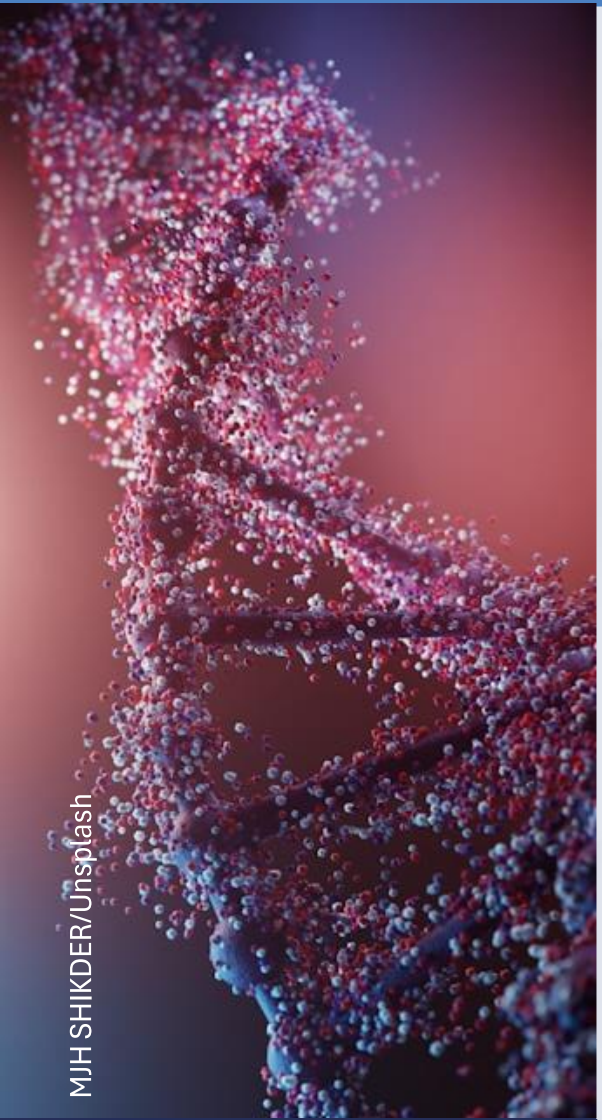

MJH SHIKDER/Unsplash

CARBOHYDRATES

BIOCHEMISTRY I LECTURE

Hans Ethan T. Coria

Instructor

Occurrence and Functions

Carbohydrates

- Most of the matter in plants, except water, is carbohydrate material.
- Carbohydrates account for 75% of dry plant material and are produced by photosynthesis.
  - Cellulose: structural element.
  - Starch/glycogen: energy reservoir.
    - small amount in human body.
- Plant products are source of carbohydrates.
  - Average human diet contains 2/3 of carbohydrates.

Photosynthesis

- A process in which plants produce carbohydrates using carbon dioxide, water and solar energy.

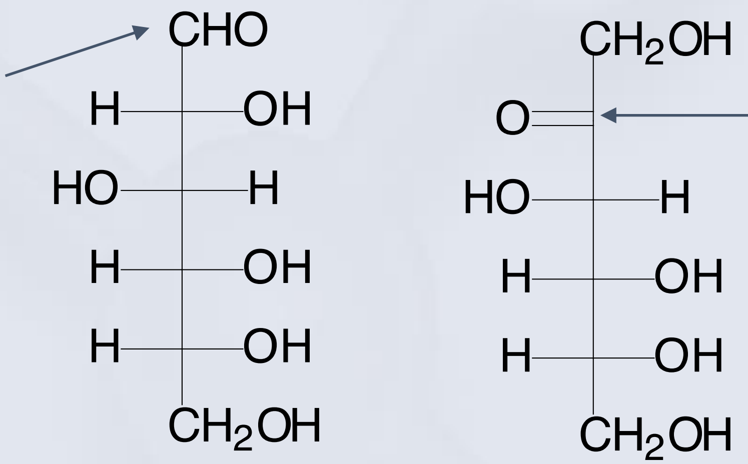
$$CO_2 + H_2O + \text{Solar Energy} \xrightarrow[\text{Plant Enzymes}]{\text{Chlorophyll}} \text{Carbohydrates} + O_2$$

Functions of Carbohydrates in the Human Body

- Provides energy through oxidation
- Source of energy reserves in the form of starch and glycogen
- Supply carbon atoms for the synthesis of other biochemical substances such as proteins, lipids, and nucleic acids
- Component of the structural framework of DNA and RNA molecules
- Linked to lipids as structural components of cell membranes
- Function in a variety of cell–cell and cell–molecule recognition processes when linked to proteins

Classification of Carbohydrates

- Carbohydrates are **polyhydroxy aldehydes** or **ketones** or compounds that produce such substances upon hydrolysis.
- Simple Formula:
  - $C_nH_{2n}O_n$ or $C_n(H_2O)_n$ (hydrates of C)
  - n= number of atoms



Aldehyde

Polyhydroxy aldehyde

Ketone

Polyhydroxy ketone

Classification of Carbohydrates

Classification Based on Size

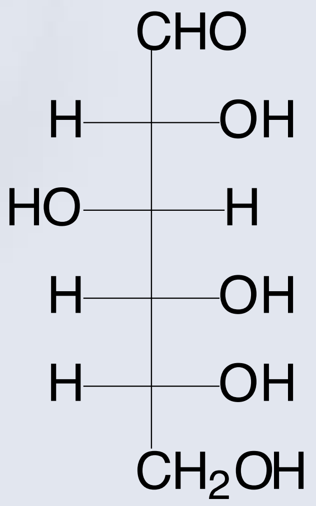
1. Monosaccharide
2. Disaccharide
3. Trisaccharide and Oligosaccharide
4. Polysaccharide

Classification of Carbohydrates

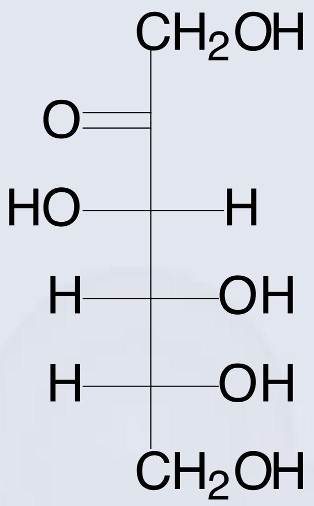
Monosaccharide

- Contains **single** polyhydroxy aldehyde or ketone unit
- Cannot be broken down into simpler substances by hydrolysis (reaction with water) reactions
- Contains 3-7 C atoms
- 5 and 6 carbon species are more common
- Water-soluble white crystalline solids

Glucose and fructose are monosaccharides



Glucose



Fructose

Classification of Carbohydrates

Disaccharides

- Contains 2 monosaccharide units covalently bonded to each other.
- Disaccharides are crystalline and water-soluble substances
- Table sugar (sucrose) and milk sugar (lactose) are common disaccharides
- Upon hydrolysis they produce monosaccharides

Trisaccharide and Oligosaccharide

- Contains 3-10 monosaccharide units - covalently bonded to each other
- Free oligosaccharides are less common in nature
- Usually found associated with proteins and lipids in complex molecules.
    - Serve structural and regulatory functions

Classification of Carbohydrates

Polysaccharide

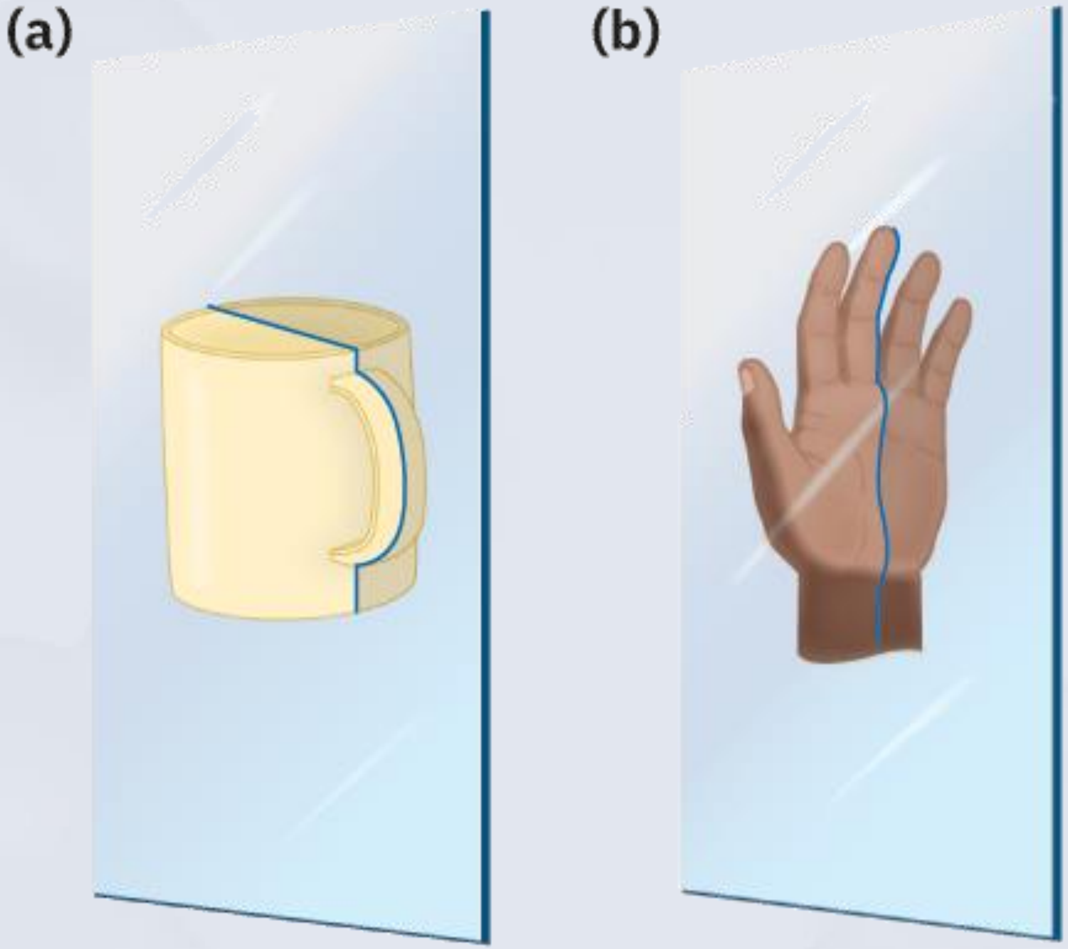
- Contains many monosaccharide units covalently bonded
- Polymers: May contain a few 100s to > million monosaccharide units

- Examples:
  - Cellulose: paper, cotton, wood
  - Starch: bread, pasta, potatoes, rice, corn, beans, peas, etc.

Chirality: Handedness in Molecules

Objects and handedness

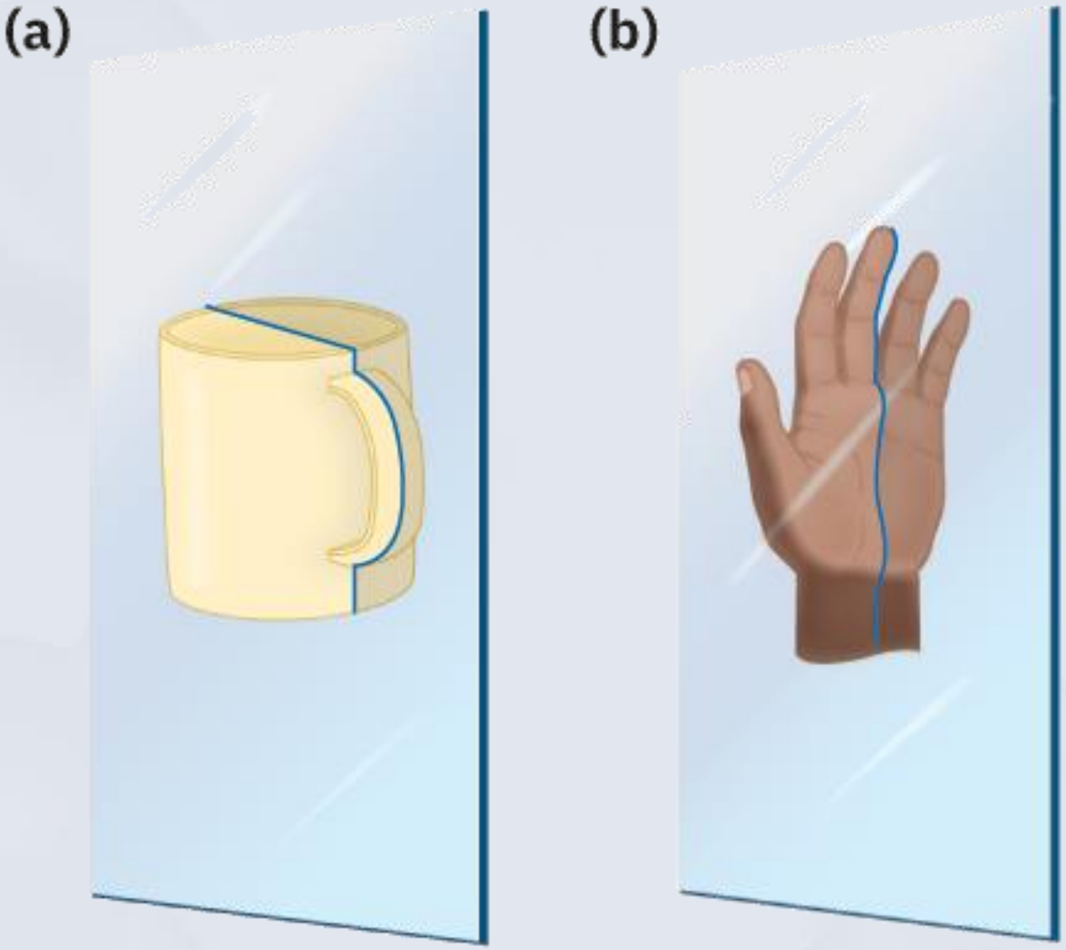
- Most biological molecules, including carbohydrates, exhibit the property of "handedness" (isomerism)
- Most monosaccharides exist in two forms: a "left-handed" and "right-handed" form - same as two hands that are "mirror images" of each other.



Chirality: Handedness in Molecules

Mirror Images

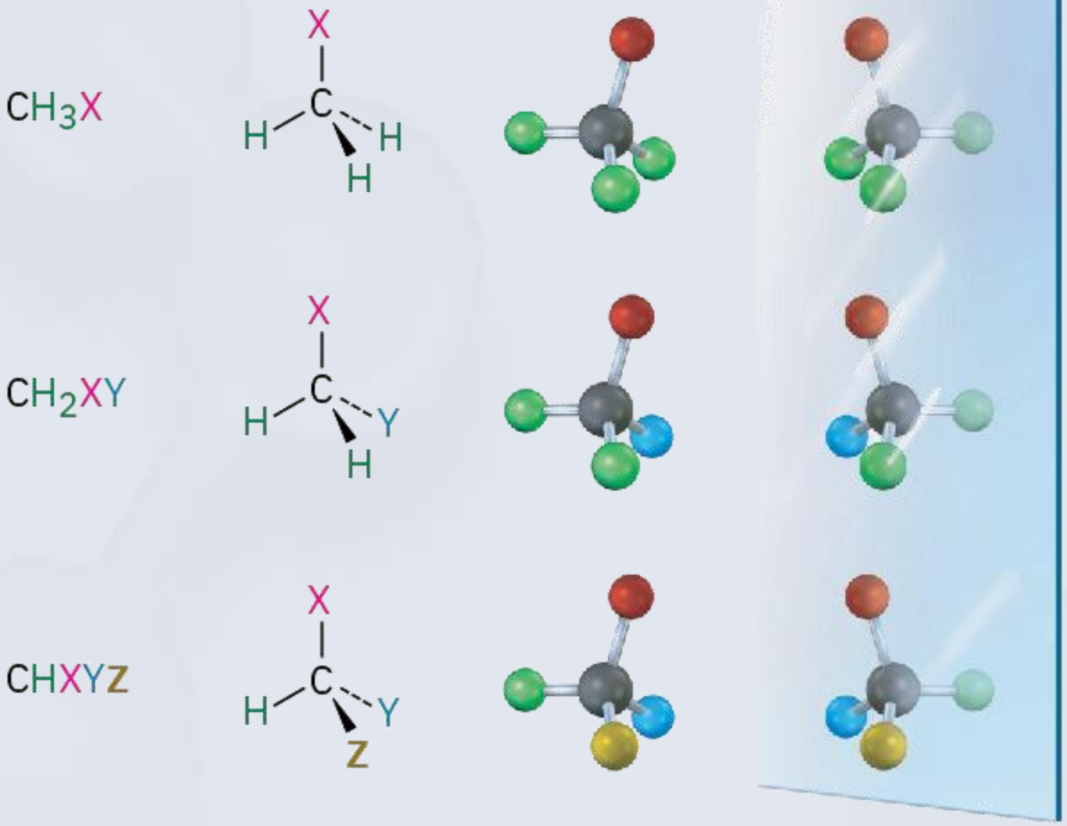
- Mirror Image: the reflection of an object in a mirror
- Two types of objects:
  - **Superimposable mirror images**: Images that coincide at all points when the images are laid upon each other – **Achiral**
  - **Non-superimposable mirror images**: Images where not all points coincide when the images are laid upon each other – **Chiral** (handedness)



Chirality: Handedness in Molecules

Chirality

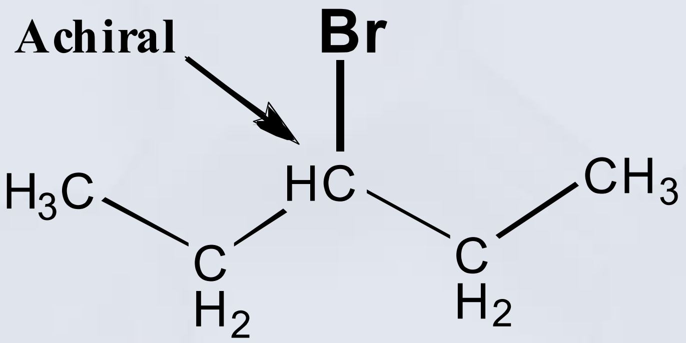
- **Chiral Center**: C atom attached to 4 different groups
- A molecule with chiral center is a chiral molecule
    - Best way to visualize - look at all C atoms and see if there are at least two H atoms then that can't be a chiral center
    - C atoms with less than one H atoms are worth looking at for their chirality.



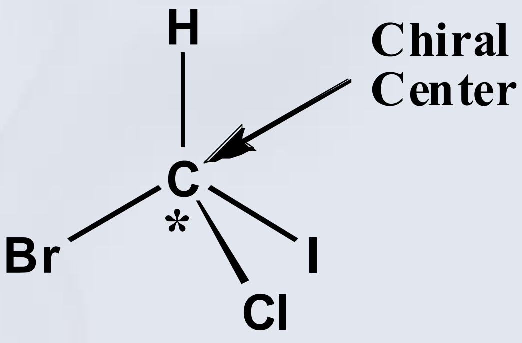
Chirality: Handedness in Molecules

Chirality

- Be careful as a C atom may apparently look similar but may not have four DIFFERENT groups.
  - e.g., 3-bromopentane – has no chiral carbons whereas, bromochloroiodomethane has a chiral carbon.
  - A chiral C is usually denoted by *



3-Bromopentane



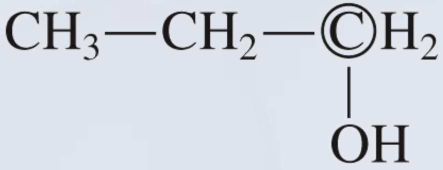
Bromochloroiodomethane

Chirality: Handedness in Molecules

Practice Exercise

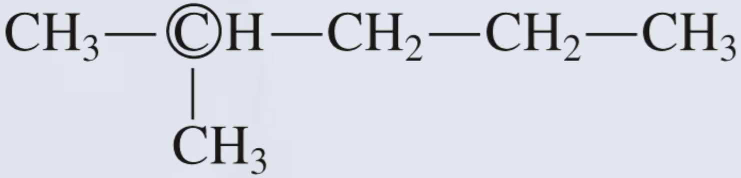
Indicate whether the circled carbon atom in each of the following molecules is a chiral center.

a.



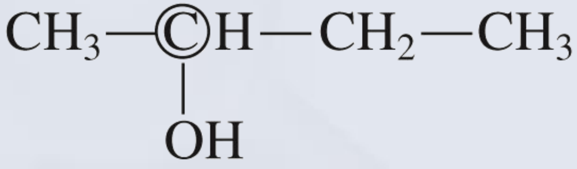
$CH_3{-}CH_2{-}\underset{\underset{\displaystyle OH}{|}}{\textcircled{C}H_2}$

b.



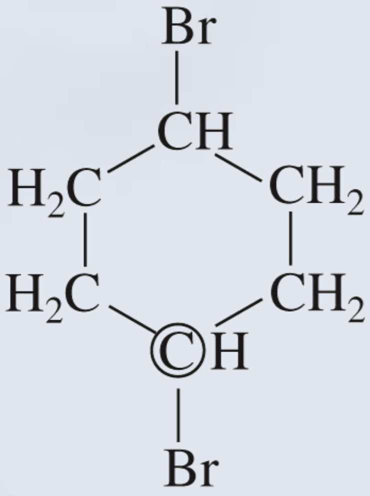
$CH_3{-}\underset{\underset{\displaystyle CH_3}{|}}{\textcircled{C}H}{-}CH_2{-}CH_2{-}CH_3$

c.



$CH_3{-}\underset{\underset{\displaystyle OH}{|}}{\textcircled{C}H}{-}CH_2{-}CH_3$

d.



