# CARBOHYDRATES: STRUCTURE AND FUNCTION

By

Dr. Amr S. Moustafa, MD, PhD

# 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:**

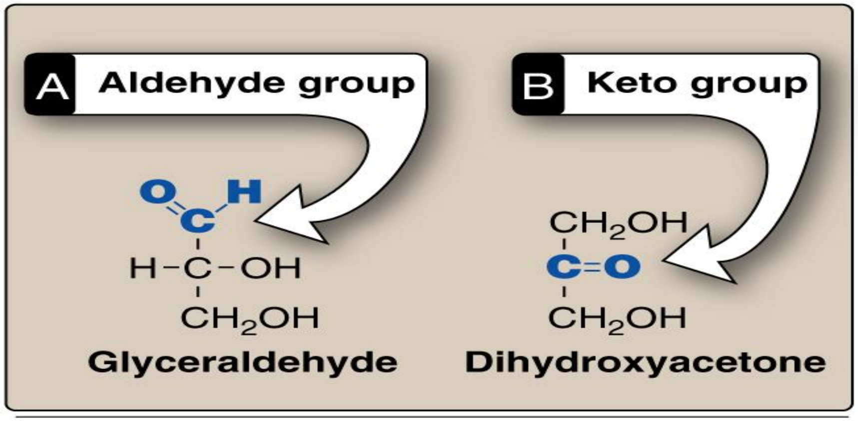
**1. No. of carbon atoms**

| 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 |

# Disaccharides

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

**Maltose** (α-1, 4)= glucose + glucose

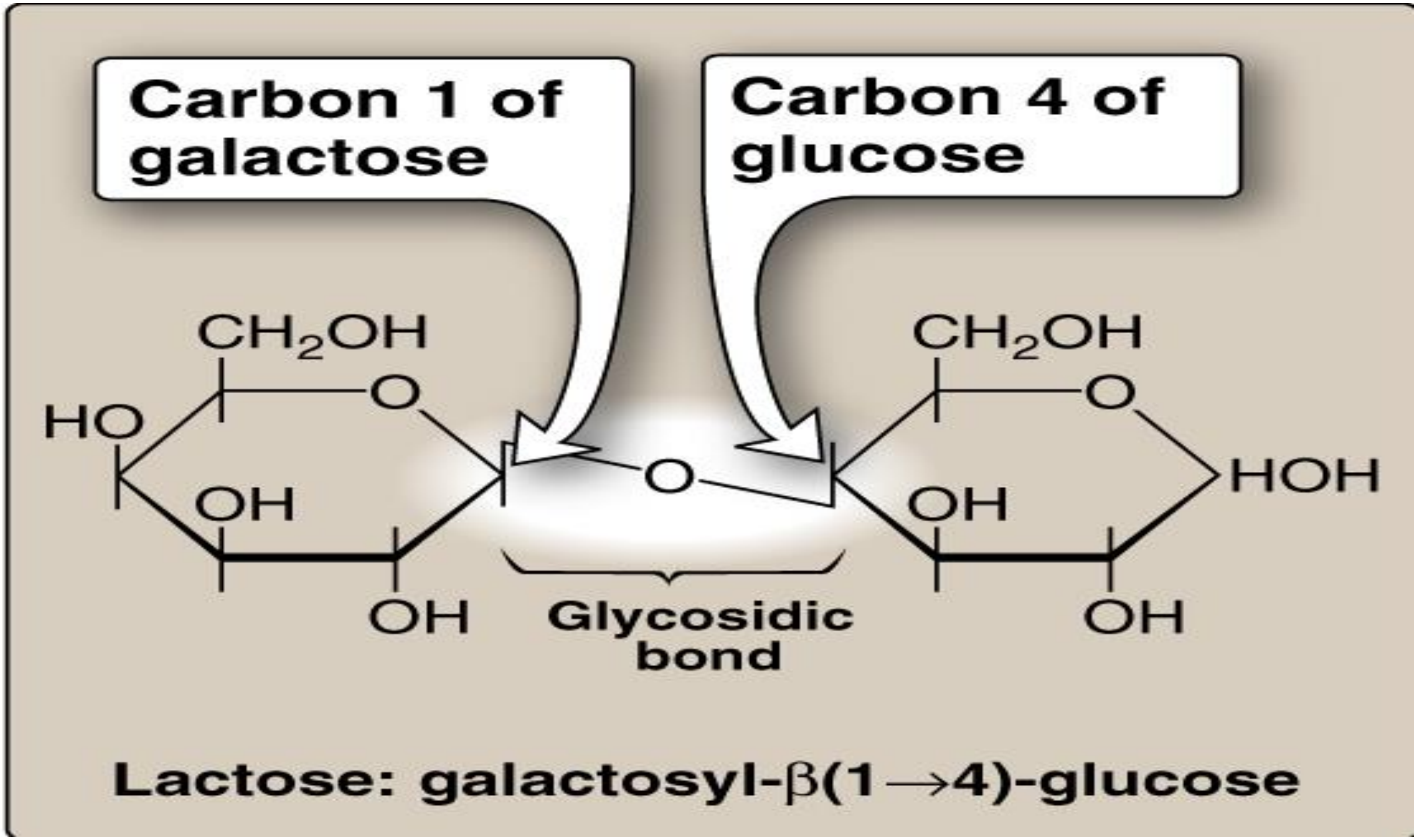
**Sucrose** (α-1,2) = glucose + fructose

