Carbohydrates

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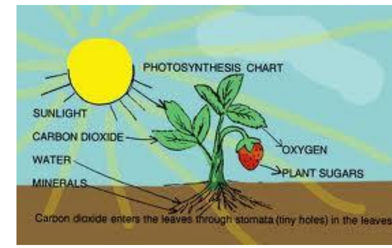
Carbohydrates: Origin & Biological Functionality



Origin: Plants use the energy from sunlight to convert carbon dioxide and water into carbohydrates:

$$6\,CO_2 + 6\,H_2O \xrightarrow{\text{Sunlight}} 6\,O_2 + \underset{\text{Glucose}}{C_6H_{12}O_6} \longrightarrow \text{Cellulose, starch}$$

Function: Carbohydrates are metabolites (sugars), energy storage (starch, glycogen), protective (gum arabic) & structural components (cellulose, pectin, gums)

Carbohydrates

- Carbohydrates make up more than 90% of the dry matter in plants. Abundant in nature, it is the most common ingredient in foods.
- They have different molecular structure, size and shape.
- Their chemical structures and physical properties are also very different.
- They are susceptible to chemical and biochemical modification and thus their properties and uses can be expanded.
- Starch, lactose, glucose, fructose and sucrose can be digested by humans and 70-80% of the total calories taken are caused by these compounds.

Carbohydrates: Origin and Food Functionality

Origin: Carbohydrates are found in a wide range of natural and processed foods

Function: Carbohydrates play many functional roles :

- Major energy source (calories)
- Desirable flavors (sweetness) and colors (browning)
- Chemical reactivity (Maillard reaction etc)
- Water-activity control (humectants)
- Texture modification & stabilization (thickeners, gelling agents, emulsifiers)

Health Attributes: Some carbohydrates impact human health:

- *Detrimental*: Obesity, heart disease, diabetes, tooth decay (sugars)
- *Beneficial*: Energy, Anti-cancer, heart disease (dietary fibers)

Carbohydrates: Common Examples

Some of the most common carbohydrates and where they are typically found:






- **Glucose:** Plants, legumes
- **Sucrose:** Table sugar
- **Fructose:** Fruit sugar
- **Lactose:** Milk sugar
- **Maltose:** Malt sugar
- **Starch:** Major energy storage component of plants
- **Cellulose:** Major structural component of plants (cell wall)
- **Pectin:** Structural component of plants (cell wall)

Carbohydrates (CHs)

- The term carbohydrate refers to a general elemental composition. This composition has the formula $C_x (H_2O)_y$ (CARBON WATER-Carbohydrate)

Exceptions:

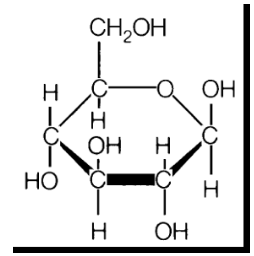
- Although they are not carbohydrates, there are compounds that fit into the same formula: CH_2O: Formaldehyde, $C_2H_4O_2$: acetic acid.
- On the other hand, some type of sugars, do not fit into this formula: Amino sugars. (eg glucose amine-$C_6H_{13}NO_5$).
- Also, some natural carbohydrates in the structure of living organisms do not fit into this formula. (eg. deoxyribose-$C_5H_{10}O_4$, which is in the structure of DNA)

- Most CHs are in the form of oligomers or polysaccharides formed by simple or modified sugars.
- Low molecular weight CHs are generally formed as a result of decomposition of polymers.

Carbohydrates: Categories

Monosaccharides: They are simple structures containing more than one OH in their structure. According to the number of carbon atoms (3, 4, 5, 6), it is called triose, tetrose, pentose or hexose.

- Single carbohydrate units
  - Number of carbon atoms
  - Relative position of OH groups
  - Functional groups (Aldehyde or Ketone)

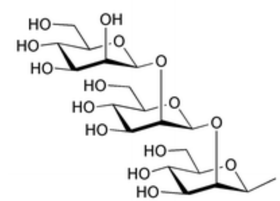


Fructose
Glucose
Galactose
Mannose

Disaccharides: Two monosaccharides are covalently linked.

Oligosaccharides: A few monosaccharides are covalently linked.

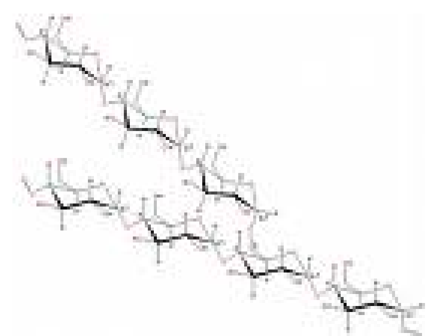
- 3 – 20 monosaccharides
  - Type of monomers
  - Sequence of monomers
  - Bond type



Maltose
Sucrose
Lactose
Inulin

Polysaccharides:They are polymers containing monosaccharide or disaccharide chain.

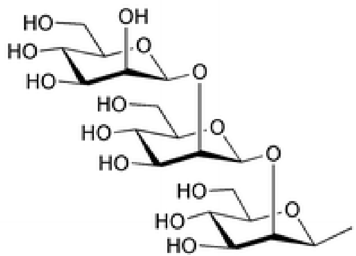
- > 20 monosaccharides
  - Type of monomers
  - Sequence of monomers
  - Bond type



Carbohydrates: General Properties

Molecular

- Molecular Weight
  - Low to High (100 - > 1,000,000 Da)
- Charge
  - Neutral (-OH, -CHO)
  - Some Negative (-SO_4^-, -CO_2^-)
  - Some Positive (-NH_3^+)
- Polarity
  - Mainly Polar
  - Some have Non-polar Side Groups

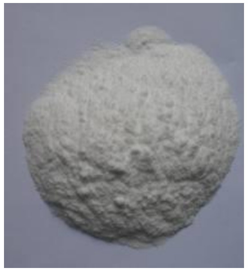


Physicochemical Properties

- Physical State
  - Solid – Crystalline or Glassy
- Solubility
  - Insoluble in oil
  - Most soluble in water, some insoluble
- Reactivity
  - Oxidation/Reduction
  - Maillard & Caramelization
  - .....

Nutritional Properties

- Digestibility
  - Digestible *versus* Non-digestible

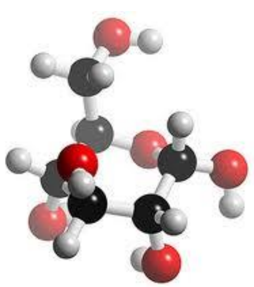


Carbohydrates: Monosaccharides

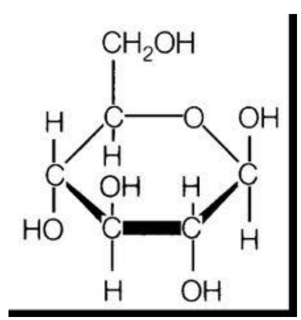
Definition: Monosaccharides are simple organic compounds that consist of a **carbon chain** with an **aldehyde** or **ketone group** attached and a **hydroxyl** group attached to each carbon atom not involved in the carbonyl group. Monosaccharides are called aldose or ketose according to their aldehyde or ketone group.

Simpler CHs that cannot be broken down and are also called **Simple Sugars.** Monomeric units combine to form larger structures.

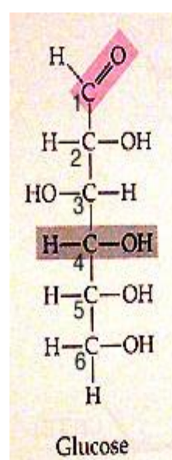
Considering the combined forms of **D-glucose** (mainly cellulose), it is the most abundant organic compound in nature.



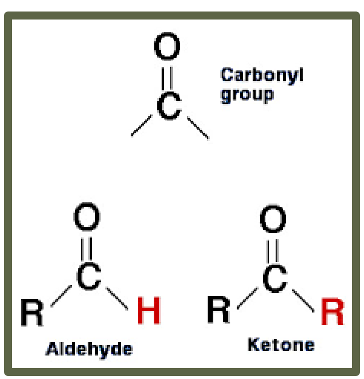
Glucose



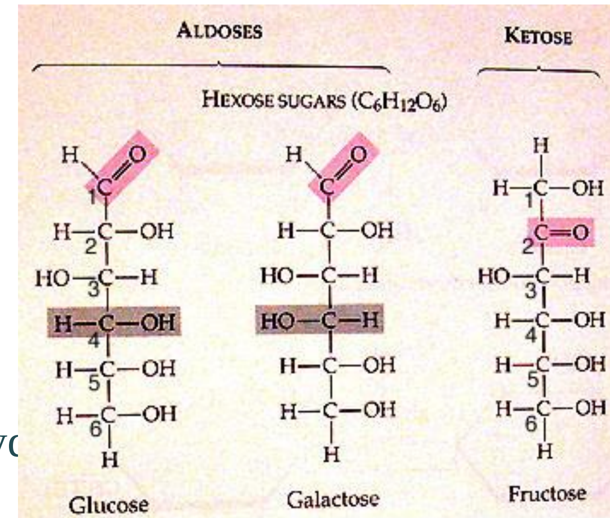
Glucose



Carbonyl



Monosaccharides: Molecular Properties



Chemical formula:

≈ $C_x(H_2O)_y$

Number of carbons:

x = 3 to 9

Typically x = 5 (pentoses) or 6 (hexoses)

Nature of functional groups:

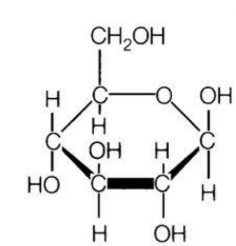
Poly-alcohols (*polyols*) (compound containing multiple hy
groups) with specific functional groups:

Aldehyde (aldoses)

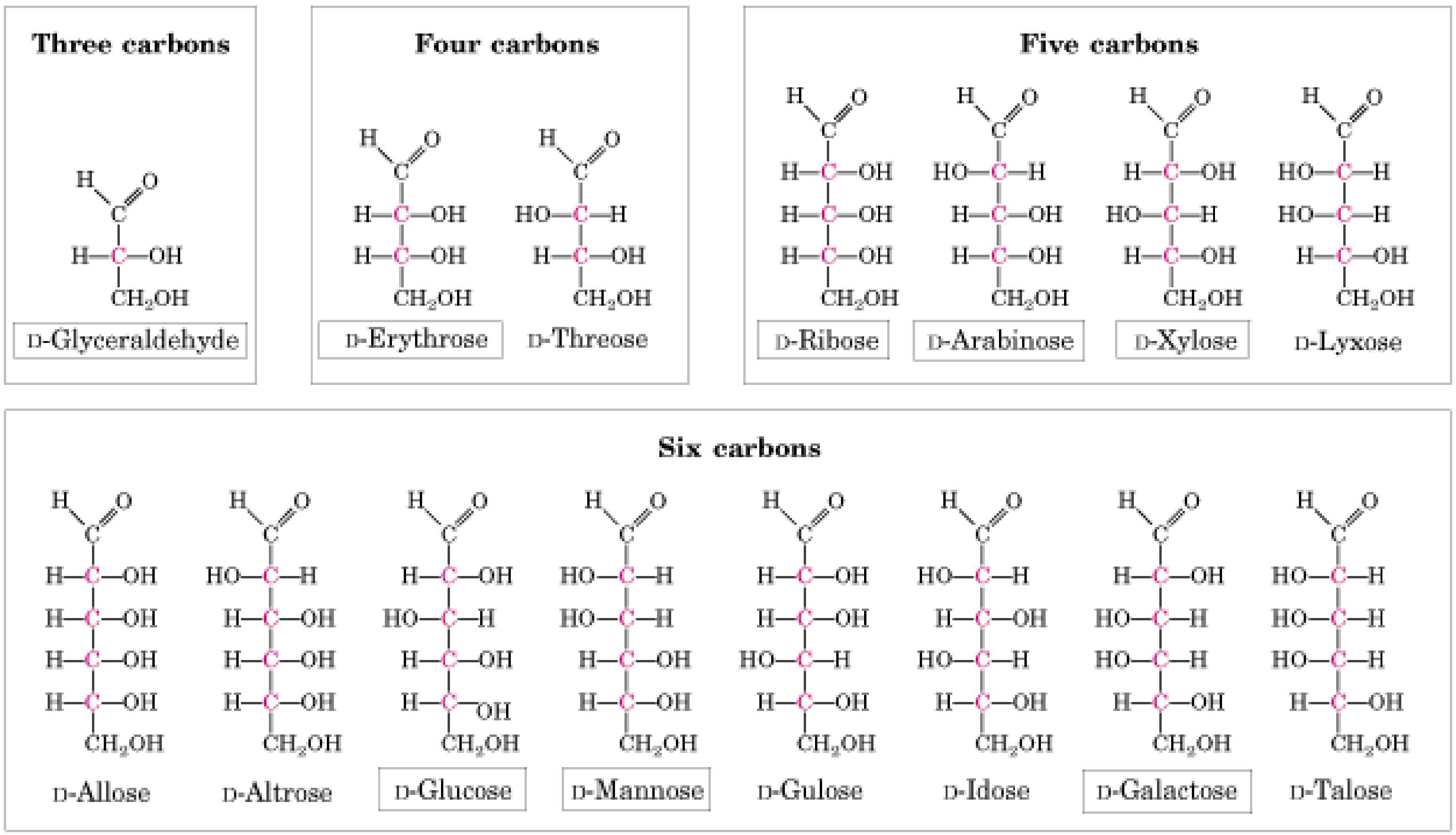
Ketone (ketoses)

Many <u>chiral</u> carbon centers: They contain asymmetric (chiral) carbon atoms in their structure.

