CARBOHYDRATES: STRUCTURE AND FUNCTION

By
Dr. Sumbul Fatma

Objectives

To understand:

- **The structure of carbohydrates of physiological significance**
- **The main role of carbohydrates in providing and storing of energy**
- **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 membranes**

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 & heteropolysaccharides

Monosaccharides

Further classified based on:

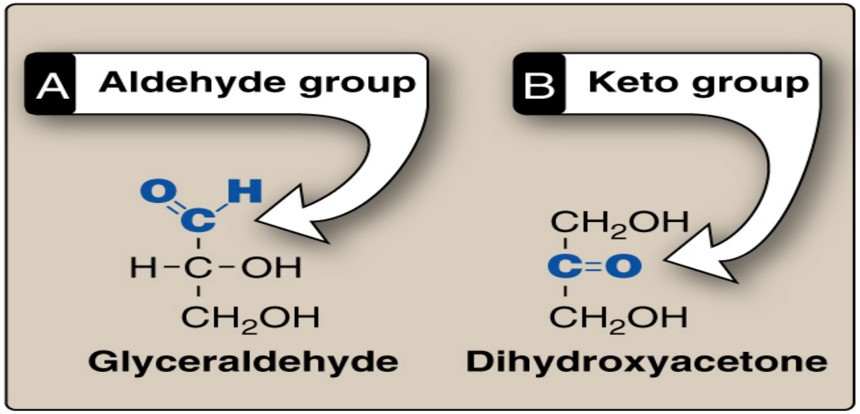
1. No. of carbon atoms

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

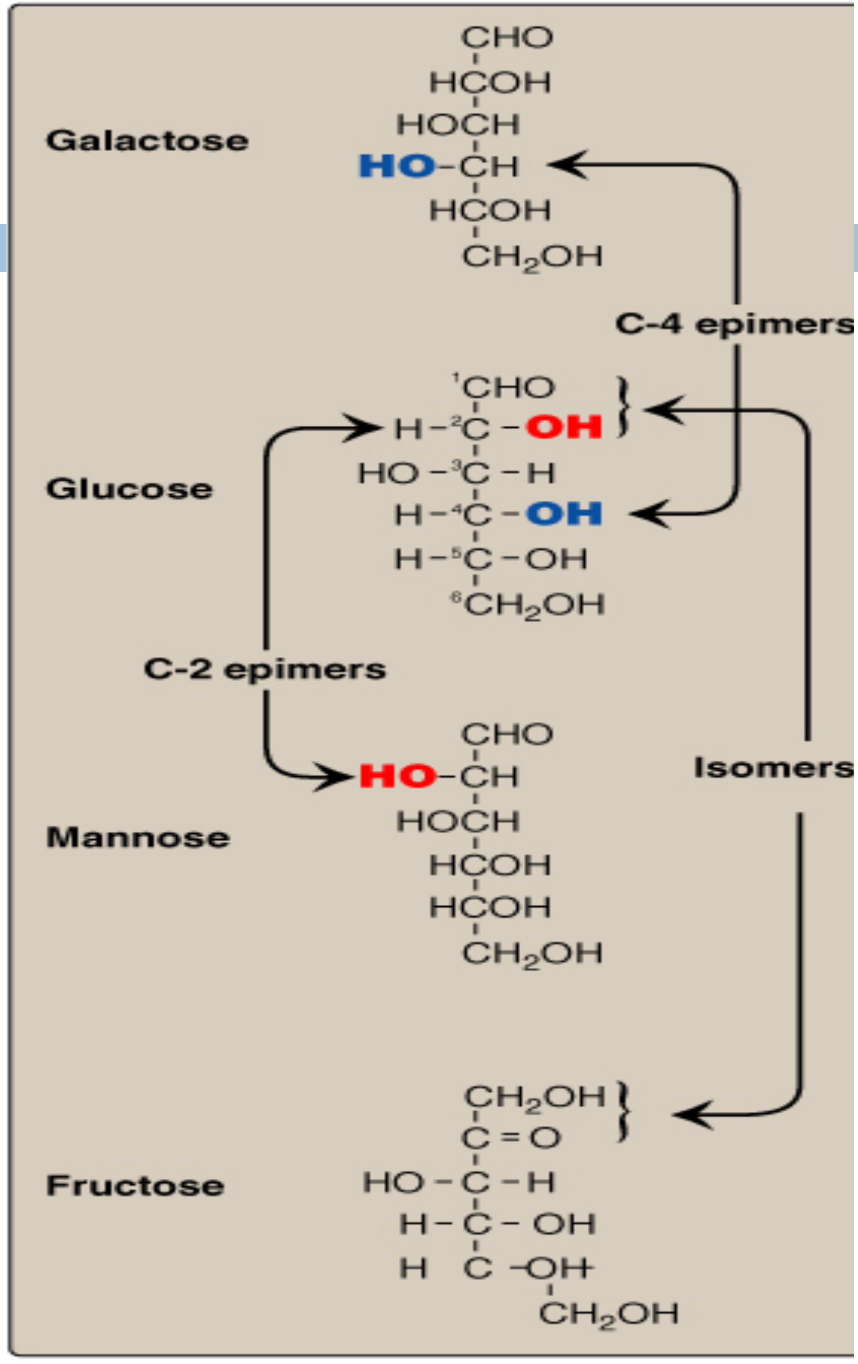
CONT'D

	Aldose	Ketose
Triose	Glyceraldehyde	Dihydroxyacetone
Pentose	Ribose	Ribulose
Hexose	Glucose	Fructose

Isomerism

- Isomers

Compounds having same chemical formula but different structural formula



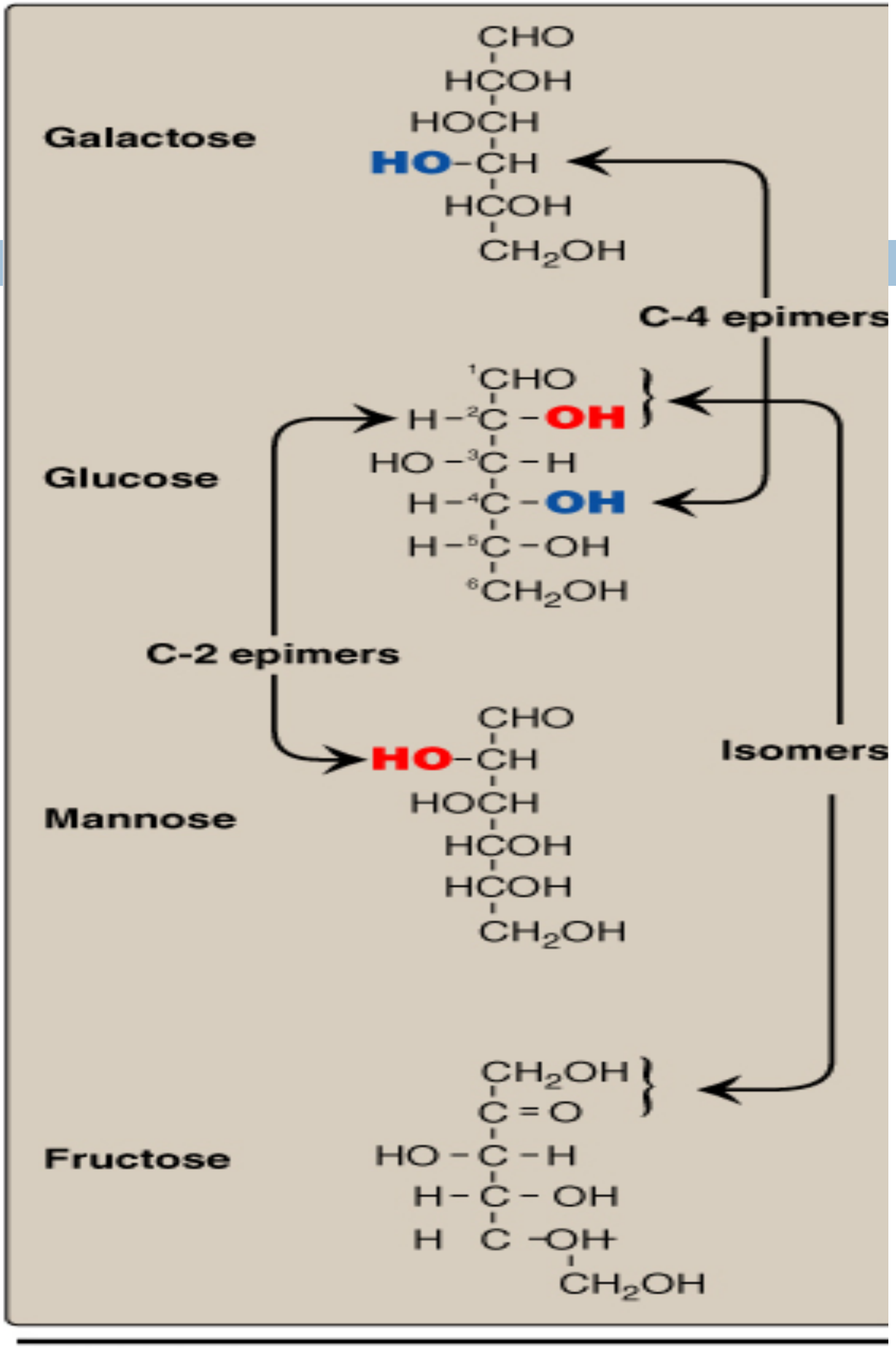
Aldo-Keto Isomers

Example:

Glucose (Aldose)

and

Fructose (Ketose)



Epimers

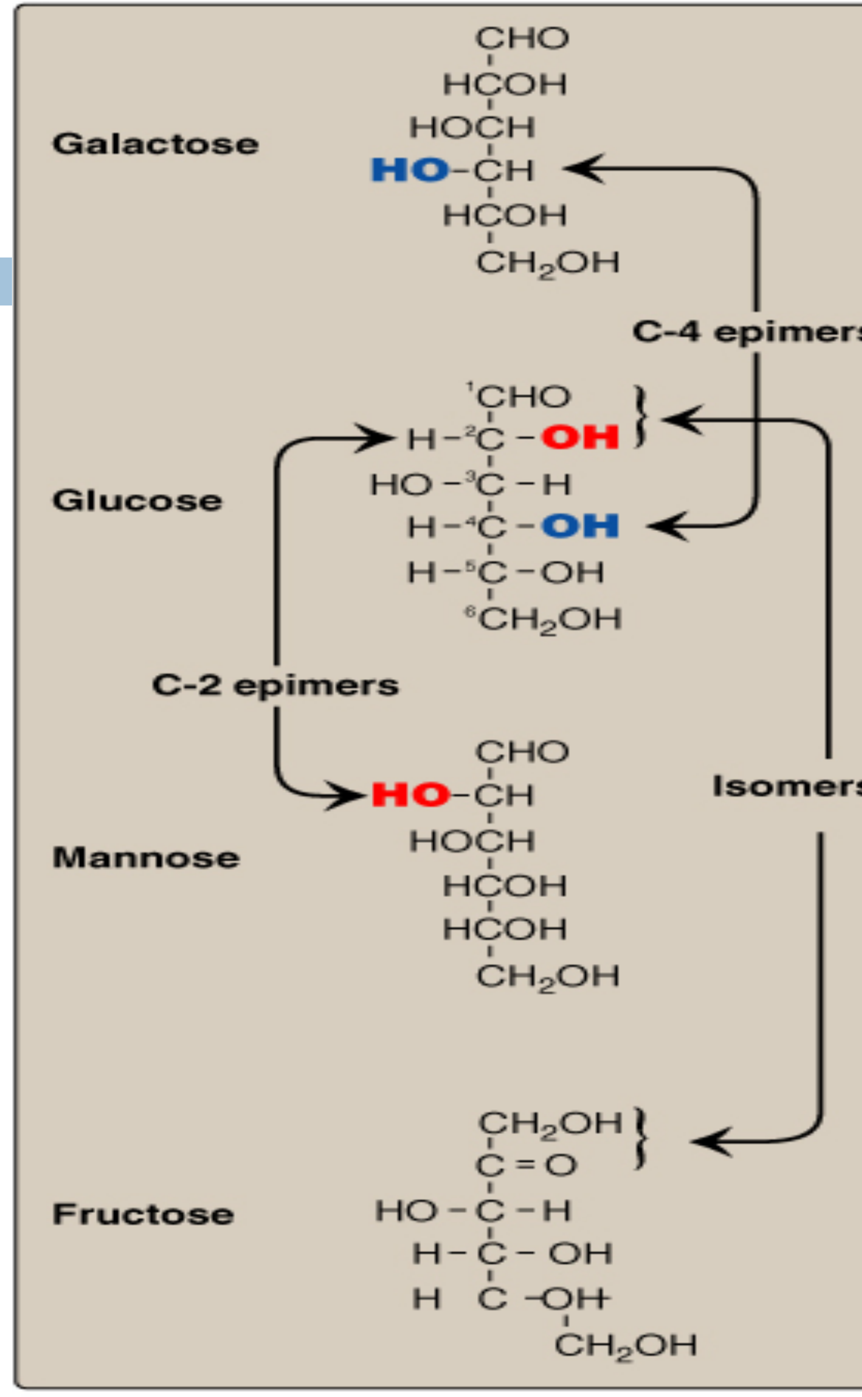
- Epimers

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

-Glucose and galactose, C4

-Glucose and Mannose, C2