Answers:

a. Not a chiral center

b. Not a chiral center

c. Chiral center

d. Not a chiral center

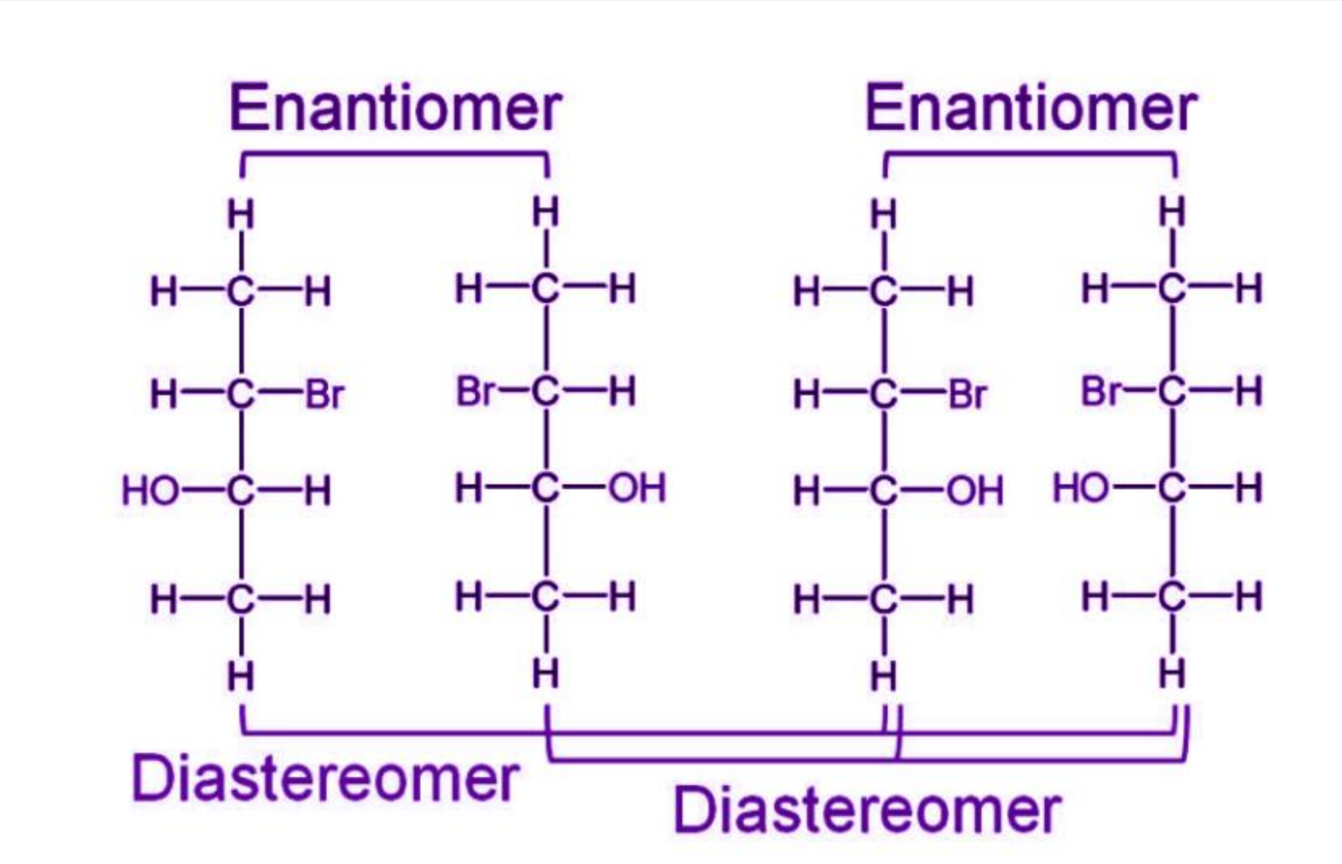
Responses of Left- and Right- Handed Forms of a Molecule in a Human Body

- Both may be active, one may be more active or one may be active and other non-active
    - Example: Right-handed hormone epinephrine is 20 times more active than left-handed form
- Almost all monosaccharides are right-handed
- Amino acids are almost always left-handed

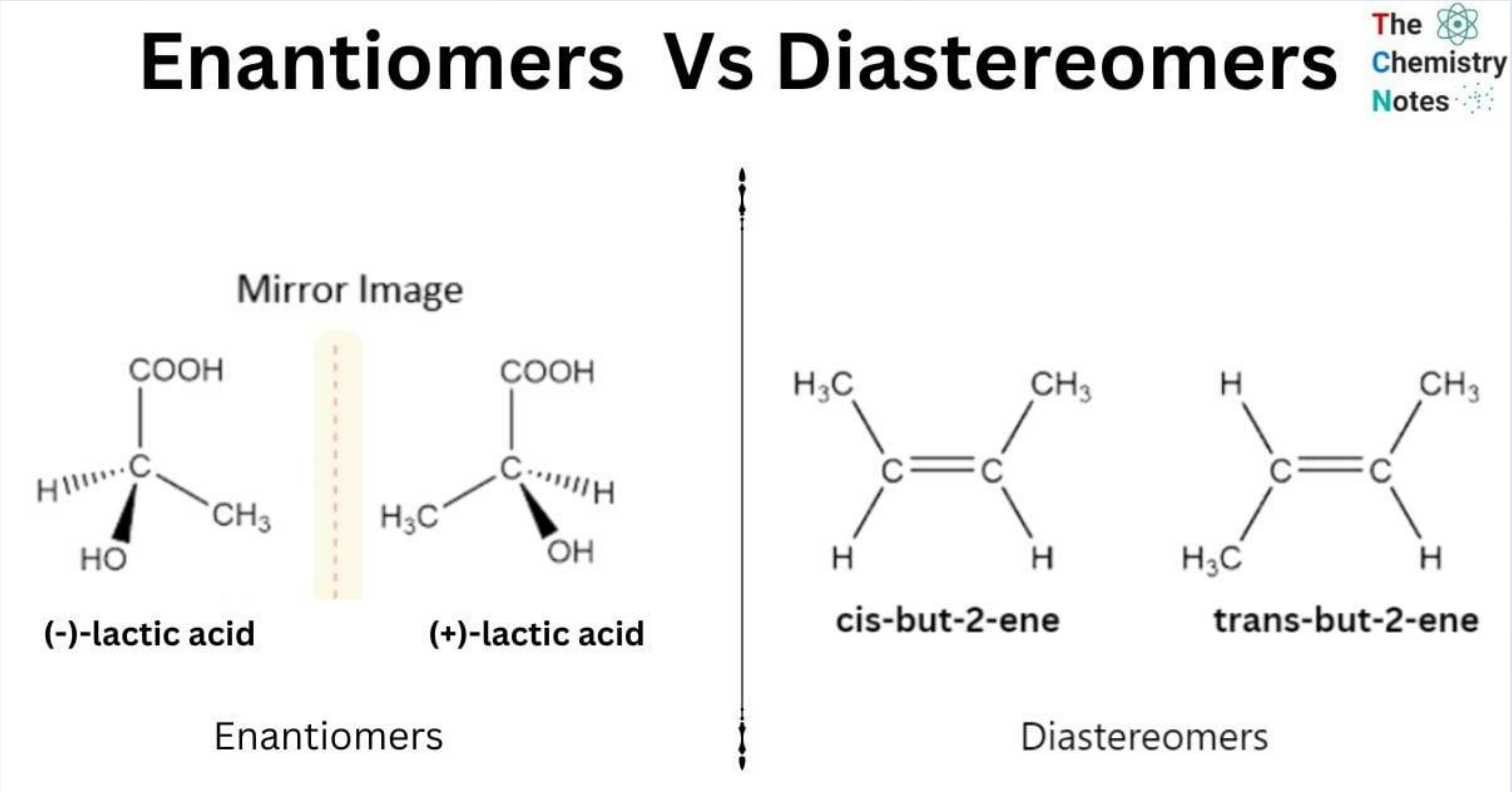
Stereoisomers

- Stereoisomers are isomers that have the same molecular and structural formulas but differ in the orientation of atoms in space.
- Two types:
  - **Enantiomers**: stereoisomers whose molecules are non-superimposable mirror images of each other. Molecules with chiral center.
  - **Diastereomers**: stereoisomers whose molecules are not mirror images of each other. Cis-Trans isomers

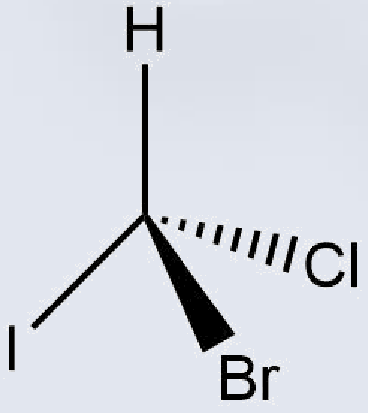
Stereoisomers



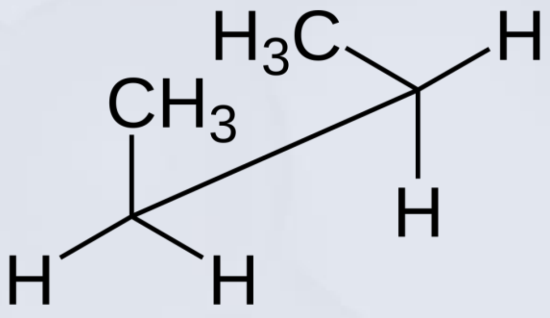
Stereoisomers



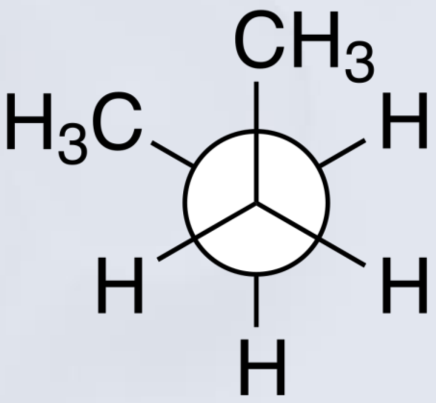
Representation of Organic Molecules



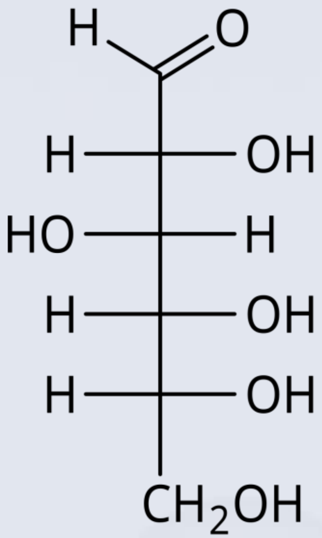
Wedge and Dash



Sawhorse



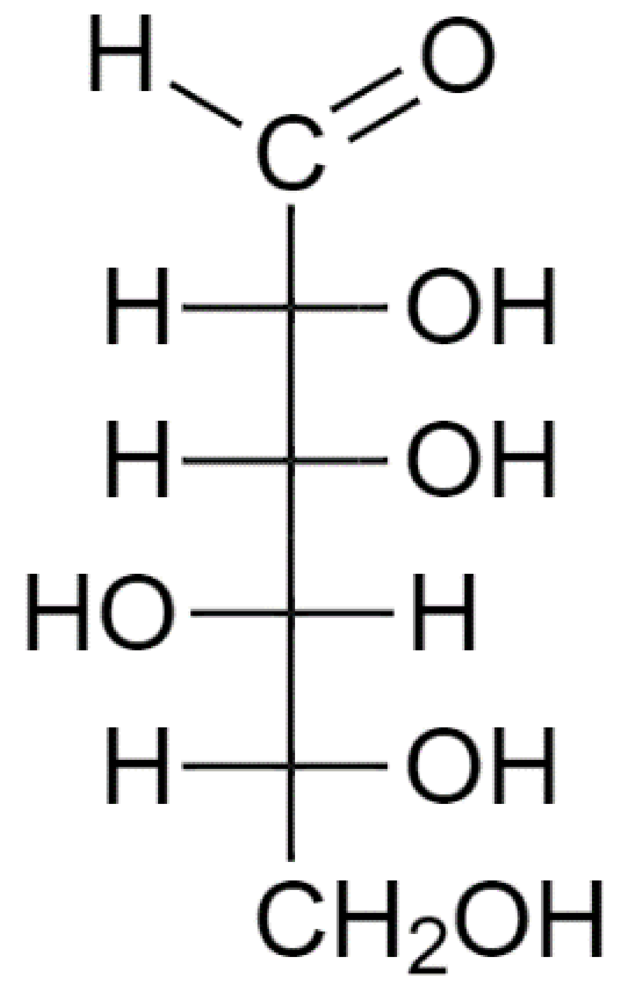
Newman



Fischer

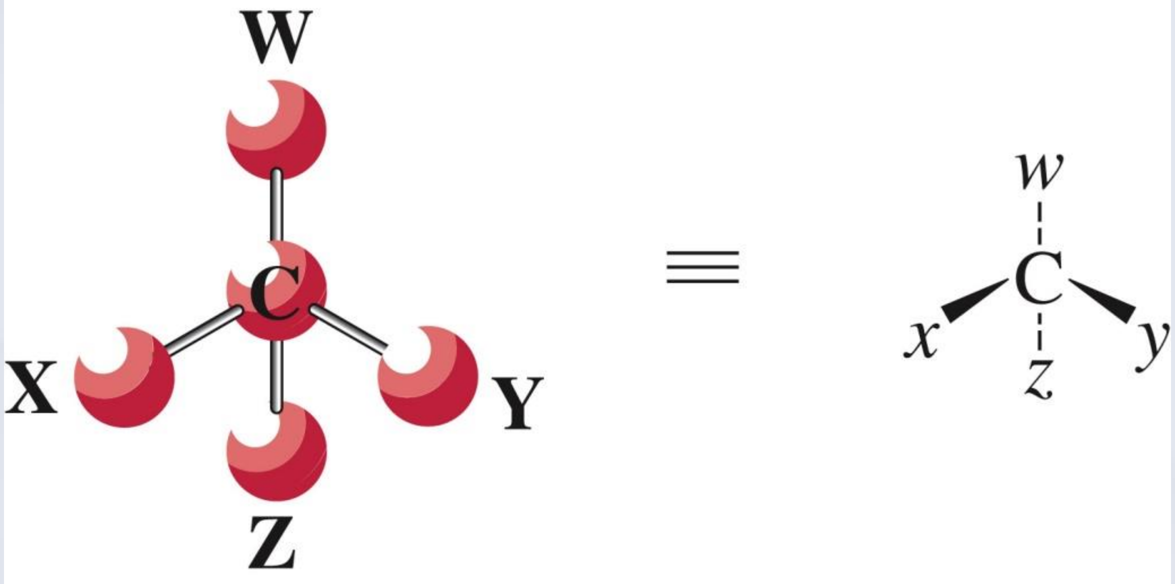
Fischer Projection Formulas

- Fischer projection formula: - A two-dimensional structural notation for showing the spatial arrangement of groups about chiral centers in molecules.
- In a Fischer projection formula, a chiral center (carbon) is represented as the intersection of vertical and horizontal lines
- Functional groups of high priority will be written at top



Tetrahedral Arrangements

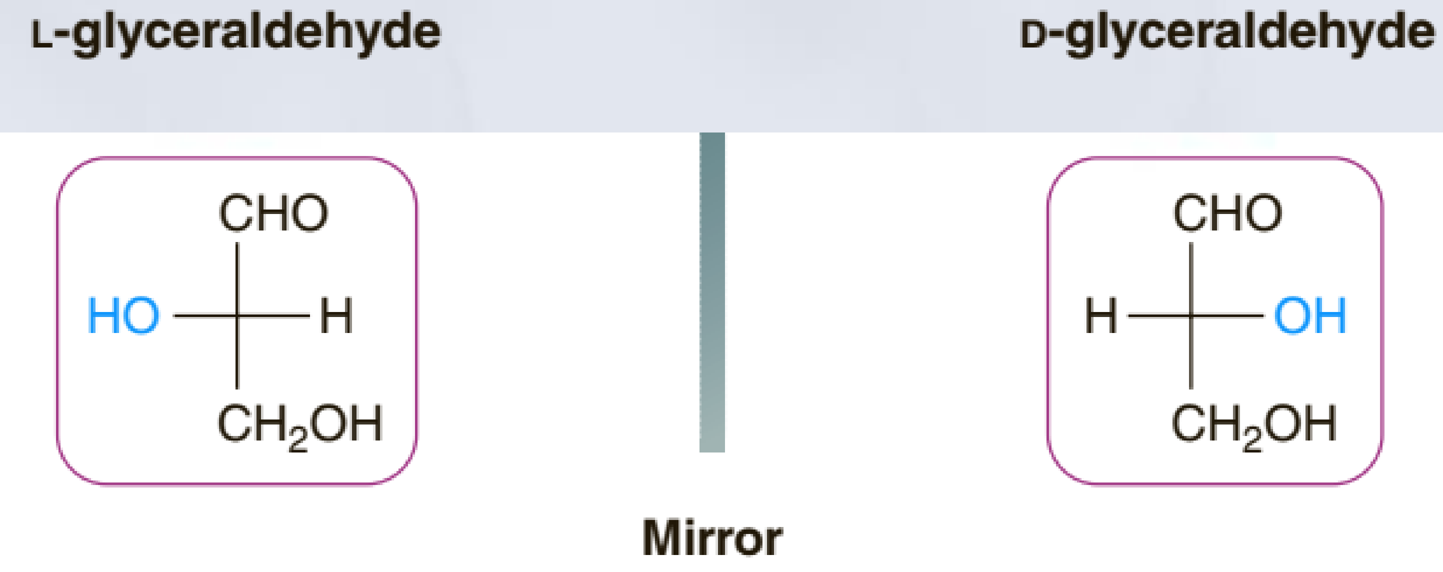
- The four groups attached to the atom at the chiral center assume a tetrahedral geometry and it is governed by the following conventions



- Cut lines from the chiral center represent bonds to groups directed into the printed page.
- Bold lines from the chiral center represent bonds to groups directed out of the printed page

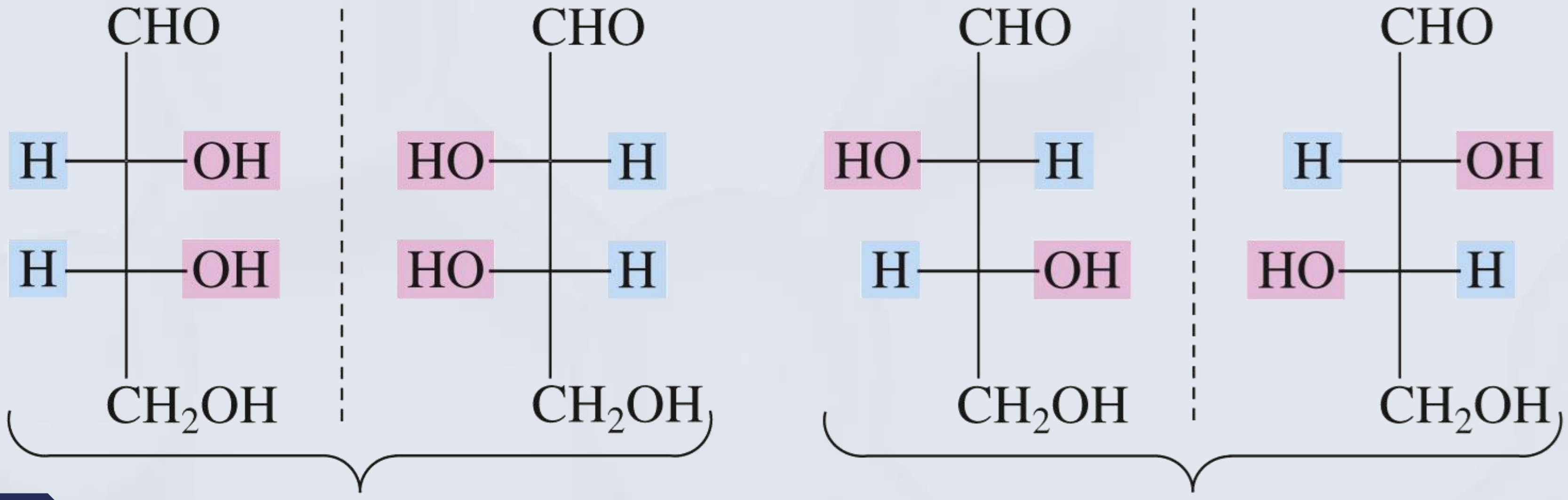
Fischer Projection Formulas

- D and L system used to designate the handedness of glyceraldehyde enantiomers (see figure below)



Fischer Projection Formulas

- We now consider Fischer projection formulas for the compound 2,3,4-trihydroxybutanal - a monosaccharide with four carbons and *two chiral centers*
- There are four stereoisomers for this compound—two pairs of enantiomers



First enantiomeric pair

Second enantiomeric pair

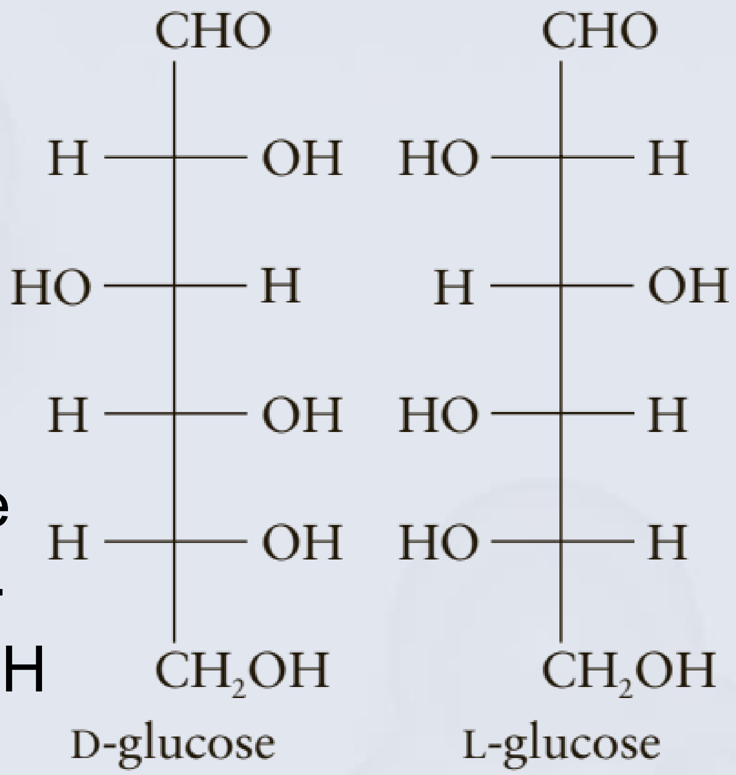
Fischer Projection Formulas

- The D,L system used to designate the handedness of glyceraldehyde enantiomers can be extended to other monosaccharides with more than one chiral center
- The carbon chain is numbered starting at the carbonyl group end of the molecule, and the highest-numbered chiral center is used to determine D or L configuration
- **Epimers:** Diastereomers whose molecules differ only in the configuration at one chiral center

Fischer Projection Formulas

The naming and numbering of carbon atom configurations follow the following convention:

- Starting with the aldehyde or ketone group, which is carbon 1 (C-1), the carbon atoms are numbered from the end of the carbon chain.
- The chiral carbon atom that is farthest from the aldehyde or ketone group determines if it is a D or L isomer.
- Glucose, an aldohexose, exists in D and L forms. The farthest chiral carbon from the aldehyde group is C-5.
- The sugar is designated “D” if the configuration of –OH at the chiral carbon is at the right side, while “L” if at the left side.