Ring structure formation



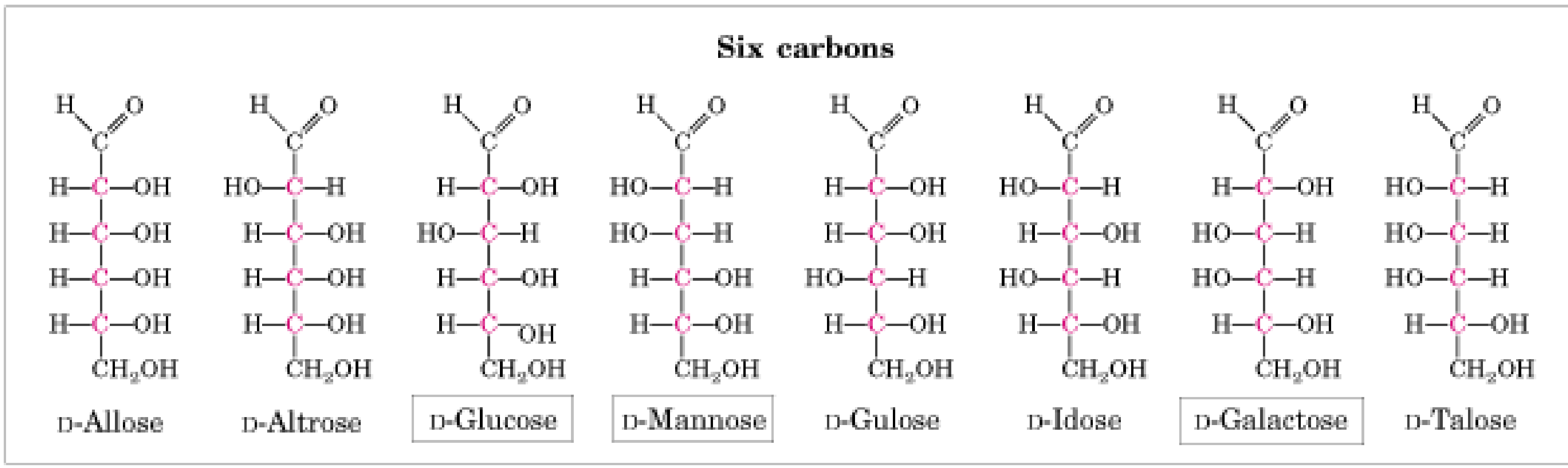
Monosaccharide Nomenclature:
Number of Carbon Atoms



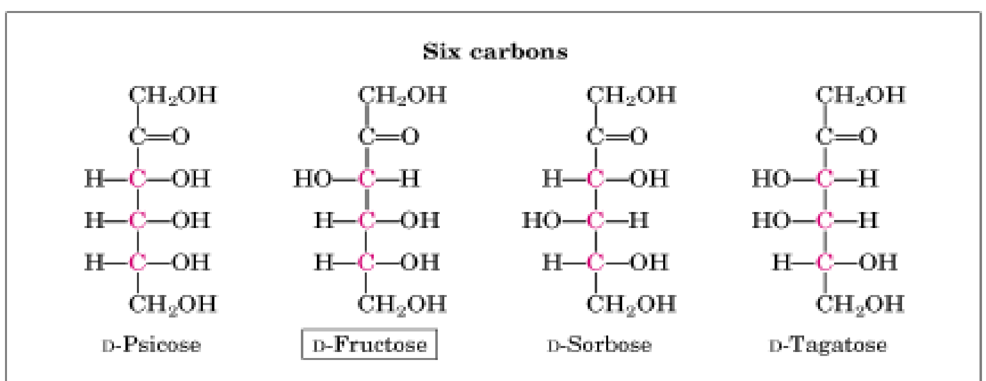
D-Aldoses

Monosaccharides may differ in the number of carbon atoms they contain

Monosaccharide Nomenclature:
Nature of the Carbonyl Group



D-Aldoses



D-Ketoses

Monosaccharides may differ in the nature of the carbonyl group: Aldehyde or Ketone

Monosaccharides: Nomenclature

In principle monosaccharides are structurally simple, but there are many variations

Functional group

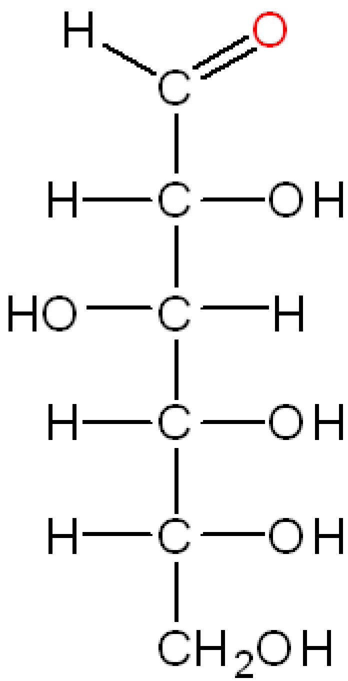
Number of carbons	**Aldoses** (Aldehyde)	**Ketoses** (Ketone)
3	Tri*ose*	Tri*ulose*
4	Tetr*ose*	Tetr*ulose*
5	Pent*ose*	Pent*ulose*
6	Hex*ose*	Hex*ulose*
7	Hept*ose*	Hept*ulose*
8	Oct*ose*	Oct*ulose*
9	Non*ose*	Non*ulose*

ose= sugar

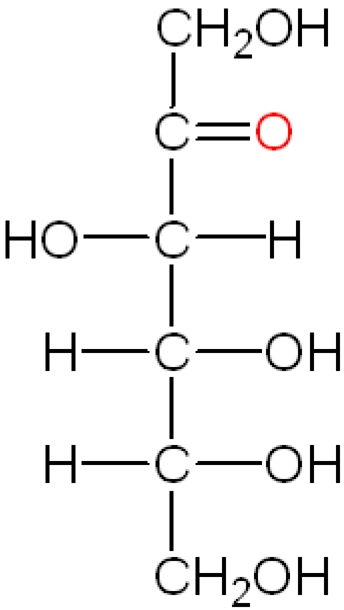
Prefix: Greek Number: **Suffix:**–*ose* (for an aldehyde) or –*ulose* (for a ketone)

Aldoses (eg glucose) contain an aldehyde group at one end.

Ketoses (eg fructose) contain the keto group (usually at C2).



d- glucose



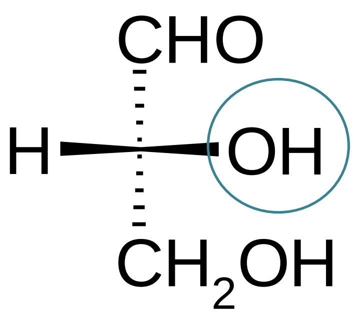
d- fructose

Monosaccharide Nomenclature:
Chirality and Enatiomers

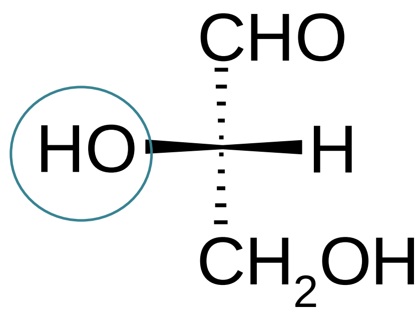
- A carbon atom is **chiral** if it has four different groups attached to it. Chiral compounds have the same molecular formula but are not superimposable – they are mirror images of each other known as **enantiomers (Enantiomers** are characterized as either L-series and D-series**). Enantiomers** are two versions of a molecule that have similar structures but different configurations.

- The relative position of hydroxyl groups in different monosaccharides varies

"D" means -OH group is on the **right** side of chiral carbon (when CHO at top)

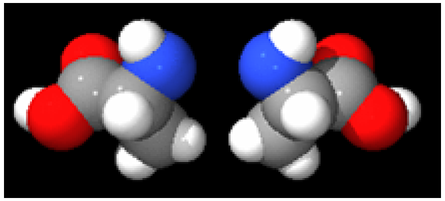


D-glyceraldehyde



L-glyceraldehyde

"L" means -OH group is on the **left** side of chiral carbon (when CHO at top)



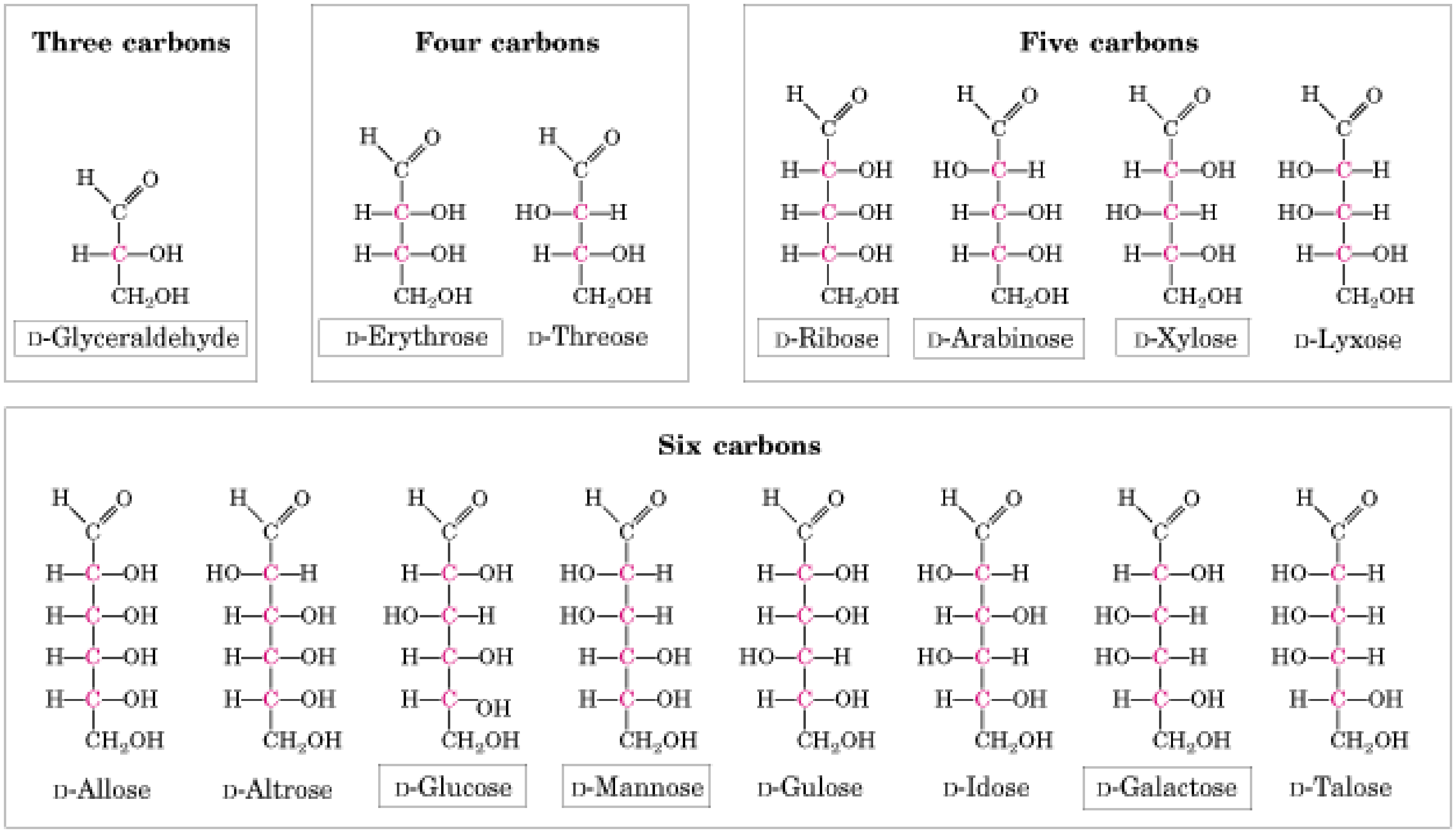
ENANTIOMERS

Number of enantiomers depends on number of chiral groups (n) = 2^n

Thus, since a 6-carbon aldose (eg glucose) has 4 chiral atoms, there is a possibility of forming **2^4** = 16 different sugars. 8 of them are D-series and the other 8 are mirror images of it, or L-series.

Monosaccharides: Aldoses

Aldoses all have an aldehyde functional group

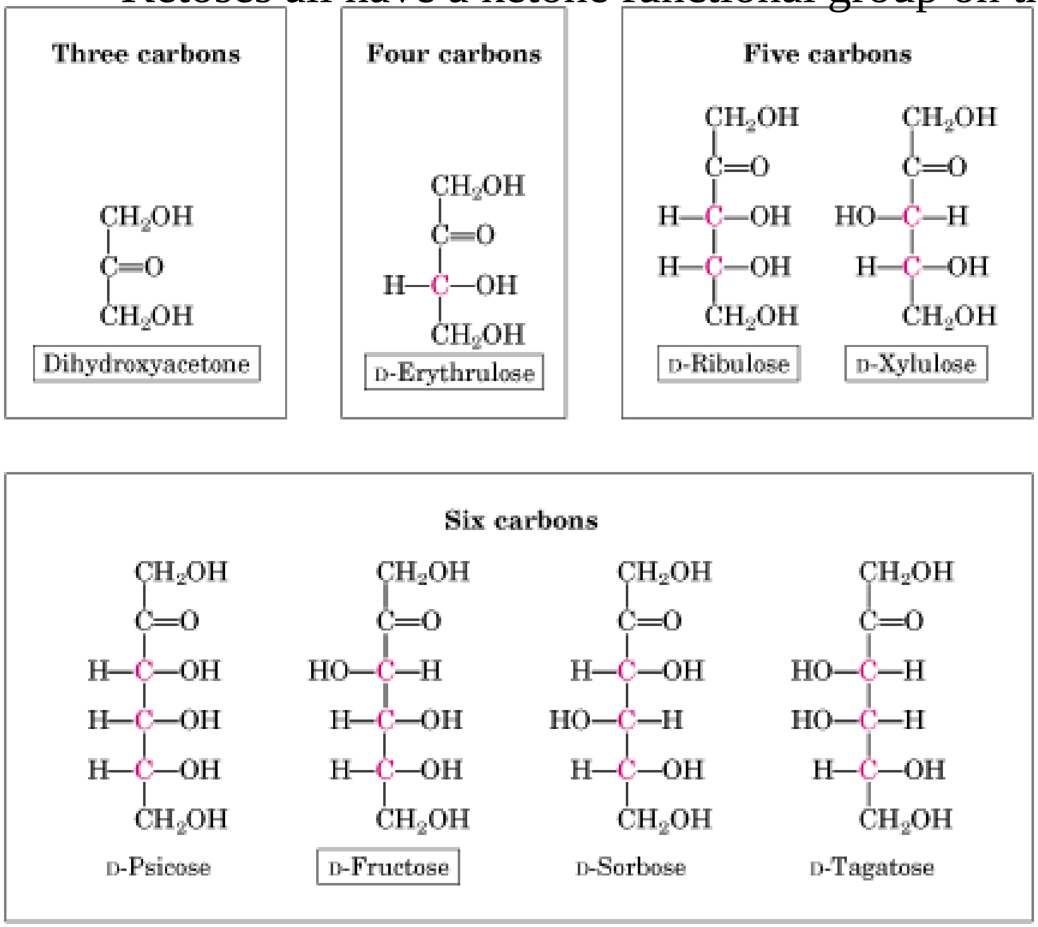


D-Aldoses

- Aldoses all have a functional aldehyde group on the first carbon atom. The “Aldo” refers to the aldehyde group, and the “ose” to a sugar (i.e., an aldehyde sugar).
- Aldoses vary in nature according to the number of C-atoms they contain. Typically five or six carbon examples are most common.

