Chapter 22: Organic and Biological Molecules

22.1: Alkanes: Saturated Hydrocarbons

Hydrocarbons: - compounds that contains hydrogen and carbon atoms.
- it may contain oxygen, nitrogen and other halogen atoms. In complex organic compound, it may even contain transition metals.

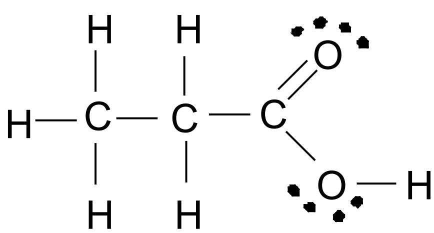
Examples: CH_4 (Methane), C_3H_8 (Propane), $C_6H_{12}O_6$ (Glucose), CH_3OH (Methanol) are hydrocarbons.
CO_2 (Carbon dioxide) and CO (Carbon monoxide) are not hydrocarbons (no hydrogen atoms).

Saturated Bonds: - bonds in hydrocarbons that are single bonds only (mainly $2sp^3$ orbitals for carbon and oxygen and $1s$ orbital for hydrogen).

Unsaturated Bonds: - bonds in hydrocarbons that are double or triple bonds ($2sp^2$ orbitals for C=C and C=O bonds; $2sp$ orbitals for C≡C and C≡N bonds).

Lewis Structure of Hydrocarbons: - each carbon has 4 valence electrons; therefore it has a maximum of 4 bonding sites.
- all lone pairs must be drawn in.

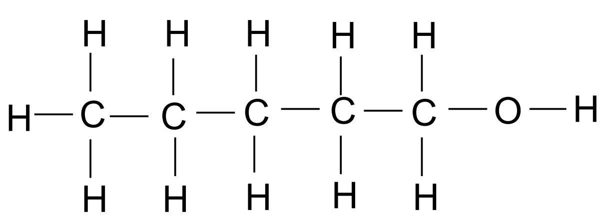
Example: C_2H_5COOH (Propanoic Acid)



Note that there are 4 bonds around each carbon atom.

Structural Formulas: - a Lewis structure without any lone pairs notations.
- there are many forms to write the structural formulas

Example: $C_5H_{11}OH$ (1-Pentanol)



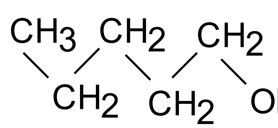
Complete Extended Structural Formula

$CH_3CH_2CH_2CH_2CH_2OH$

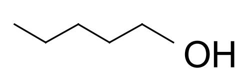
or

$CH_3(CH_2)_4OH$

(Truncated Structural Formulas)



or



Skeletal Forms
(Each endpoint of the zigzag represents a carbon atom)

(Notice the two lone pairs around the oxygen atom are not drawn)

Prefixes of Organic Compounds Nomenclature (You are responsible for the first 10 prefixes)

1 carbon – Meth~	6 carbons – Hex~	11 carbons – Undec~	20 carbons – Icos~
2 carbons – Eth~	7 carbons – Hept~	12 carbons – Dodec~	21 carbons – Henicos~
3 carbons – Prop~	8 carbons – Oct~	13 carbons – Tridec~	22 carbons – Docos~
4 carbons – But~	9 carbons – Non~	14 carbons – tetradec~	30 carbons – Triacont~
5 carbons – Pent~	10 carbons – Dec~	15 carbons – pentadec~	40 carbons – Tetracont~

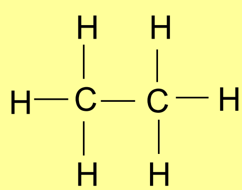
Alkane: - a group of hydrocarbons that has a molecular formula C_nH_{2n+2}.
- nomenclature of alkane involves the use of the suffix *~ane* (like in Alk **~ane**).

Normal Hydrocarbons: - also refer to as Straight Chained or Unbranched Hydrocarbons.
- hydrocarbons that do NOT branched out.

Example 1: Name the following organic compounds or give the molecular formula. Provide a structural formula for these compounds.

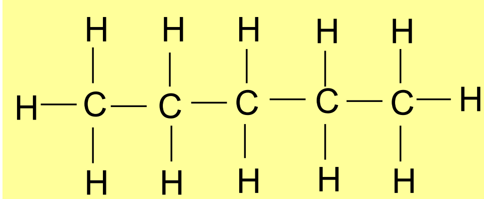
a. C_2H_6

Alkane: $C_2H_{2(2)+2}$ **Ethane**



b. C_5H_{12}

Alkane: $C_5H_{2(5)+2}$ **Pentane**



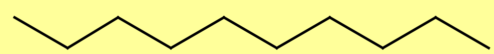
c. Octane

Alkane: $C_8H_{2(8)+2}$ **C_8H_{18}**

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
or $CH_3(CH_2)_6CH_3$

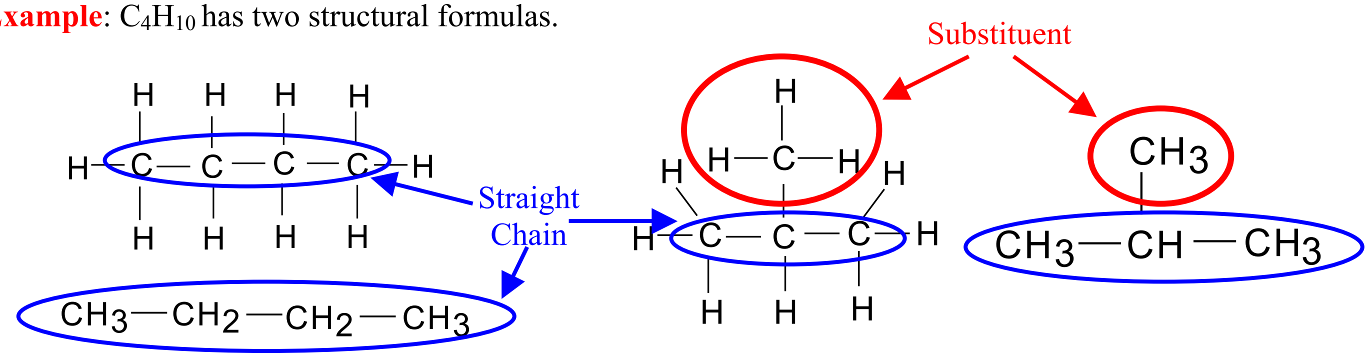
d. Decane

Alkane: $C_{10}H_{2(10)+2}$ **$C_{10}H_{22}$**



Isomers: - hydrocarbons with the same molecular formula that can have other structural formulas.
- *Iso~* means the same. Sometimes refer to as **Structural Isomers**.

Example: C_4H_{10} has two structural formulas.



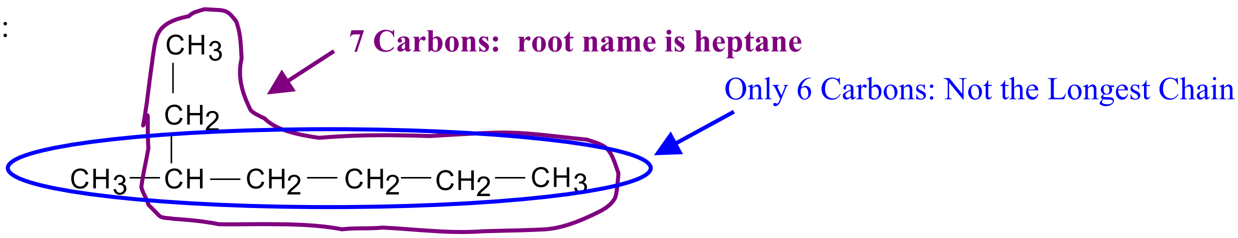
Unbranched (Straight Chain) **Branched (the branched group is called a substituent)**

Alkyl Group: - the substituent component of a branched hydrocarbon.
- nomenclature of alkyl group involves the use of the suffix *~yl* (like in Alk **~yl**). This is followed by the longest main chain of the hydrocarbons.

Nomenclature of Alkanes

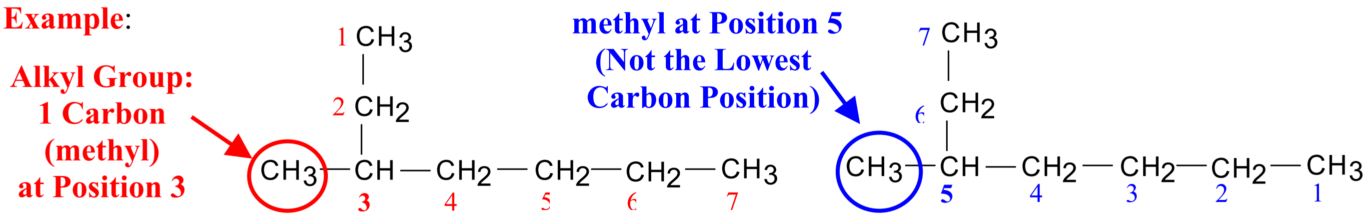
1. Identify the number of carbons in the longest chain. (It is not always the straight one. It can be bent).

Example:



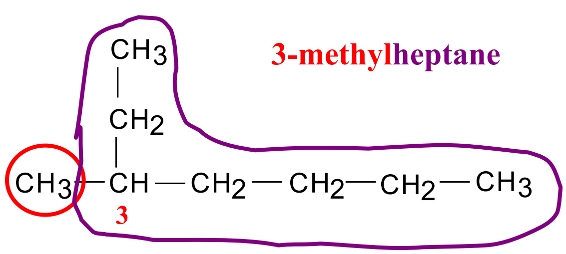
2. Number the carbons of the longest chain with the first alkyl group at the lowest carbon position possible.

Example:



3. Start with the position of the alkyl group, then the name of the alkyl group. Finally the name of the main chain (root name).

Example:

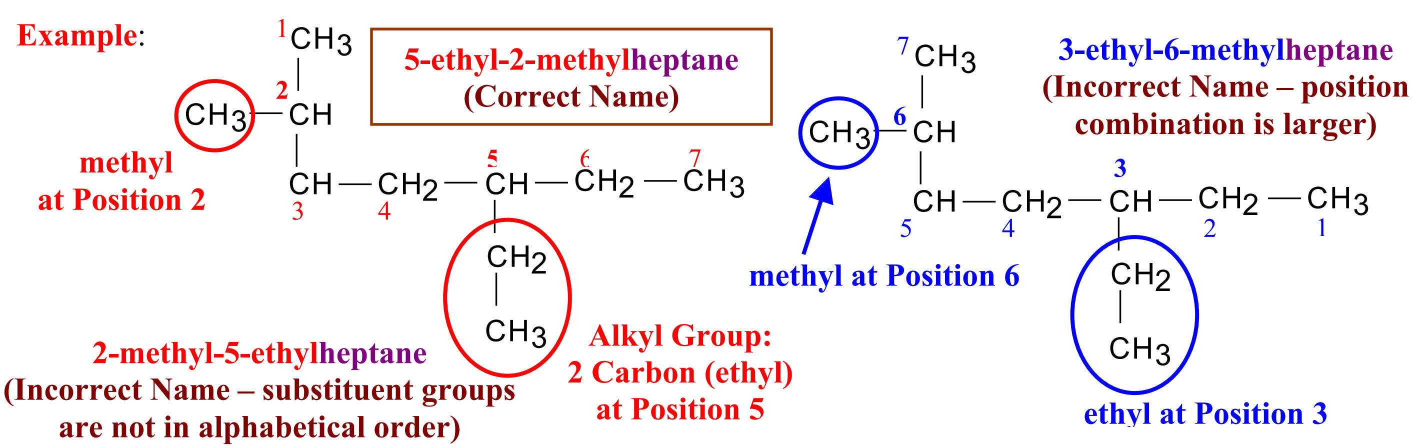


Hyphen should be added between number and alphabet.

