Carbohydrates: structure and Function

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Objectives:

To understand:

1- The structure of carbohydrates of physiological significance.

2- The main role of carbohydrates in providing and storing of energy.

3- The structure and function of glycosaminoglycans.

OVERVIEW

Carbohydrates "hydrates of carbon"

- The most abundant organic molecules in nature.
- Provide important part of energy in diet.
- structural component of cell membranes.
- Act as the storage form of energy in the body.
- The empiric formula is $(CH_2O)_n$.

Some carbohydrate metabolism disorders:

Diabetes mellitus: a chronic disease associated with abnormally high levels of the sugar glucose in the blood.

Galactosemia: condition in which the body cannot process or 'metabolise' the sugar galactose. Which means High galactose level in the blood.

Glycogen storage disease: is the result of defects in the processing of glycogen synthesis or breakdown within muscles, liver, and other cell types.

Lactose intolerance: is the inability of adults and children to digest lactose.

Classification

Monosaccharides	Disaccharides	Oligosaccharides	polysaccharides
Simple sugar	2 monosaccharide units	3-10 monosaccharide units	more than 10 sugar units

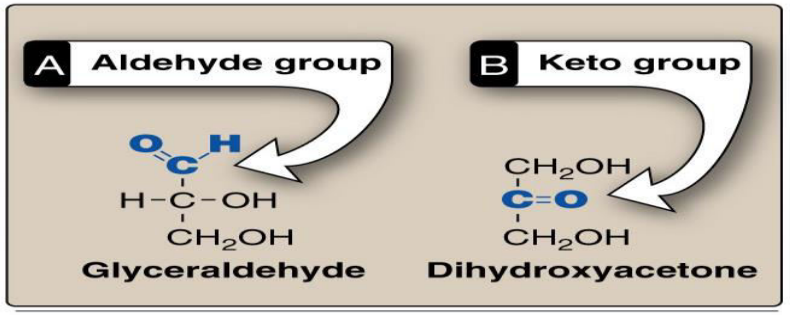
- **Homopolysaccharides**
  Same sugar unit multiple copies.
- **Heteropolysaccharides**
  Different sugar units multiple copies.

Monosaccharide

Further classified based on:

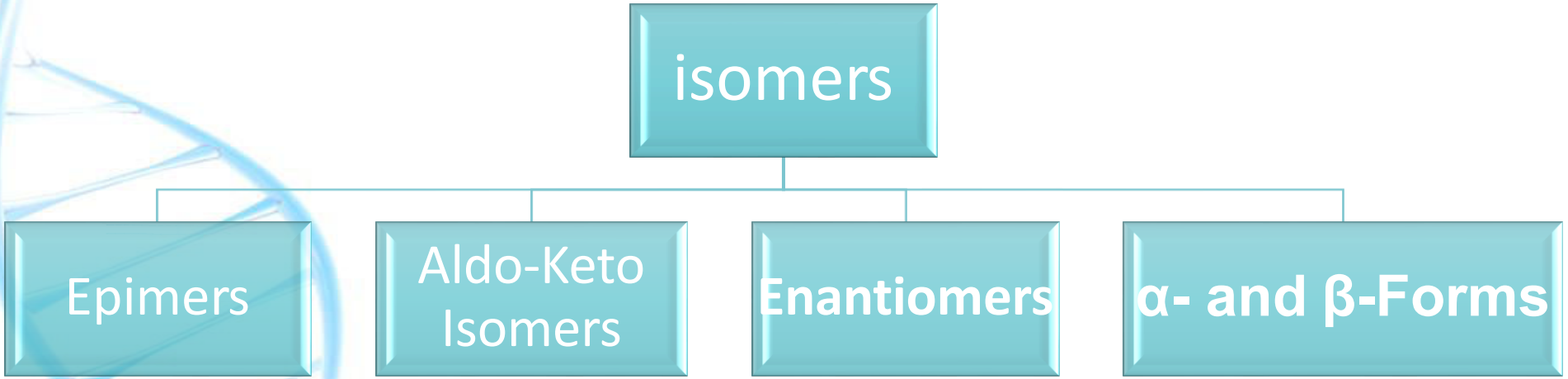
- No. of carbon atoms
- Functional sugar group
  - Aldehyde group (aldoses)
  - Keto group (ketoses)

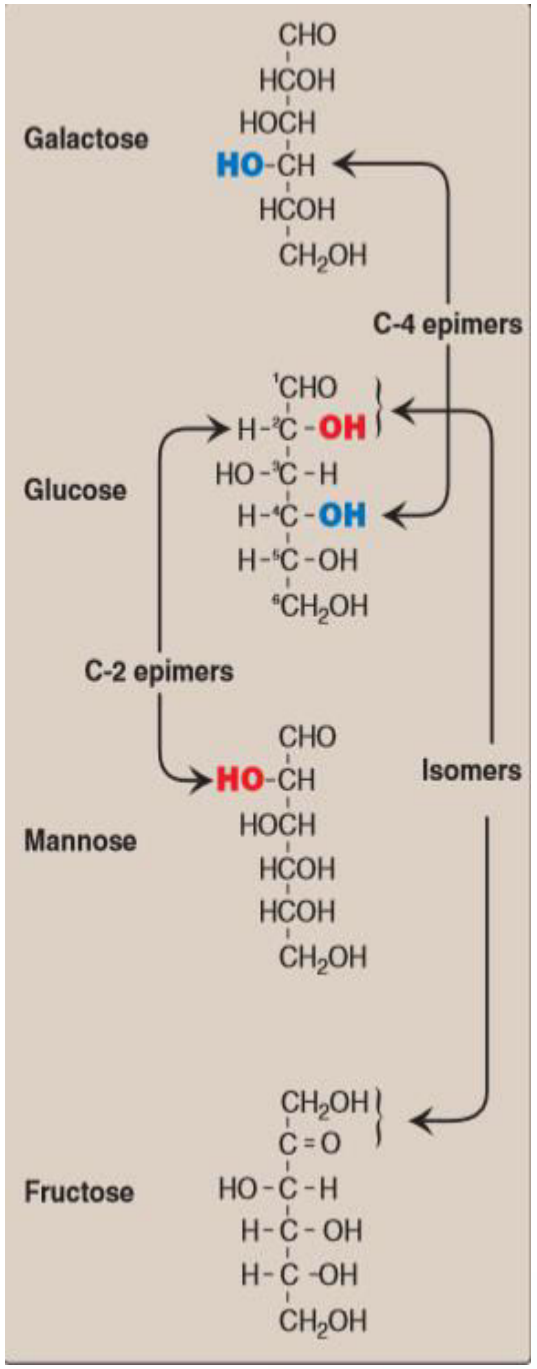
Generic names		Examples
3 carbons:	trioses	Glyceraldehyde
4 carbons:	tetroses	Erythrose
5 carbons:	pentoses	Ribose
6 carbons:	hexoses	Glucose
7 carbons:	heptoses	Sedoheptulose
9 carbons:	nonoses	Neuraminic acid



