Carbon

These Notes are to SUPPLIMENT the Text, They do NOT Replace reading the Text Book Material. Additional material that is in the Text Book will be on your tests! To get the most information, READ THE CHAPTER prior to the Lecture, bring in these lecture notes and make comments on these notes. These notes alone are NOT enough to pass any test!

NOTE THESE ARE DRAFT LECTURE NOTES!

CARBON: 4 electrons in the outer shell and sp^3 hybridized

2p ↑ ↑ ↑ sp3 ↑ ↑ ↑ ↑ sp^3 ↓↑ ↓↑ ↓↑ ↓↑
C-H Bonds

2s ↓↑

1s ↓↑ 1s ↓↑

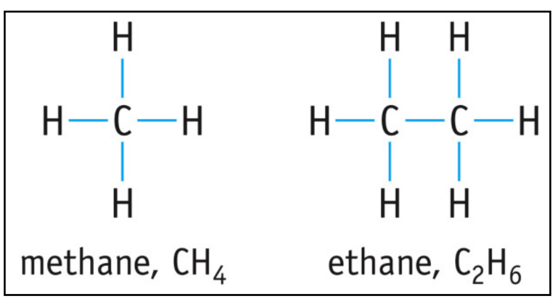
With 4 covalent bonds to many different molecules, carbon forms a large number of bonds to create more complex structures than with In-Organic compounds. Carbon can form the following types of bonds:

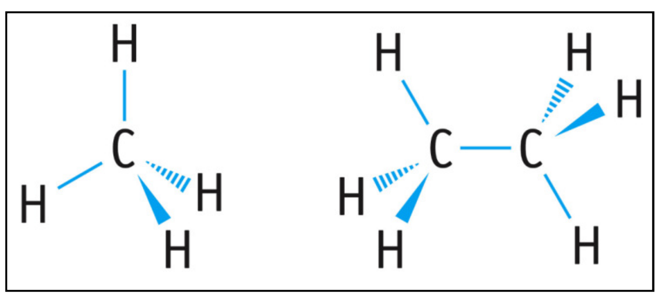
1. Single Bonds	C-C C-O C-N C-X
2. One Double Bond & Two Single Bonds	H-C=C-H $H_2C=O$ HR-C=N
3. Two Double Bonds	O=C=O
4. Triple Bond	H-C≅C-H

Remember the geometry of these:

1. Single Bonds	SP_3 Hybrid	Tetrahedral	109.5°
2. Double Bond	SP_2 Hybrid	Trigonal Planar	120°
3. Two Double Bonds or Triple Bond	SP Hybrid	Linear	180°

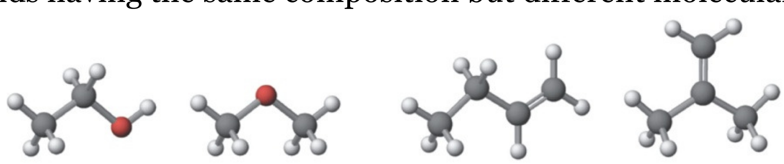
Picture the molecules in 3-D and not flat on a sheet of paper:





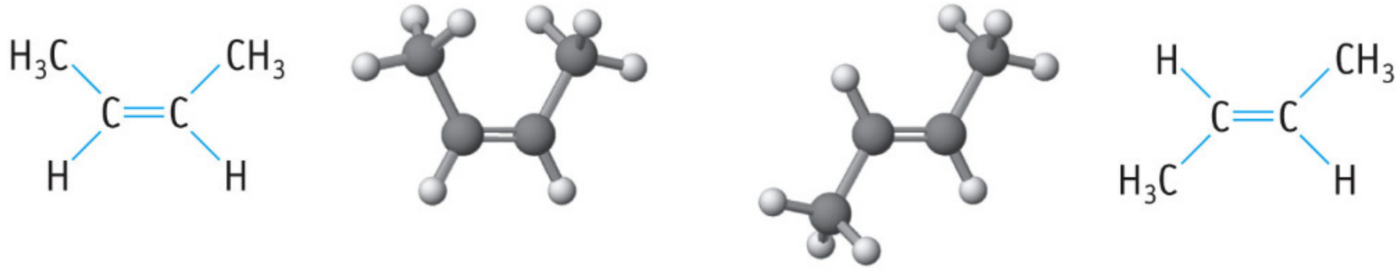
Isomers

Structural: Compounds having the same composition but different molecular geometry:



ethanol	dimethyl ether	1-butene	2-methylpropene
C_2H_6O	C_2H_6O	C_4H_8	C_4H_8
CH_3CH_2OH	CH_3OCH_3	$CH_3CH_2CH=CH_2$	$CH_3C(=CH_2)CH_3$

Stereoisomers: compounds with the same formulae and same attachments but have different orientations in space.
Geometric Isomers: Different orientations in space (e.g. cis / trans):



cis-2-butene, C_4H_8 *trans*-2-butene, C_4H_8

Optical Isomers: Molecules with structures that are mirror images of each other

Chiral: Non-superimposable mirror images

Enantiomers: Pairs of non-superimposable, mirror image molecules.

