BIO 311C
Spring 2010

Grades for Exam 1 will be available on BlackBoard by the end of today.

Your graded exam will be returned to you during your discussion period on Friday or Monday.

The mean grade for exam 1 was 72 %.
The standard deviation was 14.

Lecture 12 – Wednesday 17 Feb.

Definition:

A carbohydrate is a simple sugar, a modified sugar, or a polymer of a sugar.

Thus, in order to understand carbohydrates it is necessary to understand sugars.

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Description of a simple sugar

A simple sugar consists of a chain (usually unbranched, with 3 - 7 carbon atoms), with the following characteristics:

1. One of the carbon atoms occurs as an aldehyde or else a ketone functional group.
2. Each of the other carbon atoms occurs as an alcohol functional group
3. Hydrogen atoms are attached to all other positions on the carbon atoms in order to satisfy their covalencies.

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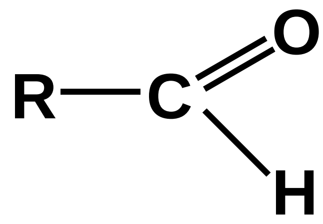
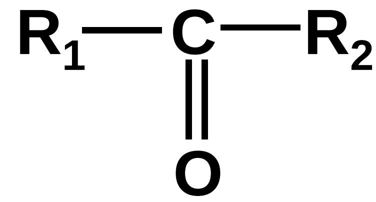
aldehyde functional group

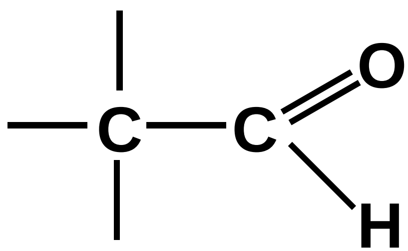
ketone functional group

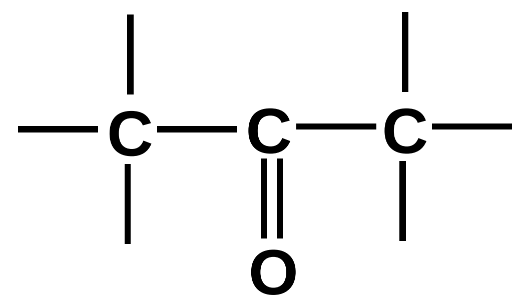
standard representation





more descriptive representation





The carbon atom that forms the aldehyde or ketone functional group must also be covalently bonded to another carbon atom or to a hydrogen atom.

Aldehyde and ketone functional groups are very similar to each other in their chemical properties and in their biological functions.

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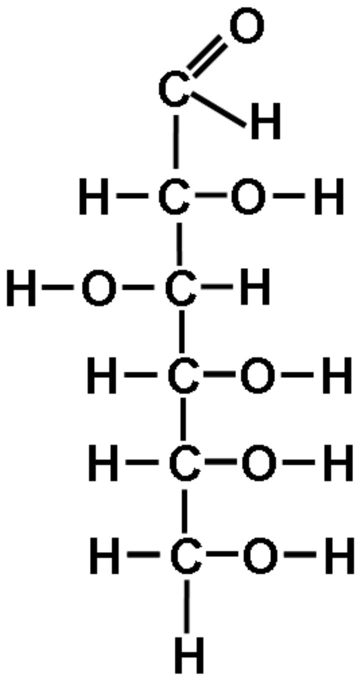
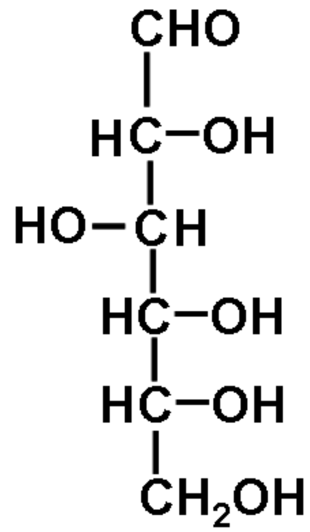
Structural Formula of a 6-carbon Sugar

formula with all covalent bonds shown



an acceptable slightly abbreviated structure, with not all covalent bonds shown



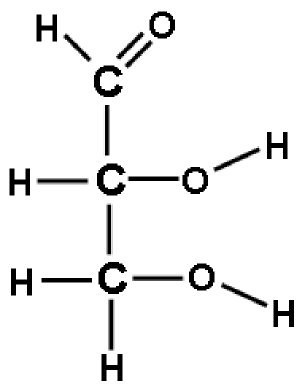
D-glucose

It is standard practice to show a sugar with the carbon atoms oriented vertically, and with the aldehyde or ketone functional group at (or near to) the top of the molecule.

