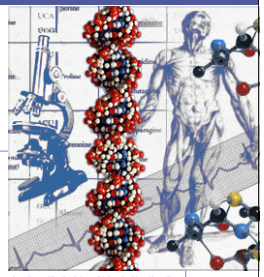
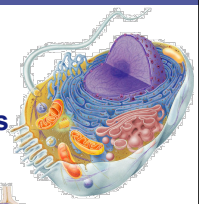
Carbon & Life's Molecular Diversity

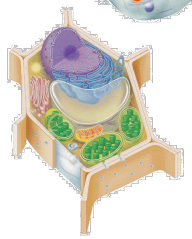


"The Building Blocks of Life"

Why study Carbon?



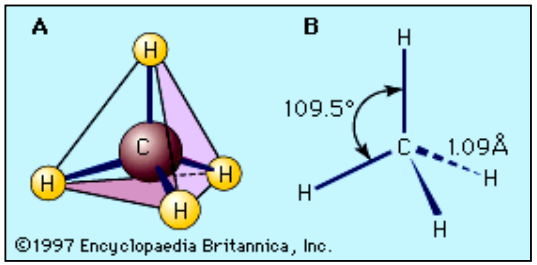
- All living things are made of one or more cells
- Cells
  - ~72% H_2O
  - ~3% salts (Na, Cl, K…)
  - ~25% carbon compounds - C is the backbone of biological macromolecules
    1. carbohydrates
    2. lipids
    3. proteins
    4. nucleic acids



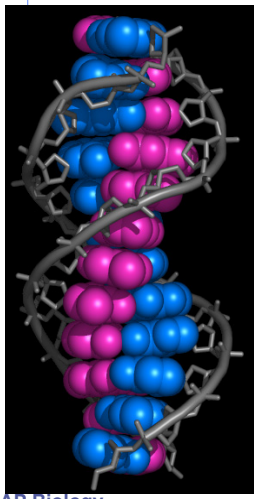
- Carbon is exceptional in its ability to form molecules that are large, complex, and diverse allowing for all the diversity of life on Earth.

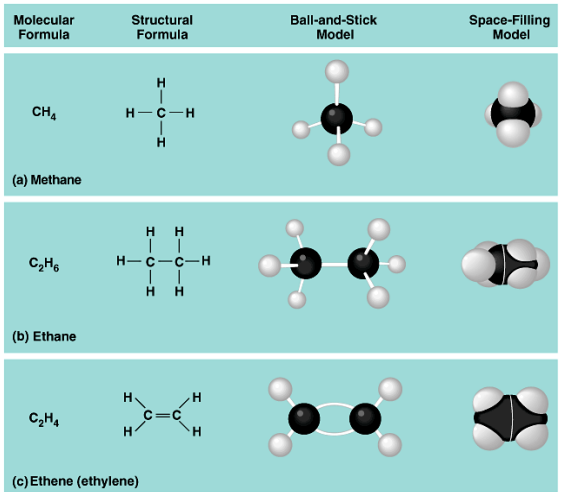
Chemistry of Life

- Organic chemistry = Study of carbon compounds
- C atoms are versatile building blocks:
  - Has 4 valence electrons.
    - *Tetravalence* allows for maximally 4 stable covalent bonds to branch off in 4 separate directions.
      - Carbon can serve as the building block of large complex and diverse molecules