	Aldose	Ketose
Triose	Glyceraldehyde (The smallest aldose)	Dihydroxyacetone
Pentose	Ribose	Ribulose
Hexose	Glucose	Fructose

* ركزوا على الامثلة والتعاريف





❖ **Isomers:** Compounds having the **same** chemical formula but **different** structural formula

Example : Glucose & Fructose are isomers

❖ **Epimers:** CHO the differ in configuration around **only one** specific carbon atom

Example :
Glucose & Mannose (C2)
Glucose & galactose (C4)

لازم تعرف الفرق في الكربون اللي اختلفوا فيه

***Epimers are isomers but with different in one location**

Galactose and mannose are not epimers
because they differ in more than one carbon atom

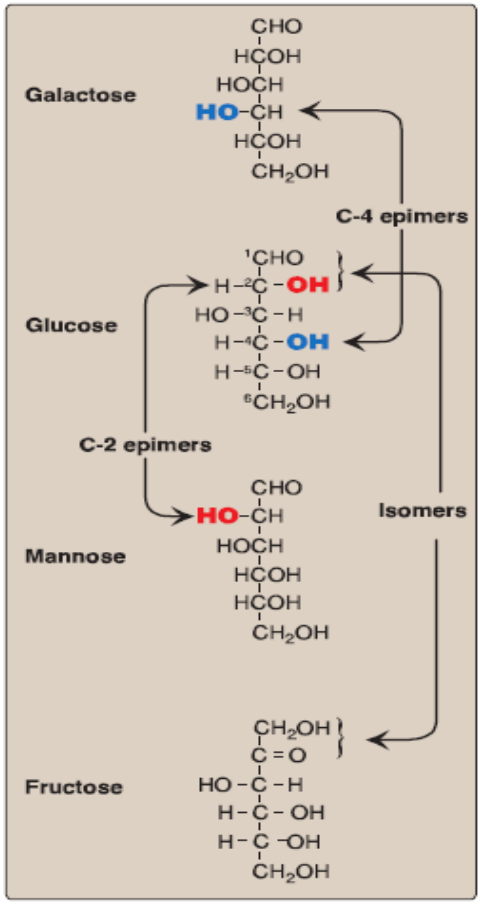
You don't have to memorize the structures

Isomers cont.

❖Aldose-ketose Isomers.

- both have the same chemical formula but one is an aldose sugar and the other is a ketose sugar

Example: Glucose (aldose) & fructose (ketose)



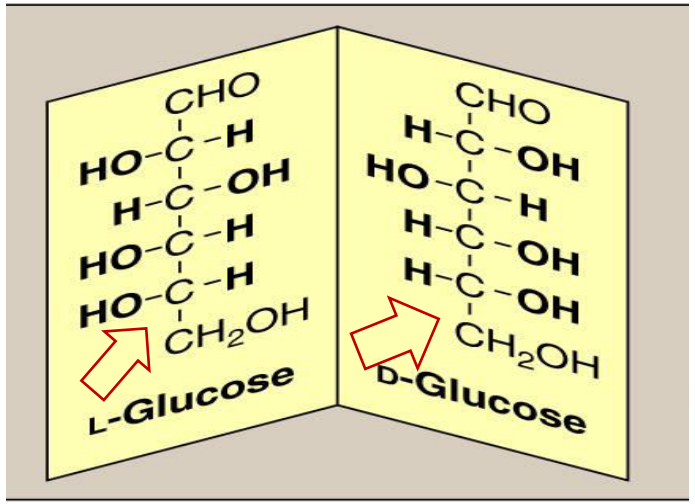
❖**Enantiomers**: Structures that are **mirror images** of each other, and they are designated as D- and L- sugars based on the position of –OH group on these conditions:

1- an **asymmetric** carbon group.

2- **the farthest carbon from the carbonyl carbon.**

Majority of sugars in humans are **D-sugars**

D: OH group on the **Right**. L: OH group on the **Left**



EXTRA:

D- and L- sugars are MIRROR IMAGES of each other (OH group in **each carbon** are **on the opposite** side of the enantiomer) but based on the position of –OH group on the **asymmetric carbon farthest from the carbonyl carbon**

We can **recognize** whether it is D or L

Isomers cont.