There is no space between the alkyl group and the root name.

4. If there are more than one alkyl groups, and they are at the different carbon positions, the alkyl groups shall be name by their positions but their appearance in the final name has to follow alphabetical order.

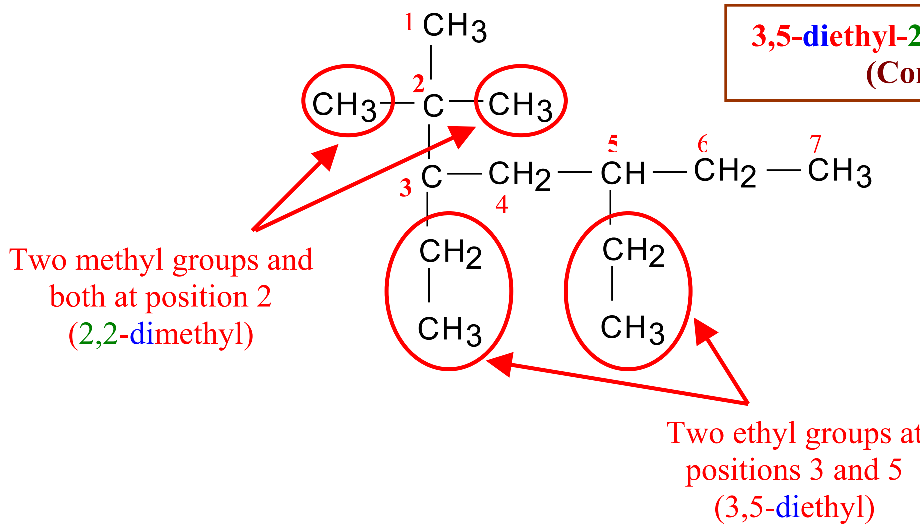
Example:



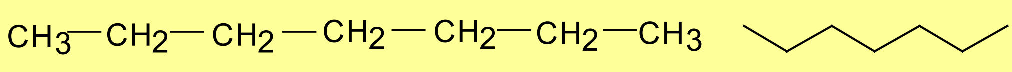
5. If there are more than one alkyl groups, and they are at the same carbon position, then we can name the position as a **repeated number separated by a comma**. In any case, we have to name all positions. If the alkyl groups have the same name, then we can use **prefixes** with the alkyl groups. **(These prefixed are the same as the ones for molecular formulas.)**

Example:

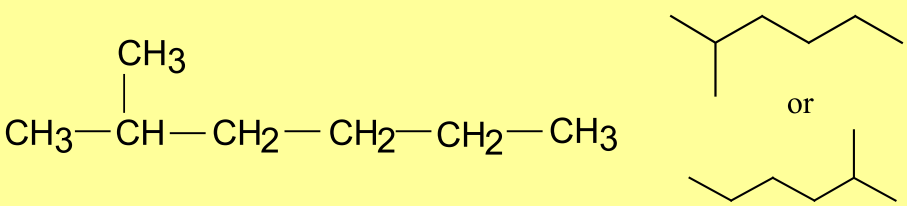
3,5-diethyl-2,2-dimethyl heptane
(Correct Name)



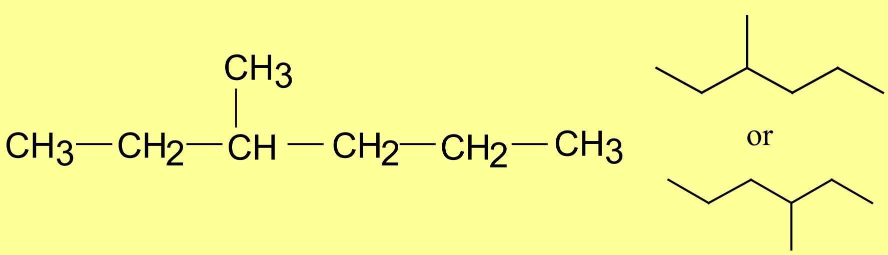
Example 2: Provide the names and structural formulas for all the isomers of heptane. (Hint: there are 9 isomers)



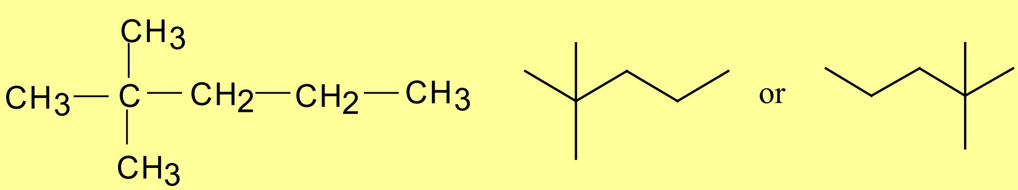
heptane
$CH_3(CH_2)_5CH_3$



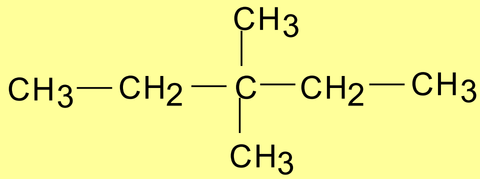
2-methylhexane
$CH_3CHCH_3(CH_2)_3CH_3$

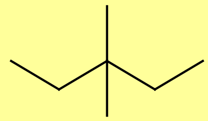


3-methylhexane
$CH_3CH_2CHCH_3(CH_2)_2CH_3$

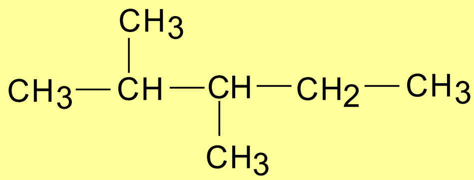


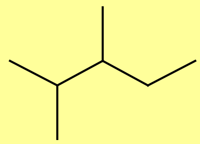
2,2-dimethylpentane
$CH_3C(CH_3)_2(CH_2)_2CH_3$





3,3-dimethylpentane
$CH_3CH_2C(CH_3)_2CH_2CH_3$





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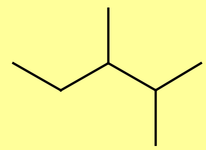
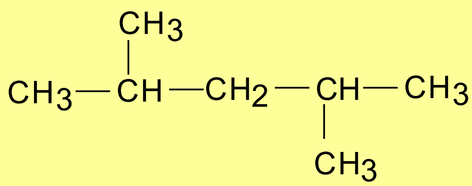
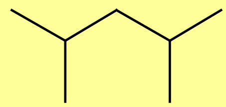
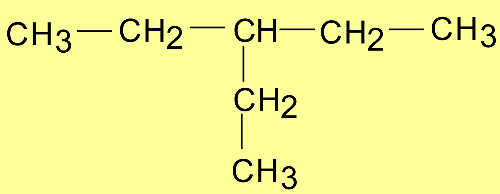


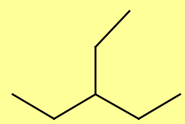
2,3-dimethylpentane
$CH_3CHCH_3CHCH_3CH_2CH_3$



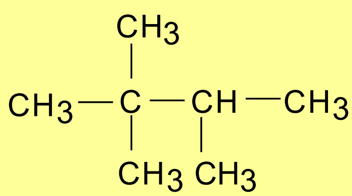


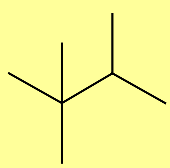
2,4-dimethylpentane
$CH_3CHCH_3CH_2CHCH_3CH_3$





3-ethylpentane
$CH_3CH_2CH(C_2H_5)CH_2CH_3$





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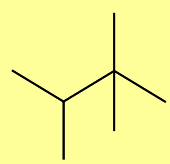
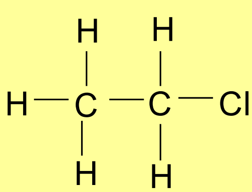


2,2,3-trimethylbutane
$CH_3C(CH_3)_2CHCH_3CH_3$

<u>Halogen Derivatives</u>: - hydrocarbons that contain halogen substituent(s).
- uses the same rules as naming branched alkanes.
- F (fluro), Cl (chloro), Br (bromo), I (iodo).

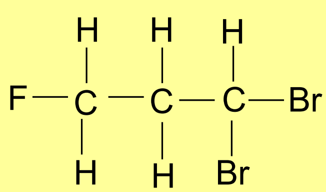
Example 3: Name the following halogen derivatives or give the molecular formula. Provide a structural formula for these compounds.

a. CH_3CH_2Cl



chloroethane

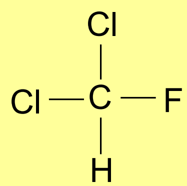
b. $CH_2FCH_2CHBr_2$



1,1-dibromo-3-fluoropropane

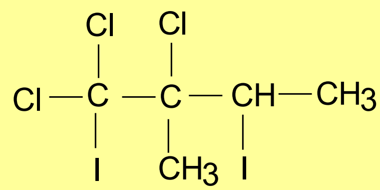
3,3-dibromo-1-fluoropropane
(Incorrect Naming – number sequence could be better)

c. dichloroflurommethane



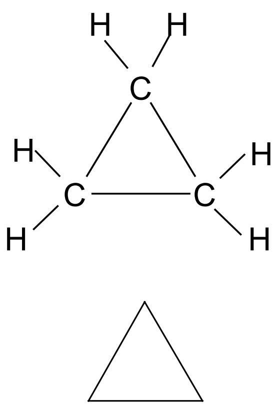
$CHCl_2F$

d. 1,1,2-trichloro-1,3-diiodo-2-methylbutane

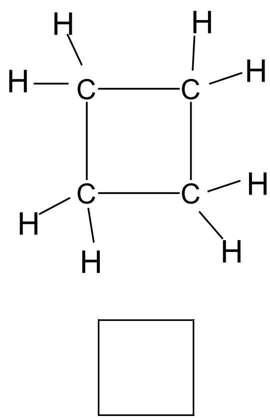


$CCl_2ICCH_3ClCHICH_3$

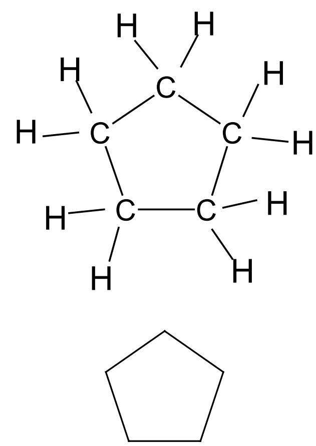
Cyclic Alkane: - where the ends of an alkane chain are connected to each other in a cyclical shape.
- the molecular formula has a form of C_nH_{2n}.
- naming contains the prefix *cyclo~* before the root name.
- substituents are named the same way as branched alkanes (pick any corner as carbon 1).