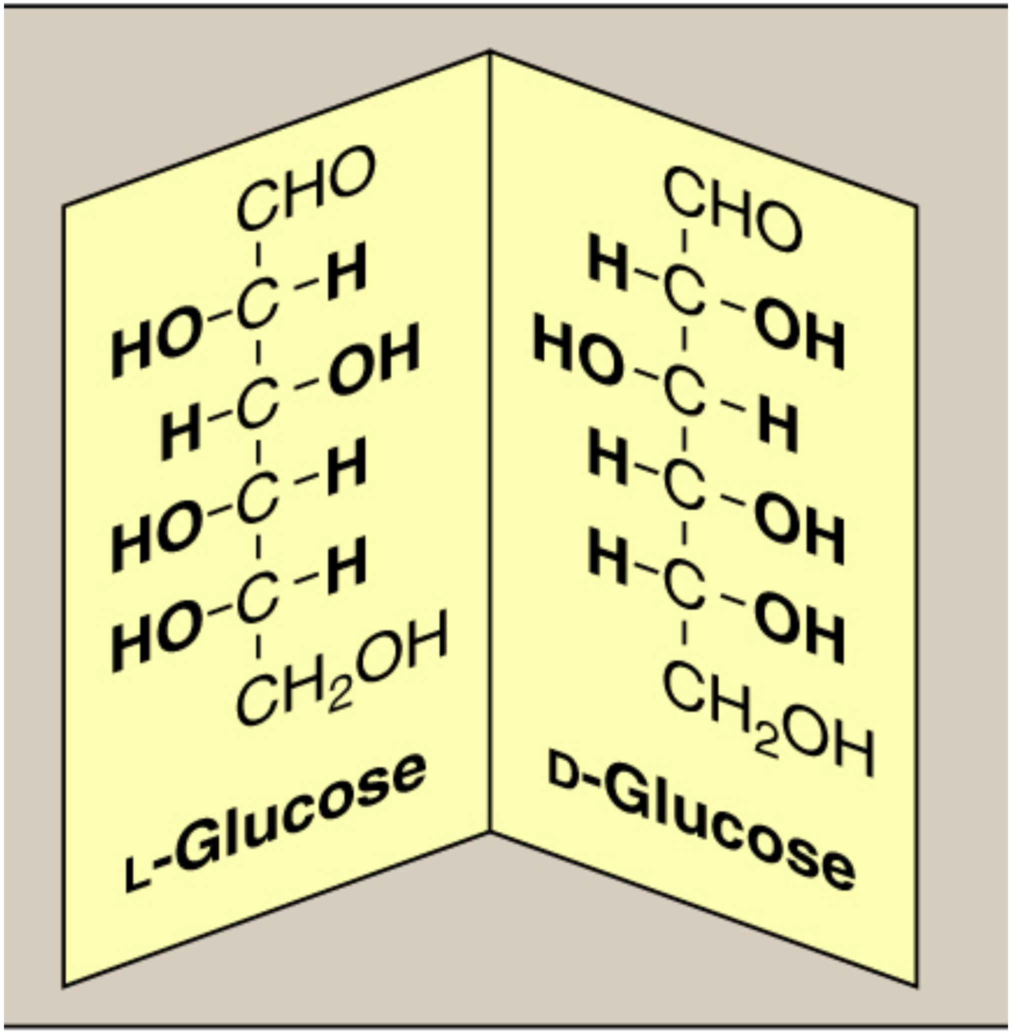
Galactose and mannose are not epimers



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**



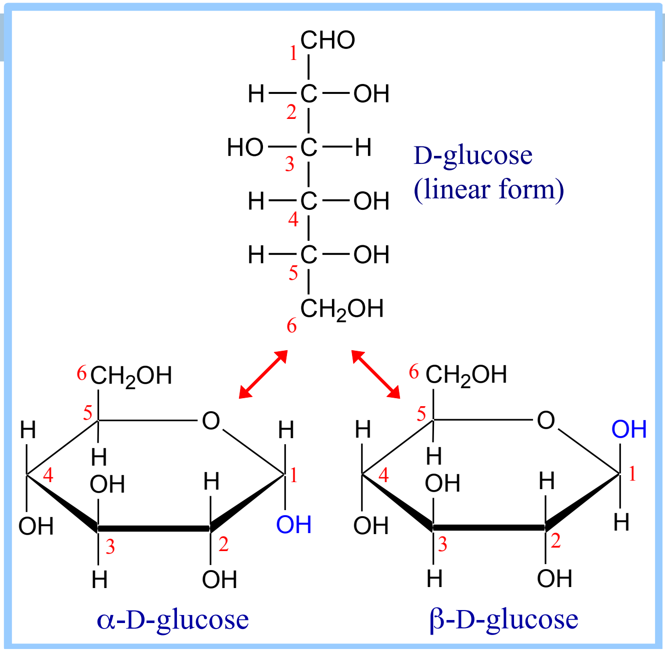
α- and β-Forms

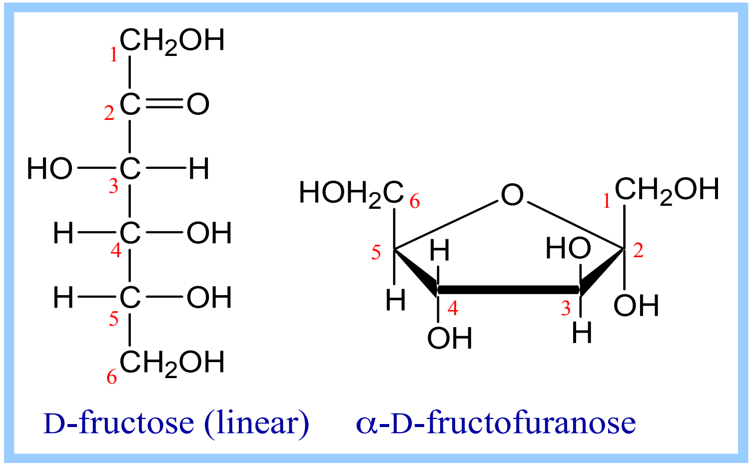