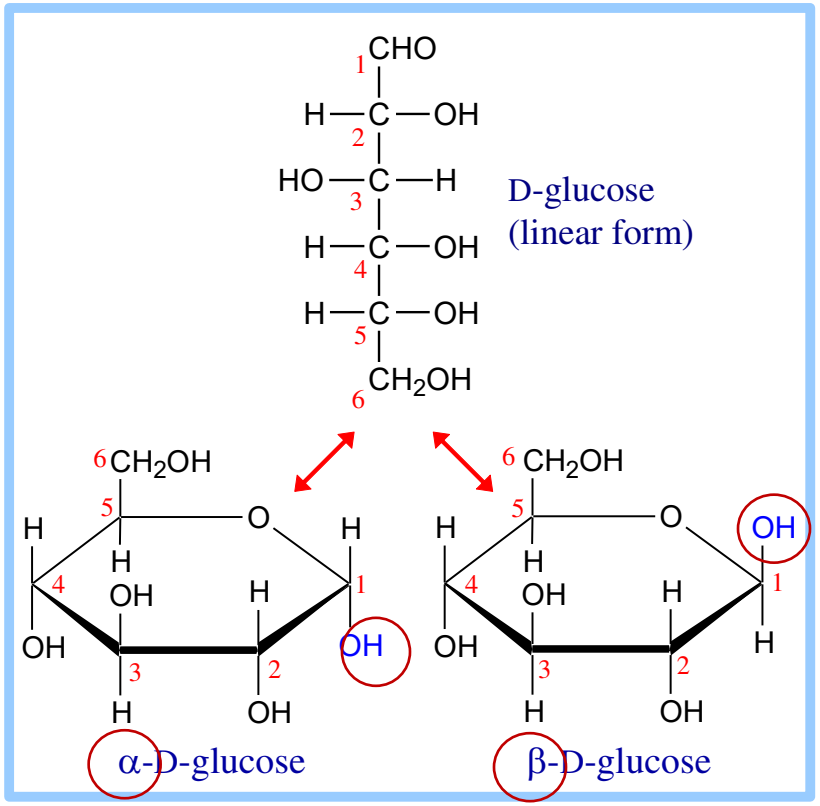
❖ α- and β-Forms

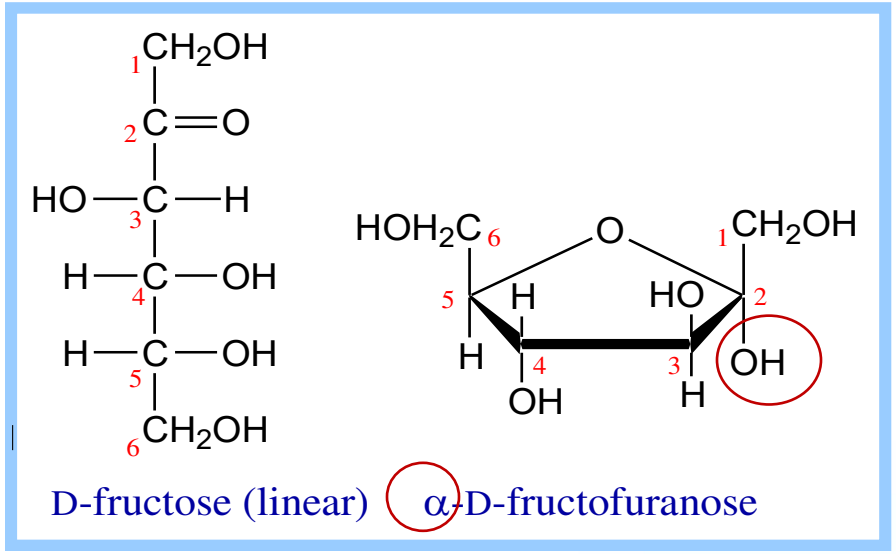
❑**Cyclization of Monosaccharides**

Monosaccharides with 5 or more carbon are predominantly found in the ring form

- The aldehyde or ketone grp reacts with the –OH grp on the same sugar

- Cyclization creates an **anomeric carbon** (former carbonyl carbon) generating the α and β configurations





You don't have to memorize the structures

Sugar Isomers

Aldo-Keto

- Same : formula
- Different : functional Group

Epimers

- Same : formula
- Different : configuration around a *single* carbon atom

L and D forms

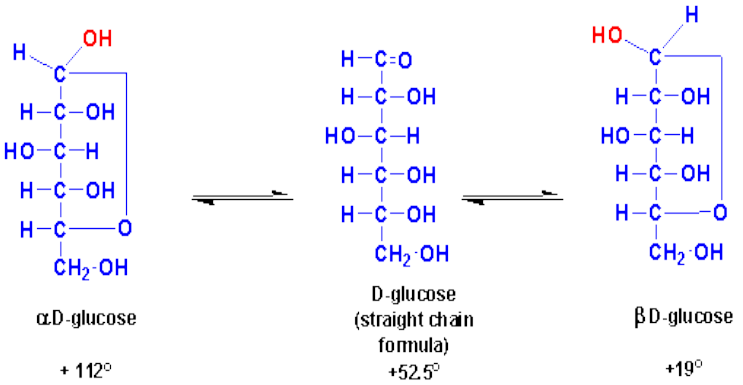
- Same : molecular formula
- Different : position of OH group on the *asymmetric carbon* farthest from carbonyl group

