

## Carbohydrates



'hydrates of carbon'

Also known as **saccharides** (Greek *sákcharon*, meaning "sugar")

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## Introduction

- Constitute  $\frac{3}{4}$  of the biological world
- Made of carbon and water  $C_n(H_2O)_n$
- They fill numerous roles in living things, such as the storage and transport of energy (eg: starch, glycogen) and structural components (eg: cellulose in plants and chitin in animals).

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## What are Carbohydrates made of?

- Chemically, carbohydrates are simple organic compounds that are aldehydes or ketones with many hydroxyl groups added, usually one on each carbon atom that is not part of the aldehyde or ketone functional group.
- The basic carbohydrate units are called **monosaccharides**, such as glucose, galactose, and fructose.

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## What are Carbohydrates made of?

- Monosaccharides can be linked together into what are called polysaccharides (or oligosaccharides) in almost limitless ways. Many carbohydrates contain one or more modified monosaccharide units that have had one or more groups replaced or removed.

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## Monosacchrides

- **Monosacchrides**

- Triose - Sugar that contains three carbons
- Tetrose - Sugar that contains four carbons
- Pentose - Sugar that contains five carbons
- Hexose - Sugar that contains six carbons

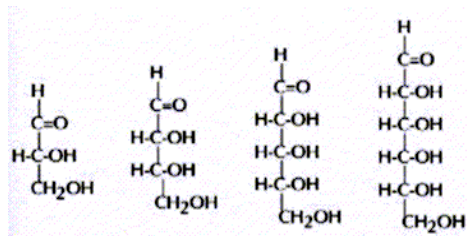
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## Monosacchrides

- Aldoses are monosaccharides with an aldehyde group and many hydroxyl (-OH) groups.
- Ketoses are monosaccharides with a ketone group and many hydroxyl (-OH) groups.

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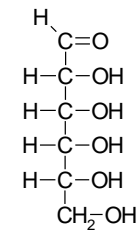
## Monosacchrides



Carbons: 3 4 5 6  
 Name: triose tetrose pentose hexose

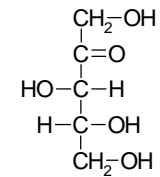
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Identify each as tetrose, pentose or hexose, and as aldose or ketose



A

aldose, hexose



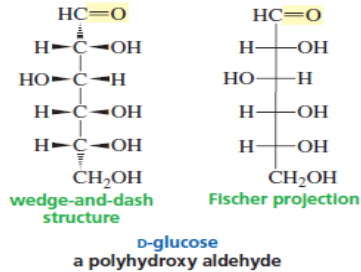
B

ketose, pentose

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## Fischer Projection

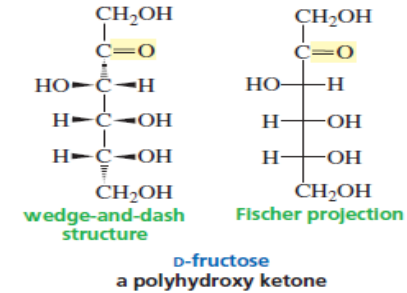
- The chemical structures of carbohydrates are commonly represented by wedge-and-dash structures



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## Fischer Projection

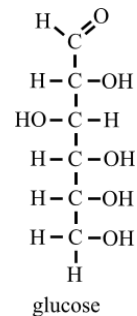
- Fischer projection of Fructose



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## Glucose - Blood Sugar

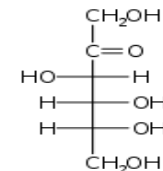
- most common carbohydrate
  - also known as dextrose
- main source of energy
- most quickly absorbed



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## Fructose - Fruit Sugar

- absorbed much slower than glucose
- predominantly metabolized in the liver
  - does not require insulin to be used
- natural sources include:
  - fruits, some vegetables
  - honey, sugar cane and sugar beets
- generally refined from corn starch
- 15 to 80% sweeter than sucrose