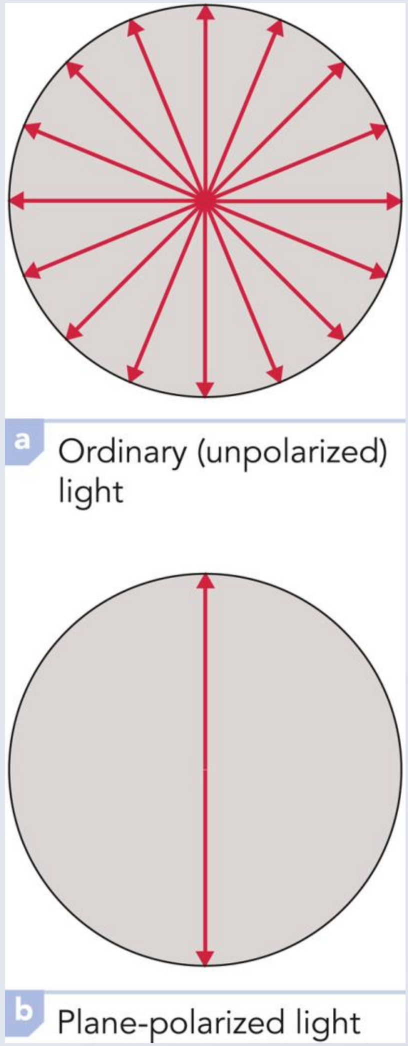


Constitutional Isomers and Diastereomers

- **Constitutional isomers** differ in most chemical and physical properties – they have different boiling and melting points.
- **Diastereomers** also differ in most chemical and physical properties – They too have different boiling and melting points.
- In contrast, nearly all the properties of a pair of enantiomers are the same
    - Two differences:
        1. Their interaction with plane polarized light
        2. Their interaction with other chiral substances

Interaction of Enantiomers with Plane-Polarized Light

- Properties of light
  - **Ordinary light** moves in all directions
  - **Plane polarized light** moves only in one direction
- Plane polarized light is rotated clockwise (to right) or counterclockwise (to left) when passed through enantiomers
- Direction and extent of rotation will depend upon the enantiomer
- Same concentration of two enantiomers rotate light to same extent but in opposite direction



Properties of Enantiomers

Dextrorotary and Levorotatory Compounds

- Enantiomers are **optically active**: Compounds that rotate plane polarized light
- **Two Types:**
    - Dextrorotatory:
        - Chiral compound that rotates light towards right (clockwise; +)
    - Levorotatory:
        - Chiral compound that rotates light towards left (counterclockwise; -)
    - **There is no correlation between D, L and +, -**
        - In D and L system you need to look at the structure
        - + and – can be determined using a polarimeter

Interactions Between Chiral Compounds

- Right- and Left-handed baseball players can’t use same glove (chiral) but can use same hat (achiral)
  - Two members of enantiomer pair (chiral) react differently with other chiral molecules
- Enantiomeric pairs have same solubility in achiral solvents like ethanol and have different solubility in chiral solvent like D-2-butanol
- Enantiomers have same boiling points, melting points and densities – all these are dependent upon intermolecular forces and chirality doesn‘t depend on them

Interactions Between Chiral Compounds

- Our body responds differently to different enantiomers:
- One may give higher rate or one may be inactive
    - Example: Body response to D form of hormone epinephrine is 20 times greater than its L isomer

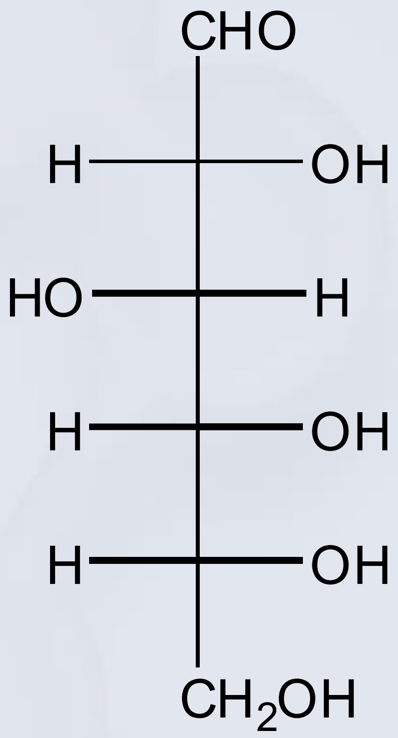
Classification of Monosaccharides

Monosaccharides

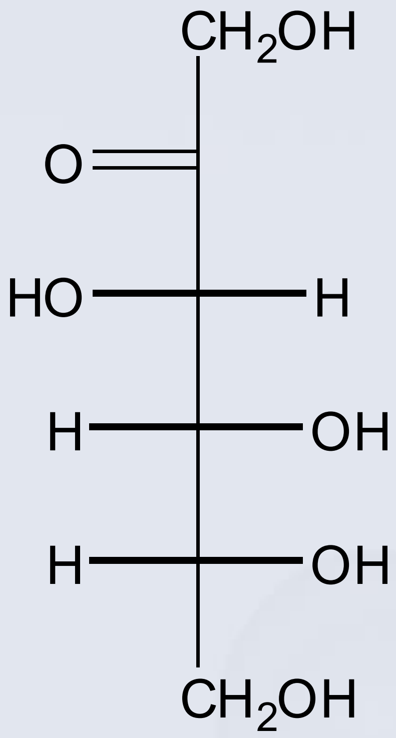
- Classification based on number of carbon atoms:
  - Triose – 3 carbon atoms
  - Tetrose – 4 carbon atoms
  - Pentoses – 5 carbon atoms
  - Hexoses – 6 carbon atoms
- Classification based on functional groups:
  - Aldoses: Monosaccharides with one aldehyde group
  - Ketoses: Monosaccharides with one ketone group
- Combined number of carbon atoms and functional group:
  - Example: Aldohexose: Monosaccharide with aldehyde group and 6 C atoms

Most Common Monosaccharides

- Example:
  - Aldohexose: Monosaccharide with aldehyde group and 6 C atoms – **D-glucose**
  - Ketohexose: Monosaccharide with ketone group and 6 C atoms – **D-fructose**

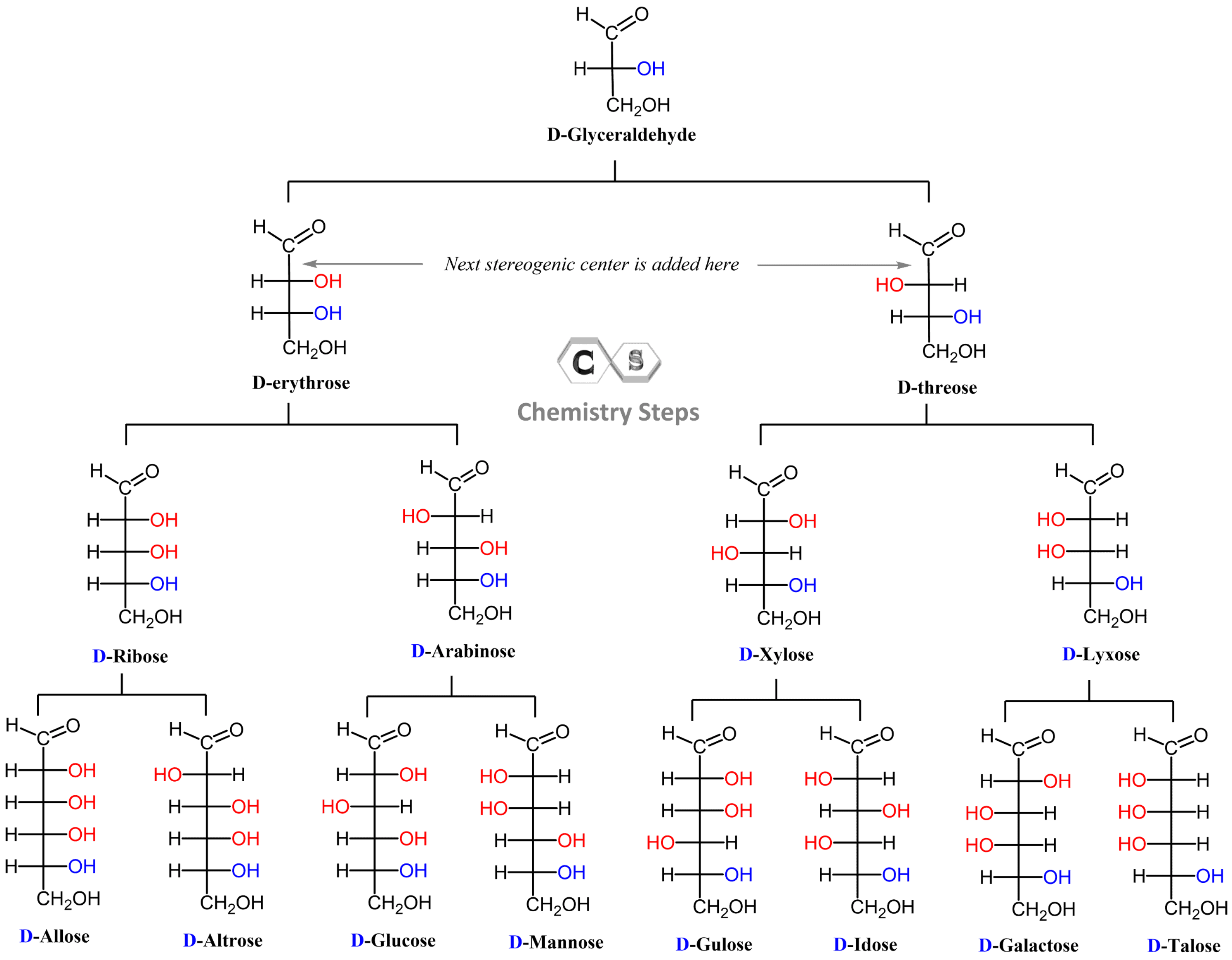


D-Glucose (aldohexose)



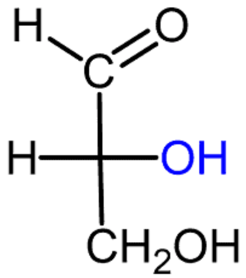
D-Fructose (ketohexose)

The family of D-aldoses

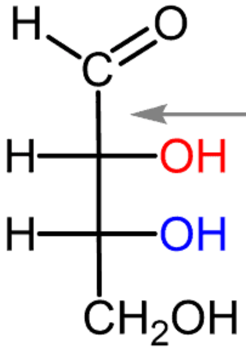


Each time a new stereogenic center is added just below the carbonyl group generating two additional stereoisomers.

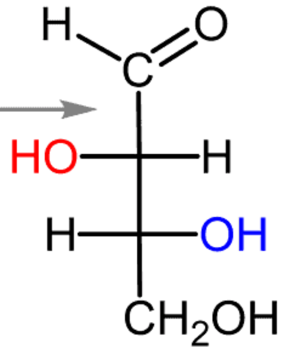
The family of D-aldoses

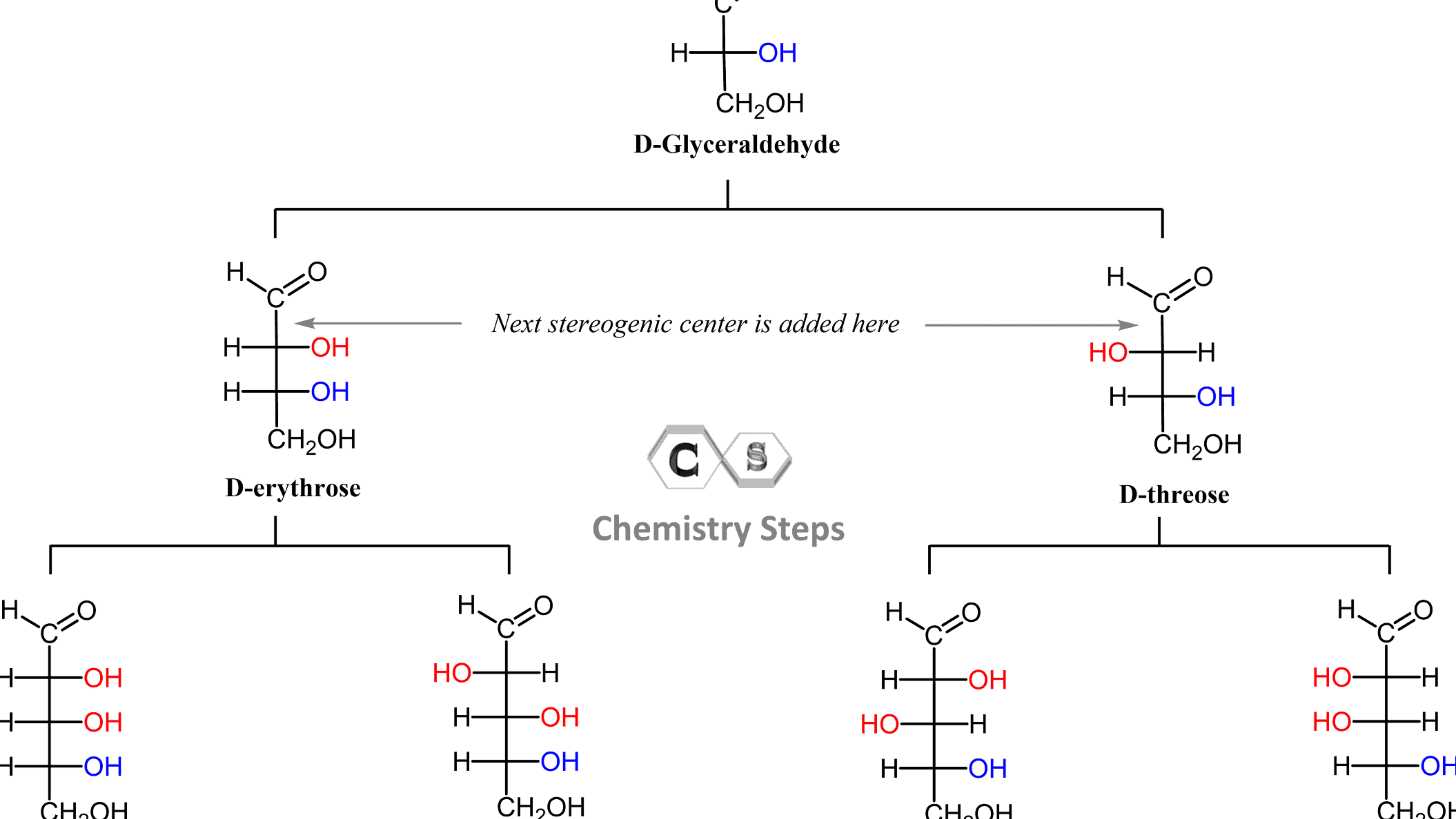


D-Glyceraldehyde

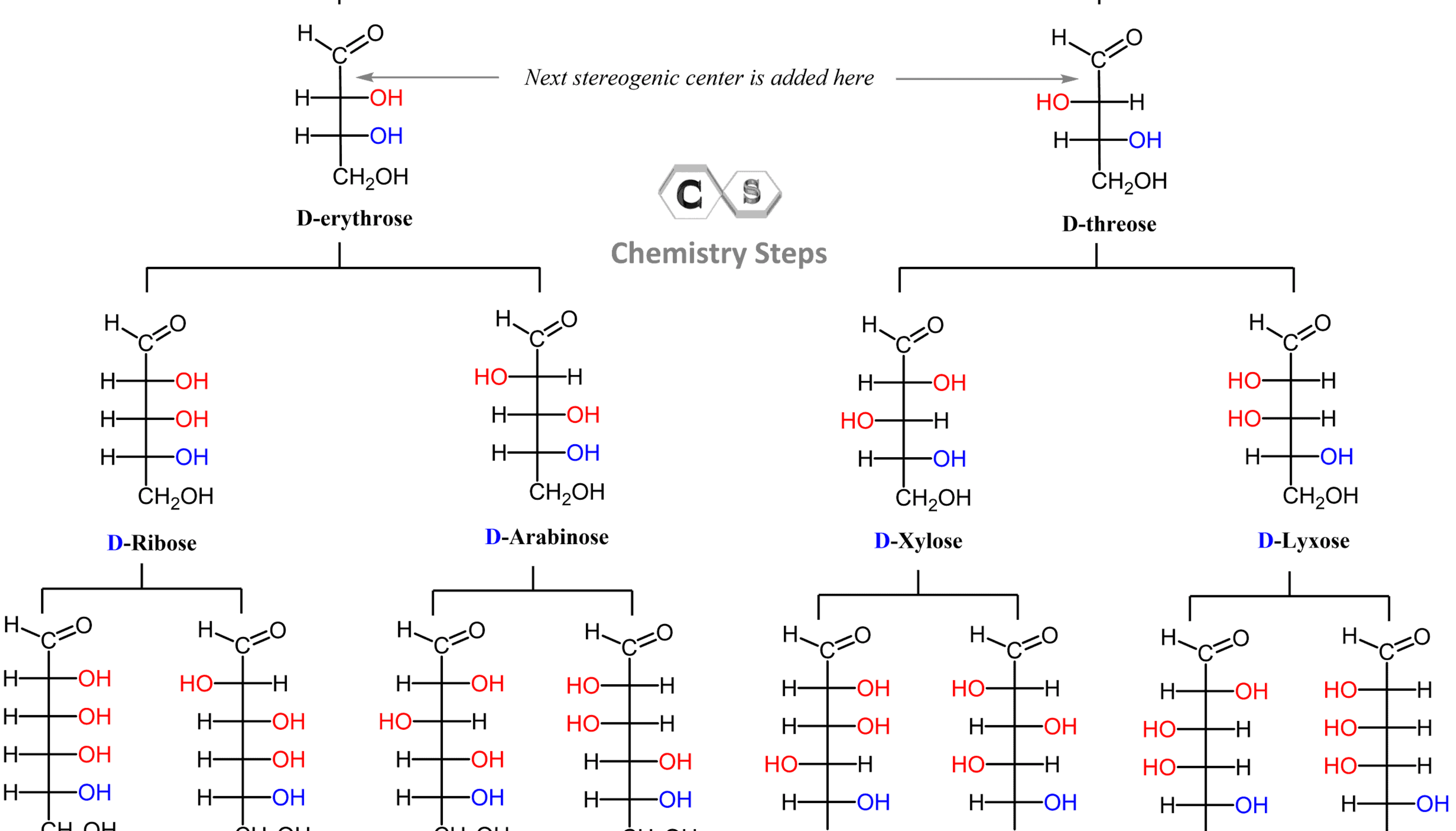


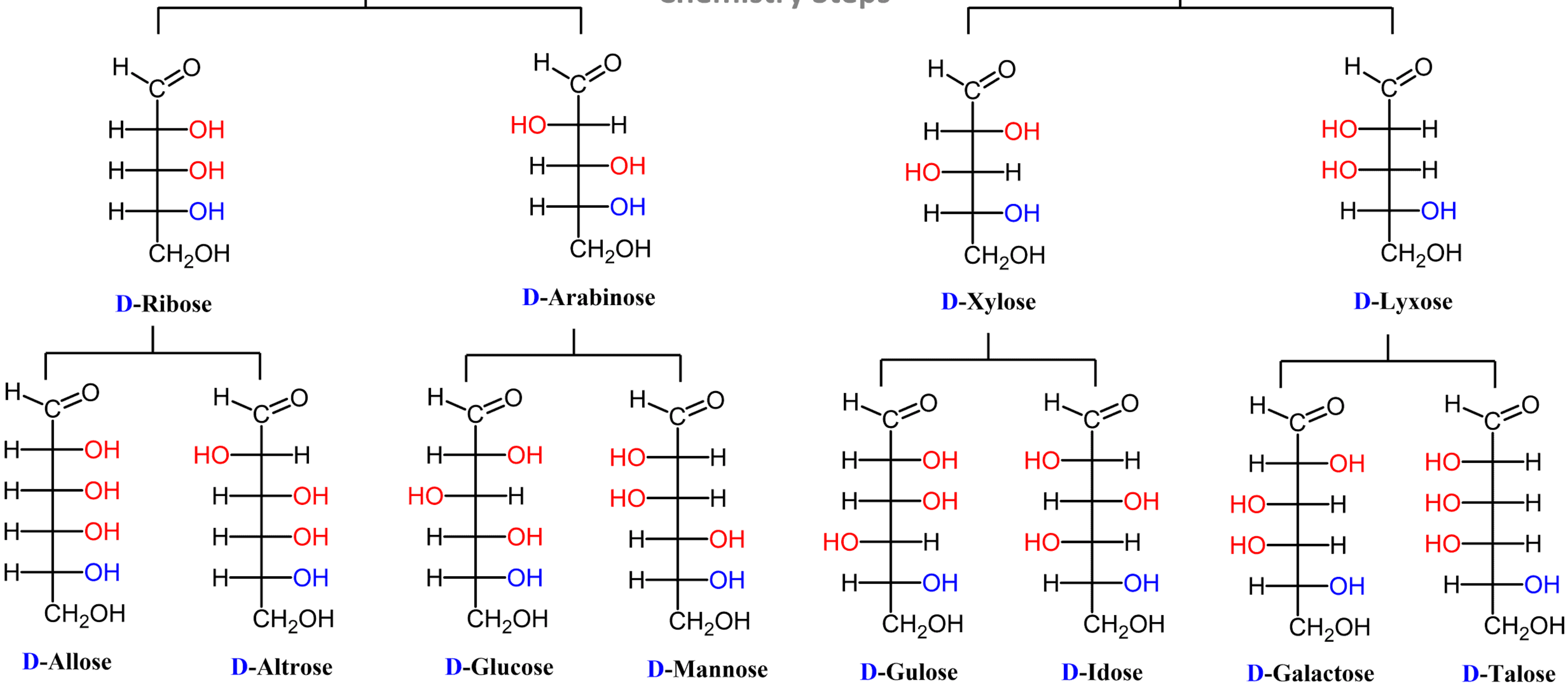
Next stereogenic center is added here





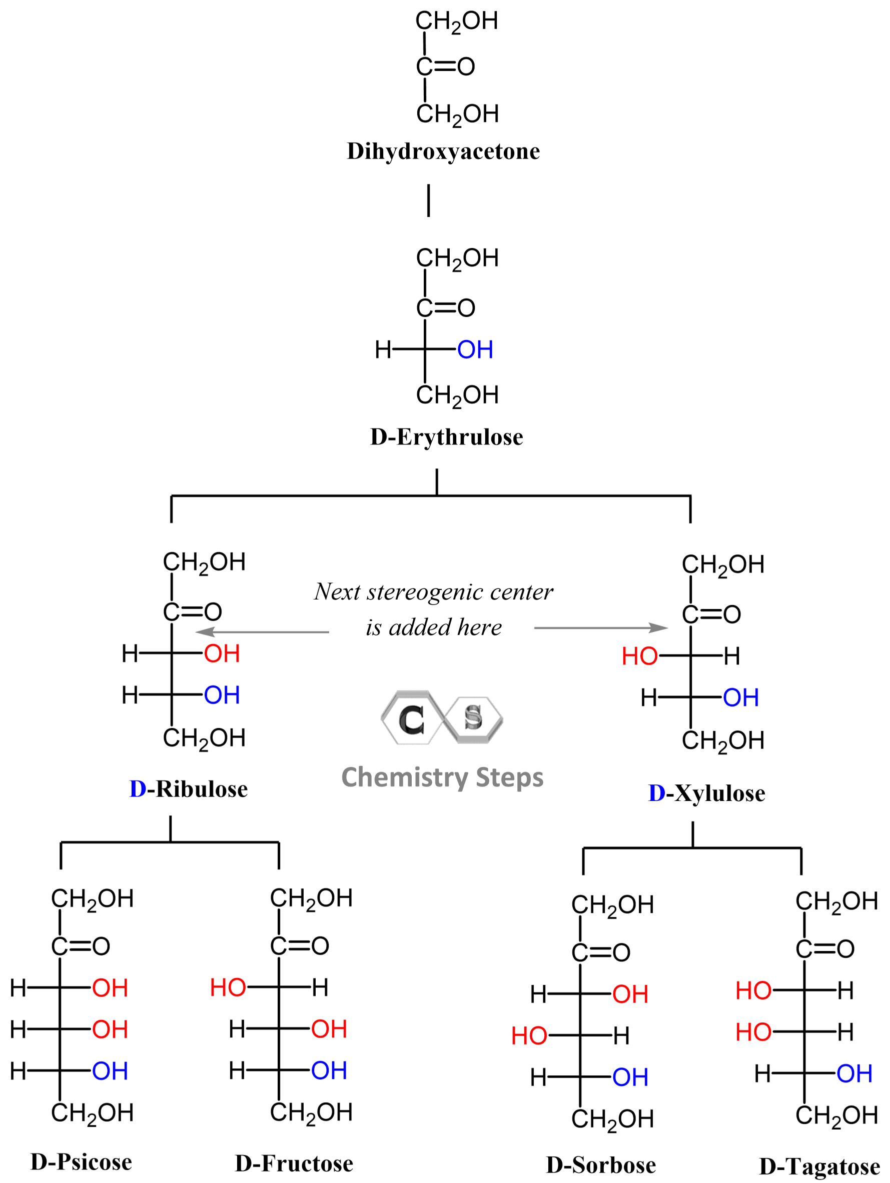
Next stereogenic center is added here


Next stereogenic center is added here
D-erythrose
D-threose
D-Ribose
D-Arabinose
D-Xylose
D-Lyxose
H
C
O
OH
HO
CH_2OH



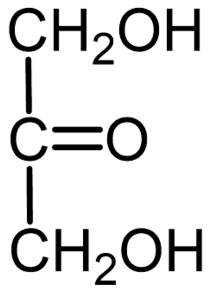
Each time a new stereogenic center is added just below the carbonyl group generating two additional stereoisomers.