α-and β-anomers

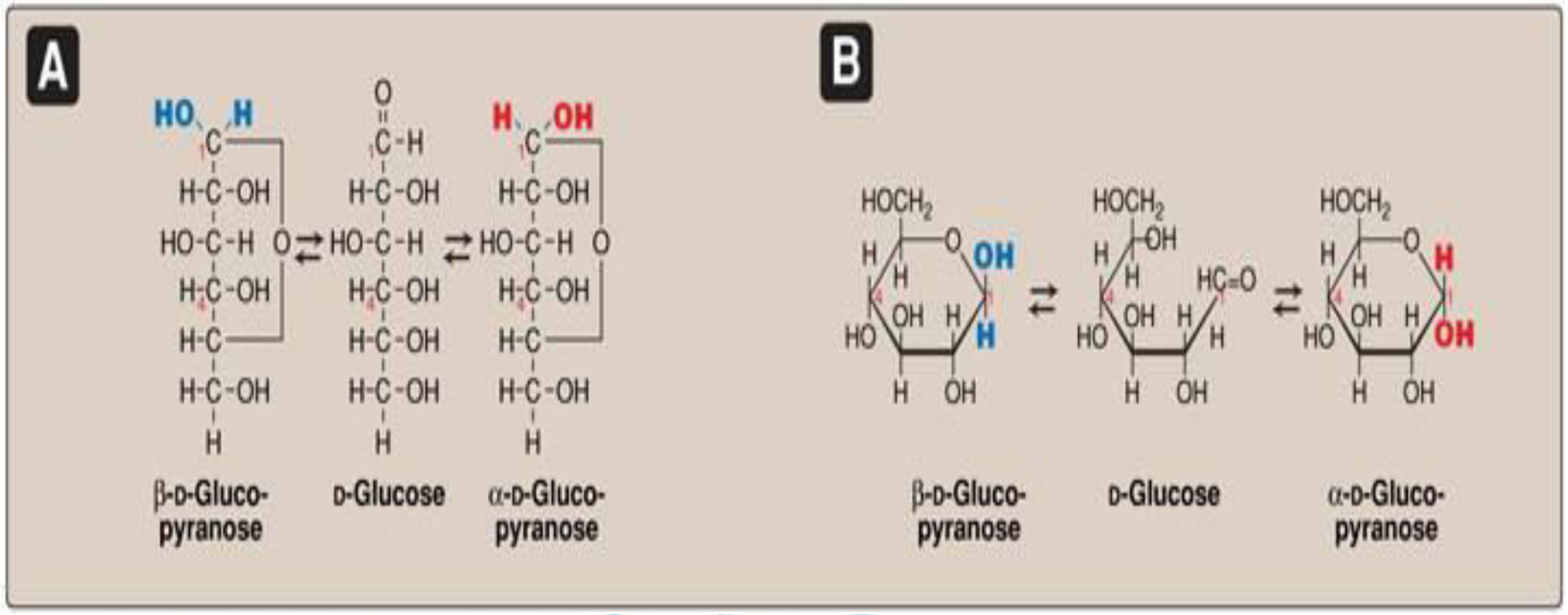
- Same : molecular formula
- Different : position of OH around anomeric carbon **(α-Down) (β-up(**

Mutarotation

- In solution, the cyclic α and β anomers of a sugar are in equilibrium with each other, and can be interconverted spontaneously



* باختصار: السكر في **حالته الطبيعية** دائمًا يأخذ الشكل **الحلقي** ولكن عندما يوضع السكر في **محلول** دائمًا تفتح الحلقة ويصبح بشكل **سلسلة مفتوحة** فبالتالي موضع OH لا يكون ثابت فتصبح احيانًا بالأسفل α واحيانً بالأعلى β



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https://youtu.be/CyvpoSRMp_c

436 NOTES:

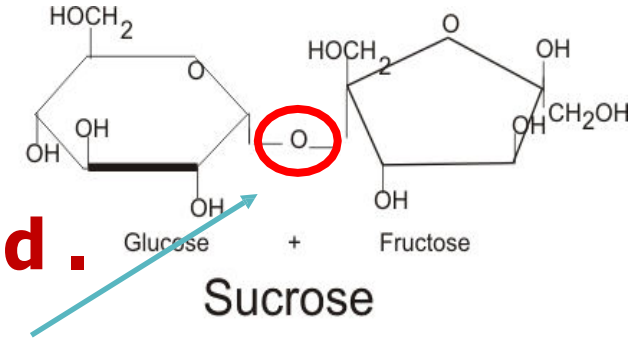
converting from beta to alpha does not required any energy or enzymes

*You don't have to memorize structures

Disaccharides

- **Joining of 2 monosaccharides: by O-glycosidic bond .**

When the two sugars combine at an oxygen atom



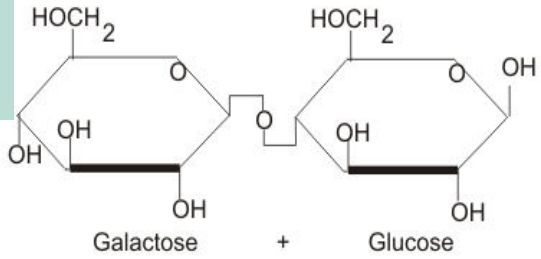
Sucrose

C4 of the second glucose molecule (the main chain)

1-Maltose(α-1, 4)= glucose + glucose

Type of anomer (OH Down)

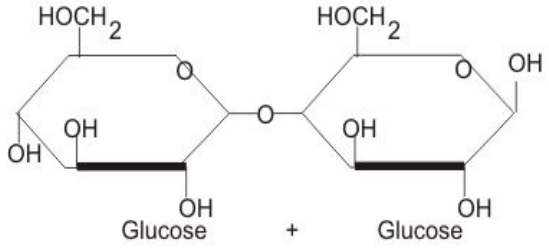
C1 of the first glucose molecule (the branch)