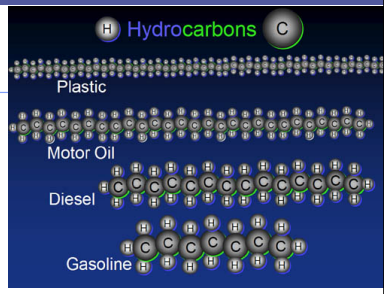


'C' allows for Complex Structural Formations

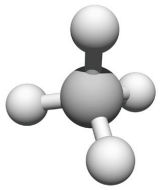




Hydrocarbons

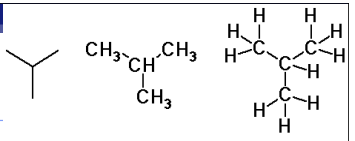


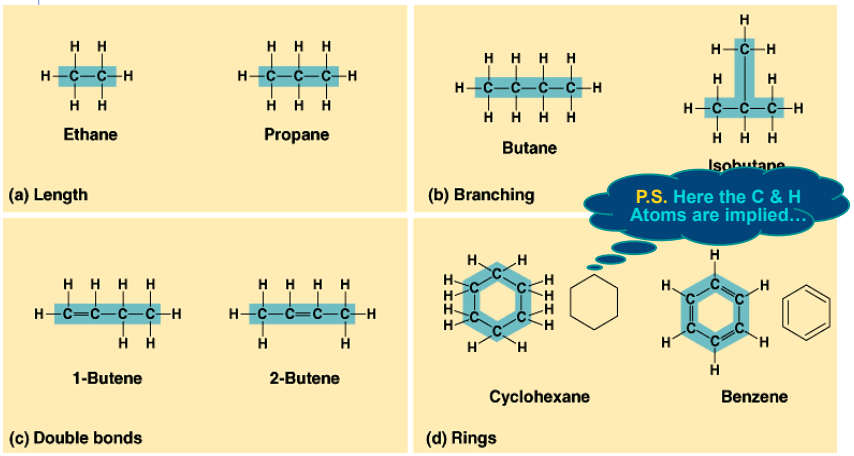
- Simplest C molecules = hydrocarbons
  - combinations of C & H atoms
    - Stable with little attraction between molecules
    - They are not soluble in H_2O
      - Why?
        - They are hydrophobic.
    - Can release a large amount of stored ENERGY
- Simplest hydrocarbon molecule = methane
  - 1 carbon bound to 4 H atoms
  - Stable & non-polar
  - Not soluble in H_2O
    - Hydrophobic
      - Gas at room temperature due the few intermolecular attractions between molecules at room temperatures *(only occasional/weak/ temporary London Dispersion Forces)*



methane
(simplest hydrocarbon)

Hydrocarbons can grow…

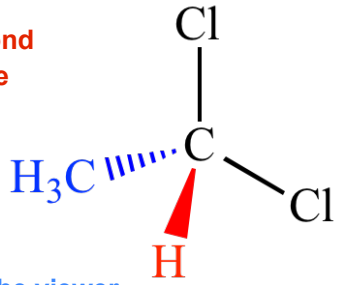




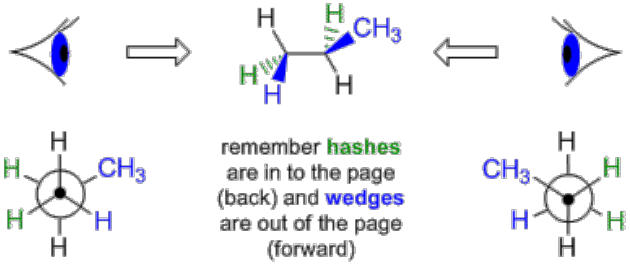
By adding C-C bonds

Indicating the 3D Orientation of Atoms

- Wedge: A symbol used to indicate the position of a bond or group relative to the plane of the paper or screen.
  1. A solid wedge indicates this bond or group is projecting out of the plane of the paper, towards the viewer.
  2. A broken (hashed) wedge indicates this bond or group is receding away from the plane of the paper, away from the viewer.
  3. The bonds represented by regular lines (i.e., not shown with wedges) lie in the plane of your computer screen.



Indicating the 3D Orientation of Atoms

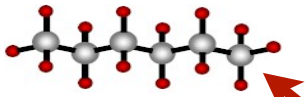


when viewed from the left (methyl group on back C and to the right)

when viewed from the right (methyl group on the front C and to the left)

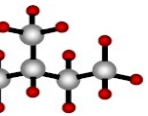
Isomers

- Are molecules with same molecular formula but different structures (shapes)
  - Even just changing the arrangement of atoms can lead to the molecule having:
    - different chemical properties
    - different biological functions