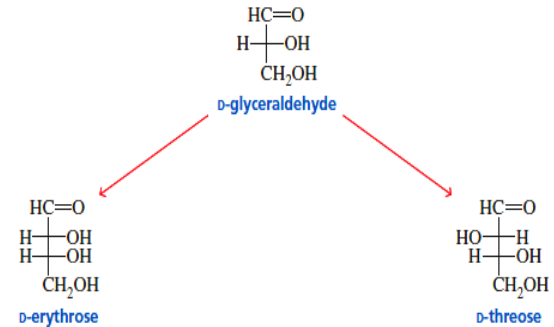
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## The D and L Notation

- The notations D and L are used to describe the configurations of carbohydrates.
- The carbonyl group is always placed on top (in the case of aldoses) or as close to the top as possible (in the case of ketoses).
- If the OH group attached to the bottom-most asymmetric carbon (the carbon that is second from the bottom) is on the right, then the compound is a D-sugar.
- If the OH group is on the left, then the compound is an L-sugar.
- Almost all sugars found in nature are D-sugars. Notice that the mirror image of a D-sugar is an L-sugar.

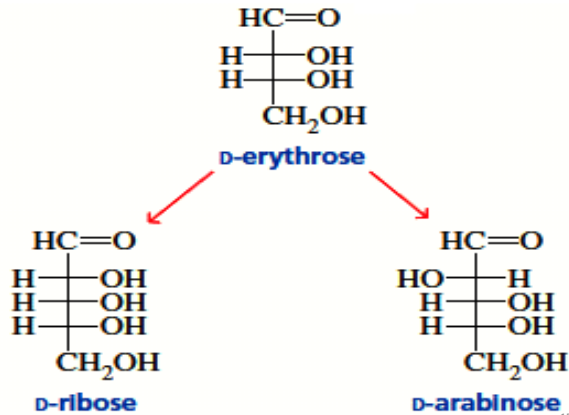
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## Configuration of Aldoses



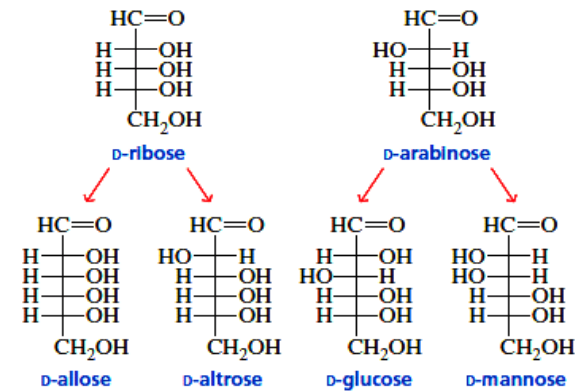
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## Configuration of Aldoses



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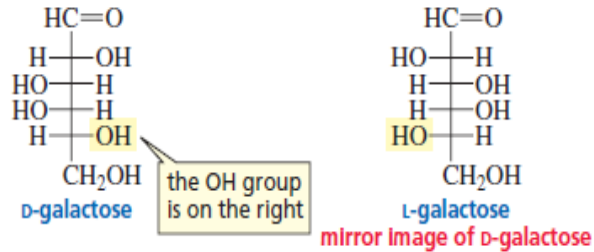
## Configuration of Aldoses



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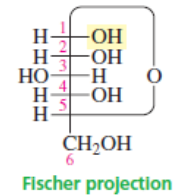
## Difference between a D and L sugar



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## Cyclic Structure of Monosaccharides

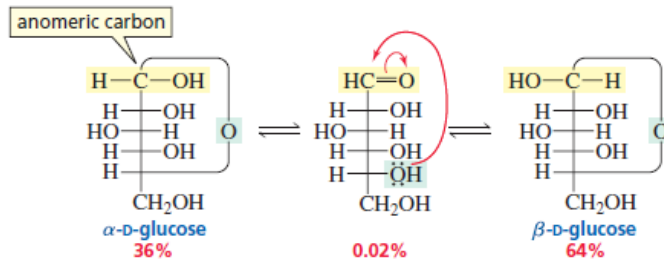
- D-Glucose exists in three different forms: the open-chain form of D-glucose that we have been discussing and two cyclic forms—  $\alpha$ -D-glucose and  $\beta$ -D-glucose
- A monosaccharide such as D-glucose has an aldehyde group and several alcohol groups.
- The alcohol group bonded to C-5 of D-glucose reacts intramolecularly with the aldehyde group, forming a six-membered ring.