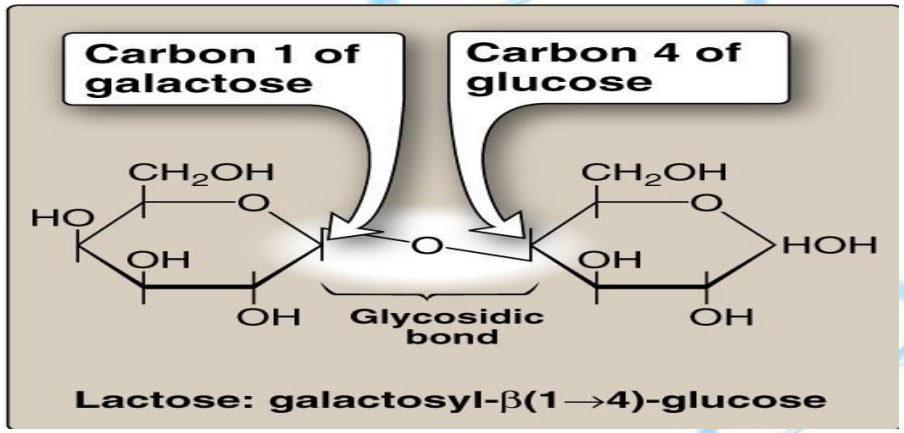
Lactose

2- Sucrose (α-1,2)= glucose + fructose

3- Lactose (β-1,4)= glucose + galactose



Maltose



Polysaccharides

Homopolysaccharides

Homo: same type of suger

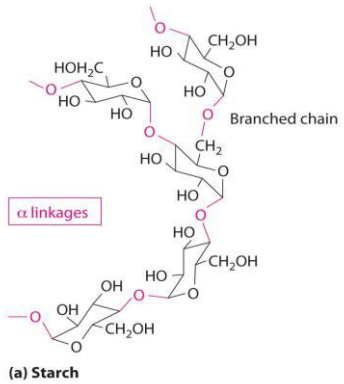
Heteropolysaccharides

Hetero: different type of suger

Example:

Glycosaminoglycans (GAGs)

Branched

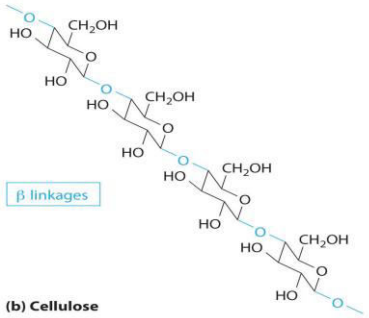


(a) Starch

Example:

Glycogen and starch (α-glycosidic polymer)

Unbranched



(b) Cellulose

Example:

Cellulose (β-glycosidicpolymer)

Reducing Sugars

When it happens?

- If the O on the anomeric C of a sugar is not attached to any other structure (Free), that sugar can act as a reducing agent

where it happens?

- **R**educing sugars reduce chromogenic agents like Benedict's reagent or Fehling's solution to give a colored precipitate

why do we need it?

- **U**rine is tested for the presence of reducing sugars using these colorimetric tests

Examples

- Monosaccharides
- Maltose
- Lactose

Sucrose is non-reducing, Why?

Sucrose is the combination of Glucose and Fructose (each of them combine with the other in the carbonyl group) and therefore none of them have a free aldehyde or ketone group. (the anomeric C is attached)

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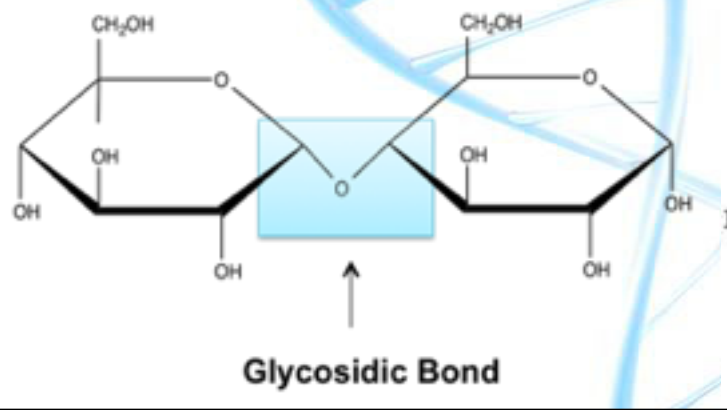
https://youtu.be/lZ_0MkUzdbo

