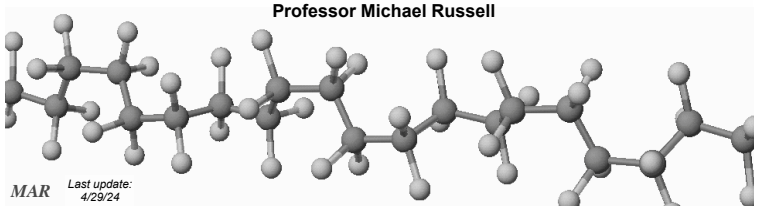
Carbon: Not Just Another Element

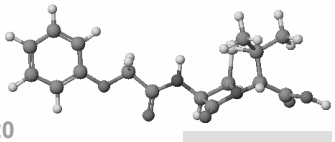
Chapter 20:
The Organic Chemistry chapter!

Chemistry 222
Professor Michael Russell



MAR *Last update: 4/29/24*

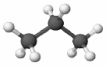
Organic Chemistry

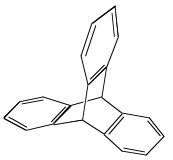


Vast majority of over 20 million known compounds are based on Carbon:
organic compounds.

Generally contain C, H + other elements

Great variety of compounds





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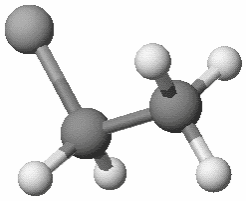
Two Major Concepts

NOMENCLATURE - Naming the molecules correctly and knowing the general classes of organic compounds

REACTIVITY - Studying patterns of reactivity within classes of compounds



We will focus primarily on nomenclature but also show examples of reactivity

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Nomenclature

Need to know Alkyl Groups -
methyl = CH_3
ethyl = CH_3CH_2
propyl = $CH_3CH_2CH_2$
butyl = $CH_3CH_2CH_2CH_2$
Also **pentyl, hexyl, heptyl, octyl,** *etc.*
R is "generic" alkyl group

Alkyl groups may be combined with other elements or alkyl groups to give classes of compounds

See the Organic Chemistry Nomenclature Guide

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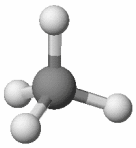
ALKANES

Generic Alkane Representation: R-H
Generic Alkane Formula: C_nH_{2n+2}
-yl +ane

Ex: **methane = CH_4**
(methyl group + H)
CH_3-H



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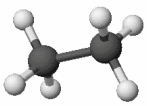
ALKANES

Generic Alkane Representation: R-H
Generic Alkane Formula: C_nH_{2n+2}
-yl +ane

Ex: **ethane = CH_3CH_3**
(ethyl group + H)
CH_3CH_2-H



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ALKANES

Generic Alkane Representation: R-H

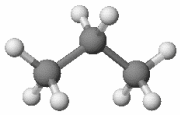
Generic Alkane Formula: C_nH_{2n+2}

-yl +ane

Ex: **propane = $CH_3CH_2CH_3$**

(propyl group + H)

$CH_3CH_2CH_2$-H



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ALKANES

Generic Alkane Representation: R-H

Generic Alkane Formula: C_nH_{2n+2}

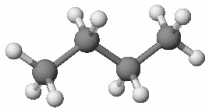
-yl +ane

Ex: **butane = $CH_3CH_2CH_2CH_3$**

(butyl group + H)

$CH_3CH_2CH_2CH_2$-H

Alkanes often called "saturated hydrocarbons" – all carbons "saturated" with H



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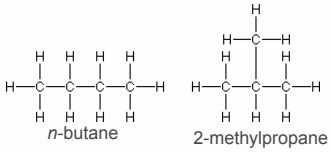
ALKANES - Isomers

But we can write butane in two ways:



n-butane 2-methylpropane

These are isomers (same formula, structurally different). Name using "longest chain" alkane preceded by numbered alkyl groups

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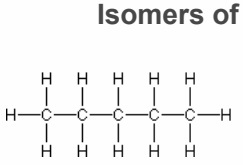
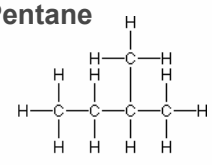
Isomers of Pentane

