# Chemistry of the Life Sciences

Part 2: Organic Chemistry

Part 1: atoms and compounds
Part 2: organic chemistry
Part 3: aqueous solutions
Part 4: biochemistry

## Introduction to Organic Compounds

- Organic compounds are composed primarily of carbon and hydrogen, but may also include oxygen, nitrogen, sulfur, phosphorus, and a few other elements.
- Biomolecules are proteins, carbohydrates, lipids, and DNA, and are all classified as organic compounds (that is the historic reason for the name organic chemistry).



## Organic vs. inorganic

- Inorganic compounds are compounds that do not contain carbon and hydrogen (no C-C bonds, no C-H bonds), e.g. NaCl, $H_2O$, $Na_2SO_4$
- Organic compounds either occur naturally or are synthesized in the laboratory (the latter was a surprise).
- Carbon is unique in that it form bonds with other carbons and can form long chains, branched chains, and rings of various sizes and shapes (more than 25 million organic compounds are known).



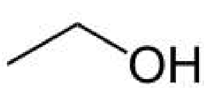
## Drawing Organic Compounds

- Lewis structures show the connectivity of the atoms in a molecule, showing all atoms, bonds, and lone pairs of electrons.
- As molecules get larger, chemists use simplified representations for the structures of organic molecules that show the entire structure, but omit some of the details.
- For example, chemists omit the lone pair of electrons on oxygen when it is present in an organic compound.



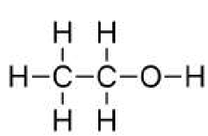
## Skeletal Structure

- Skeletal structure shows only the bonds between the carbons. Carbon and hydrogen are not shown.




skeletal structure

model




Lewis structure

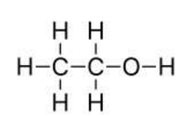


## Condensed Structural Formulas

- A condensed structural formula, also known as condensed structure, shows all the atoms in a molecule, but show as few bonds as possible. This may or may not show lone pairs. It is not useful in drawing cycloalkanes.

$CH_3CH_2OH$ condensed

$C_2H_6O$ molecular

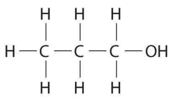



Lewis

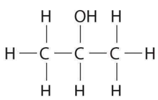
- Recall that carbon always forms four bonds and hydrogen forms one bond. This aids in interpreting condensed structures.

# Isomers: same molecular formula

**Isomer**
Same atoms,
Different bonds,
different substance

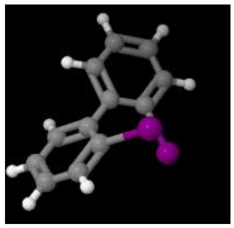



1-Propanol (*n*-propanol) $C_3H_8O$




2-Propanol (isopropanol)

**Conformer**
Same substance,
difference in shape (like sitting and standing)





# Introduction to Organic Compounds, Continued

- Organic compounds are grouped in families based on their molecular structure and composition. Members in the same family behave similarly in chemical reactions.
- An increased interest in the study of organic chemistry is due to the variety of organic compounds and the ability to manipulate them in the laboratory.



# Alkanes: just C and H with single bonds

- Alkanes make up the fossil fuels used for heating, transportation, and generating electricity. They are simple organic compounds made up solely of carbon and hydrogen.
- Example: Propane (camping cooker)
- Example: Octane (component of gasoline



# Straight-chain alkanes

- alkanes made up of carbon atoms joined to one another to form a continuous, unbranched chain of various lengths.
- Names are based on the number of carbon atoms in the chain

| # of C | name | Origin of name |
|---|---|---|
| 1 | Meth + ane | Greek. methy "wine" + hyle "wood." |
| 2 | Eth + ane | ether |
| 3 | Prop + ane | Greek: "first fat" |
| 4 | But + ane | butter |
| 5 | Pent + ane | Greek 5 |



# Names

- Alkanes of five or more carbon atoms are named with a numerical prefix followed by the ending –ane (indicating the alkane family).
- It is important to recognize the name of the first ten alkanes since they become the root names to other families of organic compounds.
- pent- = 5
- hex- = 6
- hept- = 7
- oct- = 8
- non- = 9
- deca- = 10



# Table of straight-chain alkanes

| # carbons | Name | Molecular Formula | Condensed Structural Formula | Skeletal formula |
|---|---|---|---|---|
| 1 | Methane | $CH_4$ | $CH_4$ | n/a |
| 2 | Ethane | $C_2H_6$ | $CH_3CH_3$ | n/a |
| 3 | Propane | $C_3H_8$ | $CH_3CH_2CH_3$ | |
| 4 | Butane | $C_4H_{10}$ | $CH_3(CH_2)_2CH_3$ | |
| 5 | Pentane | $C_5H_{12}$ | $CH_3(CH_2)_3CH_3$ | |
| 6 | Hexane | $C_6H_{14}$ | $CH_3(CH_2)_4CH_3$ | |
| 7 | Heptane | $C_7H_{16}$ | $CH_3(CH_2)_5CH_3$ | |
| 8 | Octane | $C_8H_{18}$ | $CH_3(CH_2)_6CH_3$ | |
| 9 | Nonane | $C_9H_{20}$ | $CH_3(CH_2)_7CH_3$ | |
| 10 | Decane | $C_{10}H_{22}$ | $CH_3(CH_2)_8CH_3$ | |

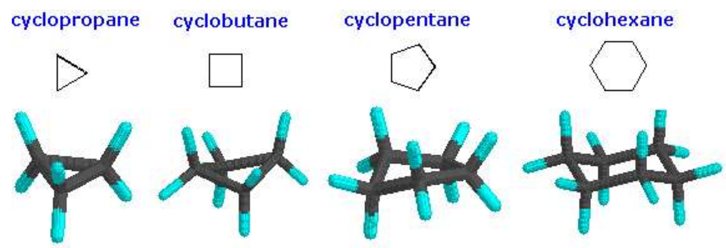
## Alkanes Are Nonpolar Compounds

- Electronegativities of carbon and hydrogen are similar enough that the bonding electrons between them are shared about equally.
- Methane is nonpolar because the very small partial positive charges on hydrogen are distributed equally around the carbon atom
- The higher alkanes are also nonpolar for all intents and purposes.



