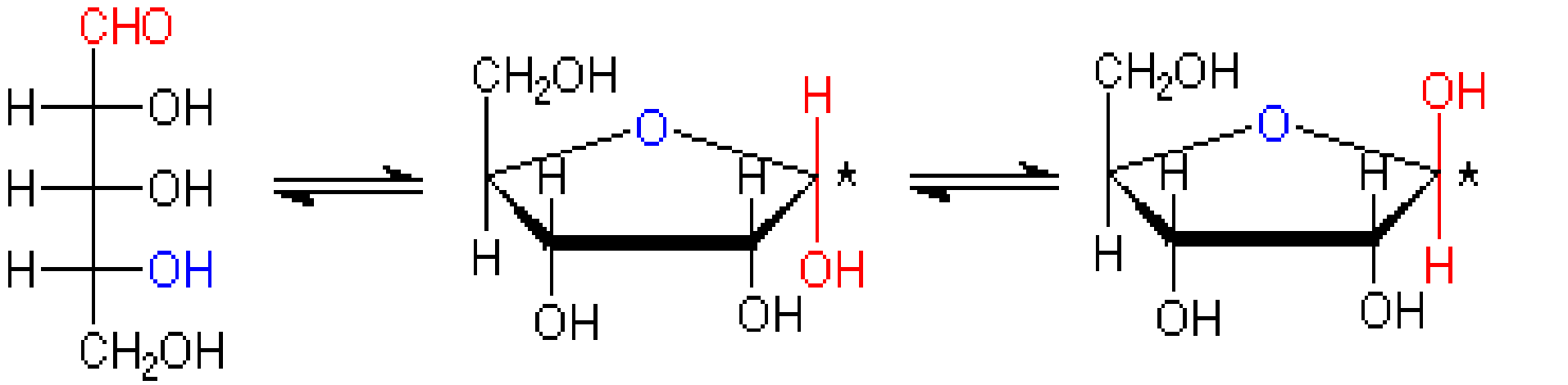
Cyclic ribofuranose

You should know this structure ***

Aldose
Pentose>>
Aldopentose

furanose (its 5-membered)

* anomeric carbon



D-ribose

α-D-ribose

OH at anomeric carbon down

β-D-ribose

OH at anomeric carbon up

Modified sugars

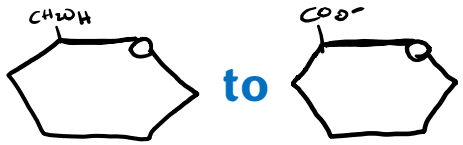
- By oxidation
- By reduction
- By esterification
- By ammonification
- By acetylation

Sugar acids (oxidation)

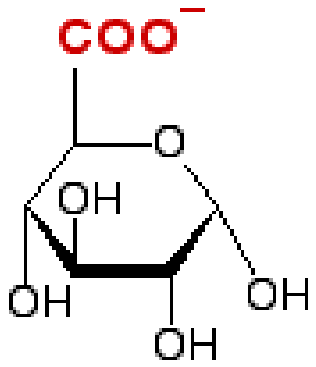
Could happen at C-1 or C-6

Do not memorize the structure but study it.

- Where is it oxidized? What does it form?

C-6 oxidation >> goes from  **to**

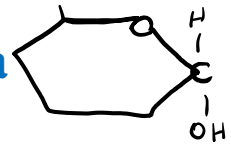
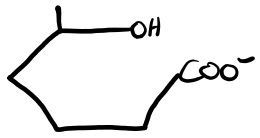
(alcohol to aldehyde to carboxyl group)



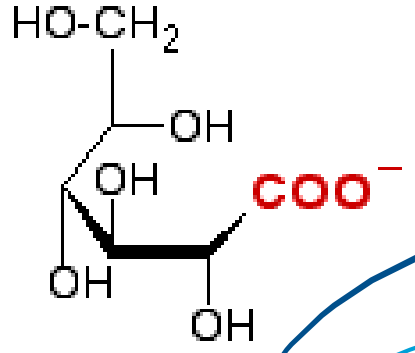
α-D-glucuronate

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

from **oxidation of glucose C6 OH**

C-1 oxidation >> goes from  **to** 

(aldehyde to carboxyl group)



D-gluconate

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

from **oxidation of glucose C1 aldehyde)**

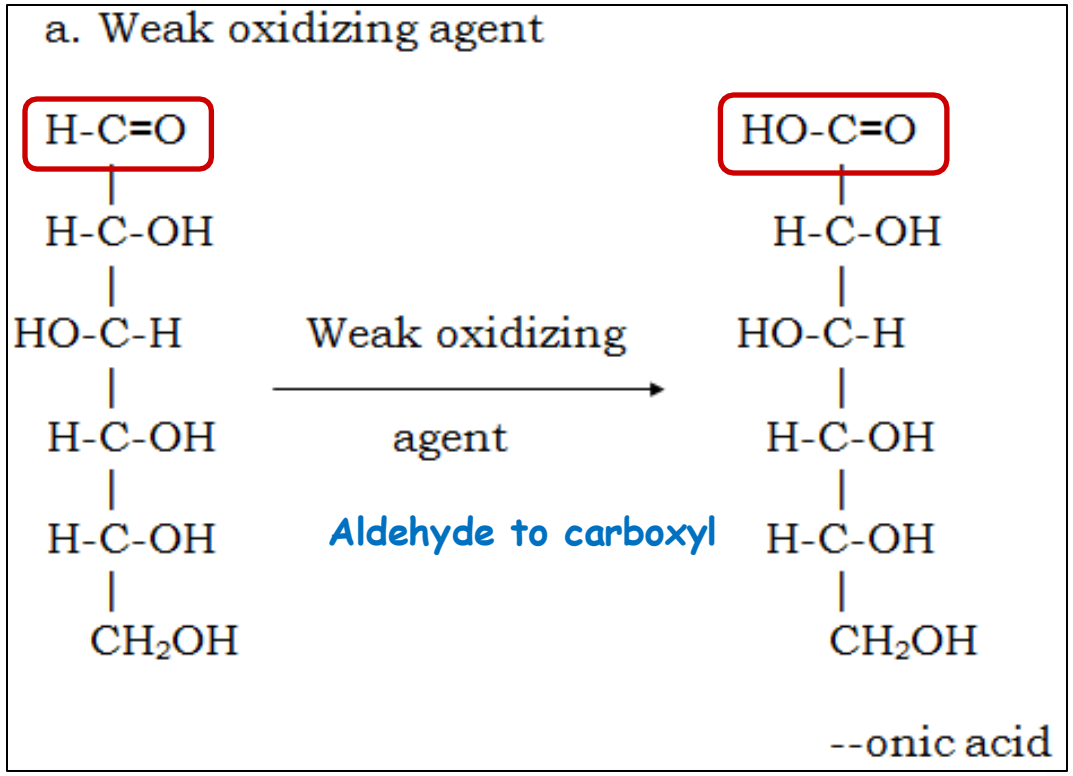
Conjugate base, carboxyl is ionized

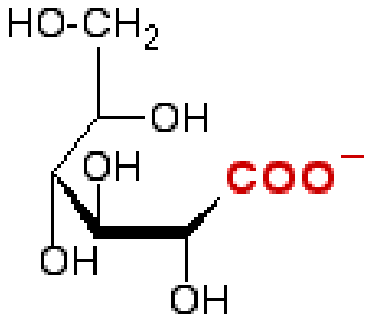
Acid, only when carboxyl is protonated (-COOH)

**The ring opens in order to completely oxidize the sugar (and it stops being a sugar after oxidation>its just a modified sugar)