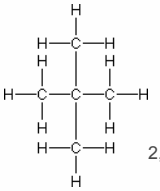


n-pentane



2-methylbutane

"3-methylbutane" would be incorrect - use smallest number possible



2,2-dimethylpropane

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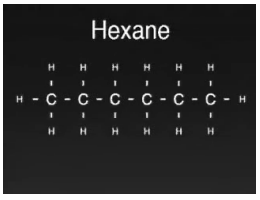
Isomers of Hexane



Number of isomers grows as number of carbons increases

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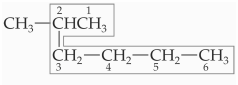
How to Name a Compound



2-Methyl*hexane*

Group	Name
CH_3—	Methyl
CH_3CH_2—	Ethyl
$CH_3CH_2CH_2$—	Propyl
$CH_3CH_2CH_2CH_2$—	Butyl
$(CH_3)_2CH$—	Isopropyl
$(CH_3)_3C$—	*tert*-Butyl

1. **Find the longest chain in the molecule.**
2. **Number the chain from the end nearest the first substituent encountered.**
3. **List the substituents as a prefix along with the number(s) of the carbon(s) to which they are attached.**

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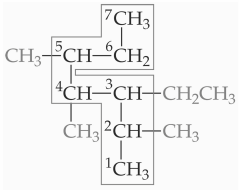
"Longest chain, smallest number"

How to Name a Compound



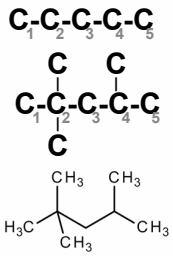
3-Ethyl-2,4,5-trimethylheptane

If there is more than one type of substituent in the molecule, list them alphabetically.

MAR "Longest chain, smallest number"

How to Create a Structure from a Name

Example: provide the structure for the following name: **2,2,4-trimethylpentane**



1. Start at the end of the name to find the chain of carbons; write them "in a row" and number them
2. Groups not in the chain will be listed at the beginning of the name (methyl = CH_3, etc.)
3. Fill in hydrogen atoms at the end if necessary

MAR "Longest chain, smallest number"

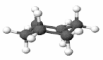
CYCLOALKANES (C_nH_{2n})

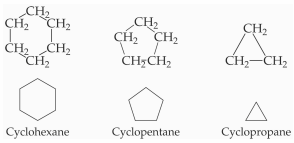
+cyclo -yl +ane

Ex: **cyclohexane = C_6H_{12}**

Generic Cycloalkane Formula: **C_nH_{2n}**

(cyclohexyl group + H)





Also cyclobutane, etc.

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Alkyl Halides

Generic Alkyl Halide Representation: R-X

X = halogen (F, Cl, Br or I)

Ex: **methyl iodide = CH_3-I**

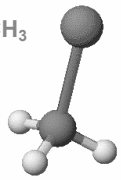
(methyl + iodide)

also known as ***iodomethane***

Ex: **2-iodopropane = CH_3-CHI-CH_3**

(2-propyl + iodide)

also known as ***2-propyl iodide***



Many other possibilities

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ALCOHOLS

Generic Alcohol Representation: R-OH

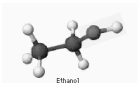
-yl +anol

Generic Alcohol Formula: **$C_nH_{2n+2}O$**

Ex: **ethanol = CH_3CH_2OH**

(ethyl group + OH)

CH_3CH_2-OH



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ALCOHOLS

Generic Alcohol Representation: R-OH

-yl +anol

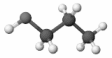
Generic Alcohol Formula: **$C_nH_{2n+2}O$**

Ex: **1-propanol = $CH_3CH_2CH_2OH$**

(propyl group + OH)

$CH_3CH_2CH_2$-OH

new: **propan-1-ol**



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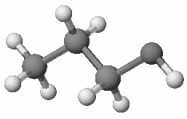
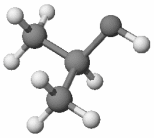
ALCOHOLS