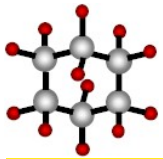
6 carbons

C_6H_{14}



C_6H_{14}

6 carbons



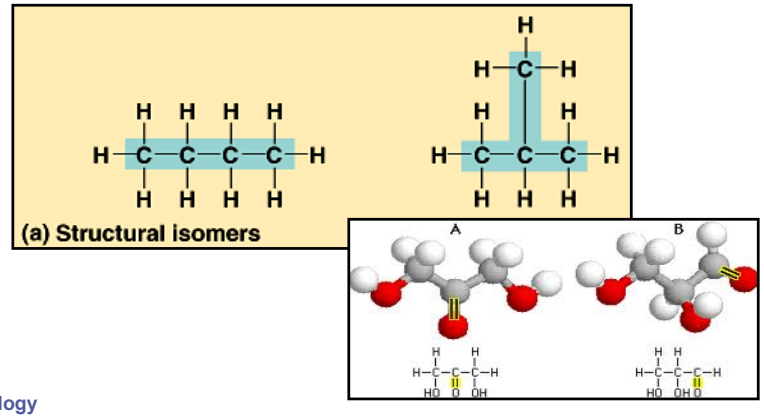
6 carbons

C_6H_{12}

Which of these 6 carbon molecules are isomers of each other?

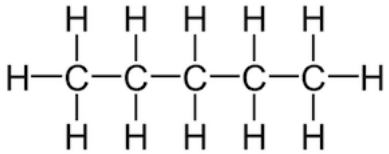
Structural isomers

- Molecules differ in structural arrangement of atoms or location of any double bonds

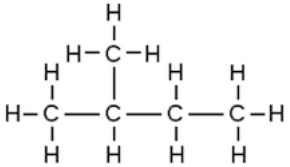


Structural isomers

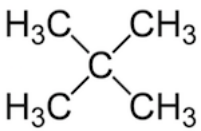
Pentane



Isopentane

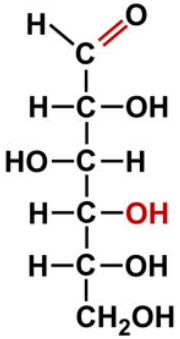


Neopentane

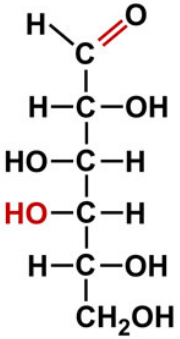


Structural isomers

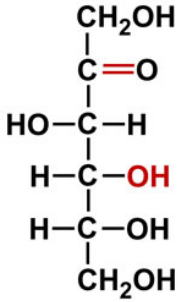
Carbohydrate Isomers



Glucose

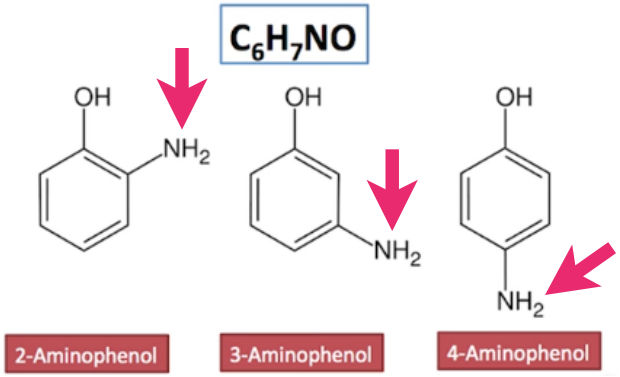


Galactose

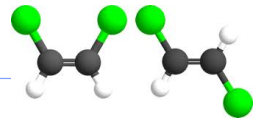


Fructose

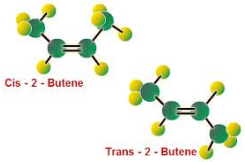
Structural isomers

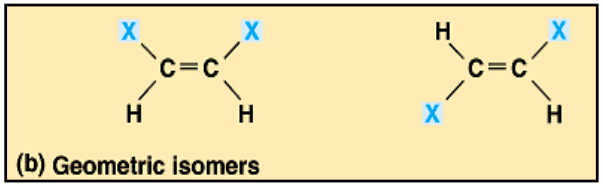


Geometric isomers



- Molecules differ in arrangement around a C=C double bond
  - Both carbons involved have the same covalent partnerships

