Carbon & The Molecular Diversity of Life

FIRST STAGE-MEDICAL CHEMISTRY

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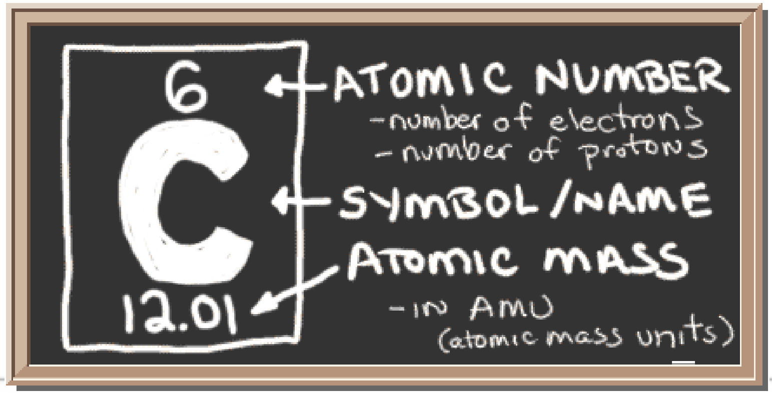
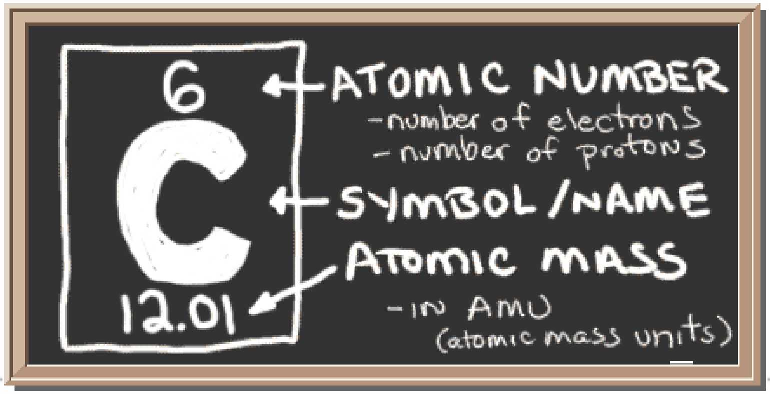
Carbon: The Backbone of Life

- Living organisms consist mostly of carbon-based compounds
- Carbon is unparalleled in its ability to form large, complex, and diverse molecules
- Proteins, DNA, carbohydrates, and other molecules that distinguish living matter are all composed of carbon compounds



Carbon: Organic Chemistry

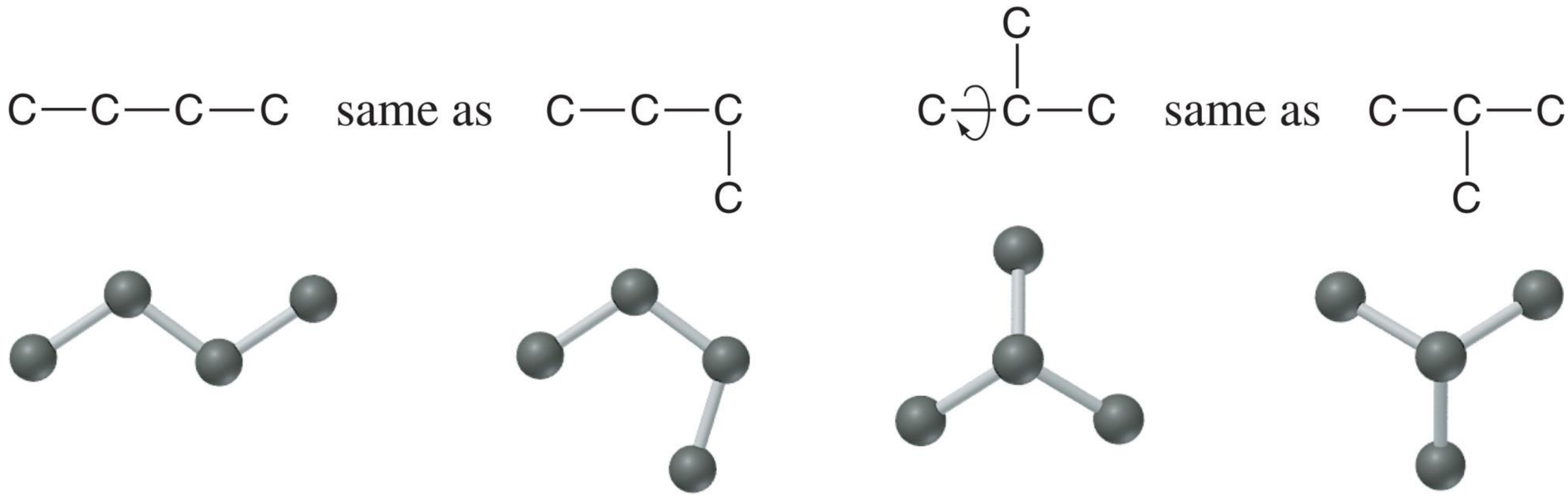
- Carbon is important enough to have it's own branch of chemistry called **Organic chemistry**
- Organic compounds range from simple molecules to colossal ones
- Most organic compounds contain hydrogen atoms in addition to carbon atoms with O, N and P among others thrown in from time to time.



Carbon Skeletons

Each C atom can form a maximum of 4 bonds.