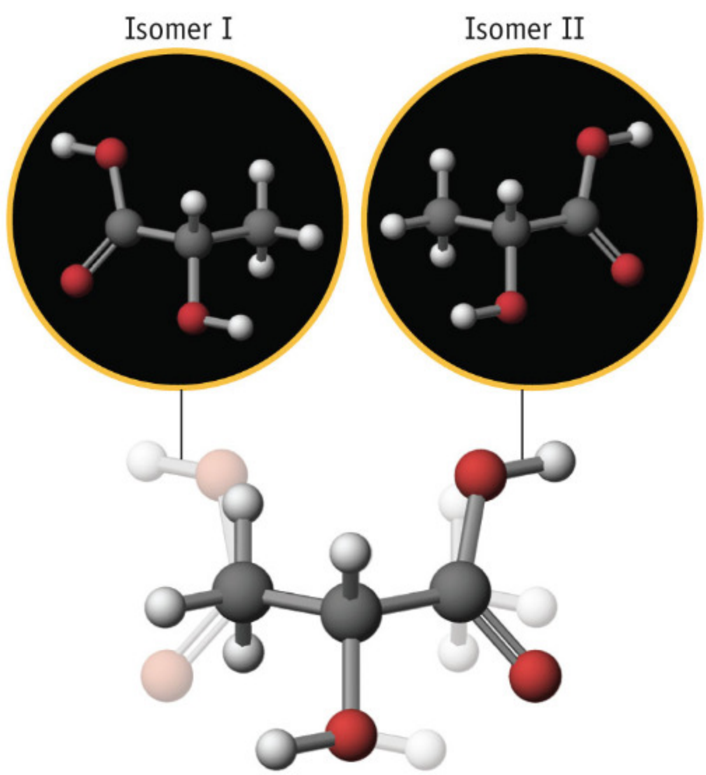
These compounds have the same physical properties: MP, BP, Density, Solubility, IR, NMR

But: in solution, pure enantiomers will roate plane-polarized light – **Optical Isomerism**

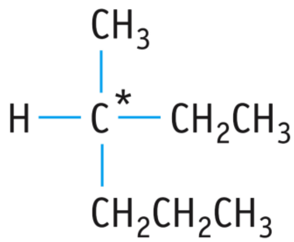
Your Left Hand is an Enantiomer for your Right Hand

They are mirror images and non-superimposable on each other.

Carbon with 4 different functional groups attached is usually Optically Active – forms L & R Isomers



(a) Lactic acid enantiomers are nonsuperimposable.



Stability of Carbon Compounds:

Organic compounds do not decompose thermally under normal conditions

10.2 Hydrocarbons: Compounds made of only Carbon and Hydrogen

Alkanes: only single bonds
CycleAlkanes: Single bonds, cyclic structure
Alkenes: at least one double bond
Alkynes: at least one triple bond
Aromatic: 6 member unsaturated ring

Alkanes: General formulae C_nH_{2n-2}

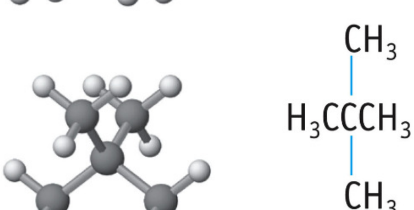
Alkanes have Carbon - Carbon single bonds and they are called **Saturated Hydrocarbons**

Remember, there is free rotation about Carbon – Carbon single bonds

n	Structure	Name	
1	CH4	Methane	
2	H3C-CH3	Ethane	
3	H3C-CH2-CH3	Propane	
4	H3C-CH2-CH2-CH3	n-Butane	n = normal
	H3-C-CH3 H3-|	iso-Butane	