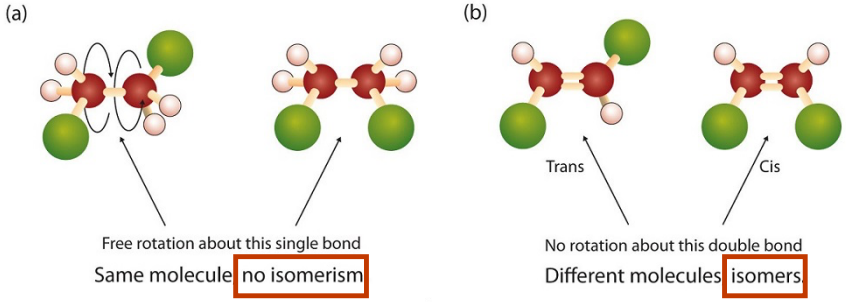




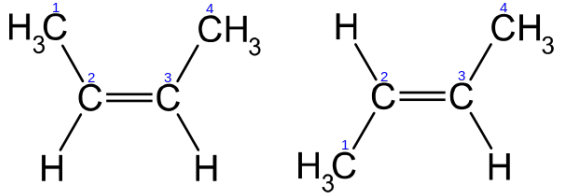
CIS TRANS

Geometric isomers

- It has to be a C=C double bond or it is not considered an isomer!



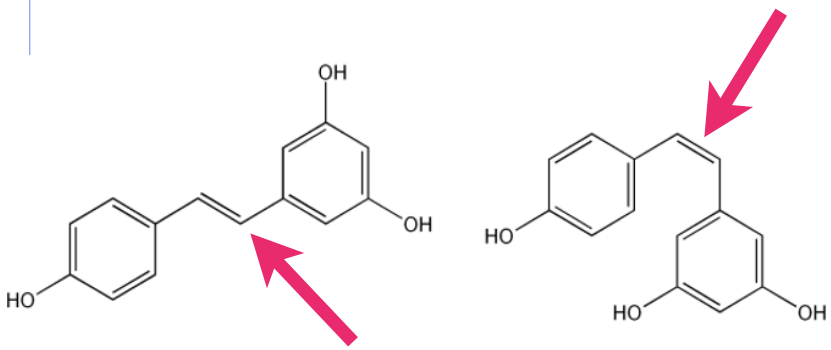
Geometric isomers



cis-but-2-ene trans-but-2-ene

cis trans

Geometric isomers

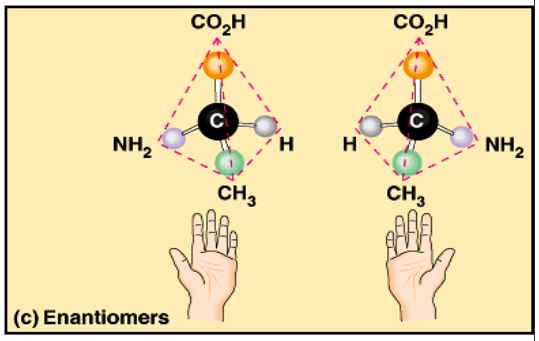


trans-Resveratrol

cis-Resveratrol

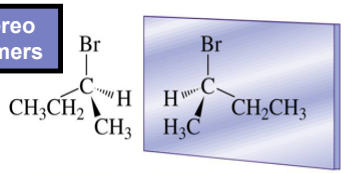
Enantiomers or Stereo Isomers

- Molecules which are mirror images of each other
  - Has a C bonded to 4 different atoms or groups of atoms
    - A.k.a. an *Asymmetric Carbon*
  - Exist as left-handed & right-handed versions referred to as the L (levo) or D (dextro) isomer, respectively.