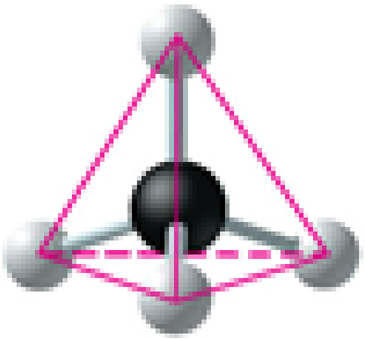
Groups joined by a single bond can rotate, so there are often several different arrangements of a given carbon skeleton that are equivalent:



Carbon has 4 valence electrons, thus makes 4 bonds

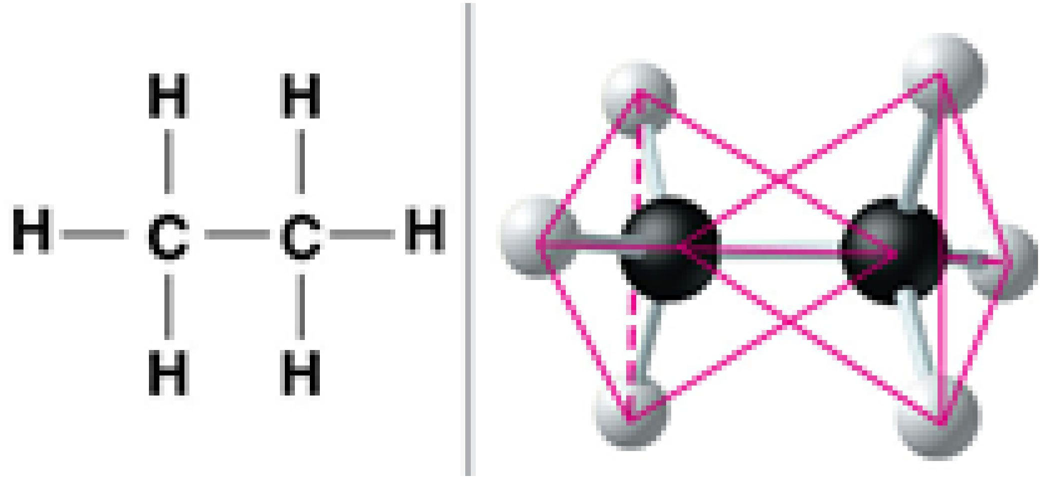
- With four valence electrons, carbon can form four **covalent bonds** with a variety of atoms
- This ability makes large, complex molecules possible
- In molecules with multiple carbons, each carbon bonded to four other atoms has a tetrahedral shape

Tetrahedron

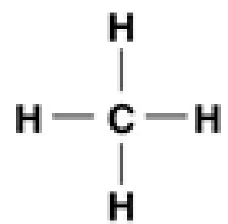
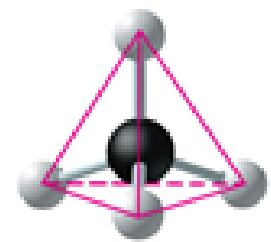
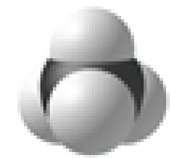
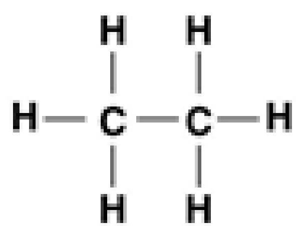
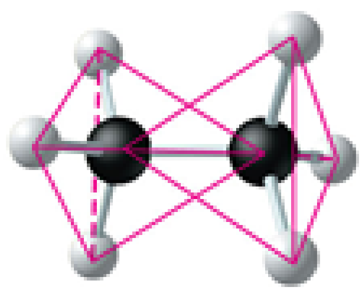
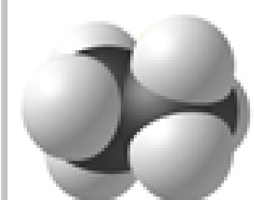
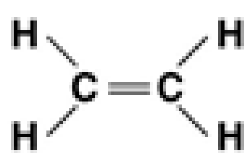
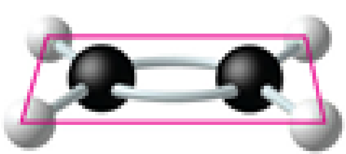
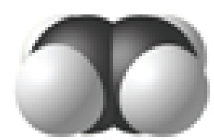


“CNOPS” can combine together to make double and triple covalent bonds

- However, when two carbon atoms are joined by a double bond, the atoms joined to the carbons are in the same plane as the carbons
- Why is this important? Because the shape of a molecule dictates its reactivity, thus its function!

