Lecture 29 (12/3/21)

TODAY

•Reading: Ch7; 220-235

•Problems: Ch7; 1,2,3,5,9

NEXT

•Reading: Ch7; 236-241, 251-254, 258-260
Ch7; 241-250

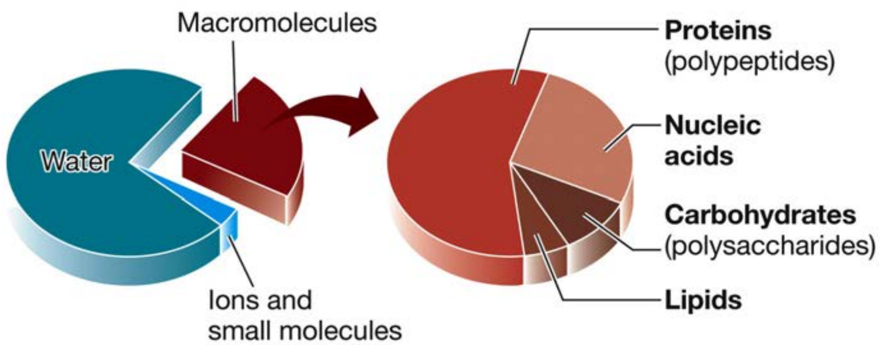
•Problems: Ch7; 4,6,7,8,13,14,15,18
Ch7; 16,17,25,27

Carbohydrates

A. Definition
B. Roles
C. Monosaccharides-Chemistry
   1. Chirality
      a. One or more asymmetric carbons
      b. Linear and ring forms
   2. Derivatives: the chemistry of carbohydrates
      a. Oxidation
         i. C1
         ii. C6
      b. Reduction
         i. C1/C2
         ii. Other carbons
      c. Ester formation
      d. Amino sugars
   3. Polymerization
      a. The Glycosidic Bond
      b. Non-covalent bonds in macro-molecular structure
D. Oligosaccharides
   1. Glycoproteins & glycolipids
   2. O-linked
   3. N-linked
   4. Sequence determination-ABO
E. Polysaccharides
   1. Polymers of glucose
   2. Polymers of disaccharides

Carbohydrates

Carbohydrates



Carbohydrates

Definition

- Carbo-Hydrate: have formula $C_n(H_2O)_n$ (for $n \geq 3$)
- The precursor-macromolecule relationship is:
  - Monosaccharide–polysaccharide (or oligosaccharide)
- Carbohydrates are everywhere (ubiquitous) and versatile in function; fulfill a variety of functions.
  - Can be covalently linked with proteins and lipids; are intimately involved in nucleic acids

	ROLES	Monosaccharide	Polysaccharide
1.	Energy source/storage	glucose, fructose, etc.	Starch, glycogen
2.	Structure	glucose, *glycerol*	Cellulose, chitin, lipids & membranes
3.	Information	ribose (nucleotides)	Nucleic acids
4.	Recognition	many	Glycolipids & glycoproteins

Carbohydrates

The 4 S's

Size — Range from as small as glyceraldehyde (M_w = 90 g/mol) to as large as amylopectin (M_w > 200,000,000 g/mol)

Shape — Depends on size and glycosidic bond

Solubility — Very polar, very soluble, until large polymers

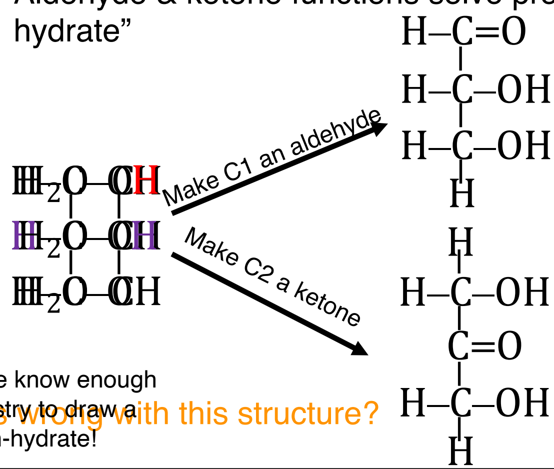
Stability — Stable due to glycosidic bond

Carbohydrates

Monosaccharides

$C_3(H_2O)_3$

- Basic nomenclature:
  - Use the suffix "-ose" — triose, tetrose, pentose, hexose
  - Aldehyde & ketone functions solve problem of a "carbo-hydrate"



= aldoses

aldotriose (triose), aldotetrose(tetrose), aldopentose, aldohexose

= ketose

Ketotriose (triulose), ketotetrose (tetrulose)… (pentulose, hexulose).