Gluconate

These two slides were discussed thoroughly in the previous slide**



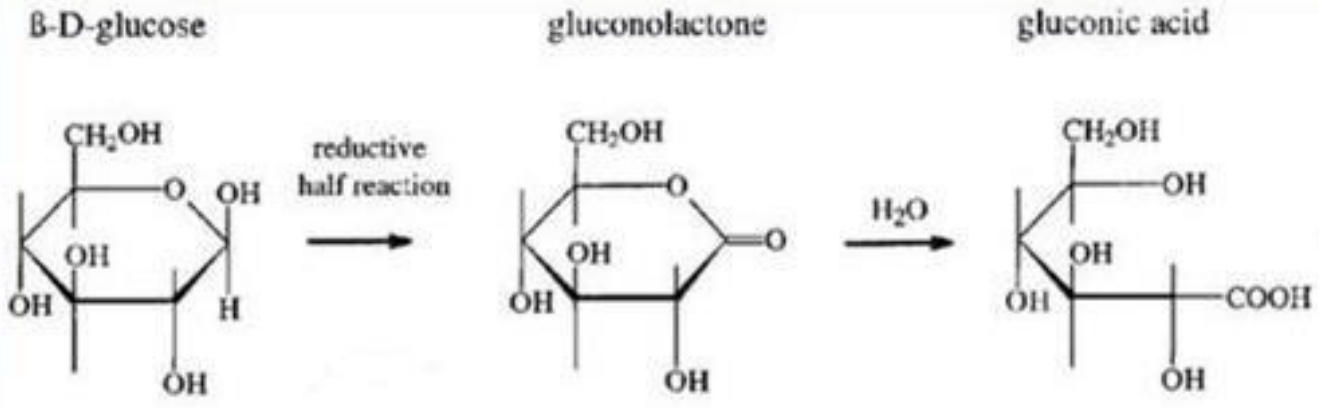


D-gluconate

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

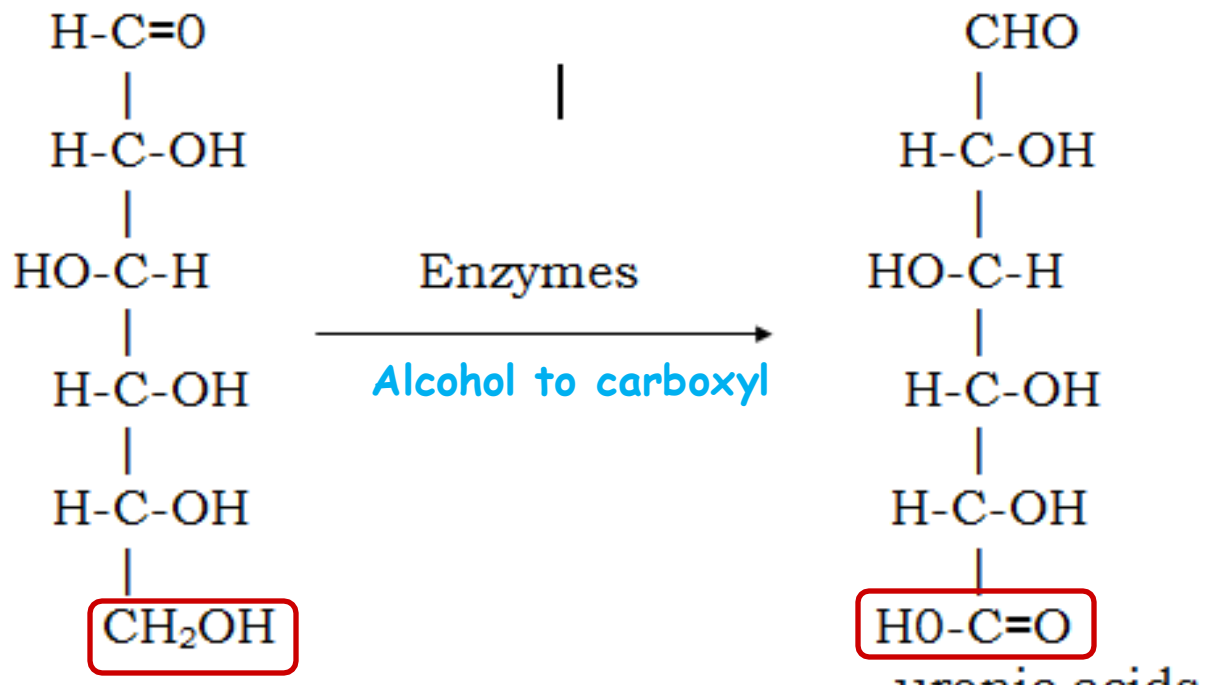
from **oxidation of glucose C1 aldehyde)**

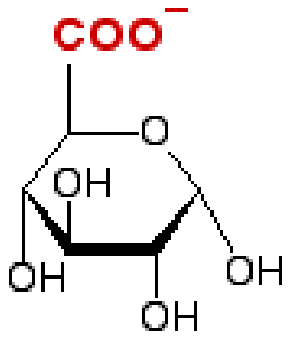
Do not memorize the structure but study it.



Glucoronate

c. Oxidation of primary alcohol end in biological systems





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

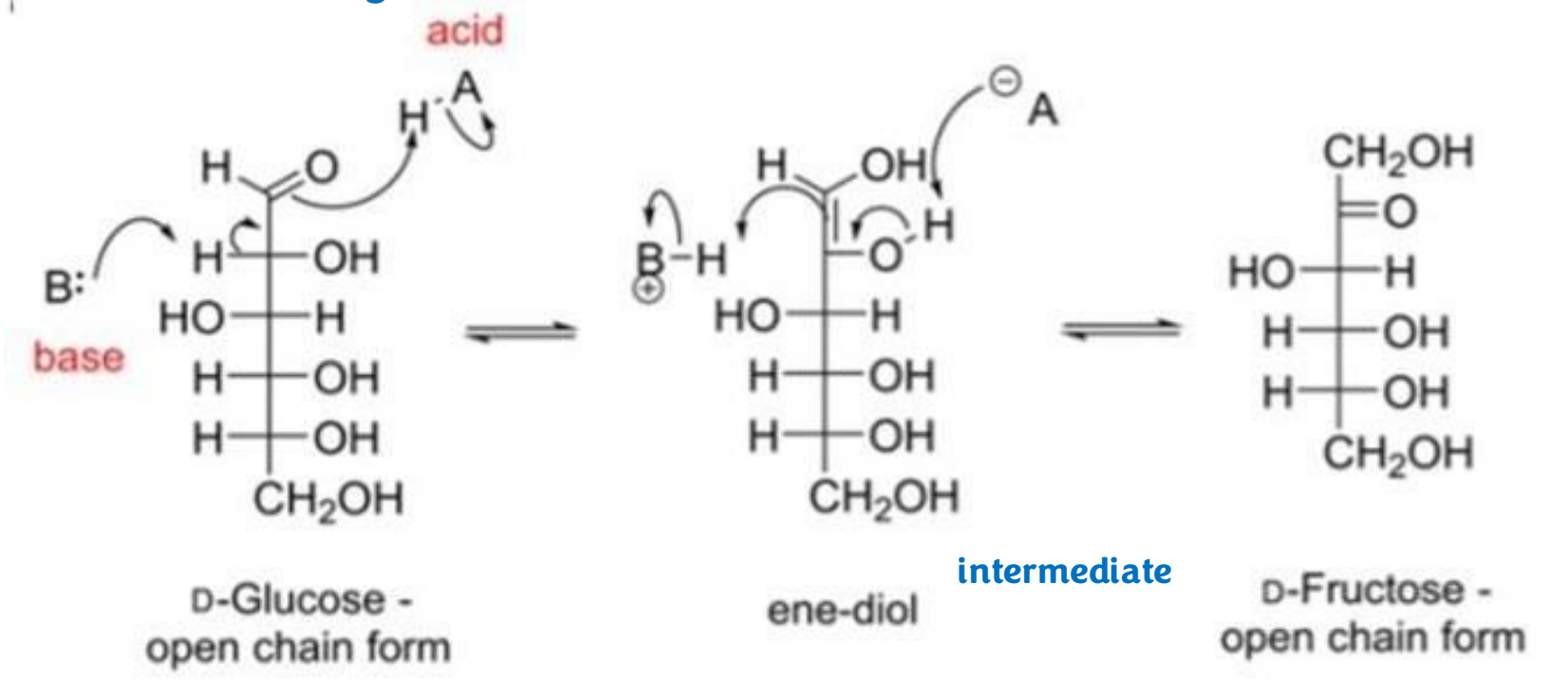
Do not memorize the structure but study it.