Generic Alcohol Representation: R-OH

Note that both 1-propanol and 2-propanol exist



1-propanol
CH_3-CH_2-CH_2OH
propan-1-ol



2-propanol
CH_3-CH(OH)-CH_3
propan-2-ol

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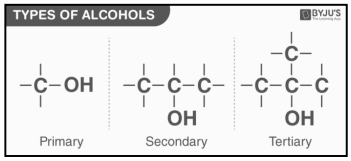
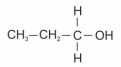
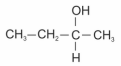
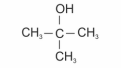
TYPES OF ALCOHOLS




Primary Alcohol
propan-1-ol


Secondary Alcohol
butan-2-ol


Tertiary Alcohol
2-methyl-propan-2-ol

Primary alcohols


ethanol

Secondary alcohols


propan-2-ol

Tertiary alcohols


2-methyl-propan-2-ol

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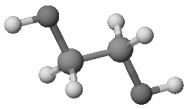
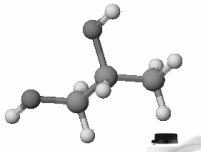
GLYCOLS

Alcohols (diols) with Two OH Groups





Ethylene glycol *(ethane-1,2-diol)*

Propylene glycol *(propane-1,2-diol)*

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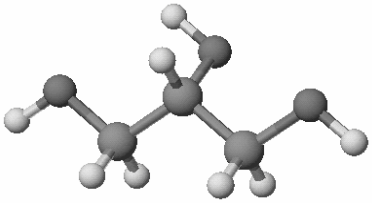
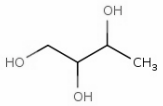
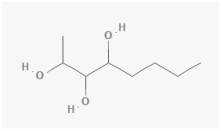
Glycerol (propane-1,2,3-triol)

Alcohol with 3 OH Groups




butane-1,2-3-triol


octane-2,3-4-triol

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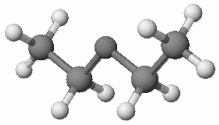
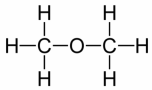
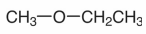
ETHERS - "old school"

Generic Ether Representation: R-O-R
Generic Ether Formula: $C_nH_{2n+2}O$
Ex: diethyl ether = CH_3CH_2-O-CH_2CH_3
(ethyl + O + ethyl)




dimethyl ether


ethyl methyl ether

Many other possibilities

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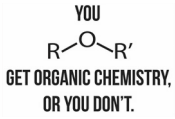
ETHERS - "IUPAC"

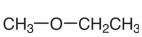
Two nomenclatures for ethers!

Ethers also use "IUPAC" Nomenclature
(shorter alkyl group -yl +oxy) (longer group -yl +ane)

Ex: 1-ethoxypropane = CH_3CH_2-O-$CH_2CH_2CH_3$
(ethyl -yl + oxy)(propyl -yl +ane)
old school: **ethyl 1-propyl ether**

Ex: 2-methoxypropane = $CH_3CH(OCH_3)$-CH_3
2-(methyl -yl + oxy)(propyl -yl +ane)
old school: **methyl 2-propyl ether**




methoxy ethane

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KETONES

Generic Ketone Representation: R-CO-R

R = alkyl group, CO = carbonyl (C=O)

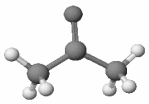
Generic Ketone Formula: $C_nH_{2n}O$

Two carbons connected to carbonyl

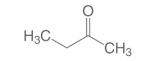
Ex: propanone = CH_3-C(=O)-CH_3

(methyl + C=O + methyl)

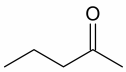
3 carbon atoms like *propane*



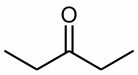
Propanone
is also known as
Acetone



butanone



2-pentanone



3-pentanone

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ALDEHYDES

Generic Aldehyde Representation: R-CO-H

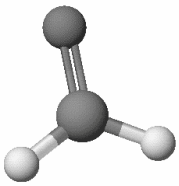
R = alkyl group or H, CO = carbonyl (C=O)