Enantiomers or Stereo Isomers

Stereo Isomers

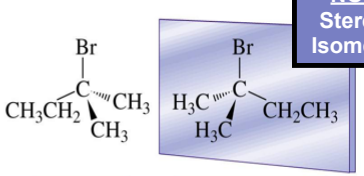


a chiral molecule

nonsuperimposable mirror image

enantiomers

NOT Stereo Isomers

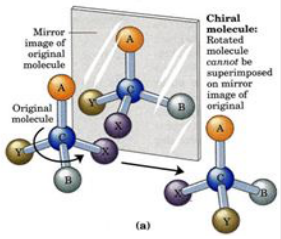


an achiral molecule

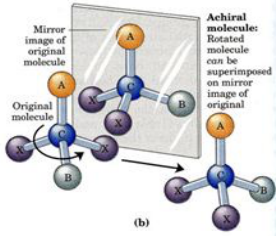
superimposable mirror image

identical molecules

Stereo Isomers

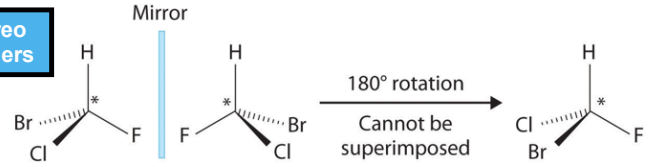


NOT Stereo Isomers



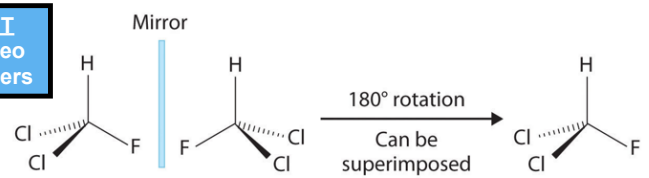
Enantiomers or Stereo Isomers

Stereo Isomers



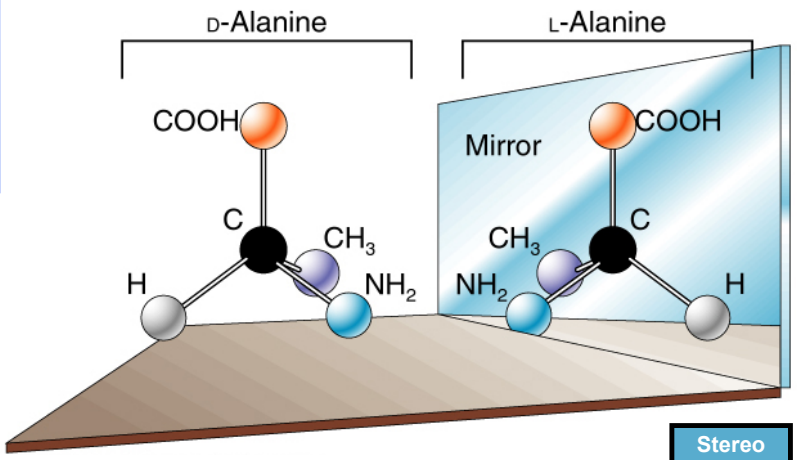
(a) Bromochlorofluoromethane

NOT Stereo Isomers



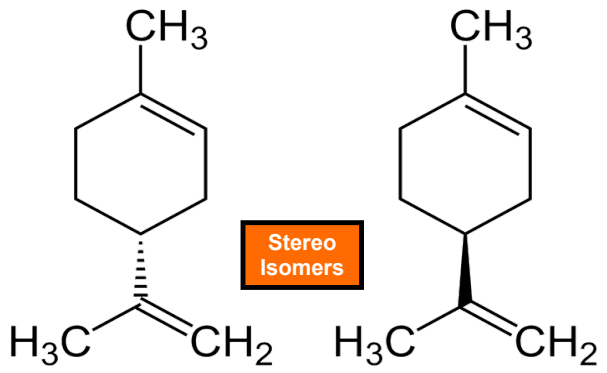
(b) Dichlorofluoromethane

Enantiomers or Stereo Isomers



Stereo Isomers

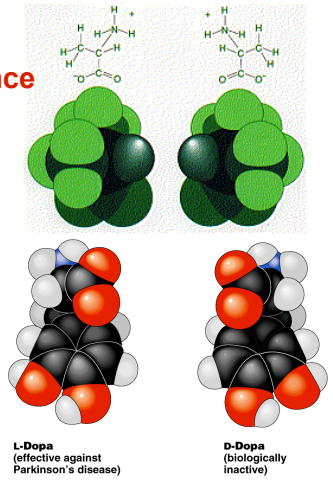
Enantiomers or Stereo Isomers



Stereo Isomers

Recurring Theme: Form affects function

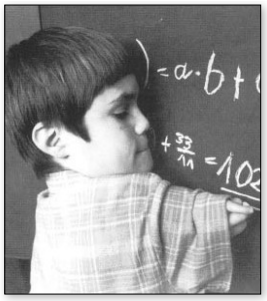
- **Structural differences create important functional significance**
  - EX: amino acid alanine
    - L-alanine used in proteins
    - but not D-alanine
  - Medicines like those for Parkinson's Disease
    - L-version active
    - but not D-version
  - Differences can cause tragic results…



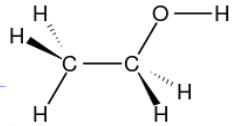
stereoisomers

Form affects function!!!

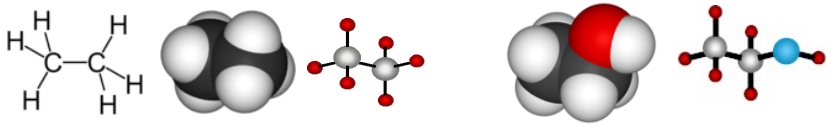
- **Ex: Thalidomide**
  - prescribed to pregnant women in 50s & 60s
  - reduced morning sickness, but…