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

# Disaccharides

CONT'D

## Lactose



# Polysaccharides

- **Homopolysaccharides:**

  **Branched:**

  **Glycogen and starch (α-glycosidic polymer)**

  **Unbranched:**

  **Cellulose (β-glycosidic polymer)**

- **Heteropolysaccharides:**

  **e.g., glycosaminoglycans (GAGs)**

# Isomerism

- Isomers

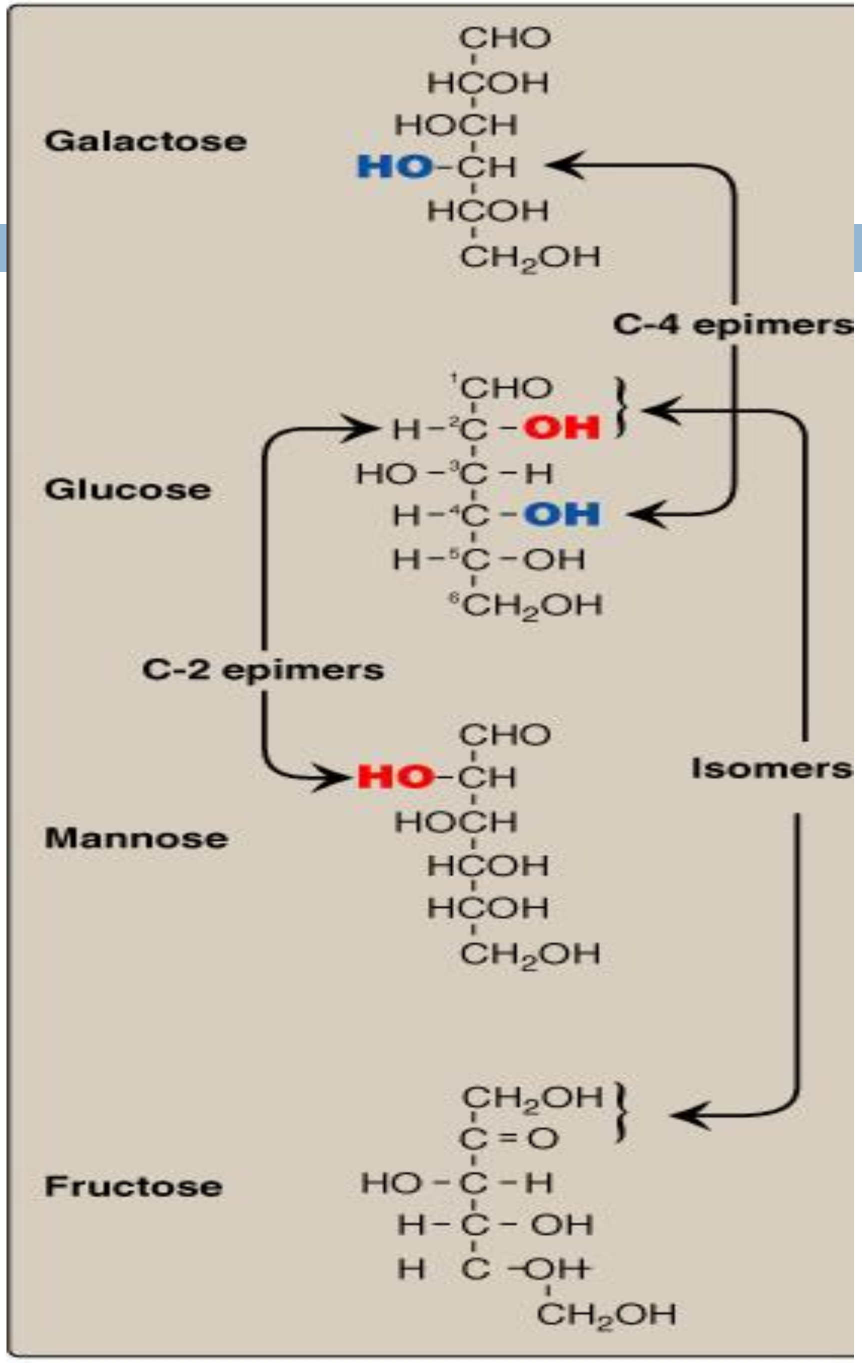
Compounds having

same chemical formula

but different

structural formula

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



