CARBOHYDRATES: STRUCTURE AND FUNCTION

By

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Objectives

- To understand the structure of carbohydrates of physiological significance
- To understand the main role of carbohydrates in providing and storing of energy
- To understand the structure and function of glycosaminoglycans

OVERVIEW

Carbohydrates:

The most abundant organic molecules in nature

The empiric formula is $(CH_2O)n$, "hydrates of carbon"

Carbohydrates:

provide important part of energy in diet

Act as the storage form of energy in the body

are structural component of cell membrane

OVERVIEW

CONT'D

- Many diseases associated with disorders of carbohydrate metabolism including:

  Diabetes mellitus

  Galactosemia

  Glycogen storage diseases

  Lactose intolerance

CLASSIFICATION

- **Monosaccharides:** Simple sugar
- **Disaccharides:** 2 monosaccharide units
- **Oligosaccharides:** 3-10 monosaccharide units
- **Polysaccharides:** more than 10 sugar units

  Homopolysaccharides and heteropolysaccharides

Monosaccharides

Further classified based on:

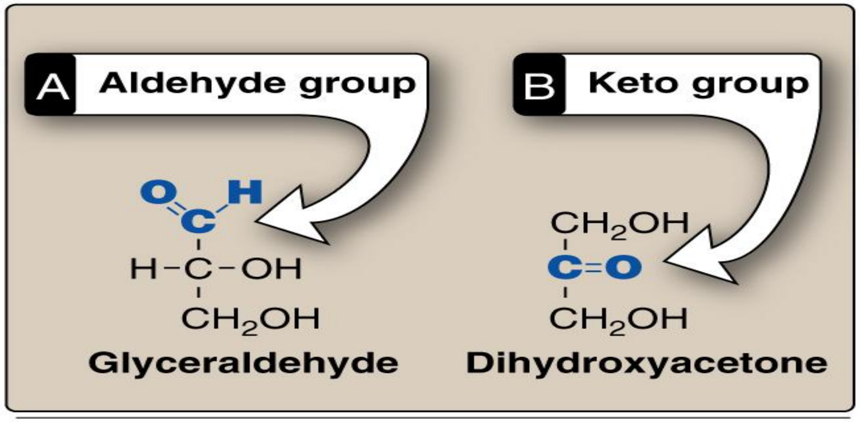
1. No. of carbon atoms

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

2. Functional sugar group:

Aldehyde group – aldoses

Keto group – ketoses



Monosaccharides

CONT'D

	Aldose	Ketose
Triose	Glyceraldehyde	Dihydroxyacetone
Pentose	Ribose	Ribulose
Hexose	Glucose	Fructose

Disaccharides

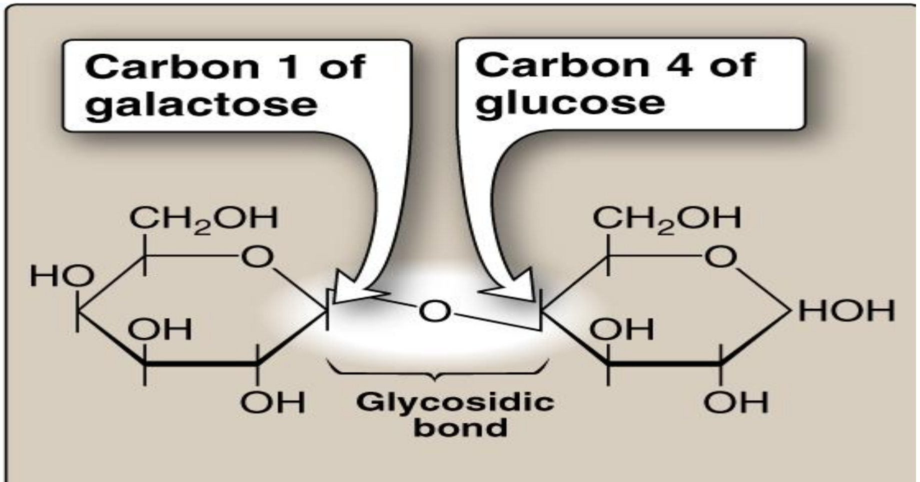
- **Joining of 2 monosaccharides** by O-glycosidic bond:

Maltose (α-1, 4)	= glucose	+	glucose
Sucrose (α-1,2)	= glucose	+	fructose
Lactose (β-1,4)	= glucose	+	galactose