    - stereoisomer caused severe birth defects



Diversity of molecules



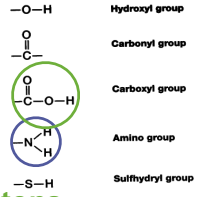
- We can substitute the H's with other atoms or groups of atoms around the carbons
  - ethane vs. ethanol (drinking alcohol)
    - H replaced by an hydroxyl group (–OH)
      - Affects polarity of the molecule
        - Changes from gas to liquid. Why?
      - Has biological effects!
        - Ethanol used in drinks is a psychoactive drug.



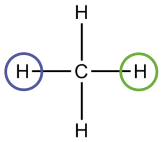
ethane (C_2H_6)

ethanol (C_2H_5OH)

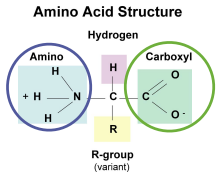
Chemical Groups



- The distinctive properties of organic molecules depend in part on:
  - The arrangement of their carbon skeletons
  - Molecular components attached to that skeleton called Chemical Groups
    - Replace 1 or more H atom bonded to the carbon skeleton with a group of other atoms



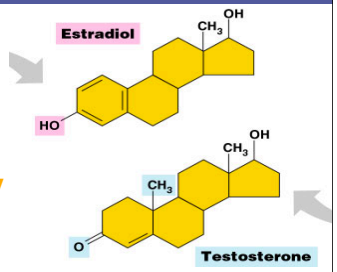
- This directly affects function by altering the chemical reactions possible by the organic molecule
- This indirectly affects function by altering the organic molecule's shape



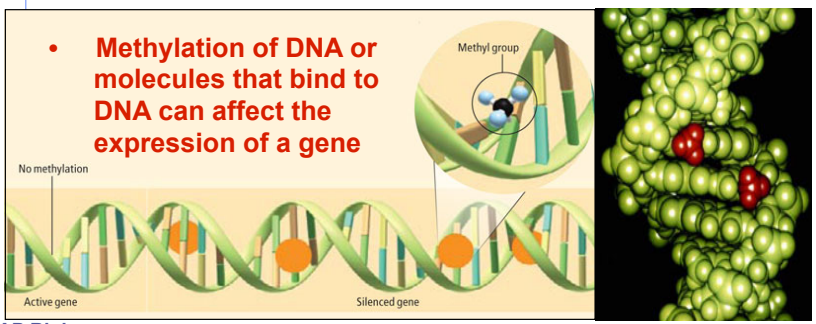
- Chemical groups that are involved in chemical reactions are referred to as Functional Groups

Methyl CH_3—

- Attachment to male and female hormones affects their shape altering the receptors in cells they can interact with, thus altering their functions in the body.