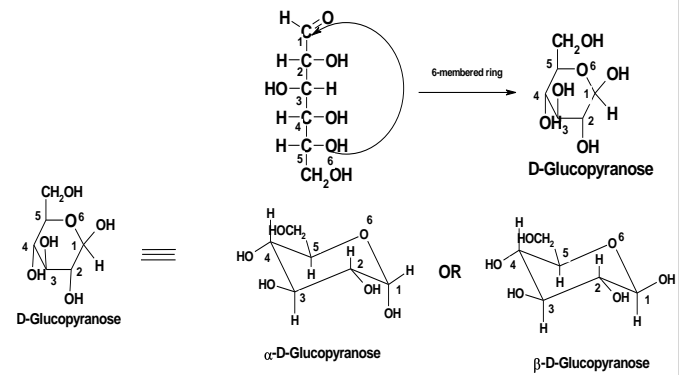
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## Cyclic Structure of Monosaccharides

- $\alpha$ -D-Glucose and  $\beta$ -D-glucose are called anomers.



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## Isomers of Glucose

- **Anomers are two sugars that differ** in configuration only at the carbon that was the carbonyl carbon in the open-chain form.
- This carbon is called the **anomeric carbon**. *Ano is Greek for "upper"; thus, anomers differ in configuration at the upper-most asymmetric carbon.*
- The anomeric carbon is the only carbon in the molecule that is bonded to two oxygens.
- The prefixes and denote the configuration about the anomeric carbon.

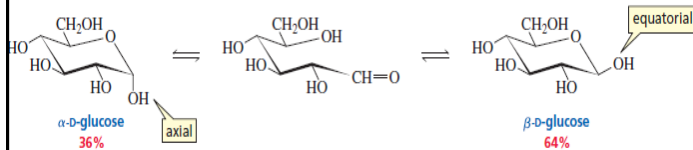
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## Isomers of Glucose

- Why is there more  $\beta$ -D-glucose than  $\alpha$ -D-glucose in an aqueous solution at equilibrium?
- The OH group bonded to the anomeric carbon is in the equatorial position in  $\beta$ -D-glucose, whereas it is in the axial position in  $\alpha$ -D-glucose. Therefore,  $\beta$ -D-glucose is more stable than  $\alpha$ -D-glucose, so  $\beta$ -D-glucose predominates at equilibrium in an aqueous solution.

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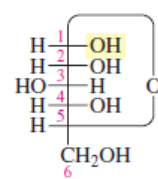
## Relationship between $\alpha$ -D-Glucose and $\beta$ -D-Glucose



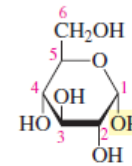
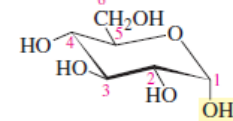
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## Different representations of $\alpha$ -D-Glucose

- The  $\alpha$ -position is to the right in a Fischer projection, down in a Haworth projection, and axial in a chair conformation.



Fischer projection

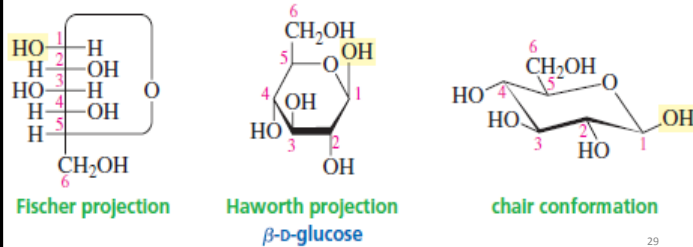
Haworth projection  
 $\alpha$ -D-glucose

chair conformation

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## Different representations of $\beta$ -D-glucose

- The  $\beta$ -position is to the left in a Fischer projection, up in a Haworth projection, and equatorial in a chair conformation.