## Skeletal structure cont

- In the skeletal structure, carbon atoms are understood to be at the corner/angle created by the intersection of two bonds or at the termination of a bond.
- Example cycloalkanes.





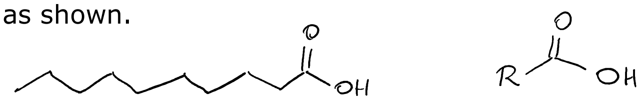

## Functional Groups, examples

| Class | General Formula | Example | Common Name (Systematic Name) | Common Suffix/Prefix (Systematic) |
|---|---|---|---|---|
| | | Oxygen-Containing Compounds | | |
| Alcohols | ROH[a] | $CH_3CH_2OH$ | ethyl alcohol (ethanol) | -ol |
| Phenols | ArOH[b] | $C_6H_5$–OH | phenol | -ol |
| Ethers | ROR′ | $H_3CH_2COCH_2CH_3$ | diethyl ether | ether |
| Aldehydes | RCHO | $CH_3CH$(=O) | acetaldehyde (ethanal) | -aldehyde (-al) |
| Ketones | RR′C=O | $CH_3C$(=O)$CH_3$ | acetone (2-propanone) | -one |
| Carboxylic acids | $RCO_2H$ | $CH_3C$(=O)$OH$ | acetic acid (ethanoic acid) | -ic acid (-oic acid) |



## The ubiquitous "R" group

- To maintain our focus on the functional group, an *R* is used to represent the rest of the molecule, and is attached to the functional group as shown.




- The *R* can represent one carbon or a more complex group.



## Unsaturated hydrocarbons - alkenes

- Alkenes are hydrocarbons that contain carbon–carbon double bond(s).
- Ethene, known as ethylene, a compound produced by ripening fruits, is the simplest alkene.

- The double bond of alkenes is shorter and stronger than the single bond of alkanes.

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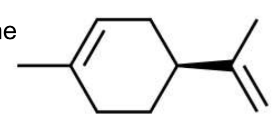
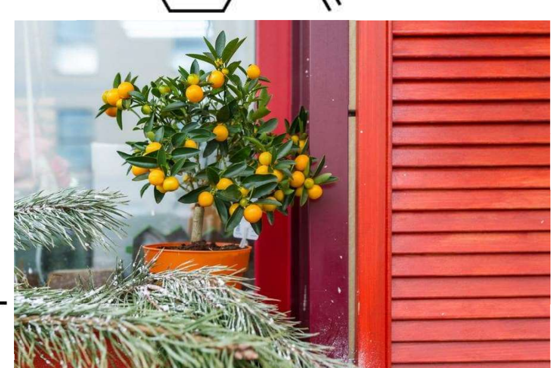
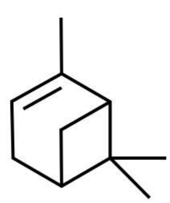
## Naturally Occurring Alkenes

Limonene





Pinene



# Alkynes

- Alkynes are organic compounds that contain a carbon–carbon triple bond.
- Ethyne (known as acetylene), a fuel used in welding torches, is the simplest alkyne.

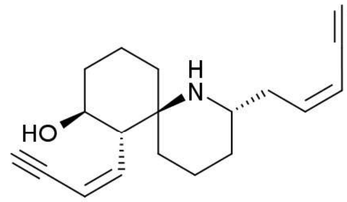
H—C≡C—H

- The triple bond is shorter and stronger than the alkene's double bond. This bond is more reactive than the double bond and is less stable.



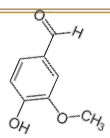
# Naturally occurring alkynes

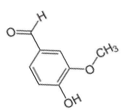
- rare
- alkynes occur mainly in short-lived compounds.
- Histrionicotoxin, a poison secreted by the poison dart frog as a defense against its predators, contains two alkyne functional groups.






# Aromatics





- Aromatic compounds are six-carbon member rings with alternating double and single bonds. The simplest aromatic compound is benzene.
- These compounds get their name, aromatic, because the first ones discovered have pleasant aromas. The fragrance of vanilla is from a compound in the aromatic family.

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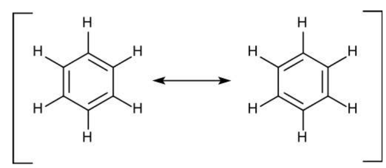
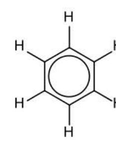
# The benzene ring is unusually stable

Unsaturated cyclic compounds like benzene, which are unusually stable, are said to exhibit **aromaticity**.



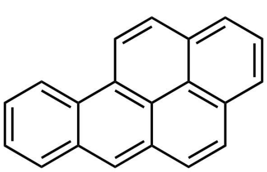
The double bonds of benzene are stable because they alternate with single bonds in a ring. The electrons of the double bond can freely move around the ring. This phenomena is known as **resonance**.

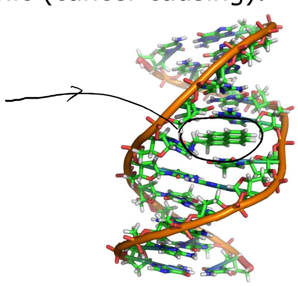




# Multiple fused benzene rings

- These compounds are called **polycyclic aromatic hydrocarbons** or PAHs. Phenanthrene and benzo[ɑ]pyrene are examples. Many have been shown to be carcinogenic (cancer causing).





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# Systematic names (IUPAC names)

- branched-chain isomer of butane, isobutane
- IUPAC name is 2-methyl-propane

- Nonsense names do exist: try 1-methyl-propane

## Fatty Acids—Biological "Hydrocarbons"

- Fatty acids have structures and properties similar to alkanes. As a result, they could be called **biological hydrocarbons**.
- Fatty acids belong to a class of biological compounds called **lipids**. Lipids are nonpolar biomolecules.
- **Saturated** fatty acids contain carbon–carbon single bonds and are the main components of saturated fats.



