Structures of Monosaccharides
Structural Representation of Monosaccharides

- Fischer projection: straight chain representation of chiral sugars
- Haworth projection: simple planar ring perspective of cyclic sugars
- Conformational representation: chair conformations
Stereochemistry of Monosaccharides

• A mastery of stereochemistry is central to understanding carbohydrate structure since it is the absolute stereochemistry that defines the true identity of any specific monosaccharide.

• The Fischer projections, used to represent stereochemistry in chiral molecules, are particularly well suited to carbohydrates because they have multiple chiral centres.

• Aldoses with at least three carbon atoms and ketoses with at least four carbon atoms possess chiral centres.

• These molecules are commonly represented in Fischer projections that allow an establishment of relationships between different sugars.
Structural Representation of Monosaccharides in Fischer Projections

As part of his Nobel Prize-winning research on carbohydrates, the German Chemist Hermann Emil Fischer, devised a simple notation that is still widely used.

He won a Nobel Prize in Chemistry in 1902 and died in 1919 from osazone (hydrazones of sugars) poisoning.
Fischer Projections of Chiral Molecules

In a Fischer projection, the four bonds to a chiral carbon are represented as a cross.

The two horizontal bonds are directed toward the viewer (forward of the chiral carbon). The two vertical bonds are directed behind the central carbon (away from the viewer).
Drawing Fischer Projections of Chiral Molecules

To generate the Fischer projection of a chiral molecule:

(i) Identify the longest carbon chain that passes through all the chiral centres.

(ii) Rotate the zigzag structure 90° on the plane so that the most oxidized carbon connected to the chiral centre(s) is vertically-oriented at the top of the plane and the remaining chain is at the bottom.

(iii) Rotate the molecule 90° off-plane on a vertical axis so that the most oxidized carbon is still vertical up, but oriented away, while the longest continuous carbon is vertical down and oriented away.

The two remaining substituents will be on the horizontal axis facing the viewer.
Relative Configuration of Sugars and Amino Acids from their Fischer Projections

When the Fischer projections of sugars and amino acids are drawn with the most oxidized carbon fragment at the top and the longest carbon chain at the bottom in a vertical alignment, the sugars and amino acids that have either the OH or NH$_2$ group on the Left at the bottom-most chiral centre are designated as L-sugars or amino acids and those that have the OH or NH$_2$ group on the right are D-sugars or amino acids.
Relative Configuration of Sugars Based on Fischer Projections

S-(-)-Glyceraldehyde

\[ \alpha = -8.7^\circ \]

R-(+)-Glyceraldehyde

\[ \alpha = +8.7^\circ \]

OH group on the Left for L-series

L-(-)-Glyceraldehyde

Longest carbon chain

OH group on the Right for D-series

D-(+)-Glyceraldehyde

Most oxidised carbon
Relative Configuration of Amino Acids Based on Fischer Projections

- S-(+)-Serine: [α] = +13.7°
- R-(−)-Serine: [α] = -13.7°

**NH₂ group on the Left for L-series**

- L-(+)-Serine: 1 CO₂H, 2 CH₂OH, 3 CH₂OH
- Most oxidised carbon

**NH₂ group on the Right for D-series**

- D-(−)-Serine: 1 CO₂H, 2 CH₂OH, 3 CH₂OH
- Longest carbon chain
Assigning D or L Notations on Fischer Projections of Sugars

- Molecules with multiple chiral centres are designated D or L based on the chiral centre at the bottom.

- Mirror images (enantiomers) of carbohydrates can be generated from Fischer Projections by inverting at each of the chiral centres.
Structures of Monosaccharides
Aldotrioses

Since sugars are chiral, the number of stereoisomers of each monosaccharide is $2^n$, where $n$ is the number of chiral centers in the sugar.

Glyceraldehyde, an aldotriose, has one chiral centre. Consequently, there are $2^1 = 2$ stereoisomers of the aldotriose that exist.