Monosaccharides: Ketoses

Ketoses all have a ketone functional group on the second carbon atom



D-Ketoses

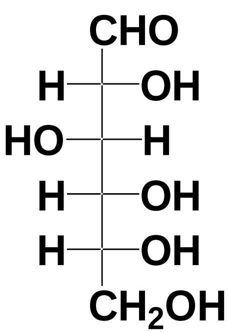
- The "Keto" refers to the ketone group, and the "ose" to a sugar (i.e., a ketone sugar).
- Ketoses vary in nature according to the number of C-atoms they contain. Typically five or six carbon examples are most common.

Monosaccharides: Nomenclature

Monosaccharides may be named in a variety of ways:

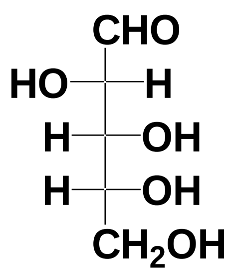
Trivial name: Monosaccharides are given a ***trivial name*** that is widely used to refer to them (such as "glucose", "fructose" or "sucrose") but does not provide information about their structure.

- **Technical name:** Monosaccharides are also given ***technical names*** based on their structures
  - **Enantiomer prefix** – specifies the enantiomer form, *i.e.,* D- or L-form
  - **Trivial prefix –** depends on arrangement of hydroxyl groups on chain, *e.g.*, "gluco-", "arabino-" *etc*.
  - **Carbon number prefix -** specifies the number of carbon atoms in chain, *e.g.*, tetr-", "pent-", "hex-" *etc*.
  - **Carbonyl group suffix** – specifies the nature of the carbonyl group, *e.g.*, "-ose" or "–ulose".



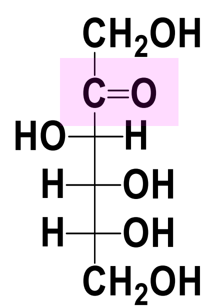
D-Glucose

D-gluco-hex-ose



D-Arabinose

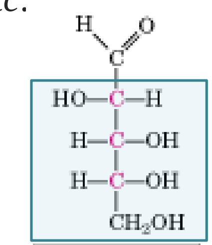
D-arabino-pent-ose

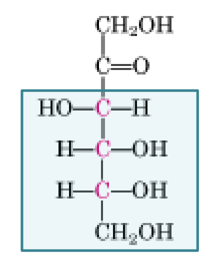


D-Fructose

D-arabino-hex-ulose

Most natural sugars are in D form.


D-Arabinose

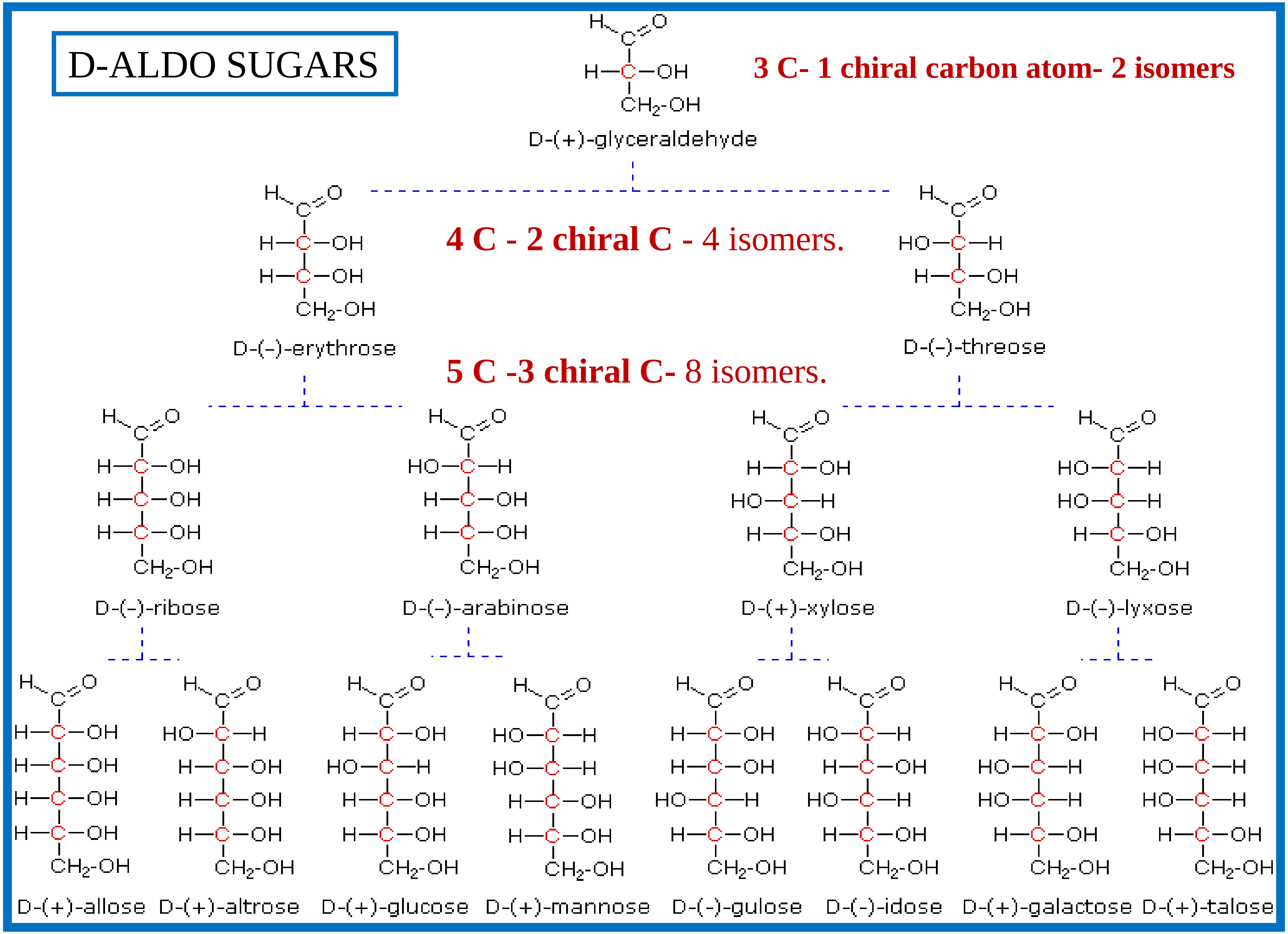

D-Fructose

- A monosaccharide can be named by adding the appropriate suffix *(e.g.,* "tetrose", "pentose", "hexose" etc.) to a *trivial* prefix ("gluco-", "arabino-" etc.) that corresponds to the appropriate carbon chain length attached to the functional group (-ose or –ulose).

- **Aldo** sugars, especially aldohexoses, are very common in nature.
- There are **2 aldoses** containing **3 C** atoms. These contain only **1 chiral carbon atom**.

  D-glyceraldehyde (D-glycerose) and L-glyceraldehyde (L-glycerose).
- Dihydroxyacetone is the simplest ketose.
- Tetroses containing **4 C** atoms (ALDO SUGAR) contain **2 chiral C** atoms and have a total of 4 isomers. (D- and L-erythrosis and D- and L- threosis)
- Tetruloses containing **4 C** atoms (KETO SUGAR) contain **1 chiral C** atom and have a total of 2 isomers (D and L erythrulose).
- Aldo pentoses containing **5 C** atoms contain **3 chiral C** atoms. It has 8 isomers. These are arabinose, lycose, ribose and xylose in 4 D and 4 L form.
- Keto pentoses containing **5 C** atoms contain **2 chiral atoms** and have a total of 4 isomers. These are the D and L forms of ribulose and xylulose.
- **6 C** aldo hexoses have **4 chiral atoms** and 16 isomers.
- **6 C** keto hexoses have **3 chiral atoms** and 8 isomers.

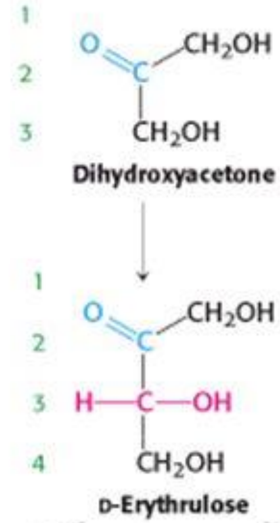
D-ALDO SUGARS



6 C- 4 chiral C – 16 isomers.

D-KETO SUGARS

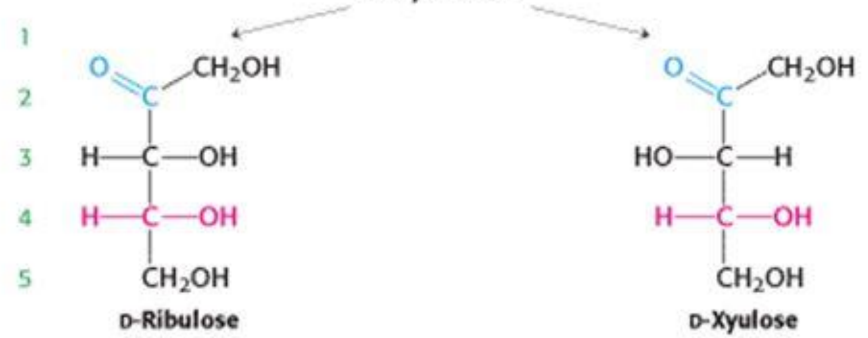
The keto group is shown in blue. The asymmetric center farthest from the keto group, which determines the D designation, is shown in red.



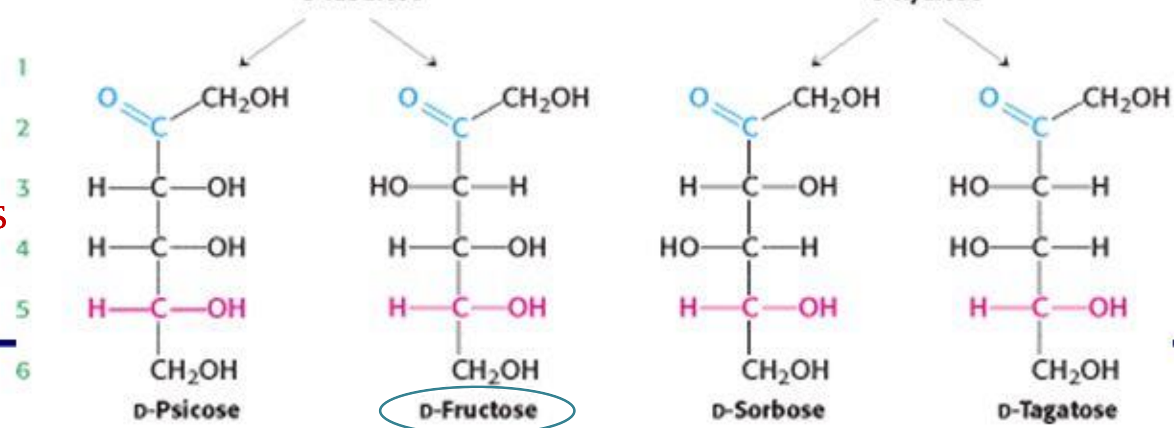
4 C- 1 chiral C - 2 isomers

Note that ketoses have one fewer asymmetric center than do aldoses with the same number of carbons.

5 C- 2 chiral atoms- 4 isomers.

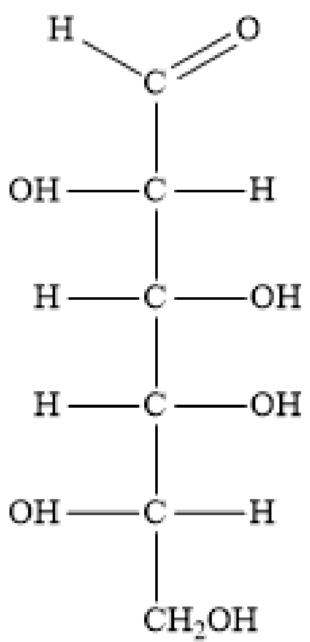


6 C- 3 chiral atoms- 8 isomers

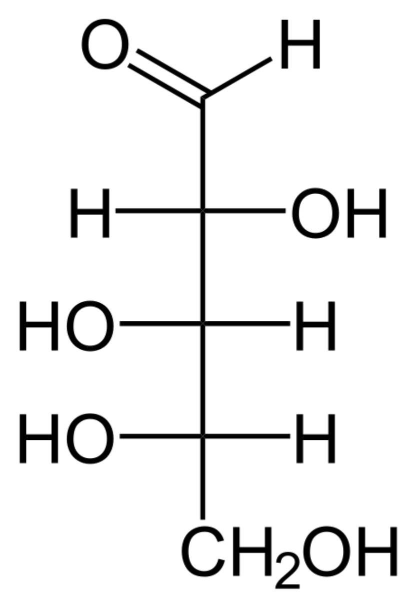


D-Fructose is the most abundant ketohexose.

- Hexoses are the most common in nature. This is followed by pentoses.
- Of all aldo hexoses, only glucose is found in a free form in foods and its amount is very small.
- L-sugars are much less in nature than D ones.
- L sugars that foods contain are L-arabinose and L-galactose. These are generally found in the structure of polysaccharides.