❑ **Cyclization of Monosaccharides**

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

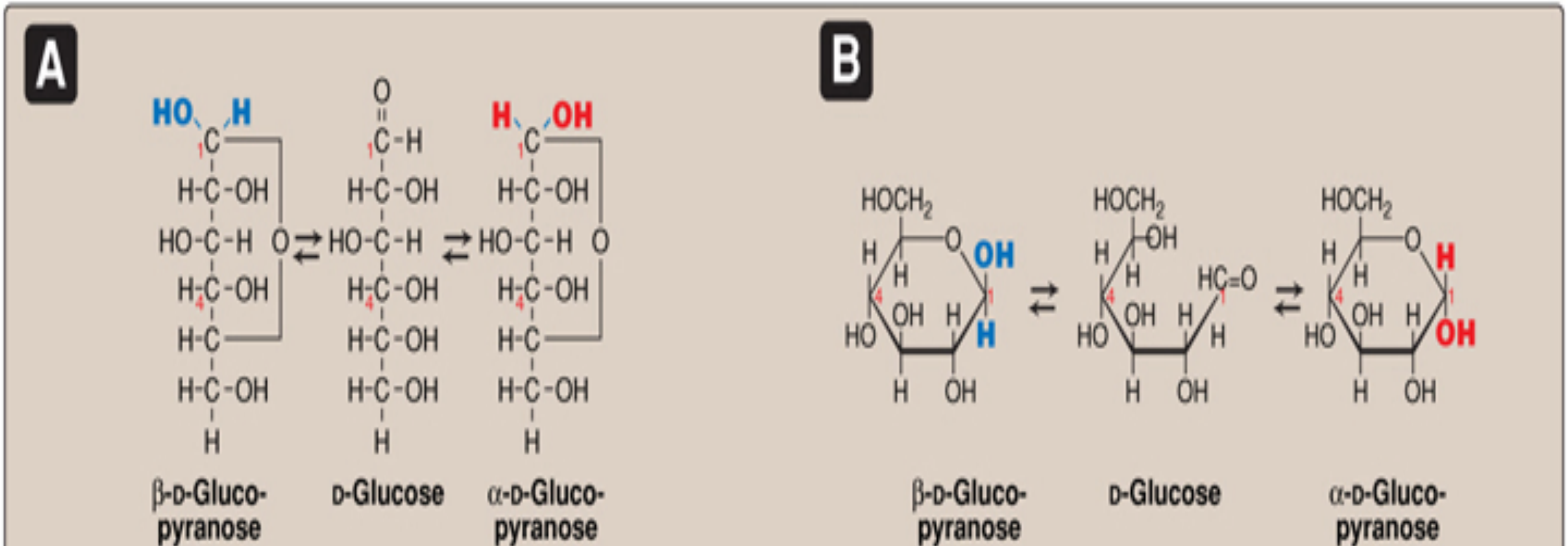
-Cyclization creates an **anomeric carbon** (former carbonyl carbon) generating the α and β configurations