Disaccharides

CONT'D

Lactose



Lactose: galactosyl-β(1→4)-glucose

Polysaccharides

- **Homopolysaccharides:**

  Branched: glycogen and starch (α-glycosidic polymer)

  Unbranched: cellulose (β-glycosidic polymer)

- **Heteropolysaccharides:**

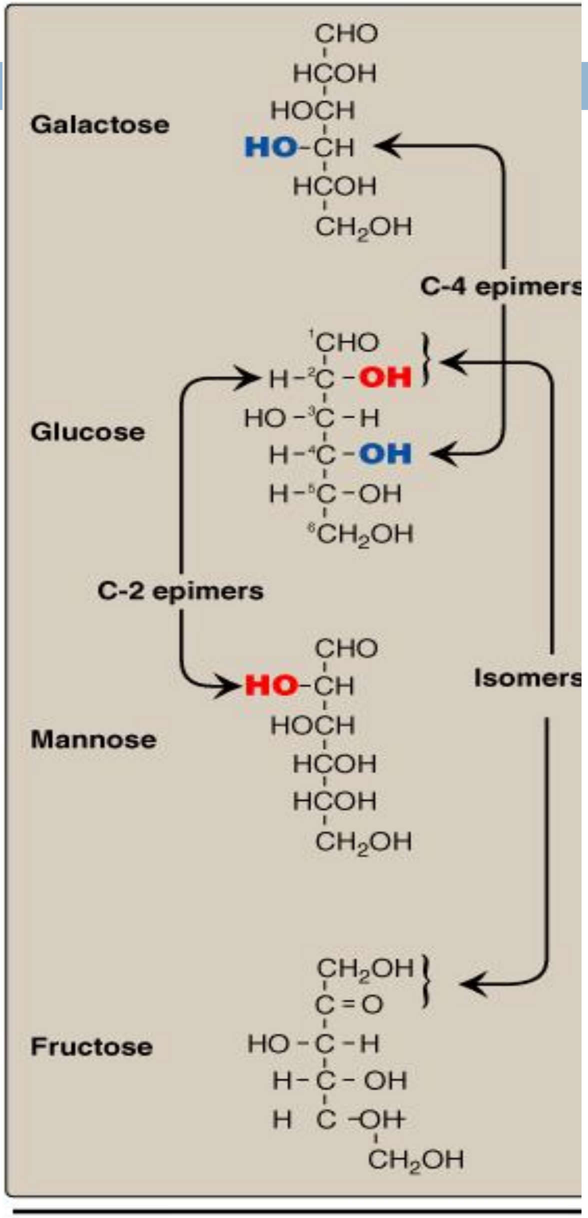
  e.g., glycosaminoglycans (GAGs)

Isomerism

- **Isomers**

Compounds having same chemical formula but different structural formula

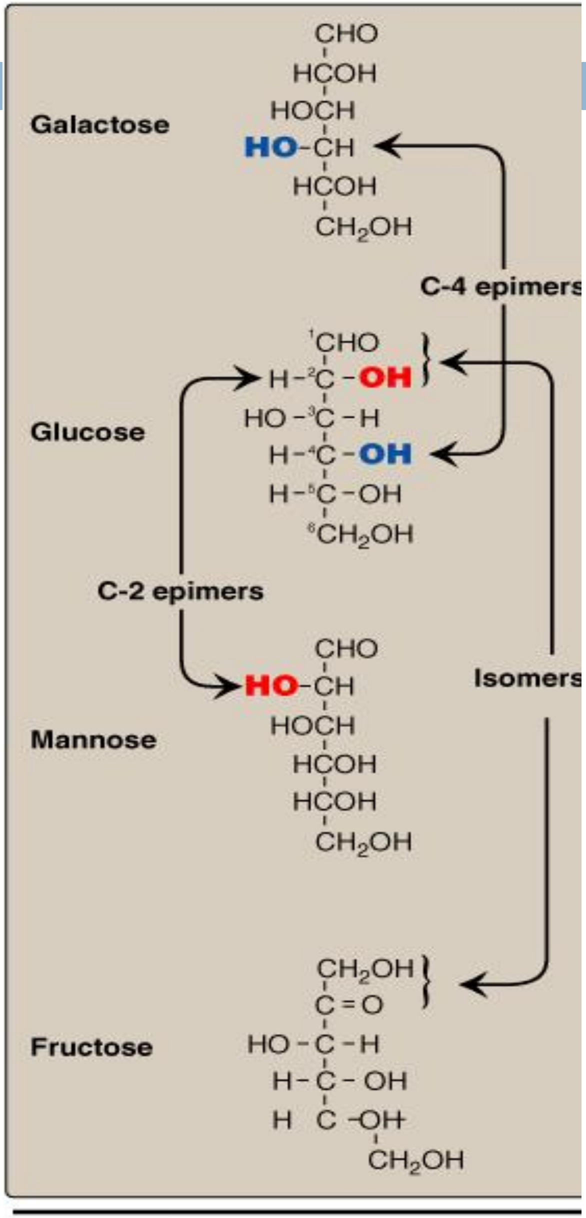
The No. of isomers depends on the No. of asymmetric C