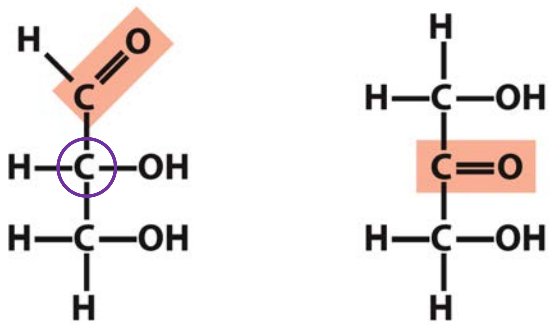
OK, we know enough chemistry to draw a carbon-hydrate!

What is wrong with this structure?

Carbohydrates

Monosaccharides

- An aldose is a carbohydrate with aldehyde functionality.
- A ketose is a carbohydrate with ketone functionality.



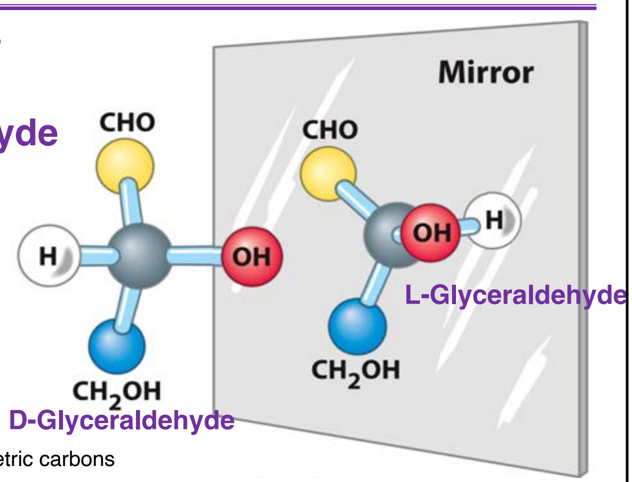
Glyceraldehyde, an aldotriose **Dihydroxyacetone, a ketotriose**

Are there any chiral carbons?

Carbohydrates

Monosaccharides

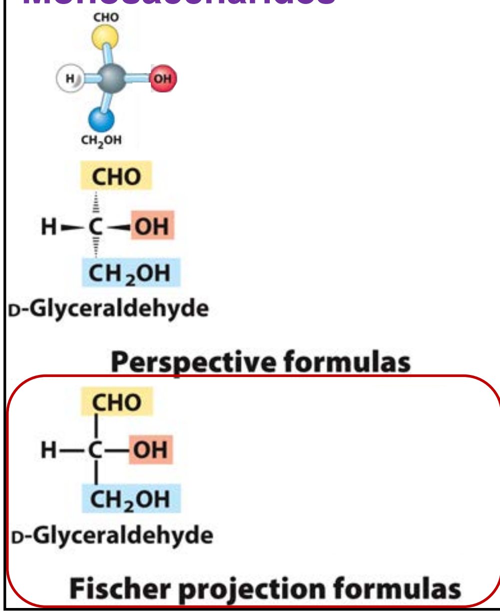
Glyceraldehyde



- Chemical Features:
  - Chirality
    - One or more asymmetric carbons
    - Linear and ring forms
  - Derivatives: the chemistry of carbohydrates
  - Polymerization
    - The Glycosidic Bond
    - Non-covalent bonds in macro-molecular structure

Carbohydrates

Monosaccharides



Fischer projections

- Vertical bonds are between carbons, with highest oxidation state at the top, AND project away from you.
- Horizontal bonds are pointing toward you.
- If hydroxyl is on the left; its **L**
- If hydroxyl is on the right; its **D**
- Here D=R & L=S

It turns out that the L form of glyceraldehyde is called L because it is "levorotary," meaning it will rotate plane-polarized light to the left, or counter-clockwise. D rotates "dextrorotary."