The family of D-ketoses

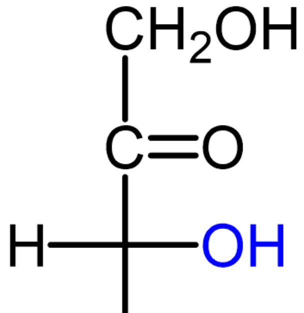


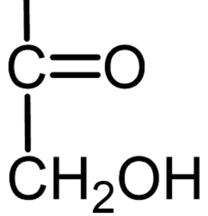
Each chiral center is added below the carbonyl group generating two additional stereoisomers.

The family of D-ketoses

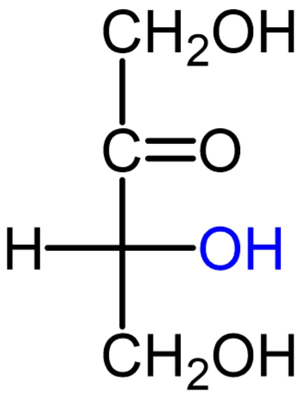


Dihydroxyacetone

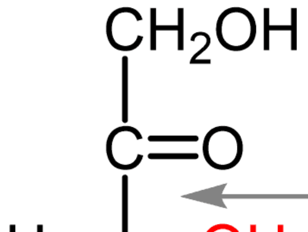




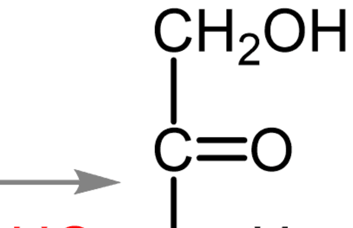
Dihydroxyacetone

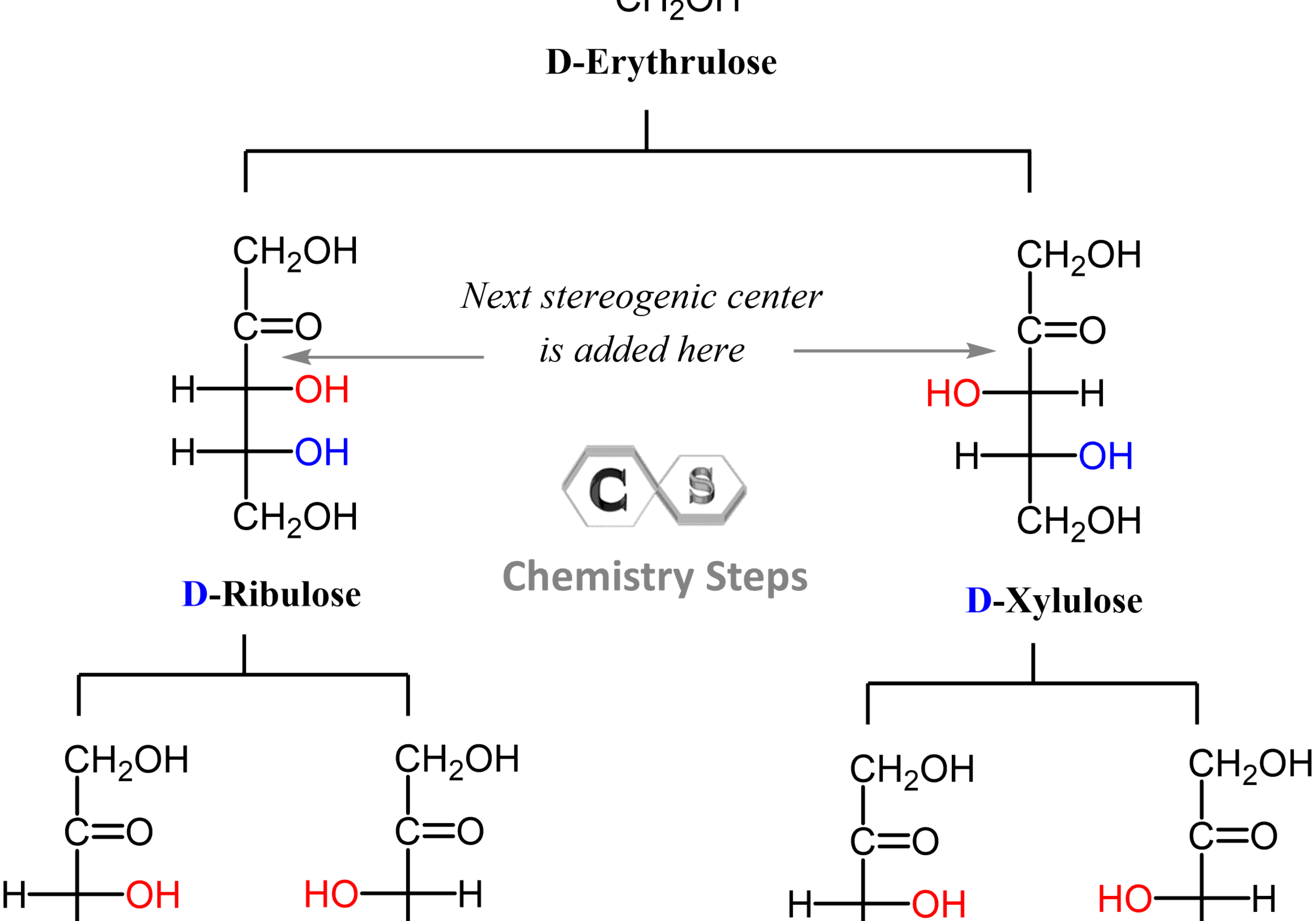


D-Erythrulose



Next stereogenic center is added here



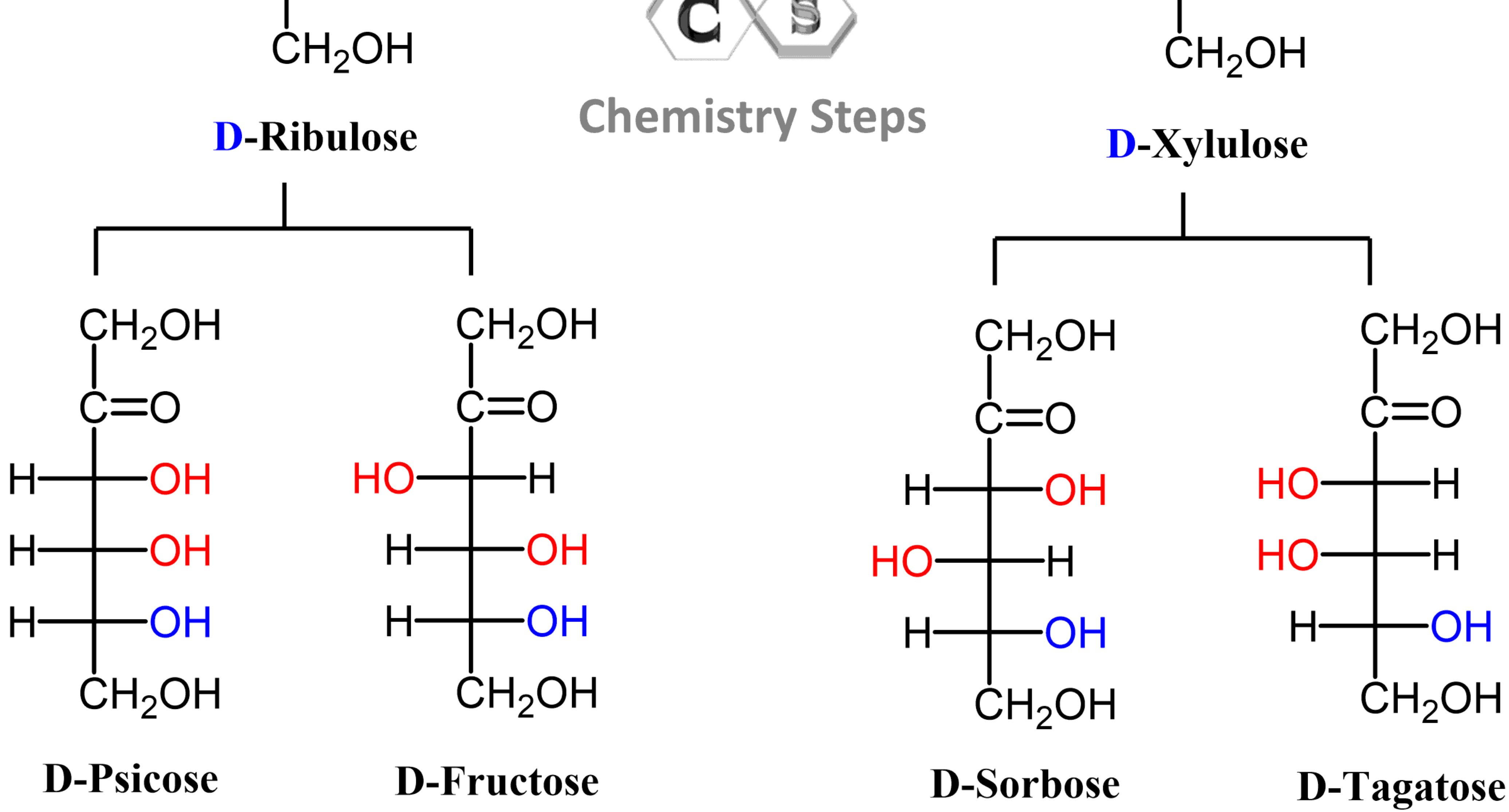


D-Erythrulose

Next stereogenic center is added here

D-Ribulose

D-Xylulose



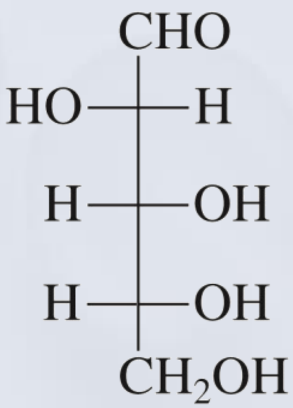
Each chiral center is added below the carbonyl group generating two additional stereoisomers.

Classification of Monosaccharides

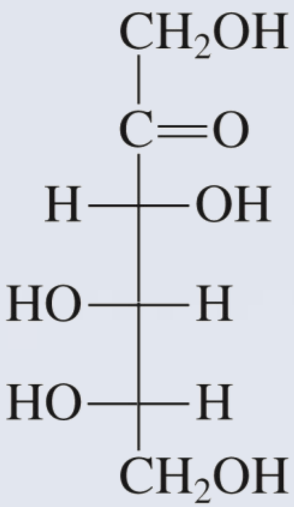
Practice Exercise

Classify each of the following monosaccharides according to both the number of carbon atoms and the type of carbonyl group present.

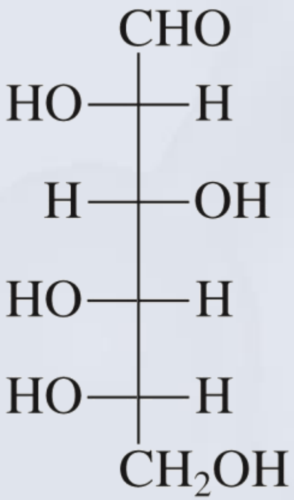
a.



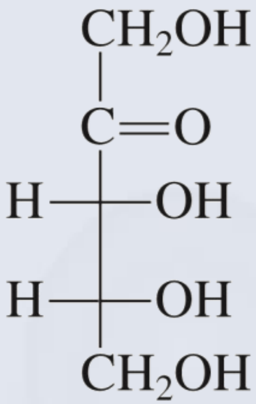
b.



c.



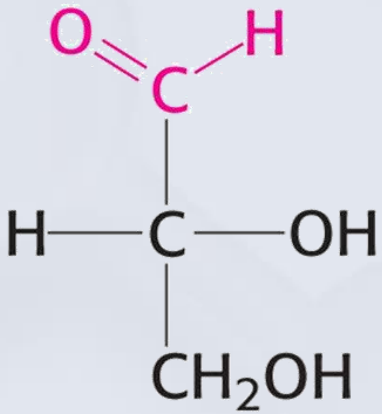
d.



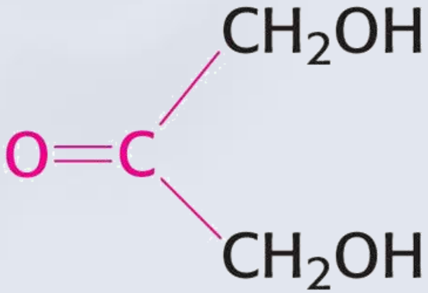
Biochemically Important Monosaccharides

D-Glyceraldehyde and Dihydroxyacetone

- The simplest monosaccharides
- One of the intermediates of glycolytic pathway- a pathway of reactions where glucose is converted into two molecules of pyruvate).



D-Glyceraldehyde
(an aldose)

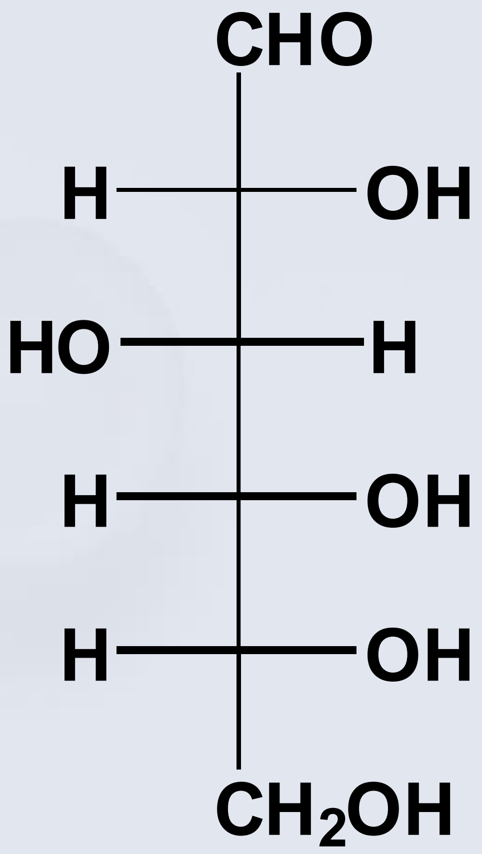


Dihydroxyacetone
(a ketose)

Biochemically Important Monosaccharides

Glucose

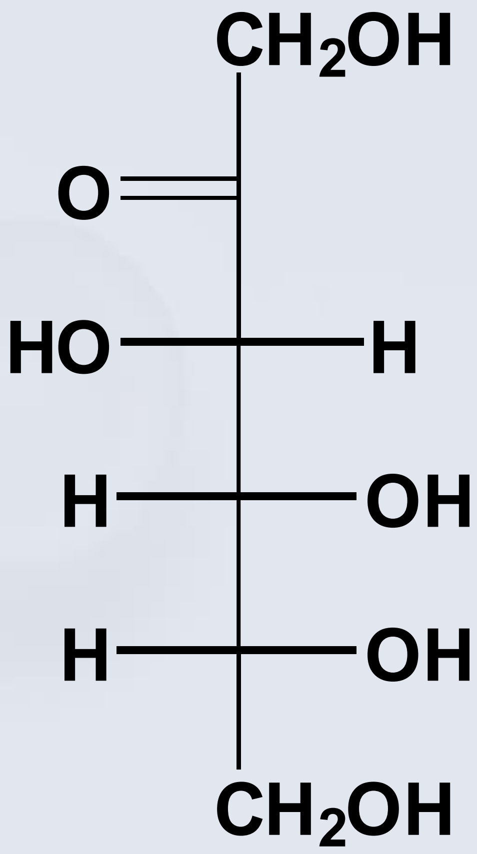
1. Most abundant in nature
2. Most important from a human nutritional standpoint.
3. 20 - 30% by mass in ripe fruits
4. Also known as dextrose (optically active D-glucose rotates plane-polarize light to the right)
5. Blood sugar (70 - 100 mg/100 mL of blood)
6. Six-membered cyclic form



D-Glucose (aldohexose)

Fructose

1. Ketohexose
2. Sweetest tasting of all sugars
3. Found in sweet fruits, honey, and corn syrup (HFCS)
4. Five-membered cyclic form

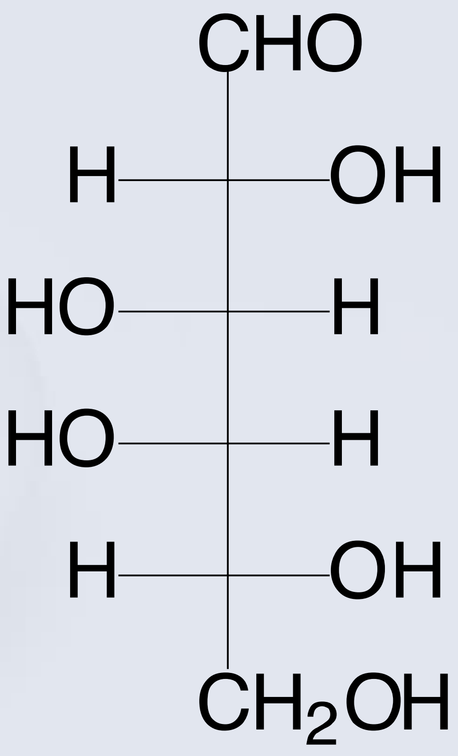


D-Fructose (ketohexose)

Biochemically Important Monosaccharides

Galactose

1. Milk sugar
2. Synthesized from glucose in mammary glands for use in the production of lactose, a disaccharide
3. Also called brain sugar – part of glycoprotein (protein-carbohydrate compounds) in brain and nerve tissue
4. Component in the chemical markers that distinguish blood types
5. Six-membered cyclic form



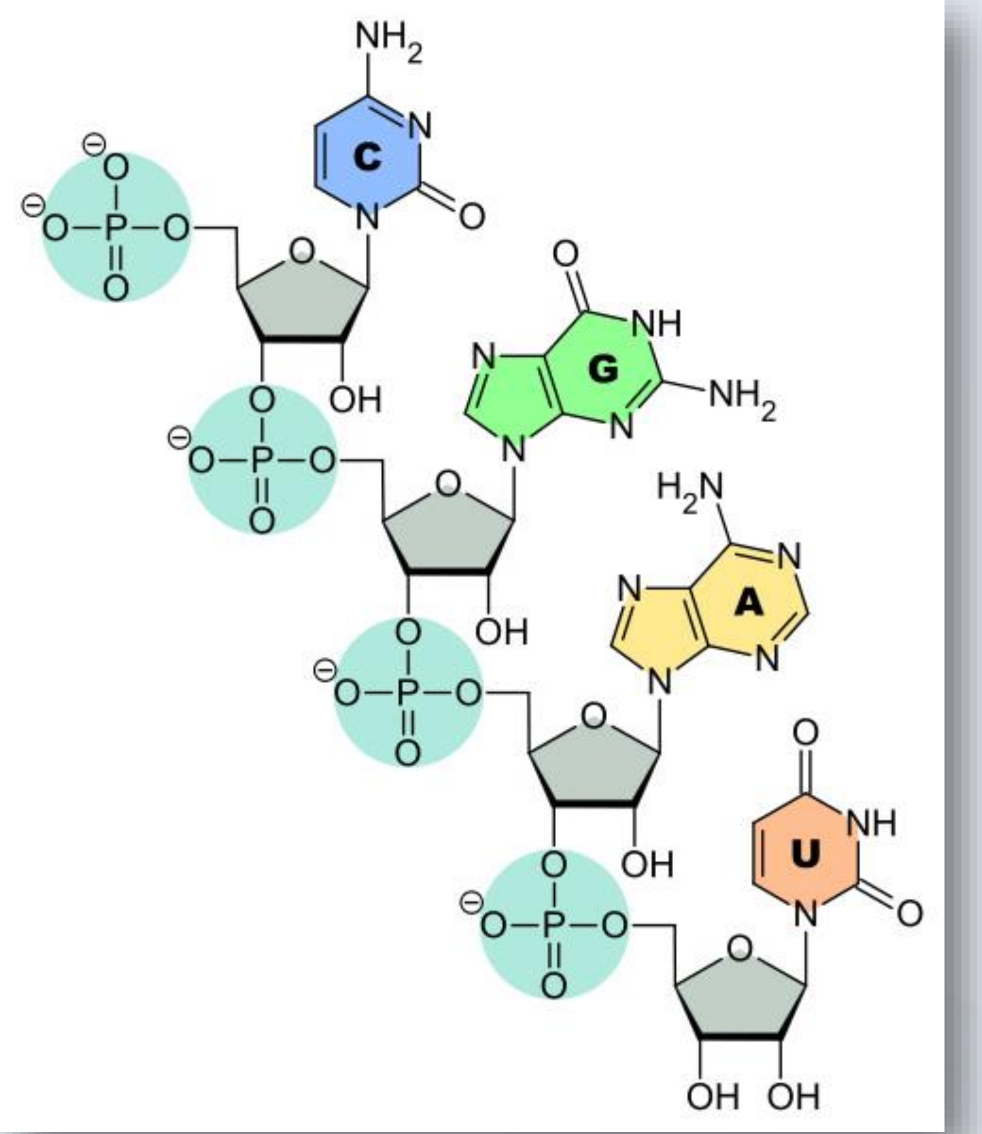
D-Galactose

(aldohexose)