Note

We know that aldehydes and alcohols could be oxidized, and that ketones can't be oxidized, so can ketoses be oxidized? –Yes

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

How so? Let's take fructose as an example on ketoses, the fructose would be Isomerized (converted into its isomer) and it would become glucose through an intermediate form, and now the glucose could be oxidized

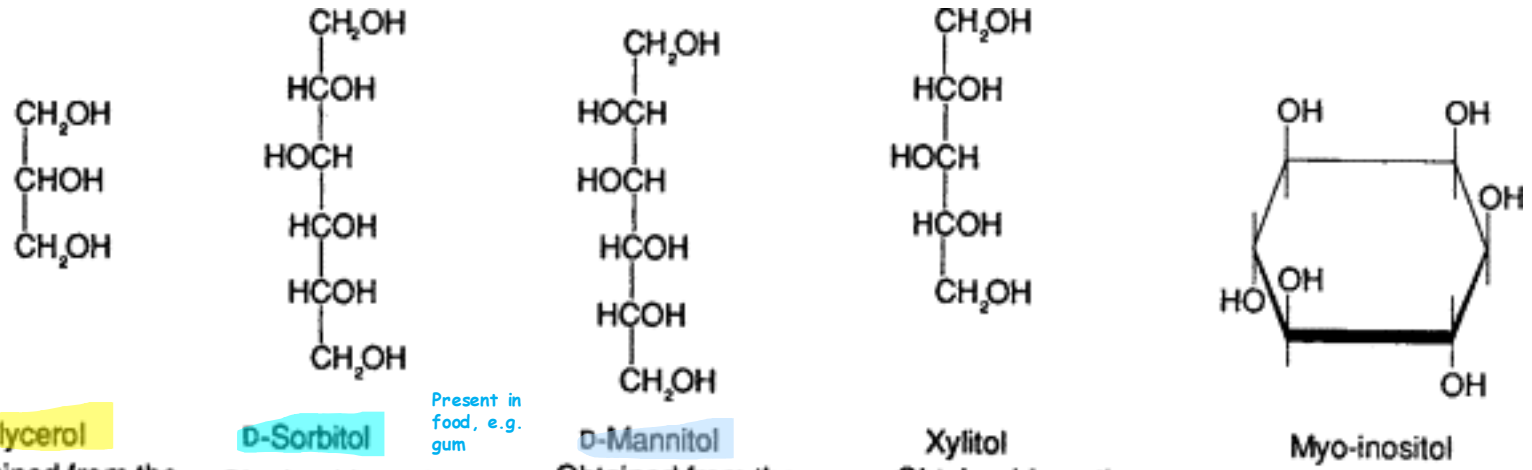


***Don't confuse ketones with ketoses:
-ketones are chemical compounds that have a carbonyl group and are NOT sugars
-ketoses are SUGARS that have a carbonyl group within them

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

Sugar alcohols (reduction)

- What does it form? **Alcohols (if it was aldehyde > primary, ketone > secondary)**
- Examples include **glycerol**, **sorbitol**, **mannitol**, and **xylitol**, which are used to sweeten food products



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

D-Sorbitol
Present in food, e.g. gum
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

Prof said these small paragraphs are "common sense" and that they aren't too important > just read over them
focus on the first 3.

We will get to this sugar in the lipids lecture

To make it easier to memorize >> all these end in *-ol* which is derived from the word alcohol. So, it's a alcohol that was made by reducing a sugar

Deoxy sugars (reduced sugars)

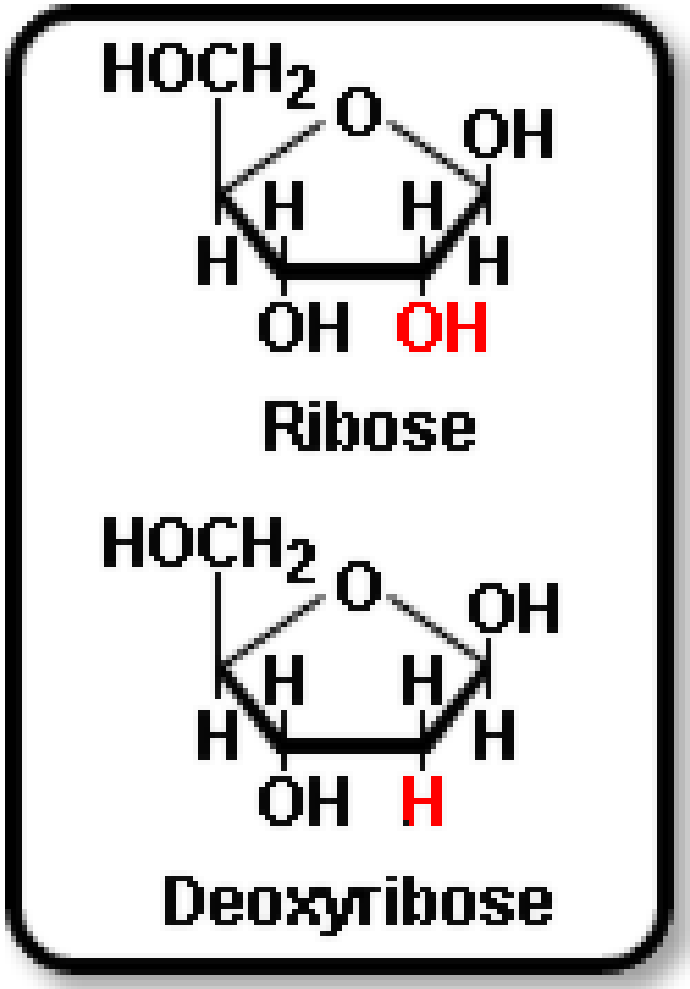
- One or more hydroxyl groups are replaced by **hydrogens**.

- An example is 2-deoxyribose, which is a constituent of DNA.

Another way for reduction: removing oxygen

The OH that's present on C-2 on ribose will be *reduced/removed (and replaced with hydrogen)* > then the ribose will become Deoxyribose (which makes up the DNA)

'Deoxy' indicates the removal of one oxygen atom compared to ribose.



sugar

Reduced sugar

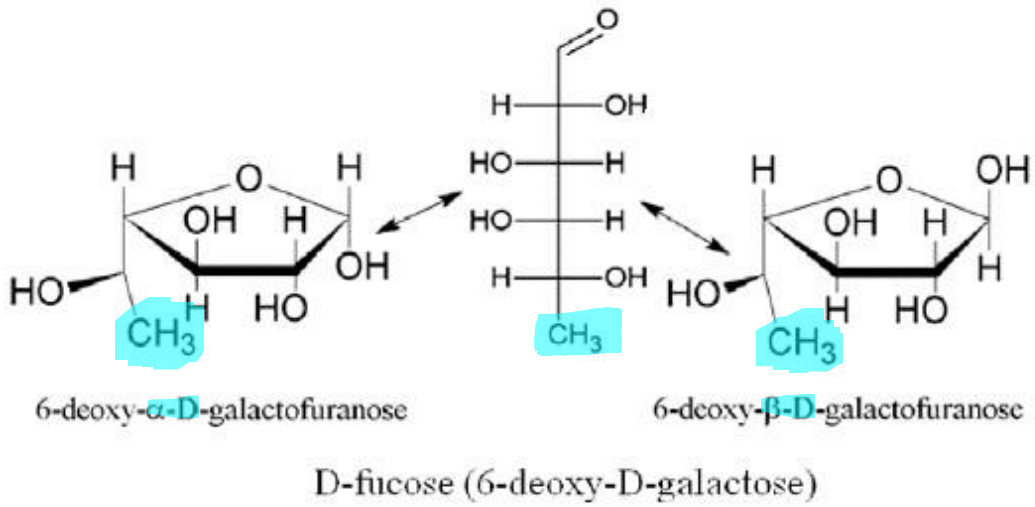
Another deoxy sugar

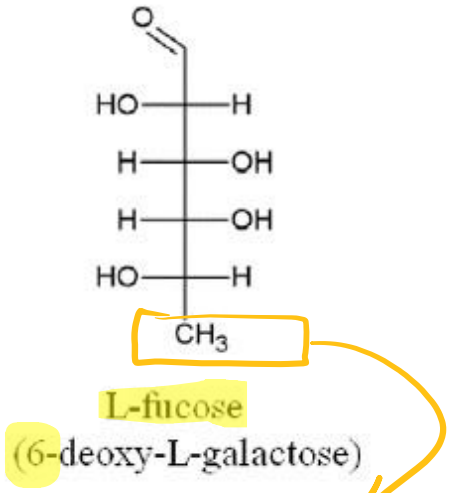
- L-fucose (L-6-deoxygalactose)
  - found in the **carbohydrate portions** of some **glycoproteins**