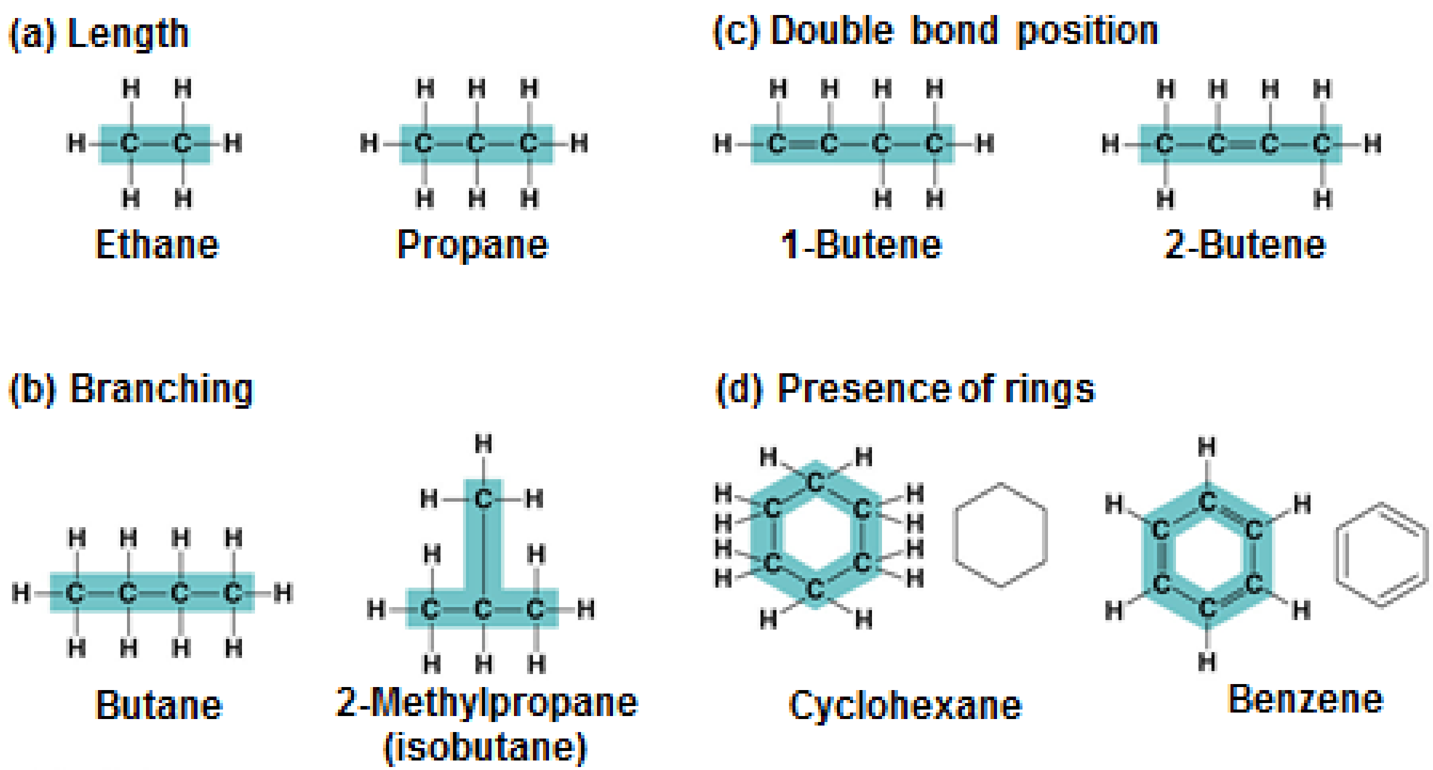


No need to memorize these!

Name and Comment	Molecular Formula	Structural Formula	Ball-and-Stick Model	Space-Filling Model
(a) Methane	CH_4			
(b) Ethane	C_2H_6			
(c) Ethene (ethylene)	C_2H_4			

Carbon Skeletons Vary

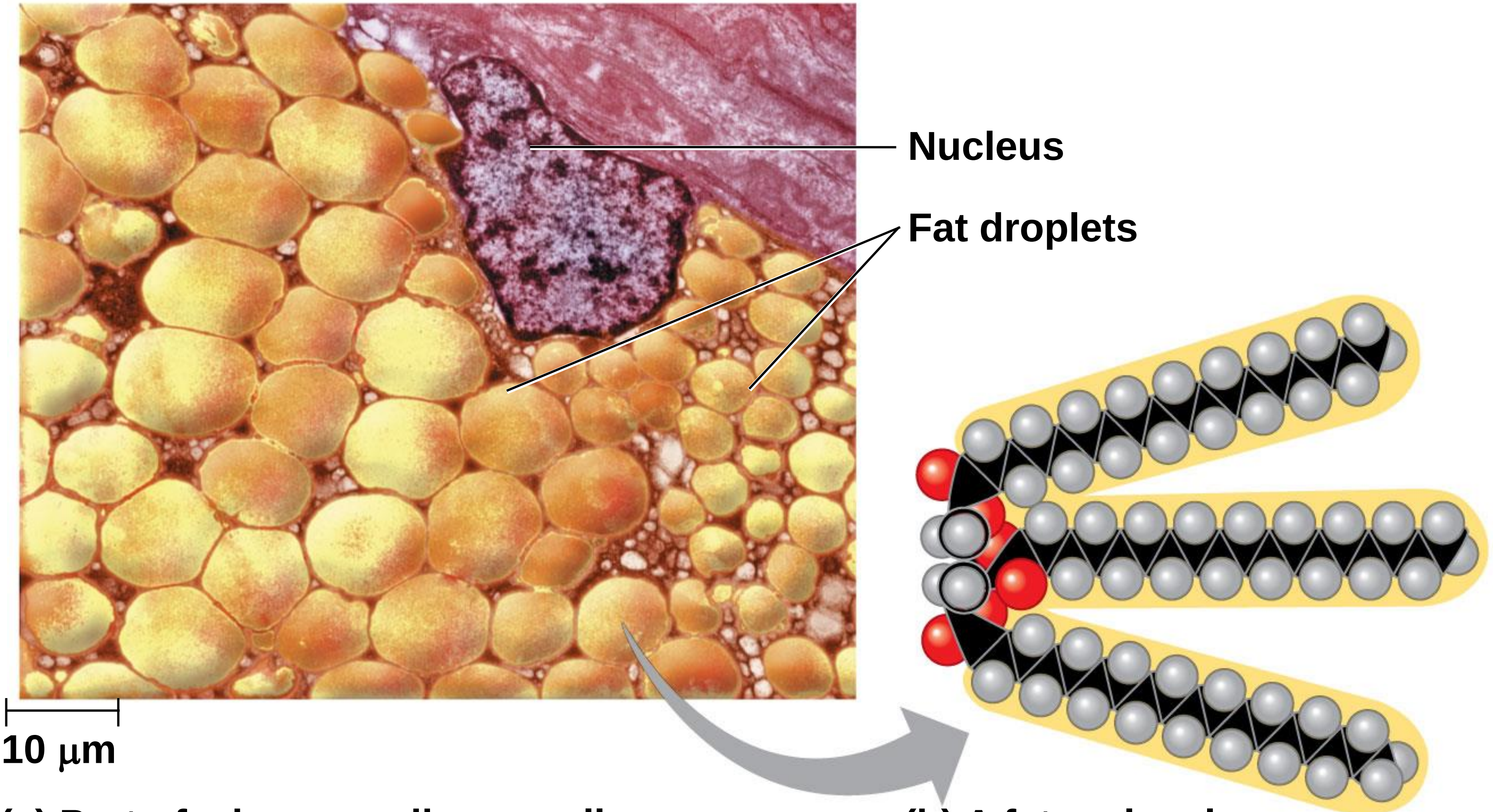
- Carbon chains form the skeletons of most organic molecules
- Carbon chains vary in length and shape