Carbohydrates

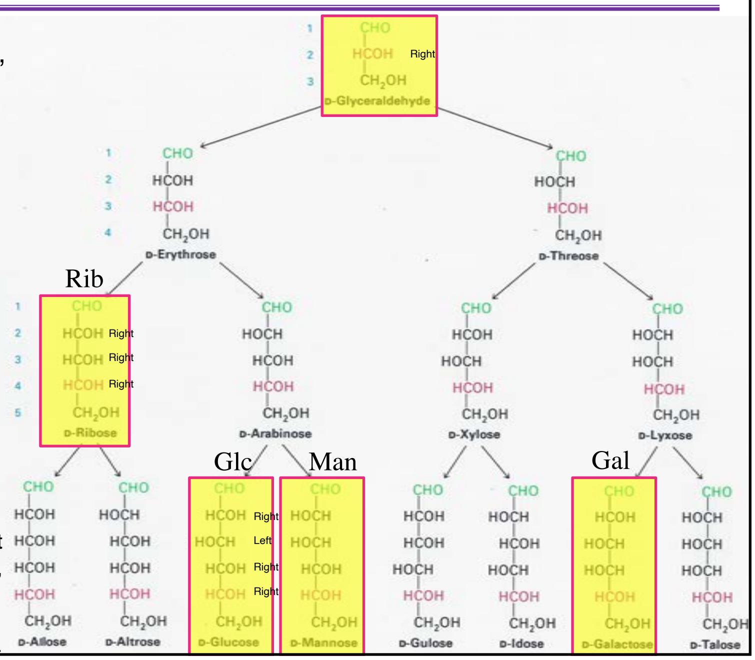
GREEN =functional group
RED=highest numbered chiral carbon

Nearly all sugars in biology are "D" (sort of like most amino acids are "L").

As you go to tetrose, pentose, etc., you are adding more chiral carbons.

A D- or L-sugar is defined by the chirality of the highest numbered carbon.

Another complete set of 15 L-aldoses exist, and are enantiomers of their D-aldose relatives shown here.



Carbohydrates

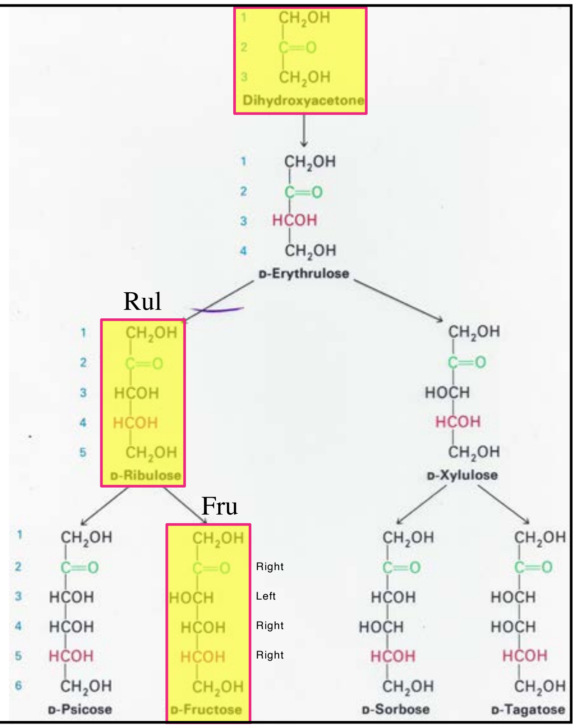
D-ketoses

The first chiral sugar is a tetrulose.

There is also another complete set of 7 L-ketoses exist, and are **enantiomers** of their D-ketose relatives shown here.