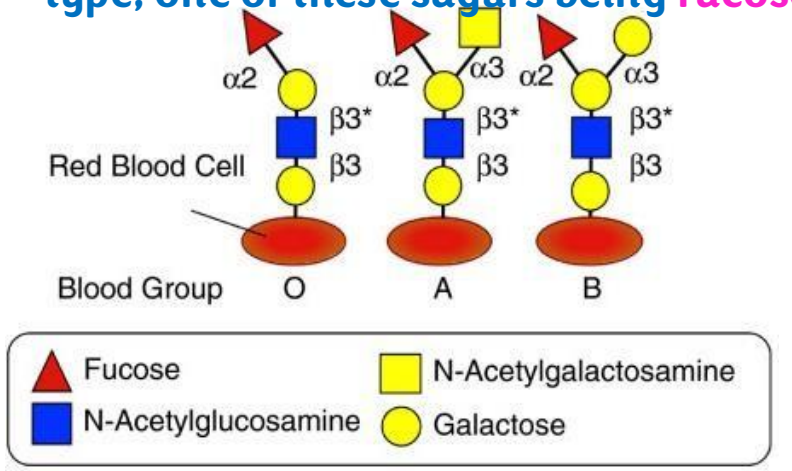
Fucose = galactose that's been deoxygenated/reduced

e.g., antigens on RBCs

All you need to know is that there's a chain of sugars attached to the surface of an RBC which determines the blood type, one of these sugars being fucose







L-fucose exists on the surface of RBC's

Do not memorize the structure but study it.

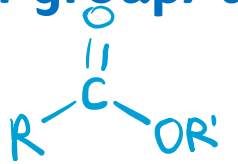
On this carbon in a normal galactose, you would see it as CH2OH, but since it's been deoxygenated, it's now CH3

Do not memorize the components except for fucose.

Sugar esters (esterification)

=formation of an ester group/ a sugar ester

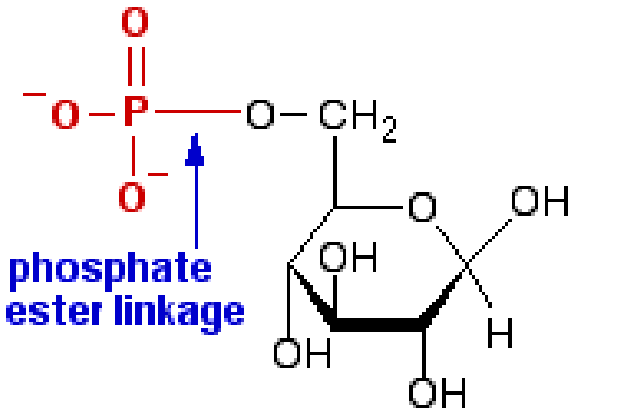
Ester group >> -COOR



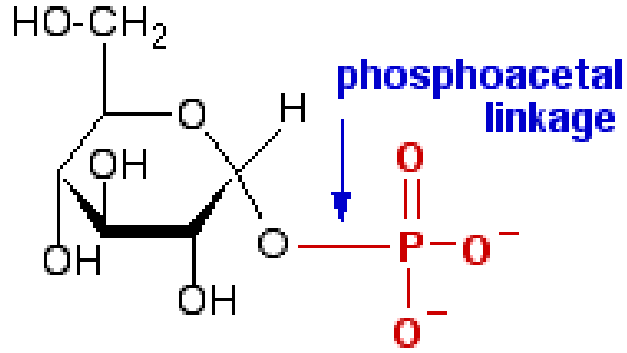
- What is the reacting functional group? Where does it react? What are the end products? Where are they used?

Phosphorylation has occurred>> which is the addition of a phosphate group to a molecule
So, sugars like glucose could be phosphorylated at C-1 or C-6 > and it becomes a phosphoester
(since esters are RCOOR' > phosphoesters are RPOOR' (*) just substitute the C with phosphate and oxygen)

The significance of phosphorylation>> it becomes a high energy molecule and that helps in metabolism



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



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

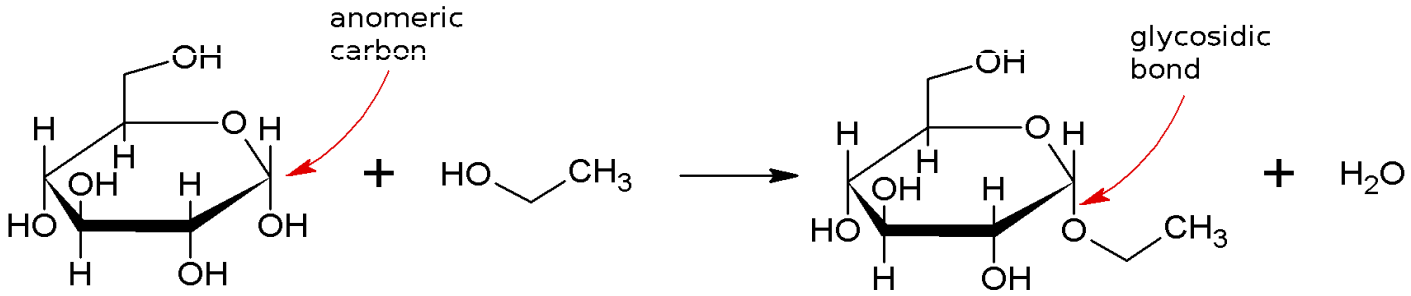
Examples of sugar esters

*Rly important molecules esp later when we talk about metabolism

O-Glycosides the reaction of the *anomeric carbon* of monosaccharide with *OH group*

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

The reaction happens at the anomeric carbon -> glycosidic bond



Sugar + Alcohol -> O-glycosidic compound

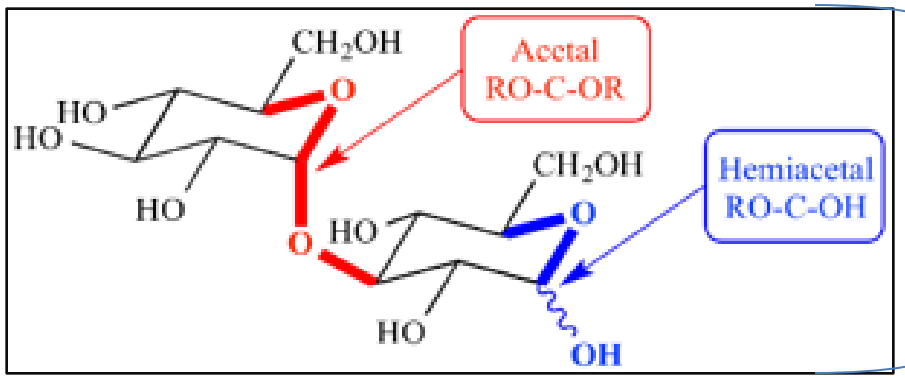
This reaction is one way to obtain an O-glycoside