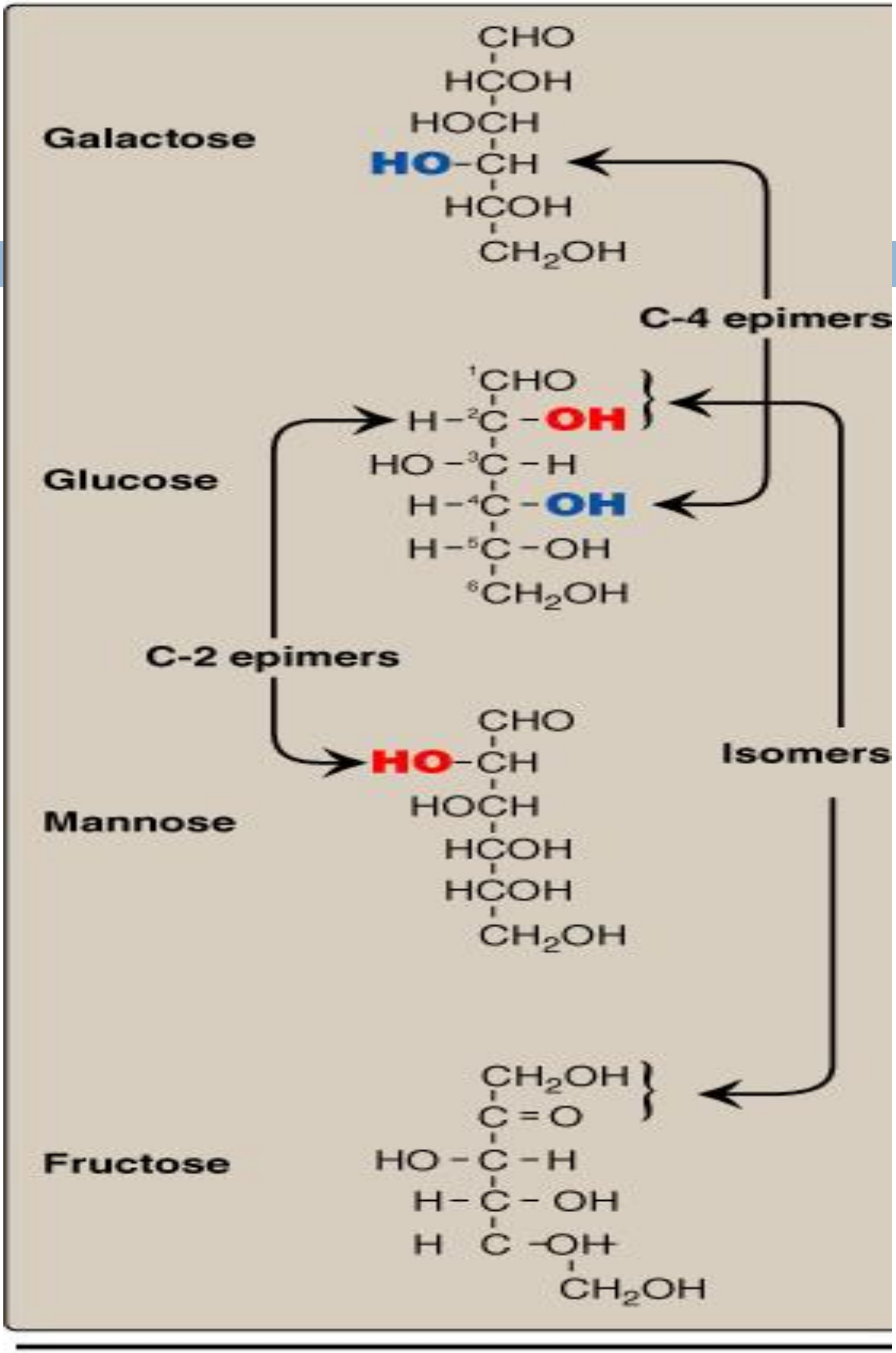
# Aldo-Keto Isomers

**Example:**

**Glucose (Aldose)**

**and**

**Fructose (Ketose)**



# Epimers

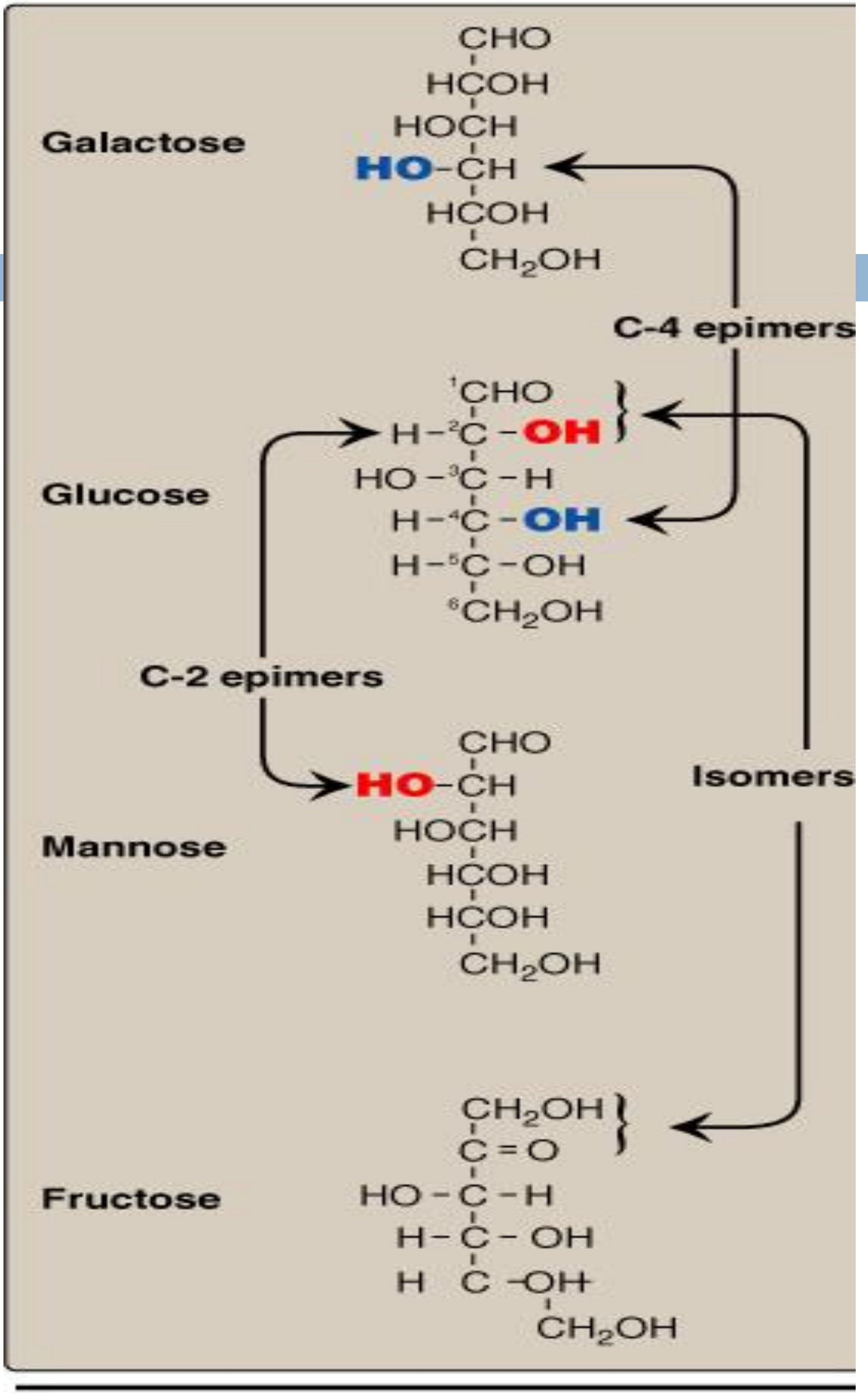
- Epimers

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