Fructose is the ketose form of glucose

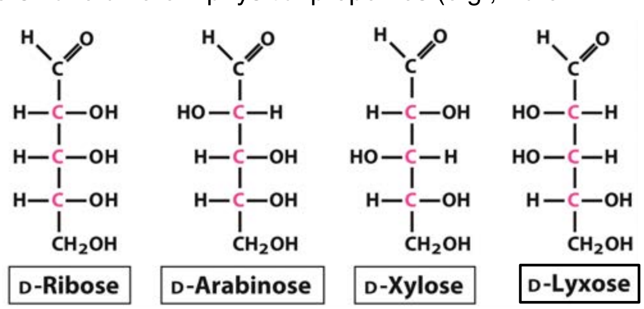
Ribulose is the ketose form of ribose



Carbohydrates

Monosaccharides: Stereoisomer Nomenclature

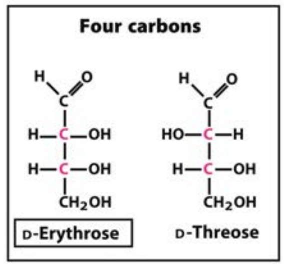
- Enantiomers
  - stereoisomers that are nonsuperimposable **complete** mirror images
  - Example: D-sugars & L-sugars
- Diastereomers
  - stereoisomers that are not complete mirror images
  - Diastereomers have different physical properties (e.g., water solubility)
  - Example:



Carbohydrates

Monosaccharides: Stereoisomer Nomenclature

- Epimers
  - Epimers are stereoisomers that differ at only **one** chiral center
  - Epimers are diastereomers; diastereomers have different physical properties (i.e., water solubility, melting temp)
  - Example:

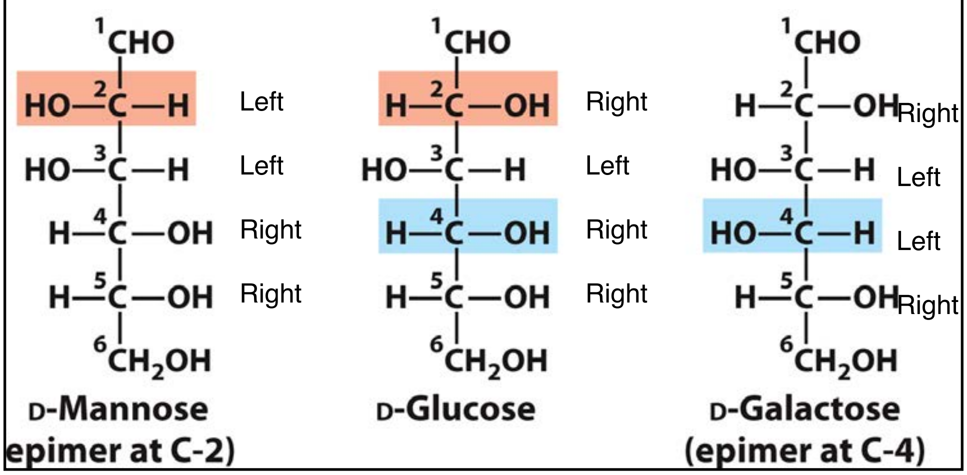


  - Glc & Man (2 epimer); Glc & Gal (4 epimer); Rib & Ara; Rib & Xyl
- Anomers
  - Anomers have different chirality at carbon involved in ring formation

Carbohydrates

Monosaccharides: Stereoisomer Nomenclature

- D-Mannose and D-galactose are both epimers of D-glucose.
- D-Mannose and D-galactose vary at more than one chiral center and are diastereomers, but not epimers.



Carbohydrates

Monosaccharides: The most important sugars

- Glyceraldehyde and dihydroxyacetone are the simplest (3 carbon) aldose and ketose, respectively.
- Ribose (Rib) is the standard five-carbon sugar.
- Glucose (Glc) is the standard six-carbon sugar.
- Galactose (Gal) is an C4-epimer of glucose.
- Mannose (Man) is an C2-epimer of glucose.
- Fructose (Fru) is the ketose form of glucose.
- Ribulose (Rul) is the ketose form of ribose.