The O refers to oxygen obtained from an alcohol

It's known as O-Glycosides bcz linkage involves and oxygen

The bond could either be α or β depending on the position of the anomeric carbon
Once the bond is formed the carbon can't undergo mutarotation (it's fixed) >> significance of the bond

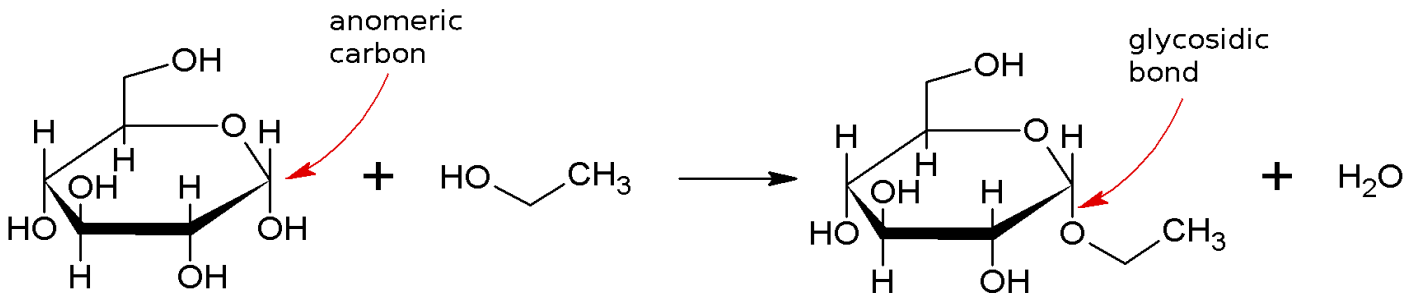
The glycosidic bond between two sugars can be at either or both anomeric carbons

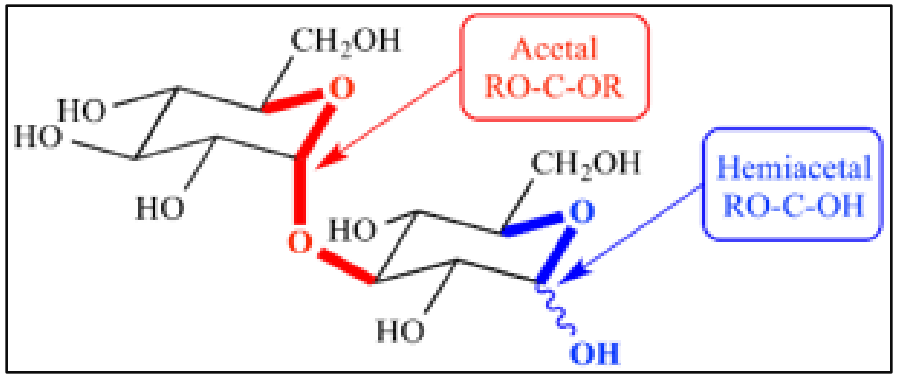


This is another way of obtaining O-glycoside: through the creation of a sugar + OH of another sugar

O-Glycosides

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





Bond between anomeric carbon with OH >>> O-Glycoside
Bond between anomeric carbon and R group comes from the alcohol group known as >>> glycosidic bond

Whenever you hear a (glycosidic bond) You should know that it's a reaction that involves the anomeric carbon
To classify a bond as a glycosidic bond >the anomeric carbon must be involved

What's the importance of the link with anomeric carbon ?

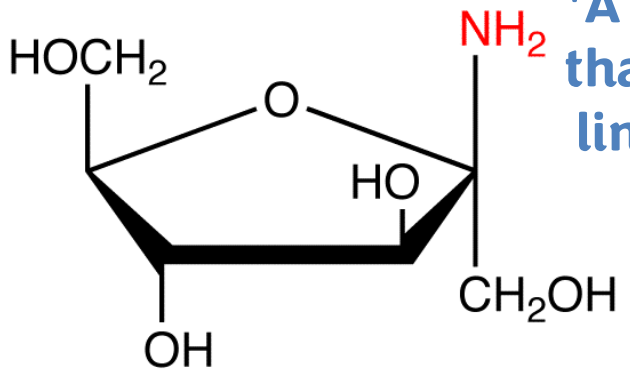
The ring doesn't open up anymore
Once the anomeric carbon is involved in (covalent linkage) with something else the ring doesn't open anymore it stays fixed

N-Glycosides

Here, however, there's a reaction between monosaccharide and an amine group forming also a glycosidic bond at the anomeric carbon too

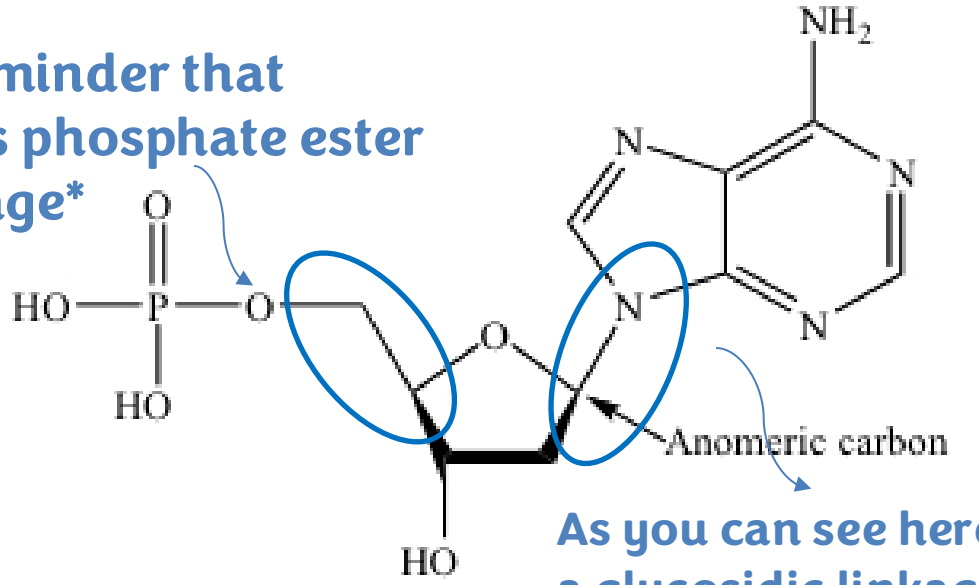
- What is the reacting functional group? Where does it react? What are the end products? Where are they used?
- Examples: nucleotides (DNA and RNA)

The glycosidic bond between two sugars can be at either or both anomeric carbons



N-glycoside

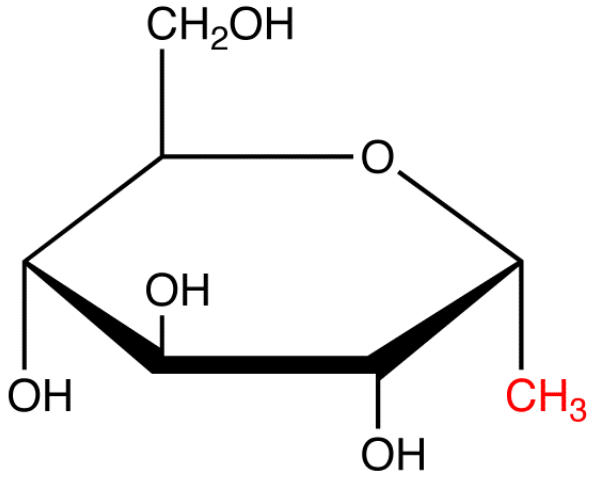
A reminder that that's phosphate ester linkage



As you can see here there's a glycosidic linkage between C and N in the nucleotide

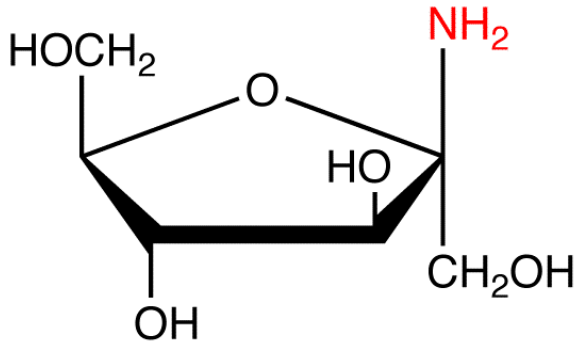
Note

- 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

C: methyl group



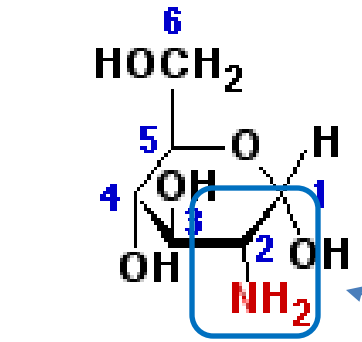
N-glycoside

Amino sugars

The addition/ reaction of an amine group with any other carbon
Also the bond here is an amine bond.