Aldo-Keto Isomers

Example:

Glucose and fructose



Epimers

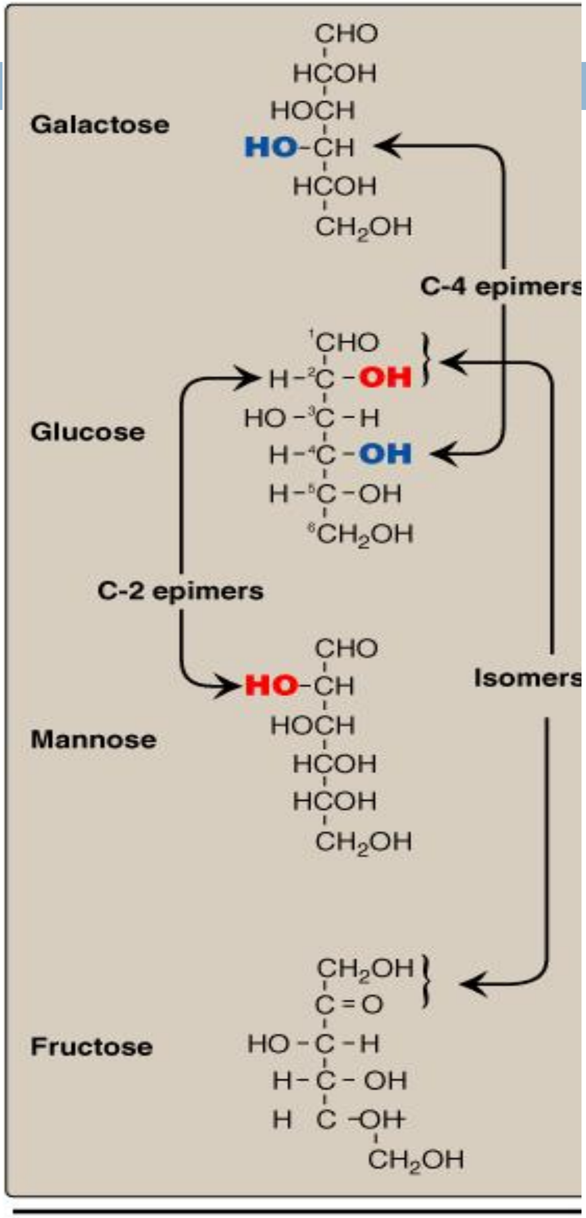
- **Epimers**

CHO dimers that differ in configuration around only one specific carbon atom

-Glucose and galactose, C4

-Glucose and Mannose, C2

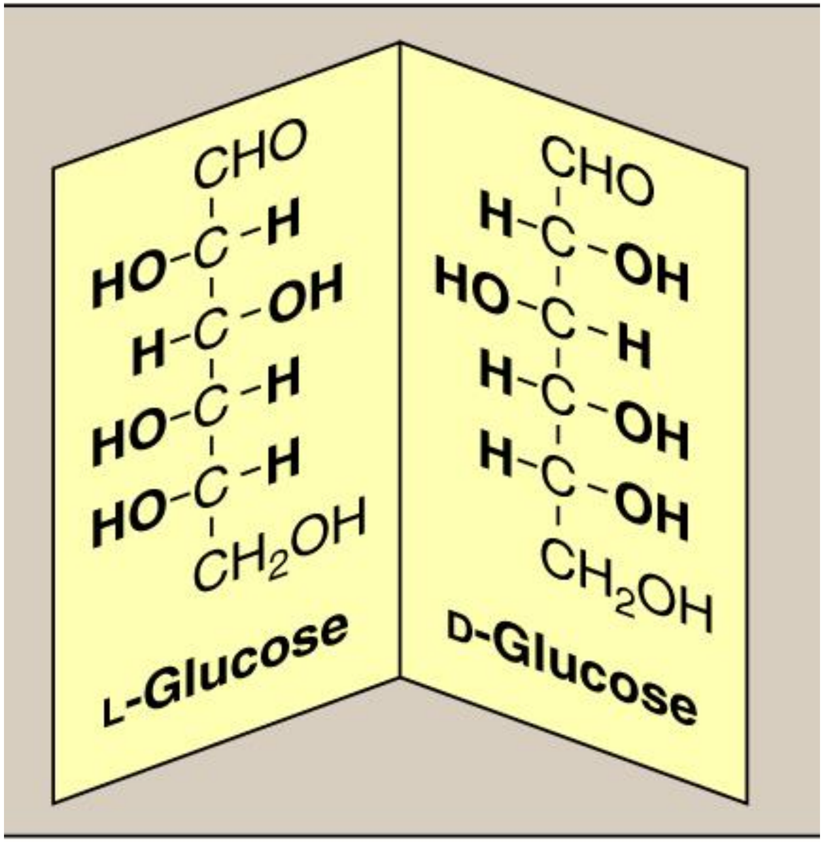
Galactose and mannose are not epimers



Enantiomers (D- and L-Forms)

Structures that are **mirror images** of each other and are designated as D- and L- sugars based on the position of –OH grp on the **asymmetric carbon farthest from the carbonyl carbon**