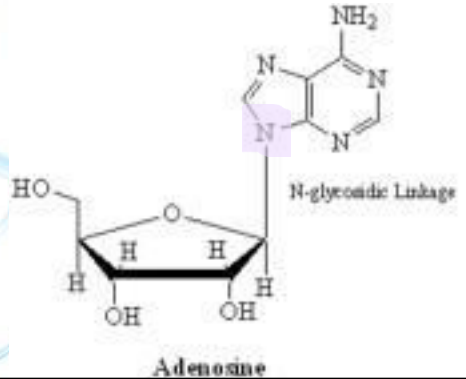
Complex Carbohydrates

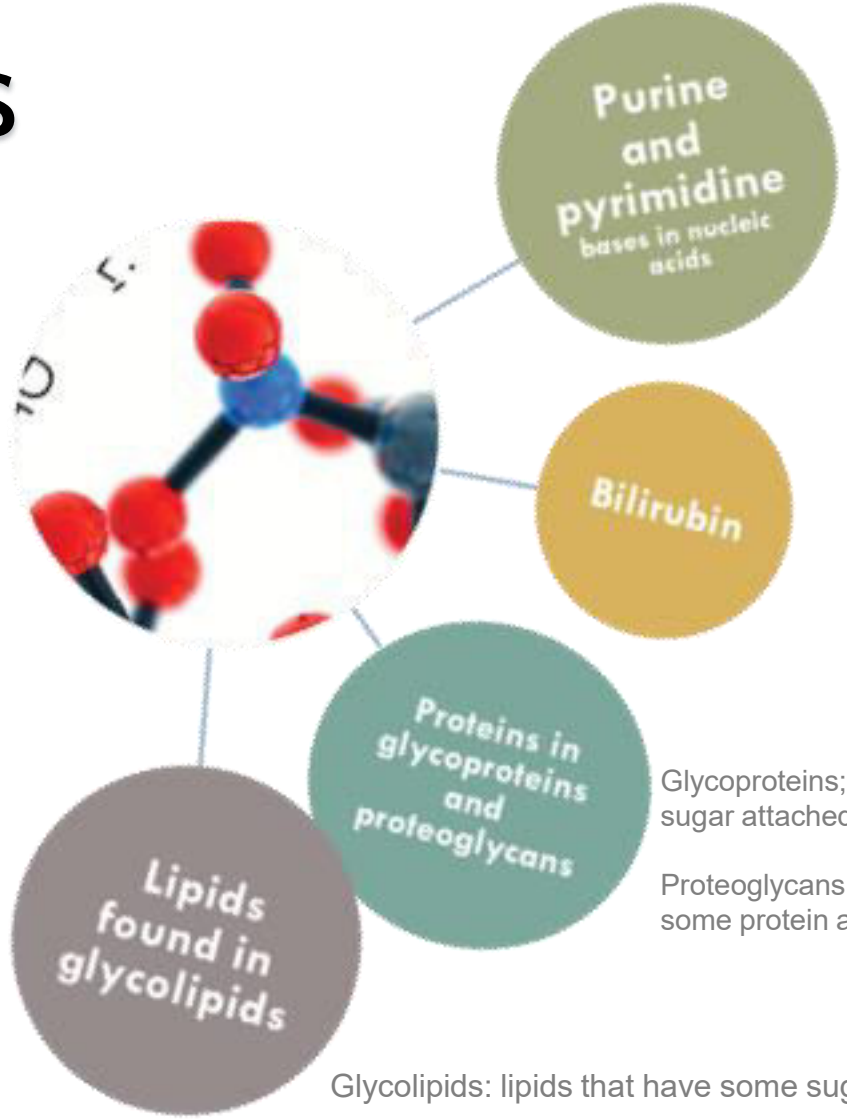
- **Carbohydrates attached to non-carbohydrate structures by glycosidic bonds (O- or N-type).**

Attachment happens at an **Oxygen** atom



Attachment happens at a **Nitrogen** atom





Glycoproteins; proteins that have some sugar attached to it.

Proteoglycans:carbohydrate having some protein attached to it.

Glycolipids: lipids that have some sugar attached to it

Glycosidic Bonds

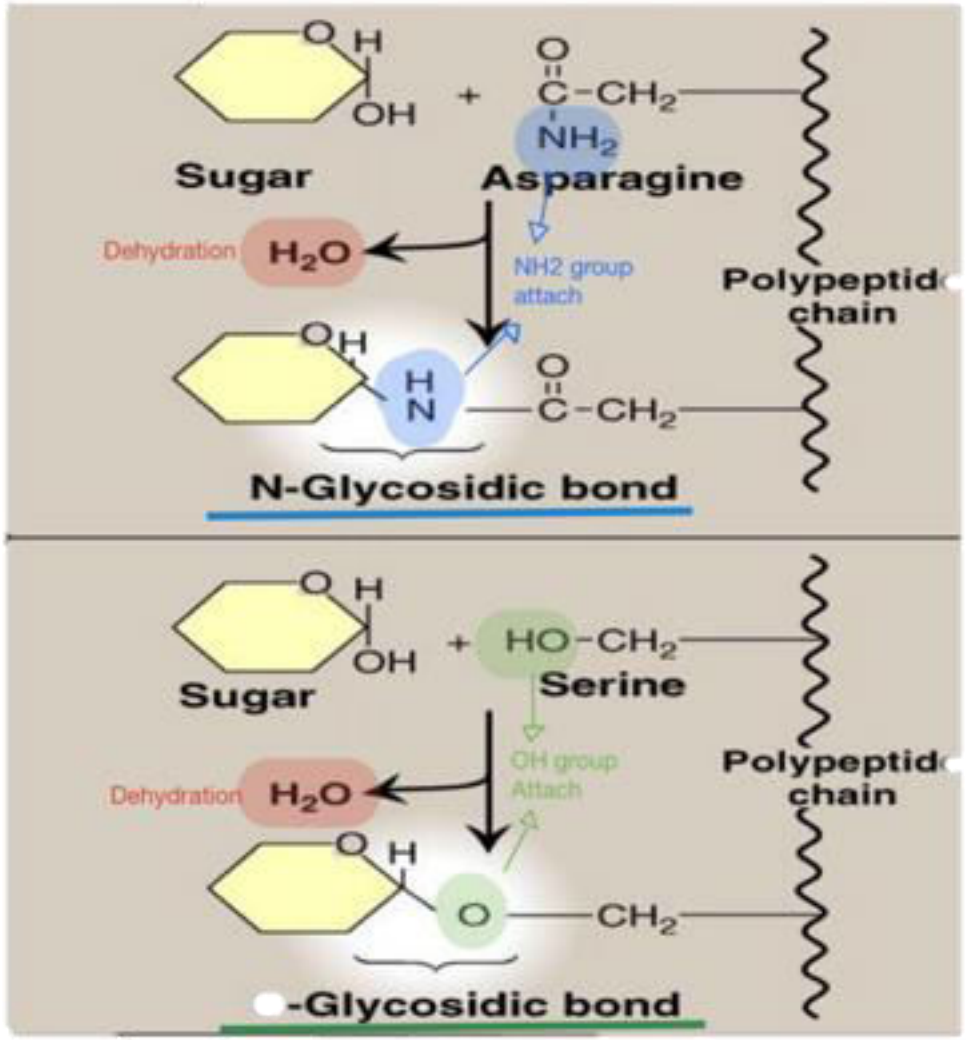
covalent bond

N-Glycosidic =

Sugar attach to —> NH2 group

O-Glycosidic =

Sugar attach to —> OH group



A Glycosidic Bond is a bond that joins a carbohydrate (sugar) molecule to another molecule, which may or may not be a carbohydrate

Glycosaminoglycans (GAGs) =

Former name: **Mucopolysaccharides**

carboxyl groups of acidic sugars are Sulfate groups

are large complexes of negatively charged heteropolysaccharide chains

+

associated with a small amount of protein.