-Glucose and galactose, C4

-Glucose and Mannose, C2

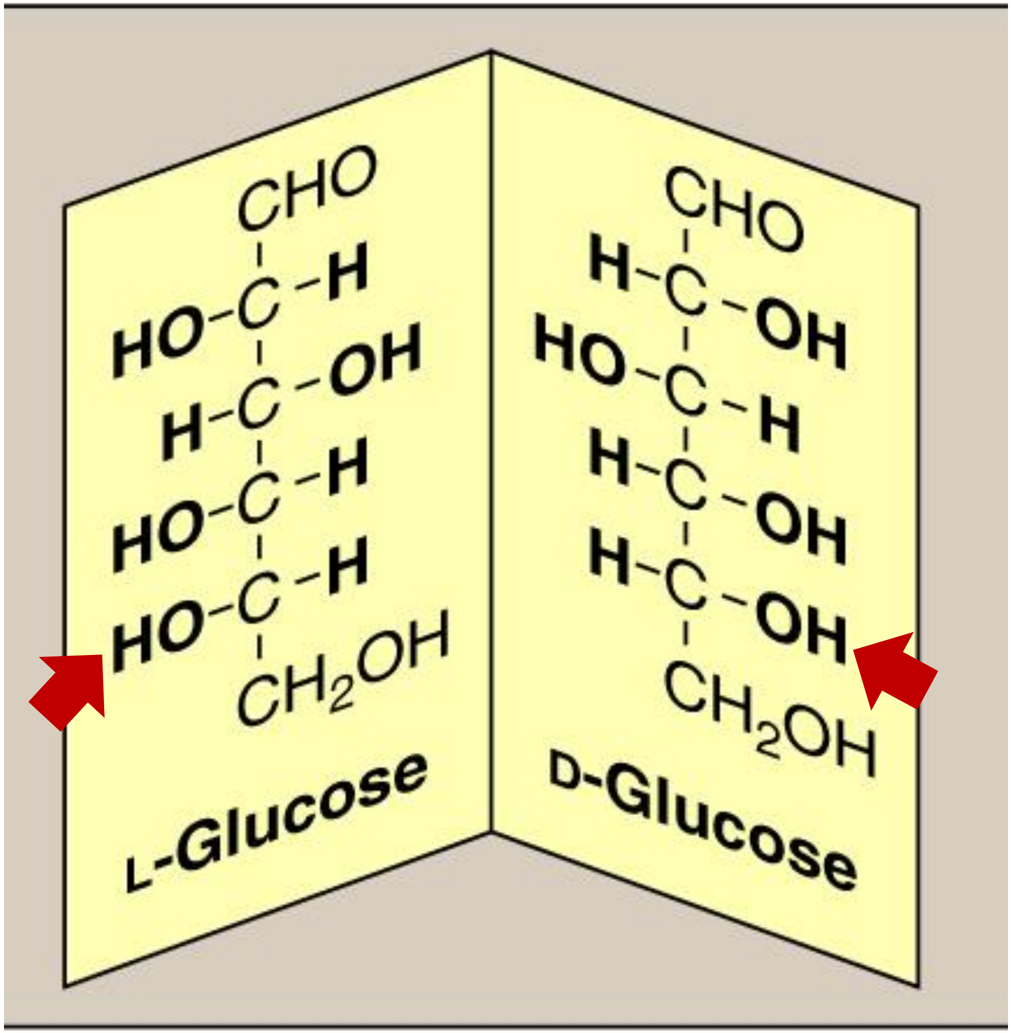
Galactose and mannose are not epimers



# Enantiomers (D- and L-Forms)

Structures that are **mirror images** of each other 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**