Hydrocarbons

- **Hydrocarbons** are organic molecules consisting of ***only*** carbon and hydrogen
- Many organic molecules, such as fats, have hydrocarbon components
- Hydrocarbons can undergo reactions that release a large amount of energy

Fats



(a) Part of a human adipose cell **(b) A fat molecule**

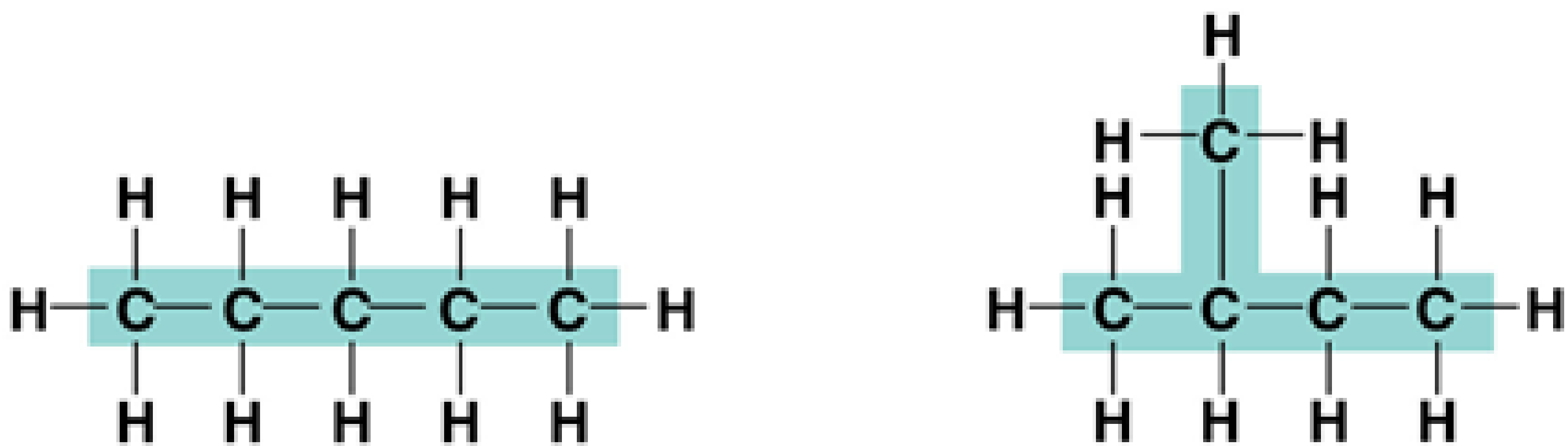
Isomers

- **Isomers** are compounds with the *same molecular formula* but *different structures,* thus *different properties.*
  - **Structural isomers** have different covalent arrangements of their atoms
  - ***Cis-trans* isomers** have the same covalent bonds but differ in spatial arrangements
  - **Enantiomers** are isomers that are mirror images of each other & rotate light differently

NATIONAL MATH + SCIENCE INITIATIVE

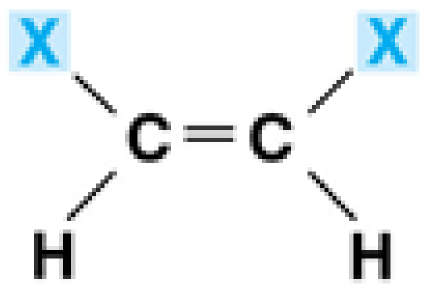
More detail than you need, but cool none the less!

(a) Structural isomers

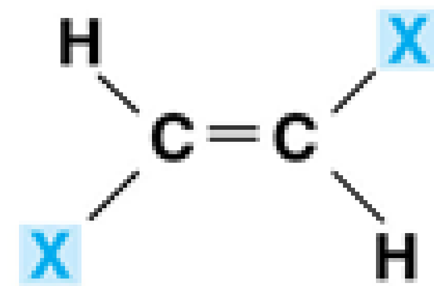


More detail than you need, but cool none the less!