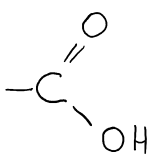
## Structure and Polarity

- Fatty acids are alkane-like compounds. Most common fatty acids are composed of 12 to 22 carbon atoms. Most naturally fatty acids contain an even number of carbon atoms.
- Alkanes and fatty acids contain "straight" chains of carbon atoms. The difference is that fatty acids contain a functional group consisting of two oxygens and a hydrogen known as a carboxylic acid group.



## Carboxylic acid

- The carboxylic acid functional group is responsible for the acid part of the name of fatty acids.

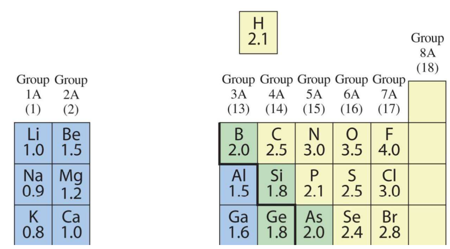



- Fatty acids are nonpolar molecules despite having two electronegative oxygen atoms. The nonpolar hydrocarbon chain is much larger than the polar carboxylic acid group and dominates the character of fatty acids.



## Molecular Polarity

- Electrons are not share equally in covalent bonds. Instead, the more electronegative atom gets a larger share, i.e. a larger part of the negative charge




- Electronegativity is the ability of an atom to attract bonding electrons of a covalent bond to itself.



## Examples

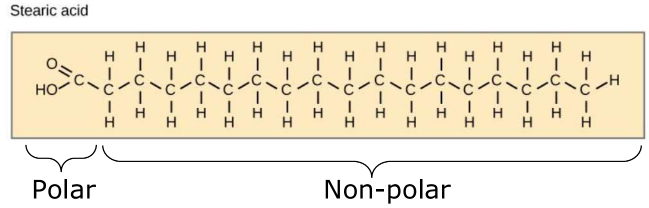
| Saturated Fatty Acids | | |
|---|---|---|
| **Formula** | **Common Name** | **Melting Point** |
| $CH_3(CH_2)_{10}CO_2H$ | lauric acid | 45 °C |
| $CH_3(CH_2)_{12}CO_2H$ | myristic acid | 55 °C |
| $CH_3(CH_2)_{14}CO_2H$ | palmitic acid | 63 °C |
| $CH_3(CH_2)_{16}CO_2H$ | stearic acid | 69 °C |
| $CH_3(CH_2)_{18}CO_2H$ | arachidic acid | 76 °C |



## A bit polar, a lot not

- Molecules like fatty acids that contain both polar and nonpolar parts are called **amphipathic** compounds.

Stearic acid



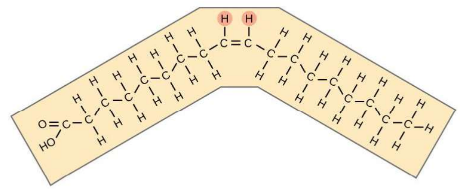
# Unsaturated Fatty Acids

- Unsaturated fatty acids are fatty acids that contain less than the maximum number of hydrogen atoms per carbon atom.
- In these fatty acids, a carbon–carbon double bond exists for each missing pair of hydrogen atoms.
- The double bond is another functional group found in organic compounds known as **alkenes**.



# Mono vs. polyunsaturated

- Fatty acids with one double bond are called monounsaturated, and those with two or more double bonds are called polyunsaturated. A double bond causes a U-shaped molecule.

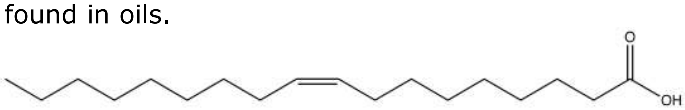



- The double bond does not affect the nonpolar nature of the unsaturated fatty acid (but the melting point).

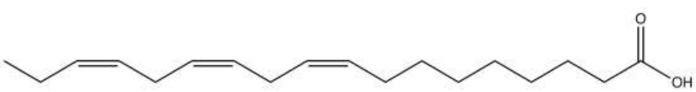


# Examples

Oleic and linolenic acid are two common fatty acids found in oils.




oleic acid




linolenic acid



# Common unsaturated fatty acids

| Symbol | common name | systematic name | structure | mp(C) |
|---|---|---|---|---|
| 16:1$^{\Delta 9}$ | Palmitoleic acid | Hexadecenoic acid | CH3(CH2)5CH=CH-(CH2)7COOH | -0.5 |
| 18:1$^{\Delta 9}$ | Oleic acid | 9-Octadecenoic acid | CH3(CH2)7CH=CH-(CH2)7COOH | 13.4 |
| 18:2$^{\Delta 9,12}$ | Linoleic acid | 9,12 -Octadecadienoic acid | CH3(CH2)4(CH=CHCH2)2(CH2)6COOH | -9 |
| 18:3$^{\Delta 9,12,15}$ | α-Linolenic acid | 9,12,15 -Octadecatrienoic acid | CH3CH2(CH=CHCH2)3(CH2)6COOH | -17 |
| 20:4$^{\Delta 5,8,11,14}$ | arachidonic acid | 5,8,11,14-Eicosatetraenoic acid | CH3(CH2)4(CH=CHCH2)4(CH2)2COOH | -49 |
| 20:5$^{\Delta 5,8,11,14,17}$ | EPA | 5,8,11,14,17-Eicosapentaenoic- acid | CH3CH2(CH=CHCH2)5(CH2)2COOH | -54 |
| 22:6 $^{\Delta 4,7,10,13,16,19}$ | DHA | Docosohexaenoic acid | 22:6w3 | |

Contributed by Henry Jakubowski



# Fatty Acids in Our Diets

- Diets low in fats have been shown to be healthier.
- Fats are needed in our diet because they play an important roles as insulation and protective coverings for our internal organs and nerve fibers.
- A maximum of 30% of the calories in a normal diet should come from fatty acids.