$CH_3CH_2CH_2CH_2CH_3$
pentane

2-methylbutane

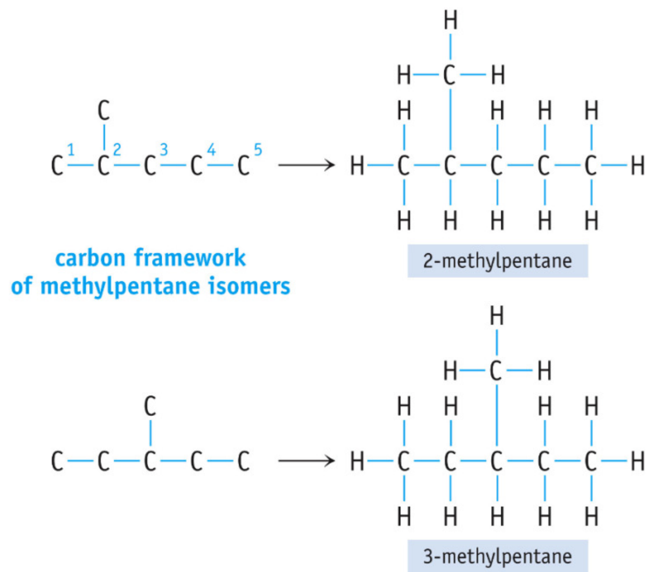


2,2-dimethylpropane

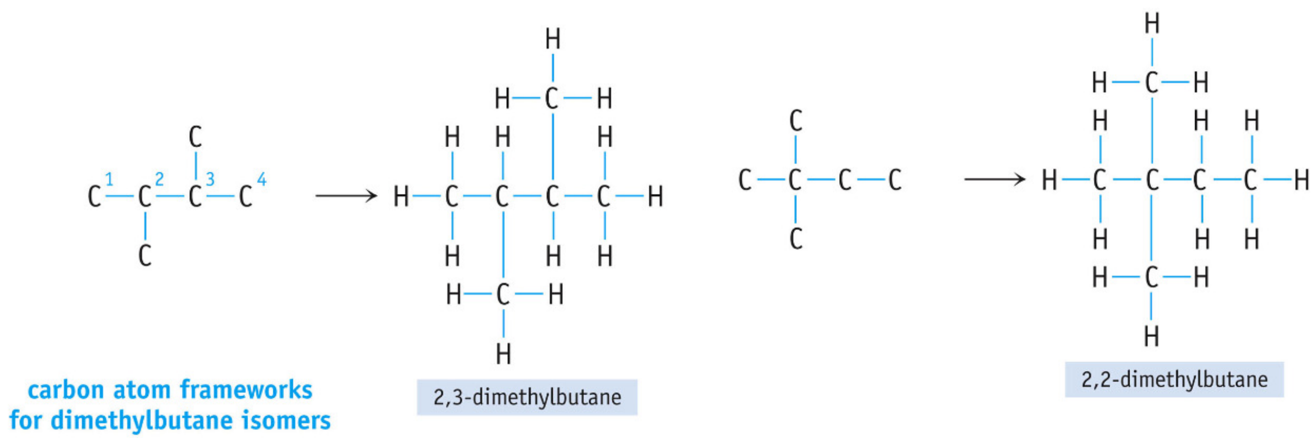
Table 10.2 Selected Hydrocarbons of the Alkane Family, C_nH_{2n+2}*

Name	Molecular Formula	State at Room Temperature
Methane	CH_4	
Ethane	C_2H_6	Gas
Propane	C_3H_8	
Butane	C_4H_{10}	
Pentane	C_5H_{12} (pent- = 5)	
Hexane	C_6H_{14} (hex- = 6)	
Heptane	C_7H_{16} (hept- = 7)	Liquid
Octane	C_8H_{18} (oct- = 8)	
Nonane	C_9H_{20} (non- = 9)	
Decane	$C_{10}H_{22}$ (dec- = 10)	
Octadecane	$C_{18}H_{38}$ (octadec- = 18)	Solid
Eicosane	$C_{20}H_{42}$ (eicos- = 20)	

Structural Isomers: Isomers that have the same molecular formulae, but different orientations is space. See above: Pentane, 2-methylbutane, 2,2-dimethylpropane

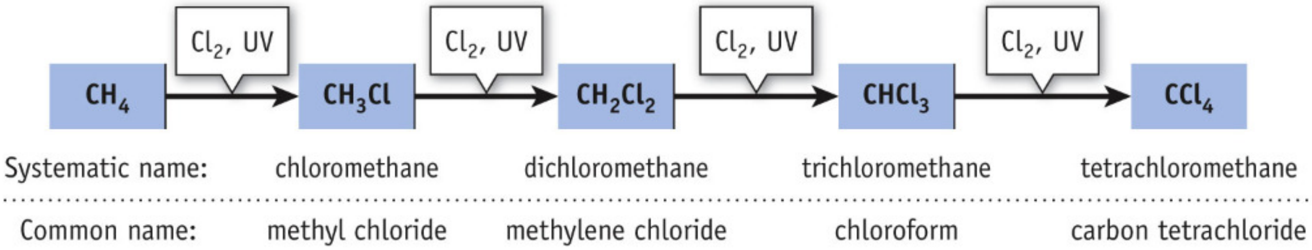


Naming:
1. Draw the structural isomer of the alkane with the longest possible C atom chain
This is the Root Structure
2. Substituent / Additional groups on the longest hydrocarbon chair are identified by a name and the position on the carbon chain. Numbering begins on the chain end tht allows the 1^{st} additional group to have the lowest possible number. Names of these Alkane Groups are called Alkyl Groups
3. If more than one group is attached to a particular long chain carbon atom, then use prefixes: di, tri and tetra. (Why is there no Mono or Hepta?).

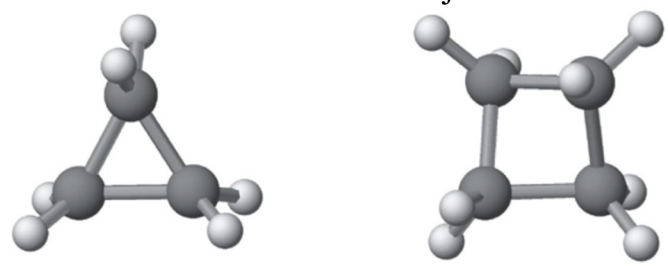


Properties of Alkanes

- Methane, Ethane, Propane and Butane are gases at RT and pressure
- Higher Mw compounds are liquids or solids
- Increase MP or BP with increase Mw
- Alkanes are colorless and insoluble in water - they are non-polar
- Alkanes burn in air to give CO2 and H2O
- Alkanes are relatively inert – they do not undergo chemical reactivity
- Alkanes do react with Chlorine:

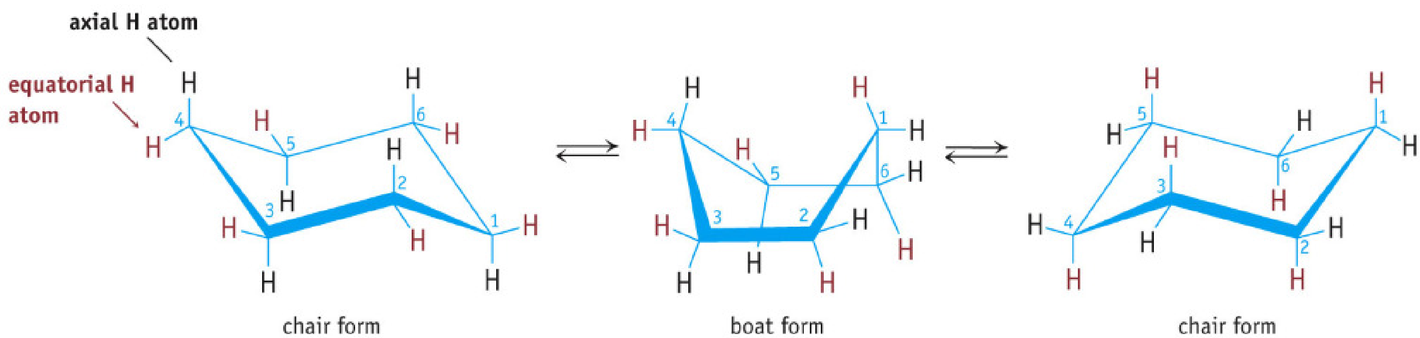


Cycloalkanes: CnH2n Formed from tetrahedral carbon joined to form a ring



cyclopropane, C_3H_6 cyclobutane, C_4H_8

Cyclohexane, C6H12 forms a 6 member ring that exists in a chair and boat 3D configuration. If the carbon atoms were flat (as in the plane of this piece of paper) they would be strained having 1200 bond angles. But in the chair/boat configuration they have the normal 109.5^o bond angle.

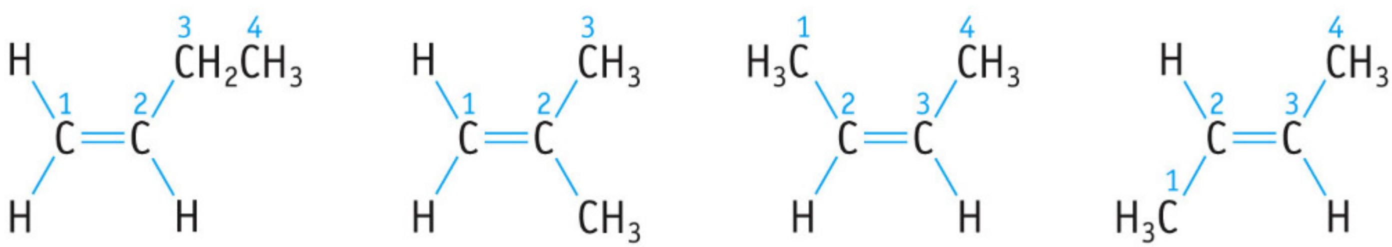


Alkenes and Alkynes

CnH2n Alkenes are hydrocarbons with one or more C=C (carbon-carbon double) bonds

CnH2n-2 Alkynes are hydrocarbons with one or more C≅C (carbon-carbon triple) bonds.

Alkenes have the base Alkane name, but end in –ene. The root name is determined by the longest carbon chain that contains the double bond. It may include the prefix: cis or trans



1-butene 2-methylpropene *cis*-2-butene *trans*-2-butene

Alkynes have the carbon-carbon triple bond. H-C≅C-H is acetylene, a welding gas

Properties of Alkenes and Alkynes

They are colorless

Low Mw compounds are gases

Are oxidized, react with air, to form CO_2 and H_2O and very exothermic

They are called **Unsaturated Compounds**

Alkenes are Trigonal Planer with bond angles of 120°

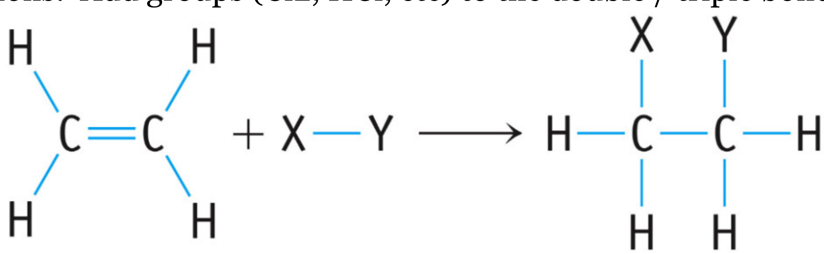
Alkyenes are Linear with bond angles of 180°

Table 10.4 Some Simple Alkynes C_nH_{2n-2}

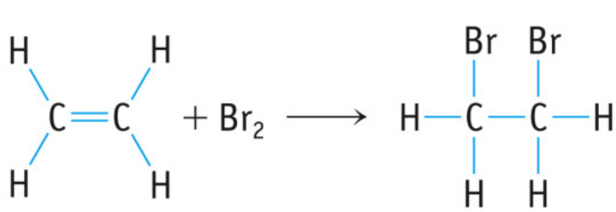
Structure	Systematic Name	Common Name	BP (°C)
$HC{\equiv}CH$	ethyne	acetylene	−85
$CH_3C{\equiv}CH$	propyne	methylacetylene	−23
$CH_3CH_2C{\equiv}CH$	1-butyne	ethylacetylene	9
$CH_3C{\equiv}CCH_3$	2-butyne	dimethylacetylene	27

Reactions:

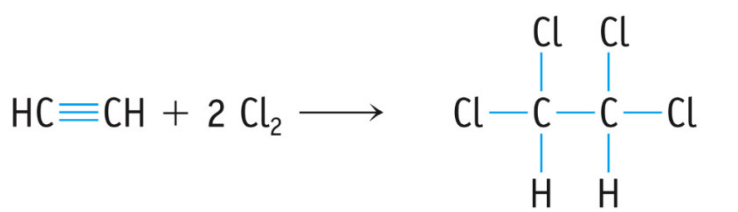
Addition Reactions: Add groups (Cl_2, HCl, etc) to the double / triple bond



$$X{-}Y = H_2,\ Cl_2,\ Br_2;\ H{-}Cl,\ H{-}Br,\ H{-}OH,\ HO{-}Cl$$

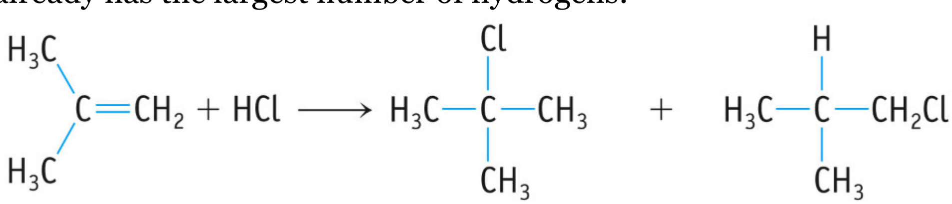


1,2-dibromoethane



1,1,2,2-tetrachloroethane

Markonvnikov's Rule: when HX is added to an unsymmetrical alkene, the hydrogen is attached to the carbon that already has the largest number of hydrogens:



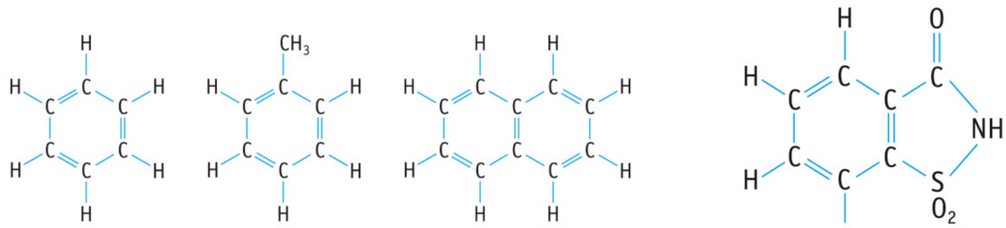
2-methylpropene

2-chloro-2-methylpropane
sole product

1-chloro-2-methylpropane
not formed

Hydrogenation: The H-X reagent is H_2. $CH_2{=}CH_2 + H_2 \rightarrow CH_3{-}CH_3$

Aromatic Compounds: C6H6 is a class of compounds with a 6 membered unsaturated ring



benzene toluene naphthalene

Properties:

Usually obtained from coal
Starting point for making many different compounds and drugs
Do not undergo the normal alkene addition reactions
Benzene is a colorless liquid
They are insoluble in water
Oxidized with oxygen to produce O2, H2O and energy (exothermic)
Very stable due to its Resonance Stabilization
Undergoes Substitution reactions in place of addition

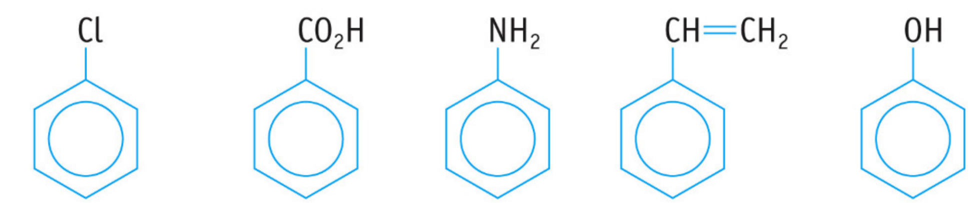
Benzene: common industrial solvent and reaction starting reactant
Toluene: from tolu balsam, pleasant smelling gum (don't smell it!)
Naphthalene: moth balls

The Benzene bonds are **Resonance Formulae :**

representations of benzene, C_6H_6

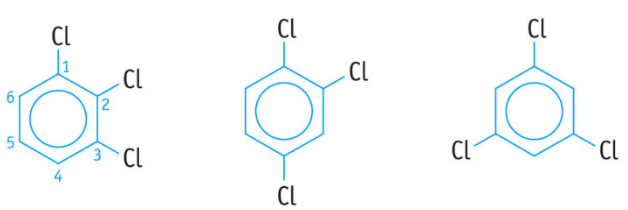
Benzene Derivatives:

Mono Substituted:



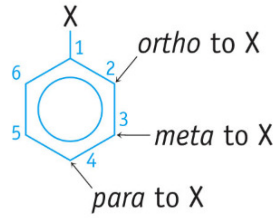
chlorobenzene benzoic acid aniline styrene phenol

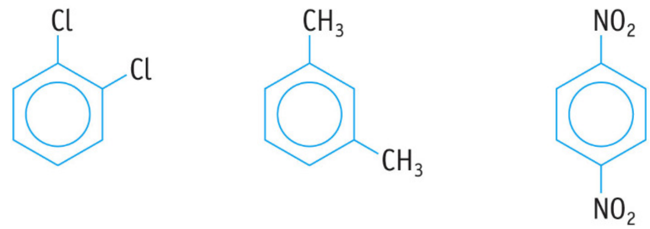
Tri Substitued:



1,2,3-trichlorobenzene 1,2,4-trichlorobenzene 1,3,5-trichlorobenzene

Di-Substituted:





Systematic name:	1,2-dichlorobenzene	1,3-dimethylbenzene	1,4-dinitrobenzene
Common name:	*o*-dichlorobenzene	*m*-xylene	*p*-dinitrobenzene