Generic Aldehyde Formula: $C_nH_{2n}O$

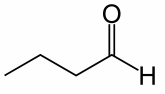
At least one H connected to carbonyl

Ex: methanal = H_2-C=O

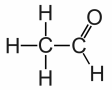
1 carbon atom like *methane*



Methanal
is also known as
Formaldehyde



butanal



ethanal (acetaldehyde)

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ALKYNES

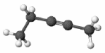
Generic Alkyne Representation: R-C≡C-R

R = alkyl group or H

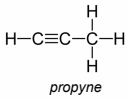
Generic Alkyne Formula: C_nH_{2n-2}

Ex: 2-pentyne = H_3C-C≡C-CH_2CH_3

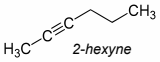
5 carbon atoms like *pentane*



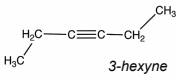
Ethyne
is also known as
Acetylene



propyne



2-hexyne



3-hexyne

MAR

ALKENES

Generic Alkene Representation: R-HC=CH-R

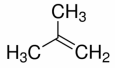
R = alkyl group or H

Generic Alkene Formula: C_nH_{2n}

Ex: *trans*-pent-2-ene = H_3C-HC=CH-CH_2CH_3

5 carbon atoms like *pentane*

but-1-ene



2-methyl propene

ethene or ethylene

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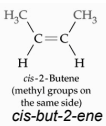
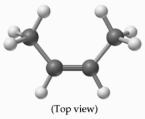
ALKENES - *cis* and *trans*

cis
(same side)

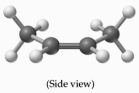


cis-2-Butene
(methyl groups on the same side)

cis-but-2-ene

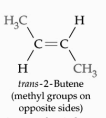


(Top view)



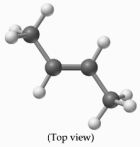
(Side view)

trans
(opposite)

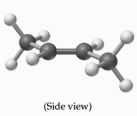


trans-2-Butene
(methyl groups on opposite sides)

trans-but-2-ene



(Top view)



(Side view)

Important!

Differing reactivity in *cis* and *trans* isomers

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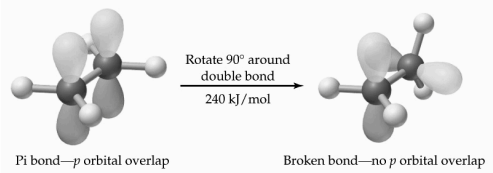
ALKENES - *cis* and *trans*

***Cis - trans* isomerism** occurs because the electronic structure of the carbon–carbon double bond makes rotation energetically unfavorable.



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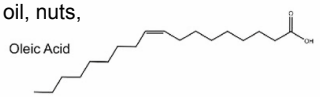
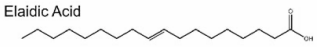
ALKENE ISOMERS - *cis* and *trans* fats

Oleic acid is a **monosaturated fat** with a ***cis*** double bond found naturally in olive oil, nuts, avocados, etc. *Healthier!*



Elaidic acid is a **trans fat** with a ***trans*** double bond which is difficult to digest and causes multiple health issues. *Dangerous!*



Both structures: $C_{18}H_{34}O_2$

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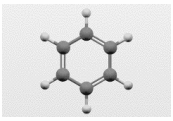
AROMATIC HYDROCARBONS

Aromatic compounds use *conjugated double bonds* for increased stability.
Flat, stable organic functional group



Simplest aromatic compound is Benzene, C_6H_6

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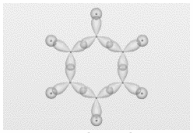
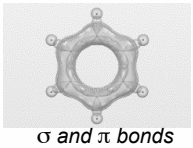
AROMATIC HYDROCARBONS

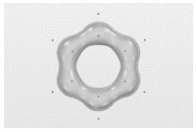
Notice: aromatic compounds are *flat rings with delocalized π electrons*