# Fatty acids are components of fats

% FATTY ACIDS IN VARIOUS FATS

| FAT | <16:0 | 16:1 | 18:0 | 18:1 | 18:2 | 18:3 | 20:0 | 22:1 | 22:2 | . |
|---|---|---|---|---|---|---|---|---|---|---|
| Coco-nut | 87 | . | 3 | 7 | 2 | . | . | . | . | . |
| Canola | 3 | . | | 11 | 13 | 10 | . | 7 | 50 | 2 |
| Olive Oil | 11 | . | 4 | 71 | 11 | 1 | . | . | . | . |
| Butter-fat | 50 | 4 | 12 | 26 | 4 | 1 | 2 | . | . | . |

Contributed by Henry Jakubowski

## Functional Groups

- Organic compounds are classified into families based on common functional groups.
- Each functional group has specific properties and reactivity, and organic compounds that contain the same functional group behave similarly.
- To understand the properties and reactivity of the many organic compounds, we need only to identify the functional group they contain.



## Heteroatoms

- Most functional groups contain atoms other than carbon and hydrogen. These atoms in their structure are called heteroatoms.
- Most common heteroatoms are oxygen, nitrogen, sulfur, and the halogens.
- Example: alcohols carry an hydroxyl group, -OH



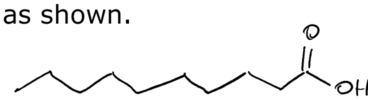
## Functional groups without heteroatoms

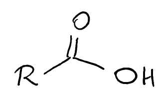
- The first four functional groups—alkanes, alkenes, alkynes, and aromatics—will be considered in this chapter.
- Those functional groups containing heteroatoms will be considered when they appear in the structure of biomolecules as they are studied.
- The functional group is the reactive part of an organic molecule.



## The ubiquitous "R" group

- To maintain our focus on the functional group, an *R* is used to represent the rest of the molecule, and is attached to the functional group as shown.






- The *R* can represent one carbon or a more complex group.



## Systematic names: with heteroatoms

- Haloalkanes, Alkanes with F, Cl, Br, I substituting for a hydrogen
- Example: 2-chloro 3-fluoro butane
- Example: 1-chloro 2-methyl propane



## Systematic names: ring structures

- Cycloalkanes, Alkanes that form a ring
- Example: 2-chloro 3-fluoro cyclohexane
- Example: 1-chloro 2-methyl cyclopentane

## Introduction to Carbohydrates

- One major class of biomolecules (and food ingr.)
  - Lipids (Fat)
  - Carbohydrates (Sugar, starch)
  - Amino acids (Protein)
- Carbohydrates are sugars and provide energy when consumed.
- Our bodies break down carbohydrates to extract energy. Oxygen is used and carbon dioxide and water are released in the process.
- **Glucose** is the primary carbohydrate our bodies use to produce energy (brain food).

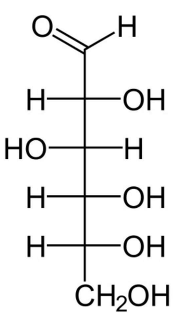


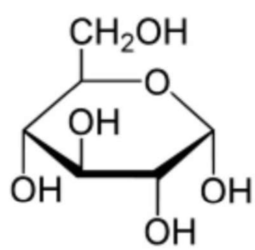
## Glucose in nature and medicine

- most abundant monosaccharide found in nature.
- also known as dextrose, blood sugar, and grape sugar.
- broken down in cells to produce energy.
- one of the building blocks of sucrose (table sugar) and lactose (milk sugar) as well as the polysaccharides glycogen, starch, and cellulose.
- Diabetics have difficulty getting glucose in their cells, which is why they must monitor their blood glucose levels regularly.



## Glucose structure





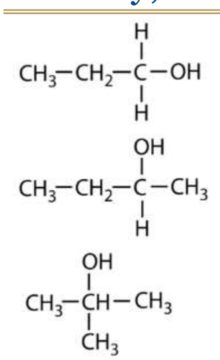


## Hydroxyl functional group: Alcohols

- One of the functional groups in monosaccharide
- Alcohol is an organic compound containing the –OH (hydroxyl) group.
- Ethanol is one of the simplest alcohols and is prepared from the fermentation of simple sugars in grains and fruits. Ethanol is present in beer and liquors, and is used as an alternative fuel blend, such as gasohol and E85 (85% ethanol and 15% gasoline).
- Hydroxyl and hydroxide are different



## Primary, secondary, tertiary alcohols



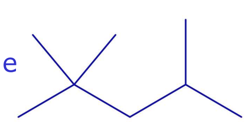
Primary Alcohol

Secondary Alcohol

Tertiary Alcohol

- We count how many C-C bonds are at the carbon to which OH is attached
- What kind of alcohol groups do we find in glucose?

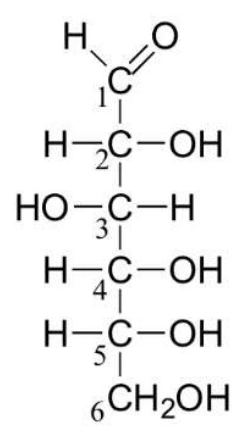
How do we turn 2,2,4 trimethyl pentane into a 1°, 2° or 3° alcohol?