Need to know, recognize, draw Fisher Projection, name, abbreviate

Carbohydrates

Monosaccharides: Stereoisomer Nomenclature

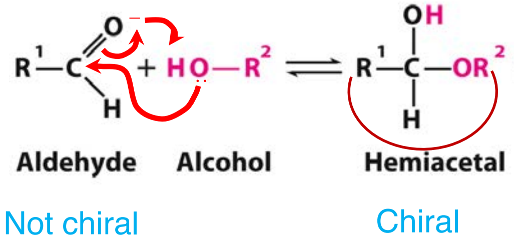
- Enantiomers
  - stereoisomers that are nonsuperimposable **complete** mirror images
  - Example: D-sugars & L-sugars
- Diastereomers
  - stereoisomers that are not complete mirror images
  - Diastereomers have different physical properties (e.g., water solubility)
  - Example: ribose & lyxose
- Epimers
  - Epimers are stereoisomers that differ at only **one** chiral center
  - Epimers are diastereomers; diastereomers have different physical properties (i.e., water solubility, melting temp)
  - Example:
  - Glc & Man (2 epimer); Glc & Gal (4 epimer); Rib & Ara; Rib & Xyl
- Anomers
  - Anomers have different chirality at carbon involved in ring formation

Carbohydrates

Monosaccharides: What are these "ring" forms?

- SUGARS WITH ≥5 CARBONS RAPIDLY AND STABLY FORM **RINGS** THROUGH HEMIACETAL (ALDOSES) AND HEMIKETAL (KETOSES) BONDS.

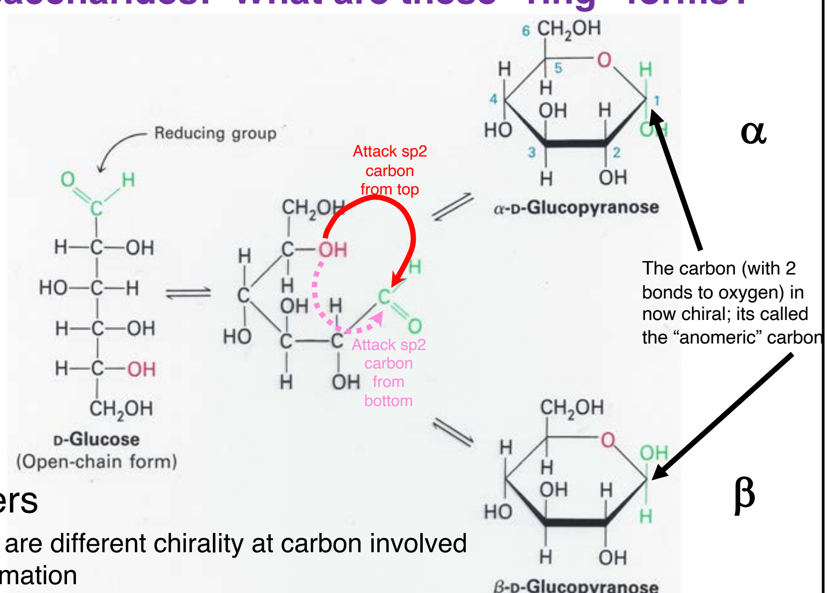
Hemiacetals



- If the aldehyde (R^1) and the alcohol (R^2) are on the same molecule, you have a RING!
- Due to the oxygen, the ring is heterocyclic

Carbohydrates

Monosaccharides: What are these "ring" forms?



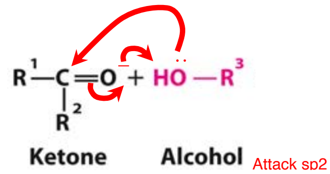
- Anomers
  - Anomers are different chirality at carbon involved in ring formation
  - These are designated α (OH down) or β (OH up)

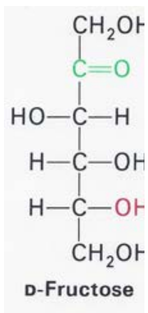
*for D-sugars

Carbohydrates

Monosaccharides: What are these "ring" forms?