Formulas that represent sugars

$C_3H_6O_3$

chemical formula

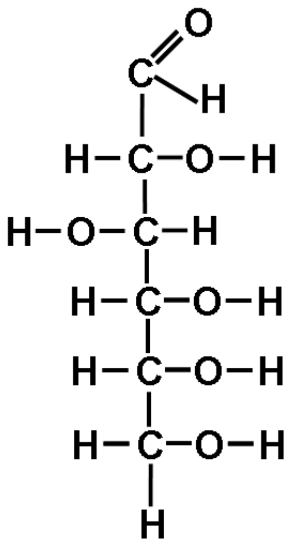


structural formula

A 3-carbon sugar (also called a C_3 sugar)

$C_6H_{12}O_6$

chemical formula



structural formula

A 6-carbon sugar (also called a C_6 sugar)

note that C, H and O occur in a 1:2:1 ratio ($C_nH_{2n}O_n$) or $(CH_2O)_n$ in sugars.

The name carbohydrate indicates "carbon-water", suggested by the ratios of the atoms that occur in sugars.

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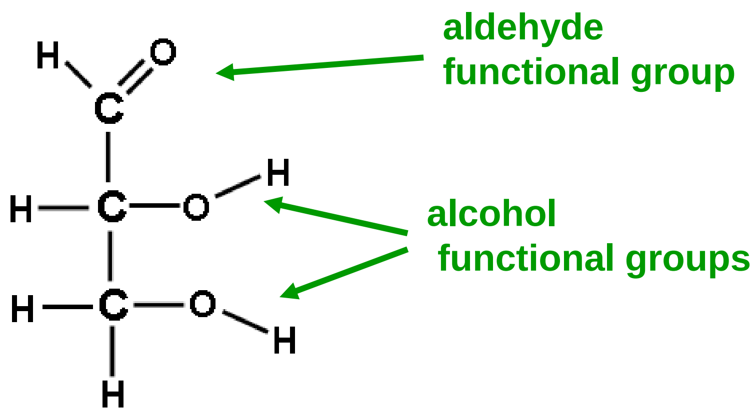
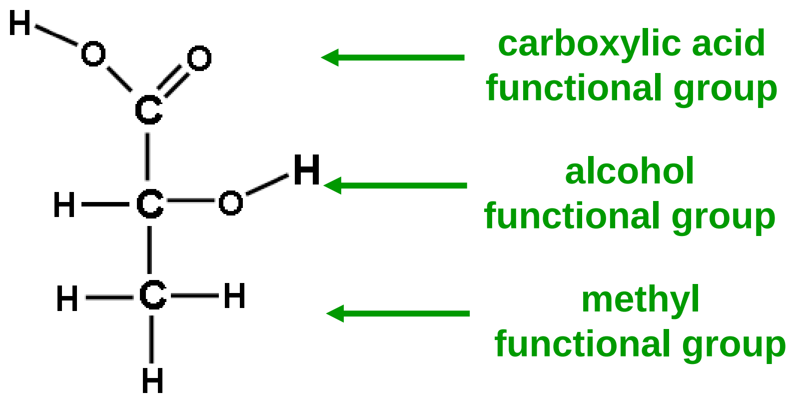
Chemical formulas are generally not sufficient to represent the chemical nature of sugars.

Example: Two compounds, each with the chemical formula $C_3H_6O_3$, but with very different structural formulas and even different functional groups:



a C_3 sugar
($C_3H_6O_3$)



a C_3 compound that is <u>not</u> a sugar
($C_3H_6O_3$)

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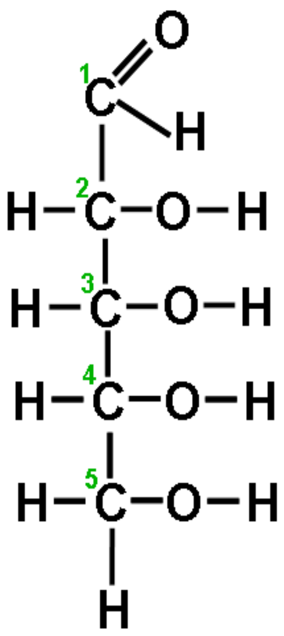
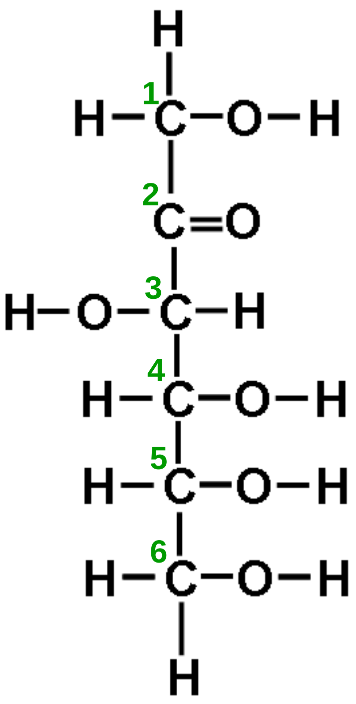
Carbon atoms of sugars are numbered from the top down.