- Methylation of DNA or molecules that bind to DNA can affect the expression of a gene



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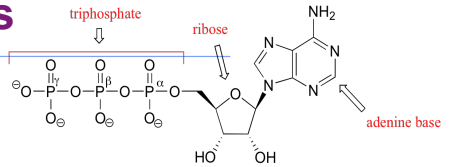
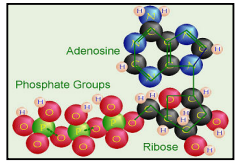
Functional Groups

- Give organic molecules distinctive properties
  - Examples include:

hydroxyl
carbonyl
carboxyl
amino
sulfhydryl
phosphate

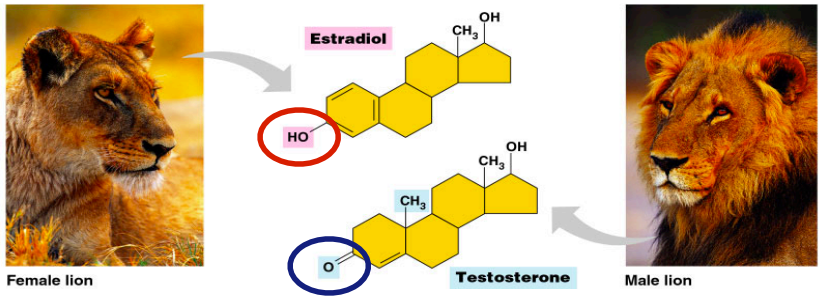




- Affect chemical reactivity of the molecule
  - These make hydrocarbons more hydrophilic
    - These functional groups contain polar bonds and thus dipoles resulting in areas of positive and negative partial charges
  - They help increase a molecule's solubility in water

Vive la Difference!

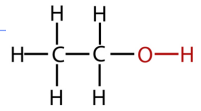
- Basic structure of male & female hormones is nearly identical
  - Identical carbon skeletons of 4 fused rings, but...
  - Differ in the attachment of chemical groups
    - Now they interact with different targets in the body
      - Result: Different effects on the body



Hydroxyl ···· OH

- –OH
  - organic compounds with -OH often belong to molecules known as alcohols
    - their names typically end in *-ol*
      - Ex: ethanol, propanol, butanol

Ethanol



Structural formula

C_2H_5OH

Molecular formula

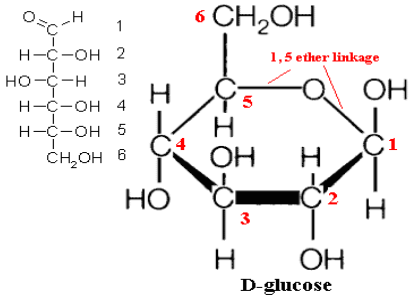
Table 4.1 Functional Groups of Organic Compounds			
Functional Group	Formula	Name of Compounds	Example
Hydroxyl	—OH	Alcohols	Ethanol (the drug of alcoholic beverages)

Properties of Group:

- Polar
- Allows for hydrogen bond formation with water and each other
- Helps dissolve organic compounds like sugar in water

Hydroxyl ···· OH

- –OH
  - Organic compounds with -OH do NOT have to be alcohols, however.
    - Sugars, for example, also have many hydroxyls on them.
    - This glucose will dissolve in water because all the O's became partially negatively charged & those H's covalently bonded to an O atom become partially positively charged



  - Glucose can hydrogen bond with water
    - *Remember, the H's bonded to carbon do not become partially charged*

Carbonyl

- C=O
  - O double bonded to C
    - if C=O at end molecule = aldehyde
    - if C=O in middle of molecule = ketone

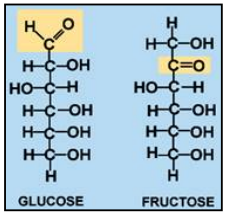
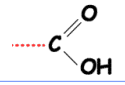