Cyclopropane (C_3H_6)
(bond angle 60°)
(Too tight – unstable)

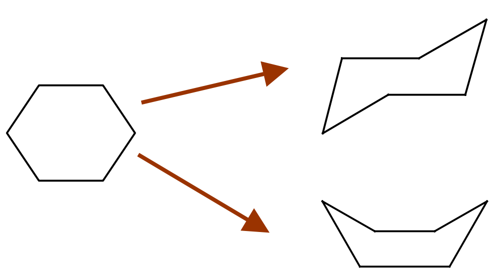


Cyclobutane (C_4H_8)
(bond angle 90°)
(still tight – unstable)

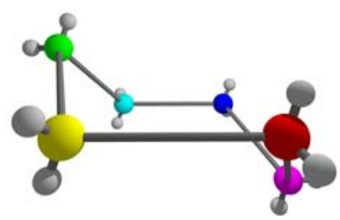


Cyclopentane (C_5H_{10})
(bond angle 108° - close to tetrahedral - stable)

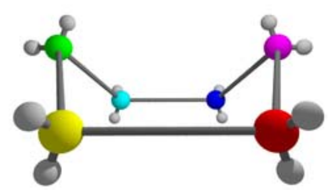
3-D (use molecular model to demonstrate)



"Chair" Conformation



"Boat" Conformation

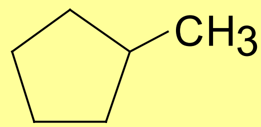


Cyclohexane (C_6H_{12})
(bond angle 109.5° - same as tetrahedral)
(very stable)

The Chair formation is slightly more stable

Example 4: Provide a structural formula for these organic compounds below.

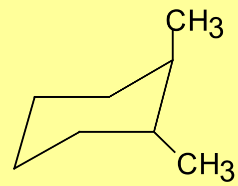
a. methylcyclopentane



$CHCH_3(CH_2)_4$

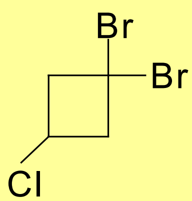
Whenever the position of the substituent is not stated, it is always assume as position 1.

b. 1,2-dimethylcyclohexane



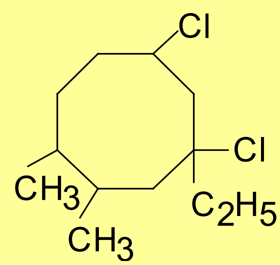
$CHCH_3CHCH_3(CH_2)_4$

c. 1,1-dibromo-3-chlorocyclobutane



$CBr_2CH_2CHCl\,CH_2$

d. 1,3-dichloro-3-ethyl-5,6-dimethylcycloctane



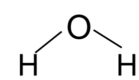
$CHClCH_2CC_2H_5ClCH_2CHCH_3CHCH_3(CH_2)_2$

Reactions of Alkanes

1. **Combustion**: **Alkane + Oxygen → Carbon Dioxide + Water Vapour**

Example: Propane + Oxygen → Carbon Dioxide + Water Vapour

$C_3H_{8\,(g)}$ + $5\ O_{2\,(g)}$ → $3\ CO_{2\,(g)}$ + $4\ H_2O_{(g)}$

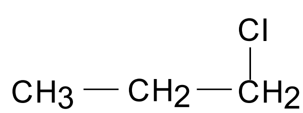
$CH_3 - CH_2 - CH_3$ + $5\ O = O$ → $3\ \ O = C = O$ + 4 

2. **Substitution**: **Alkane + Halogen (X_2) $\xrightarrow{h\nu}$ Halogen Derivate + HX** ***hν* = light energy**

(Check out animation at http://www.jbpub.com/organic-online/movies/chlormet.htm)

Example: Propane + Chlorine $\xrightarrow{h\nu}$ 1-chloropropane + Hydrogen Chloride

$C_3H_{8\,(g)}$ + $Cl_{2\,(g)}$ $\xrightarrow{h\nu}$ $CH_3CH_2CH_2Cl_{(g)}$ + $HCl_{(g)}$

$CH_3 - CH_2 - CH_3$ + $Cl - Cl$ $\xrightarrow{h\nu}$  + $H - Cl$

3. **Dehydrogenation**: **Alkane $\xrightarrow{Pt}$ Alkene (double bond) + Hydrogen**

Example: Ethane $\xrightarrow{Pt}$ Ethene + Hydrogen

$C_2H_{6\,(g)}$ $\xrightarrow{Pt}$ $C_2H_{4\,(g)}$ + $H_{2\,(g)}$

$CH_3 - CH_3$ $\xrightarrow{Pt}$ $CH_2 = CH_2$ + $H - H$

Assignment
22.1 pg. 1091 – 1092 #23 to 30

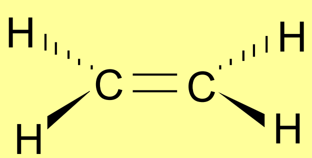
22.2: Alkenes and Alkynes

Alkenes: - hydrocarbons that contain a C = C (double bond)
- nomenclature of alkane involves the use of the suffix *~ene* (like in Alk **~ene**).
- hydrocarbons with two double bonds are named with the suffix *~diene* (~**di ene** as in two double bonds).
- hydrocarbons with three double bonds are named with the suffix *~triene* (~**tri ene** as in three double bonds).
- unless it is understood, all double bond locations along the longest carbon chain must be identified.
- prefixes to indicate the number of carbon atoms in the longest chain along with the naming of any alkyl group remains the same as alkane compounds with the lowest numerical combination given to the double bonds. ***Note: The alkene group takes precedent in the root naming over any substituents.***
- **for one double bond alkenes, the molecular formula C_nH_{2n}.** ***Note:*** It is the same as cycloalkanes. Therefore, ***one double bond alkenes are isomers to cycloalkanes***.

Example 1: Name the following alkenes or give the molecular formula or vice-versa. Provide a structural formula for these compounds.

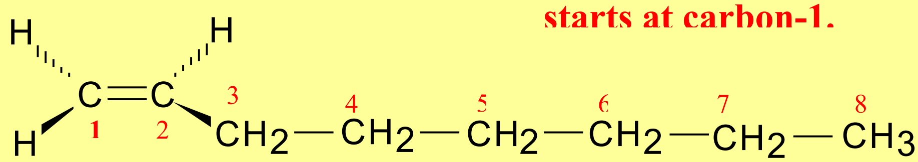
a. C_2H_4

Alkene: $C_2H_{2(2)}$ **Ethene**



b. 1-octene

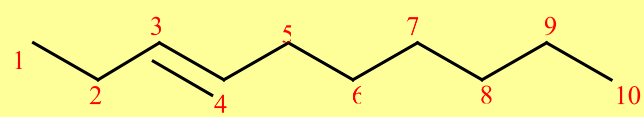
Alkene: $C_8H_{2(8)}$ **C_8H_{18}** **The double bond starts at carbon-1.**

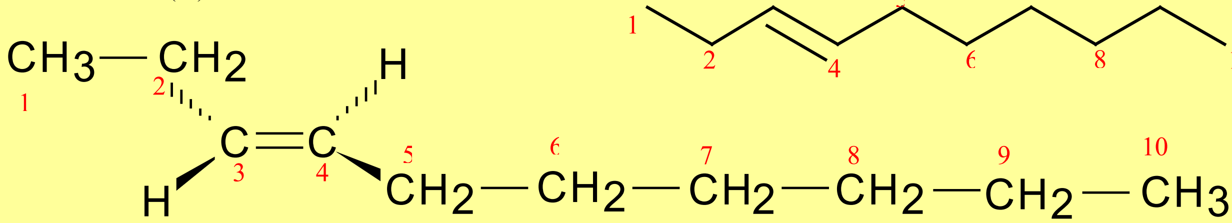


CH_2=$CHCH_2CH_2CH_2CH_2CH_2CH_3$
or $CH_2CH(CH_2)_5CH_3$

c. 3-decene

Alkene: $C_{10}H_{2(10)}$ **$C_{10}H_{20}$**



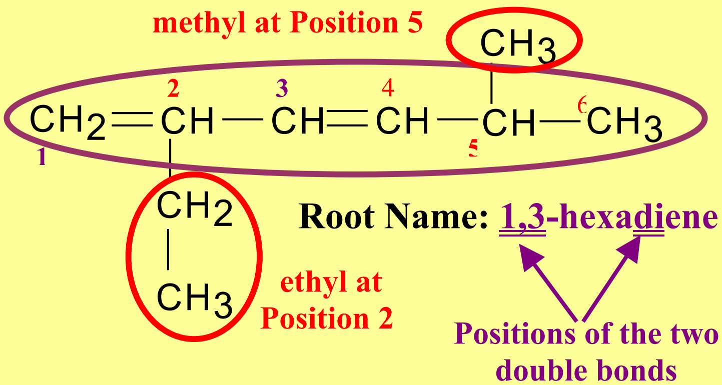


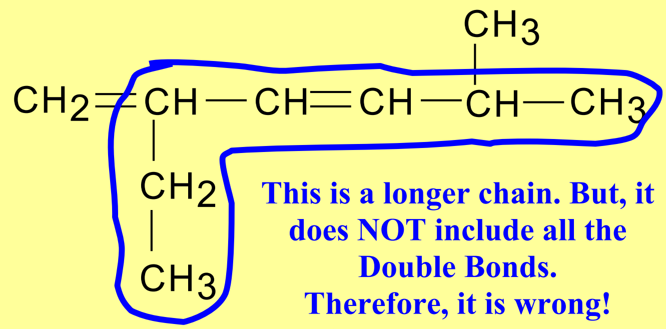
The double bond starts at carbon-3.

CH_3CH_2CH=$CHCH_2CH_2CH_2CH_2CH_2CH_3$
or $CH_3CH_2CHCH(CH_2)_5CH_3$

d. $CH_2{=}CH(C_2H_5)CH{=}CH{-}CH(CH_3)CH_3$

First, we draw the structural formula.



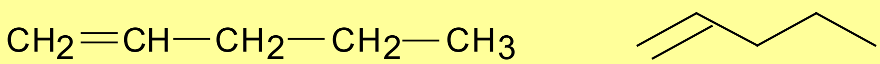


This is a longer chain. But, it does NOT include all the Double Bonds. Therefore, it is wrong! (Double Bonds take precedent over substituents)

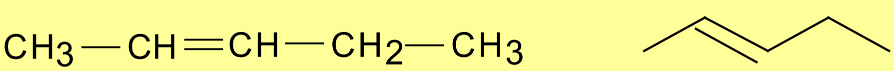
2-ethyl-5-methyl-1,3-hexadiene (Correct Name)

Example 2: Provide the names and structural formulas for all the isomers of C_5H_{10}.