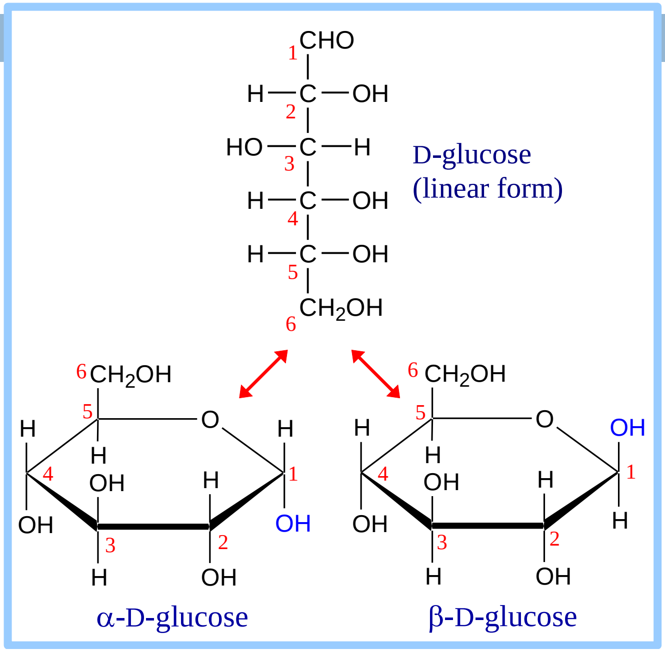
# α- and β-Forms

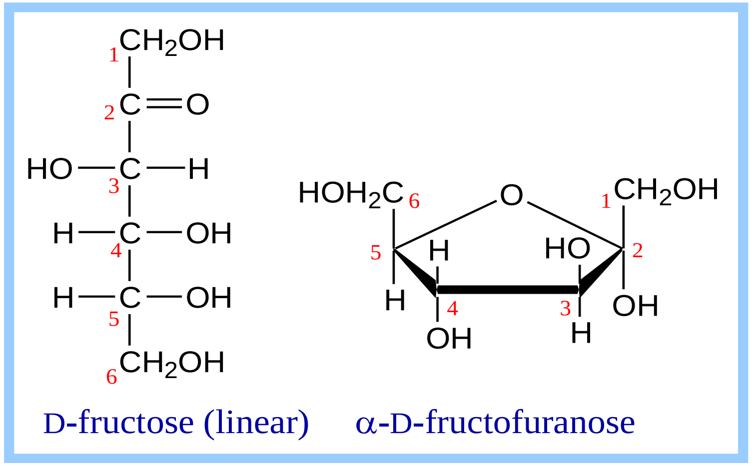
- **Cyclization of Monosaccharides**

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

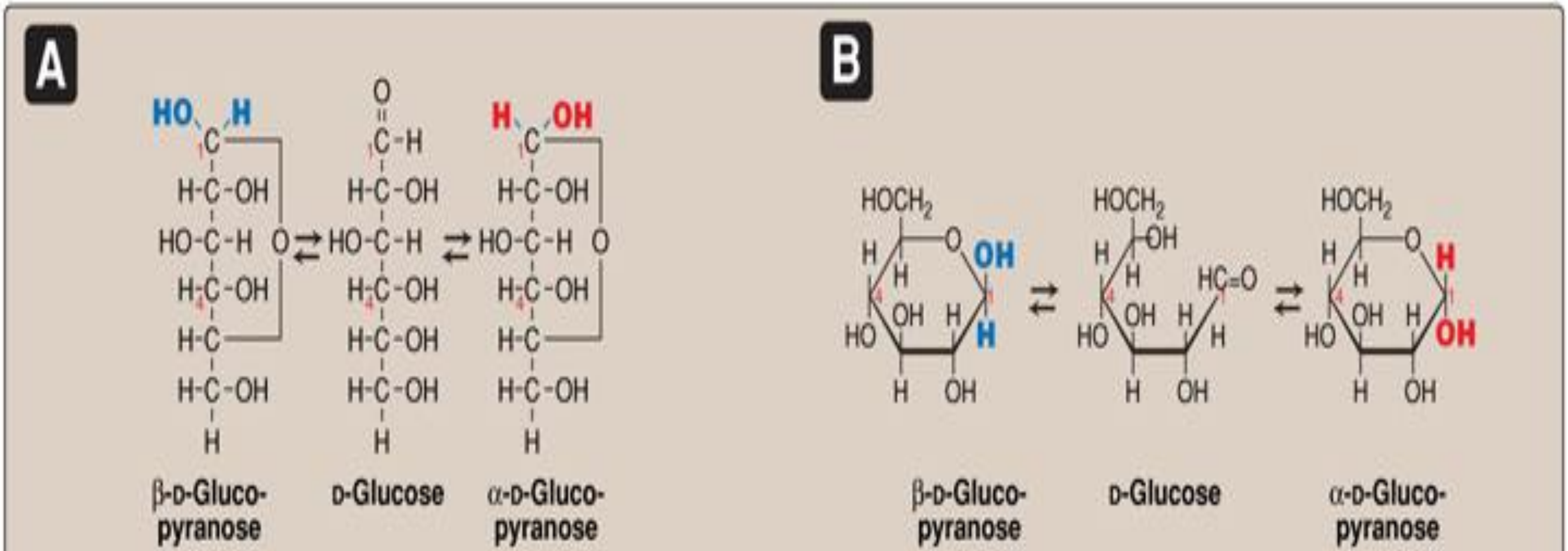
-Cyclization creates an **anomeric carbon** (former carbonyl carbon) generating the α and β configurations



# 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 **(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 periceptate
- **In the past, u**rine was 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?**