σ *bonds*



σ *and* π *bonds*



π *bonds*

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AROMATIC HYDROCARBONS

More on *The Ring*

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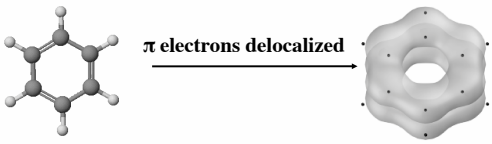
Resonance in Benzene

- C–C single bond: 154 pm
  C=C bond: 134 pm
- CC bonds in benzene: 139 pm
- CC bond order is _____



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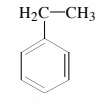
AROMATICS - Examples

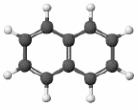


ethylbenzene

nitrobenzene

bromobenzene

toluene
methylbenzene



Naphthalene

phenol

benzoic acid

See *Handout*

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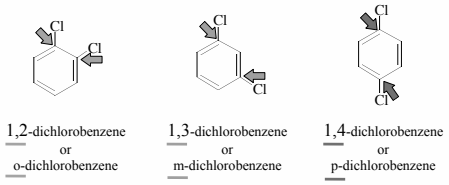
AROMATICS - Examples

ortho position | *meta* position | *para* position



1,2-dichlorobenzene or o-dichlorobenzene

1,3-dichlorobenzene or m-dichlorobenzene

1,4-dichlorobenzene or p-dichlorobenzene

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See ***Handout***

CARBOXYLIC ACIDS

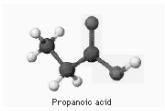
Generic Carboxylic Acid Representation:

R-COOH

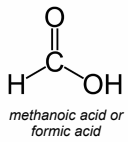
Generic Carboxylic Acid Formula: $C_nH_{2n}O_2$

Ex: propanoic acid = CH_3CH_2-CO-OH

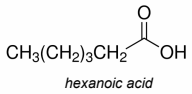
(propyl -2H + =O + OH)



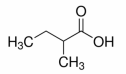
Propanoic acid



methanoic acid or formic acid



hexanoic acid



2-methyl-butanoic acid

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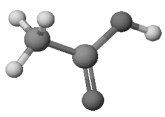
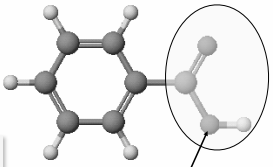
Many other possibilities!

Carboxylic Acids

Acetic acid



Benzoic acid



Acids are found in many natural substances: bread, fruits, milk, wine

Carboxylic acid group with acidic H+ All are WEAK acids

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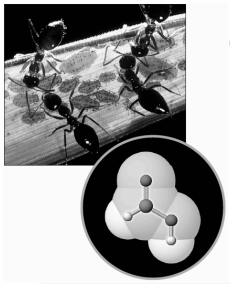
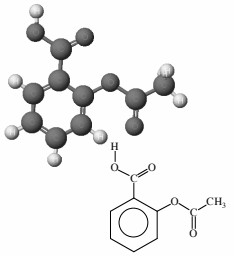
Vinegar *is essentially acetic acid!*



Formic acid, HCO_2H, gives the sting to ants.

Carboxylic Acids



Aspirin, acetylsalicylic acid

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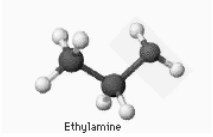
AMINES

Generic Amine Representation: $R_{(3-x)}$-NH_x

Ex: ethylamine = CH_3CH_2-NH_2

(ethyl + NH_2)



Ethylamine

Also diethylamine and triethylamine

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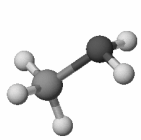
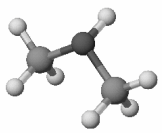
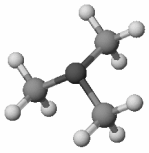


Methylamine

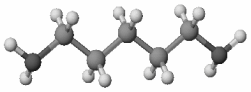


Dimethylamine

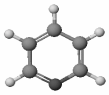


Trimethylamine

Amines generally have terrible odors!