(b) *Cis-trans* isomers

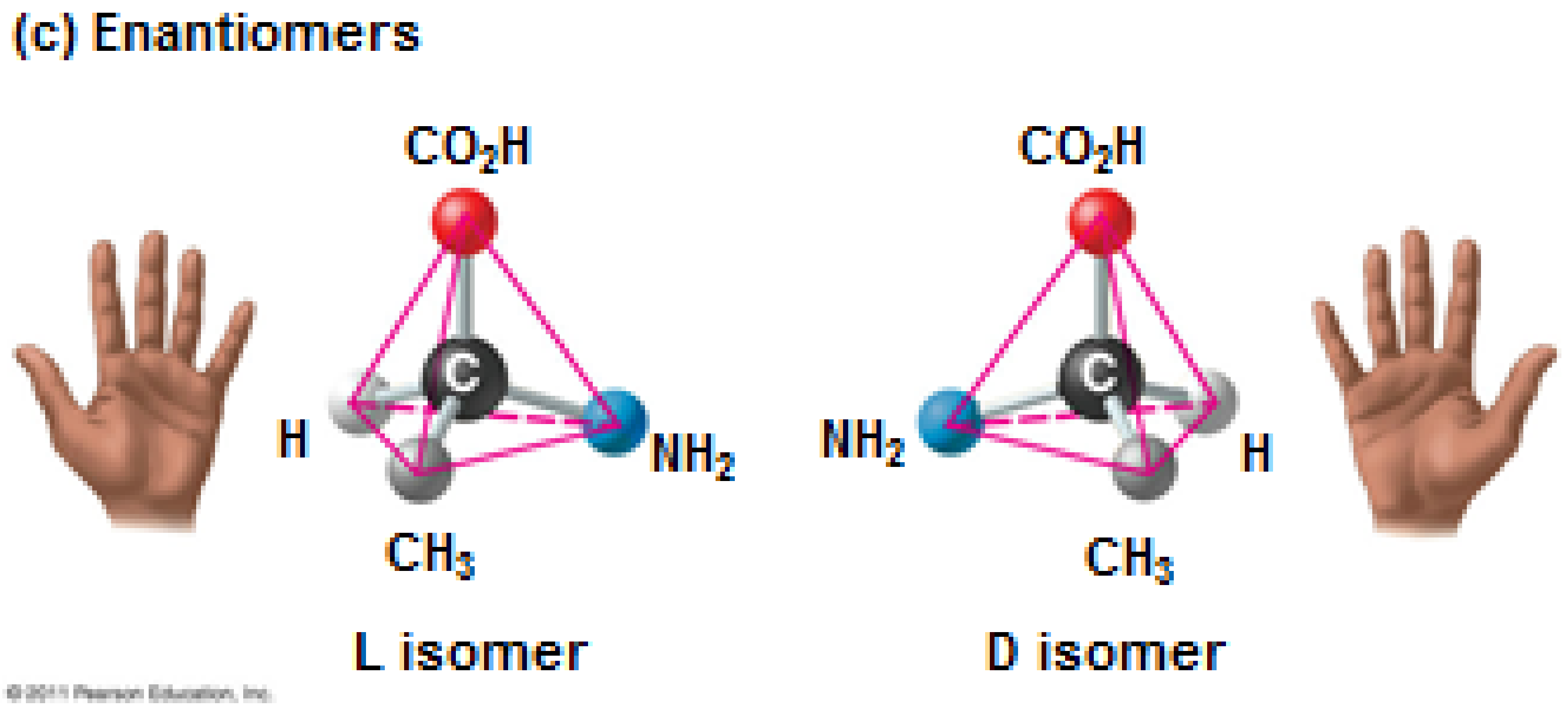


cis isomer: The two Xs are on the same side.



trans isomer: The two Xs are on opposite sides.

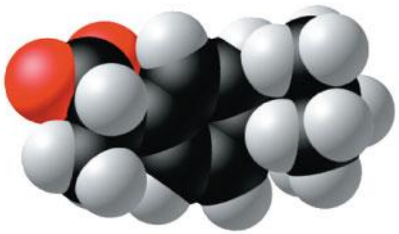
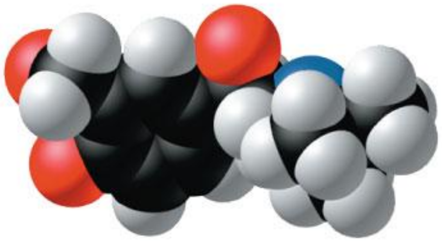
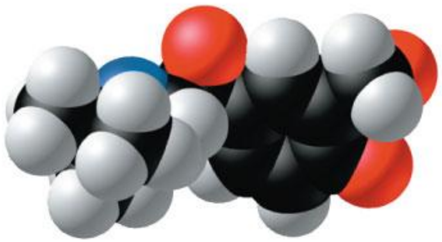
More detail than you need, but cool none the less!



More detail than you need, but cool none the less!

- Enantiomers are important in the pharmaceutical industry
- Two enantiomers of a drug may have different effects
- Usually only one isomer is biologically active
- Differing effects of enantiomers demonstrate that organisms are sensitive to even subtle variations in molecules

Note the mirror imaging

Drug	Condition	Effective Enantiomer	Ineffective Enantiomer
Ibuprofen	Pain; inflammation	 *S*-Ibuprofen	 *R*-Ibuprofen
Albuterol	Asthma	 *R*-Albuterol	 *S*-Albuterol

Functional Groups

A few chemical groups are key to the functioning of molecules

- Distinctive properties of organic molecules depend on the carbon skeleton and on the molecular components attached to it
- A number of characteristic groups can replace the hydrogens attached to skeletons of organic molecules

Functional Groups

- **Functional groups** are the components of organic molecules that are most commonly involved in chemical reactions
- The number and arrangement of functional groups give each molecule its unique properties