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



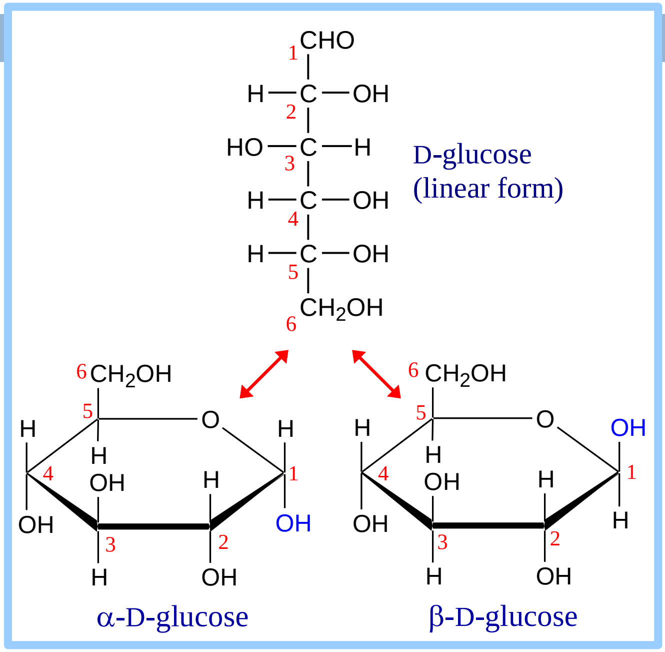
α- and β-Forms

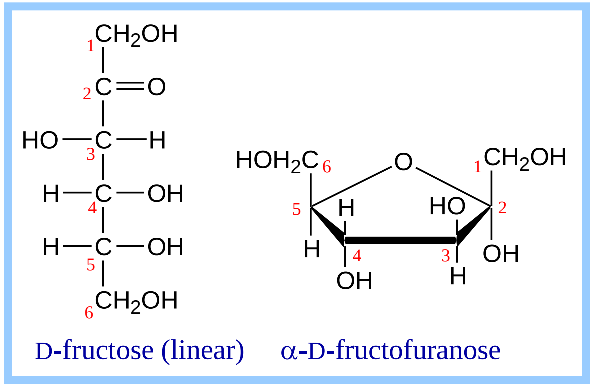
❑ **Cyclization of Monosaccharides**

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

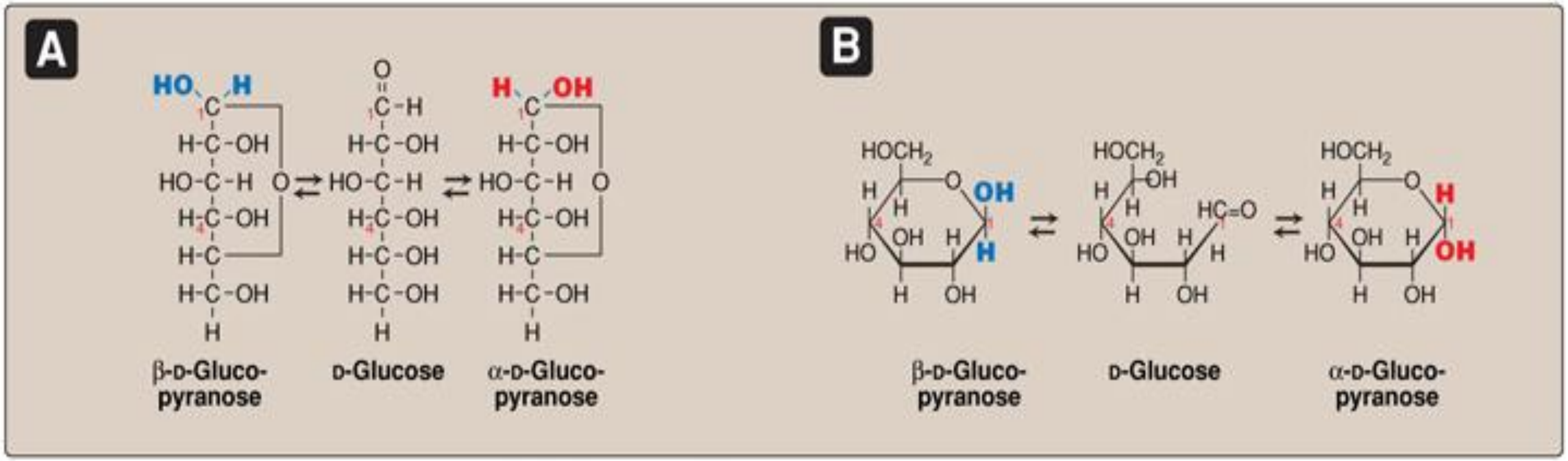
-Cyclization creates an **anomeric carbon** (former carbonyl carbon) generating the α and β configurations





Mutarotation

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



Fischer Projection **Haworth Projection**

Sugar Isomers

1. Aldo-keto
2. Epimers
3. D- and L-Forms
4. α- and β-anomers

Reducing Sugars