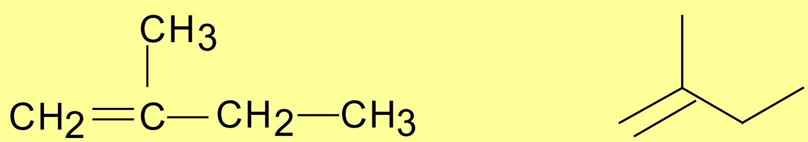
There are 9 isomers to C_5H_{10}.



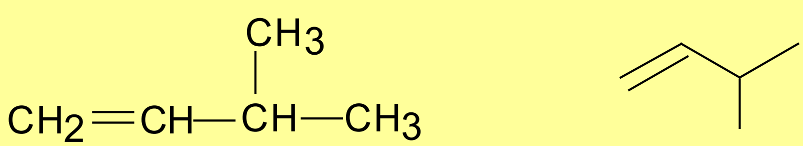
1-pentene
$CH_2CHCH_2CH_2CH_3$



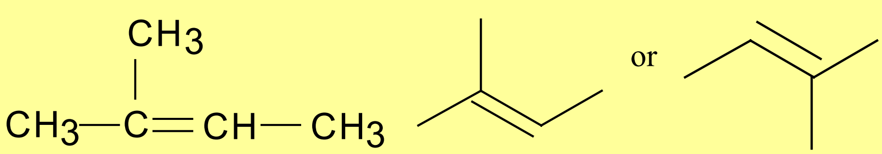
2-pentene
$CH_3CHCHCH_2CH_3$



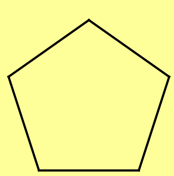
2-methyl-1-butene
$CH_2C(CH_3)CH_2CH_3$



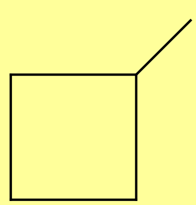
3-methyl-1-butene
$CH_2CHCH(CH_3)CH_3$



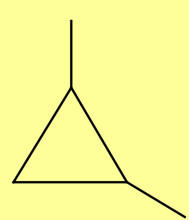
2-methyl-2-butene
$CH_3C(CH_3)CHCH_3$



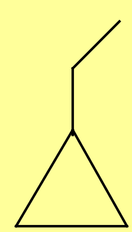
cyclopentane
$(CH_2)_5$



methylcyclobutane
$CH(CH_3)CH_2CH_2CH_2$



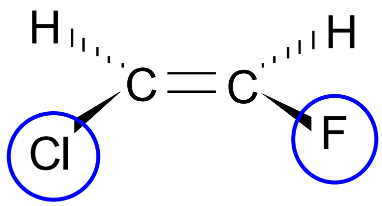
dimethylcycloproane
$CH(CH_3)CH(CH_3)CH_2$



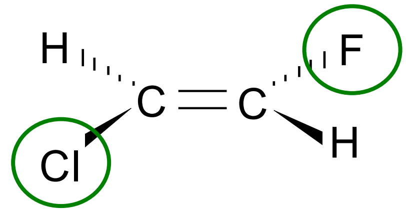
ethylcycloproane
$CH(C_2H_5)CH_2CH_2$

***cis-trans* isomerism**: - **geometrical isomers** of hydrocarbons or cycloalkanes which differ in the positions of atoms (or groups) relative to a reference plane
- in the ***cis*-isomer** the atoms are **on the same side**.
- in the ***trans*-isomer** they **are on opposite sides**.

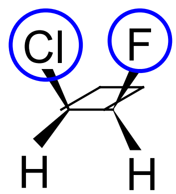
Examples:



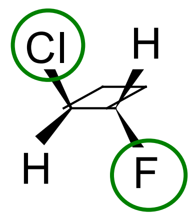
***cis*-1-fluoro-2-chloroethene**



***trans*-1-fluoro-2-chloroethene**



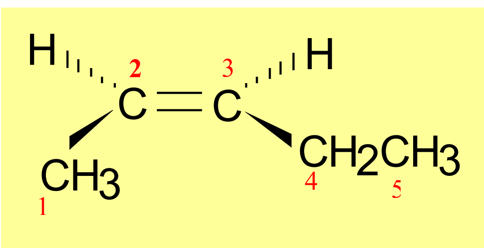
***cis*-1-fluoro-2-chlorocyclobutane**



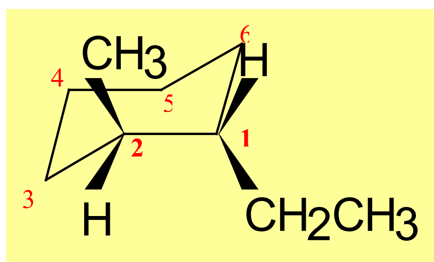
***trans*-1-fluoro-2-chlorocyclobutane**

Example 3: Draw the structural formula and state the name for the following organic compounds.

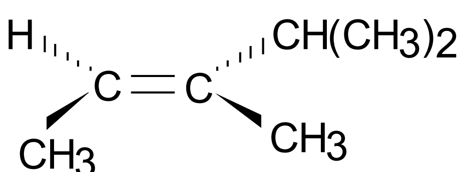
a. *cis*-2-pentene

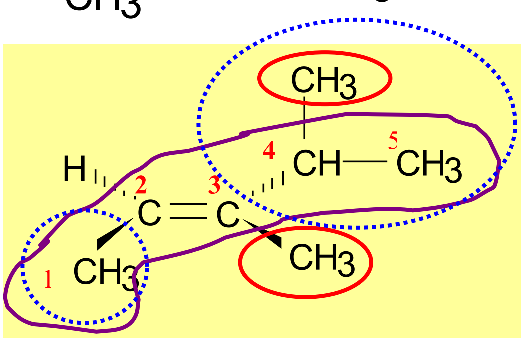


b. *trans*-1-ethyl-2-methylcyclohexane



c.

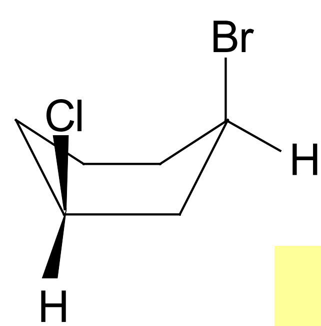


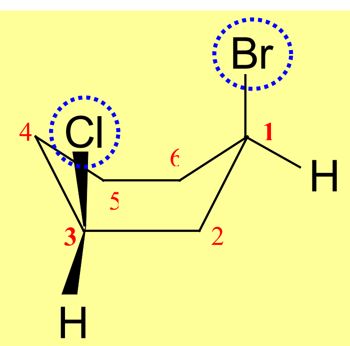


***trans*-3,4-dimethyl-2-pentene**

(*trans* are on the main chain)

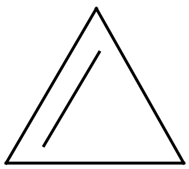
d.



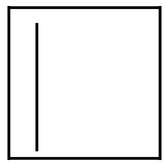


***cis*-1-bromo-3-chlorocyclohexane**

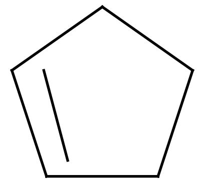
Cyclic Alkene: - where the ends of an alkene chain are connected to each other in a cyclical shape.
- the molecular formula has a form of C_nH_{2n-2}.
- naming contains the prefix *cyclo~* before the root name.
- substituents are named the same way as branched alkenes (pick any corner as carbon 1).



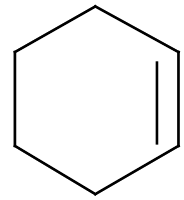
Cyclopropene (C_3H_4)



Cyclobutene (C_4H_6)



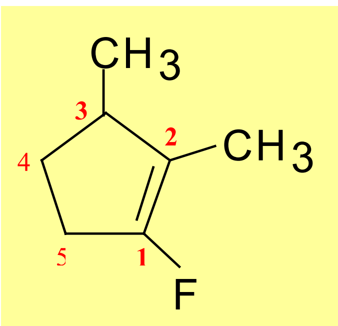
Cyclopentene (C_5H_8)



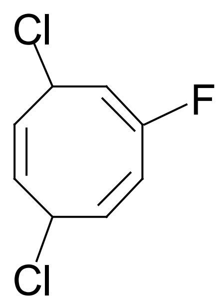
Cyclohexene (C_6H_{10})

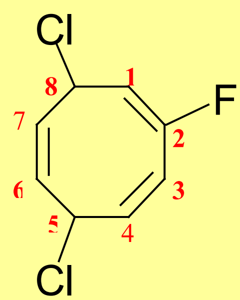
Example 4: Draw the structural formula and state the name for the following organic compounds.

a. 1-fluoro-2,3-dimethylcyclopentene



b.





5,8-dichloro-2-fluoro-1,3,6-cyclooctatriene

Positions of the three double bonds

Alkynes: - hydrocarbons that contain a C ≡ C (triple bond)
- nomenclature of alkane involves the use of the suffix *~yne* (like in Alk **~yne**).
- hydrocarbons with two triple bonds are named with the suffix *~diyne* (~**di yne** as in two triple bonds).
- hydrocarbons with three triple bonds are named with the suffix *~triyne* (~**tri yne** as in three triple bonds).
- unless it is understood, all triple bond locations along the longest carbon chain must be identified.
- prefixes to indicate the number of carbon atoms in the longest chain along with the naming of any alkyl group remains the same as alkane compounds with the lowest numerical combination given to the triple bonds. ***Note: The alkyne group takes precedent in the root naming over any substituents.***
- **for one triple bond alkenes, the molecular formula C_nH_{2n-2}.** ***Note:*** It is the same as cycloalkenes. Therefore, ***one triple bond alkynes are isomers to cycloalkenes***.