Hemiketals





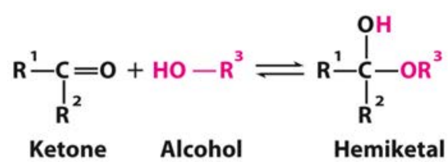
α (OH down) or β (OH up)

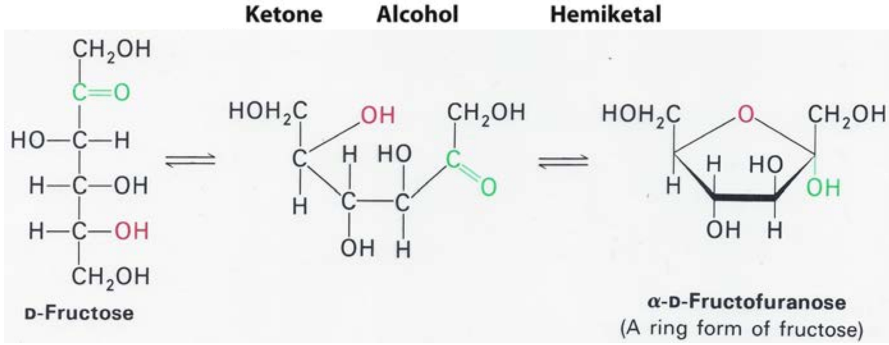
Besides the α & β, what is this pyran and furan?
Its all about which alcohols are used in these reactions.

Carbohydrates

Monosaccharides: What are these "ring" forms?

Hemiketals





α (OH down) or β (OH up)

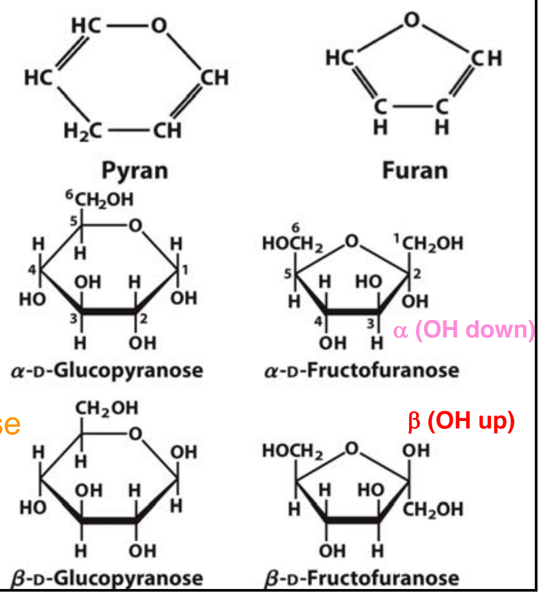
Besides the α & β, what is this pyran and furan?
Its all about which alcohols are used in these reactions.

Carbohydrates

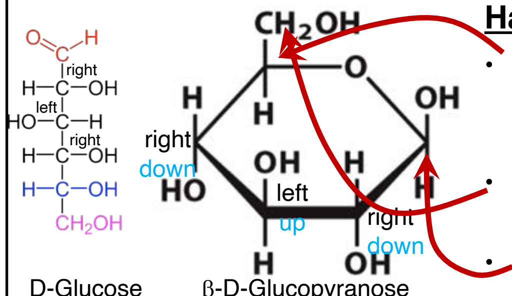
Monosaccharides: What are these "ring" forms?

- Six-membered oxygen-containing rings are called pyranoses after the pyran ring structure.
- Five-membered oxygen-containing rings are called furanoses after the furan ring structure.

The way we are drawing these sugars is called a Haworth projection…..

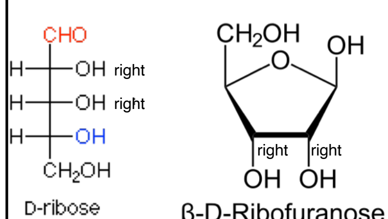


Carbohydrates



Haworth projections

- Highest carbon with hemiacetal/hemiketal alcohol in back; oxygen to right.
- If chiral (as for D-sugars), next highest carbon up if D, or down if L.
- The anomeric carbon is usually drawn on the right side.
- Other chiral carbons are down if right in Fisher projection and up if left in Fisher