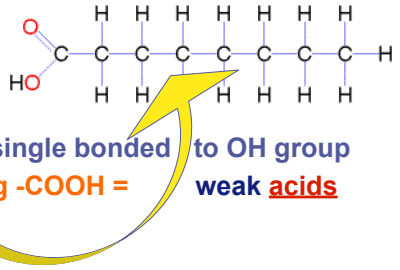
Table 4.1 Functional Groups of Organic Compounds			
Functional Group	Formula	Name of Compounds	Example
Carbonyl		Aldehydes	Propanal
		Ketones	Acetone

Properties of Group:

- Ketone & Aldehyde can be structural isomers with different properties as in the case of glucose and fructose
- Aldose is a sugar aldehyde and ketose is a sugar ketone

Carboxyl





- –COOH
  - C double bonded to O & single bonded to OH group
    - compounds containing -COOH = weak acids
      - Ex: fatty acids
      - Ex: amino acids

Table 4.1 Functional Groups of Organic Compounds

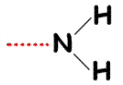
Functional Group	Formula	Name of Compounds	Example
Carboxyl	(non-ionized) (ionized)	Carboxylic acids	Acetic acid* (the acid of vinegar)

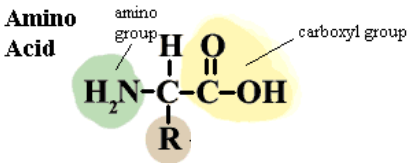
prevalent under normal cellular conditions

Properties of Group:

- Source of Hydrogen ions (protons) *(acting as an acid)* because the oxygen is highly electronegative making the covalent bond so polar that, at times, the proton of the H atom "pops off" and into solution

Amino





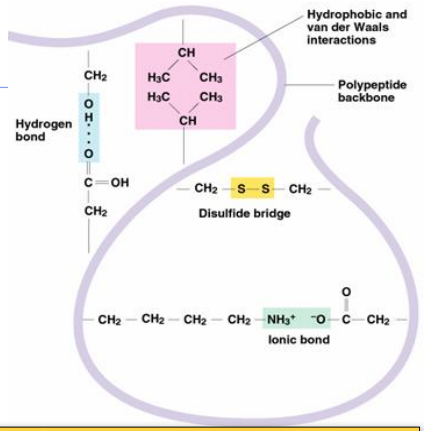
- $-NH_2$
  - N attached to 2 H's
    - compounds with NH_2 = amines
      - Ex: amino acids
    - NH_2 acts as base
      - ammonia picks up H^+ from solution, decreasing the concentration of H+ in solution

Table 4.1 Functional Groups of Organic Compounds

Functional Group	Formula	Name of Compounds	Example
Amino	(non-ionized) (ionized)	Amines	Glycine*

prevalent under normal cellular conditions

Sulfhydryl

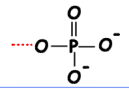


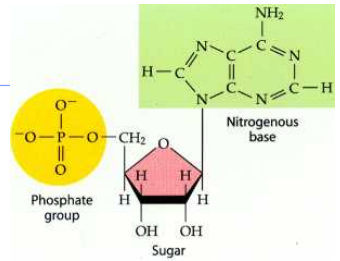
- –SH
  - S bonded to H
    - compounds with SH = thiols
- S-H groups stabilize the structure of proteins by forming covalent cross links known as *Disulfide Bridges* that hold distant parts of protein chains together.

Table 4.1 Functional Groups of Organic Compounds

Functional Group	Formula	Name of Compounds	Example
Sulfhydryl	—SH	Thiols	Ethanethiol

Phosphate





- $-PO_4$
  - P bound to 4 O atoms
    - connects to a C of an organic molecule through one of the phosphate's O's
    - lots of O = lots of negative charge
      - highly reactive
        - Transferring this group from 1 molecule to another is 1 way the cell transfers energy
        - Ex: ATP, GTP, etc.

Table 4.1 Functional Groups of Organic Compounds

Functional Group	Formula	Name of Compounds	Example
Phosphate		Organic phosphates	Glycerol phosphate