+

bind with large amounts of water, producing the gel- like matrix that forms body's ground substance

Ground substances are the non-fibrous portion of our extracellular matrix (the stuff outside the cells of our bodies) in which the other components are held in place

linear polymers of repeating disaccharide units

GAGs are acids

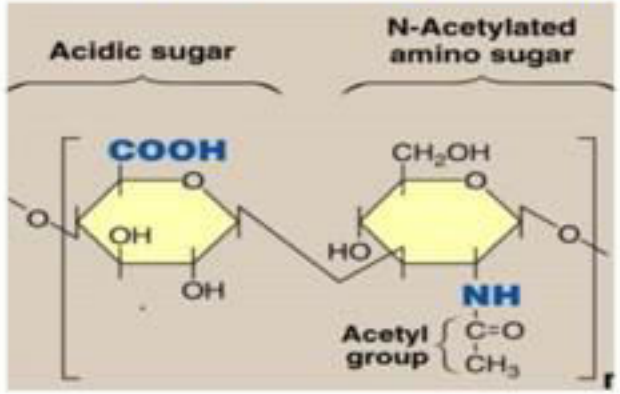
proteoglycans=
95% carbohydrate
5% protein

Formula:[acidic sugar-amino sugar]n

D-glucuronic acid or L-iduronic acid

Usually sulfates

D-glucosamine or D-galactosamine



Examples of GAGs:

Chondroitin sulfates
Most abundant GAG

Keratan sulfates
Most heterogeneous GAGs

Hyaluronic acid
Compared to other GAGs, it is unsulfated and not covalently attached to protein

Heparin
is intracellular "unlike other GAGs" and serves as an anticoagulant (prevents clots)

They have viscous; lubricating properties ; they cause the properties of mucous secretion

which led to the original naming of these compounds as mucopolysaccharides

➢ Extra Info:

-Sulfate and carboxyl “proton donator” groups tend to be negatively charged at physiological **pH**. Thereby having a net negative charged for **GAGs**.

-A Covalent bond is a bond that involves the sharing of electrons between two atoms, can be either polar or non-polar depending on the difference in electronegativity.

-An anti-coagulant, is a chemical agent that prevents blood from clotting, it is useful to prevent a blood vessel blockage by a clot which leads to depriving cells of nutrients. So it helps in establishing the flow of the blood and nutrients.

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https://youtu.be/l3W60xr9ac4

Resilience (مرونة) of GAGs

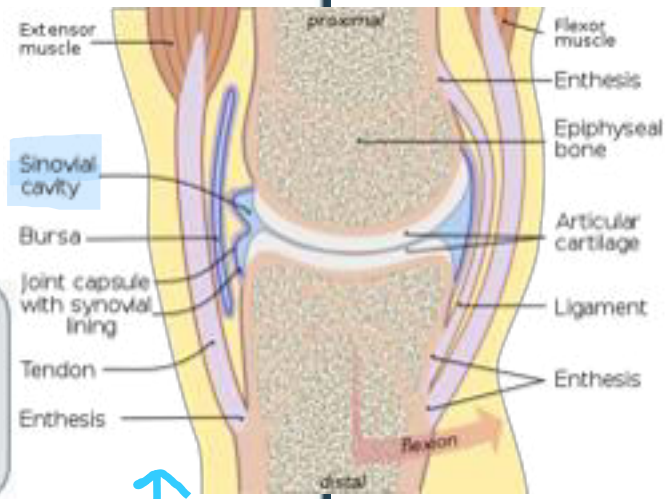
Effect of the GAGs negative charge in solution

chain is extended:
They repel each other.

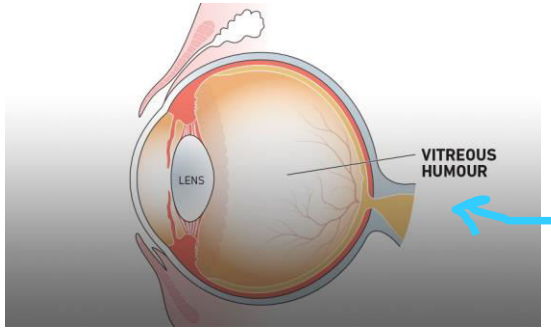
+

Chain brought together:
Slip past each other

Produce → **slippery consistency** of mucous (مخاطي) secretions and synovial fluid



synovial fluid:
سائل يتواجد بين المفاصل ويمنع الاحتكاك



vitreous humor:
سائل يتواجد داخل العين

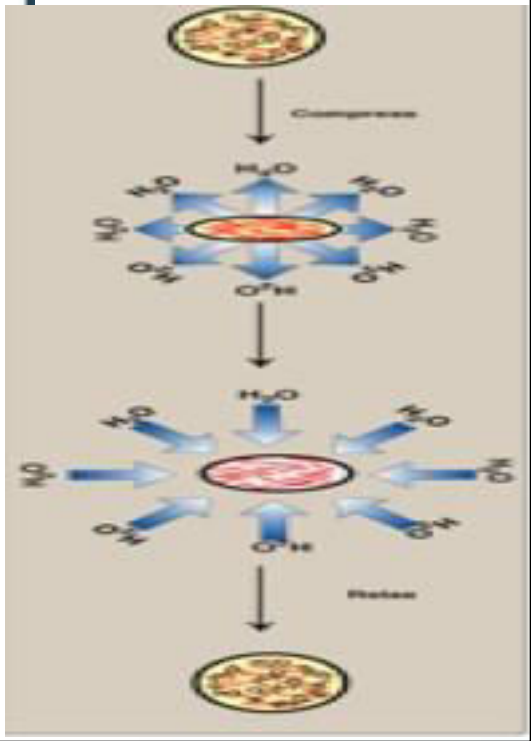
GAGs is compressed:
water is "squeezed out",
GAGs forced to occupy a smaller volume

compression is released
the GAGs spring back to their original, hydrated volume

Like a sponge

Contributes in → resilience of synovial fluid and the vitreous humor of the eye

because of the repulsion of their negative charges



➢ Extra Info:

-Since GAGs are atoms comprising larger molecules, they are bound by electromagnetic forces that force them to repel since they possess the same negative charge.