Biochemically Important Monosaccharides

Ribose

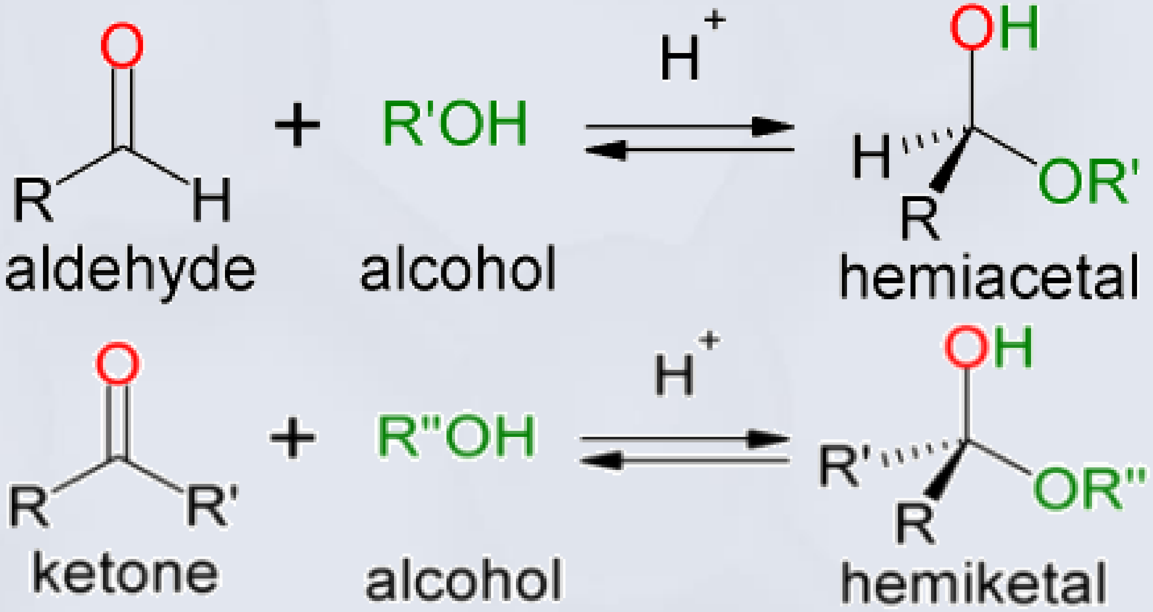
1. Component of ribonucleic acids (RNAs) and adenosine triphosphate (ATP)
2. Five-membered cyclic form



Cyclic Forms of Monosaccharides

Formation of Cyclic Structures

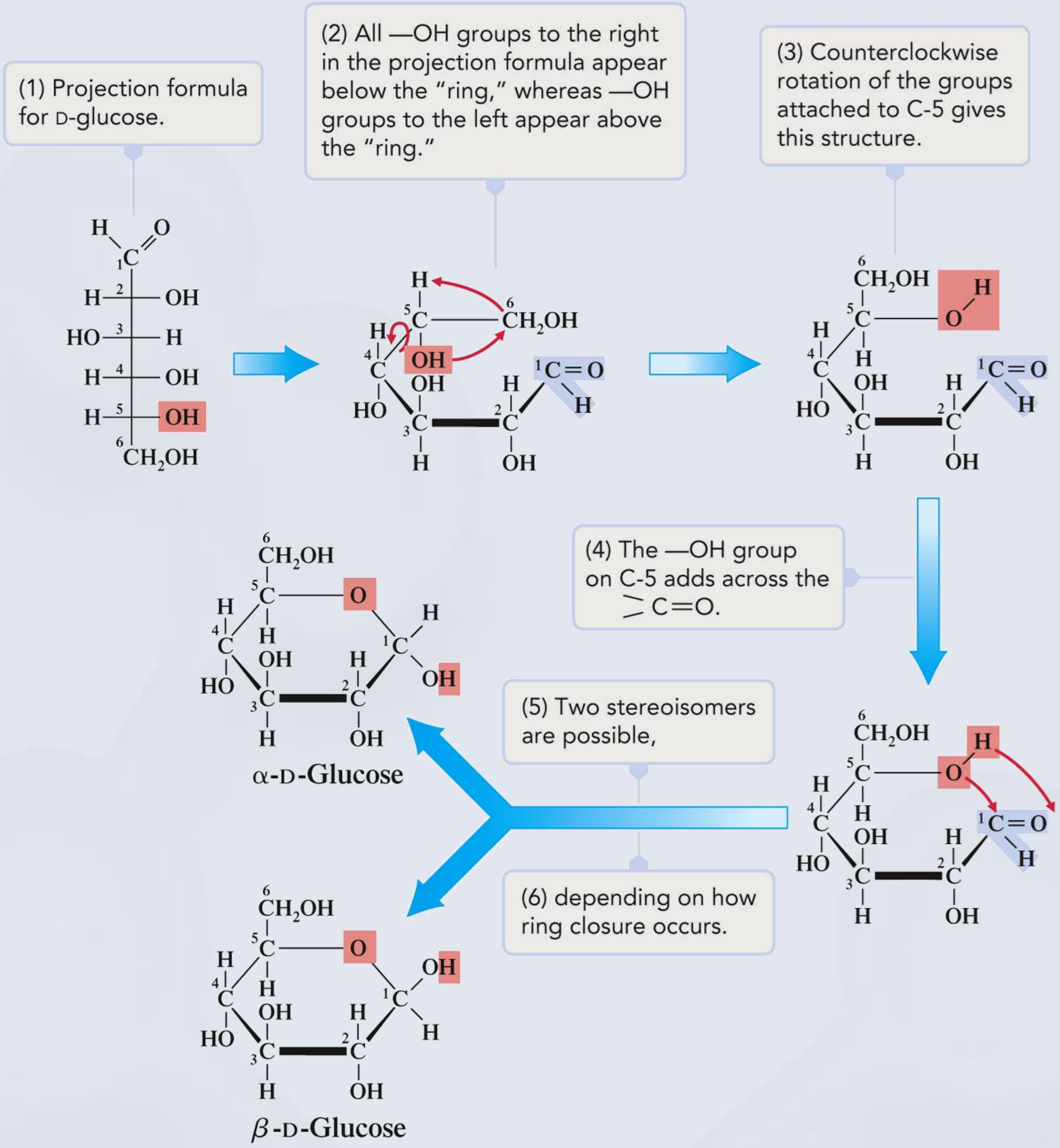
Cyclic formation results from the intramolecular reaction between the carbonyl group (aldose) and a hydroxyl group to form **hemiacetal** and **hemiketal** results from the ability of ketone (ketose) to react with hydroxyl group.



Cyclic Forms of Monosaccharides

Cyclic Hemiacetal Forms of Monosaccharides

- Dominant form of monosaccharides with 5 or more C atoms is cyclic
- Cyclic forms are in equilibrium with open chain form
- Cyclic forms are formed by the reaction of carbonyl group (C=O) with hydroxyl (-OH) group on carbon 5



(1) Projection formula for D-glucose.

(2) All —OH groups to the right in the projection formula appear below the "ring," whereas —OH groups to the left appear above the "ring."

(3) Counterclockwise rotation of the groups attached to C-5 gives this structure.

(4) The —OH group on C-5 adds across the >C=O.

(5) Two stereoisomers are possible,

(6) depending on how ring closure occurs.

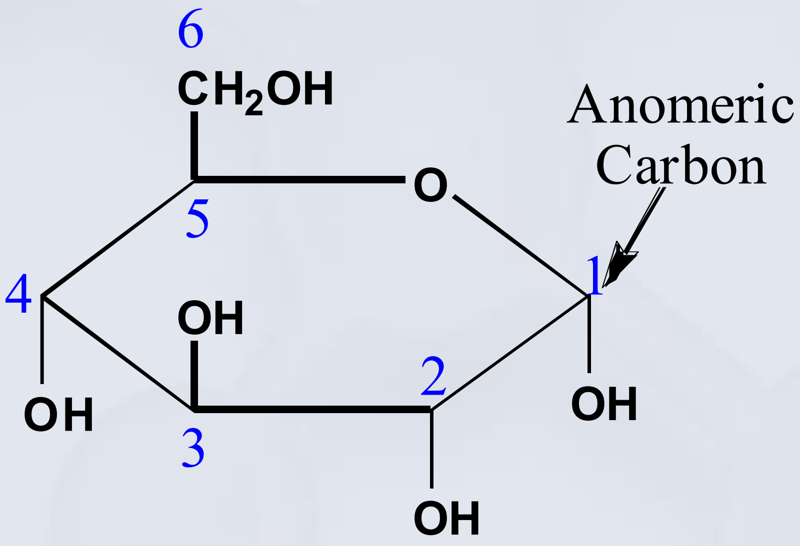
α-D-Glucose

β-D-Glucose

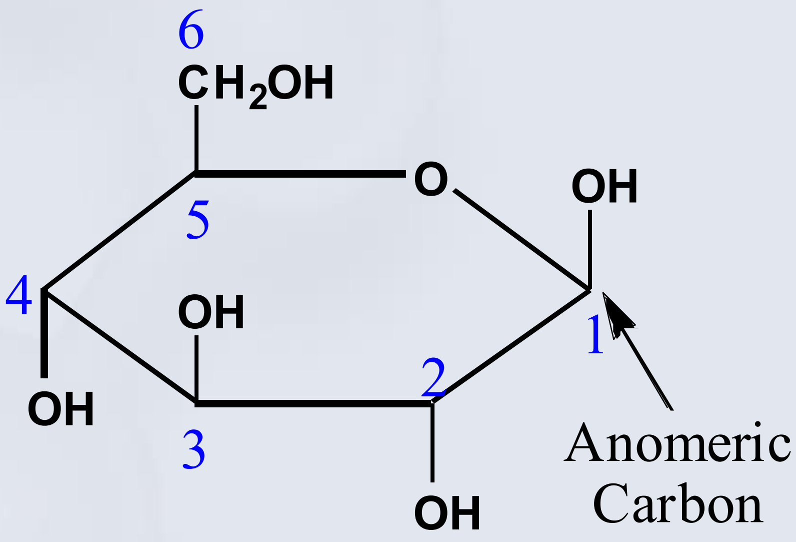
Cyclic Hemiacetal Forms of Monosaccharides

2 forms of D-glucose:

- Alpha-form: -OH of C1 and CH_2OH of C5 are on opposite sides
- Beta-form: -OH of C1 and CH_2OH of C5 are on same sides



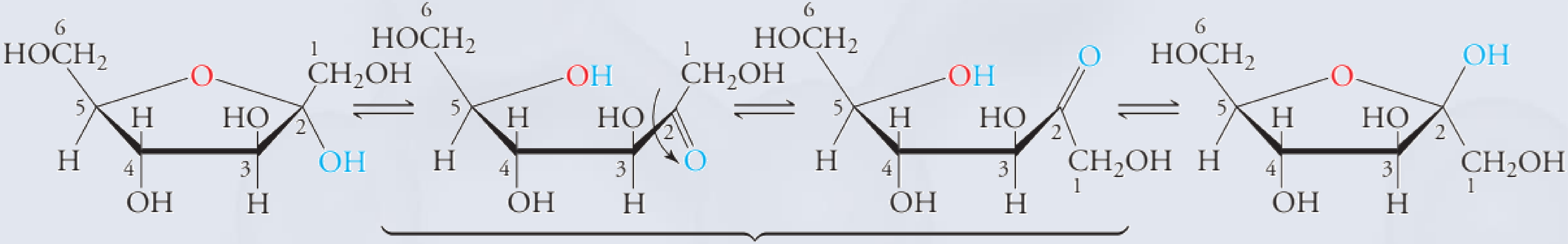
α-D-Glucose



β-D-Glucose

Cyclic Hemiacetal Forms of Monosaccharides

- **Anomers**: Cyclic monosaccharides that differ only in the position of the substituents on the anomeric carbon atom.
- An **anomeric carbon** is a carbon atom in a sugar molecule that becomes a stereogenic center when the sugar cyclizes
- The anomers of D-fructose are shown below:



α-D-Fructofuranose

Open form of D-Fructose

β-D-Fructofuranose

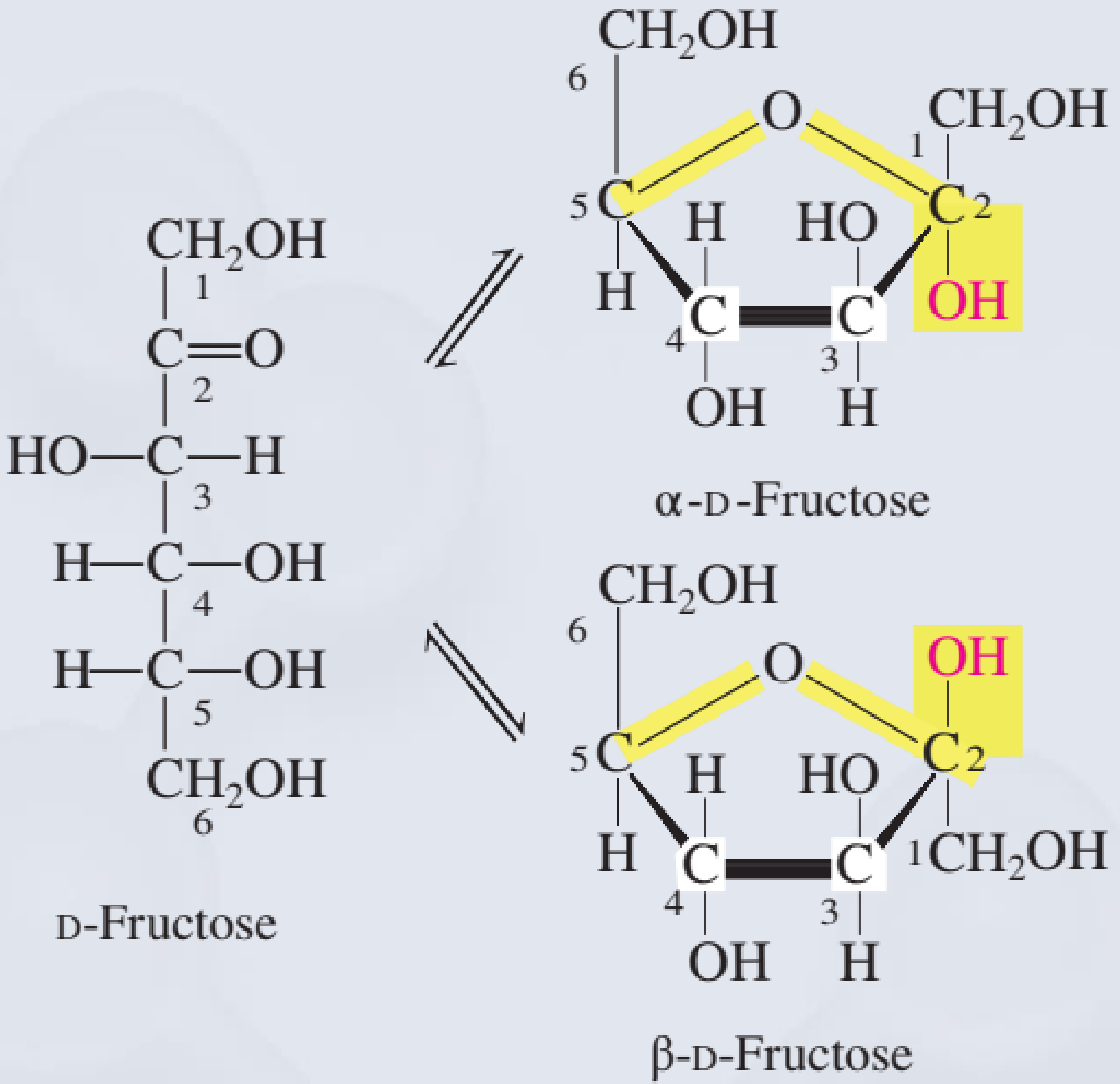
Formation of Cyclic Structures

- In an aqueous solution of D-glucose, a **dynamic equilibrium** exists among the α, β, and open-chain forms, and there is **continual inter-conversion** among them.
- Less than 0.01% of the molecules are in the open-chain state, and ~63% of the molecules are β-D-glucose, 37% are α-D-glucose, when equilibrium is reached.
- While D-fructose and D-ribose both make five-membered rings, galactose, like glucose, produces a six-membered ring.
- Other ketoses with enough carbon atoms, such as fructose, can also cyclize.

Cyclic Forms of Monosaccharides

Mutarotation

- In solutions, the cyclic hemiacetal groups of α and β anomers undergo continuous change.
- The process of converting back and forth from an α anomer to the open form to the β anomer is called **mutarotation**.



D-Fructose

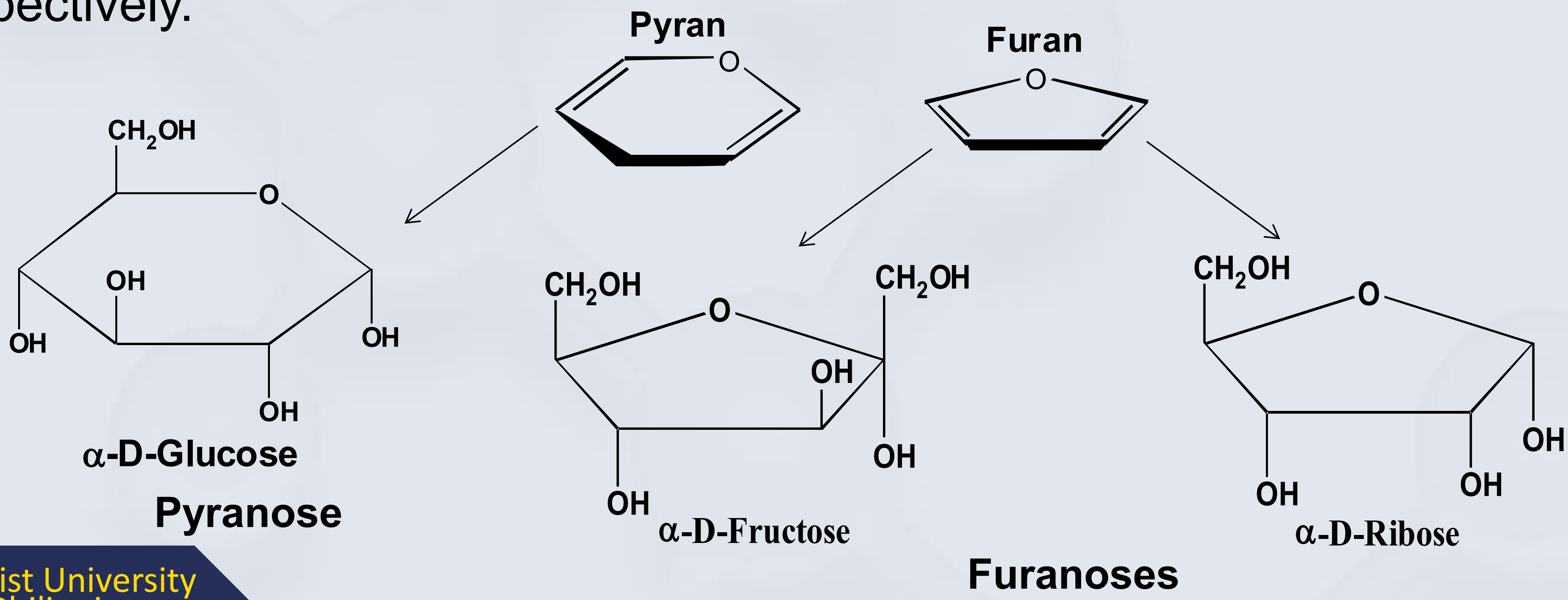
α-D-Fructose

β-D-Fructose

Cyclic Forms of Monosaccharides

Pyranose and Furanose

- A cyclic monosaccharide containing a six-atom ring is called a ***pyranose***, and one containing a five-atom ring is called ***furanose*** because their ring structures resemble the ring structures in the cyclic ethers pyran and furan respectively.



α-D-Glucose

Pyranose

α-D-Fructose

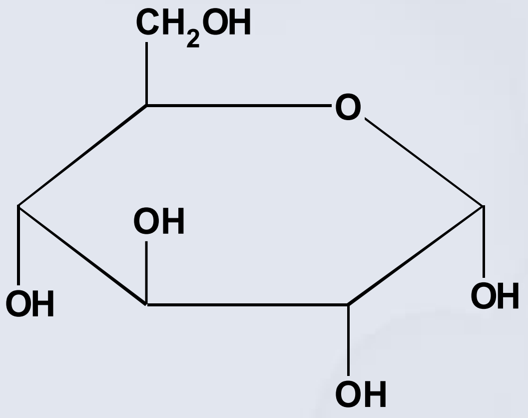
α-D-Ribose

Furanoses

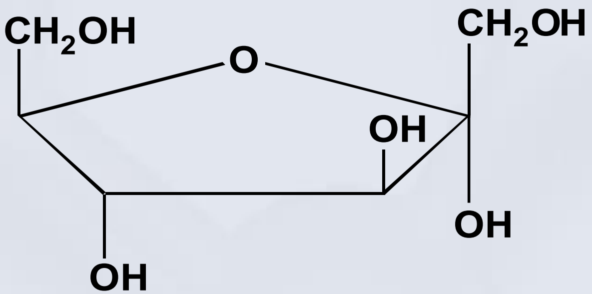
Haworth Projection Formulas

Haworth Projection

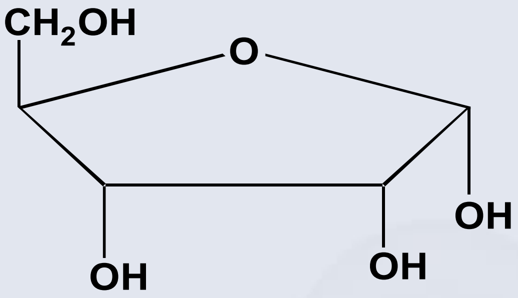
- A **Haworth projection formula** is a two-dimensional structural notation that specifies the three-dimensional structure of a cyclic form of a monosaccharide.