A C_5 sugar



A C_6 sugar

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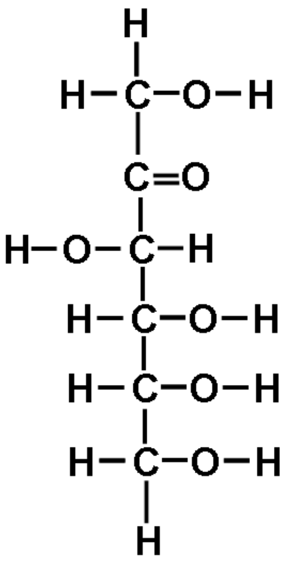
Generic names of sugars:

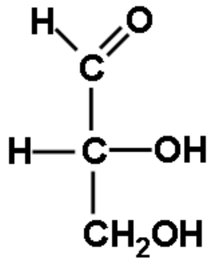
(1) indicate whether the sugar contains an aldehyde or a ketone functional group;

(2) indicate the number of carbon atoms in the sugar;

(3) indicate that it is a carbohydrate, by giving it a suffix of "-ose".



A ketone sugar (ketose)
A 6-carbon sugar (hexose)
A more complete name is ketohexose



An aldehyde sugar (aldose)
A 3-carbon sugar (triose)
A more complete name is aldotriose

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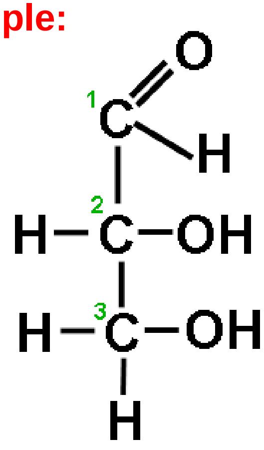
Description of an Asymmetric Carbon Atom
(A Carbon Chiral Center)

A carbon atom in an organic molecule is a center of asymmetry if:

1. **There are 4 chemical groups* bound to the carbon atom (no double bonds), and**
2. **Each of the four chemical groups is distinct as viewed from the carbon atom.**

Example:



glyceraldehyde

Why is carbon atom 2 of this molecule asymmetric, while carbon atoms 1 and 3 are not?

glyceraldehyde, the simplest of sugars, is one of only a very few sugars whose name does not end in "ose".

***The term "chemical group", as used here, can be as simple as a single hydrogen atom or can be a large and complex portion of the molecule.**

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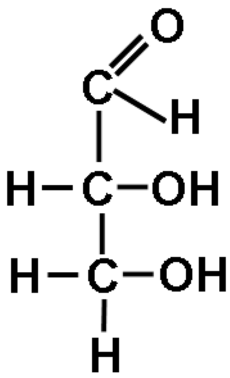
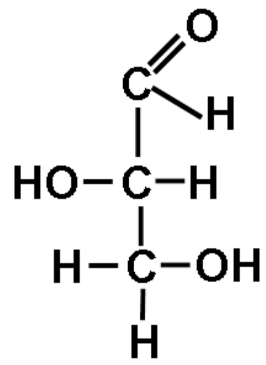
Enantiomers of Glyceraldehyde

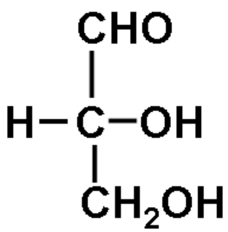


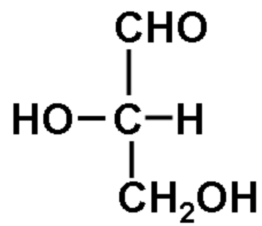


All atoms and covalent bonds shown

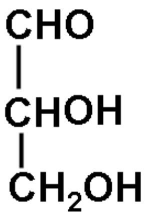
D-glyceraldehyde

L-glyceraldehyde





Not all covalent bonds are shown, but the structure remains sufficiently detailed to know the complete structural formula.



The structural formula of glyceraldehyde shown here is too abbreviated to reveal its structural formula because it does not indicate if the molecule is D or L glyceraldehyde.