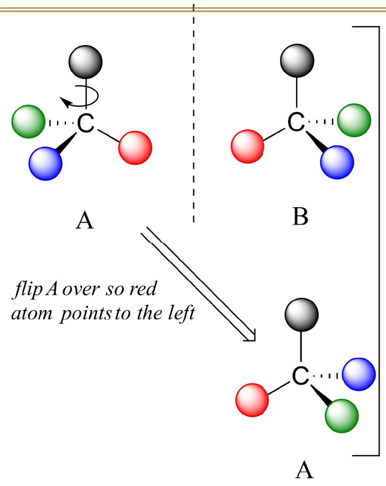


## Glucose has multiple chiral centers

- Carbons 2 through 5 of glucose are tetrahedral and have four different atoms or groups of atoms attached.
- For each chiral center, there are two mirror images, which result in stereoisomers.
- Glucose has 4 chiral centers, so there are 2*2*2*2 possibilities (not all of these stereoisomers are called glucose)



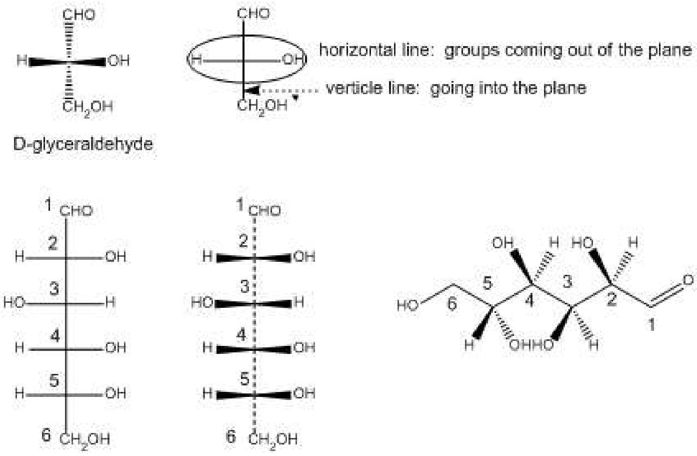
## Molecules with handedness (chirality)




*A and B cannot be superimposed: they are **not** the same molecule!*



## Fischer projection



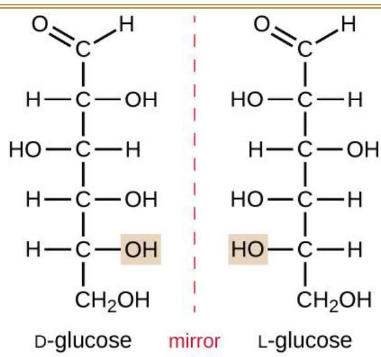

Fischer Wedge-and-dash



## D vs. L glucose

D-glucose has an enantiomer called L-glucose.

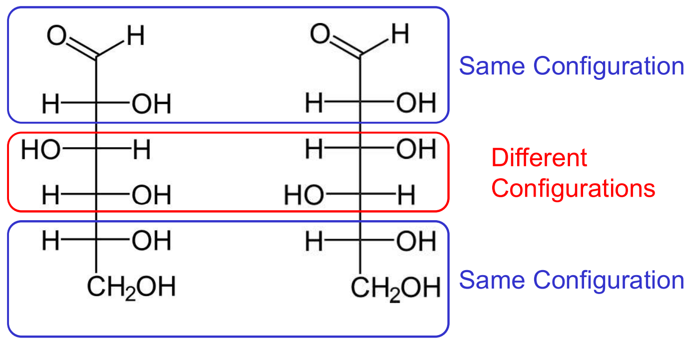
How are they different from each other?




All D-sugars have the –OH on the chiral carbon farthest from the carbonyl group on the right side of the molecule. Most sugars in nature have the D designation.



## What about the other 14 possibilities?




**D-Glucose** **D-Gulose**

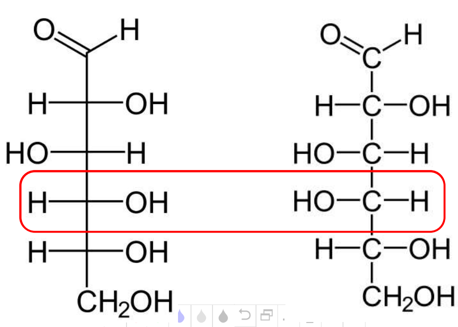
- Diastereomers are stereoisomers that are not exact mirror images. Diastereomers of D-glucose are not called glucose, but have different names.



## Epimer, a special case of diastereomer

- Epimers are stereoisomers with a change in only a single chiral center.

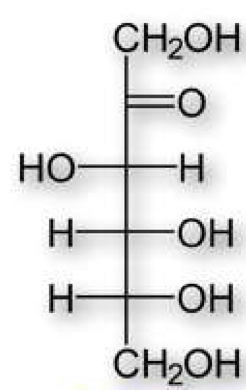
**D-Glucose** **D-Galactose**





## Fructose

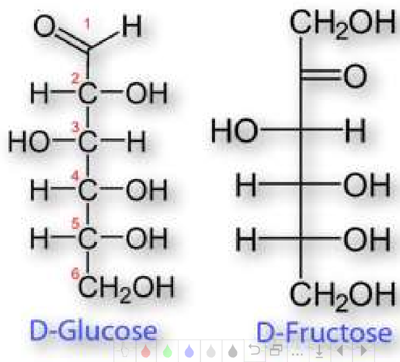
- Fructose is commonly referred to as fruit sugar or levulose.
- Fructose is combined with glucose to give sucrose, or table sugar.
- Fructose is the sweetest monosaccharide and is found in fruits, vegetables, and honey.
- Fructose is a structural isomer of glucose. Like glucose, it can be broken down for energy in the body.



D-Fructose

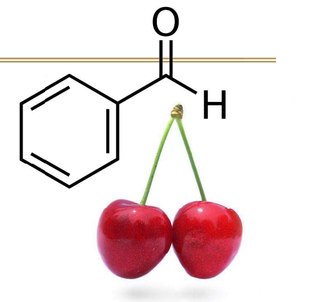
## Ketones vs. Aldehydes

- Both carry the carbonyl group
- Ketones: in the middle of the chain R(C=O)R
- Aldehyde: at the end of the chain R(C=O)H

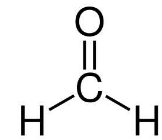





## Aldehydes



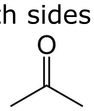
- organic compound containing the carbonyl group.
- Benzaldehyde, a compound responsible for the aroma of almonds and cherries, is one example.
- contain a carbonyl group with a hydrogen atom bonded to one side
- formaldehyde (a preservative) has two hydrogens bonded to the carbonyl group.



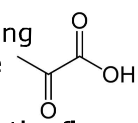


## Ketones

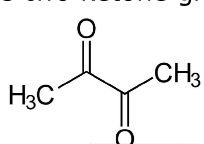
- A ketone also contains the carbonyl group, but has an alkyl or aromatic group on both sides of the carbonyl group.
- Acetone is the simplest ketone. It is used as nail polish remover.