α-D-Glucose



α-D-Fructose

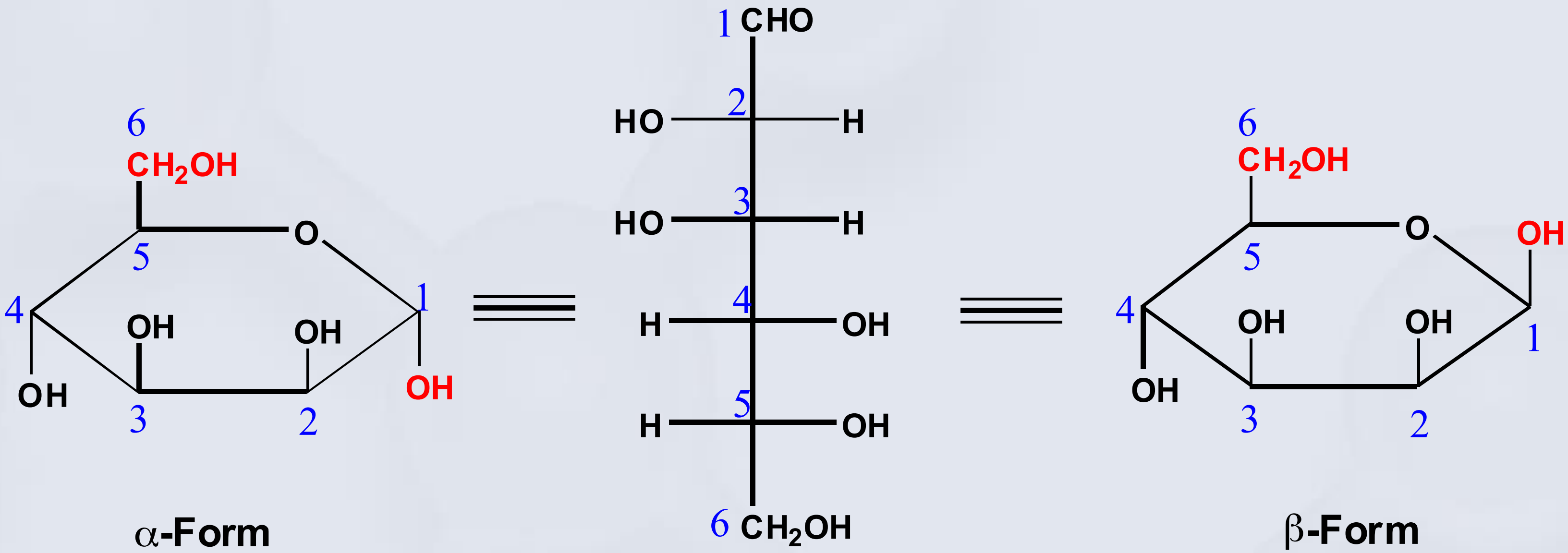


α-D-Ribose

Haworth Projection Formulas

Alpha (α-) and Beta (β-) Configuration

- Alpha or Beta configuration is determined by the position of the –OH group on C1 relative to the CH_2OH group that determines D or L series.
- In an **Alpha** configuration, the two groups point in opposite directions.
- In a **Beta** configuration, both of these groups point in the same direction



α-Form

D-Mannose

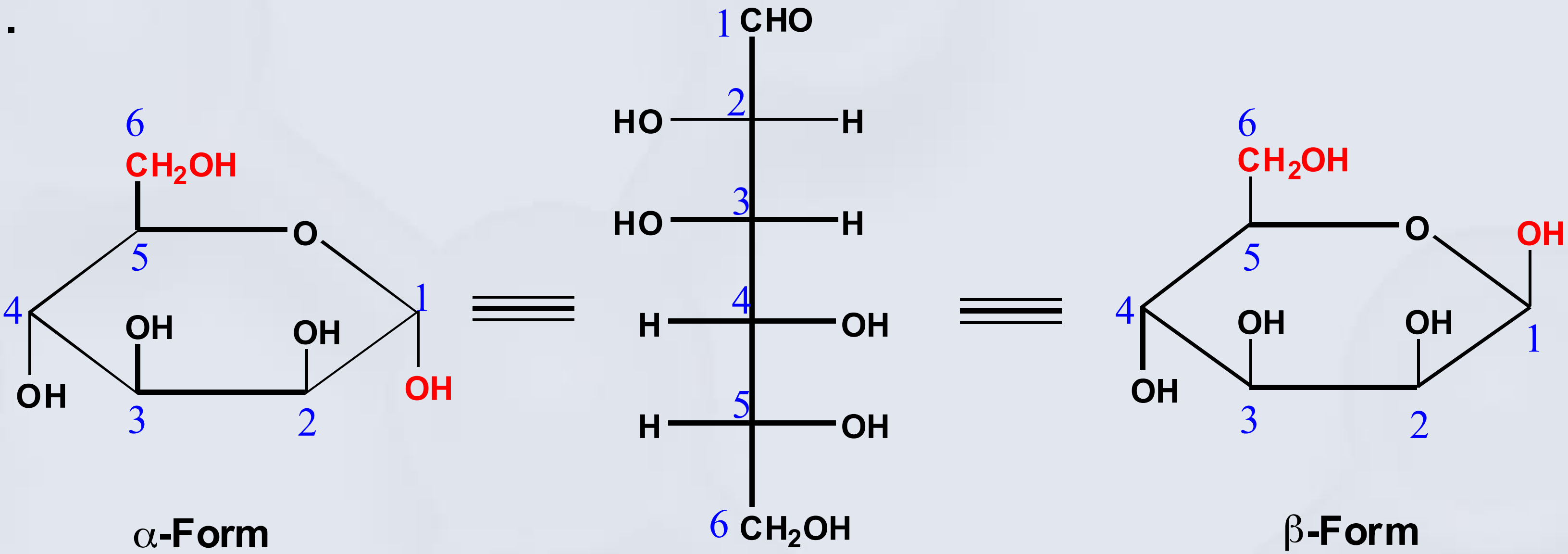
β-Form

Haworth Projection Formulas

–OH Group Position

- The specific identity of a monosaccharide is determined by the positioning of the other –OH groups in the Haworth projection formula.
- Any –OH group at a chiral center that is to the **right** in a Fischer projection formula **points down** in the Haworth projection formula and any –OH group to the **left** in a Fischer projection formula **points up** in the Haworth projection formula.

In summary:
Right = Down
Left = Up



α-Form

D-Mannose

β-Form

Reactions of Monosaccharides

- Some important reactions of monosaccharides:
  - Oxidation to acidic sugars
  - Reduction to sugar alcohols
  - Glycoside formation*
  - Phosphate ester formation*
  - Amino sugar formation*
- These reactions will be considered with respect to glucose.
- Other aldoses, as well as ketoses, undergo similar reactions.

Reactions of Monosaccharides

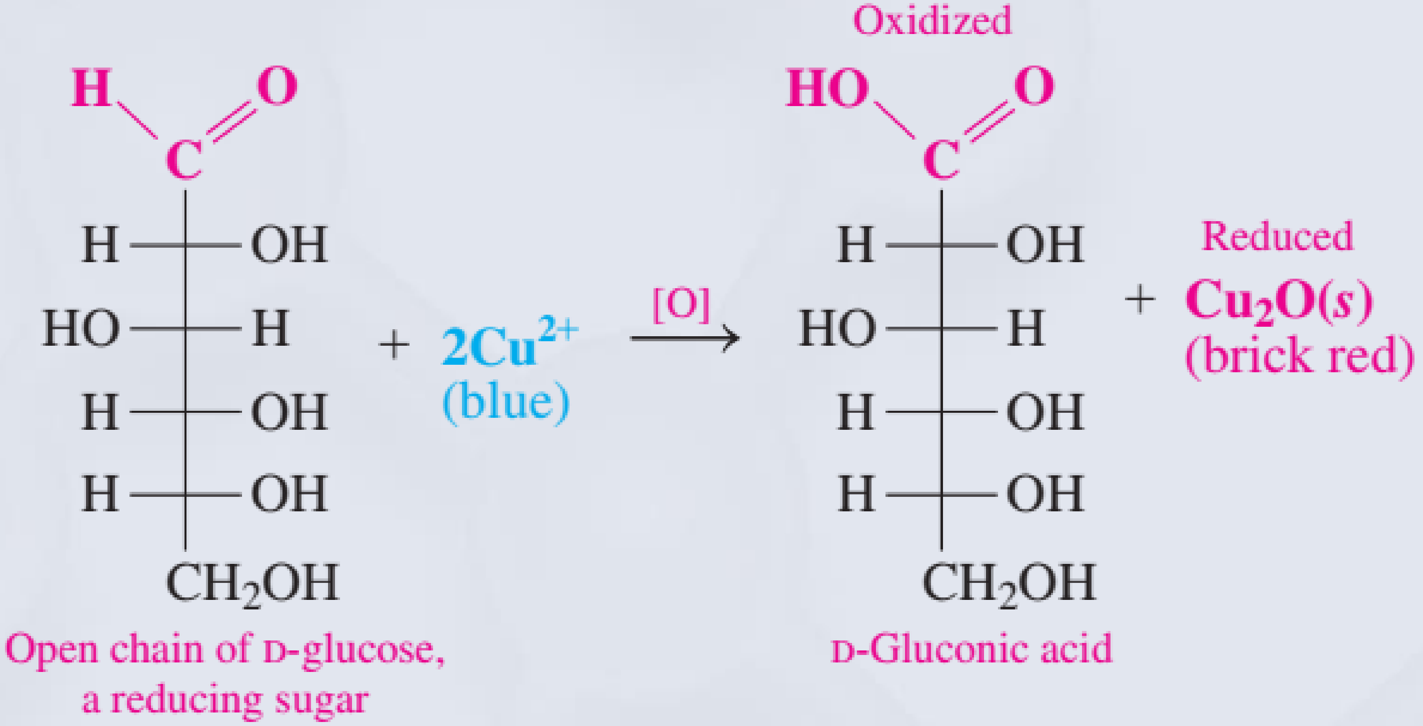
Oxidation

- **Oxidation to acidic sugars**: The redox chemistry of monosaccharides is closely linked to the alcohol and aldehyde functional groups present in them.
- Oxidation can yield three different types of acidic sugars depending on the type of oxidizing agent used:
  - **Weak oxidizing agents** oxidize the aldehyde end to give an **aldonic acid**
  - **Strong oxidizing agents** can oxidize both ends at the same time to produce a dicarboxylic acid known as **aldaric acids**
  - **Enzymes** can oxidize the primary alcohol end without oxidation of the aldehyde group to produce an **alduronic acid**

Reactions of Monosaccharides

Oxidation

- **Weak oxidizing agents** such as Tollens and Benedict's solutions oxidize the aldehyde end to give an **aldonic acid**
  - e.g., glucose to gluconic acid

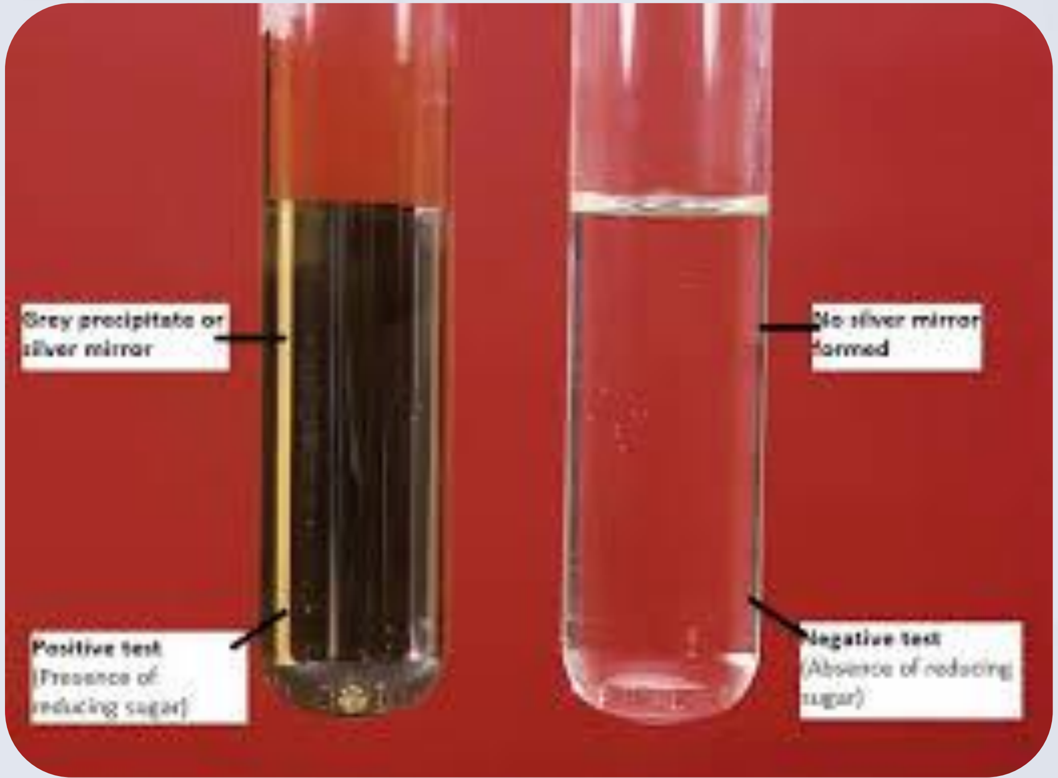


Open chain of D-glucose, a reducing sugar

D-Gluconic acid

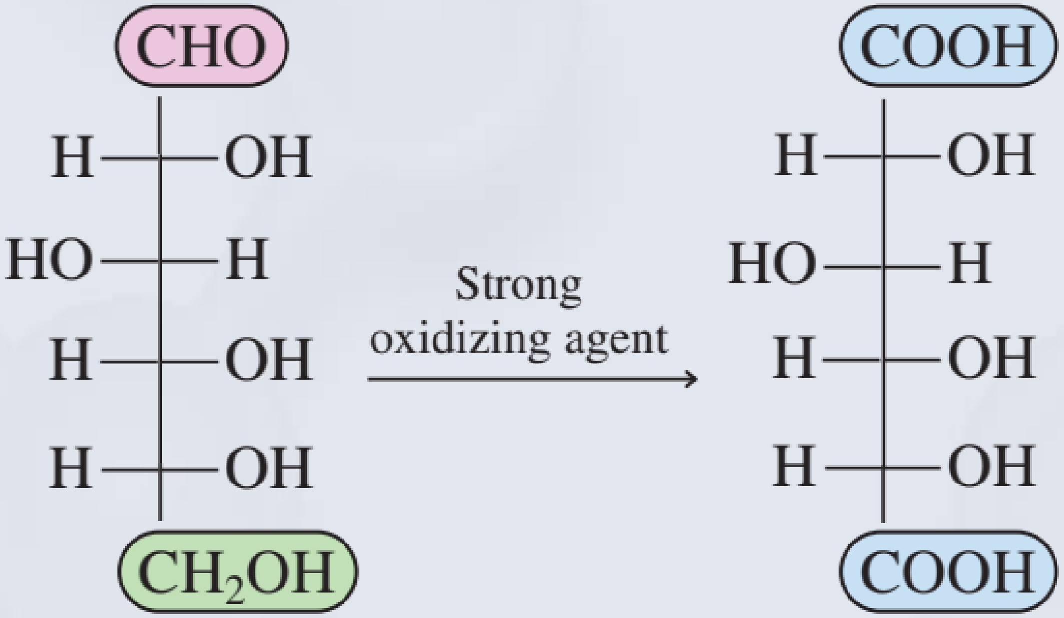
Reactions of Monosaccharides

Oxidation



Oxidation

- **Strong oxidizing agents** such as nitric acid can oxidize both ends of a monosaccharide at the same time (the carbonyl group and the terminal primary alcohol group) to produce a dicarboxylic acid. **Aldaric acids** are a class of polyhydroxy dicarboxylic acids.
  - e.g., glucose to glucaric acid

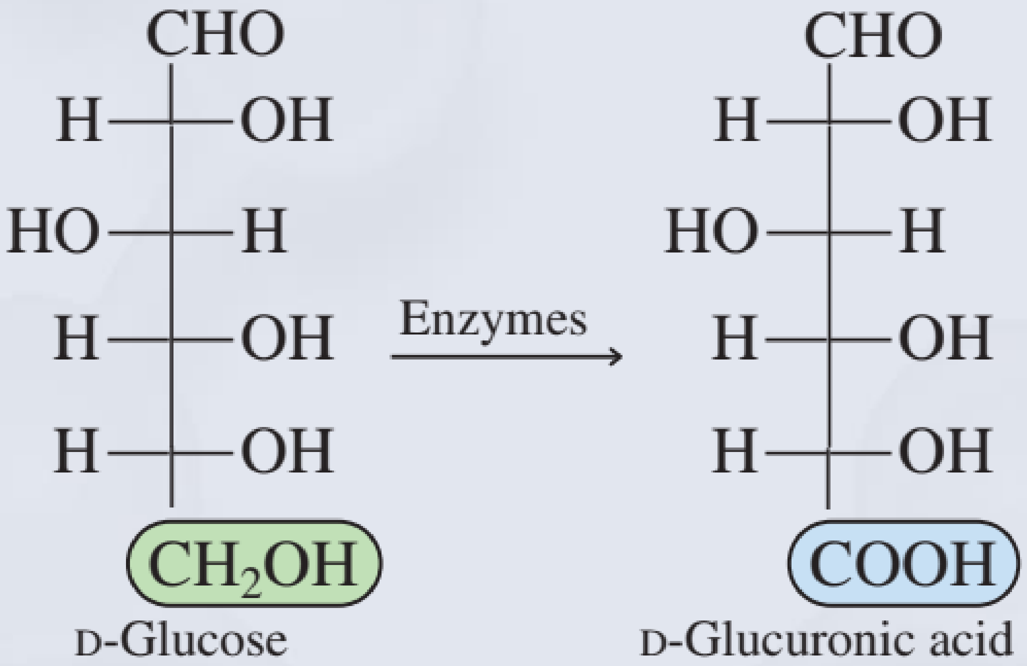


D-Glucose

D-Glucaric acid

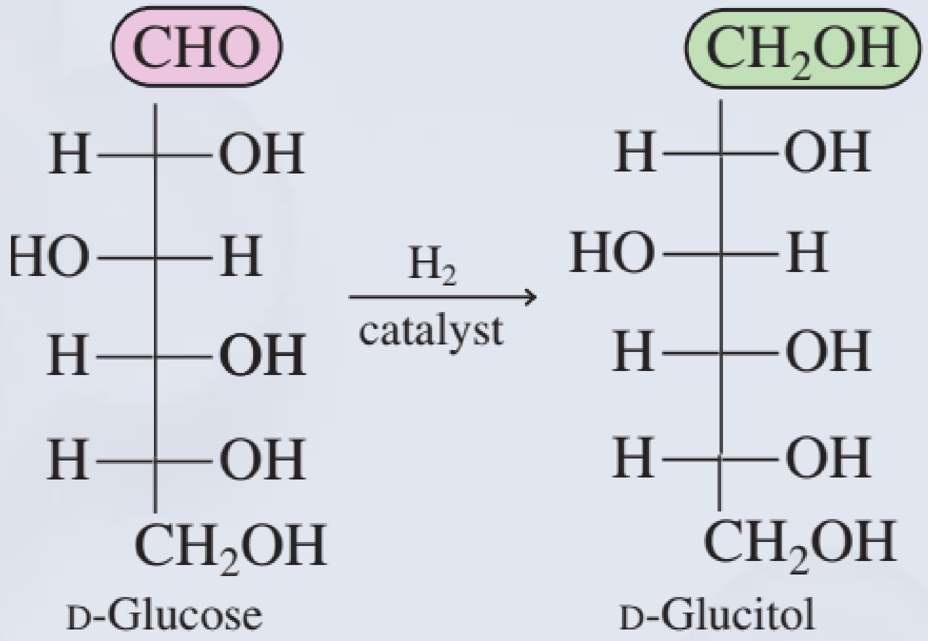
Oxidation

- In biochemical systems, **enzymes** can oxidize the primary alcohol end of an aldose such as glucose, without oxidation of the aldehyde group, to produce an **alduronic acid**.
  - e.g., glucose to glucuronic acid



Reduction

- Reduction to sugar alcohols: The carbonyl group in a monosaccharide (either an aldose or a ketose) is reduced to a hydroxyl group using hydrogen as the reducing agent.
  - The product is the corresponding polyhydroxy alcohol - *sugar alcohol.*
  - **Sorbitol** - used as moisturizing agents in foods and cosmetics and as a sweetening agent in chewing gum

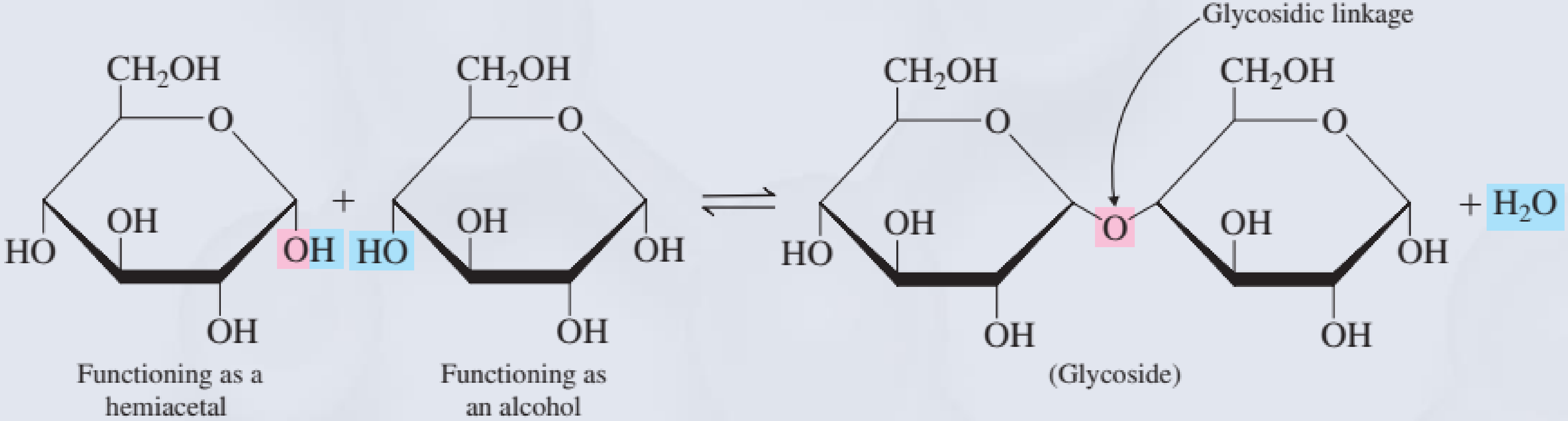


Disaccharides

- Two monosaccharides can react to form a disaccharide
- One monosaccharide act as a hemiacetal and other as alcohol and the resulting ether bond is a **glycosidic linkage**.