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## Relationship between Haworth and Fischer projections

- In a Haworth projection of a D-pyranose, the six-membered ring is represented as flat and is viewed edge on.
- The ring oxygen is always placed in the back right-hand corner of the ring, with the anomeric carbon (C-1) on the right-hand side and the primary alcohol group drawn up from the back left-hand corner (C-5).
- Groups on the right in a Fischer projection are down in a Haworth projection, whereas groups on the left in a Fischer projection are up in a Haworth projection.

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## Use of Monosaccharides in living organisms

- Monosaccharides are the major source of fuel for metabolism, being used both as an energy source (glucose being the most important in nature) and in biosynthesis.
- When monosaccharides are not immediately needed by many cells they are often converted to more space efficient forms, often polysaccharides.
- In many animals, including humans, this storage form is glycogen, especially in liver and muscle cells. In plants, starch is used for the same purpose.

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## Disaccharides




- Two joined monosaccharides are called a disaccharides and these are the simplest polysaccharides.
- Examples include sucrose , lactose (containing Glucose and galactose) and maltose (containing two glucose molecules)

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**All** carbohydrates are composed of single sugars, alone or in various combinations

- Monosaccharides

- Glucose 
- Fructose 
- Galactose 

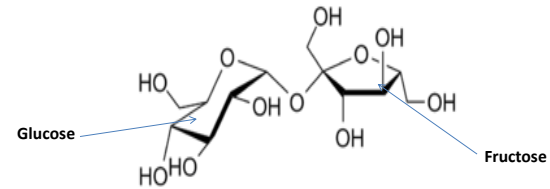
- Disaccharides

- Sucrose 
- Lactose 
- Maltose 

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## Sucrose

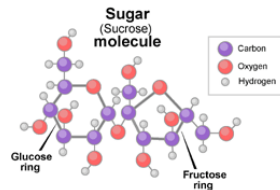
- Sucrose, also known as table sugar, is a common disaccharide. It is composed of two monosaccharides: glucose (left) and fructose (right).



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## Sucrose

- Single most abundant pure organic chemical in the world
- Table sugar
- Whether raw or refined, common sugar is sucrose



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## Oligosaccharides and Polysaccharides

- Oligosaccharides and polysaccharides are composed of longer chains of monosaccharide units bound together by glycosidic bonds.
- The distinction between the two is based upon the number of monosaccharide units present in the chain.

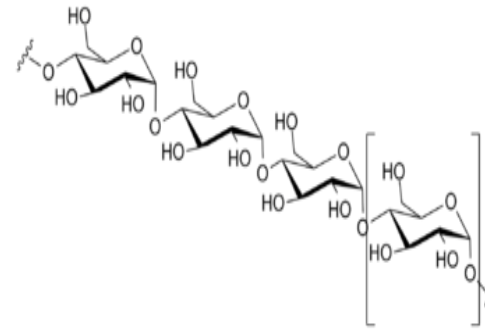
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### Oligosaccharides and polysaccharides

- Oligosaccharides typically contain between three and nine monosaccharide units
- Polysaccharides contain greater than ten monosaccharide units.
- Cellulose and starch are examples of structural polysaccharides.

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### Oligosaccharides and polysaccharides



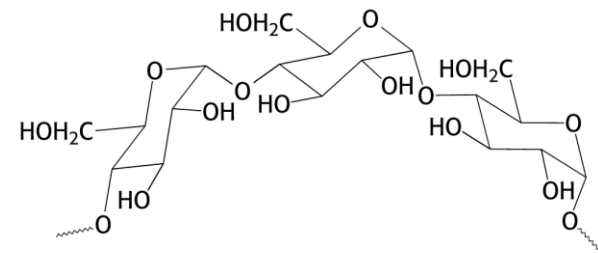
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## STARCH

- Starch is the plant form of carbohydrate ingested by humans.
- Plants synthesize two forms of starch, amylose and amylopectin
- About 20% of starch is in the amylose form and the rest is amylopectin.
- Amylose is an unbranched starch comprised of glucose units ( $\alpha$ -1,4 linkage).
- Amylopectin is the branched form with  $\alpha$ -1,4 linkage to the  $\alpha$ -1,6 linkage.
- $\alpha$ -amylase secreted by salivary glands and the pancreas hydrolyzes amylose and amylopectin.