- If the O on the anomeric C of a sugar is not attached to any other structure, that sugar can act as a reducing agent
- **R**educing sugars reduce chromogenic agents like Benedict's reagent or Fehling's solution to give a colored periceptate
- **U**rine is tested for the presence of reducing sugars using these colorimetric tests

Reducing Sugars

CONT'D

- Examples:

  Monosaccharides

  Maltose and Lactose

Sucrose is non-reducing, Why?

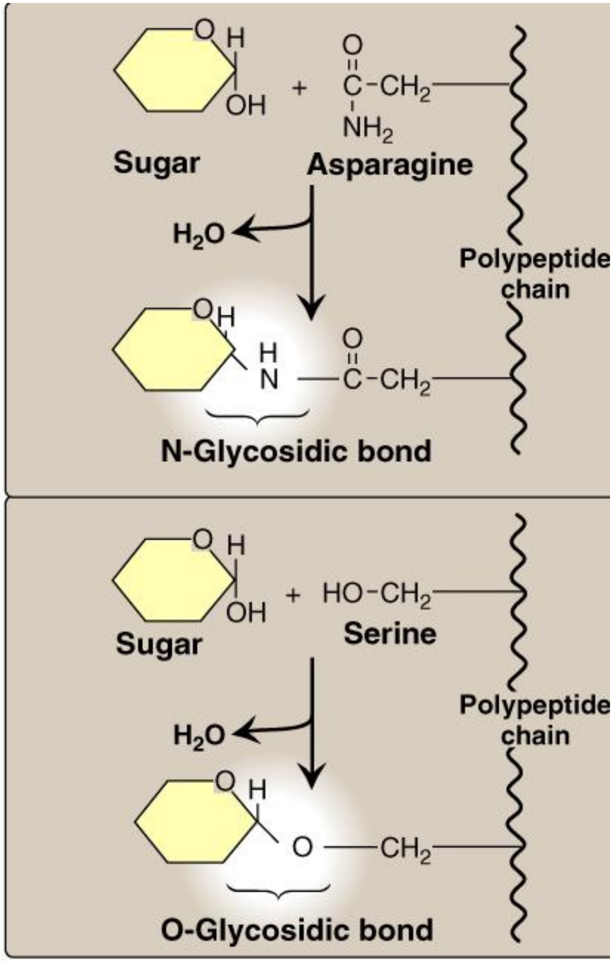
Complex Carbohydrates

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

1. Purine and pyrimidine bases in nucleic acids
2. Bilirubin
3. Proteins in glycoproteins and proteoglycans
4. Lipids found in glycolipids