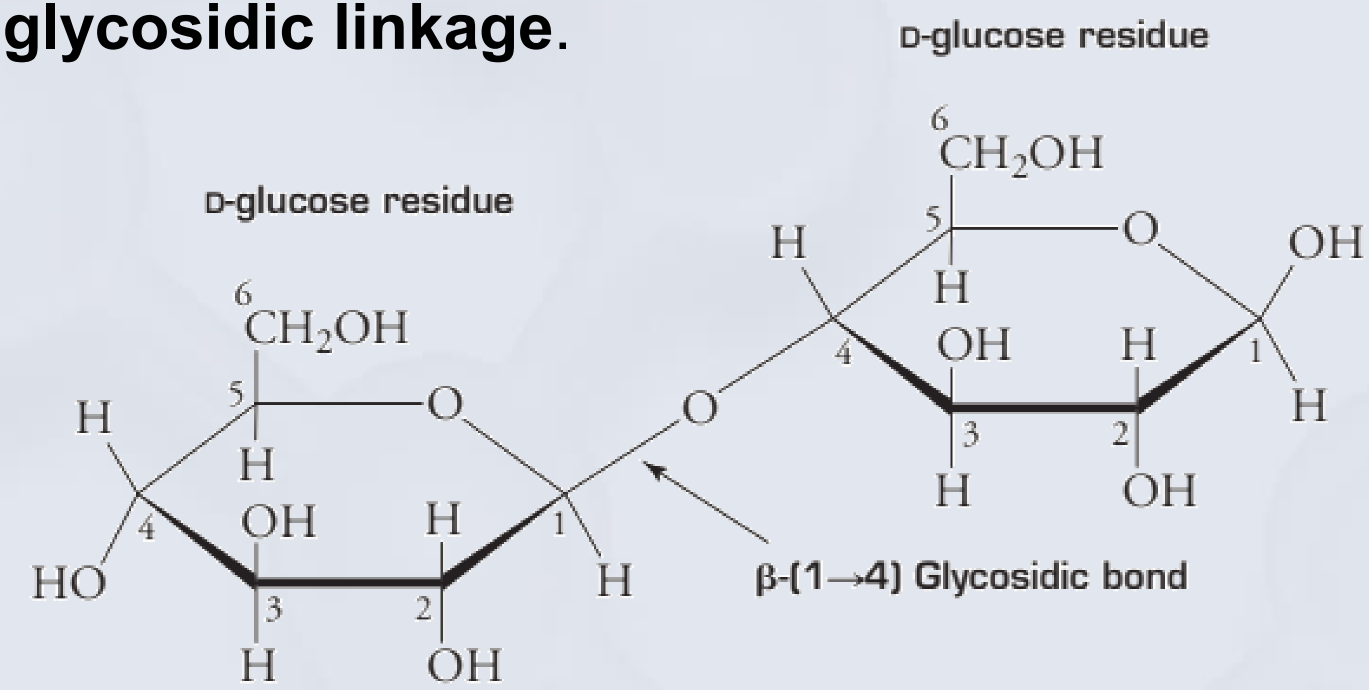
Monosaccharide + monosaccharide $\longrightarrow$ disaccharide + H_2O

(Functioning as a hemiacetal) (Functioning as an alcohol) (Glycoside)



Cellobiose

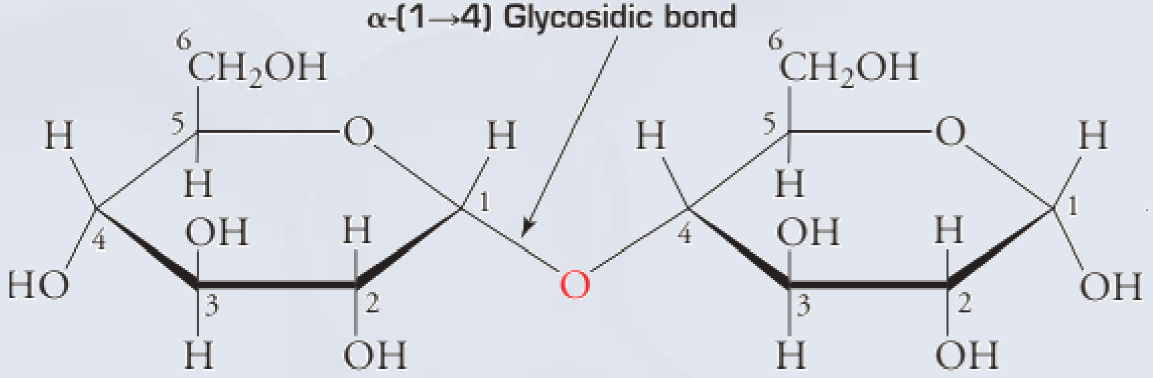
- Cellobiose is produced as an intermediate in the hydrolysis of the polysaccharide cellulose:
  - Cellobiose contains two β-D-glucose monosaccharide units linked through a **β(1→4) glycosidic linkage**.



Cellobiose

Maltose

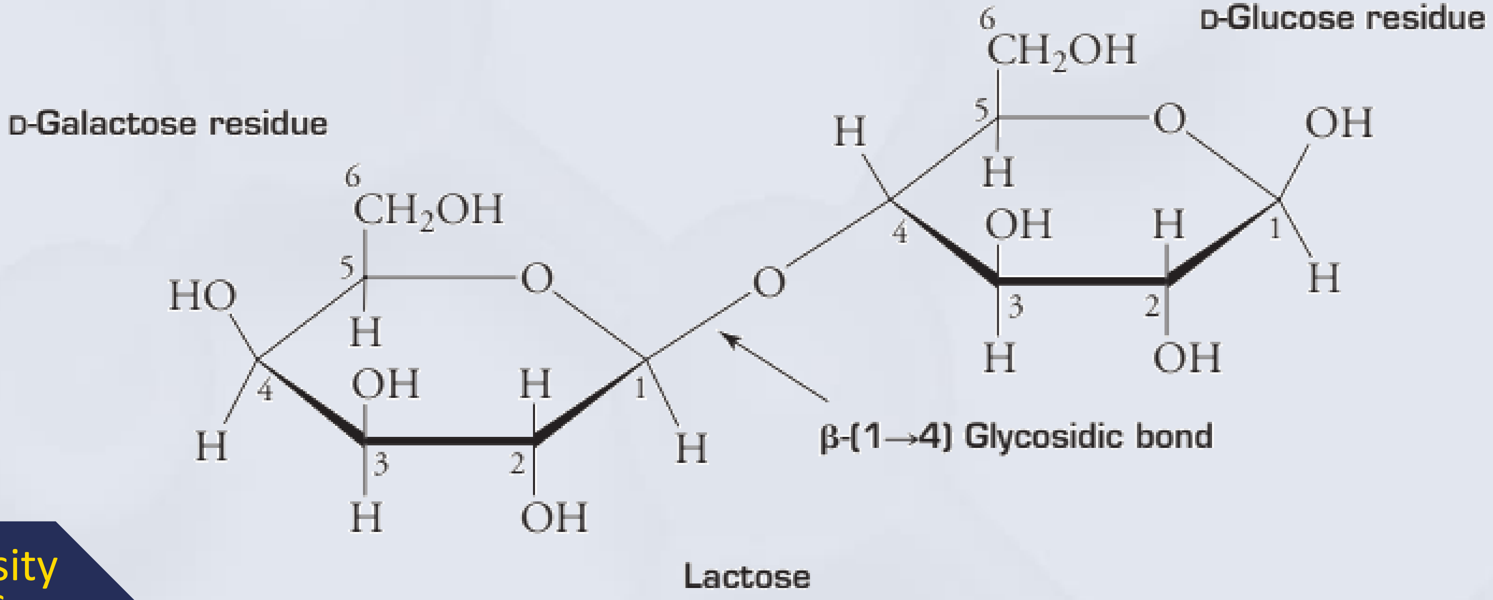
- Also known as **malt sugar**; intermediate product of starch degradation
  - Structurally maltose made of two α-D-glucose units linked via an **α(1→4) glycosidic linkage**.
  - Maltose is digested easily by humans because of the enzyme **maltase**, that can break α(1→4) linkages, but not β(1→4) linkages of cellobiose. Therefore, cellobiose cannot be digested by humans.



Maltose

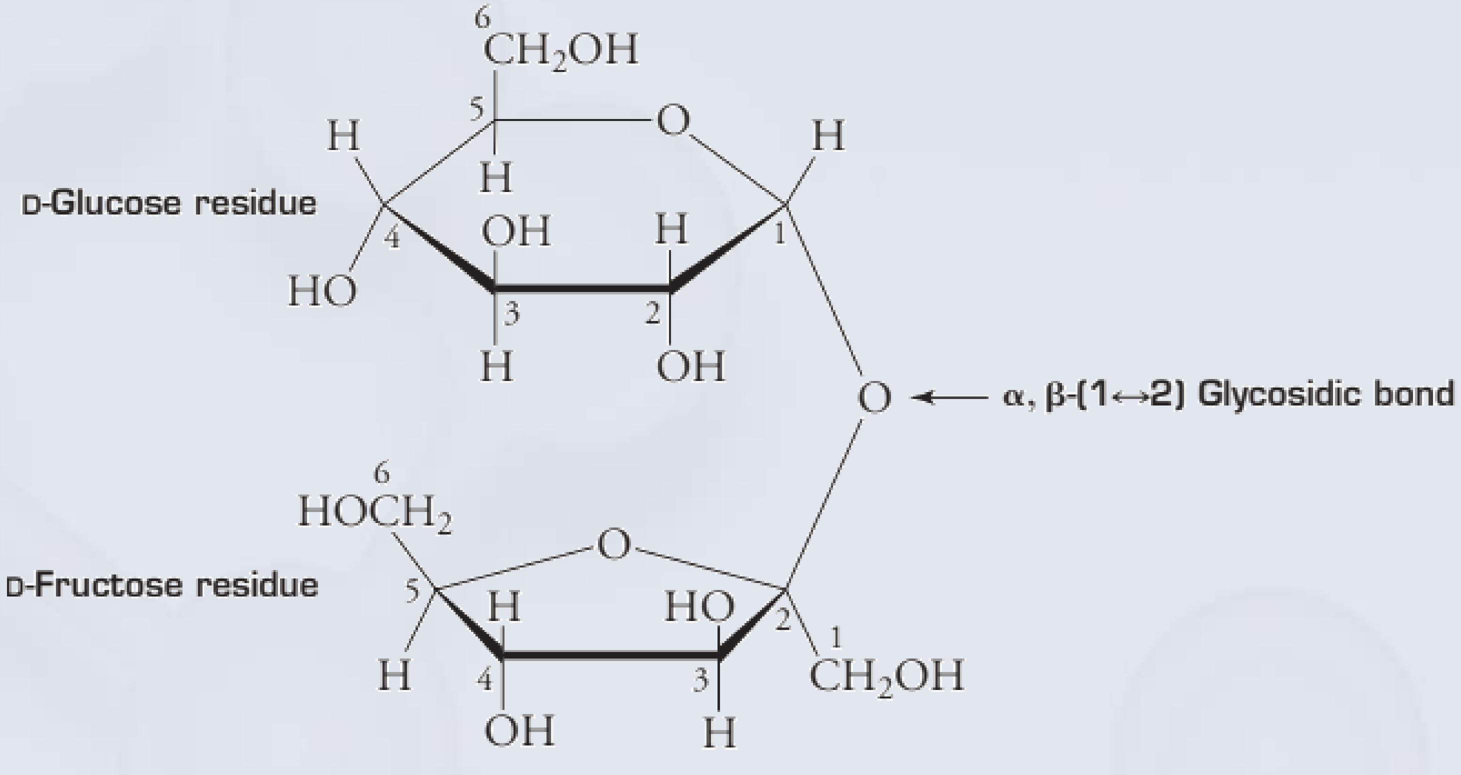
Lactose

- Lactose is made up of β-D-galactose unit and a β-D-glucose unit joined by a **β(1→4) glycosidic linkage**.
  - Milk is rich in lactose.
  - May be hydrolyzed by an acid or the enzyme **lactase**, resulting in the formation of an equimolar combination of galactose and glucose.



Sucrose

- The common **table sugar** and is the most abundant of all disaccharides.
  - Composed of α-D-glucose and β-D-fructose joined by **α,β(1→2) glycosidic linkage**.
  - A **nonreducing sugar**.

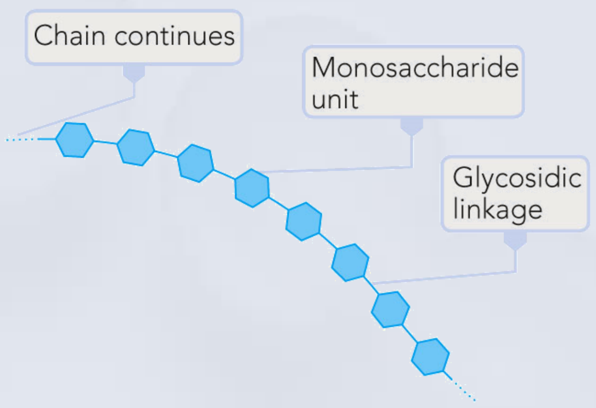


Sucrose

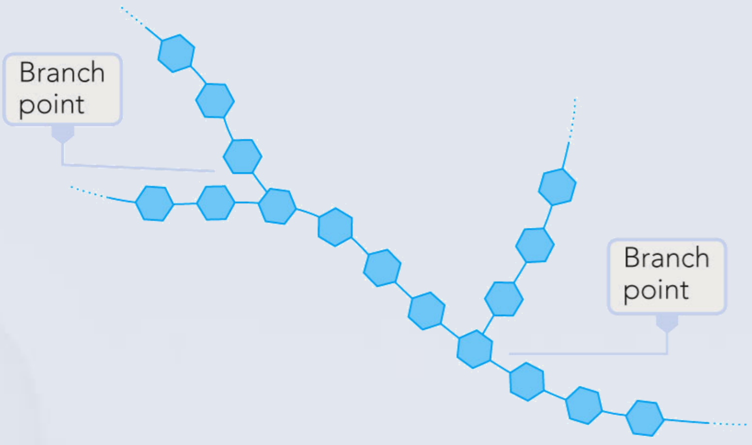
Polysaccharides

The Polymer Chain

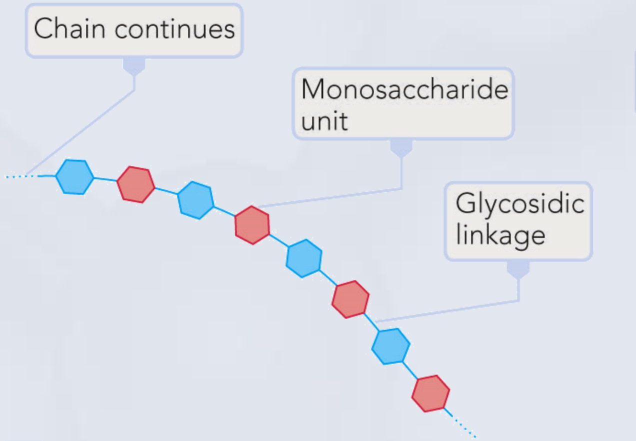
- Polymers of many monosaccharide units bonded with glycosidic linkages
- Also known as glycans
- Types:
  - Linear and branched
  - Homoglycans and heteroglycans



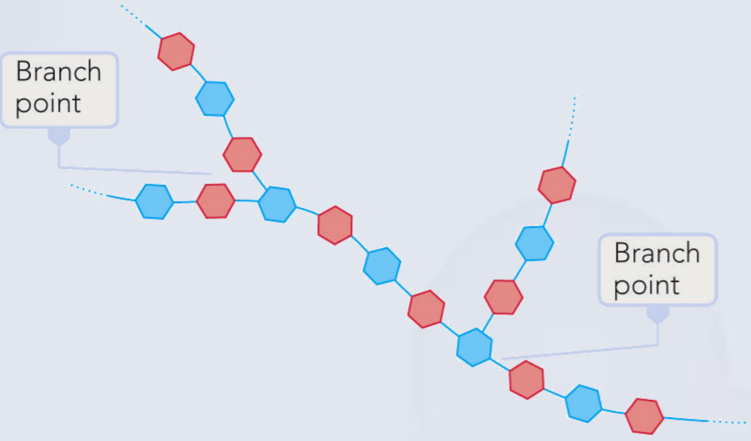
a Unbranched-chain homopolysaccharide



b Branched-chain homopolysaccharide



c Unbranched-chain heteropolysaccharide

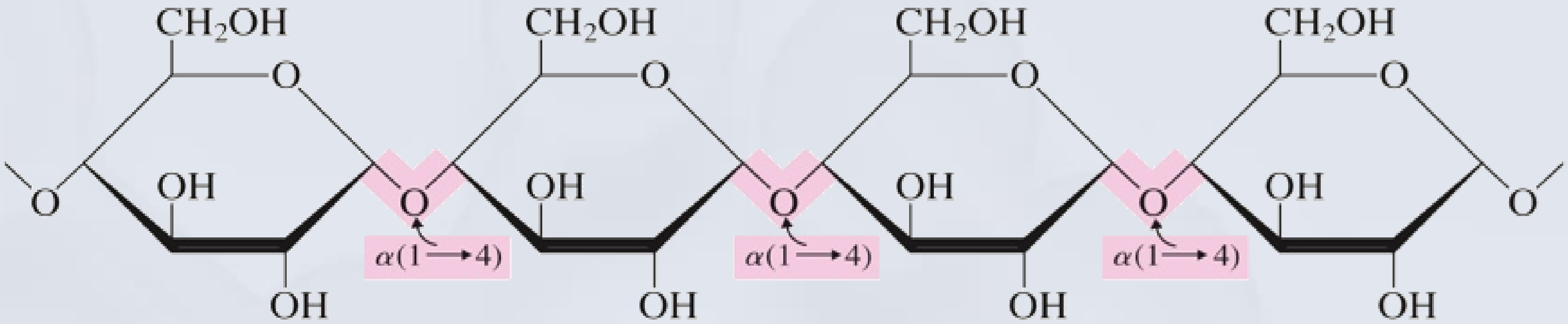


d Branched-chain heteropolysaccharide

General Characteristics of Polysaccharides

- Polysaccharides are not sweet and don’t show positive tests with Tollen’s and Benedict’s solutions whereas monosaccharides are sweet and show positive tests
- Limited water solubility
  - Size **prevents them from dispersing** well in water like smaller sugars do.
- Examples:
  - Cellulose, starch in plants
  - Glycogen in animals
  - Chitin in arthropods

Storage Polysaccharides



Starch (amylose)

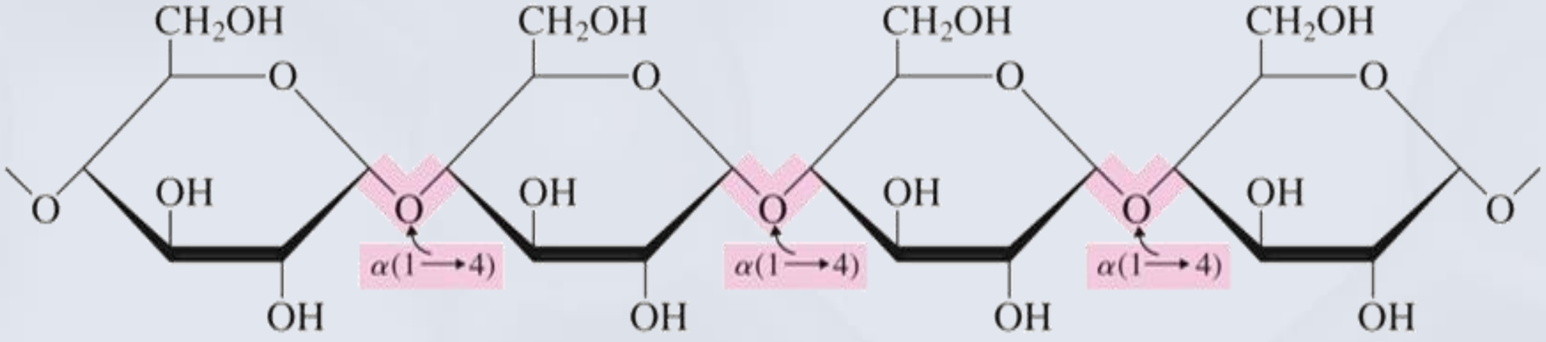
- A **storage polysaccharide** is a polysaccharide that is a storage form for monosaccharides and is used as an energy source in cells.

Storage Polysaccharides

Starch

- Glucose is the monomeric unit
- Storage polysaccharide in plants
- Two types of polysaccharides isolated from starch:

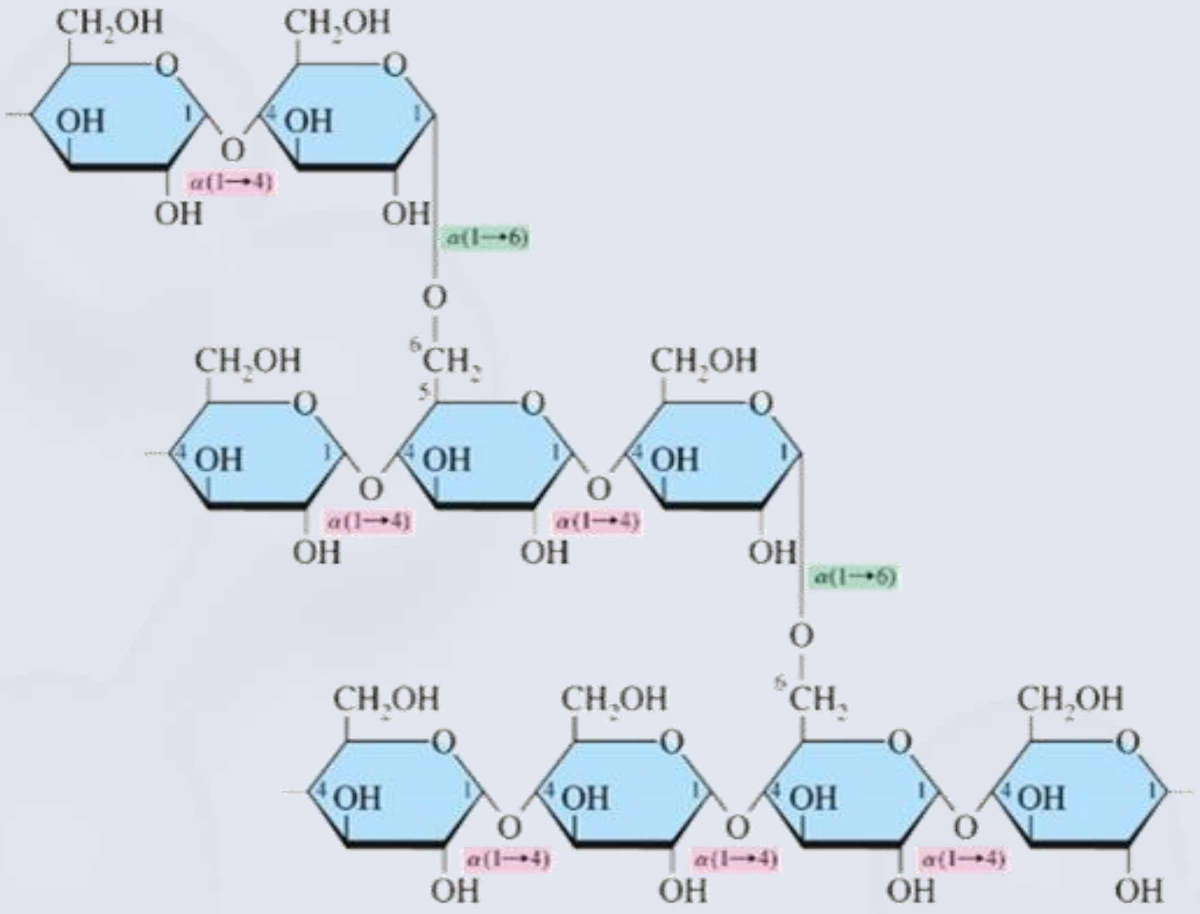
1. **Amylose**
   - Straight chain polymer - 15 - 20% of the starch and has **α(1→4) glycosidic bonds**
   - Molecular Mass: 50,000 amu (up to 1000 glucose units)