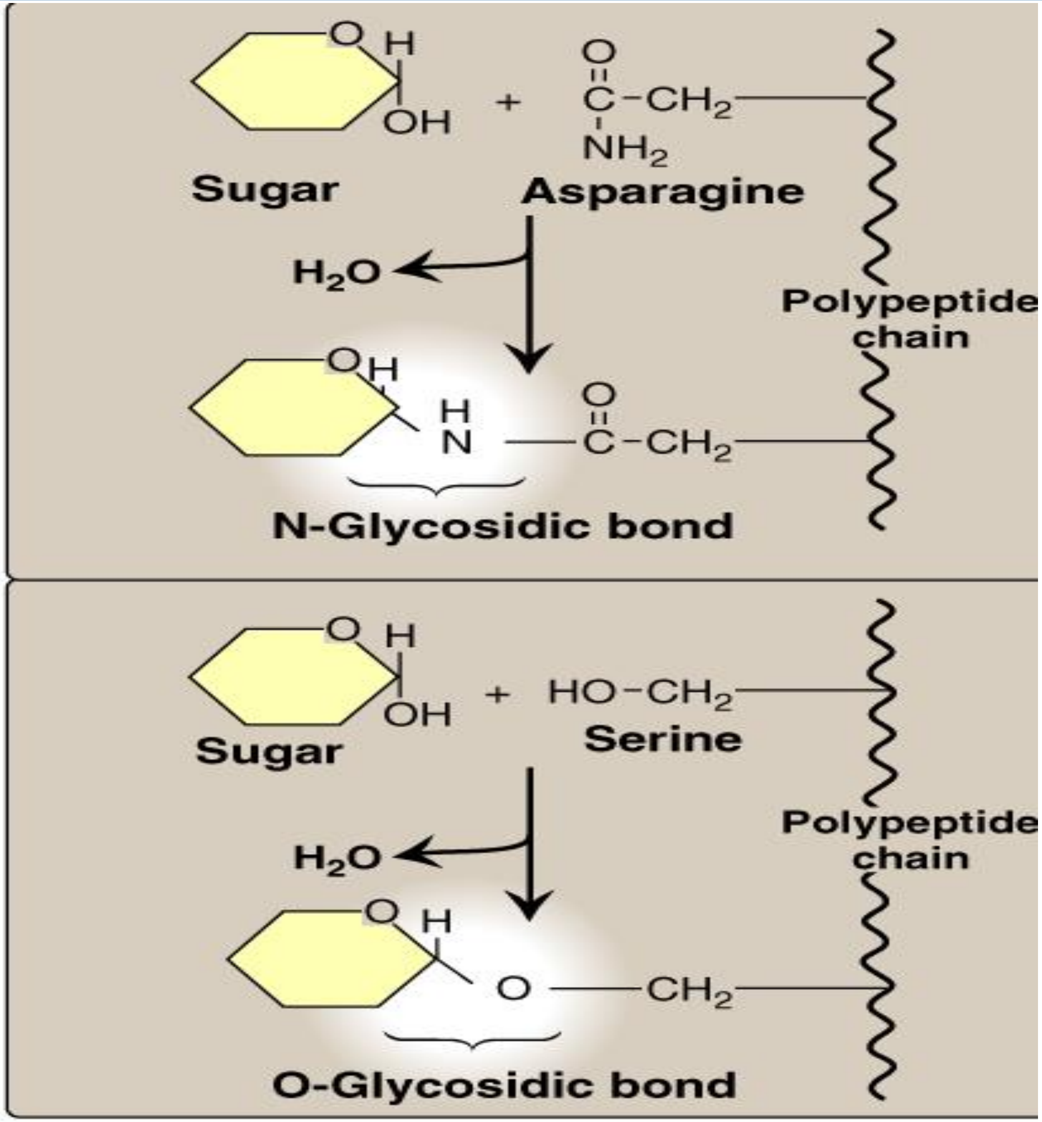
# Complex Carbohydrates

- 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**

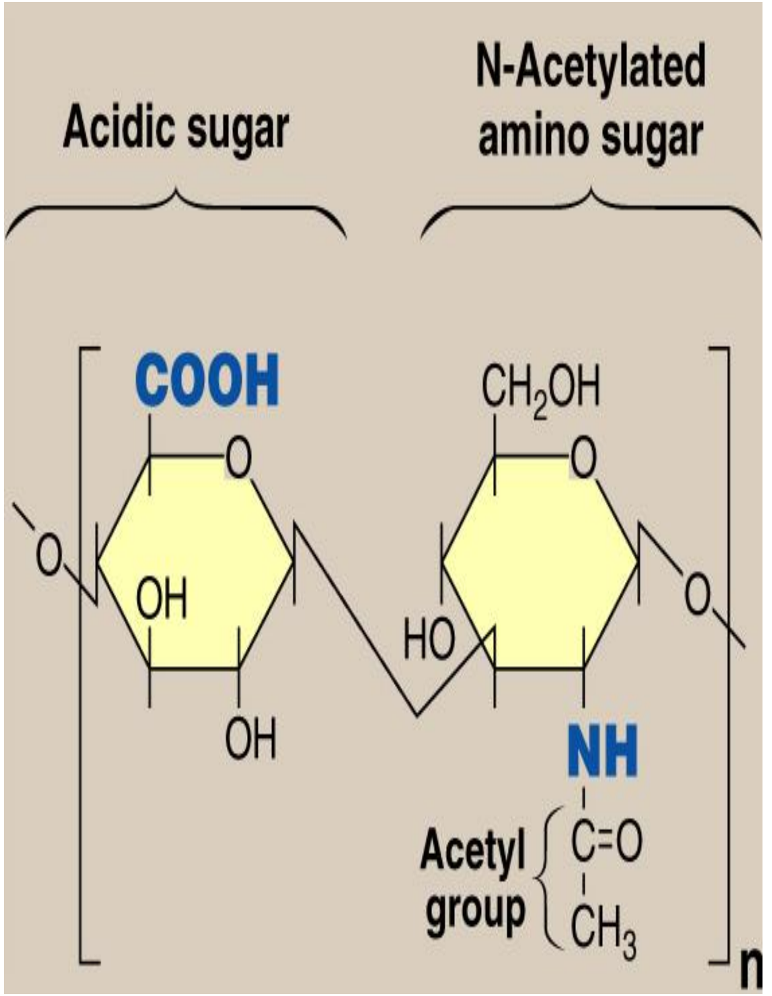
- The acidic sugar is either

  **D-glucuronic acid or L-iduronic acid**

- GAGs are strongly negatively-charged:

  **carboxyl groups of acidic sugars**

  **Sulfate groups**



# Resilience of GAGs

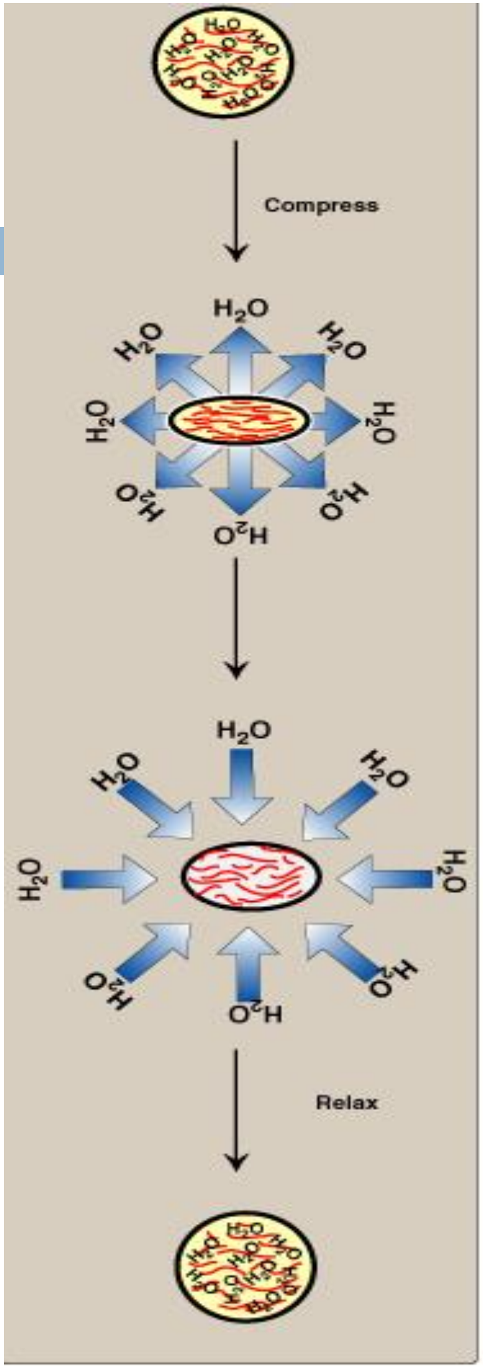
**Relationship between glycosaminoglycan structure and function**

- 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** 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