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**

Disaccharides

- Joining of 2 monosaccharides by O-glycosidic bond:

Maltose (α-1, 4)= glucose + glucose

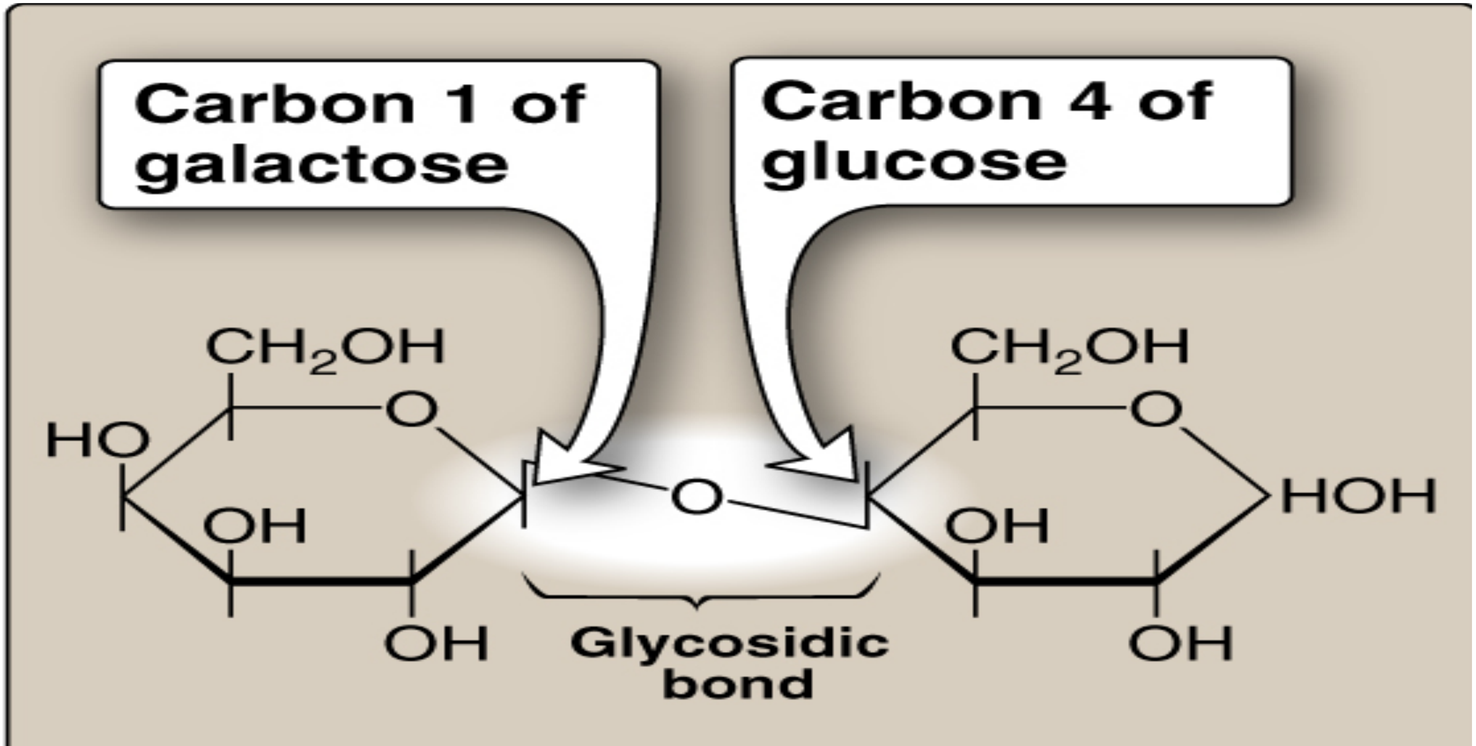
Sucrose (α-1,2) = glucose + fructose

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)