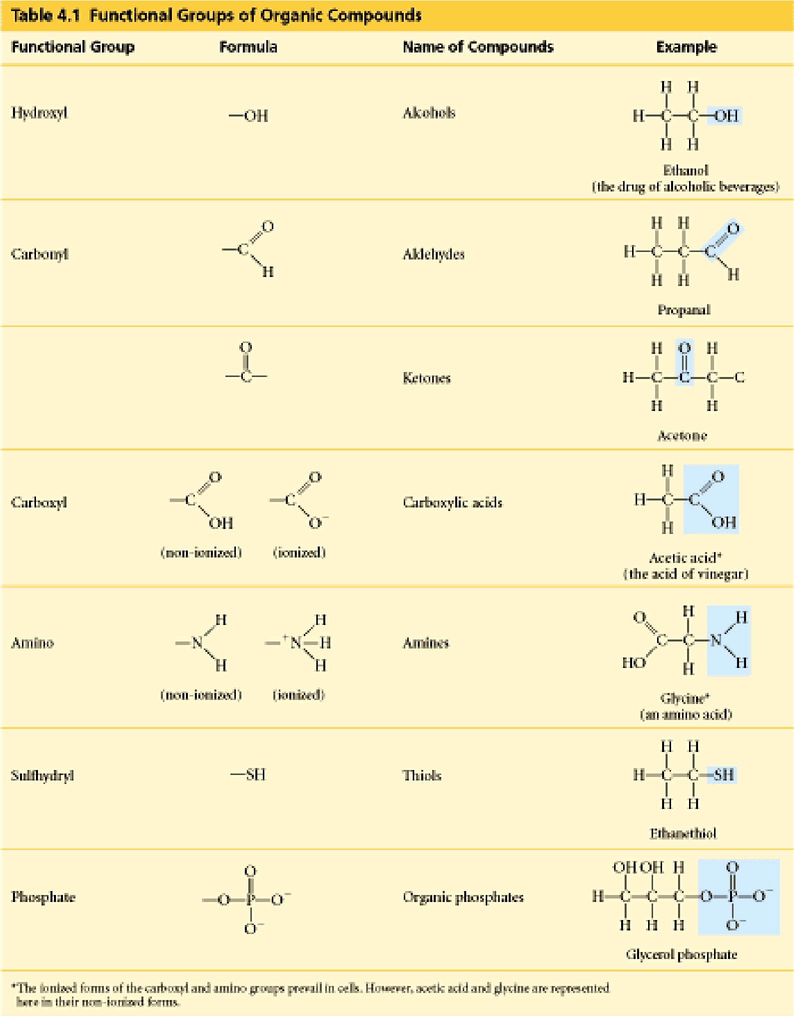


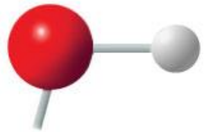
Table 4.1 Functional Groups of Organic Compounds

Functional Group	Formula	Name of Compounds	Example
Hydroxyl	—OH	Alcohols	Ethanol (the drug of alcoholic beverages)
Carbonyl	—CHO	Aldehydes	Propanal
	—CO—	Ketones	Acetone
Carboxyl	—COOH (non-ionized); $—COO^-$ (ionized)	Carboxylic acids	Acetic acid* (the acid of vinegar)
Amino	$—NH_2$ (non-ionized); $—^+NH_3$ (ionized)	Amines	Glycine* (an amino acid)
Sulfhydryl	—SH	Thiols	Ethanethiol
Phosphate	$—OPO_3^{2-}$	Organic phosphates	Glycerol phosphate

*The ionized forms of the carboxyl and amino groups prevail in cells. However, acetic acid and glycine are represented here in their non-ionized forms.

Hydroxyl

STRUCTURE



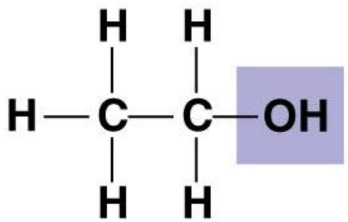
—OH

(may be written HO—)

NAME OF COMPOUND

Alcohols (Their specific names usually end in *-ol*.)

EXAMPLE



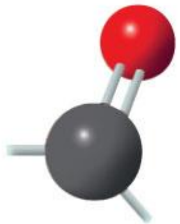
Ethanol

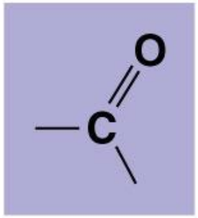
FUNCTIONAL PROPERTIES

- Is polar as a result of the electrons spending more time near the electronegative oxygen atom.
- Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.

Carbonyl

STRUCTURE



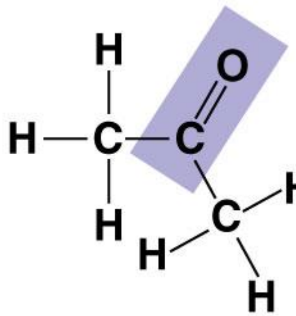


NAME OF COMPOUND

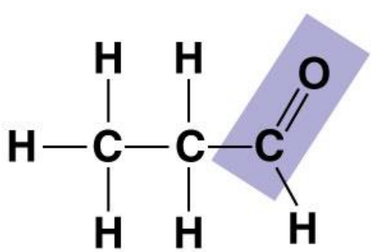
Ketones if the carbonyl group is within a carbon skeleton

Aldehydes if the carbonyl group is at the end of the carbon skeleton

EXAMPLE



Acetone



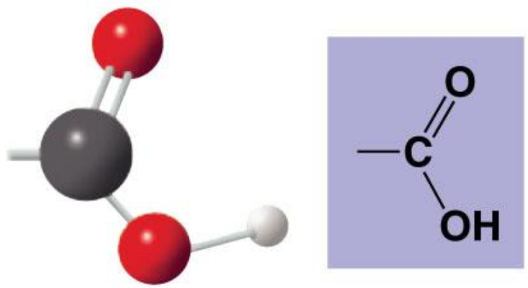
Propanal

FUNCTIONAL PROPERTIES

- A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal.
- Ketone and aldehyde groups are also found in sugars, giving rise to two major groups of sugars: ketoses (containing ketone groups) and aldoses (containing aldehyde groups).