- Pyruvate is a ketone-containing compound formed during the breakdown of glucose.



- Butanedione (a.k.a diacetyl), the flavor of butter, contains two ketone groups





## Oxidation and Reduction Reactions

- When copper metal (shiny orange metal) is exposed to oxygen, an ionic compound, copper(II) oxide, is produced. This compound is greenish in color. This reaction is shown as:

$$2\,\mathrm{Cu}(s) + \mathrm{CO_2}(g) + \mathrm{H_2O}(l) + \mathrm{O_2}(g) \longrightarrow \mathrm{CuCO_3}(s) + \mathrm{Cu(OH)_2}(s)$$

- The copper atoms in the reactant lose electrons to form the $Cu^{2+}$ ions in the product. The copper has undergone oxidation.
- oxidation or reduction?

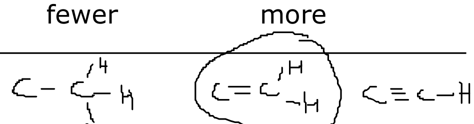
$$2\,\mathrm{Na}(s) + \mathrm{Cl_2}(g) \longrightarrow 2\,\mathrm{NaCl}(s)$$



## Redox reactions in organic chemistry

- Shortcut for carbon: check whether the number of bonds with hydrogen or oxygen changes.

| | bonds with oxygen | bonds with hydrogen |
|---|---|---|
| Oxidation | more | fewer |
| Reduction | fewer | more |

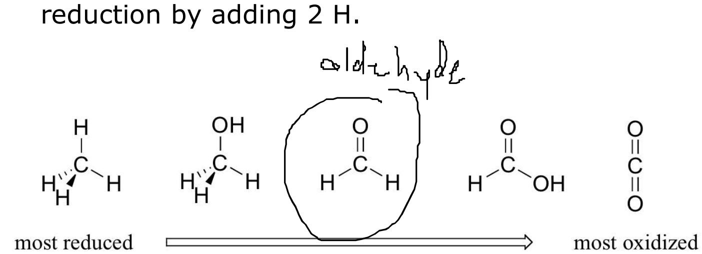


- Try for ethane, ethene and ethyne



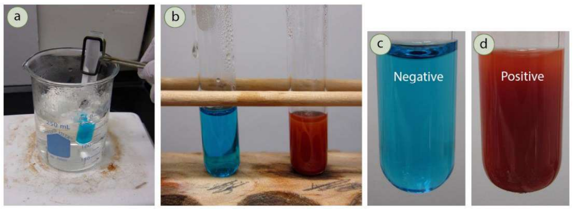
## Monosaccharides and Redox

- An aldehyde functional group can undergo oxidation by adding 1 O or it can undergo reduction by adding 2 H.



## Benedict's test for aldehydes

- Aldoses are easily oxidized. They serve as reducing agents and are referred to as reducing sugars
- Aldose sugars are oxidized by $Cu^{2+}$ ion, while the $Cu^{2+}$ ion is reduced to $Cu^{+}$ ion.
- Copper(I) oxide ($Cu_2O$), is not soluble and forms a brick red precipitate in solution.

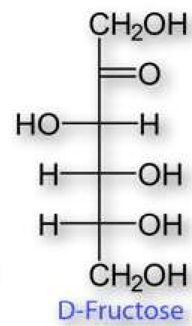



Excess glucose in urine suggests high levels of glucose in blood, which is an indicator of diabetes.



## Alpha-Ketoses are reducing sugars as well

- Fructose and other alpha-ketoses react as well
- Explanation: rearrangement under basic conditions produces aldehyde group

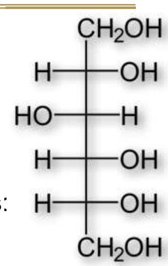





## Reducing sugars to sugar alcohols

- Aldoses or ketoses can be reduced by hydrogen under the correct conditions, producing sugar alcohols.
- Sugar alcohols are produced commercially as artificial sweeteners and found in sugar-free foods.
- Reduction of glucose produces the sugar alcohol, sorbitol, which is an artificial sweetener

Redution of Glucose yields:



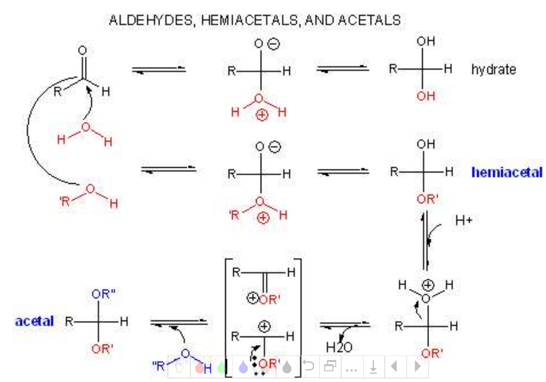

Sorbitol (Glucitol)

- When glucose levels are high in the blood stream, sorbitol can be produced by an enzyme called aldose reductase.
- High levels of sorbitol can contribute to cataracts, which is a clouding of the lens in the eye. Cataracts are common in diabetics.



## Ring formation

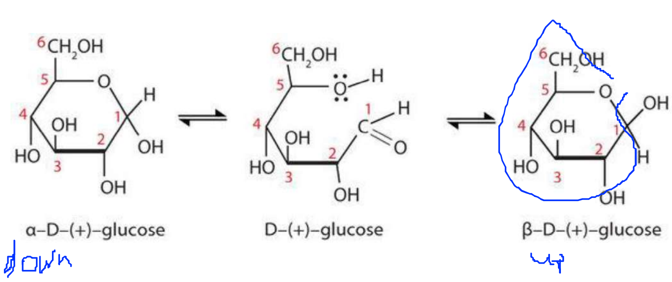
- Carbonyl groups (ketone, aldehyde) react with a hydroxyl functional group (–OH).
- hemiacetal functional group is formed as shown:






## 6-membered ring

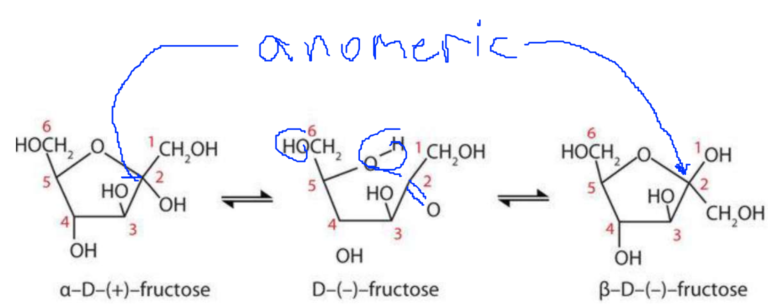
- A hemiacetal can form within a monosaccharide since it contains both a carbonyl and several hydroxyl functional groups.