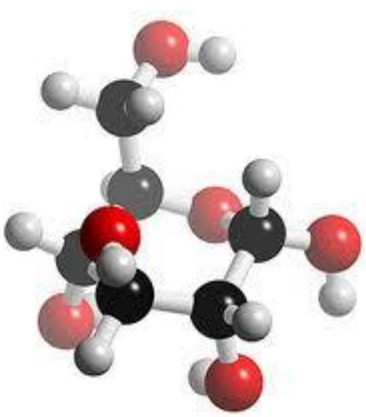
L- Galactose



L-Arabinose

CHs and health

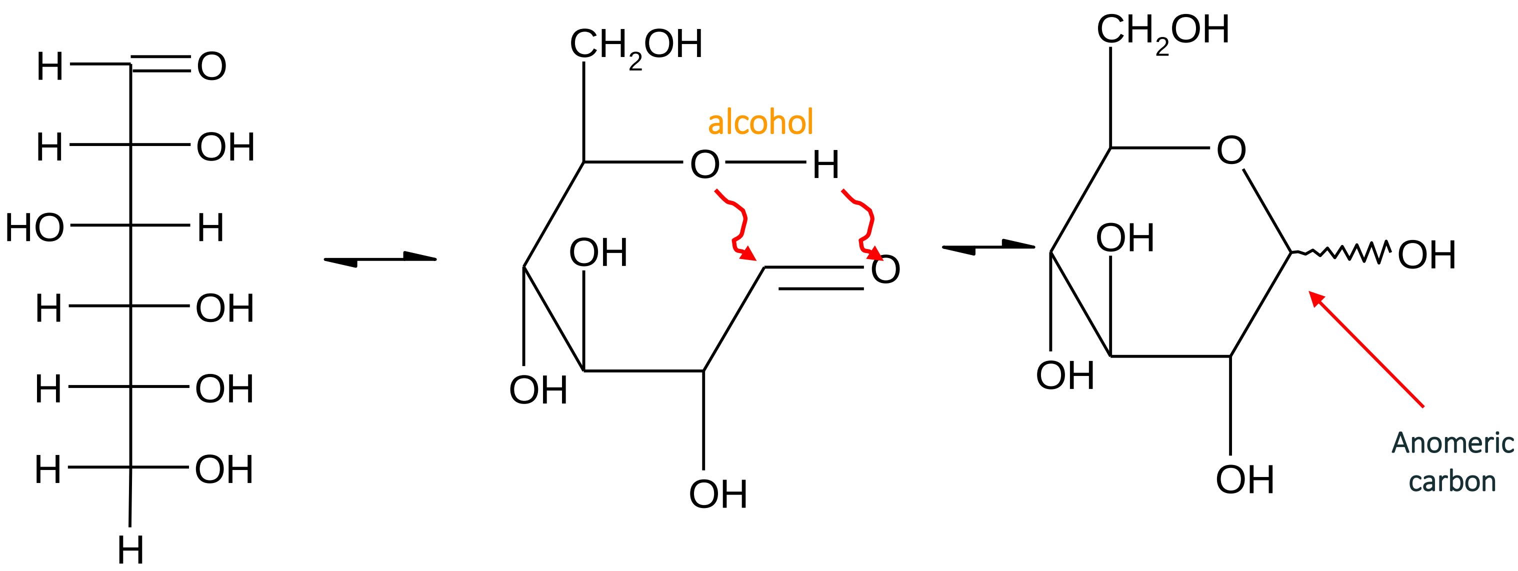
Overconsumption of sugar may be primary cause of Obesity, Diabetes, CVDs, Hypertension



Body Mass Index (BMI): Weight / square of height
<18.5 underweight
18.5-24.9 normal
25-29.9 overweight
> 30 obese

Increased sugar leads to insulin resistance

Monosaccharide Nomenclature:
Ring Formation & Anomers



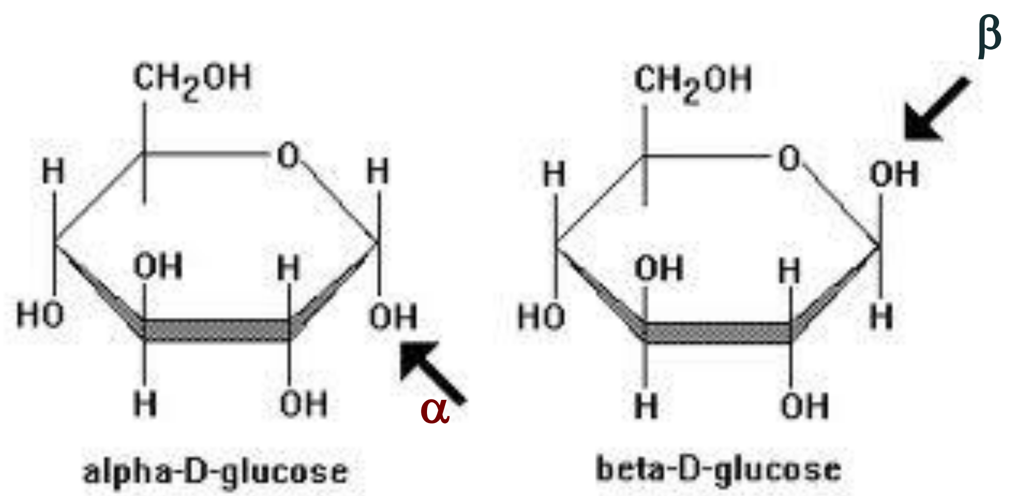
Linear Chain | Hemiacetal formation | Ring Structure

Ring Formation: In aqueous solutions monosaccharides undergo a intra-molecular reaction between alcohol and carbonyl groups leading to the formation of a *ring structure*.

Anomers

The -OH group on the anomeric carbon in the resulting monosaccharide can point either *downwards* or *upwards*.

- If -OH group points downwards it is designated the **α-anomeric** form
- If -OH group points upwards it is designated the **β-anomeric** form



❖ Ring formation in glucose leads to the formation of a new asymmetric center in C1. These two stereoisomers are called anomers (α and β anomers)

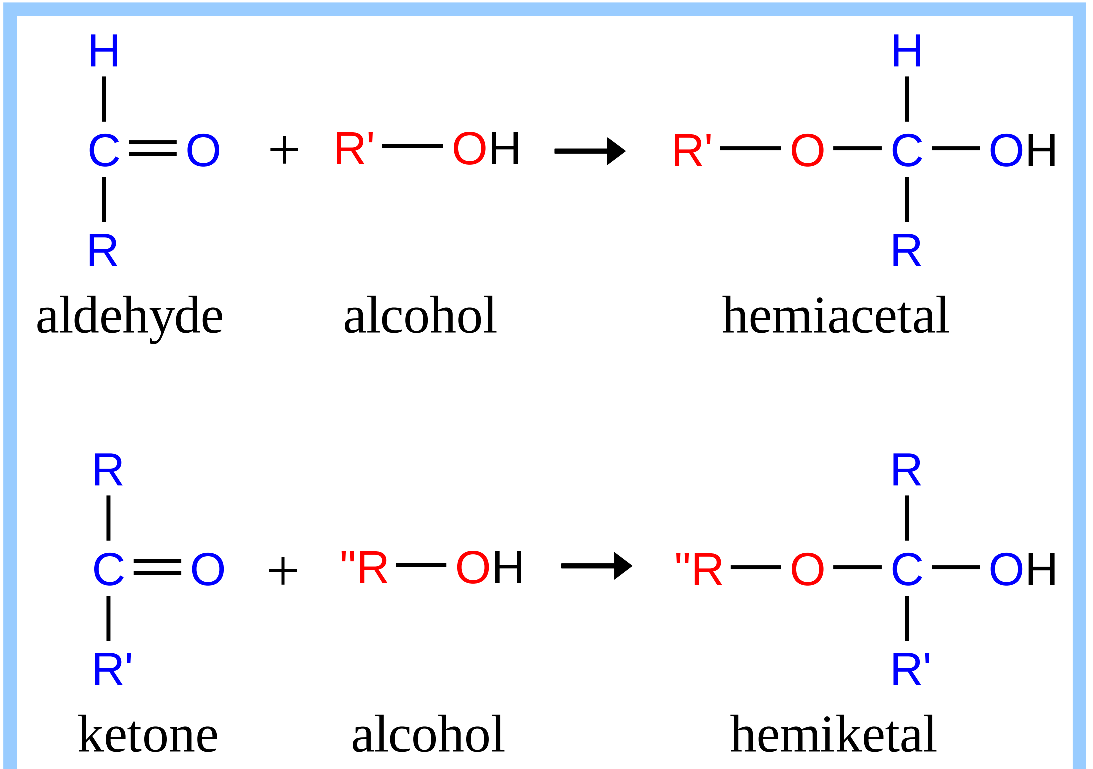
Hemiacetal and hemiketal formation

The predominant forms of ribose, glucose, fructose, and many other sugars in solution are not open chains. Rather, the open-chain forms of these sugars cyclize into rings.

In general, an aldehyde can react with an alcohol to form a ***hemiacetal***.
Similarly, a ketone can react with an alcohol to form a ***hemiketal***.

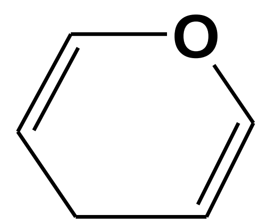
An aldehyde reacts with an alcohol and forms hemiacetal.

A ketone reacts with an alcohol and forms hemiketal.

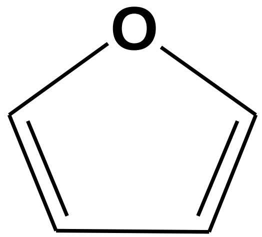


Monosaccharides: Ring Structure Formation

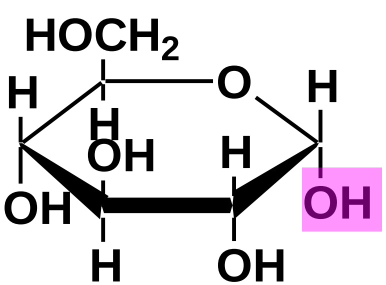
- Intra-molecular reaction between **alcohol** and **carbonyl** to form a ring
- Both aldoses and ketoses undergo **ring formation**.
- Most sugars in nature are present in 5 (**furanose**) or 6 (**pyranose**) membered rings.
- Pyranose ring form is most common.
- Generates two anomers: α- and β-



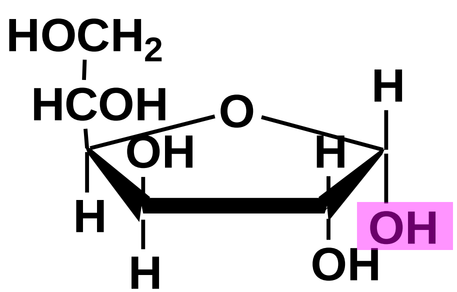
Pyran



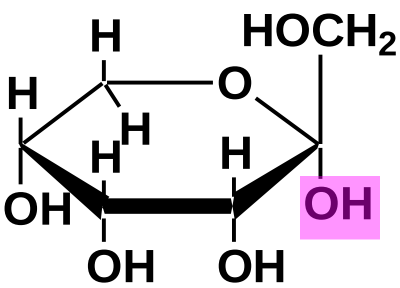
Furan



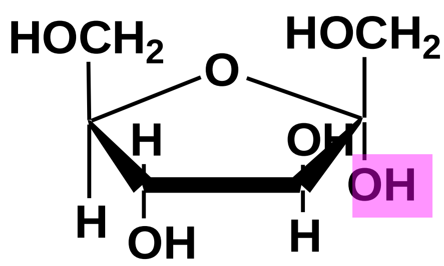
α-D-Glucopyranose



α-D-Glucofuranose



α-D-Fructopyranose



α-D-Fructofuranose

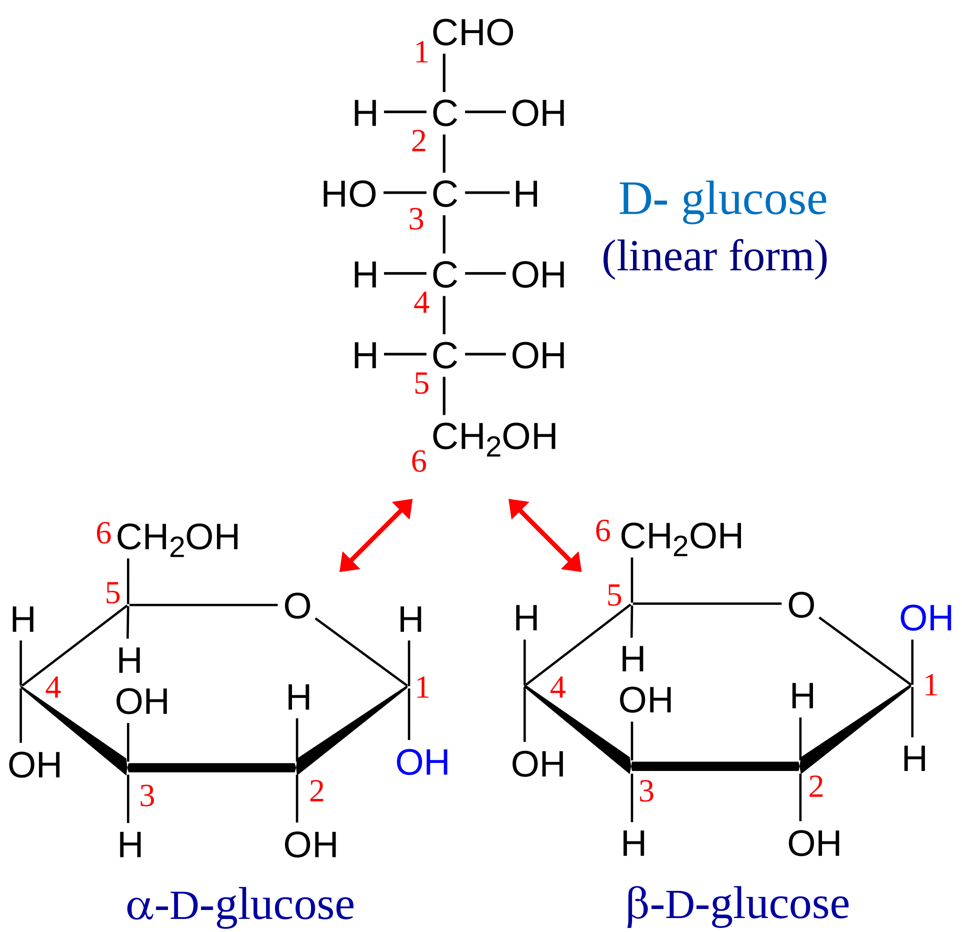
Another way of Naming Monosaccharides!