Glycosidic Bonds

- N-Glycosidic
- O-Glycosidic



Glycosaminoglycans (GAGs)

- Glycosaminoglycans (GAGs) are large complexes of **negatively** charged **hetero**polysaccharide chains
- are associated with a small amount of protein, forming **proteoglycans**, which consist of over 95 percent carbohydrate
- bind with large amounts of water, producing the gel-like matrix that forms body's ground substance
- The viscous, lubricating properties of mucous secretions also result from GAGs, which led to the original naming of these compounds as mucopolysaccharides

Glycosaminoglycans (GAGs)

- **GAGs** are linear polymers of **repeating disaccharide** units

  [acidic sugar-amino sugar]n

- The amino sugar (usually sulfated) is either

  D-glucosamine or D-galactosamine

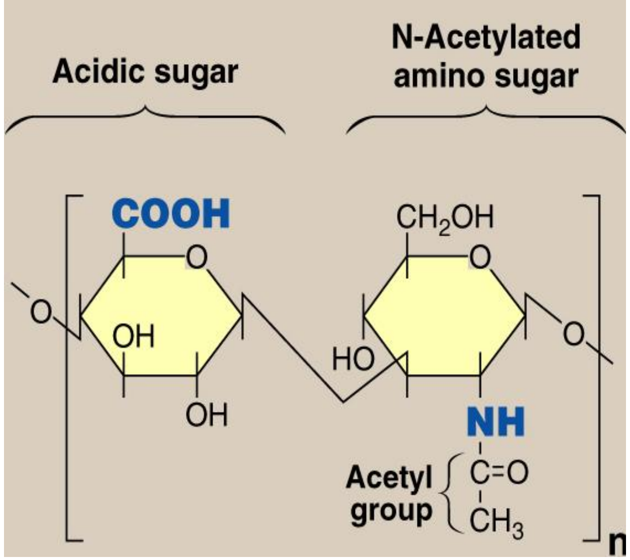
- The acidic sugar is either

  D-glucuronic acid or L-iduronic acid

- GAGs are strongly negatively-charged:

  carboxyl groups of acidic sugars

  Sulfate groups



Resilience of GAGs

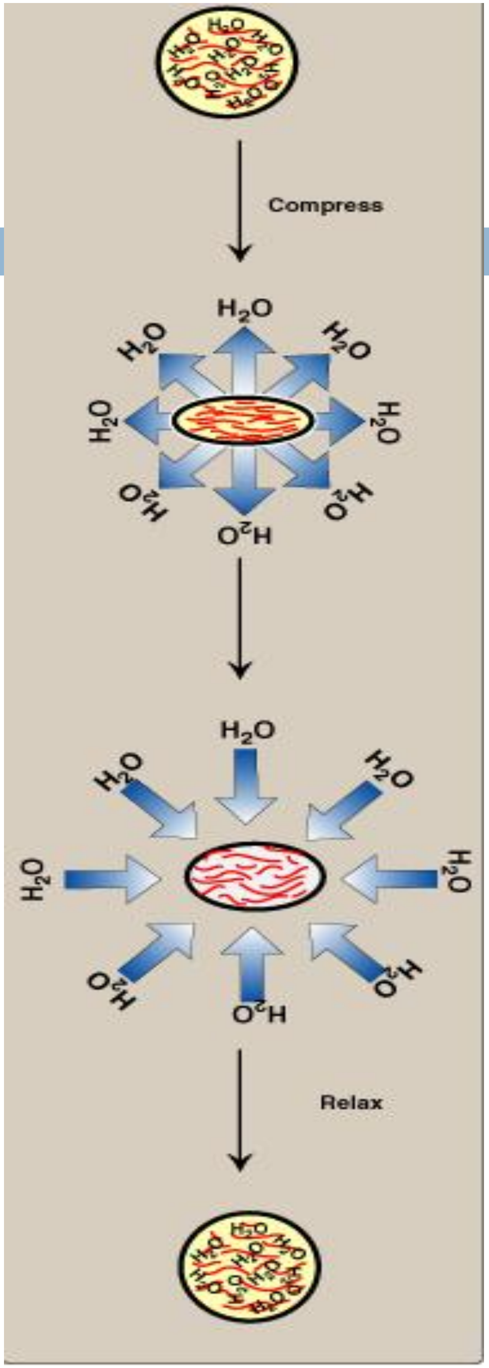
Relationship between glycosaminoglycan structure and function