Substitution Reactions: require a strong Bronsted Acid

Nitration: $C_6H_6(\ell) + HNO_3(\ell) \xrightarrow{H_2SO_4} C_6H_5NO_2(\ell) + H_2O(\ell)$

Alkylation: $C_6H_6(\ell) + CH_3Cl(\ell) \xrightarrow{AlCl_3} C_6H_5CH_3(\ell) + HCl(g)$

Halogenation: $C_6H_6(\ell) + Br_2(\ell) \xrightarrow{FeBr_3} C_6H_5Br(\ell) + HBr(g)$

10.3 Alcohols, Ethers and Amines

Functional Group (X): an atom or group of atoms attached to a carbon atom in the hydrocarbon. R-X

-X = Alcohol –OH, Amine –NH2, Ether C-O-C, Halogen, Acid COOH.

Table 10.6 Common Functional Groups and Derivatives of Alkanes

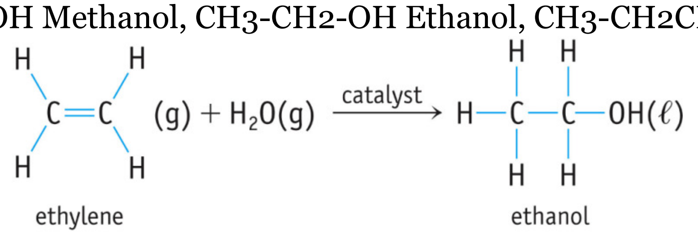
Functional Group*	General Formula*	Class of Compound	Examples
F, Cl, Br, I	RF, RCl, RBr, RI	Haloalkane	CH_3CH_2Cl, chloroethane
OH	ROH	Alcohol	CH_3CH_2OH, ethanol
OR′	ROR′	Ether	$(CH_3CH_2)_2O$, diethyl ether
NH_2†	RNH_2	(Primary) Amine	$CH_3CH_2NH_2$, ethylamine
—C(=O)H	RCHO	Aldehyde	CH_3CHO, ethanal (acetaldehyde)
—C(=O)—R′	RCOR′	Ketone	CH_3COCH_3, propanone (acetone)
—C(=O)—OH	RCO_2H	Carboxylic acid	CH_3CO_2H, ethanoic acid (acetic acid)
—C(=O)—OR′	RCO_2R'	Ester	$CH_3CO_2CH_3$, methyl acetate
—C(=O)—NH_2	$RCONH_2$	Amide	CH_3CONH_2, acetamide

* R and R′ can be the same or different hydrocarbon groups.

† Secondary amines (R_2NH) and tertiary amines (R_3N) are also possible, see discussion in the text.

Alcohols and Ethers

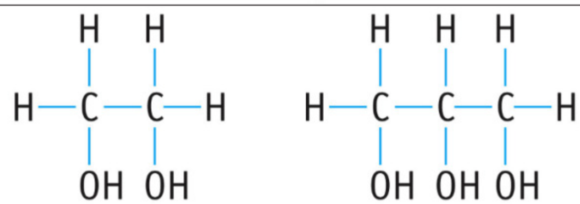
Alcohol: R-OH CH3-OH Methanol, CH3-CH2-OH Ethanol, CH3-CH2CH2-OH n-Propanol



Usually prepared by Fermentation.
C3 and above alcohols can have structural isomers:
Ethanol is used in "Beverages" IsoPropyl Alcohol is rubbing alcohol

Table 10.7 Some Important Alcohols

Condensed Formula	BP (°C)	Systematic Name	Common Name	Use
CH_3OH	65.0	Methanol	Methyl alcohol	Fuel, gasoline additive, making formaldehyde
CH_3CH_2OH	78.5	Ethanol	Ethyl alcohol	Beverages, gasoline additive, solvent
$CH_3CH_2CH_2OH$	97.4	1-Propanol	Propyl alcohol	Industrial solvent
$CH_3CH(OH)CH_3$	82.4	2-Propanol	Isopropyl alcohol	Rubbing alcohol
$HOCH_2CH_2OH$	198	1,2-Ethanediol	Ethylene glycol	Antifreeze
$HOCH_2CH(OH)CH_2OH$	290	1,2,3-Propanetriol	Glycerol (glycerin)	Moisturizer in consumer products



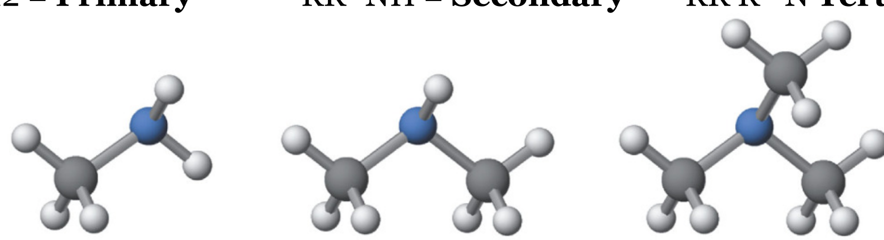
Systematic name:	1,2-ethanediol	1,2,3-propanetriol
Common name:	ethylene glycol	glycerol or glycerin

Ethylene Glycol   Car antifreeze
Glycerol   Backbone for soap and living organic matter

Ether: R-O-R'   H3C-CH2-O-CH2-CH3   Diethyl Ether
Lower BP than the corresponding alcohol – Why??
Lower Mw is slightly soluble in water

Properties of Alcohols
Methane CH4 a gas, Methanol CH3OH a liquid soluble in water
Alcohols are polar, like water, hydrogen bond and are soluble in polar solvents
As R in R-OH increases, the BP increases and solubility in water decreases (Why ??)