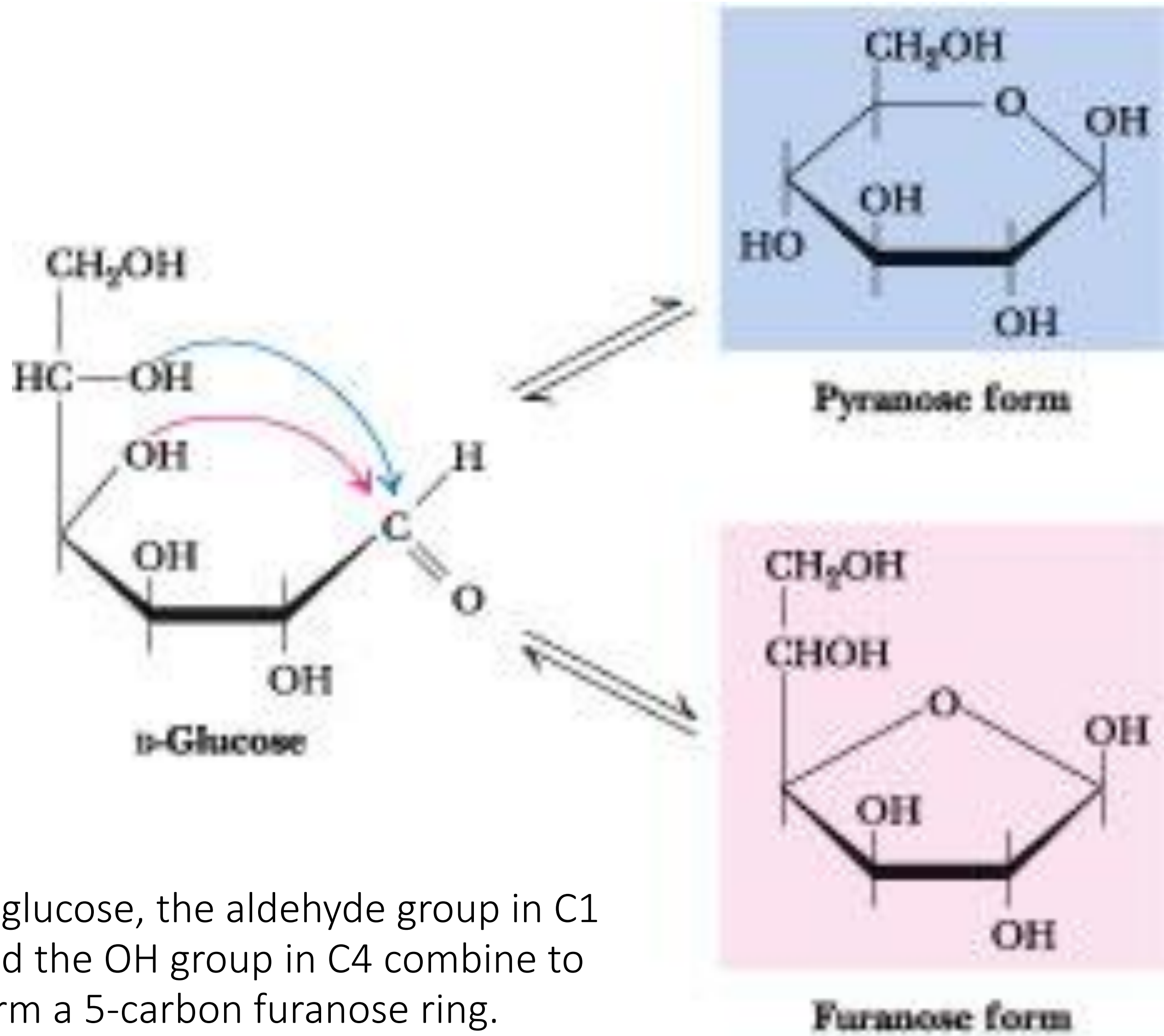
Monosaccharides: Ring Structure Formation

Pentoses and hexoses can form a ring. **There are two ring options (furanose and pyranose)**

In glucose, the aldehyde group in C1 and the OH group in C5 combine to form a 6-carbon pyranose ring.

The representation of the sugars in this ring structure is called the **Haworth projection.**





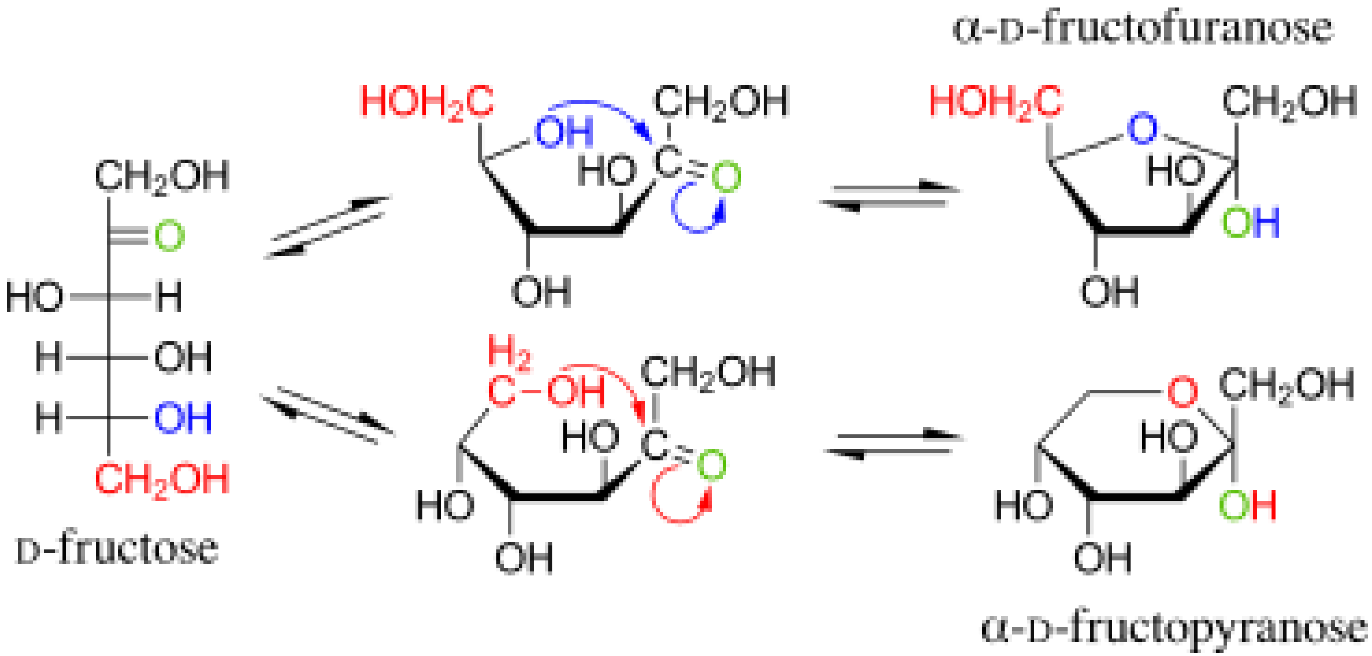
In glucose, the aldehyde group in C1 and the OH group in C4 combine to form a 5-carbon furanose ring.

Monosaccharides: Ring Structure Formation

For fructose :

a) 6 Carbon **pyranose** ring forms when keto group at C2 combines with OH in C6

b) 5 Carbon **furanose** ring forms when keto group at C2 combines with OH in C5



Monosaccharides:
Representing their structures

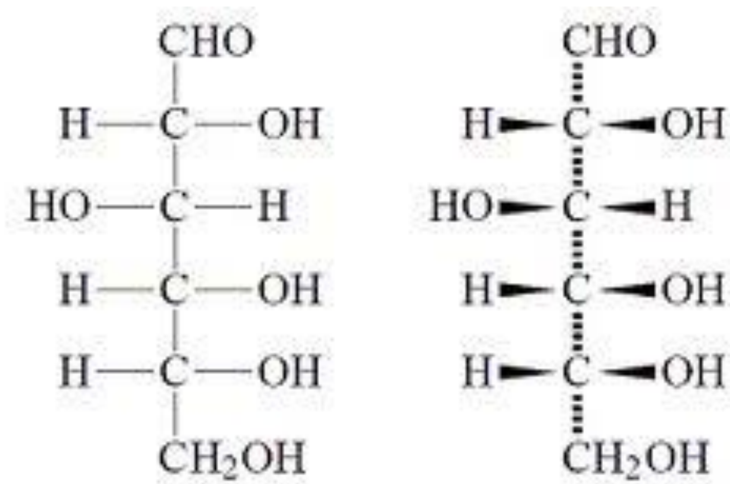
Fisher projection

A method of representing 3-D molecular structures in 2-D by projection.

Carbon chain is depicted vertically

C-1 is depicted at the top (carbonyl group end)

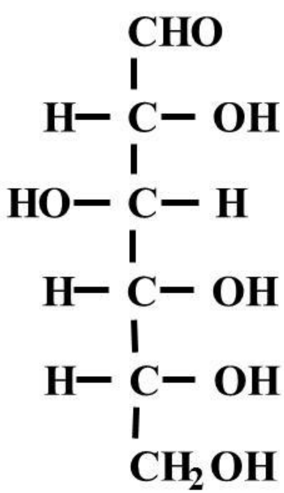
C-1
C-2
C-3
C-4
C-5
C-6



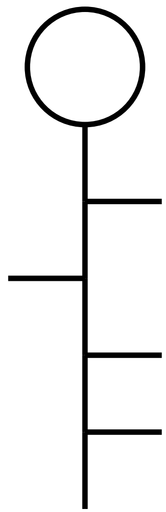
D-Glucose

Monosaccharides:
Representing their structures

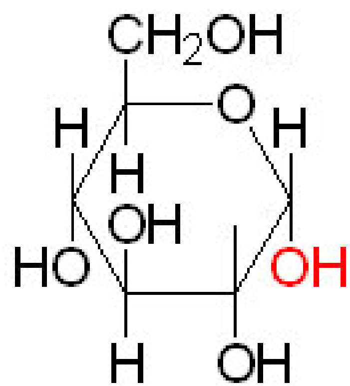
There are many different ways of representing monosaccharide structures:



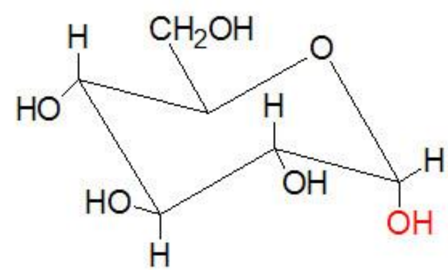
Fisher Projection



Rosanoff Projection

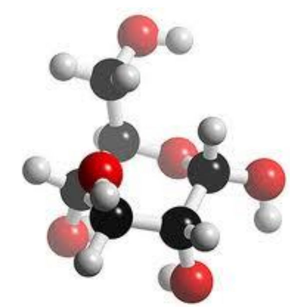


Haworth Projection



pyranose sugars resemble a "chair" or "boat".

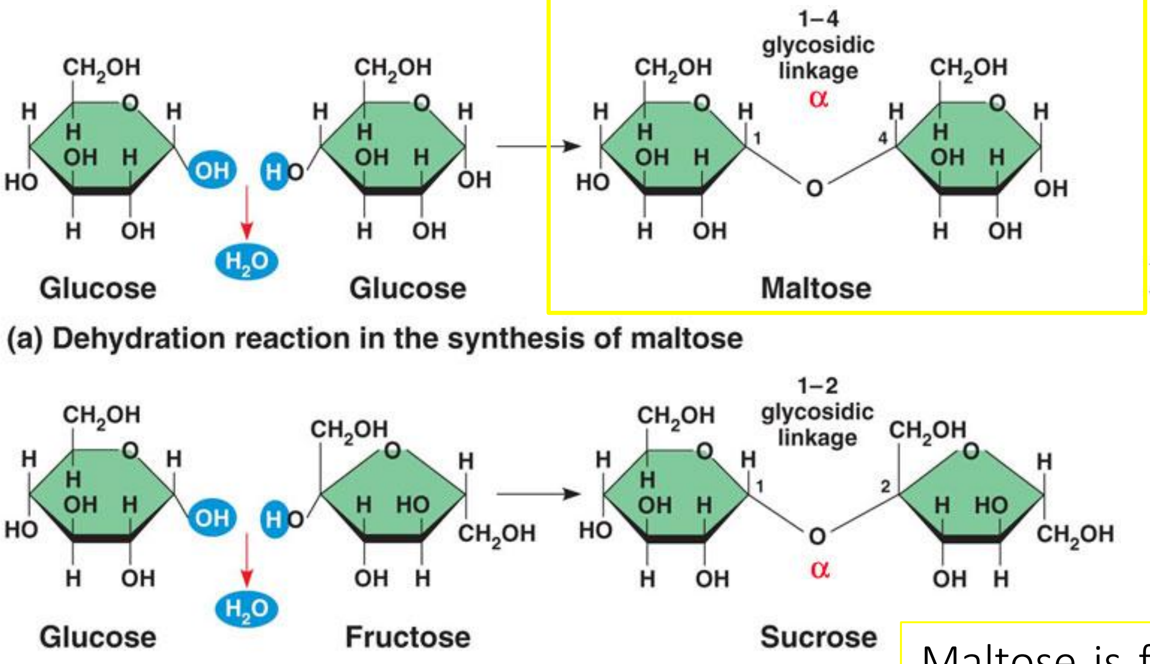
Chair/Boat Conformation



3-D Structure

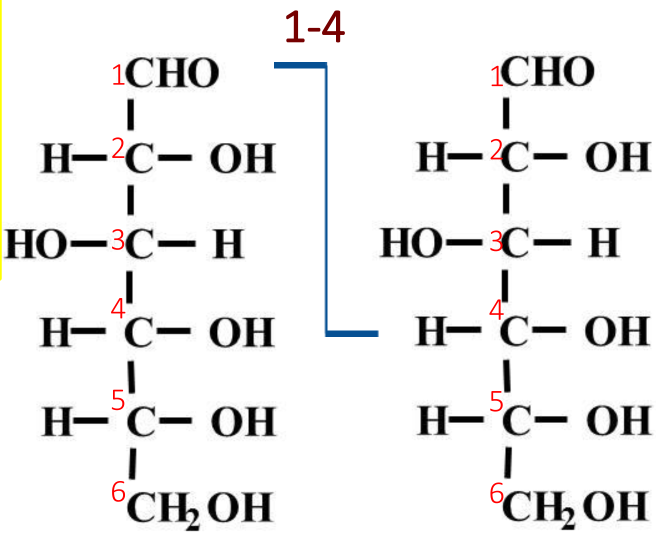
The Rosanoff projection is another, more simplified, way of showing sugar structures. The carboxyl group appears as an “O”, while the hydroxyl groups appear as branches. The hydrogen groups are not shown.