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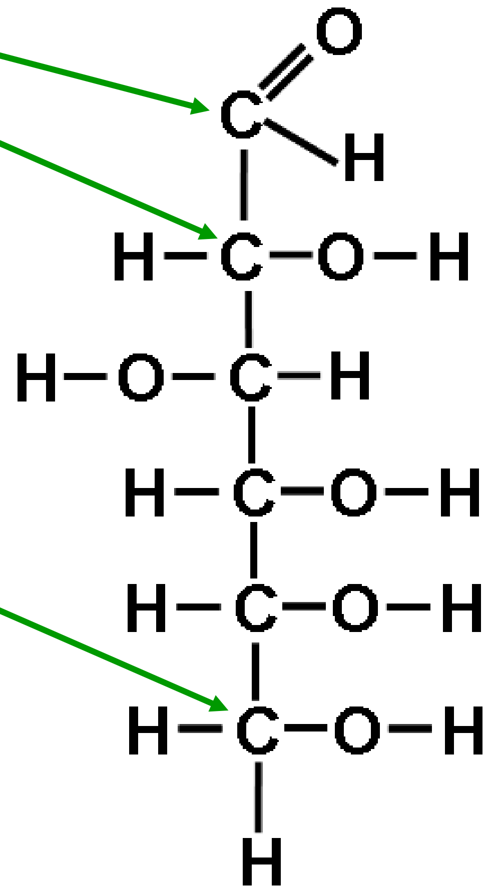
Asymmetric Carbons in an Aldohexose

Is carbon-atom 1 asymmetric?

Is carbon-atom 2 asymmetric?

Is carbon-atom 6 asymmetric?



Glucose

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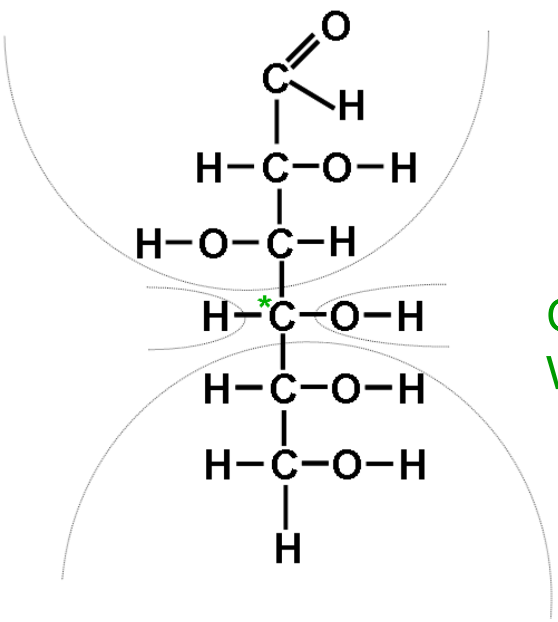
Asymmetric Carbon Atoms in Glucose



Glucose

Carbon atom 4 is an asymmetric carbon atom.
What about carbon atoms 2, 3 and 5?

To determine if a carbon atom is asymmetric, it is necessary to compare each entire unit (chemical group) projecting from the carbon atom, not just the immediately adjacent atom or functional group.

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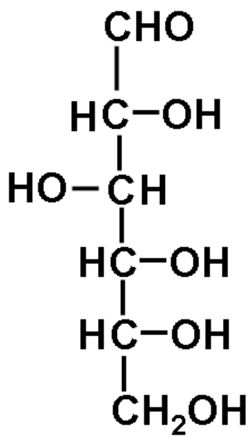
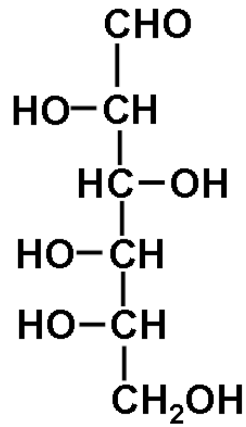
There are two forms of glucose.
They are "mirror images" of each other.



D-glucose



L-glucose

The two enantiomers of glucose appear to be identical in ordinary chemical reactions. Yet they are easily distinguishable by living cells. Cells actively take up D-glucose from their environment, they can synthesize it, and they use it extensively as a source of both food and energy. Cells do not incorporate, synthesize or utilize L-glucose. They ignore it.