Example 5: Name the following alkynes or give the molecular formula or vice-versa. Provide a structural formula for these compounds.

a. C_3H_4

Alkyne: $C_3H_{2(3)-2}$ **Propyne**

$H—C{\equiv}C—CH_3$

b. 3-heptyne

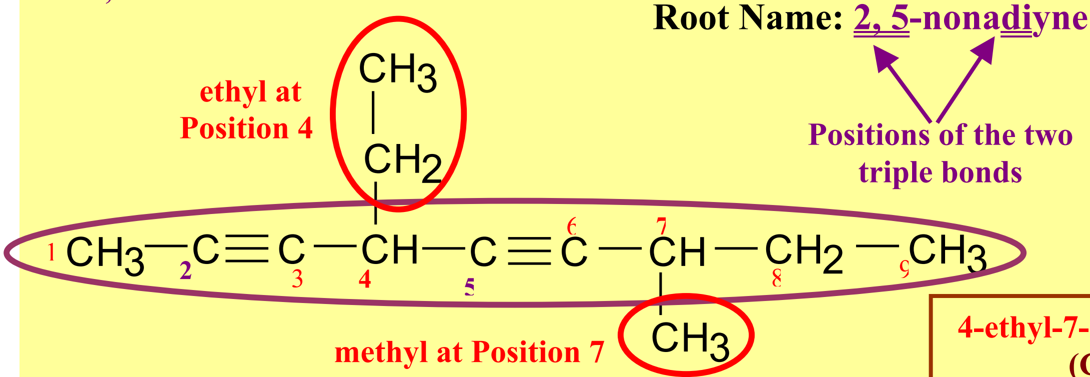
Alkene: $C_7H_{2(7)-2}$ **C_7H_{12}** **The triple bond starts at carbon-3.**

$CH_3—CH_2—C{\equiv}C—CH_2—CH_2—CH_3$

$CH_3CH_2CCCH_2CH_2CH_3$
or $CH_3CH_2CC(CH_2)_2CH_3$

c. $CH_3C{\equiv}CCH(C_2H_5)C{\equiv}CCH(CH_3)CH_2CH_3$

First, we draw the structural formula.



4-ethyl-7-methyl-2,5-nonadiyne (Correct Name)

Reactions of Alkenes and Alkynes

1. **Hydrogenation**: - when hydrogen is added across a double bond or triple bond (π bond) to form single bond (σ bond).

Alkyne + Hydrogen $\xrightarrow{\text{catalyst}}$ **Alkene** **Alkene + Hydrogen** $\xrightarrow{\text{catalyst}}$ **Alkane**

(Check out the animation at http://www.jbpub.com/organic-online/movies/cathyd.htm)

Example:

Propyne	+	Hydrogen	$\xrightarrow{\text{catalyst}}$	Propene
$C_3H_{4\,(g)}$	+	$H_{2\,(g)}$	$\xrightarrow{\text{catalyst}}$	$C_3H_{6\,(g)}$
$CH \equiv C - CH_3$	+	$H - H$	$\xrightarrow{\text{catalyst}}$	$CH_2 = CH - CH_3$

Example:

Propene	+	Hydrogen	$\xrightarrow{\text{catalyst}}$	Propane
$C_3H_{6\,(g)}$	+	$H_{2\,(g)}$	$\xrightarrow{\text{catalyst}}$	$C_3H_{8\,(g)}$
$CH_2 = CH - CH_3$	+	$H - H$	$\xrightarrow{\text{catalyst}}$	$CH_3 - CH_2 - CH_3$

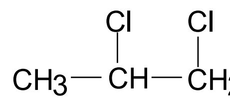
(*Note*: From Propyne to Propane Hydrogenation, it is stepwise.)

2. **Halogenations (Addition)**: - when halogens (X_2) or hydrogen halide (HX) is added across a double bond or triple bond to form halogen derivatives.

Alkene (C_nH_{2n}) + Halogen (X_2) → Alkane Halogen Derivative ($C_nH_{2n}X_2$)
Alkene (C_nH_{2n}) + Hydrogen Halide (HX) → Alkane Halogen Derivatives ($C_nH_{2n+1}X$)

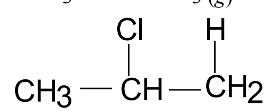
(Check out the animation at http://www.jbpub.com/organic-online/movies/brompent.htm)

Example: Propene + Chlorine → 1,2-dichloropropane
$C_3H_{6\,(g)}$ + $Cl_{2\,(g)}$ → $CH_3CHClCH_2Cl_{(g)}$
$CH_3 - CH = CH_2$ + Cl–Cl →

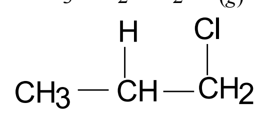


(Check out the animation at http://www.jbpub.com/organic-online/movies/addhx.htm)

Example: Propene + Hydrogen Chloride → 2-chloropropane + 1-chloropropane
$C_3H_{6\,(g)}$ + $HCl_{(g)}$ → $CH_3CHClCH_{3\,(g)}$ + $CH_3CH_2CH_2Cl_{(g)}$
$CH_3 - CH = CH_2$ + H–Cl →



(major product)



(minor product)

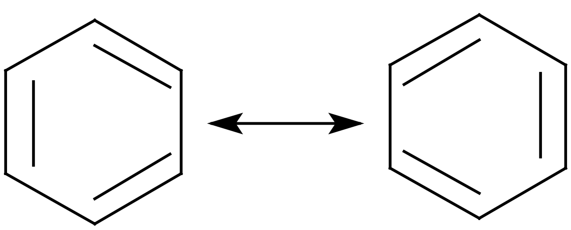
According to Markovnikov's rule, halogen atom tends to bond with the carbon with the least number of hydrogen atoms.

22.3: Aromatic Hydrocarbons

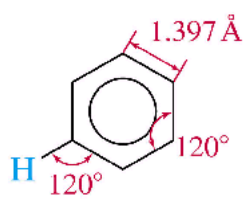
Aliphatic Hydrocarbons: - alkanes, alkenes and alkynes that show distinct reactivity based on the σ or π bonds.

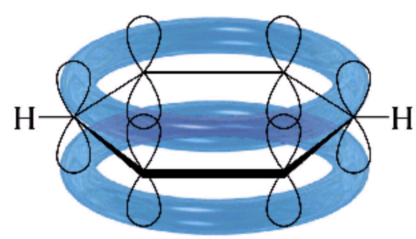
Aromatic Hydrocarbons: - a class of cyclic hydrocarbons characterize by alternating double bonds (delocalised π bonds).

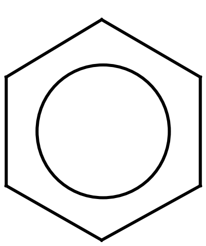
Example: C_6H_6 (Benzene): a very stable compound due to the delocalized double bonds to form a ring.



Resonance structures for benzene







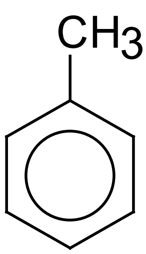
The π bonding framework for benzene

Naming Aromatic Compounds:

1. If benzene is used as the main group then the word "benzene" becomes the root name.
2. If benzene is used as a substituent as C_6H_5 – (like CH_3 – methyl from CH_4), then the substituent name becomes ***phenyl***.
3. The positions of substituents on the benzene ring is like those on the cyclo-aliphatic hydrocarbons. We pick a substituent corner and call it carbon position 1. Then, we go around the benzene ring such that the final combinations of the positions are the lowest.

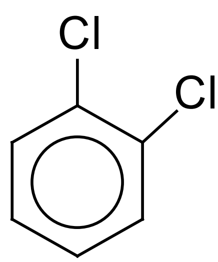
Example 6: Name the following aromatic compounds

a.



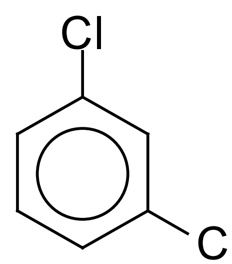
methylbenzene
Common name: Toluene

b.



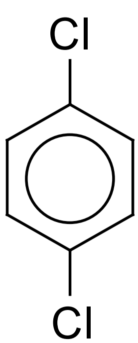
1,2-dichlorobenzene
(*ortho*-dichlorobenzene)

c.



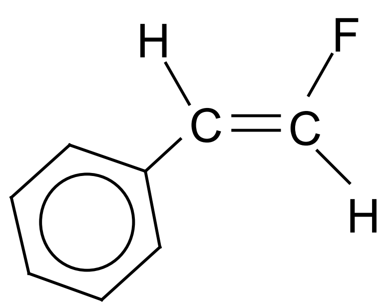
1,3-dichlorobenzene
(*meta*-dichlorobenzene)

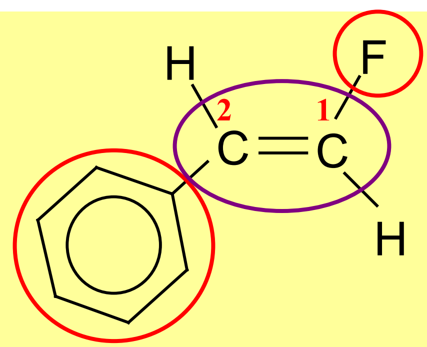
d.



1,4-dichlorobenzene
(*para*-dicholrobenzene)

e.





***trans*-1-fluoro-2-phenylethene**

Assignment
22.2 pg. 1092 #31 to 34, 37, 39 to 48, 62
22.3 pg. 1092 #35, 36, 38, 61, 63

22.4: Hydrocarbon Derivatives

Hydrocarbon Derivatives: - an almost unlimited number of carbon compounds that can be formed by addition of other elements like halogen (halogen derivatives-organic halides) and/or **functional groups** to a hydrocarbon.

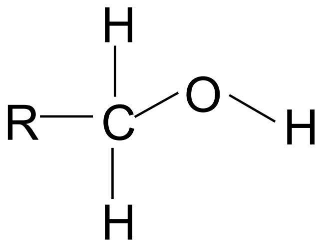
Functional Group: - a reactive portion of a molecule that gives the resulting hydrocarbon derivatives their special chemical and physical properties.

1. **Alcohols**: - organic compounds containing a **hydroxyl functional group**, (***R*-OH**), substituted for a hydrogen atom. **(*R* – represent the rest of the carbon main chain.)**
   - **polar molecules** (due to oxygen's two lone pairs); **very soluble in water** (*R*-OH compares to H–OH)
   - naming of alcohols starts with the prefix of the number of carbon in the longest chain including the –OH group but end with the suffix *~ol* (like in Alcoh **~ol**).
   - hydrocarbons with two –OH groups are named with the suffix *~diol* (~**di ol** as in two –OH groups).
   - hydrocarbons with three –OH groups are named with the suffix *~triol* (~**tri ol** as in 3 –OH groups).
   - unless it is understood, all –OH locations along the longest carbon chain must be identified.
   - prefixes to indicate the number of carbon atoms in the longest chain along with the naming of any alkyl group remains the same as alkane compounds with the lowest numerical combination given to the –OH group. ***Note: The alcohol group takes precedent in the root naming over any substituents (alkyl and halogen substituents).*** **If –OH is a substituent because of higher precedent functional group, it is called –*hydroxy*.**

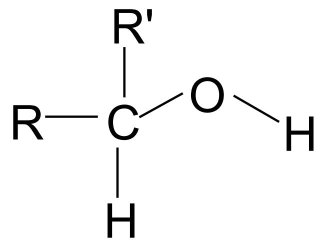
   a. **Primary Alcohol**: - **–OH group attaches to a carbon with one alkyl group**.
   - can react to form functional group like **aldehydes** (will be explain later).
   - higher boiling point than secondary and tertiary alcohols because of the strong hydrogen bonding between molecules (–OH group is at a carbon site that is least crowded; making strong O----H intermolecular bonds possible).

   b. **Secondary Alcohol**: - **–OH group attaches to a carbon with two alkyl groups**.
   - can react to form functional group like **ketones** (will be explain later).
   - lower boiling point than primary but higher than tertiary alcohols. This is because of the somewhat weaker hydrogen bonding between molecules compared to primary alcohol (–OH group is at a carbon site that is more crowded; making O----H intermolecular bonds weaker).