Disaccharides: Molecular Properties



(a) Dehydration reaction in the synthesis of maltose

(b) Dehydration reaction in the synthesis of sucrose



Maltose is formed during the transformation of barley into malt. There is a $\alpha(1\rightarrow 4)$ glycoside bond between C1-C4 of two glucose molecules in the structure.

Molecular Characteristics:

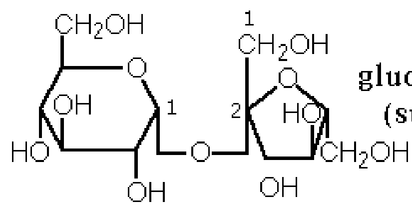
- Type of Monosaccharides
- Nature of Glycosidic Bond
  - Carbon atoms involved from different monosaccharides
  - Anomeric form of the hydroxyl group at C_1

Physical Characteristics:

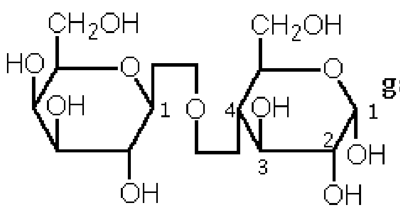
- Crystalline, Water-soluble, Sweet

Disaccharides: Examples

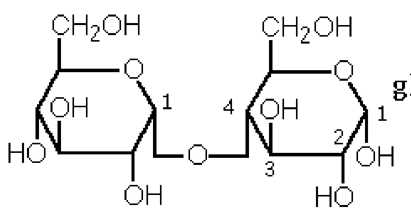
Disaccharides consist of two monosaccharides linked together by a covalent (glycosidic) bond



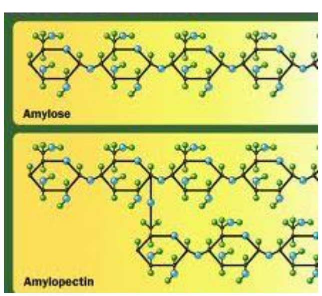
glucose α 1-2 fructose (sucrose)



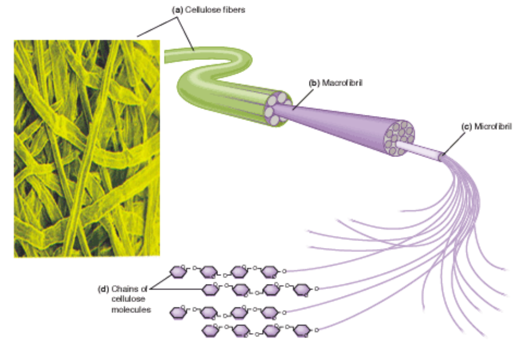
galactose β 1-4 glucose (lactose)



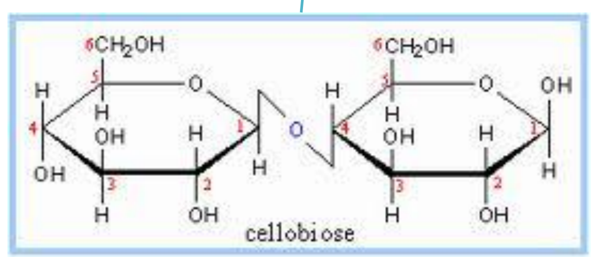
glucose α 1-4 glucose (maltose)



Starch (Water soluble, Digestible)



Cellulose (Water insoluble, indigestible)

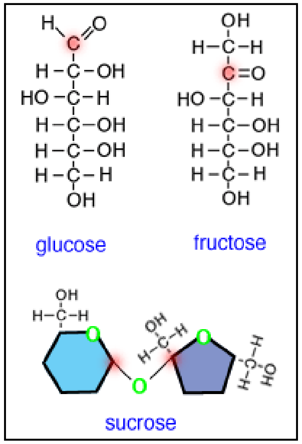


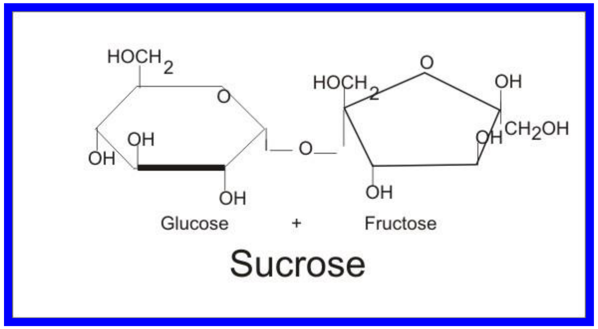
Glucose β 1-4 glucose (Cellobiose)

The nature of the glycosidic bond plays a major role in determining functional properties.

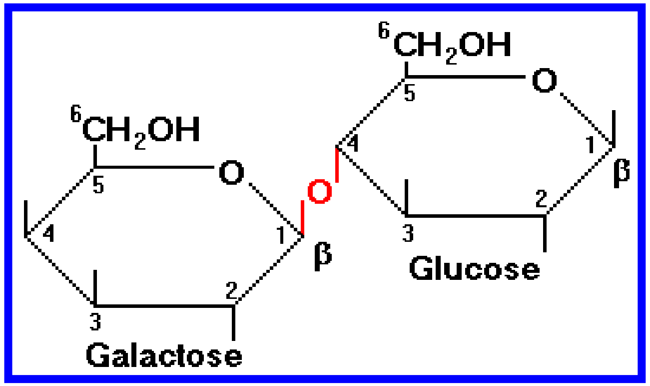
Other disaccharides:

❖**Sucrose** (table sugar): Glucose and fructose are linked together by a α(1→2) bond. It is mostly consumed with other foods, not directly. If hydrolyzed with enzymes or acid, invert sugar is formed.



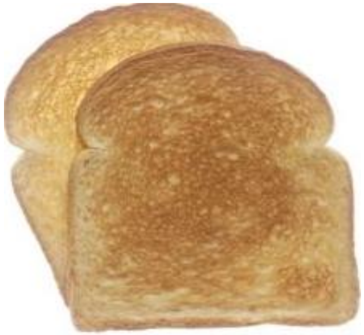


❖**Lactose** (milk sugar): Galactose and glucose are linked together by a β(1→4) bond. (Cow's milk 4.5%, breast milk 7%). Its amount is reduced in *fermented* milk products. If the-galactosidase enzyme is missing, «<u>lactose intolerance</u>» is observed. Lactose cannot be decomposed by enzymes in the small intestine, but goes through anaerobic digestion in the large intestine. So, lactic acid and short-chain acids are formed, cramps ocur due to extra gas. To avoid this, *lactose can be fermented, lactase can be added to milk, or ß-galactosidase can be taken with milk.*



Carbohydrates: Chemical Reactivity

- Isomerization
- Reduction/Oxidation
- Hydrolysis
  - Acid and Alkali
- Browning Reactions
  - Maillard
  - Caramelization

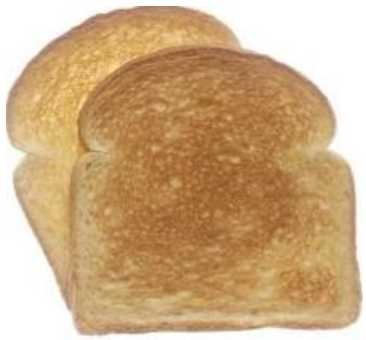


The chemical reactivity of carbohydrates is important for many reasons:

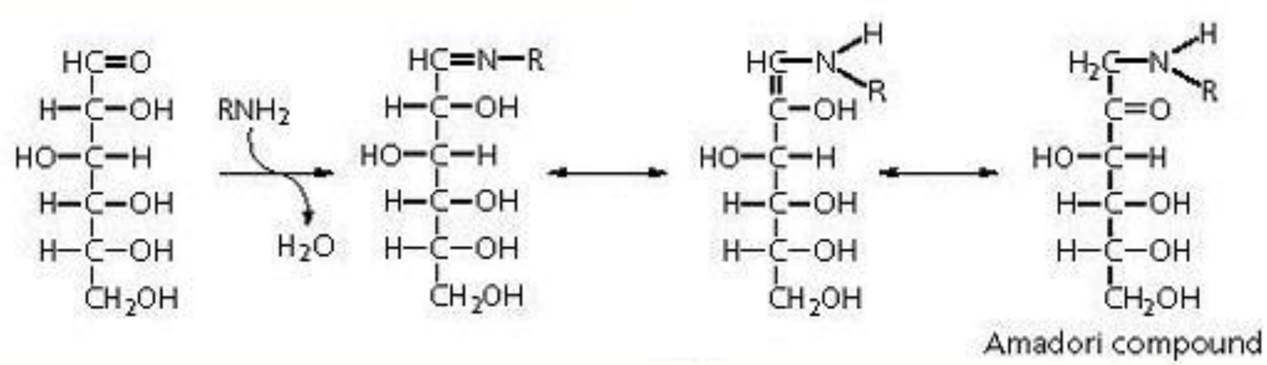
- Influences food quality: flavor, color, stability & safety
- Used in analytical methods to measure carbohydrate concentration
- Used to create new ingredients from carbohydrates

Carbohydrates: Chemical Reactivity

Understanding Chemical Reactions:

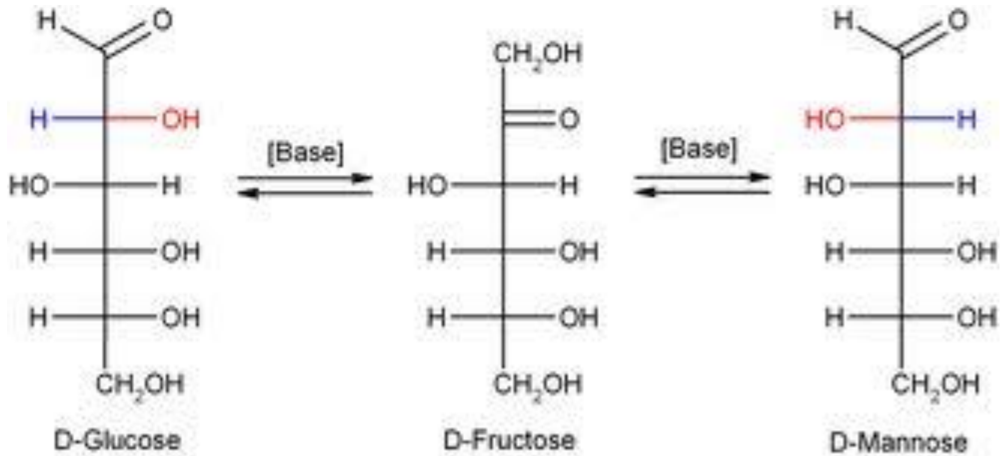


- What molecules are involved: reactants, products, catalysts, inhibitors?
- What is the mechanism & pathway of reaction?
- How fast does reaction occur?
- What factors influence reaction?
  - *Temperature, light, oxygen, moisture, pH…*



Isomerization: Method to Convert Monosaccharide Types

aldose ketose aldose



- An aldose is converted to another aldose and a ketose under basic conditions
  - For example, the **aldehyde** on glucose is isomerized to a **ketone** on fructose & another **aldehyde** on mannose
- Isomerization can be used to convert glucose to fructose, which is much sweeter
- Can be achieved using alkali or enzyme treatments
- High fructose corn syrup (HFCS) is commonly used to sweeten foods

Proportional Sweetness of Some Sugars and Substances Used as Sugar Substitutes (Sucrose = 1.0)

Fructose	**1.73**	**(monosaccharide)**	Inverted sugar 1.30	(glucose + fructose mixture)
Sucrose	*1.00*	*(disaccharide)*	Glucose 0.74	(monosaccharide)
Xylose	0.40	(monosaccharide)	Maltose 0.32	(disaccharide)
Galakctose	0.22	(monosaccharide)	Laktose 0.16	(disaccharide)

Fructose is sweeter than glucose

Sugar replacer	Function*	Relative sweetness (compared to sugar)[1,2]	Energy (kcal/g)**
Sugar (Sucrose)	**Many**	**1**	**4**
Acesulfame K	Low-calorie sweeteners	200	0
Aspartame		180-200	4***
Cyclamates		30-50	0
Neotame		7000-13000	0
Saccharin		300-500	0
Glycyrrhizin		30-50	0
Stevia (steviol glycosides)		200-480	0
Sucralose		600	0
Thaumatin		2000-3000	4***
Inulin	Bulking agents	0.1	2
Polydextrose		0	2
Lactitol	Bulk sweeteners	0.5	2.4
Maltitol		1.0	2.4
Mannitol		0.7	2.4
Sorbitol		0.5-1.0	2.4
Erythritol		0.6-0.8	0
Xylitol		1	2.4
Pectin	Gum/ Thickeners	0	2
Starch		0	4
Guar		0	2

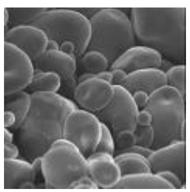
Isomerization: High Fructose Corn Syrup

Corn

Corn Starch

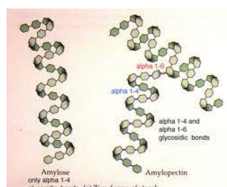
Corn Syrup

High Fructose Corn Syrup



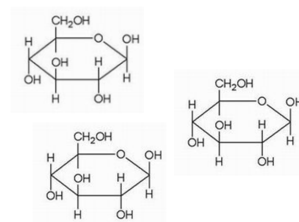
Starch granules

Grind
Heat
Water



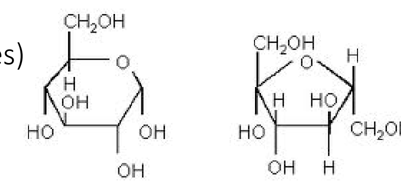
Starch molecules

Enzymes
(Amylases)