Starch

2. Amylopectin

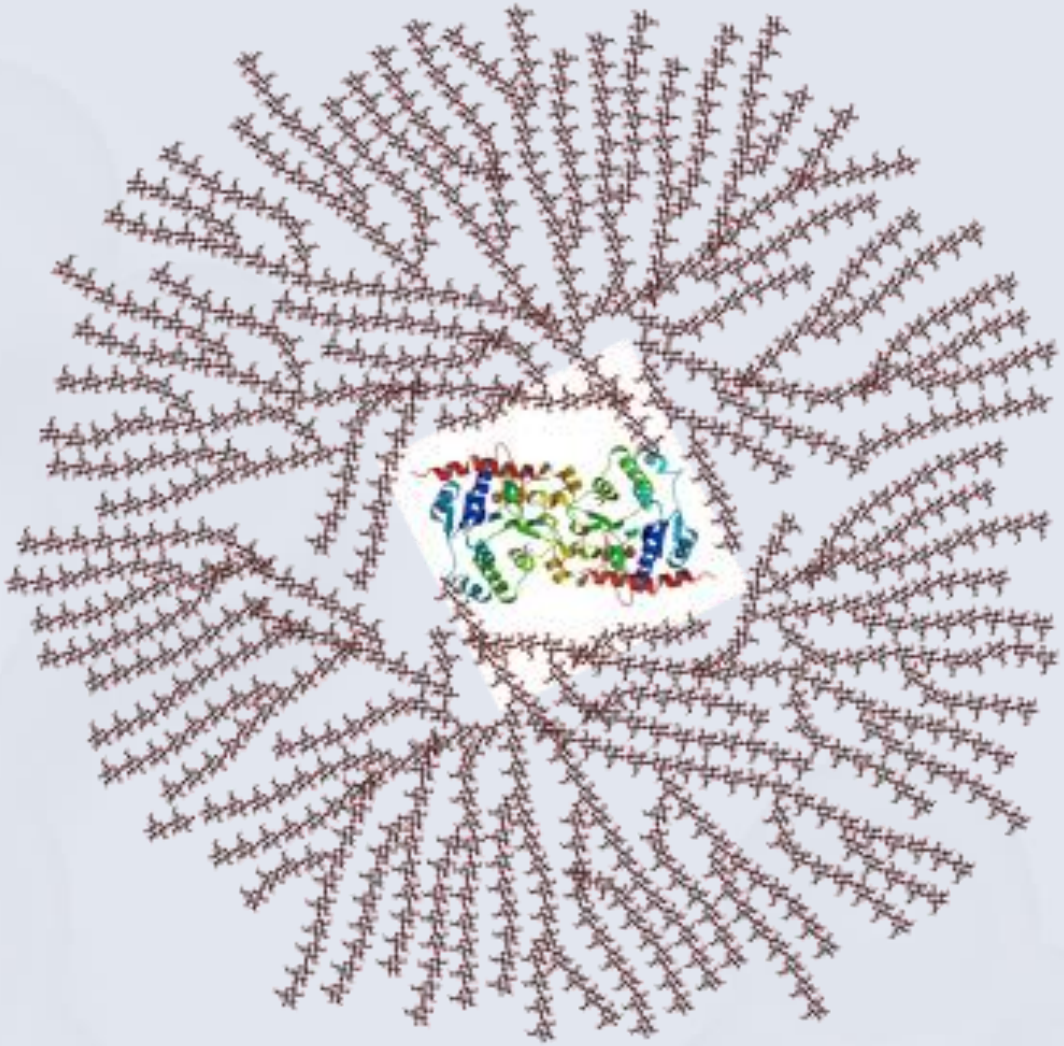
- Branched chain polymer - 80 - 85 % of the starch α(1→4) glycosidic bond for straight chain and α(1→6) for branch
- Molecular Mass: 300,000 amu (up to 100,000 glucose units) – higher than amylose
- Amylopectin is digested more readily by humans (can hydrolyze alpha linkages but not beta linkages)



Storage Polysaccharides

Glycogen

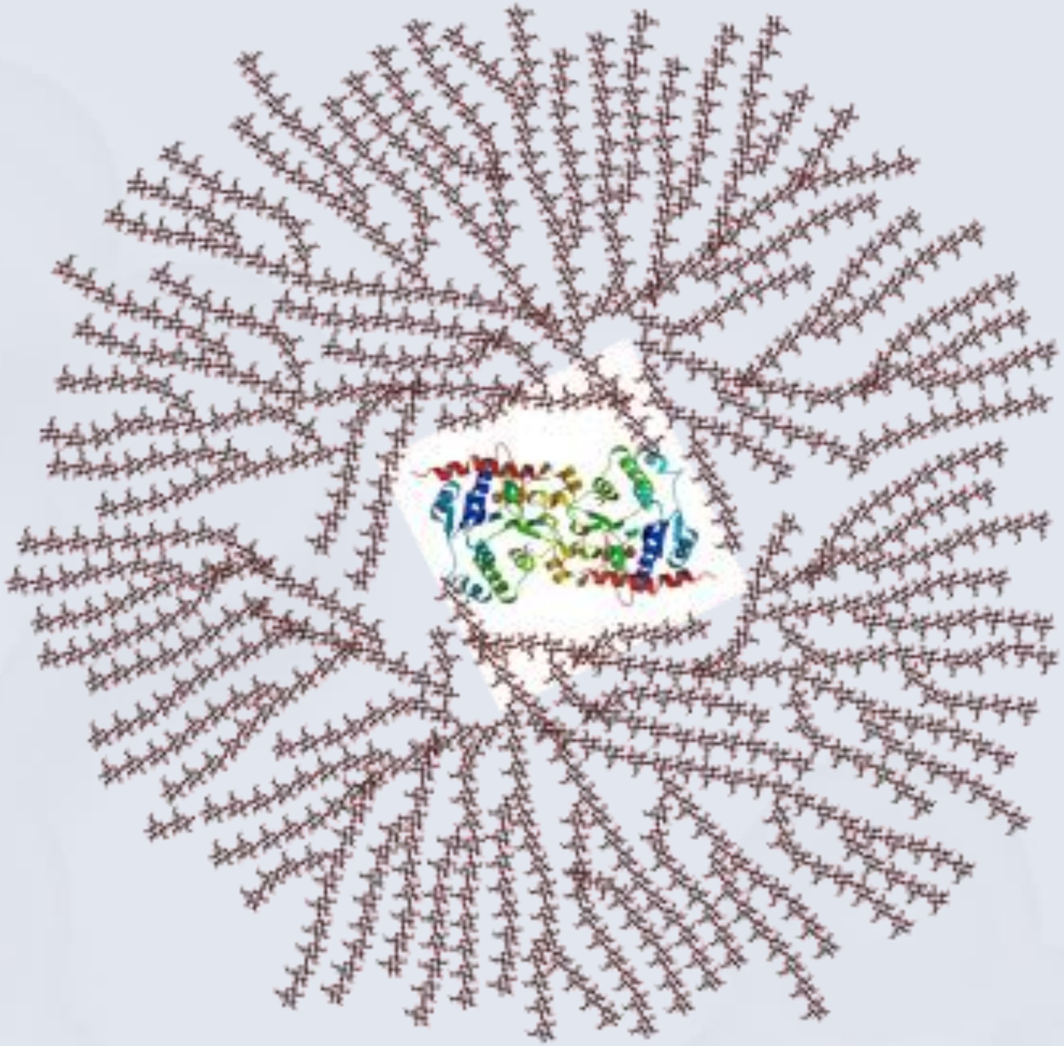
- Human and animal storage polysaccharide
- Contains only glucose units
- Branched chain polymer – α(1 → 4) glycosidic bonds in straight chains and α(1 → 6) in branches



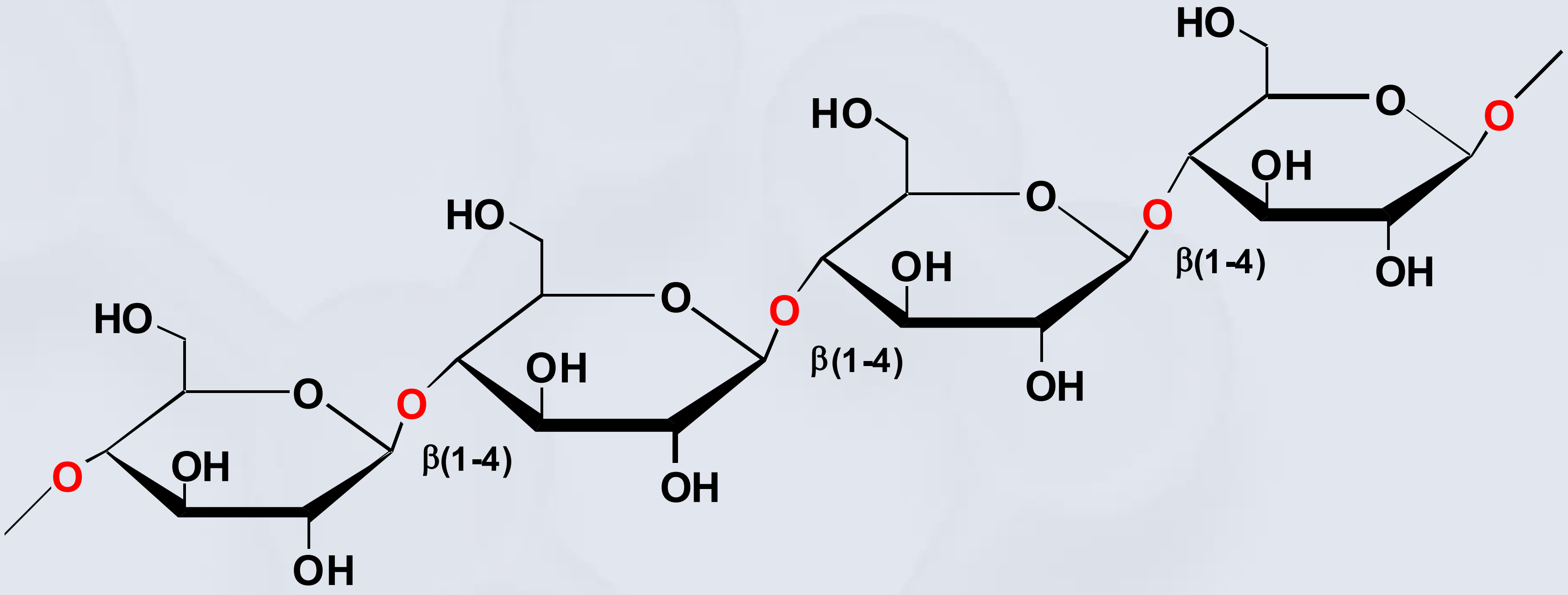
Storage Polysaccharides

Glycogen

- Molecular Mass: 3,000,000 amu (up to 1,000,000 glucose units)
- Three times more highly branched than amylopectin in starch
- Excess glucose in blood stored in the form of glycogen



Structural Polysaccharides



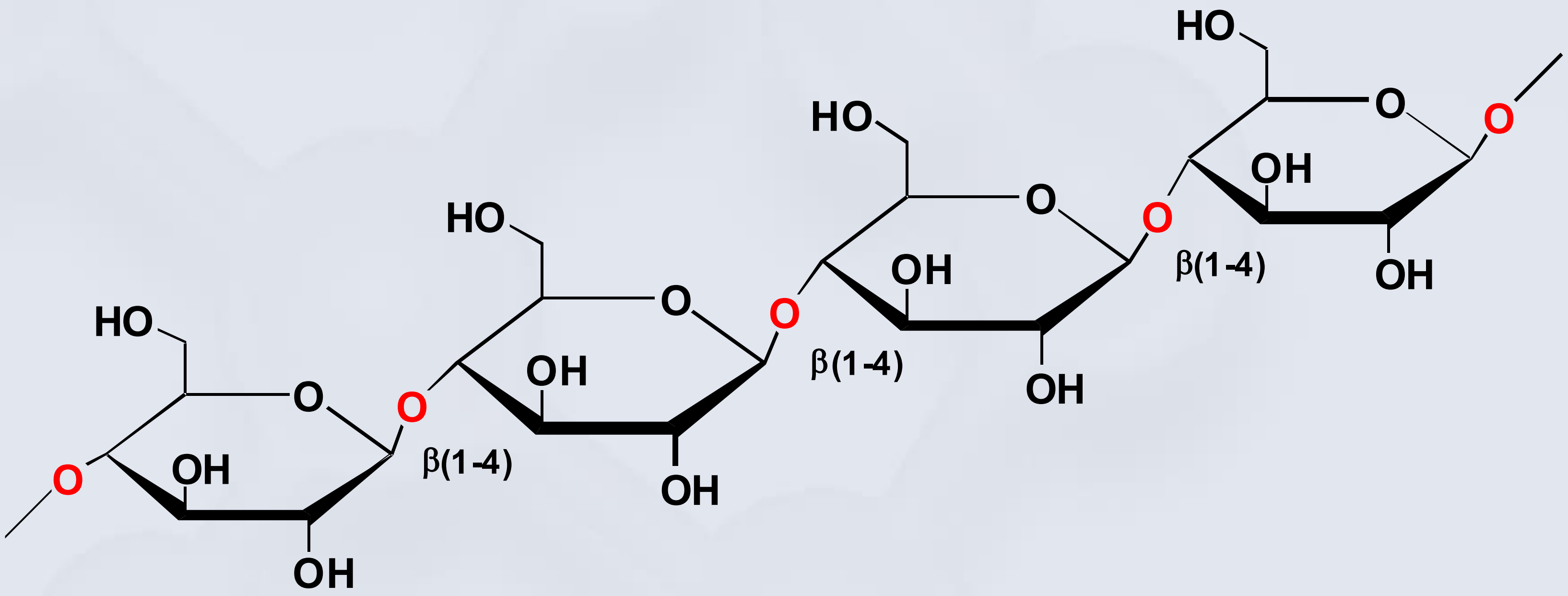
- **Structural polysaccharides** serve as a structural element in plant cell walls and animal exoskeletons.

Cellulose

- Linear homopolysaccharide with β(1→4) glycosidic bond
- Up to 5000 glucose units with molecular mass of ~900,000 amu
  - Cotton ~95% cellulose, and wood ~50% cellulose
  - Cannot be digested by humans because of the absence of **cellulase**, the enzyme that hydrolyzes beta (1→4) linkages
  - Animals lack these enzyme too, but they can digest cellulose because they have bacteria in their guts to hydrolyze cellulose
  - It serves as **dietary fiber** in food – readily absorbs water and results in softer stools (20-35 g of dietary fiber is desired everyday)

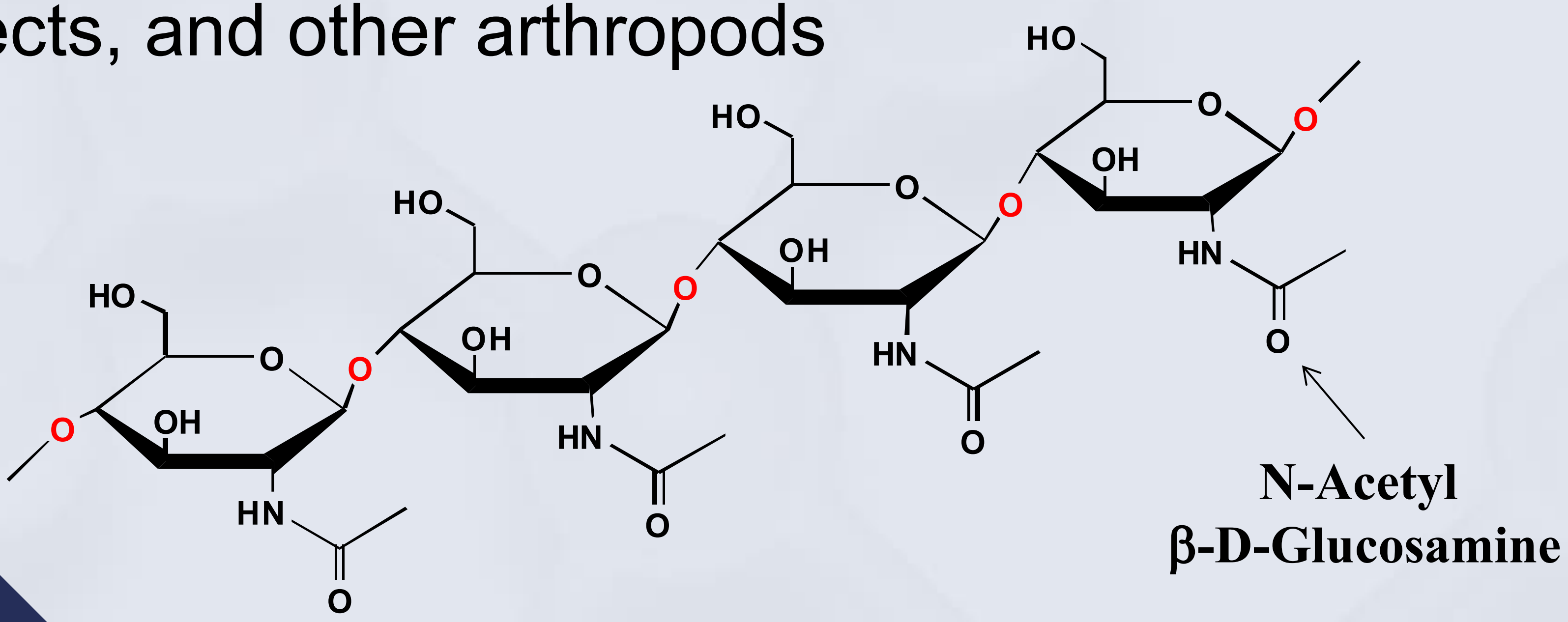
Structural Polysaccharides

Cellulose



Chitin

- Similar to cellulose in both function and structure
- Linear polymer with all **β(1→4) glycosidic linkages** – it has a **N-acetyl amino derivatives of glucose**
- Function is to give rigidity to the exoskeletons of crabs, lobsters, shrimp, insects, and other arthropods

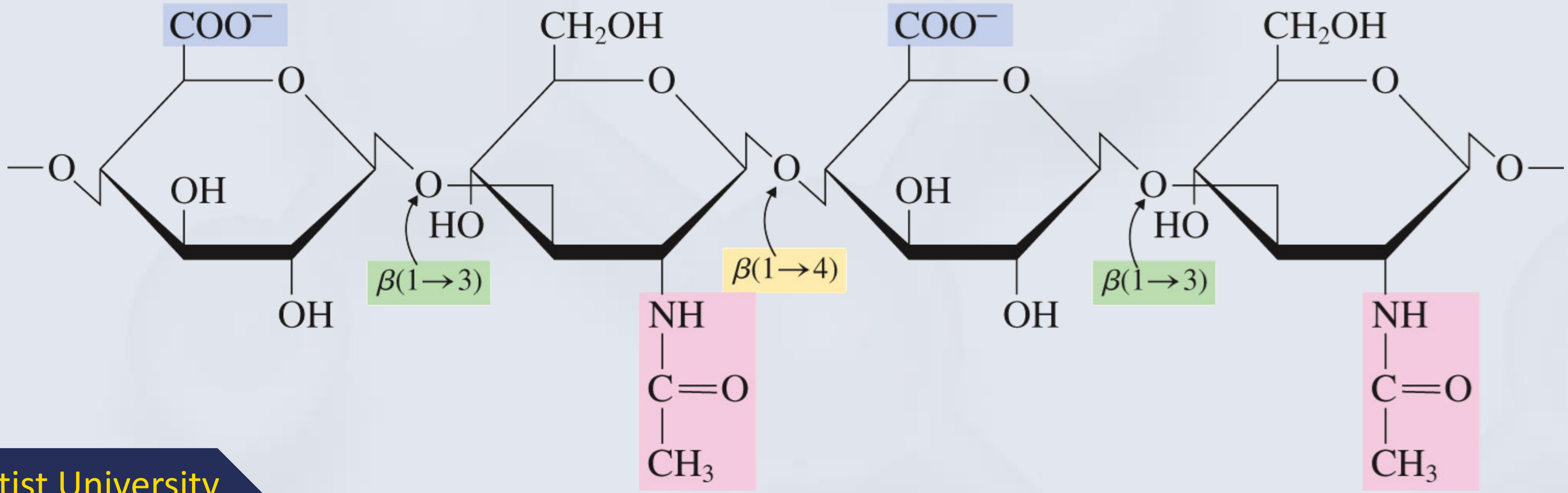


Acidic Polysaccharides

- Polysaccharides with a repeating disaccharide unit containing an amino sugar and a sugar with a negative charge due to a sulfate or a carboxyl group.
- Structural polysaccharide present in connective tissue associated with joints, cartilage, synovial fluids in animals and humans
  - Primary function is lubrication necessary for joint movement
  - These are heteropolysaccharides – have more than one type of monosaccharide monomers is present.

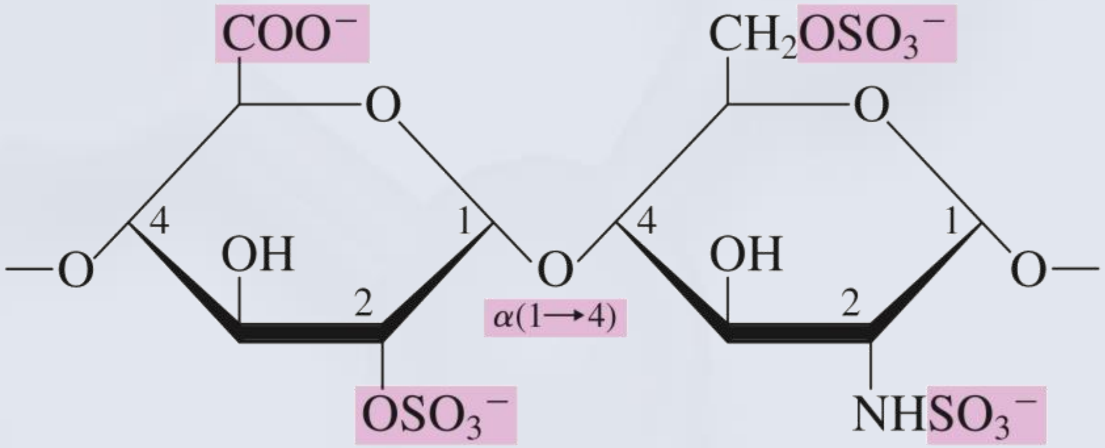
Hyaluronic Acid

- Alternating residues of N-acetyl-beta-D-glucosamine and D-glucuronic acid.
- Highly viscous; serve as lubricants in the fluid of joints and part of vitreous humor of the eye.



Heparin

- An anticoagulant; it helps prevent blood clots; it binds strongly to a protein involved in terminating the process of blood clotting, thus inhibiting blood clotting.
- Composed of repeating units of *D-glucuronate-2-sulfate* and *N-sulfo-D-glucosamine-6-sulfate*



D-Glucuronate-
2-sulfate

N-Sulfo-
D-glucosamine-6-sulfate

Glycolipids and Glycoproteins

Glycolipid

- a lipid molecule that has one or more carbohydrate (or carbohydrate derivative) units covalently bonded to it.

Glycoprotein

- a protein molecule that has one or more carbohydrate (or carbohydrate derivative) units covalently bonded to it.

- Such carbohydrate complexes are **very important in cellular functions** such as cell-cell recognition, cell adhesion and cellular communication.
- The carbohydrate (oligosaccharide) portion of the glycolipid or glycoprotein serves as a **marker** on the outer cell membrane surface, while the lipid or protein portion is integrated into the structure of the cell membrane.

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