Cadaverine



Pyridine

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ESTERS

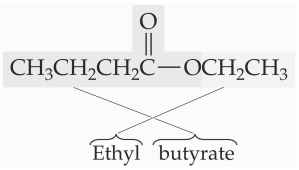
Generic Ester Representation: R_1-COO-R_2

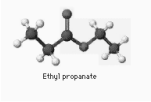
Generic Ester Formula: $C_nH_{2n}O_2$

Ex: ethyl propanate = CH_3CH_2-COO-CH_2CH_3

(propyl -2H + =O + O + ethyl)

Similar to carboxylic acids





Name R_2 first, then R_1

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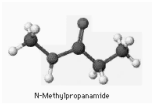
AMIDES

Generic Amide Representation:
R_x-CO-$NH_yR_{(2-y)}$

Ex: *N*-methylpropanamide
CH_3NH-CO-CH_2CH_3



N-*groups off of nitrogen atom*

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Nomenclature and Models

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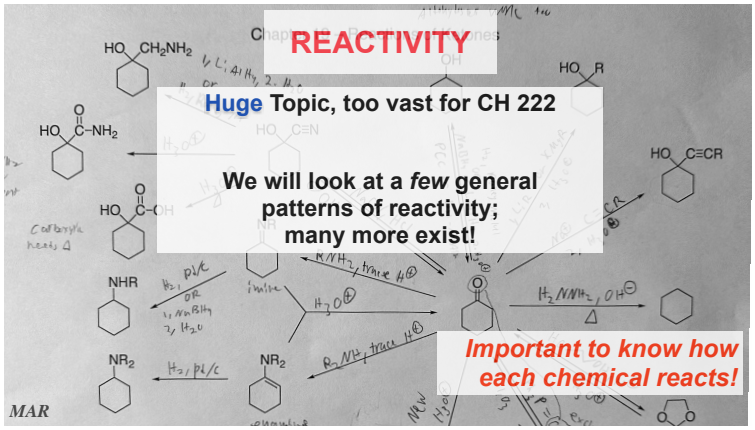
REACTIVITY

Huge Topic, too vast for CH 222

We will look at a *few* general patterns of reactivity; many more exist!



Important to know how each chemical reacts!

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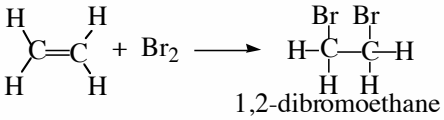
Reactions of Alkenes: ADDITION REACTIONS

Alkenes are unsaturated — more bonds can form to the C atoms

Molecules such as Br_2, H_2, HCl, HBr, and H_2O add to the double bond



1,2-dibromoethane

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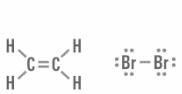
C_2H_4 + Br_2 → CH_2Br-CH_2Br

REACTIVITY

A few minutes →



Ethylene

Example #1:
Addition Reactions
Diatomics adding across double bond

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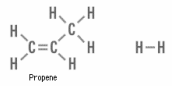
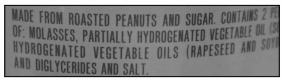
REACTIVITY

Example #2: **Addition Reactions** **Diatomics adding across double bond**



$H_2C=CH-CH_3 + H_2 \rightarrow CH_3-CH_2-CH_3$

Fats can be "hydrogenated" with H_2.
Many foods have hydrogenated fats



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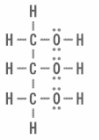
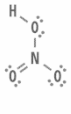
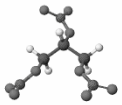
REACTIVITY

Example #3: **Substitution Reactions**
Functional groups switch places





-OH ***+NO_3***



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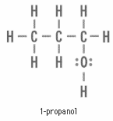
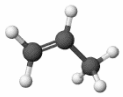
REACTIVITY

Example #4: **Elimination Reactions**
***sp* or *sp^2* bond formation**





$CH_3CH_2-CH_2OH + H^+ \rightarrow CH_3-CH=CH_2 + H_2O + H^+$

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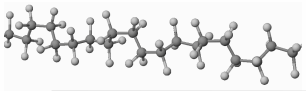
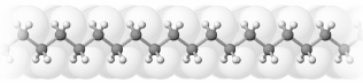


Polymers

Giant molecules made by joining many small molecules called monomers

Average production is *150 kg per person annually* in the U.S. (!)