Reducing Sugars

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

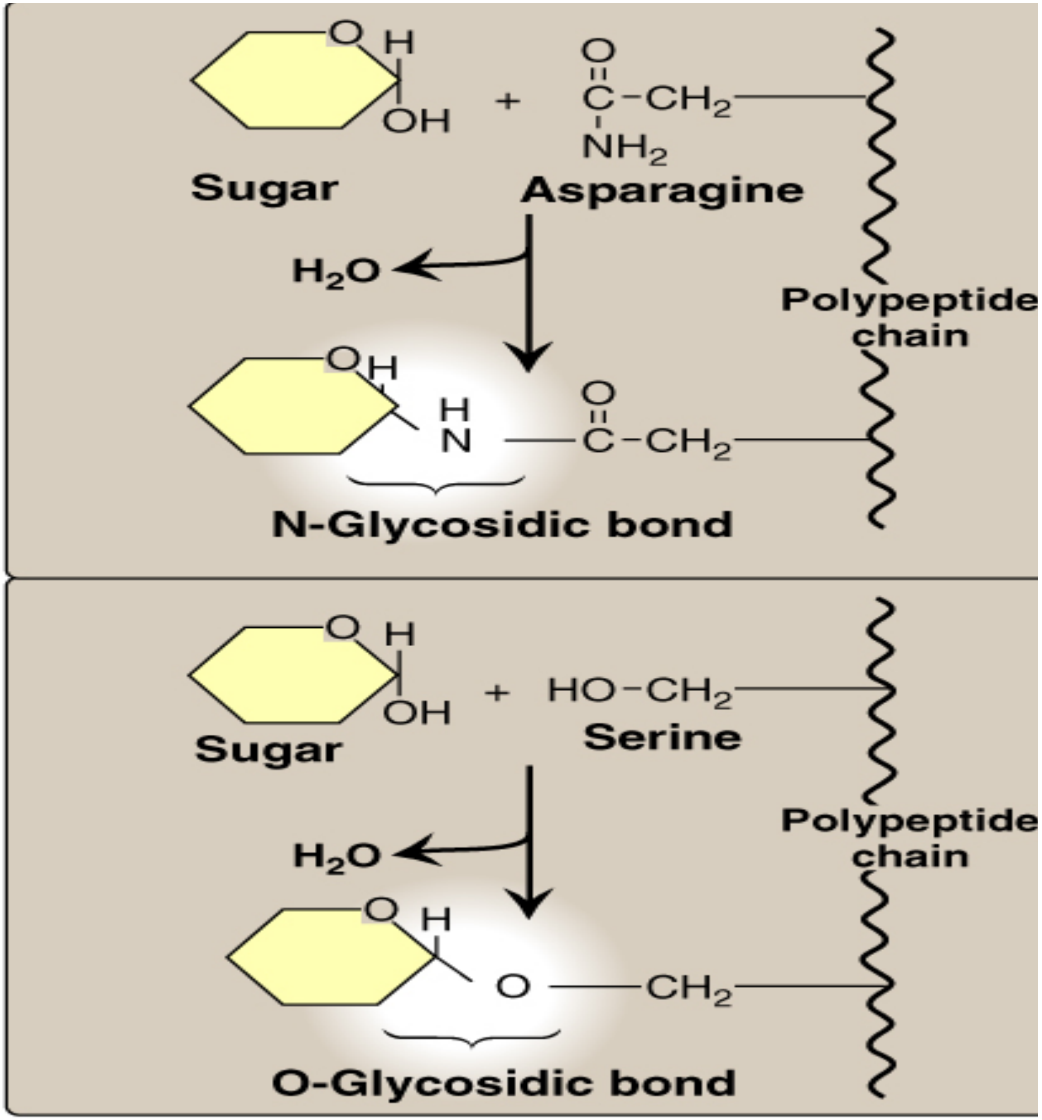
Complex Carbohydrates

- 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

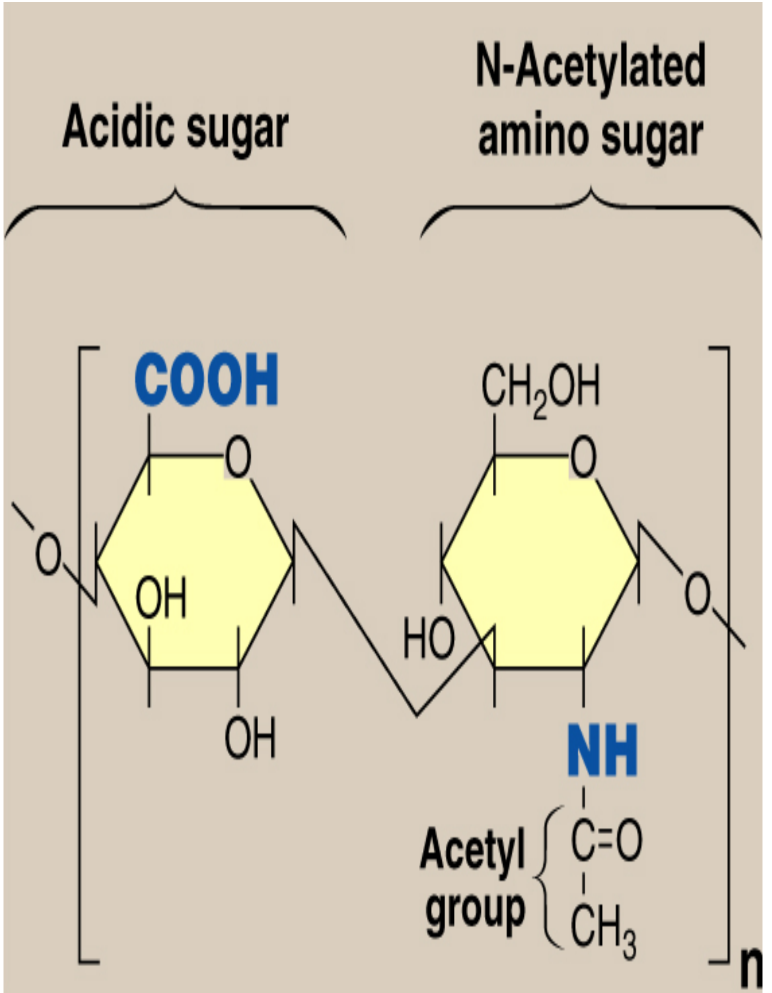
- The acidic sugar is either

  D-glucuronic acid or L-iduronic acid

- GAGs are strongly negatively-charged:

  carboxyl groups of acidic sugars

  Sulfate groups



Resilience of GAGs

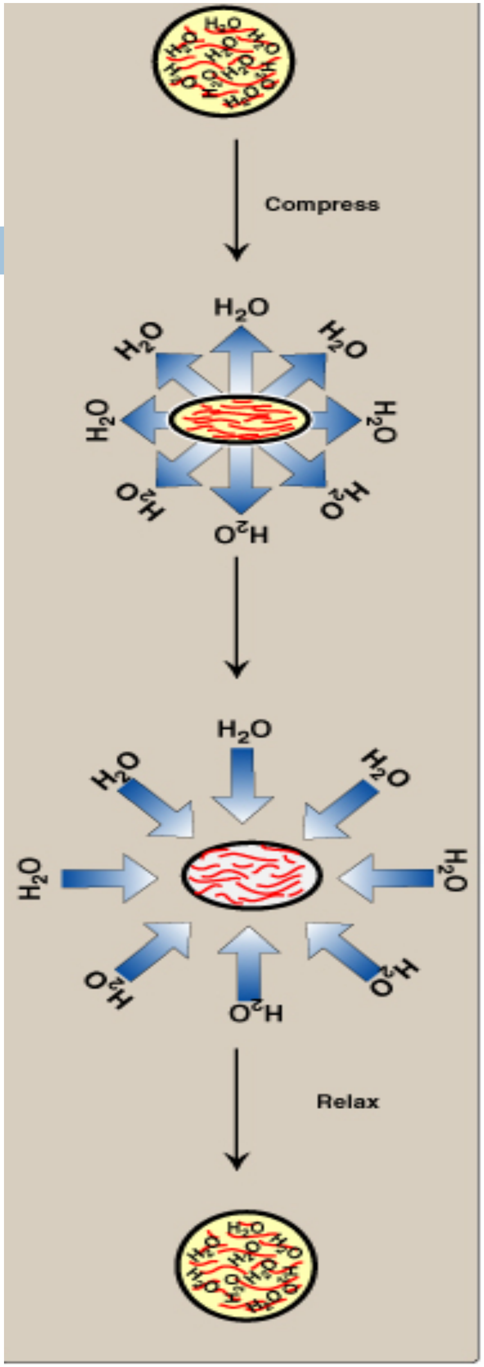
Relationship between glycosaminoglycan structure and function

- 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: Most abundant GAG**
2. **Keratan sulfates**: Most heterogeneous GAGs
3. **Hyaluronic acid: Compared to other GAGs, it is unsulfated and not covalently attached to protein**
4. **Heparin: Unlike other GAGs**, Unlike other GAGs that are extracellular, heparin is **intracellular and serves as an 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

Reference

- Lippincott's Illustrated reviews- Biochemistry, 6th Edition, pages- 83-86 and 157-159