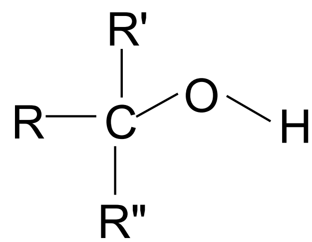
   c. **Tertiary Alcohol**: - **–OH group attaches to a carbon with three alkyl groups**.
   - do not usually react to form other functional groups (**chemically stable**).
   - lower boiling point compared to primary and secondary alcohols (**physically volatile**). This is because of the weakest hydrogen bonding between molecules compared to primary and secondary alcohols (–OH group is at a carbon site that is most crowded; making O----H intermolecular bonds weakest).



Primary Alcohol
(one alkyl group R attached to C which attached to –OH group)



Secondary Alcohol
(two alkyl groups R and R' attached to C which attached to –OH group)

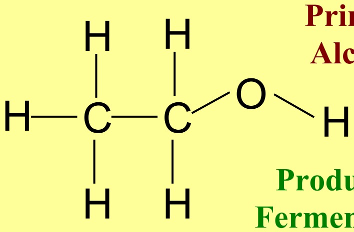


Tertiary Alcohol
(three alkyl groups R, R', and R" attached to C which attached to –OH group)

Example 1: Name the following alcohols or give the molecular formula or vice-versa. Provide a structural formula for these compounds. Indicate whether the alcohol is primary, secondary or tertiary.

a. C_2H_5OH

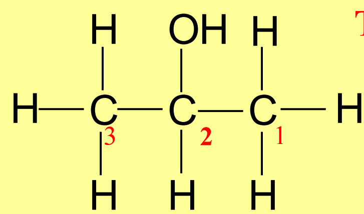
Alcohol: C_2H_5OH **Ethanol**



Primary Alcohol

Product of Fermentation

b. 2-propanol



The –OH group is at carbon-2.

Rubbing Alcohol

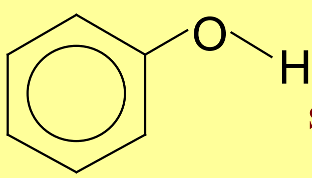
Secondary Alcohol

$CH_3CH(OH)CH_3$

c. C_6H_5OH

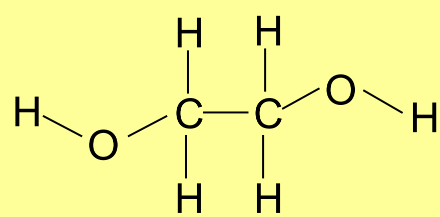
Alcohol with Benzene

Benzenol (or Phenol)



Secondary Alcohol

d. 1,2-ethandiol



The –OH groups are at both carbons.

Commonly known as ethylene glycol (Automobile Antifreeze)

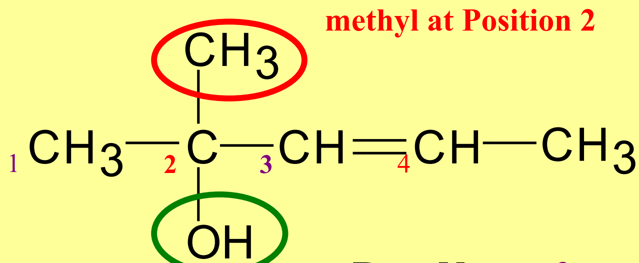
Primary Alcohol

$CH_2(OH)CH_2(OH)$

e. $CH_3C(CH_3)OHCHCHCH_3$

First, we draw the structural formula.

methyl at Position 2



hydroxyl at Position 2

Root Name: <u>3</u>-pent<u>en</u>-2-ol

Positions of the double bond

2-methyl-3-penten-2-ol

Tertiary Alcohol

Hydroxyl group takes precedent over alkene double bond when numbering carbon chain

2. Ethers: - organic compounds containing a hydroxyl functional group, (***R*–O–*R'***), substituted for a hydrogen atom. **(*R* and *R'* – represent the two alkyl groups.)**

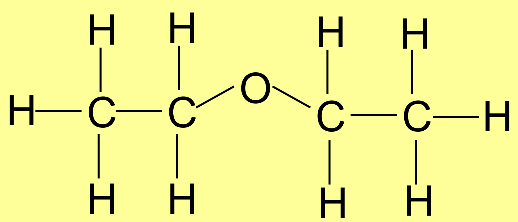
- **polar molecules** (due to oxygen's two lone pairs); **very soluble in water** (hydrogen bonding between water and ether)
- naming of ethers starts with the two alkyl groups (in alphabetical order) ending with ***ether.***
- hydrocarbons with two similar alkyl groups can use the prefix ***di~***.

***Note:* If *R*–O– is a substituent because of higher precedent functional group, it is called *prefix of R–oxy*.**

Example 2: Name the following ethers or give the molecular formula or vice-versa. Provide a structural formula for these compounds.

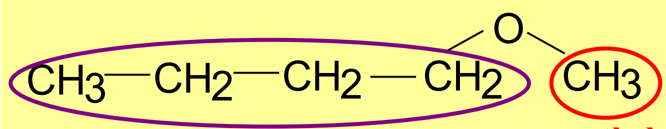
a. diethyl ether

Ether with two ethyl groups: **$C_2H_5OC_2H_5$**



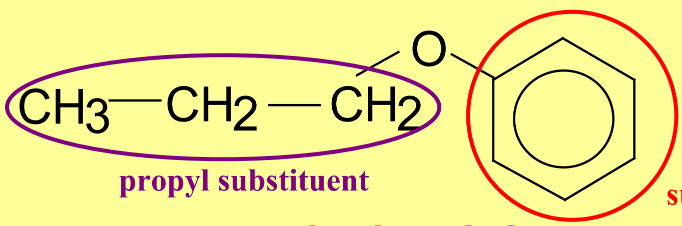
Used as anaesthetic in the past.
Now it is an industrial solvent.

b. $C_4H_9OCH_3$

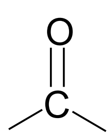


butylmethyl ether

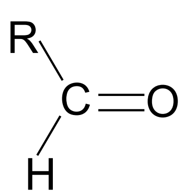
c. $C_3H_7OC_6H_5$



phenylpropyl ether

Carbonyl Group: - a  group.

3. Aldehydes: - compound containing a carbonyl group with at least one hydrogen atom **(R-CHO)** attached to it. ***Note that it is CHO as aldehyde not C–OH as alcohol.***



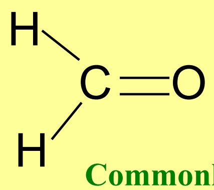
- **polar molecules** (due to oxygen's two lone pairs); **very soluble in water** (hydrogen bonding between water and carbonyl group).
- **Aromatic aldehydes are commonly used as artificial flavours.**
- naming of aldehydes starts with the prefix of the number of carbon in the longest chain including the –C=O group but end with the suffix *~al* (like in **al -**dehyde).

Note: The aldehyde carbonyl group takes precedent in the root naming over any substituents (hydroxy, oxy, alkyl and halogen substituents).

Example 3: Name the following aldehydes or give the molecular formula or vice-versa. Provide a structural formula for these compounds.

a. methanal

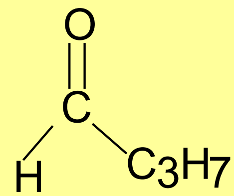
Aldehyde: Methanal (1-Carbon) **HCHO**



Commonly known as formaldehyde.
Used as embalming fluid in mortuary.

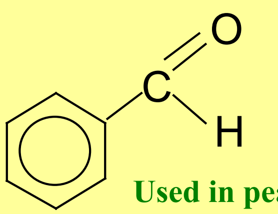
b. C_3H_7CHO

Aldehyde: 4-Carbons **Butanal**



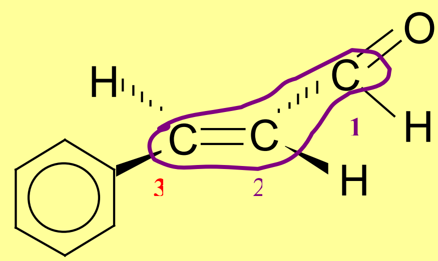
c. C_6H_5CHO

Aldehyde: Benzene (C_6H_5–) **Benzenal**



Used in peaches, cherries and almond flavours.

d. *trans*-3-phenyl-2-propenal (cinnamaldehyde)

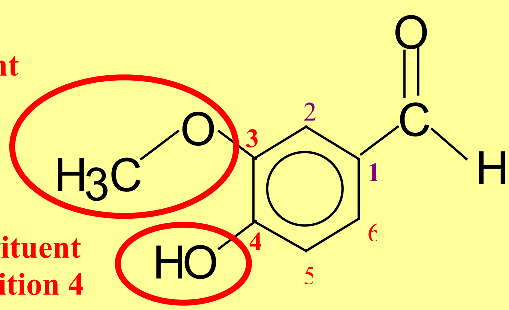


$OHCCHCH(C_6H_5)$
Used as cinnamon flavour.

e. 4-hydroxy-3-methoxy-benzenal

(CH_3–O–) as substituent
***meth*oxy at Position 3**

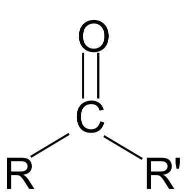
(–OH) as substituent
hydroxy at Position 4



Aldehyde Functional Group takes precedent over ether or alcohol functional groups.

Used in vanilla oil.

4. **Ketones**: - compound containing a carbonyl group with no hydrogen atom **(R-C=OR')** attached to it.
Note that it is **R–C=OR'** *as ketone not* **R–O–R'** *as ether.*



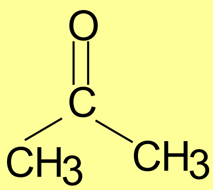
- **polar molecules** (due to oxygen's two lone pairs); **very soluble in water** (hydrogen bonding between water and carbonyl group).
- **Aromatic ketones are commonly used as artificial flavours.**
- naming of ketones starts with the prefix of the number of carbon in the longest chain including the –C=O group but end with the suffix *~one* (like in ket**~one**). The carbonyl position along the longest carbon chain must be indicated.

Note: The ketone carbonyl group takes precedent in the root naming over any substituents (hydroxy, oxy, alkyl and halogen substituents).