## 5-membered ring

Fructose mostly forms 5-membered rings



## Monosaccharide classification

- Monosaccharides contain the elements carbon, hydrogen, and oxygen, and have the general formula $C_n(H_2O)_n$, where n is a whole number 3 or greater.
- Monosaccharides that contain an aldehyde group are referred to as an **aldose**. Those that contain a ketone group are referred to as a **ketose**.
- Monosaccharides are classified according to the number of carbon atoms.
  - Triose contains three carbons.
  - Tetrose contains four carbons.
  - **Pentos**e contains five carbons.
  - **Hexose** contains six carbons.



## Examples for classification

- Glucose, the most abundant monosaccharide found is nature, contains six carbons and an aldehyde group. It is classified as an aldohexose.
- Fructose, known as fruit sugar, contains six carbons and a ketone group. It is classified as a ketohexose.
- Aldohexose and ketopentose differ in the number of carbon atoms and in the type of carbonyl group they contain



## Building blocks for larger carbs

- Monosaccharides are the simplest carbohydrates. They cannot be broken down to smaller carbohydrates without breaking C-C bonds.
- Disaccharides consist of two monosaccharide units joined together; they can be split into two monosaccharides.
- Oligosaccharides contain anywhere from three to nine monosaccharide units



## Joining monosaccharide building blocks

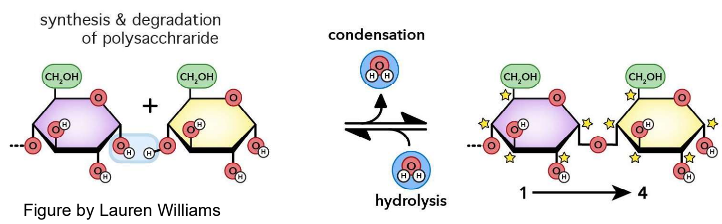



Figure by Lauren Williams
https://ww2.chemistry.gatech.edu/~lw26/structure/molecular_interactions/mol_int.html#PB1

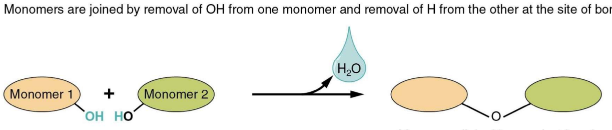
- OH on anomeric carbon is replaced by hydroxyl oxygen from another building block
- The new bond joining the building blocks is called **glycosidic bond**.
- Once there is a glycosidic bond, the sugar ring can no longer open up (no longer a reducing sugar)



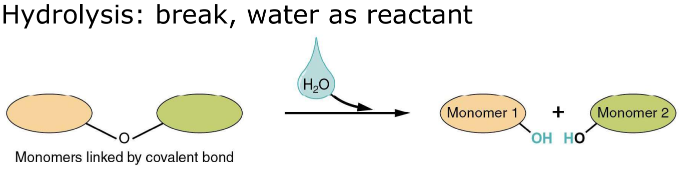
## Condensation and hydrolysis reactions

Condensation: link, water as product

Monomers are joined by removal of OH from one monomer and removal of H from the other at the site of bond formation.




Hydrolysis: break, water as reactant

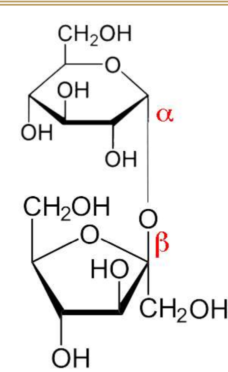



Polysaccharides, Proteins, DNA and RNA are all made from their building blocks by condensation reactions



## Sucrose

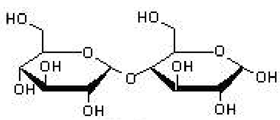
- known as table sugar
- most abundant natural disaccharide
- found in sugar cane and sugar beets
- glycosidic bond between glucose and fructose is β (1→2).
- Both anomeric carbons of the monosaccharides in sucrose are bonded, therefore, sucrose is not a reducing sugar.




Sucrose

Will it react with Benedict's reagent?

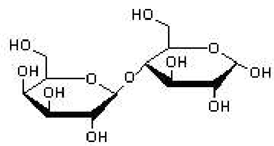
## Maltose vs. lactose



Maltose


α-D-glucose + D-glucose → maltose + $H_2O$ [glycosidic bond α(1 → 4)]

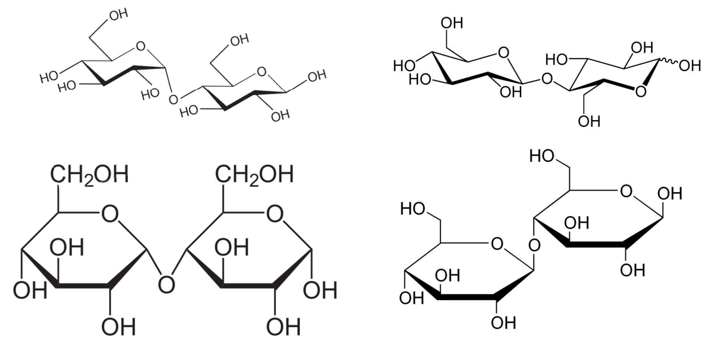
β-D-galactose + D-glucose → lactose + $H_2O$ [glycosidic bond β(1 → 4)]



Lactose



## Alpha or beta makes a difference now



Maltose and cellobiose

are two different compounds



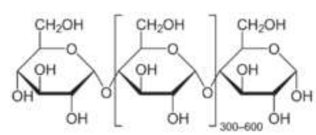
## Polysaccharides

- large molecules of monosaccharides that are connected to each other through their anomeric carbons.
- **Storage polysaccharides** contain only α-glucose units. Three important ones are starch, glycogen, and amylopectin.
- **Structural polysaccharides** contain only β-glucose units. Two important ones are cellulose and chitin. Chitin contains a modified β-glucose unit.