Carboxyl

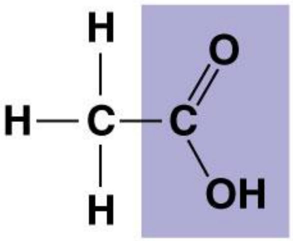
STRUCTURE



NAME OF COMPOUND

Carboxylic acids, or organic acids

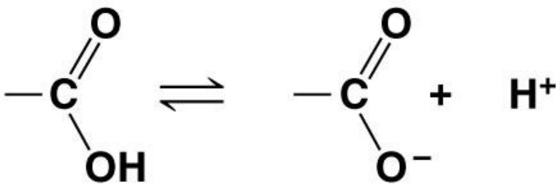
EXAMPLE



Acetic acid

FUNCTIONAL PROPERTIES

- Acts as an acid; can donate an H^+ because the covalent bond between oxygen and hydrogen is so polar:

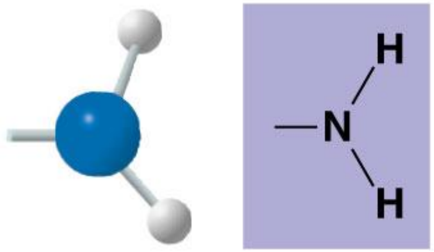


Nonionized   Ionized

- Found in cells in the ionized form with a charge of 1– and called a carboxylate ion.

Amino

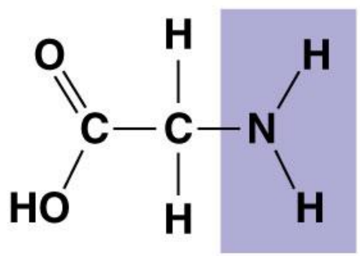
STRUCTURE



NAME OF COMPOUND

Amines

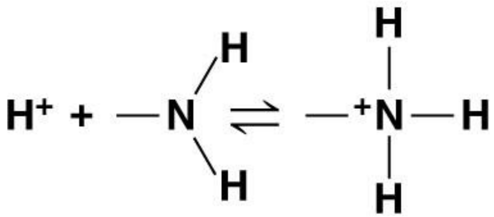
EXAMPLE



Glycine

FUNCTIONAL PROPERTIES

- Acts as a base; can pick up an H^+ from the surrounding solution (water, in living organisms):

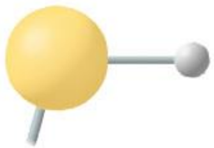


Nonionized Ionized

- Found in cells in the ionized form with a charge of 1+.

Sulfhydryl

STRUCTURE



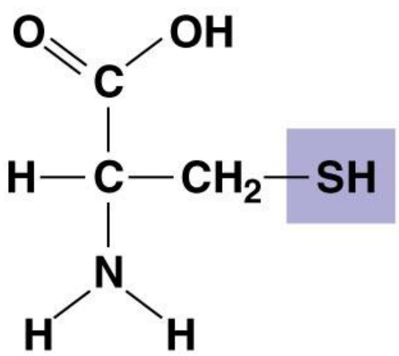
—SH

(may be written HS—)

NAME OF COMPOUND

Thiols

EXAMPLE



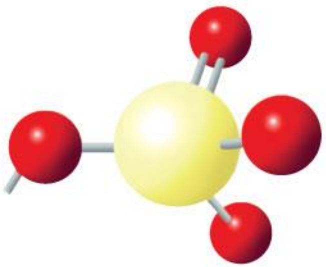
Cysteine

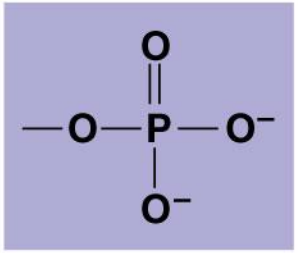
FUNCTIONAL PROPERTIES

- Two sulfhydryl groups can react, forming a covalent bond. This “cross-linking” helps stabilize protein structure.
- Cross-linking of cysteines in hair proteins maintains the curliness or straightness of hair. Straight hair can be “permanently” curled by shaping it around curlers and then breaking and re-forming the cross-linking bonds.

Phosphate

STRUCTURE

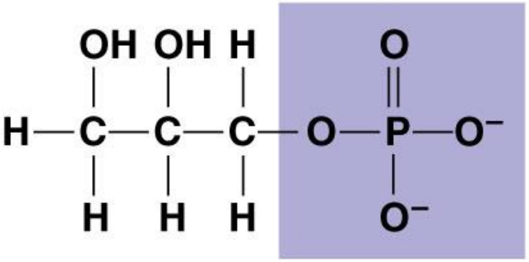




Organic phosphates

NAME OF COMPOUND

EXAMPLE



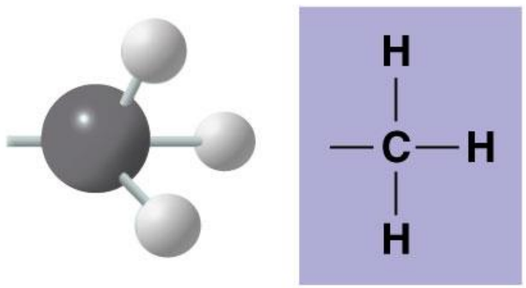
Glycerol phosphate

- Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule, as at left; 1– when located internally in a chain of phosphates).
- Molecules containing phosphate groups have the potential to react with water, releasing energy.