Glucose molecules

Enzymes
(Isomerases)

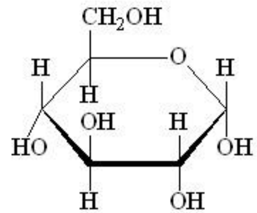


glucose fructose

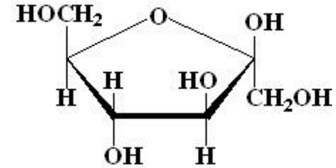
Mixture

- **Definition**: Corn syrup that has undergone enzyme treatment to convert its glucose into fructose, and has then been mixed with pure corn syrup (100% glucose) to produce a desired sweetness
- **Applications:** Sweetener
- **Products:** Breads, cereals, breakfast bars, lunch meats, yogurts, soups and condiments, beverages

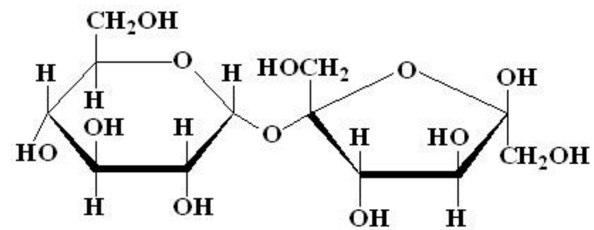
High Fructose Corn Syrup *vs.* Sucrose



glucose



fructose



sucrose

Common Types of High Fructose Corn Syrup:

- HFCS 55: 55% fructose & 42% glucose (mainly used in soft drinks)
- HFCS 42: 42% fructose & 53% glucose (mainly used in processed foods, cereals, and baked goods)
- 3 and 5 % other sugars/polysaccharides (glucose chains)

Reducing & Non-Reducing Sugars

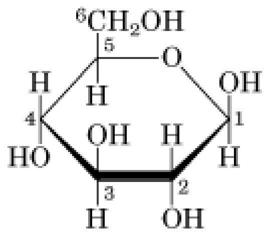
Reducing Sugars

Monosaccharides

Glucose

Fructose

Galactose



β-D-Glucose

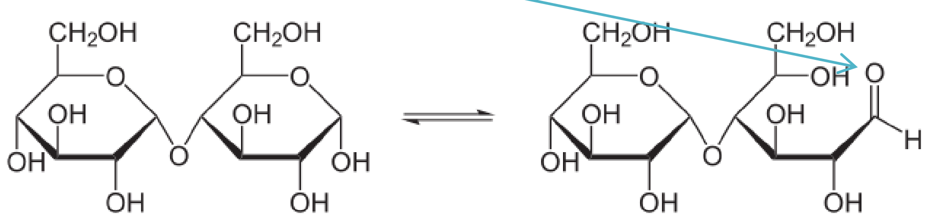
Disaccharides

Lactose

Maltose

A sugar is only a **reducing sugar** if it has an **open chain** with an aldehyde or a ketone group

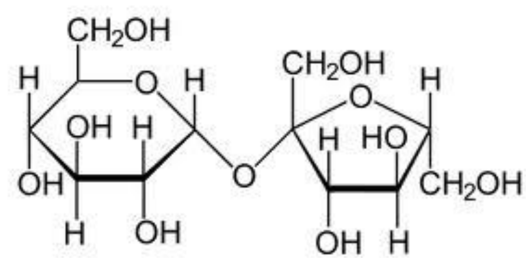
One of monomer chains can open



Equilibrium between cyclic and open-chain form in one ring of maltose

Non-Reducing Sugars

- **Disaccharides**
  - Sucrose
  - Trehalose

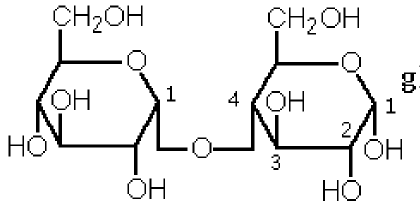


Sucrose

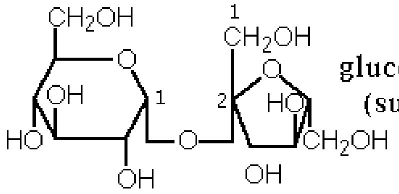
In sucrose the chains cannot open, therefore it is a non-reducing sugar

Reducing *versus* Non-Reducing Sugars

Reducing	Non-reducing
Mutarotation*	No Mutarotation
Reduce metal ions	Don’t reduce metal ions
Hydrolyzed by acid	Hydrolyzed by acid
Hydrolyzed by alkali	Not hydrolyzed by alkali
Participate in Maillard reaction	Don’t participate in Maillard reaction



glucose α 1-4 glucose (maltose)

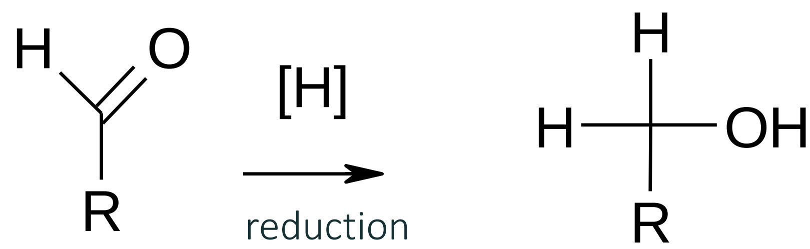


glucose α 1-2 fructose (sucrose)

*Mutarotation is the change in the optical rotation

Reduction: Production of Sugar alcohols

Carbonyl groups can be reduced to alcohols by catalytic hydrogenation

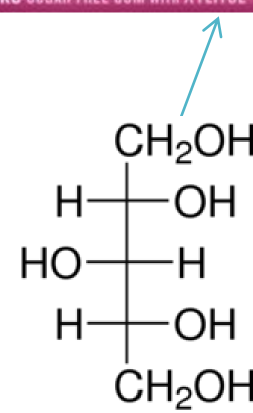


Common Sugar alcohols

Glucose reduced to glucitol ("sorbitol ")

Fructose reduced to glucitol and mannitol

Xylose reduced to xylitol



xylitol

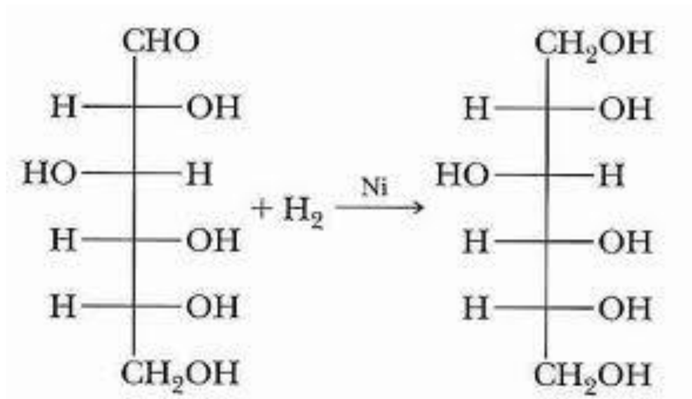
Properties

no aldehyde or ketone group

Sweet, water soluble, water activity modifiers

Slowly absorbed, Less calories, Less dental carries

Glucitols: Food Applications



Glucose Sorbitol

Applications

Texture Modifiers

Low Calorie Sweeteners

Water Activity Control (Humectant)

Products

Chewing gum, Bakery, Desserts, Meats, Confections

Sugars: Functional Properties

Most sugars are *monosaccharides* or *disaccharides*. They are used in foods for a variety of reasons:

Sweeteners

They provide sweetness due to their ability to react with taste-buds in the mouth

Flavor profile & color

The form characteristics flavors and colors during non-enzymatic browning reactions (Maillard or caramelization)

Water Activity

They lower the water activity

Cryoprotectants

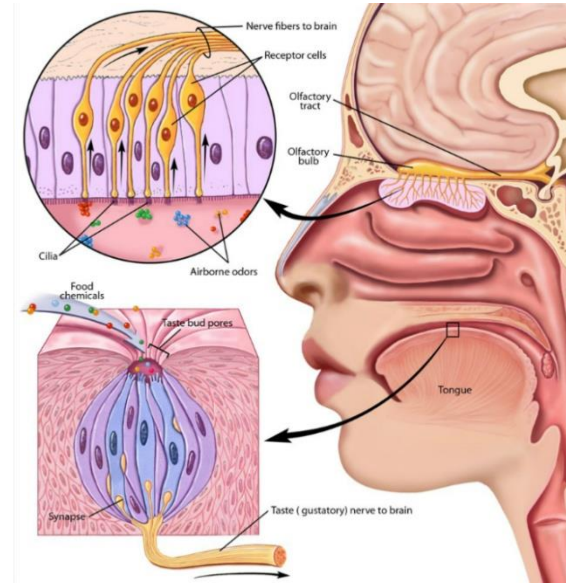
They can prevent damage to foods during freezing, thawing, and dehydration

Texture/Stability

They form glassy or crystalline structures that contribute to texture and stability of foods, such as bulking agents, wall materials during drying, and humectants.

Sugars: Sweeteners

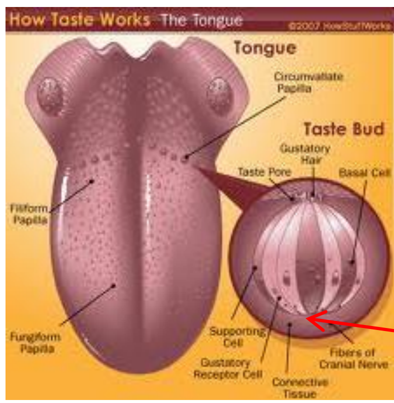
Aroma



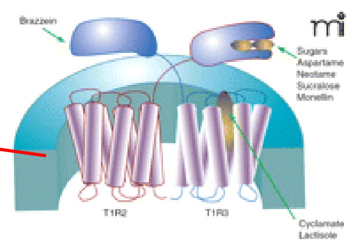
Taste

Sweeteners bind to specific receptors on the human tongue, which generates a signal that is sent to the brain

Old Model: Specific taste receptors localized in specific regions of tongue



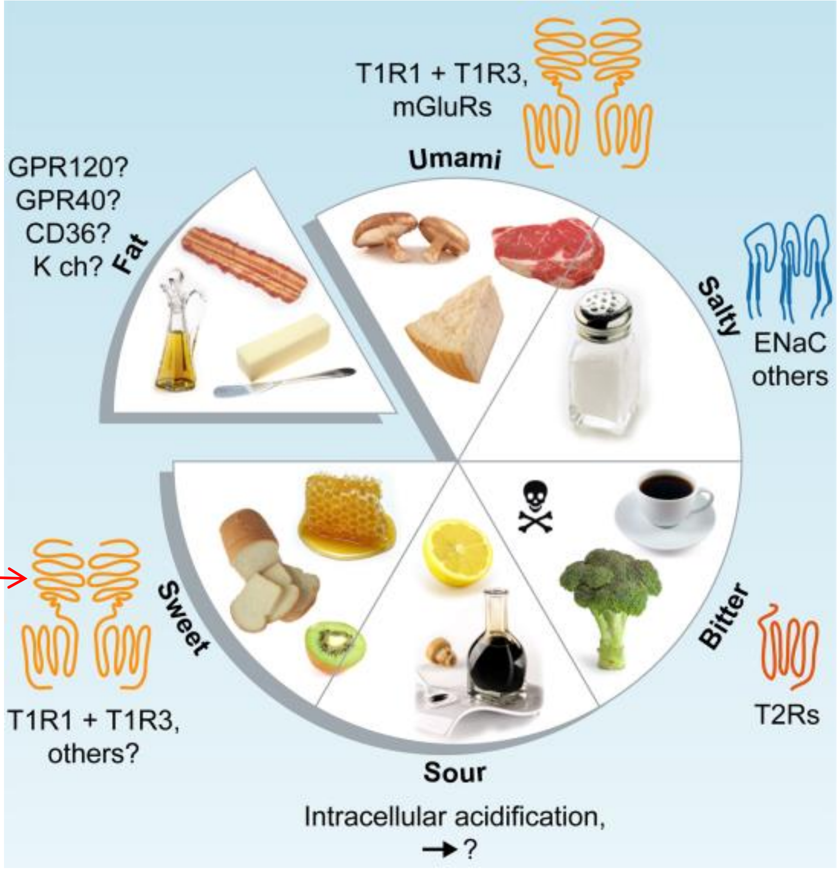
New Model: Specific taste receptors are spread across whole of tongue, but higher concentrations in certain regions of tongue



Sweet Receptor: Responds to sugars and other molecules

"The cell biology of taste" N. Chaudhari and S.D. Roper. J. Cell Biol. Vol. 190 No. 3, 285–296