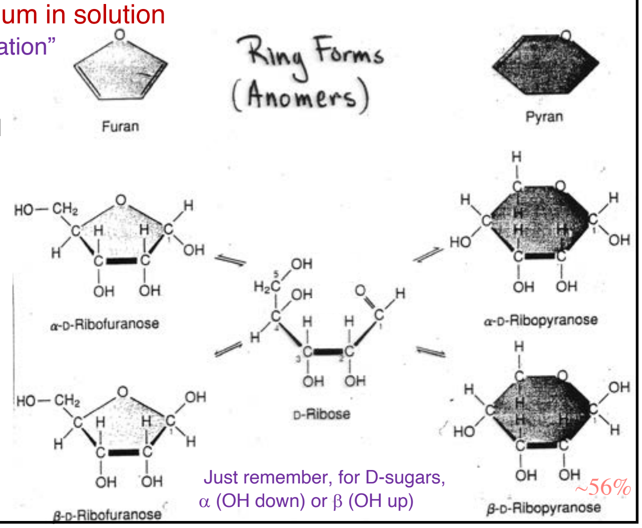
- β-D-Glc pyranose goes up, down, up down, up as you go from C5 to C1
- β-D-Rib furanose goes up, down, down, up as you go from C4 to C1

Carbohydrates

- Pentoses and hexoses readily undergo intramolecular cyclization.
- The former carbonyl carbon becomes a new chiral center, called the anomeric carbon.
- ALL forms are in equilibrium in solution

  Process is called "mutarotation"

  - When the former carbonyl oxygen becomes a hydroxyl group, the position of this group determines if the anomer is *α* or *β*.
  - If the hydroxyl group is on the opposite side (trans) of the ring as the CH_2OH moiety, the configuration is *α*.
  - If the hydroxyl group is on the same side (cis) of the ring as the CH_2OH moiety, the configuration is *β*.



Just remember, for D-sugars,
α (OH down) or β (OH up)

Carbohydrates

Relative amounts of tautomeric forms for some monosaccharide sugars at equilibrium in water at 40°C[a]

Monosaccharide	Relative Amount (%)				
	α-Pyranose	β-Pyranose	α-Furanose	β-Furanose	Total Furanose
➡ Ribose	20	56	6	18	24
Lyxose	71	29	b	b	<1
Altrose	27	40	20	13	33
➡ Glucose	36	64	b	b	<1
➡ Mannose	67	33	b	b	<1
➡ Fructose	3	57	9	31	40

[a] In all cases, the open-chain form is much less than 1%. For data on other sugars, see S. J. Angyal, The composition and conformation of sugars in solution, *Angew. Chem.* 8:157–226(1969).

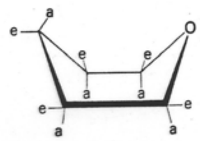
[b] Much less than 1%.

Why is the β-Glc more stable than α-Glc, and *visa versa* for Man?
to answer this, we need to look at **ACTUAL** structures.
These Haworth Projections are not the actual conformation…. What is?

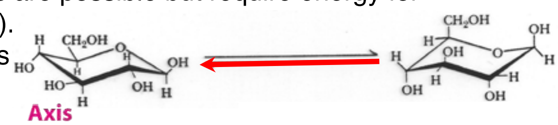
Carbohydrates

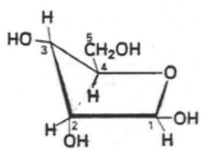
Actual Conformations of Cyclized Monosaccharides

- Cyclohexane rings have “chair” or “boat” conformations.

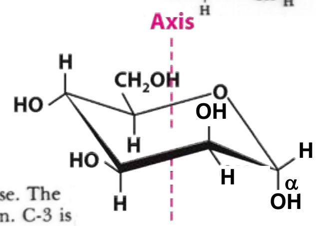



- Pyranose rings favor “chair” conformations.
- Multiple “chair” conformations are possible but require energy for interconversion (~46 kJ/mole).
- Furanose rings are envelopes





An envelope form of β-D-ribose. The $C_{3'}$-*endo* conformation is shown. C-3 is out of plane on the same side as C-5.



We can understand why there is a 2:1 ratio of β:α glucose….. steric hindrance

AND why α–mannose is favored (2:1 ratio of α:β)

Two possible chair forms of β-D-glucopyranose