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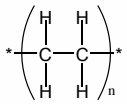
Polymers

A Polymer literally means "many parts"

Many *mer* (or *monomer*) units combined to make a *polymer*

Polymers have high molar masses (10^7 g mol^{-1} or more!) and are used for plastic, fabric, Teflon, much more

Synthesized by addition and condensation reactions



polyethylene

MAR

REACTIVITY

Example #5: **Addition Polymerization Reactions**

Polymers built from *sp^2* carbons (pi bonds)

A polymer with a molar mass of $1e^6$ has about 360,000 units.

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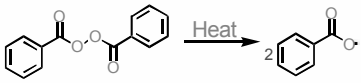
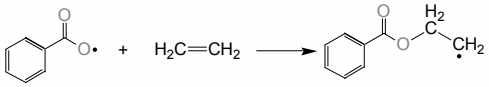
Polyethylene Synthesis

Chain initiator: benzoyl peroxide



Initiation Step: Reaction of benzoyl radical



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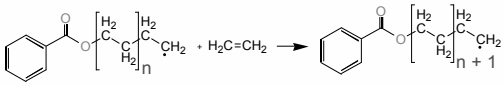
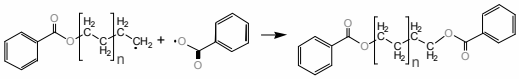
Polyethylene Synthesis

Chain Propagation: Addition of further ethylene



Chain Termination: Reaction of two radicals



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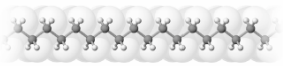
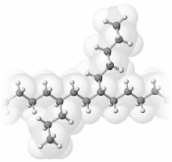
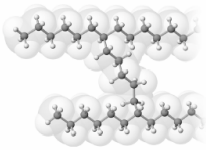
Types of Polyethylene



Linear, high density PE (HDPE)



Branched, low density PE, LDPE



Cross-linked PE, CLPE

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Polystyrene

Polystyrene (PS) is a nonpolar material and dissolves in organic solvents.

PS foam is mostly air, and when it dissolves it collapses to a *much* smaller volume.

MAR

REACTIVITY

Example #6: **Condensation Polymerization Reactions**

Condensation reactions combine different functional groups to make polymers with different properties

Very powerful reaction mechanism; used in contact lenses, nylon, much more

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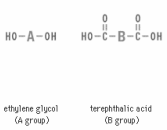
REACTIVITY

Example #6: **Condensation Polymerization Reactions**



Polyester

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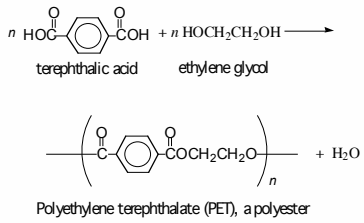
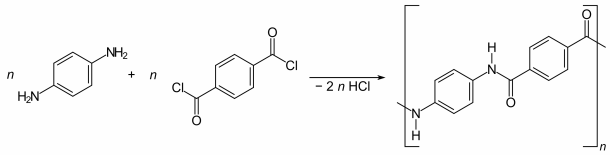
Condensation Polymerization Reactions



Polyethylene terephthalate (PET), a polyester

Formation of polyester

Formation of Kevlar



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Polyesters (PET)

Jackets made from recycled PET soda bottles

Soda bottles, mylar film.

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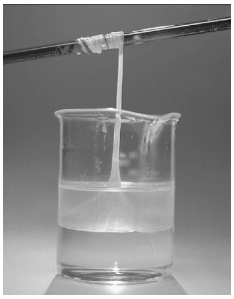
REACTIVITY

Example #6: **Condensation Polymerization Reactions**

Nylon-6,6



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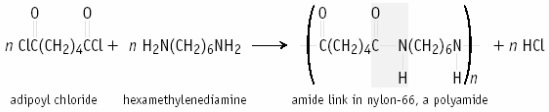
Polyamides: Nylon



Each monomer has 6 C atoms in its chain.