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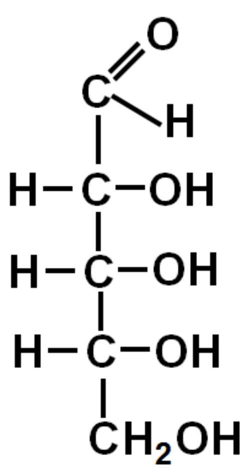
Definition:

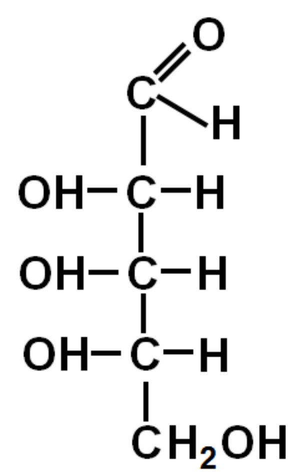
<u>A pair of enantiomers</u> - Two compounds whose structural formulas are identical except that they are mirror images of each other.

The two compounds of an enantiomer pair appear to be identical in virtually all chemical reactions and physical properties. Yet they are easily distinguished by living cells, and they are chemically and physically treated very differently by cells.

Example



D-ribose



L-ribose

An enantiomer pair

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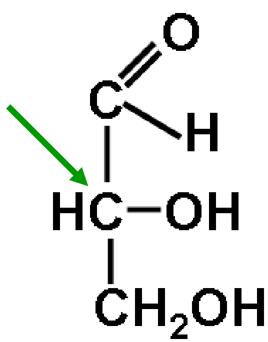
Rule: When a sugar molecule is written in standard form with the carbon atoms shown vertically, then it is a "D" sugar if the alcohol functional group on the next-to-last carbon atom is written to the right. It is an "L" sugar if the alcohol functional group on the next-to-last carbon atom is written to the left.

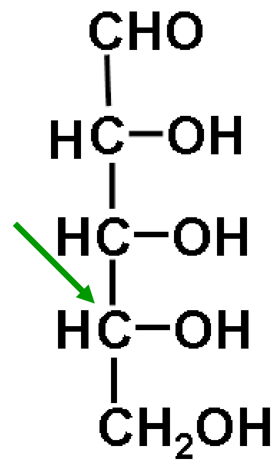
Nearly all naturally-occurring sugars are "D" sugars.

Examples:

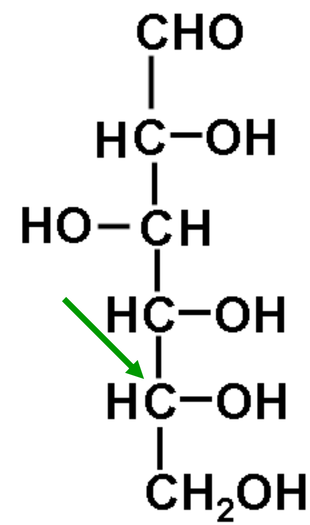
Arrows point to the next-to-last carbon atom.



D-glyceraldehyde



D-ribose



D-glucose

Note: the next-to-last carbon atom is the last asymmetric carbon atom.

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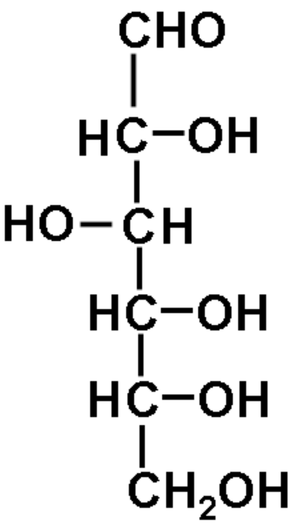
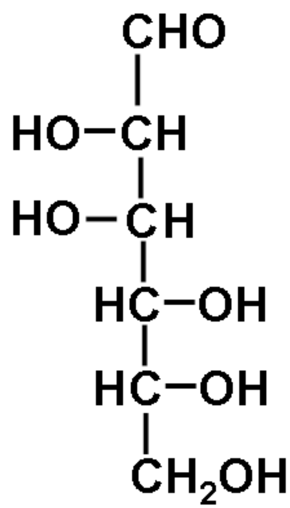
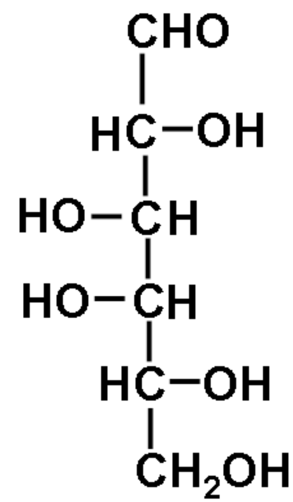
Several different D-aldohexoses, each with its own distinct chemical properties, have important functions in living cells:



D-glucose



D-mannose



D-galactose

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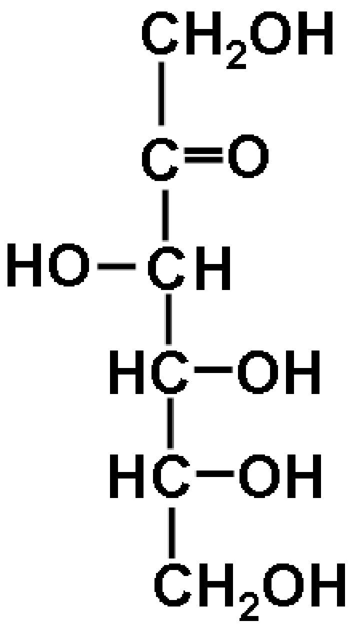
Some questions that could be asked about this molecule:



Is it a sugar?