- Because of negative charges, the GAG chains tend to be extended in solution and repel each other and when brought together, they "slip" past each other

This produces the **"slippery" consistency of mucous secretions and synovial fluid**

- When a solution of GAGs is compressed, the water is "squeezed out" and the GAGs are forced to occupy a smaller volume. When the compression is released, the GAGs spring back to their original, hydrated volume because of the repulsion of their negative charges

This property contributes to the **resilience of synovial fluid and the vitreous humor of the eye**



Members of GAGs

Examples of GAGs are:

1. **Chondroitin sulfates**
2. **Keratan sulfates**
3. **Hyaluronic acid**
4. **Heparin**

CHONDROITIN SULFATES

- Disaccharide unit:

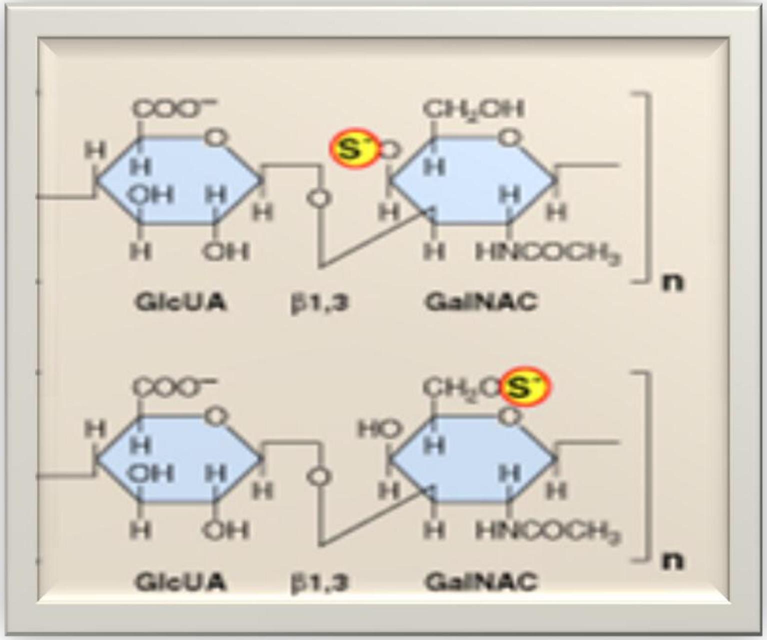
  Sulfated N-acetylgalactosamine
  Glucuronic acid

- Most abundant GAG in the body

- Form proteoglycan aggregates

- Found in cartilage, tendons, ligaments, and aorta

- In cartilage, they bind collagen and hold fibers in a tight, strong network



KERATAN SULFATES

- Disaccharide unit:

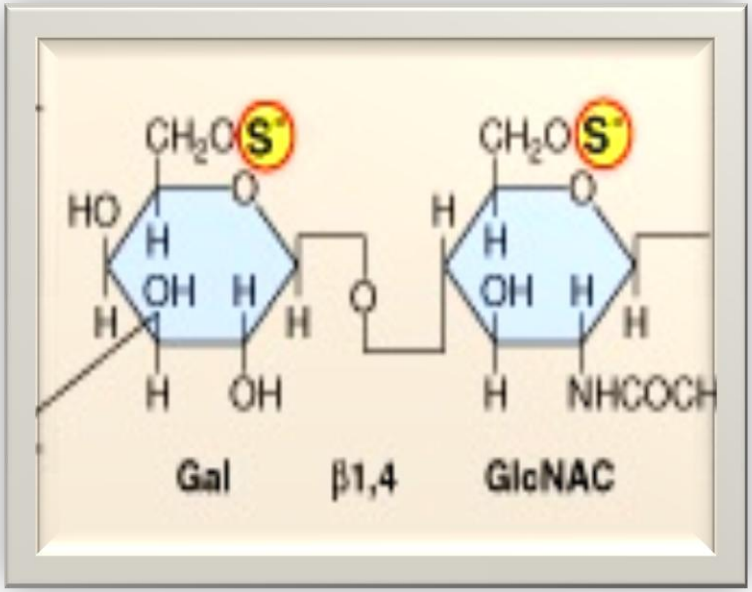
  N-acetylglucosamine

  Galactose (no uronic acid)