Example 4: Name the following ketones or give the molecular formula or vice-versa. Provide a structural formula for these compounds.

a. CH_3COCH_3

Ketone: (3-Carbons) **Propanone**

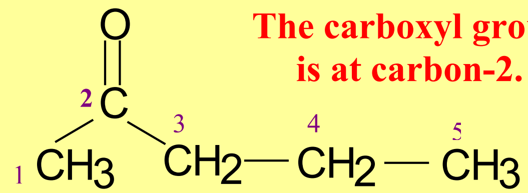


No need to label 2-propanone because the ketone carboxyl group can only exist in this case at carbon 2. Otherwise it would be an aldehyde.

b. 2-pentanone

Ketone: (5-Carbons) **$CH_3CO(CH_2)_2CH_3$**

The carboxyl group is at carbon-2.

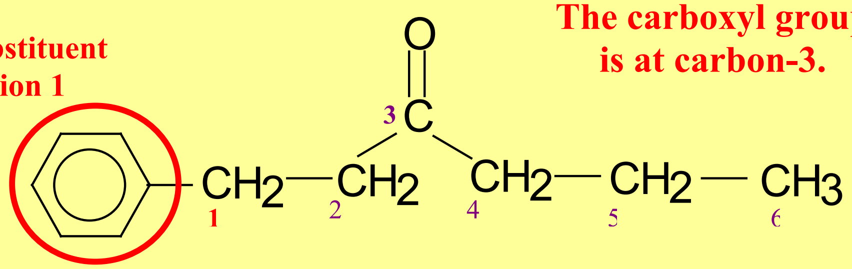


c. 1-phenyl-3-hexanone

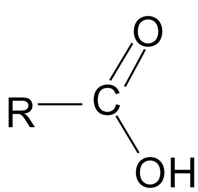
Ketone: (6-Carbons Main Chain) **$C_6H_5CH_2CO(CH_2)_2CH_3$**

phenyl substituent at Position 1

The carboxyl group is at carbon-3.



5. <u>Carboxylic Acids</u>: - compound containing a carbonyl group **(R-COOH)**.



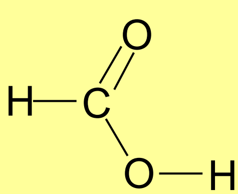
- **polar molecules** (due to oxygens' four lone pairs); **very soluble in water** (hydrogen bonding between water and carbonyl group).
- naming of carboxylic acid starts with the prefix of the number of carbon in the longest chain including the –COOH group but end with the suffix *~oic acid* (like in carb~**o**~xyl~**ic acid**).

Note: The carboxylic acid group takes precedent in the root naming over any substituents (hydroxy, oxy, alkyl and halogen substituents).

Example 5: Name the following carboxylic acid or give the molecular formula or vice-versa. Provide a structural formula for these compounds.

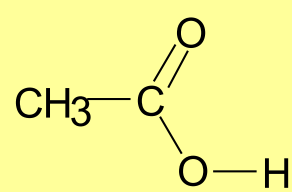
a. methanoic acid

Carboxylic Acid: (Methanoic Acid) –1 carbon **HCOOH**



b. CH_3COOH

Carboxylic Acid: (2 carbons) **Ethanoic Acid**

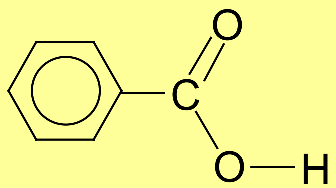


Commonly known as Acetic Acid (Vinegar)

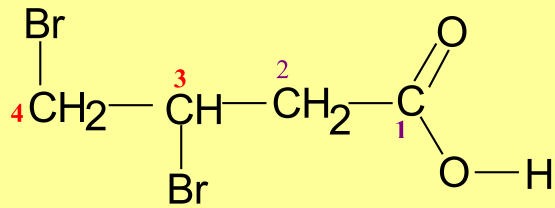
c. C_6H_5COOH

Carboxylic Acid with Benzene

Benzenoic Acid

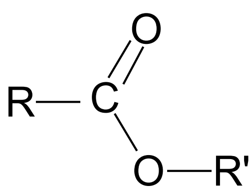


d. 3,4-dibromo-butanoic acid



$CH_2BrCHBrCH_2COOH$

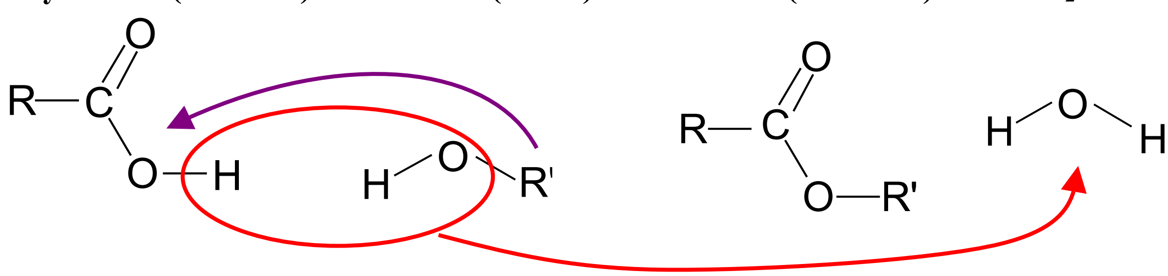
6. <u>Ester</u>: - compound containing a carbonyl group **(RCOOR')**.



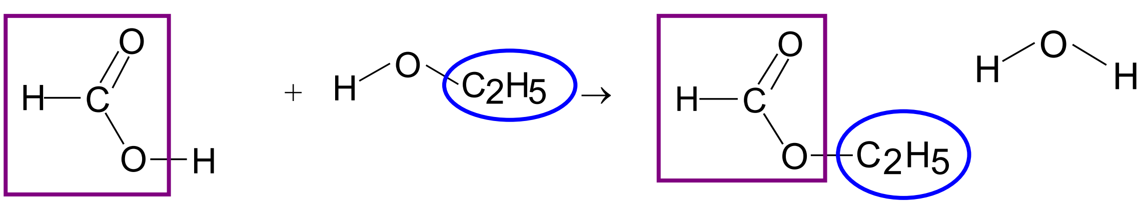
- **polar molecules** (due to oxygens' four lone pairs); **very soluble in water** (hydrogen bonding between water and carbonyl group).
- commonly use as artifical flavorings.
- **form when alcohol is reacted with carboxylic acid.**
- naming of ester starts with the **alkyl group –R'**, then the <u>prefix of the number of carbon in the longest chain</u> including and connected to the RCOO– group and ends with the suffix ***~oate***.
  Note: The ester group takes precedent in the root naming over any substituents (hydroxy, oxy, alkyl and halogen substituents).

<u>Esterification (Ester Condensation)</u>: - **when <u>alcohol reacts with carboxylic acid to form ester and water</u> (condensation because water is produced)**.
- the alcohol chain becomes the alkyl group of the ester (R').
- the carboxylic acid chain becomes main carbon chain for the ester functional group.

Carboxylic Acid (*R*COOH) + Alcohol (*R'*OH) → Ester (*R*COO*R'*) + H_2O



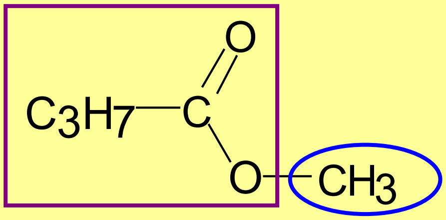
Example:	**Methanoic Acid**	+	**Ethanol**	→	**ethyl methanoate**	+	water
	$HCOOH_{(l)}$	+	$C_2H_5OH_{(l)}$	→	$HCOOC_2H_5\ _{(l)}$	+	$H_2O_{(l)}$



Used as Rum flavouring

Example 6: Name the following esters or give the molecular formula or vice-versa. Provide a structural formula for these compounds. Suggest an esterification reaction to produce each ester below.

a. methyl butanoate

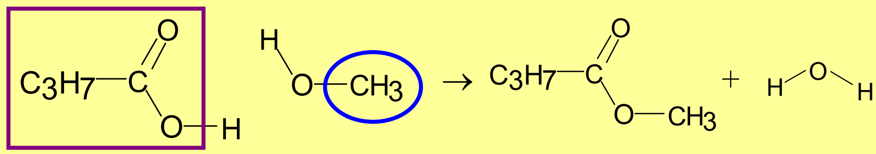


butanoate main chain including carboxyl group

methyl substituent at single bond O

Butanoic Acid + **Methanol** → **methyl butanoate** + water

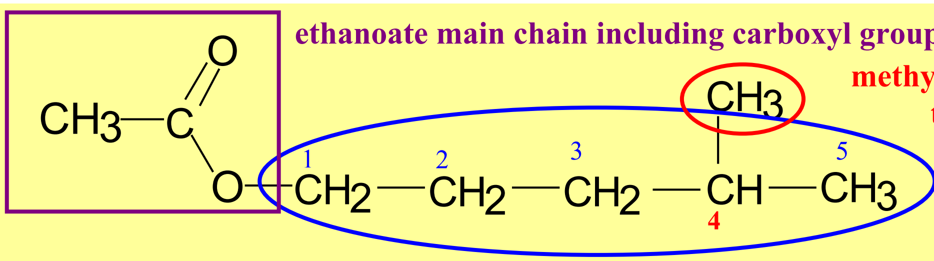
$C_3H_7COOH_{(l)}$ + $CH_3OH_{(l)}$ → $C_3H_7COOCH_{3\,(l)}$ + $H_2O_{(l)}$



Used as Apple flavouring

b. $CH_3COO(CH_2)_3CH(CH_3)_2$

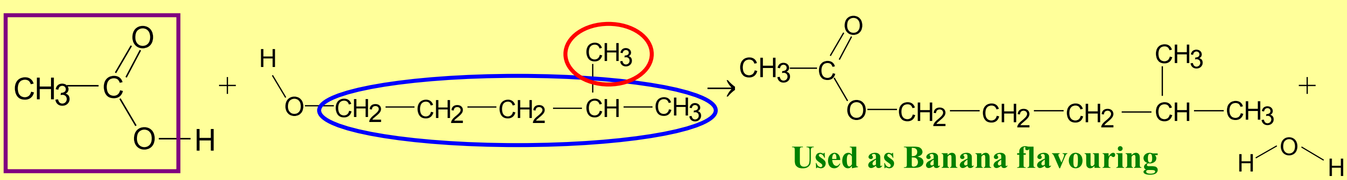
ethanoate main chain including carboxyl group



methyl substituent at Position 4 of the pentyl substitutent

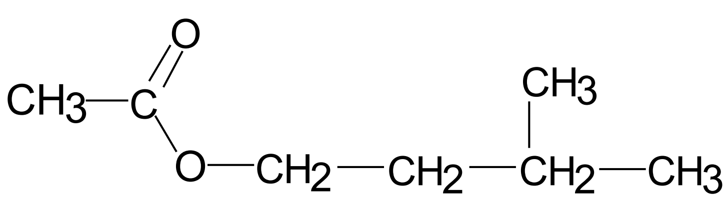
4-methylpentyl substituent at single bond O

Ethanoic Acid	+	**4-methyl-1-pentanol**	→	**4-methylpentylethanoate**	+	water
$CH_3COOH_{(l)}$	+	$CH_3CH(CH_3)(CH_2)_3OH_{(l)}$	→	$CH_3COO(CH_2)_3CH(CH_3)_{2\,(l)}$	+	$H_2O_{(l)}$

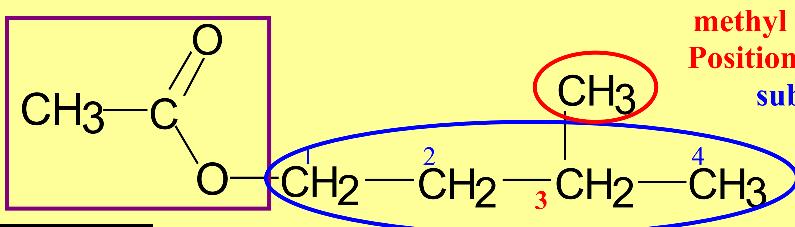


Used as Banana flavouring

Example 7: Name the following organic compound given the structural formula below.



ethanoate main chain including carboxyl group



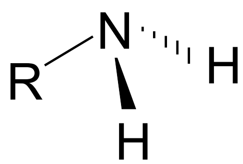
methyl substituent at Position 3 of the butyl substitutent

3-methylbutyl substituent at single bond O

Used as Pear flavouring

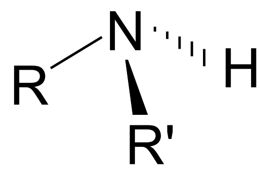
3-methylbutylethanoate

7. **Amine**: - compound containing a nitrogen atom attaching to one, two or three alkyl groups.
   - **polar molecules** (due to nitrogen's lone pair)
   - have fish-like odour.