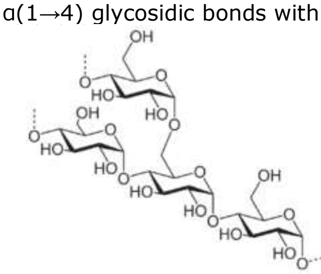


## Storage Polysaccharides

- Amylose and amylopectin—starch
- Starch is a mixture of amylose and amylopectin and is found in plant foods.
- Amylose makes up 20% of plant starch; 250–4000 D-glucose units bonded α(1→4) in a continuous chain.
- Amylopectin makes up 80% of plant starch and is made up of D-glucose units connected by α(1→4) glycosidic bonds with α(1→6) branches.




amylose

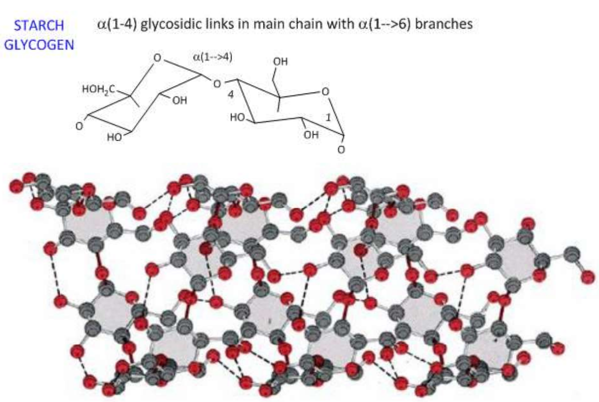


amylopectin



## Starch structure

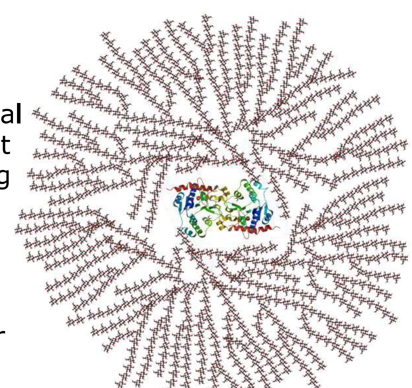
- Long chains of amylose tend to coil.




(b)

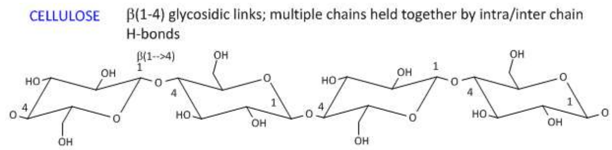
## Glycogen

- Glycogen is a storage polysaccharide found in animals.
- Glycogen is stored in the liver and muscles.
- Its structure is identical to amylopectin, except that α(1→6) branching occurs about every 12 glucose units.
- When glucose is needed, glycogen is hydrolyzed in the liver to glucose.



## Structural Polysaccharides: Cellulose

- contains glucose units bonded β(1→4).

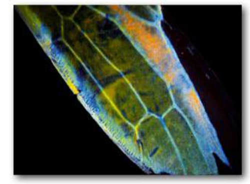



- This glycosidic bond configuration changes the three-dimensional shape of cellulose compared with that of amylose.
- The chain of glucose units is straight. This allows chains to align next to each other to form a strong rigid structure.
- Water insoluble - we can't digest it (dietary fiber)

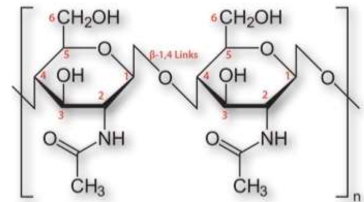


## Structural Polysaccharides: Chitin

- makes up the exoskeleton of insects and crustaceans and cell walls of some fungi.
- made up of N-acetylglucosamine containing β(1→4) glycosidic bonds.
- structurally strong.
- used as surgical thread that biodegrades as a wound heals.



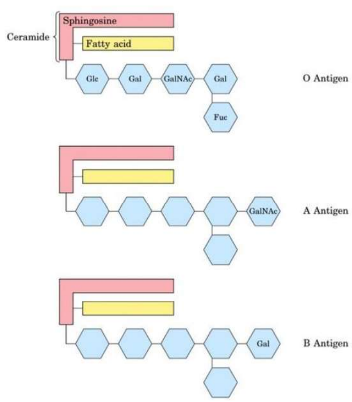
Chitin in the wing of a sap beetle






## Blood types are determined by carbs

- ABO blood types refer to carbohydrates on red blood cells.
- These chemical markers are oligosaccharides that contain either three or four sugar units.
- Sugar building blocks are
  - D-galactose
  - L-fucose
  - N-acetylglucosamine,
  - N-acetylgalactosamine






## Blood type compatibility

- Type O blood is considered the universal donor while type AB blood is considered the universal acceptor.

| | Group A | Group B | Group AB | Group O |
|---|---|---|---|---|
| Red blood cell type | A | B | AB | O |
| Antibodies in Plasma | Anti-B | Anti-A | None | Anti-A and Anti-B |
| Antigens in Red Blood Cell | A antigen | B antigen | A and B antigens | None |



## Polysaccharides: Heparin

- medically important polysaccharide because it prevents clotting in the bloodstream.
- highly ionic polysaccharide of repeating disaccharide units of an oxidized monosaccharide and D-glucosamine. Heparin also contains sulfate groups that are negatively charged.
- It belongs to a group of polysaccharides called glycosamino-glycans.