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### Glycoside linkages in Glucose and Glycogen (to be discussed shortly)



**Starch and Glycogen**  
( $\alpha$ -1,4 linkages)

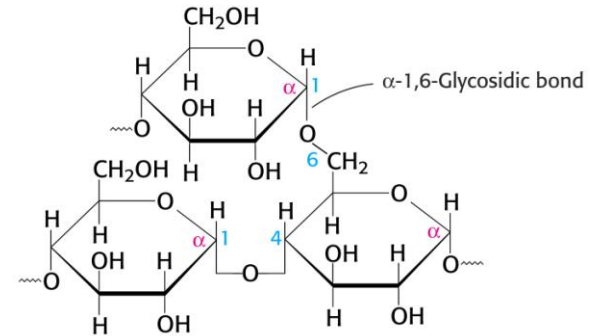
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## Glycogen – a homopolymer of Glucose

- The most common homopolymer in animal cells is glycogen.
- Glycogen is the storage form of glucose.
- Predominantly found in liver and muscle.
- Glycogen is a highly branched polysaccharide made of multiple glucose units linked by  $\alpha$ -1,4 and  $\alpha$ -1,6-glycosidic bonds.

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## Structure of Glycogen



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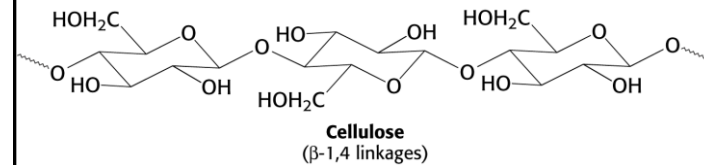
## Cellulose

- The most abundant cell-wall and structural polysaccharide in the plant world is cellulose, a linear polymer of D-glucose with  $\beta$ (1-4) linkages.
- Cellulose is the principal component of wood and thus of paper; cotton is approximately 72% (by weight) pure cellulose.

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## Structure of Cellulose

The only chemical difference between starch and cellulose, both homopolysaccharides of D-glucose, is that starch has  $\alpha$ (1-4) linkages and cellulose  $\beta$ (1-4).



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## Cellulose

- Enzymes capable of hydrolyzing the  $\beta(1-4)$  linkages of cellulose are not secreted in the digestive tract of most mammals, which therefore cannot use cellulose as food.
- **Cellulase** is an enzyme that hydrolyses cellulose to its constituent monosaccharide (glucose) and disaccharide (cellobiose) units. It is present in the digestive juices of some wood-boring insects and in various micro-organisms, but not in mammals

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## Why mammals cannot digest Cellulose

- Mammals (except ruminants) lack cellulases and therefore can not digest cellulose.
- The ruminants, however, are an exception: they can digest cellulose since bacteria in the rumen form the enzyme cellulase which hydrolyzes cellulose to D-glucose.
- a **ruminant** is a mammal that digests plant-based food by initially softening it within the animal's first stomach, known as the rumen, then regurgitating the semi-digested mass, now known as cud, and chewing it again.

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## Why mammals cannot digest Cellulose

- The process of rechewing the cud to further break down plant matter and stimulate digestion is called "ruminating".
- Ruminating mammals include cattle, goats, sheep, giraffes, bison, yaks, water buffalo, deer, camels, alpacas, llamas, wildebeest, antelope, etc.

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## Carbohydrates in diet

- Carbohydrates are not essential nutrients in humans: the body can obtain all its energy from protein and fats
- Foods high in carbohydrates include breads, pastas, beans, potatoes, bran, rice and cereals. Most such foods are high in starch.

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