Amines   R-NH2 = **Primary**   RR'-NH = **Secondary**   RR'R"-N **Tertiary Amine**



CH_3NH_2 primary amine methylamine $(CH_3)_2NH$ secondary amine dimethylamine $(CH_3)_3N$ tertiary amine trimethylamine

Remember: Nitrogen is Trigonal Pyramidal with a lone pair of electrons sticking out!

Properties of Amines:

Offensive Odors:

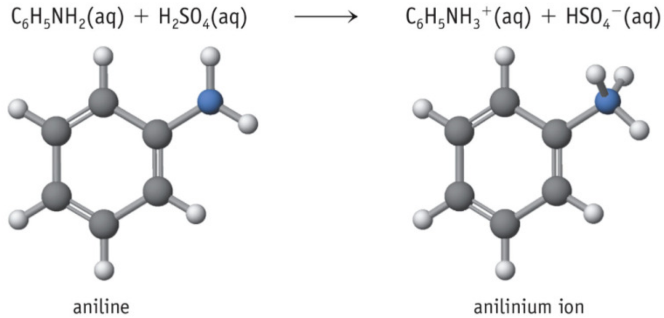
$H_2NCH_2CH_2CH_2CH_2NH_2$ putrescine 1,4-butanediamine

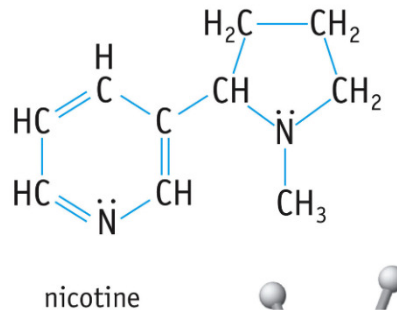
$H_2NCH_2CH_2CH_2CH_2CH_2NH_2$ cadaverine 1,5-pentanediamine

Low Mw amines are soluble in water

All amines are bases and react with acids to give a salt (H^+ reacts with N-: Nitrogen lone pair)

Aromatic Amines:





Aldehydes: RCH=O CH2=O Formaldehyde

Ketones: R-CO-R‘ CH3-CO-CH3 Acetone

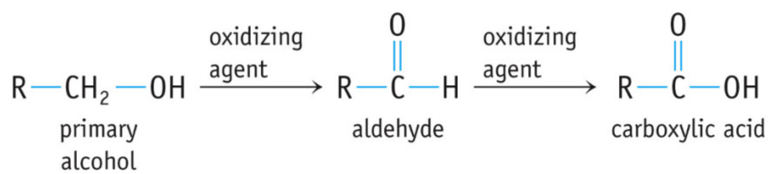
Carboxylic Acids R-COOH CH3-COOH Acetic Acid

Have a sour taste

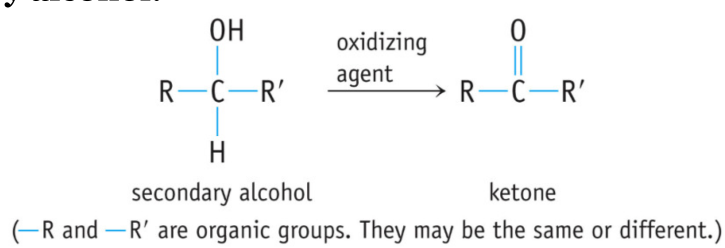
Ester R-COO-R’ CH3-COO-CH2-CH3 Ethyl Acetate (Nail Polish Remover)

Amide R-CONRR’, R-CONHR, R-CONH2

Oxidation of a **primary alcohol:**



Oxidation of a **secondary alcohol:**

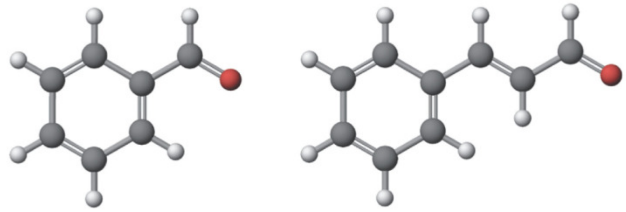


Oxidation of a **tertary alcohol:**

$$(CH_3)_3COH \xrightarrow{\text{oxidizing agent}} \text{no reaction}$$

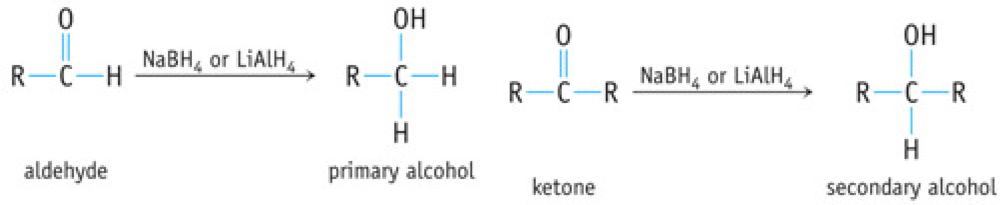
Aldehydes and Ketones

Have a pleasant odor



benzaldehyde, C_6H_5CHO *trans*-cinnamaldehyde, $C_6H_5CH{=}CHCHO$

Aldehydes and ketones are the oxidation products of primary and secondary alcohols
Reduction of Aldehydes and ketones yield the alcohol