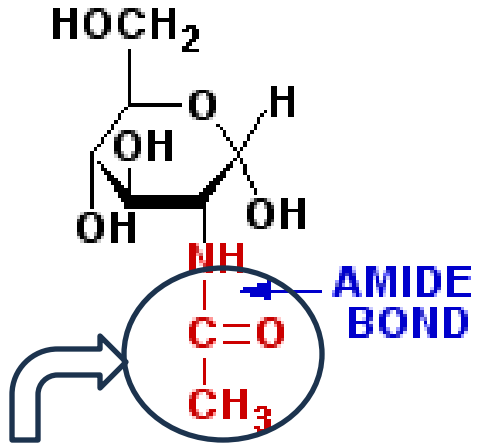
- What is the reacting functional group? Where does it react? What are the end products? Where are they used?
- Further modification by acetylation

The difference between amino sugars and N-glycoside:
N-glycoside= is a sugar molecule that is formed as a result forming a covalent linkage between the anomeric carbon of the sugar with an amine group-> name of the bond: glycosidic bond.
Amine sugar= results from a reaction between a sugar and amino group whereby the amino group replaces one of the hydroxyl groups of the sugar except the one on the anomeric carbon-> we don't have a glycosidic bone=> amine bond.



α-D-2-glucosamine
(GlcN)

NH2 replaces any hydroxyl group on any carbon usually carbon 2



N-acetyl-α-D-2-glucosamine
(GlcNAc)

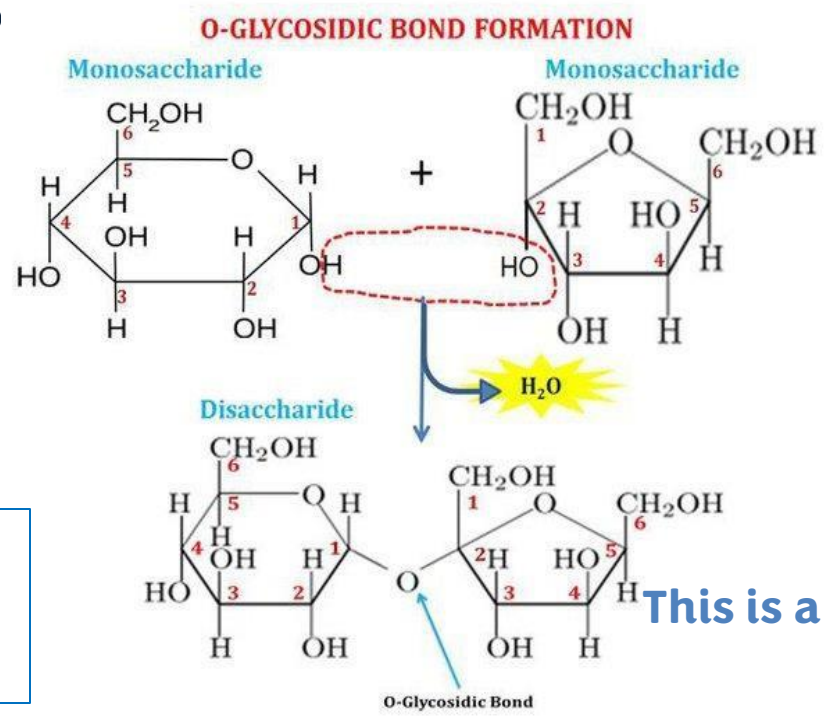
Disaccharides

Molecules that contain 2 sugars

Hetero: two different sugars.
Homo: two of the same sugar.

- What are disaccharide? Oligosaccharides? Hetero- vs. homo-?
- What is the type of reaction? Condensation: releases H2O
- What is a residue? Each" subunit" of the dimers is called a residue-> glucose in lactose called a residue
- Synthesizing enzymes are glycosyltransferases. They transfer sugar molecules
- Do they undergo mutarotation?
- Are products stable?

Involves at least one anomeric carbon



The reaction doesn't happen spontaneously it needs enzymes to drive/ catalyze the reaction

the bond is glycosidic because it involves the anomeric carbon of the first sugar
[the first carbon in the reaction is the one on the left and it acts as a" carrier" for the second carbon]

No, it doesn't because as discussed earlier the bond prevents the opening of the ring-> so yes the products are stable.

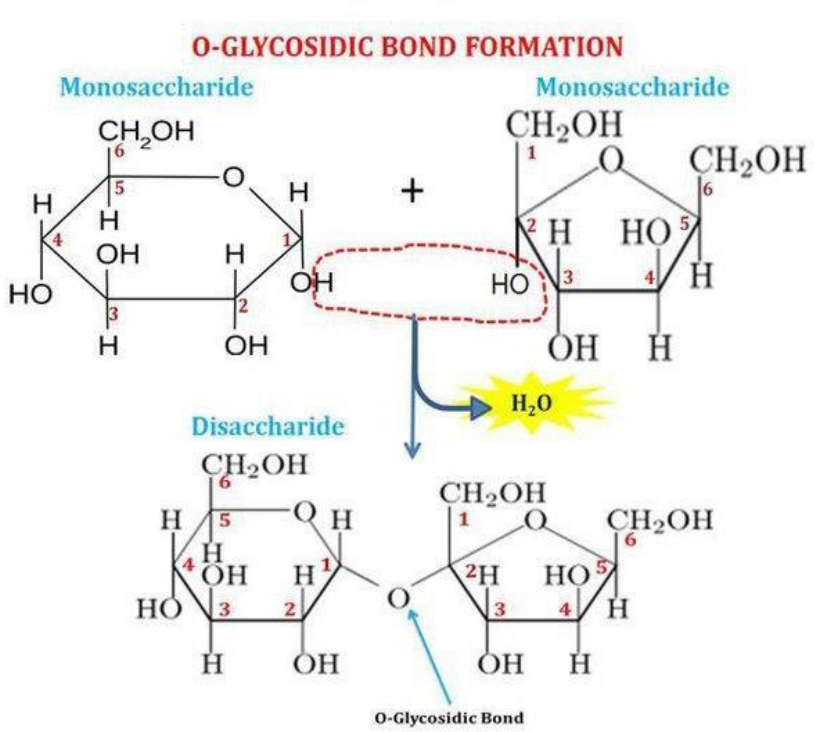
This is a hetero- disaccharide

Disaccharides

**for further explanation for the figures watch the lecture

- 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?