-The principal function of synovial fluid is to prevent friction between the articular cartilage, as a result, it allows for smooth movement to occur more easily. It is considered a Transcellular Fluid.

Carbohydrates (CH_2O)

Monosaccharides
Can be classified according to:

- NO. Of C atoms
  - **Aldoses**
    - Glyceraldehyde ← Trios "3C"
    - Ribose ← Pentos "5C"
    - glucose ← Hexos "6C"
  - **Ketoses**
    - Dihydroxyaceto
    - Ribulose
    - fructose
- Functional gr.

Disaccharide
"2 Mono units"
Bond: O-glycosidic
*Sucrose= glucose+fructose
* Maltose= glucose+glucose
*Lactose= glucose+galactose

Oligosaccharide
(3-10) monosaccharide

Polysaccharide
(more than 10)

- Homopolysaccharide
  - **Branched**
    *glycogen
    *starch
  - **Unbranched**
    *cellulose
- Heteropolysaccharide
  e.g: Glycosaminoglycan (GAG)

*it has a negative charge
*Linear
*forms Proteoglycan, it has 95% carbohydrates
*forms a Gel-like matrix
*forms viscous and lubricating the mucos (mucopolysaccharide)

*consists of repeated disaccharide units

- **Amino sugar (sulfated)**
  D-glucosamine
  Or D-galactosamine
- **Acidic sugar**
  D-glucuronic acid
  L-iduronic acid

Review

MCQs

Q1-The empiric formula is:

A. $(CH_2O)n_2$
B. $(CHO_2)n$
C. $(CH_2O)n$
D. $(CHO_2)n_2$

Q2-Which of the following is an aldo-keto Isomer?

A- (glucose+fructose)
B- (glucose+galactose)
C- (mannose+galactose)
D- (Fructose+galactose)

Q3-we can call the GAGs as anions

A- True B- False

Q4-Majority of sugars in humans are?

A- (D-sugars)
B- (L-sugars)

Answer key:

Question no.1	C
Question no.2	A
Question no.3	A
Question no.4	A

SAQs

A- Why do GAG molecules tend to repel each other, and for why is this considered an advantage for mucous secretions and the synovial fluid?

They repel each other because they're negatively charged molecules, and like repels like. It is an advantage since it produces the slippery consistency of synovial fluid and mucous secretions.

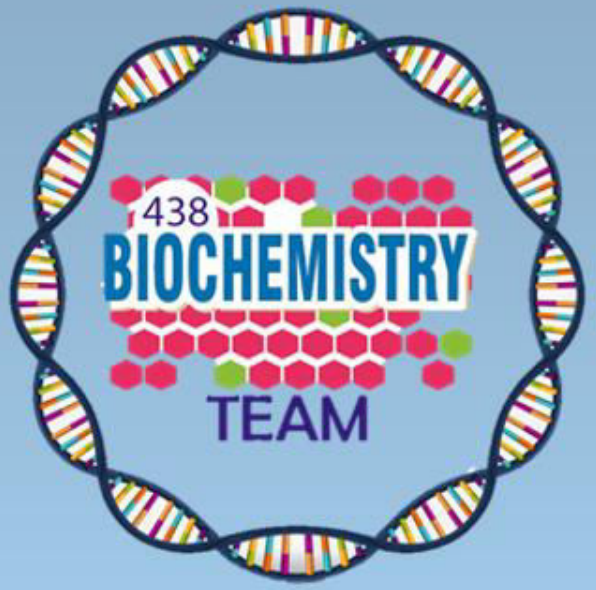
B- To which group of polysaccharides does Heparin belong, and with respect to the cell, where does it reside in the body and what does it serve as inside the body?

Heteropolysaccharids, GAGs to be exact. It resides inside the cell "Intracellular" and it serves as an anticoagulant.

C- Enantiomers are divided into L-sugars and D-sugars depending on what ?

Depending on the position of the hydroxyl group on the asymmetric carbon farthest from the carbonyl carbon, if the OH group is on the left then it's considered L-sugar and if it was one the right then it's a D-sugar

- Special thanks to:



Our logo designer:

Reem AlMazyad

swereem@hotmail.com

Biochemistry Team 435

@435biochemteam

435biochemistryteam@gmail.com

@biochemteam435

BIO TEAM

teambiochem437@gmail.com

Biochemistry team 436

@436biochemteam

biochemistrytem436@gmail.com

Girls team:

- أجيد آل رشود
- الوتين البلوي
- إيلاف المسيحل
- جود الخليفة
- جود العتيبي
- سارة الهلال
- شهد السلامه
- طيف العتيبي
- عبير الخضير
- غيداء البريثن
- لينا العصيمي
- نورة التركي
- نورة المزروع
- نوف الحميضي
- هيفاء الوايلي

Boys team:

- بدر الشهري
- حميد حميد
- سهيل باسهيل
- عمر الغامدي
- مهند القرني
- نايف السبر

438 BIOCHEMISTRY TEAM

MED438
KING SAUD UNIVERSITY

Team leaders:

ديما المزيد
رائد العجيري

Contact us:

Biochemistryteam438@gmail.com