FUNCTIONAL PROPERTIES

Methyl

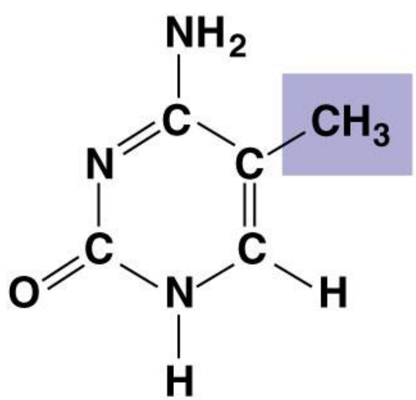
STRUCTURE



Methylated compounds

NAME OF COMPOUND

EXAMPLE



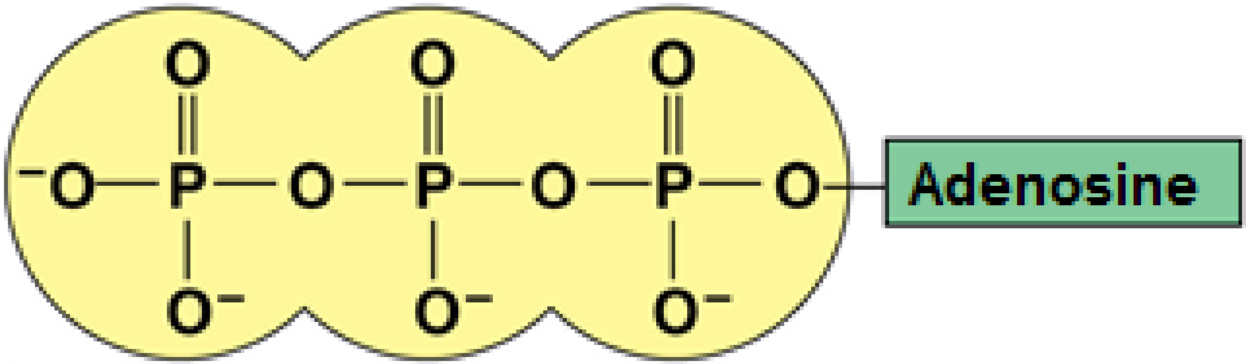
5-Methyl cytidine

- **Addition of a methyl group to DNA, or to molecules bound to DNA, affects the expression of genes.**
- **Arrangement of methyl groups in male and female sex hormones affects their shape and function.**

FUNCTIONAL PROPERTIES

ATP: An Important Source of Energy for Cellular Processes

- One phosphate molecule, **adenosine triphosphate** (**ATP**), is the primary energy-transferring molecule in the cell
- ATP consists of an organic molecule called adenosine attached to a string of three phosphate groups



Final Thoughts

- The versatility of carbon makes possible the great diversity of organic molecules

- Variation at the molecular level lies at the foundation of all biological diversity

Nucleophilic and Electrophilic Reagents

reagents that participate in substitution reactions

Nucleophilic reagents, or nucleophiles, replace the leaving group of a molecule and provide a pair of electrons for the formation of a new bond. The leaving group departs with the pair of electrons that had formed the old bond. Such reactions are called nucleophilic substitutions

.In the following examples of nucleophilic substitution ، Y is the nucleophile, R is an organic radical, and X is the leaving group:

$Y\!:^{-} + RX \rightarrow RY + X^{-}$

$Y\!: + RX \rightarrow RY^{+} + X^{-}$

Nucleophilic reagents comprise negatively charged ions, including OH^-, CN^-, NO_2^-, OR^-, RS^-, NH_2^-, RCO_2 and halogen ions neutral [molecules]() with a free pair of electrons, for example, H_2O, NH_3, R_3N, R_2S, R_3P, ROH, and RCO_2H; and those organometallic compounds (designated RMe), that are capable of forming carban ionsthat is, those in which a bond between a carbon atom and the metal is sufficiently

polarized. Nucleophilic substitution is characteristic mainly of aliphatic compounds. Examples of nucleophilic substitution include hydrolysis, with the nucleophiles OH and H_2O; alcoholysis, in which the nucleophiles are ROand ROH; acidolysis, with the nucleophiles RCOOand RCOOH; amination, involving such nucleophiles as NH_2^-, NH_3, and RNH_2; and cyanation, with the nucleophile CN^-

Electrophilic reagents, or electrophiles, replace the leaving group of a molecule and act as electron pair acceptors in the formation of a new bond. The leaving group departs as a positively charged species. Electrophilic reagents include positively charged ions, for example, H^+ and NO_2^+; neutral molecules with an electron deficiency, for example, SO_3; and highly polarized molecules, for example $CH_3CO_2^{-}Br^{+}$

Such polarization is achieved efficiently by complexing with Lewis acids, for example, Hal^{+}—$Hal^{-}\cdot A$, R^{+}—$CL^{-}A$, and RCO^{+}—$Cl^{-}\cdot A$, where A = $AlCl_3$, $SbCl_5$, or BF_3. Substitution reactions that involve electrophiles are called electrophilic substitutions. These include the most important reactions of aromatic hydrocarbons, for example, nitration, halogenation, sulfonation, and Friedel-Crafts alkylation


THANK
YOU!