How many asymmetric carbon atoms does it have?

What kinds of functional groups does it have?

What name could be given to this molecule that describes (1) its number of carbon atoms, (2) whether it is an aldehyde of a ketone, and (3) the general class of molecules to which it belongs.

Is it a D sugar or is it an L sugar?

Although exams in BIO 311C will not require you to be able to reproduce exact structures of specific sugars from memory, you will be expected to draw different classes of biological molecules, and to recognize various features of specific molecules.

The molecule whose structure is shown above is called D-fructose. It is a component of table sugar (sucrose) molecules.

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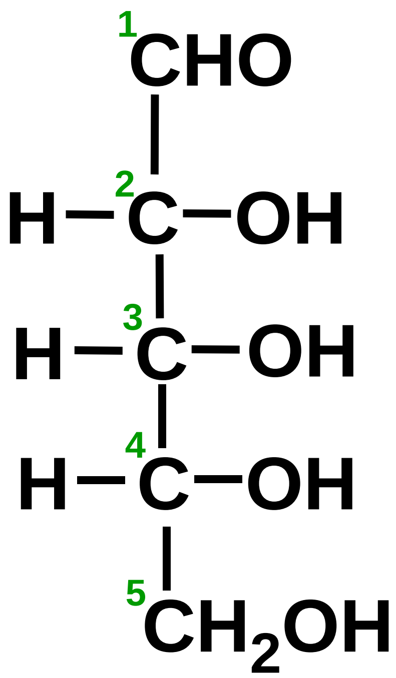
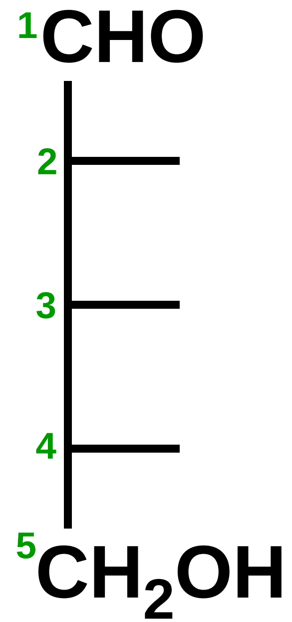
A Very Abbreviated Way of Showing the Structural Formula of a Simple Sugar

Less abbreviated



More abbreviated



D-ribose

In the more abbreviated form
- each intersection of lines represents the location of a carbon atom,
- the horizontal lines each represent alcohol functional groups, and
- an additional hydrogen atom is located on each of carbon of atoms 2, 3 and 4.