- Sulfate content is variable and may be present on C-6 of either sugar

- Most heterogeneous GAGs

- Present in loose connective tissue and cornea



HYALURONIC ACID

- Disaccharide unit:

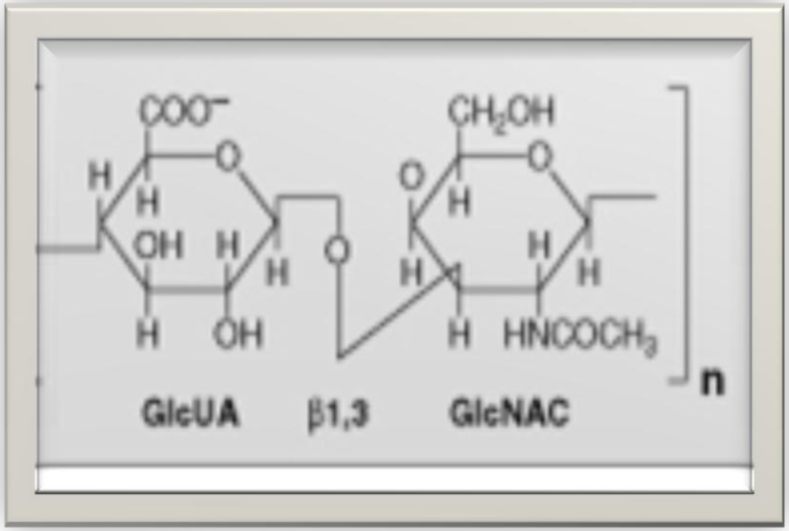
  N-acetylglucosamine

  Glucuronic acid
- Different from other GAGs:

  Unsulfated

  Not covalently attached to protein

  The only GAG found in bacteria
- Serves as a lubricant and shock absorber
- Found in synovial fluid of joints, vitreous humor of the eye, the umbilical cord, and cartilage



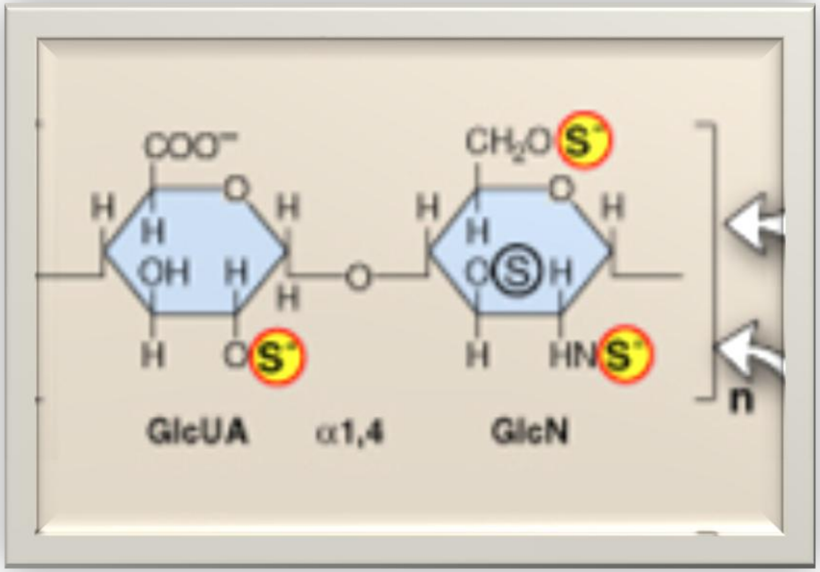
HEPARIN

- Disaccharide unit:

  Glucosamine and

  Glucuronic or iduronic acids
- Sulfate is found on glucosamine and uronic acid

  (an average of 2.5 **S** per disaccharide unit)
- Unlike other GAGs that are extracellular, heparin is an **intracellular** component of mast cells that line arteries, especially liver, lungs and skin
- Serves as **anticoagulant**



Take home Message

Structure and function of carbohydrates

- Mono-, Di-, and Poly-saccharides
- Sugar Isomers: Aldo-keto, epimers, D- and L-, α- and β-anomers
- Complex carbohydrates:

  e.g., Glycosaminoglycans and proteoglycans
- Structure and function of GAGs
- Examples of GAGs: chondroitin sulfate, keratin sulfate, hyaluronic acid and heparin