Mutarotation means That when the hydroxyl grop existed in the anomeric carbon changes its orientation form alpha to beta but once glycosidic bond is formed the ring won't open and the atom linked to the anomeric carbon won't rotate anymore (fixed) For example if it was alpha it will remain alpha



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 required for the exam are D sugars, " because glucose(the major sugar in human blood) and most other sugars in human tissues belong to the D series, sugars are assumed to be D unless L is specifically added to the name"

Abundant disaccharides

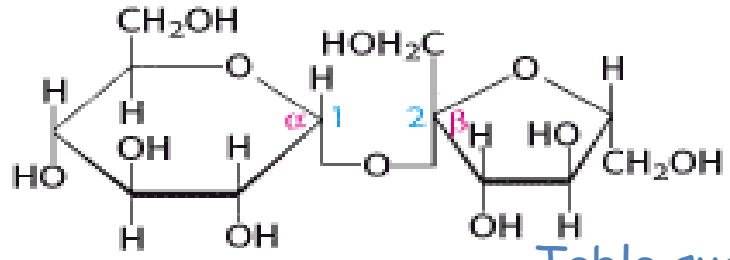
- Configuration
- Designation
- Naming (common vs. systematic)
- Reducing vs. non-reducing

To determine the identity of the sugar:
1- is it pyran or furan?
2- OH on C2 is it above or below?
3- OH on C4 is it above or below?

Pyran- OH2 below- OH4 below=> Glucose

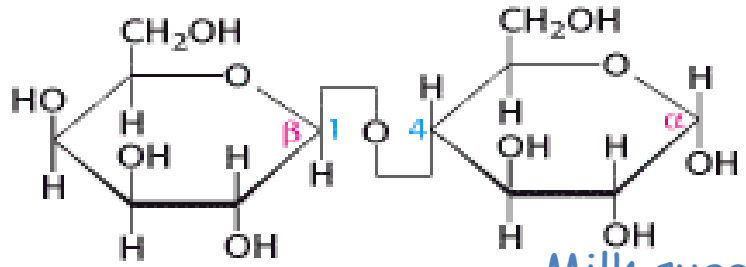
Pyran- OH2 below- OH4 above=> Galactose
Furan-> fructose.

Things to keep in mind whilst observing the following figure:*I'll take this as an example*
a-D-Glucopyranosyl
a: anomeric configuration
D: sterioconfiguration
Gluco: glucose
Pyran: 6 membered ring
Osyl: suffix referring to the first residue of the disaccharide



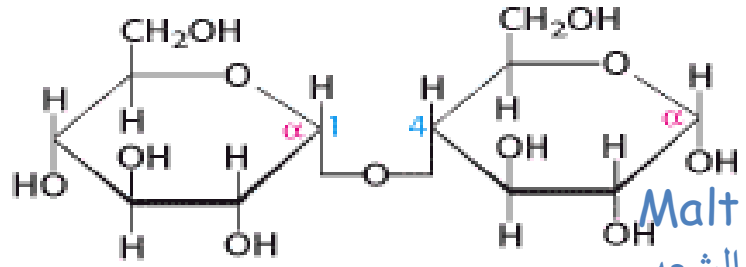
Sucrose
(α-D-Glucopyranosyl-(1→2)-β-D-fructofuranose

Table sugar



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

Milk sugar



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

Malt sugar
سكر الشعير

Abundant disaccharides

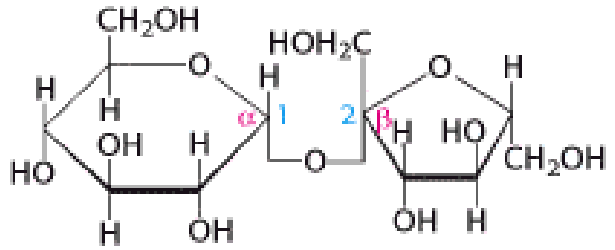
- Configuration
- Designation
- Naming (common vs. systematic) Reducing vs. non-reducing

Again, at least one anomeric carbon involved

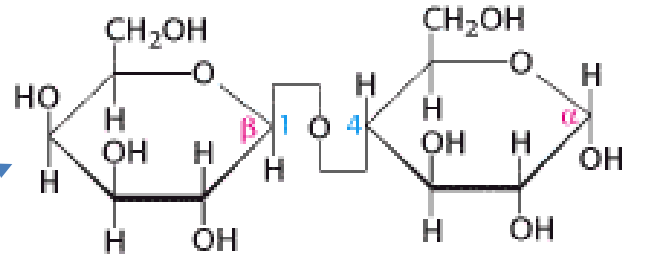
Now it's imp to know how many anomeric carbons are involved in classifying the disaccharide into reducing or non-reducing
~Reducing at least one free anomeric carbon(then all monosaccharides are reducing)
~Non-reducing= no free anomeric carbon

For sucrose for example both carbons in the reaction are anomeric for further explanation on how refer to slide 26 here
or 46 OG

non-reducing- both are occupied

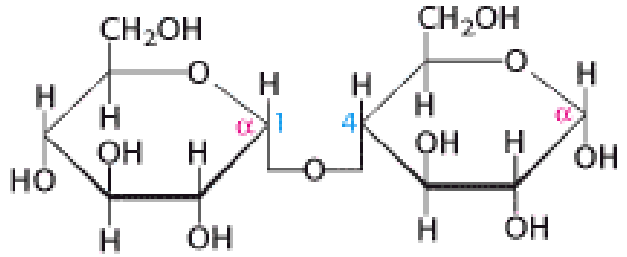


Sucrose
(α-D-Glucopyranosyl-(1→2)-β-D-fructofuranose



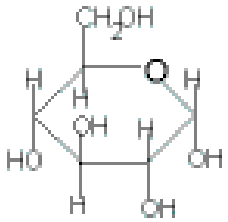
Lactose
(β-D-Galactopyranosyl-(1→4)-α-D-glucopyranose

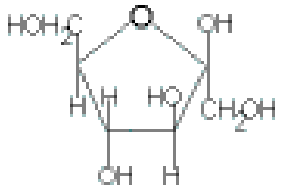
Reducing- free on the 2nd sugar

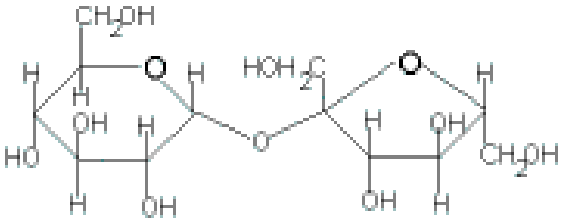


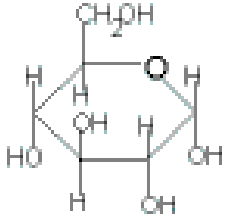
Maltose
(α-D-Glucopyranosyl-(1→4)-α-D-glucopyranose

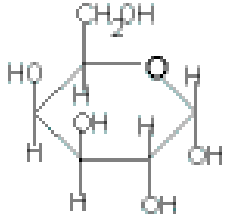
Name	Formula	Formed from	Structure
sucrose	$C_{12}H_{22}O_{11}$	glucose + fructose	---> sucrose + H_2O
lactose	$C_{12}H_{22}O_{11}$	glucose + galactose	---> lactose + H_2O
maltose	$C_{12}H_{22}O_{11}$	glucose + glucose	---> maltose + H_2O