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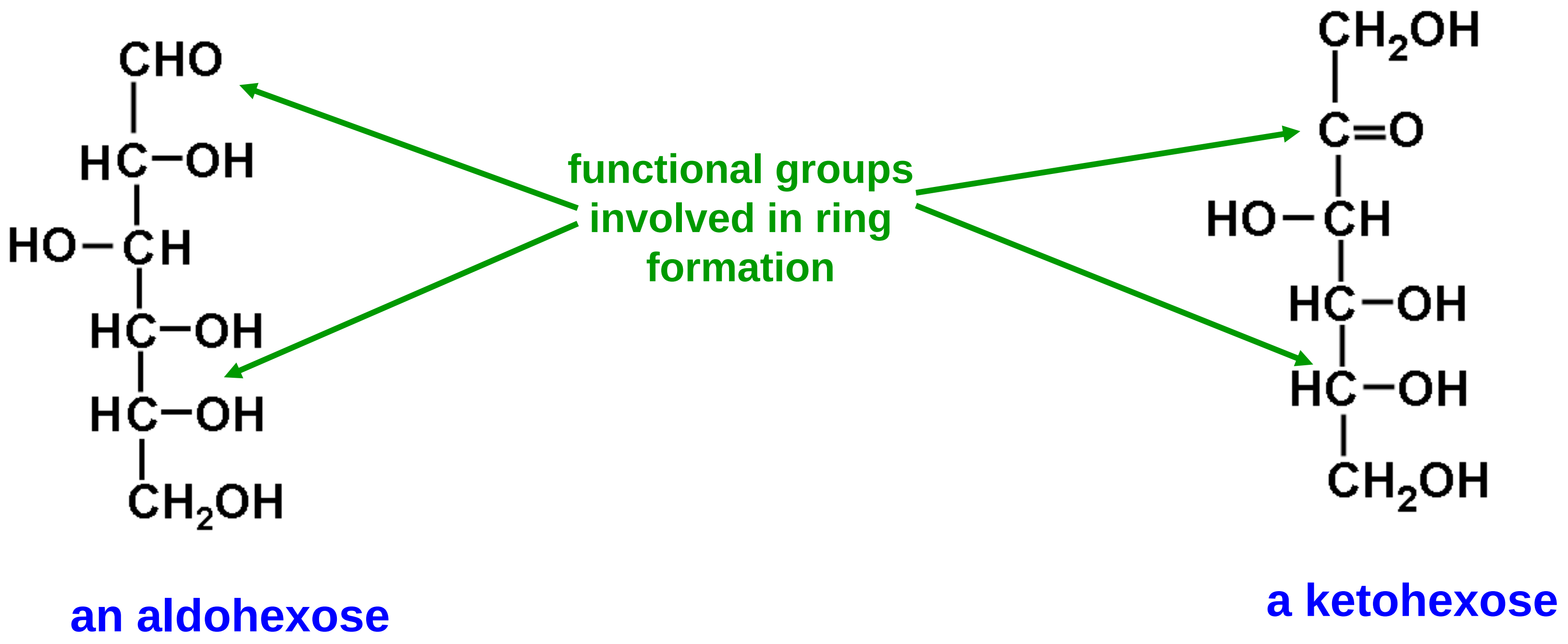
Ring formation in simple sugars

Sugars with 5, 6 or 7 carbon atoms can spontaneously convert into a ring form when dissolved in water. The ring forms between the aldehyde or ketone functional group and the next-to-last carbon atom of the sugar.



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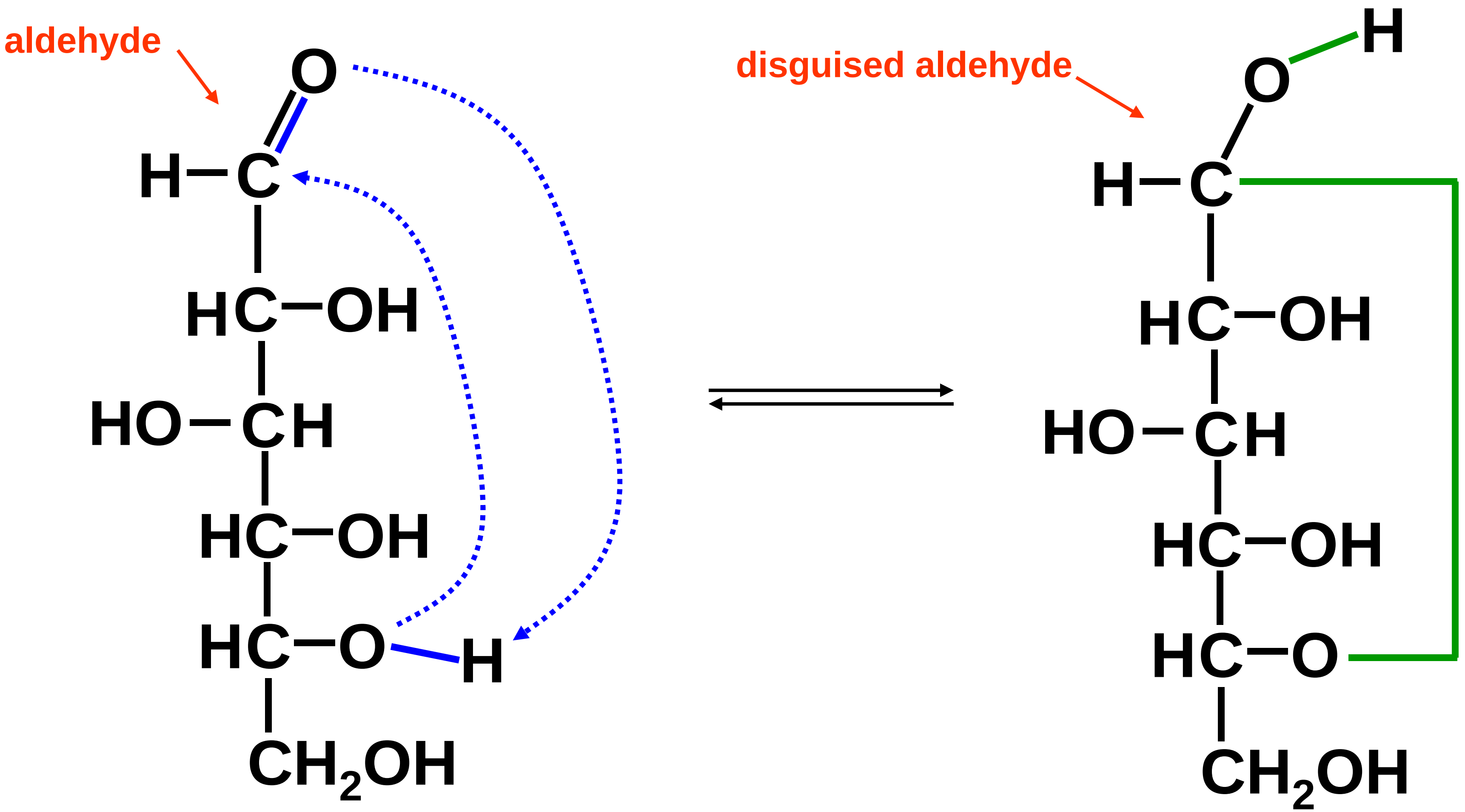
Reversible interconversion of the straight-chain form and a ring form of D-glusose