D-Glyceraldehyde can be used to generate D-series sugars, while L-Glyceraldehyde can be used as a template for generating L-series sugars.
An aldotetrose has two chiral centres. Consequently, there are $2^2 = 4$ stereoismeric aldotetroses. Two of these are D-series and two are L-tetroses.

D-(-)-erythrose  L-(+)-erythrose  D-(-)-threose  L-(+)-threose

only these two are found in nature
Structures of Monosaccharides
Aldopentoses

An aldopentose has three chiral centres. Consequently, there are $2^3 = 8$ stereoisomeric aldotetrose. Four of these are D-series and four are L-pentoses.

Aldopentoses: 3 chiral carbons, 8 stereoisomers (4 D & 4 L)

\[
\begin{align*}
\text{D-(-)-ribose} & \quad \text{D-(-)-arabinose} & \quad \text{D-(+)-xylose} & \quad \text{D-(-)-lyxose} \\
\text{D-(-)-ribose} & \quad \text{D-(-)-arabinose} & \quad \text{D-(+)-xylose} & \quad \text{D-(-)-lyxose} \\
\text{D-(-)-ribose} & \quad \text{D-(-)-arabinose} & \quad \text{D-(+)-xylose} & \quad \text{D-(-)-lyxose} \\
\text{D-(-)-ribose} & \quad \text{D-(-)-arabinose} & \quad \text{D-(+)-xylose} & \quad \text{D-(-)-lyxose} \\
\end{align*}
\]

Drawn in this order, the names of the four aldopentoses (ribose, arabinose, xylose and lyxose) are remembered by the mnemonic: Ribs are extra lean (RAXL).
The mnemonic for the eight aldohexoses (allose, altrose, glucose, mannose, gulose, idose, galactose and talose) is “All altruists gladly make gum in gallon tanks.”
• Recognizing the stereochemical relationships between certain key stereoisomeric sugars can significantly aid in deriving their structures.

• The D-aldoses (erythrose, ribose and allose) have all their OH groups on the right hand side of the molecules. These can be remembered by the acronym ERA (erythrose, ribose and allose).

• Xylose and idose are the only monosaccharides with alternating OH groups on each successive chiral centre.
Structures of Monosaccharides
Stereochemical Relationships between D-Aldohexoses

The following key D-aldohexoses are epimers: differ in stereochemistry at only one chiral centre.

**Allose epimer**

- D-(+)-Allose
  - C-2 epimers
- Allose
  - C-4 epimers

**Glucose epimers**

- D-(+)-Glucose
  - C-2 epimers
- Glucose
  - C-4 epimers

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Change in Stereochemistry at Only One Chiral Centre
Structures of Monosaccharides
Things to Note

• In nature, most monosaccharides possess the D-configuration at their chiral centres. The natural preference for D-sugars was established by apparently random choices early in evolution. They persist because of the stereospecificity of the enzymes that synthesize and metabolize them.

• Most naturally occurring monosaccharides are pentoses and hexoses.

• Among the aldopentoses D-ribose is a component of many biologically important substances, most notably the ribonucleic acids.
Structures of Monosaccharides

Things to Note

• Of all the monosaccharides, hexoses are the most abundant in nature.

• The aldohexose, D- (+)-glucose is the best known, most important and most abundant organic compound on earth.

• The formation of glucose from carbon dioxide, water and sunlight is the central theme of photosynthesis.

• D- (+)-Galactose is a constituent of numerous polysaccharides. It is best obtained by acid hydrolysis of lactose (milk sugar), a disaccharide of D-glucose and D-galactose.
Structures of Monosaccharides

Things to Note

• L-Monosaccharides do exist in nature but play relatively limited and specialized roles.

• L-arabinose is a component of plant hemicelluloses (plant cell-wall components).

• Interestingly, bacteria that degrade hemicelluloses do so by first converting L-arabinose into D-arabinose, after which they can either incorporate it in their cell walls or metabolize it for energy.