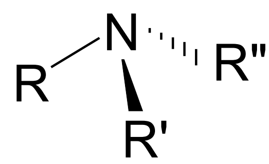
Primary Amine (RNH_2)
(one alkyl group R attached to a Nitrogen atom)

Naming with alkyl group follow by suffix ~*amine*.



Secondary Amine (RR'NH)
(two alkyl groups R and R' attached to a Nitrogen atom)

Naming with the longest chain of carbons takes the root name (*alkanamine*) and the other chain becomes a substituent.



Tertiary Amine (RR'NR")
(three alkyl groups R, R', and R" attached to a Nitrogen atom)

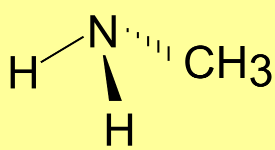
Naming with the longest chain of carbons takes the root name (*alkanamine*) and the other chains become substituents.

Example 8: Name the following amides or give the molecular formula or vice-versa. Provide a structural formula for these compounds. Indicate whether the amine is primary, secondary or tertiary.

a. methylamine

Amine: (methylamine) – one methyl group

CH_3NH_2

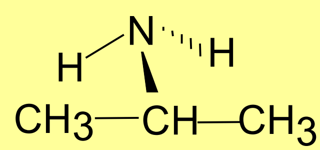


Primary Amine

b. $CH_3CH(NH_2)CH_3$

Amine: (3 carbons with nitrogen at position 2 using one propyl group)

propyl-2-amine

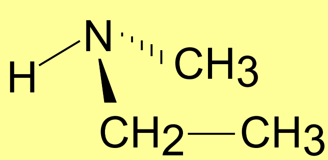


Primary Amine

c. methylethylamine

Amine: (methyl ethyl amine) – one methyl group and one ethyl group

$C_2H_5NH(CH_3)$



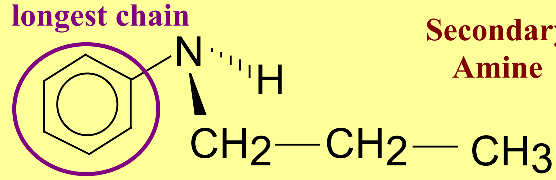
Secondary Amine

d. $C_6H_5NHC_3H_7$

Amine: (a phenyl group and a propyl group)

propylphenylamine

phenyl is the longest chain

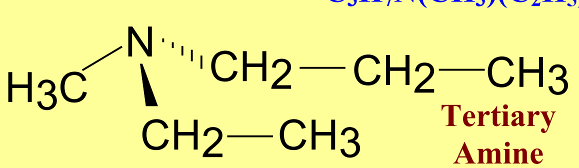


Secondary Amine

e. ethylmethylpropylamine

Amine: (ethyl methyl propyl amine) – one methyl group, one ethyl group, and one propyl group

$C_3H_7N(CH_3)(C_2H_5)$

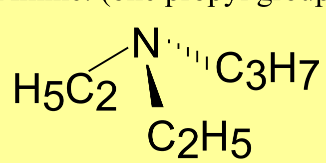


Tertiary Amine

f. $C_3H_7N(C_2H_5)(C_2H_5)$

Amine: (one propyl group, two ethyl groups)

diethylpropylamine



Tertiary Amine

Assignment
22.4 pg. 1093–1094 #51 to 53, 55 to 60, 65, 66, 67, 69

22.5: Polymers

Polymers: - are large organic molecules that are often chainlike.
- include plastics (Polyethylene, Polyvinyl chloride [PVC]), synthetic fibres (polyesters, nylon), and a wide variety of modern day materials (Teflon, synthetic rubber, polypropylene, polyurethane).

Monomers: - small units that are the building blocks of the chainlike polymers. (*Mono* means one unit)
- usually contain a set of double bond or active functional groups on either end of the monomer molecule.

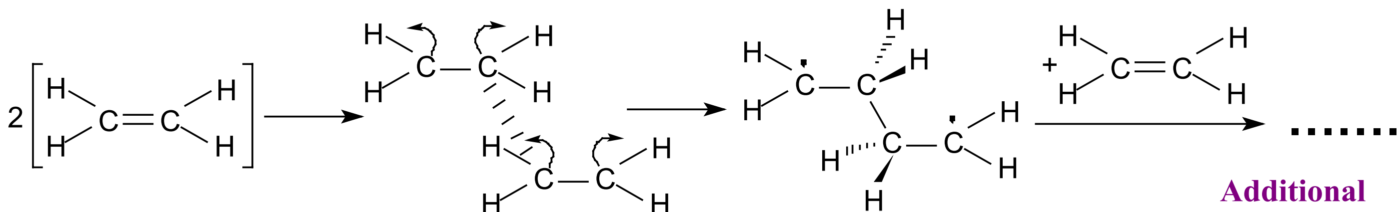
Polymerization: - molecules react with one another much like train carts hooking up to form a long train.

Dimers: - the resulting molecule when two monomer molecules combined (*Di* means two units) which can undergo further polymerization with other monomers.
- dimer is usually a **free radical** (a molecule with unpaired electron(s)), which allows it to "hook" up more monomer for further polymerization.

Addition Polymerization: - polymerization process involving the addition of monomers across their double bonds.

Condensation Polymerization: - polymerization process involving the esterification of monomers across their carboxylic acid functional group with the alcohol function group.

Example: The Polymerization of **Ethene** into ***Polyethylene***. **(Addition Polymerization)**

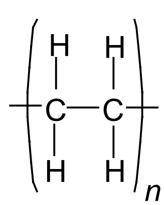


2 monomers start the polymerization | **Double bonds open up** | **Dimer results (with two free radical sites)** | **Additional polymerizations**

(Check out animation at http://chemistry.boisestate.edu/rbanks/organic/polymerization.gif)

Condensed Notation for Polymerization of Ethene into Polyethylene:

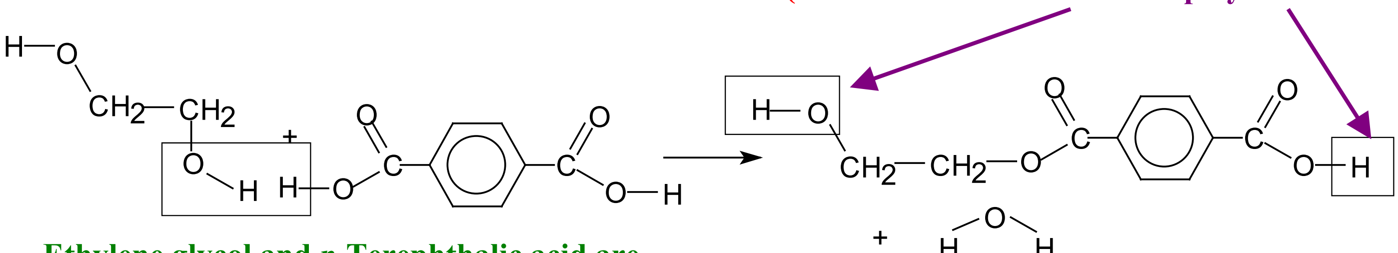
***n* represents many monomer molecules**

$n\ CH_2 = CH_2 \rightarrow$ 

***n* represents many units of chained monomers**

Example: The Polymerization of **Ethylene glycol** and ***p*-Terephthalic acid** into ***Polyester***. **(Condensation Polymerization)**

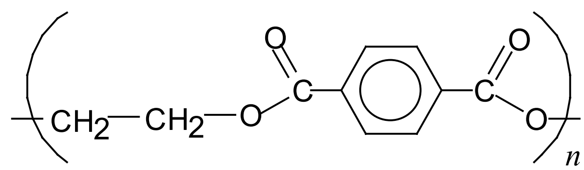
Dimer results (with two sites for additional polymerizations)



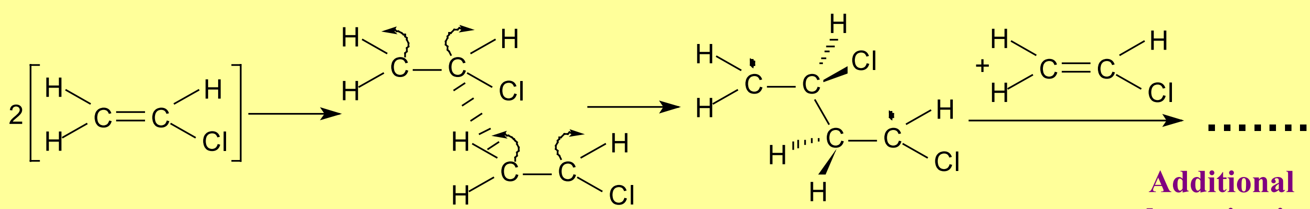
Ethylene glycol and *p*-Terephthalic acid are the monomers of the polymerization

Condensation of Water

n CH$_2$(OH)CH$_2$OH + n p- C$_6$H$_4$(COOH)$_2$ → n H$_2$O +



Example 1: Describe the polymerization of **Chloroethene (Vinyl Chloride)** into ***Polyvinyl chloride (PVC)***.



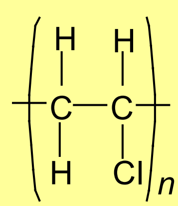
2 monomers start the polymerization

Double bonds open up

Dimer results (with two free radical sites)

Additional polymerizations

n CH$_2$ = CHCl →



Assignment

22.5 pg. 1096 #71, 72 and 75