A polyamide link forms on elimination of HCl

Result = nylon-6,6

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USES FOR POLYMERS

Examples of Polymers:

- **Teflon** - *polytetrafluoroethylene*
- **Fabric** - *polyester, polyacrylonitrile*
- **Milk & soda bottles** - *(High Density) Polyethylene*
- **Styrofoam** - *polystyrene*
- **plastic wrap (Saran)** - *poly(vinylidene chloride)*
- **contact lenses** - *poly(methyl methacrylate)*
- *Other uses:*

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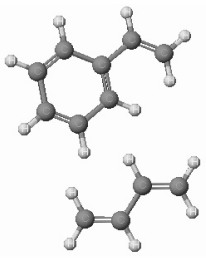
Bubble Gum! A copolymer



Styrene + butadiene

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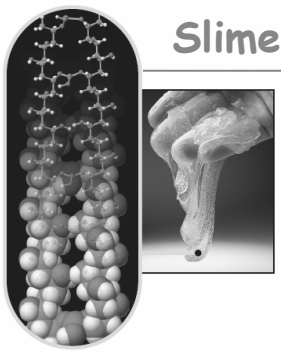
Slime!



Slime is polyvinylalcohol cross-linked with boric acid

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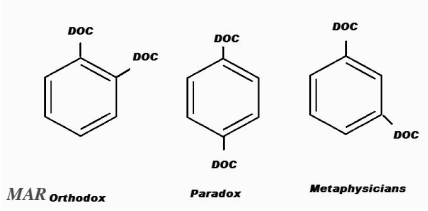
Polymer Recyc

1 PETE	**PETE =**	**Polyethylene terephtha**
2 HDPE	**HDPE =**	**High density PE, 0.941**
3 PVC	**V =**	**PVC (polyvinyl chlorid**
4 LDPE	**LDPE =**	**Low density PE, 0.910-**
5 PP	**PP =**	**Polypropylene, 0.90-0.**
6 PS	**PS =**	**Polystyrene, 1.03-1.06**
7 OTHER	**Other =**	**Other plastics (varies)**

End of Chapter 20

See:

- *Chapter Twenty Study Guide*
- *Chapter Twenty Concept Guide*
- *Important Equations (following this slide)*
- *End of Chapter Problems (following this slide)*



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Important Equations, Constants, and Handouts from this Chapter:

- *be able to* **name organic compounds** *using the* **functional group** *along with the* **"longest chain, shortest number"** *concept*
- **recognize some common organic chemistry reactions**
- *see the* **Organic Chemistry Nomenclature Guide** *(handout)*

Organic Chemistry: alkyl group, alkane, cycloalkane, alkyl halide, alcohol, ether, ketones, aldehydes, alkynes, alkenes, aromatic compounds, carboxylic acids, amines, isomers

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End of Chapter Problems: ***Test Yourself***

Be sure to view practice problem set #3 and self quizzes for ***organic chemistry nomenclature*** *examples and practice*

1. Name a straight chain alkane with six carbon atoms.
2. Name this compound: **$CH_3CH_2CH_2OH$** Provide two isomers of this compound and name them.
3. Draw structural formulas for all four compounds with the formula $C_4H_{10}Br$. Give the systematic name of each.
4. Provide IUPAC numbered names for the following three compounds: *m*-dibromobenzene, *o*-dibromobenzene, *p*-dibromobenzene
5. Which of the following would exhibit *cis, trans* isomerization? 1-pentene, propene, 2-butene

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End of Chapter Problems: ***Answers***

1. n-hexane
2. 1-propanol. 2-propanol and 1-methoxy propane would be isomers.
3. 1-bromobutane, 2-bromobutane, 2-bromo-2-methylpropane, 1-bromo-2-methylpropane
4. *m*-dibromobenzene = 1,3-dibromobenzene, *o*-dibromobenzene = 1,2-dibromobenzene, *p*-dibromobenzene = 1,4-dibromobenzene
5. only 2-butene would exhibit *cis, trans* isomerization.

Be sure to view practice problem set #3 and self quizzes for ***organic chemistry nomenclature*** *examples and practice*

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