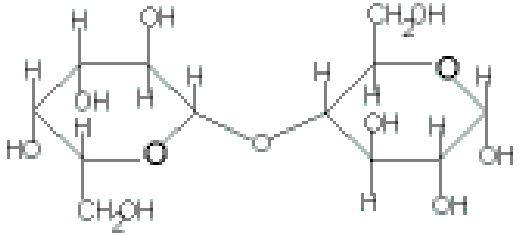


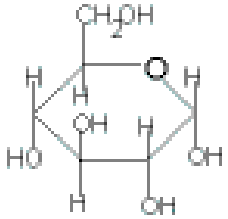


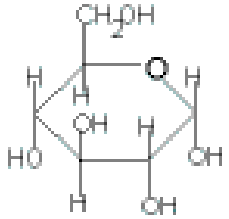


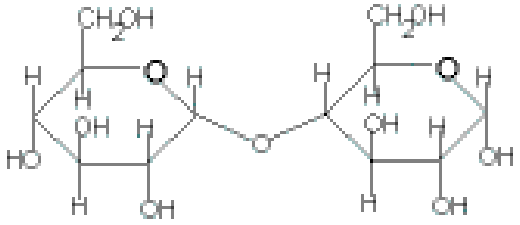






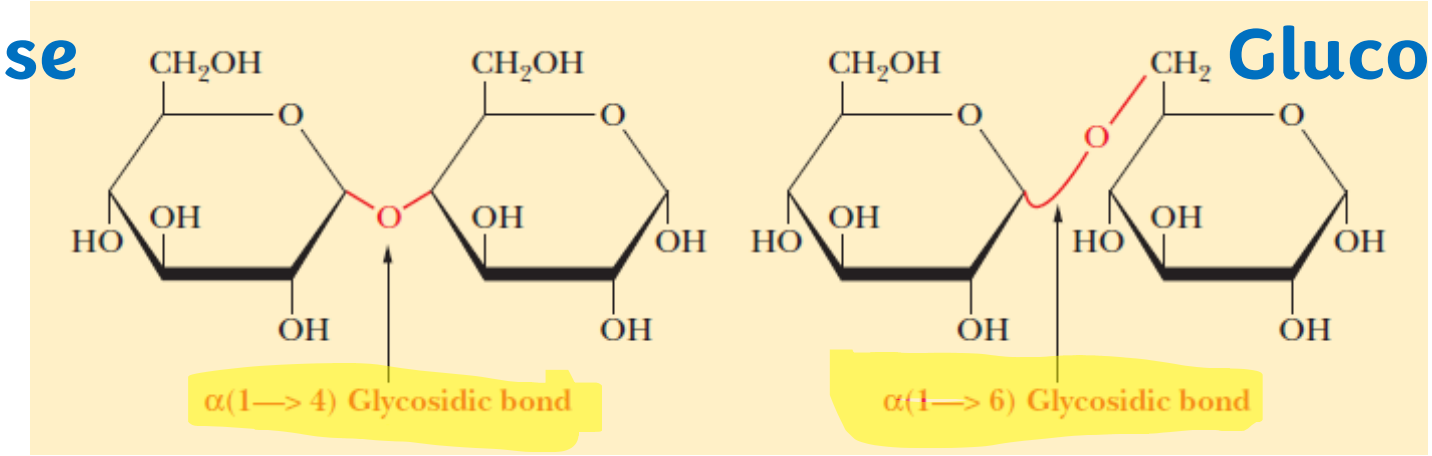






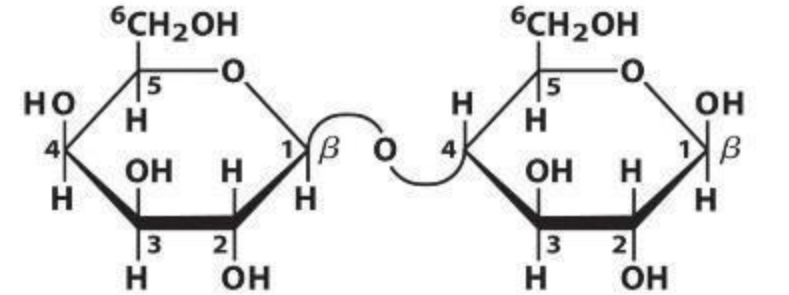
Different forms of disaccharides

Glucose



Glucose

Galactose

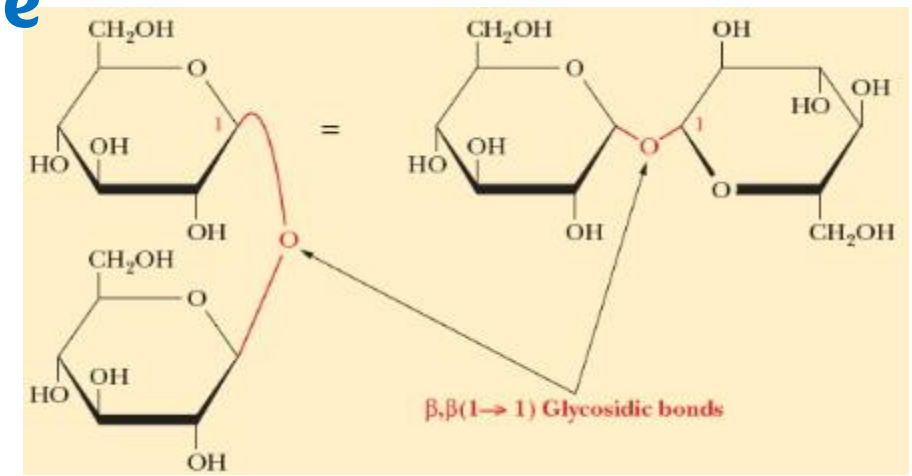


Lactose (β form)

β-D-galactopyranosyl-(1 $\rightarrow$4)-β-D-glucopyranose

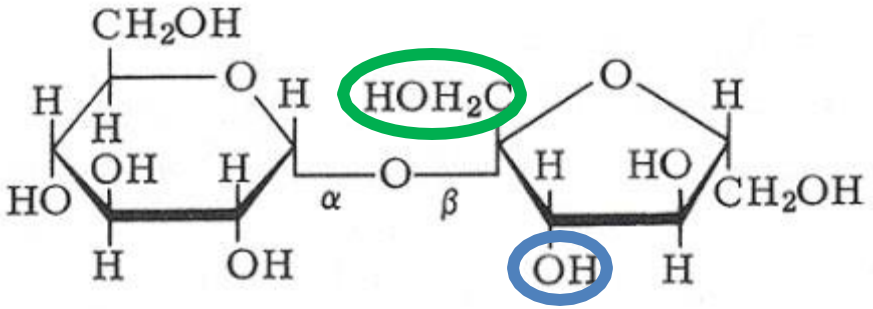
Gal(β1$\rightarrow$4)Glc

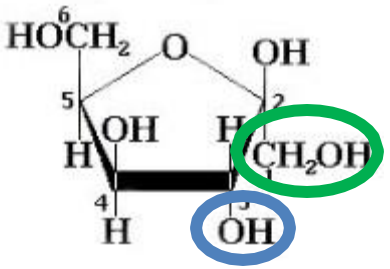
Glucose

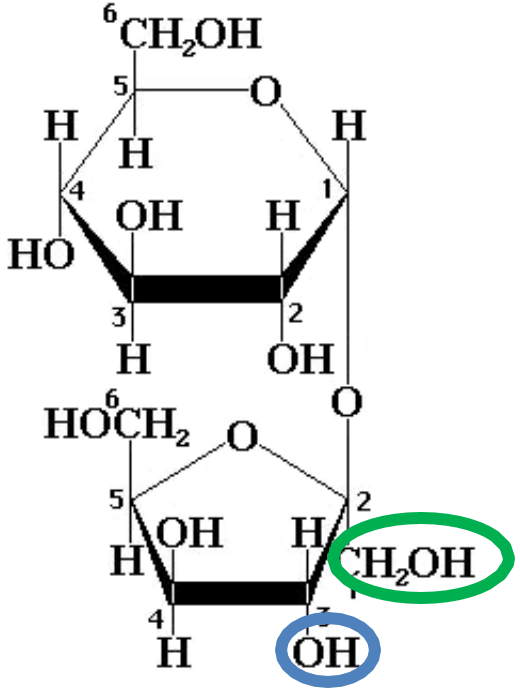


A disaccharide of β-D-glucose.

Sucrose







This is extra

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

Corrections from previous versions:

Versions	Slide # and Place of Error	Before Correction	After Correction
V1 → V2	#2 #4 #7 #11 #13	Carboxyl group Determining D\L in rings by OH C-1 (on the right image) "sugar was made by reducing an alcohol" D-fucose is on the surface of RBC's	Carbonyl group Determining D\L in rings by CH2OH C-6 "alcohol was made by reducing a sugar" L-fucose is on the surface of RBC's
V2 → V3			
V3 → V4			

Additional Resources:

رسالة من الفريق العلمي:

1. Mark's basic medicsl biochemistry- 5th edition:
   Chapter 5
   Page 160- 168
2. carbohydates playlist on youtube

"Never set your eyes only on the outcome, fall in love with the process"