Solid blue lines represent covalent bonds broken in order to produce the ring; dotted blue lines show atoms that are attracted together in order to form new covalent bonds. Solid green lines represent new covalent bonds that are formed.

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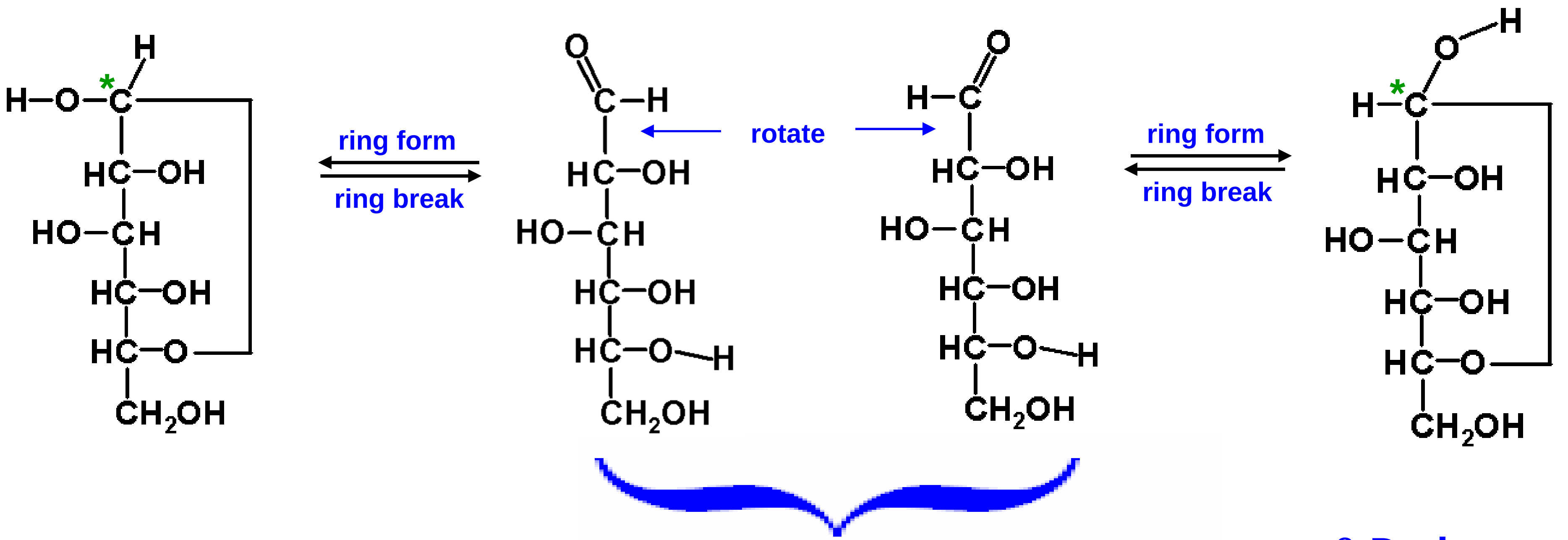
The straight-chain form and two ring forms of D-glucose



α-D-glucose

D-glucose
(the same molecule)

β-D-glucose

The straight-chain form has 4 asymmetric carbon atoms.
Ring forms have 5 asymmetric carbon atoms.
Asterisks show the position of the new asymmetric carbon atom.

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