Carboxylic Acids Produced by the oxidation of an alcohol or aldehyde (Why not ketone ?)
Sour taste: Acetic Acid, Tartaric Acid, Citric Acid, Formic Acid, Butyric Acid
Named by adding "oic" to the alkane name
Low Mw acids dissolve in water

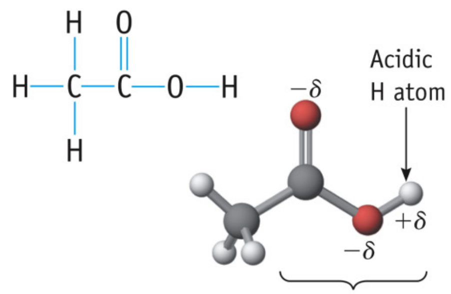


Table 10.9 **Some Naturally Occurring Carboxylic Acids**

Name	Structure	Natural Source
Benzoic acid	 $-CO_2H$	Berries
Citric acid	$HO_2C-CH_2-C(OH)(CO_2H)-CH_2-CO_2H$	Citrus fruits
Lactic acid	$H_3C-CH(OH)-CO_2H$	Sour milk
Malic acid	$HO_2C-CH_2-CH(OH)-CO_2H$	Apples
Oleic acid	$CH_3(CH_2)_7-CH{=}CH-(CH_2)_7-CO_2H$	Vegetable oils
Oxalic acid	HO_2C-CO_2H	Rhubarb, spinach, cabbage, tomatoes
Stearic acid	$CH_3(CH_2)_{16}-CO_2H$	Animal fats
Tartaric acid	$HO_2C-CH(OH)-CH(OH)-CO_2H$	Grape juice, wine

Table 10.10 Some Simple Carboxylic Acids

Structure	Common Name	Systematic Name	BP (°C)
$H\overset{O}{\overset{\|}{C}}OH$	Formic acid	Methanoic acid	101
$CH_3\overset{O}{\overset{\|}{C}}OH$	Acetic acid	Ethanoic acid	118
$CH_3CH_2\overset{O}{\overset{\|}{C}}OH$	Propionic acid	Propanoic acid	141
$CH_3(CH_2)_2\overset{O}{\overset{\|}{C}}OH$	Butyric acid	Butanoic acid	163
$CH_3(CH_2)_3\overset{O}{\overset{\|}{C}}OH$	Valeric acid	Pentanoic acid	187

Esters: RCOOR'

$$R\overset{O}{\overset{\|}{C}}-O-H + R'-O-H \xrightarrow{H_3O^+} R\overset{O}{\overset{\|}{C}}-O-R' + H_2O$$

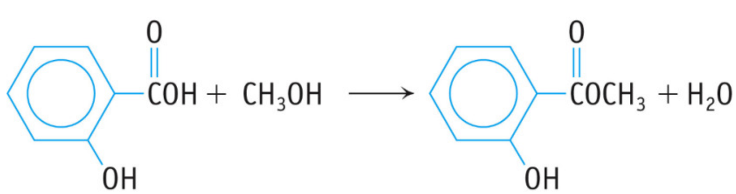
carboxylic acid alcohol ester

$$CH_3\overset{O}{\overset{\|}{C}}OH + CH_3CH_2OH \xrightarrow{H_3O^+} CH_3\overset{O}{\overset{\|}{C}}OCH_2CH_3 + H_2O$$

acetic acid ethanol ethyl acetate

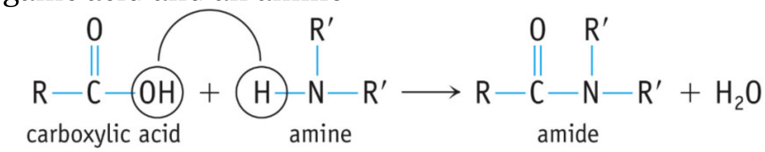
Table 10.11 Some Acids, Alcohols, and Their Esters

Acid	Alcohol	Ester	Odor of Ester
CH_3CO_2H acetic acid	$CH_3\overset{CH_3}{\overset{\|}{C}}HCH_2CH_2OH$ 3-methyl-1-butanol	$CH_3\overset{O}{\overset{\|}{C}}OCH_2CH_2\overset{CH_3}{\overset{\|}{C}}HCH_3$ 3-methylbutyl acetate	Banana
$CH_3CH_2CH_2CO_2H$ butanoic acid	$CH_3CH_2CH_2CH_2OH$ 1-butanol	$CH_3CH_2CH_2\overset{O}{\overset{\|}{C}}OCH_2CH_2CH_2CH_3$ butyl butanoate	Pineapple
$CH_3CH_2CH_2CO_2H$ butanoic acid	$-CH_2OH$ benzyl alcohol	$CH_3CH_2CH_2\overset{O}{\overset{\|}{C}}OCH_2-$ benzyl butanoate	Rose



salicylic acid methanol methyl salicylate, oil of wintergreen

Amides: From a organic acid and an amine



10.5 Polymers From many parts, or a giant molecule made from small molecules or monomers

Thermoplastics Polyethylene soften and flow when heated and harden when cooled
Thermosetting Formica initially soft, but set hard when heated and cannot be resoftened

Addition Polymers made directly by adding monomer units
Condensation Polymers made by combing monomer units and splitting out a small molecule such as water

We will not go into

Addition Polymers
- Polyethylene and other Polyolefins
- Natural and Synthetic Rubber

Condensation Polymers
- Polyesters
- Polyamids