Flavor Perception: Sweetness

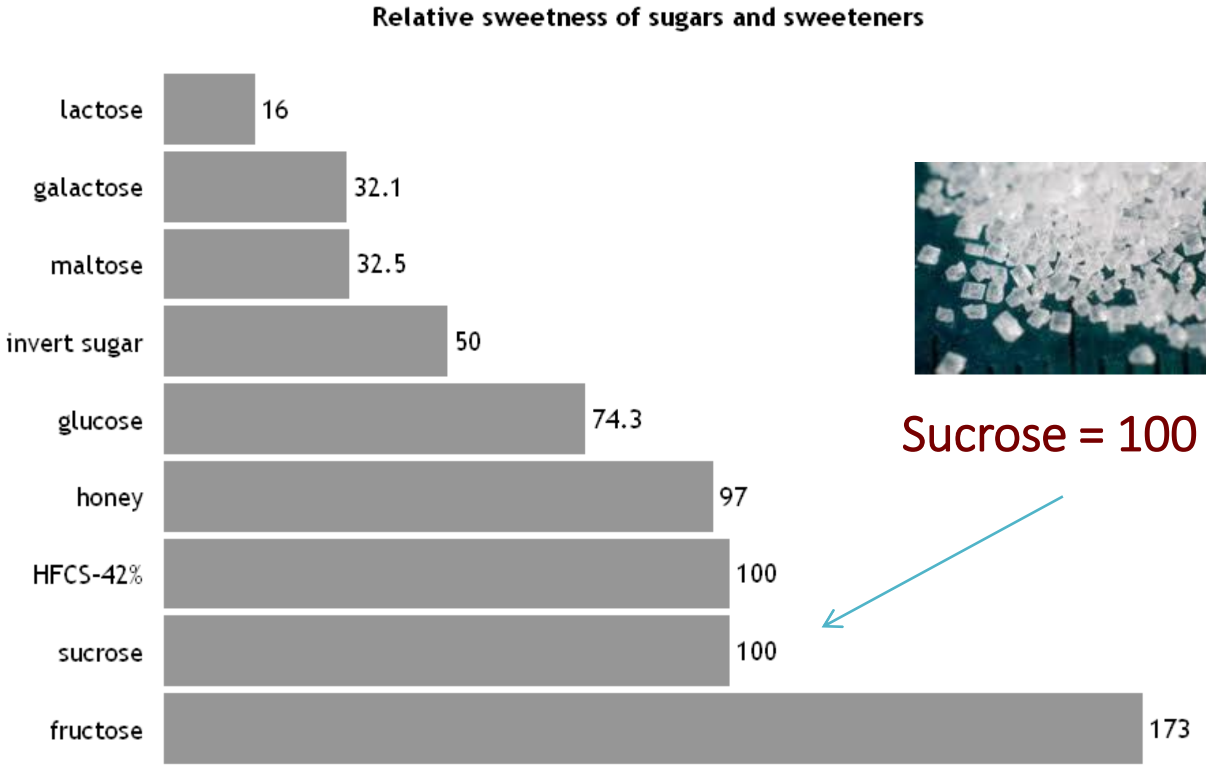


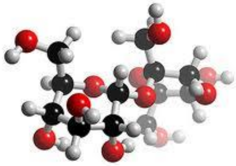
Sweet Receptor: Specific receptors respond to sugars and other molecules

"The cell biology of taste" N. Chaudhari and S.D. Roper. J. Cell Biol. Vol. 190 No. 3 285–296

Sugars: Sweeteners

The relative "sweetness" of sweeteners is established by comparing to that of sucrose using sensory tests





Sucrose = 100

Sugar Substitutes: Artificial Sweeteners

Problems with Sugars:

- High calories
- Overweight, obesity and diabetes
- Tooth decay

Sugar Substitutes:

- Food additives that provides sweetness, but with less calories
- Their “sweetness” profile differs from that of natural sugars
- Removing sugars may affect other food properties (*e.g.,* water activity, texture)

Examples of Sugar Substitutes:

- **High Intensity:** Saccharin, aspartame, sucralose, acesulfame potassium (K)
- **Low Intensity:** Sugar alcohols (*e.g.,* Sorbitol, Xylitol, Mannitol)

http://en.wikipedia.org/wiki/Sweeteners

Sugar Substitutes: Relative Sweetness

Sweetener (Low Intensity)	Relative Sweetness*	Energy Density*	Sweetener (High Intensity)	Relative Sweetness*
Erythitol	0.7	0.05	Acesulfame K	200
Glycerol	0.6	1.08	Aspartame	200
Lactitol	0.4	0.5	Cyclamate	30
Mannitol	0.5	0.53	Neotame	8,000
Sorbitol	0.6	0.65	Saccharine	300
Xylitol	1.0	0.6	Sucralose	600

*Compared to sucrose by weight

Differences: Artificial sweeteners differ in their flavor profiles, environmental stability, cost, and legal status

Aspartame

Properties

White crystalline powder

Formed by reaction of two amino acids

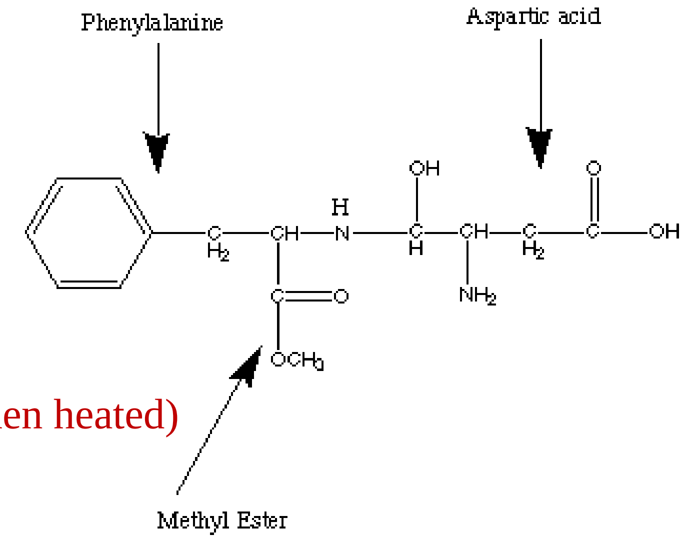
150-200 times as sweet as sucrose

No bitter aftertaste

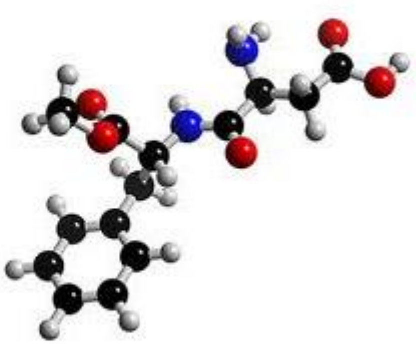
Limited heat stability (breaks down and looses sweetness when heated)

Can participate in non-enzymatic browning

Aspartame



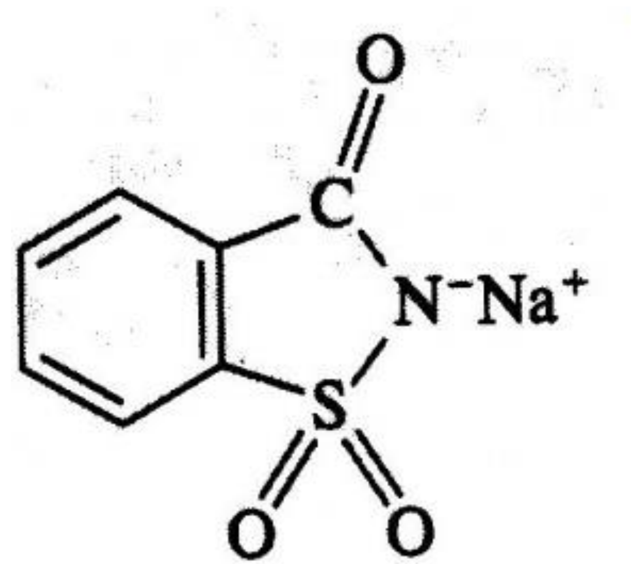
α-L-aspartyl-L-phenylalanine methyl ester

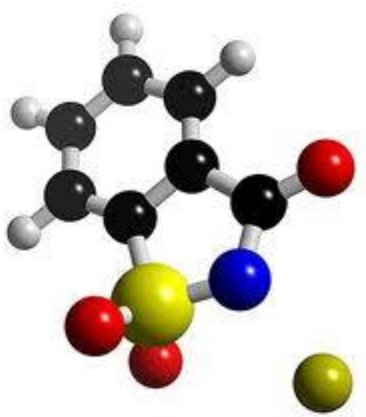


Saccharin

Properties

- White crystalline powder
- Sugar of lead
- **Bitter aftertaste**
- 300 times as sweet as sucrose
- Not legal in Canada (possible carcinogenesis)

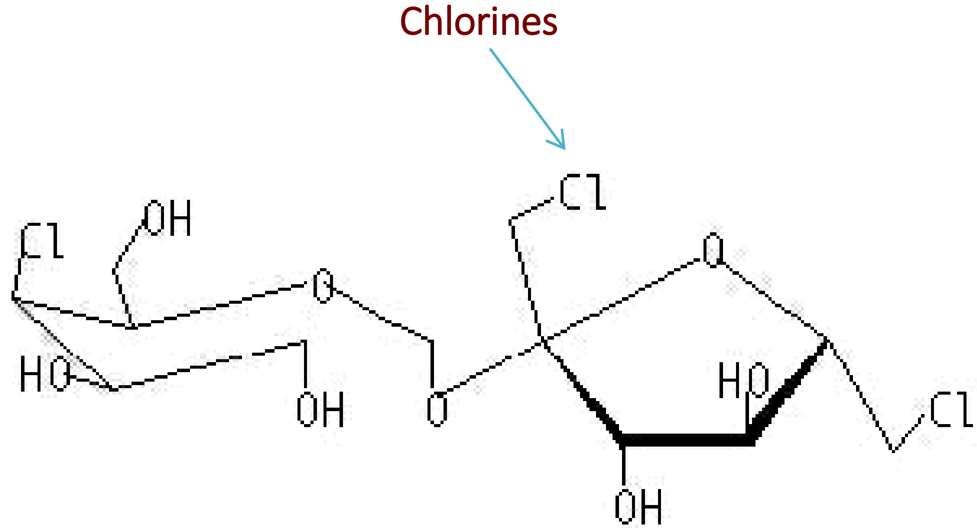




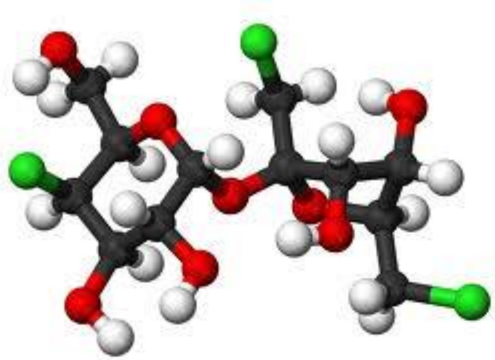
Sucralose

Properties

- White crystalline powder
- Formed by chlorinating sugar
- 600 times as sweet as sucrose
- Heat Stable



4,1',6' trichlorosucrose

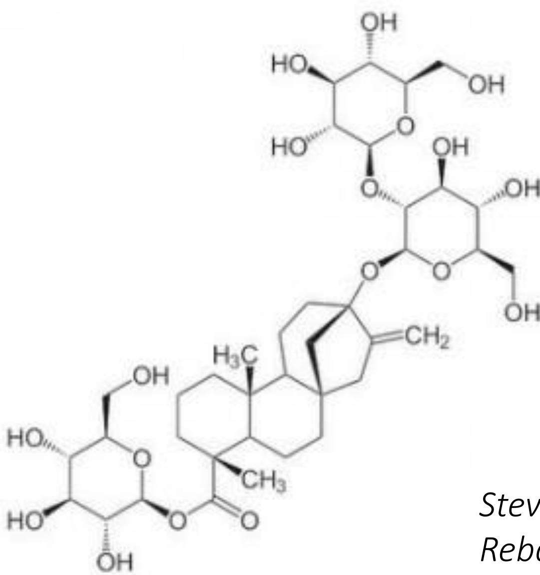


Stevia

Properties

- White crystalline powder
- Isolated from Stevia plants (natural)
- **Bitterness, astringency, metallic flavors**
- Mixture of various molecules

Glycosides



Stevioside and Rebaudioside A

Sugars: Functional Properties

Sugar crystals

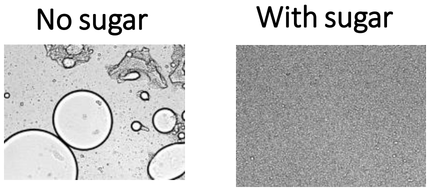
Bulking Agents: Bulking agents are ingredients added to foods to increase their "bulk" or "volume", *i.e.,* as a space filler. Sugars and polysaccharides (such as starch) or often used for this purpose in solid foods, but polyols may also be used so as to decrease the calorie content and tooth decay.

Wall Materials: Carbohydrates are often used as "wall materials" in food ingredients that are encapsulated using dehydration processes such as spray drying or freeze drying. The wall materials are designed to slow down undesirable chemical reactions and to improve flow characteristics of powdered foods.

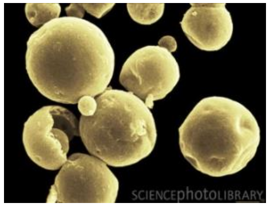
Humectants: Humectants are ingredients added to foods to prevent them from drying out. Carbohydrates are polar molecules that are able to bind water molecules to their surfaces, and therefore retard their loss through evaporation or migration.

Water Activity Controllers: Carbohydrates may be incorporated into foods to control their water activity. As more solute is added to an aqueous solution the water activity decreases. It is often important to control the water activity of a food so as to inhibit microbial growth, enhance chemical stability, or control physical properties (such as texture).

Cryoprotectants: Cryoprotectants are incorporated into foods to control the amount and size of the ice crystals formed during the freezing process. Carbohydrates decrease the melting point of water and increase its viscosity. When a food containing dissolved carbohydrate is frozen, the system may separate into two phases: ice crystals and a concentrated carbohydrate solution. The formation of a freeze-concentrated carbohydrate solution can prevent undesirable effects from occurring such as droplet aggregation, and cell disruption.



Frozen/Thawed Emulsion



Spray Dried Milk

Raisins

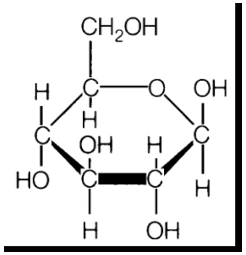
Monosaccharides

Origin:

Monosaccharides found in wide range of natural and processed food products

Chemistry

- Number of carbon atoms
- Relative position of OH groups
- Functional groups (Aldehyde or Ketone)
- Structure in solution



Functions:

Energy source (calories)
Desirable flavors (sweetness) and colors (browning)
Chemical reactivity (Maillard reaction, caramelization *etc*)
Water-activity control (Biological, chemical, & physical properties)
Texture/stability (bulking agents, wall materials, humectants)

A **humectant** is a hygroscopic substance, i.e., it absorbs water from the environment. They are frequently used in foods as desiccants to control water activity. Humectants are often molecules that contain many hydrophilic groups: In the case of carbohydrates these are hydroxyl groups.