UNIT 5: ORGANIC CHEMISTRY

Chapter 25: Hydrocarbon Compounds

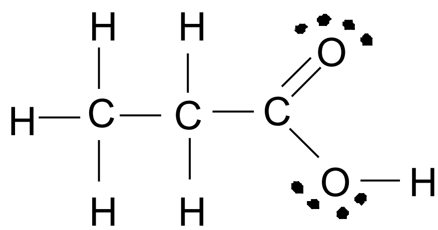
25.1: Hydrocarbons

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).

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.

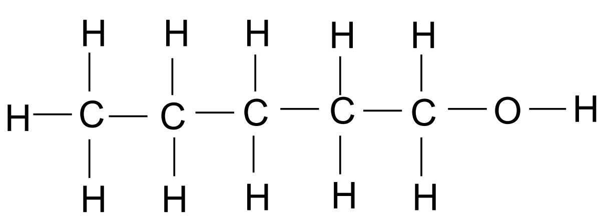
Example: C_2H_5COOH (Propanoic Acid)



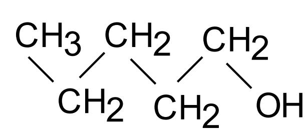
Note that there are 4 bonds around each carbon atom.

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

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



Complete Structural Formula



or

$CH_3 –CH_2 – CH_2 – CH_2 – OH$

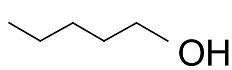
or

$CH_3CH_2CH_2CH_2CH_2OH$

or

$CH_3(CH_2)_4OH$

(Condensed Structural Formulas)



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~

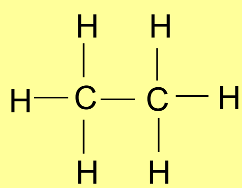
Alkane: - a group of hydrocarbons that has a molecular formula C_nH_{2n+2}.
- nomenclature of alkane involves the use of the suffix *~ane* (like in Alk **~ane**).

Straight Chained Hydrocarbons: - also called **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.

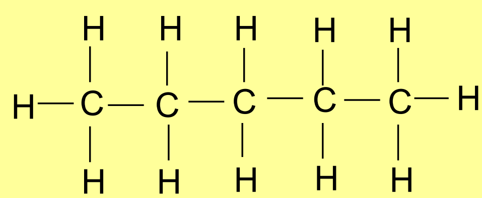
a. C_2H_6

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



b. C_5H_{12}

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



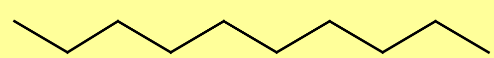
c. Octane

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

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
or $CH_3(CH_2)_6CH_3$

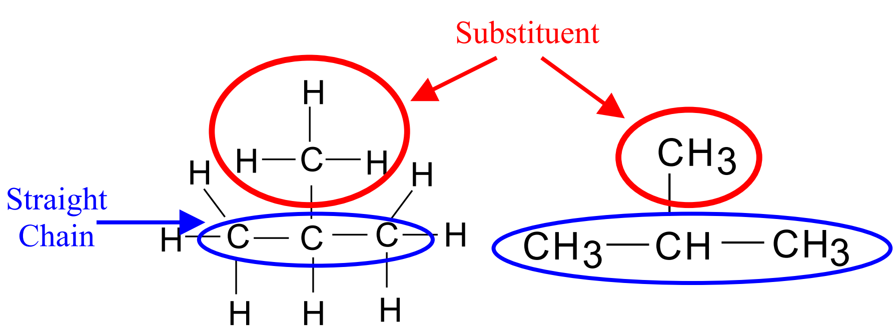
d. Decane

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



Branched Hydrocarbons: - hydrocarbons that consist of a main chain along with substituent groups

Example:



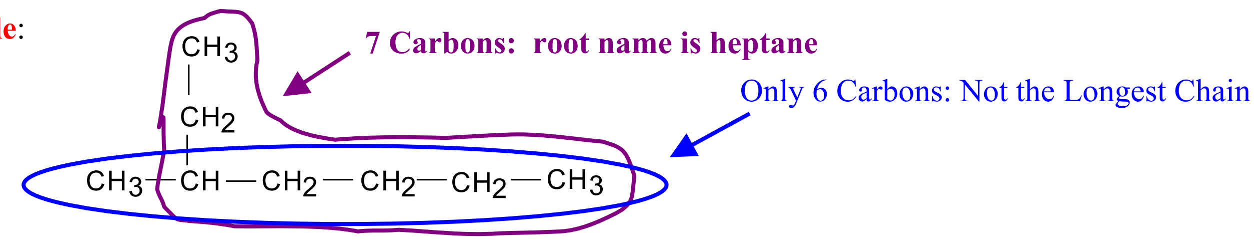
Branched (the branched group is called a substituent)

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

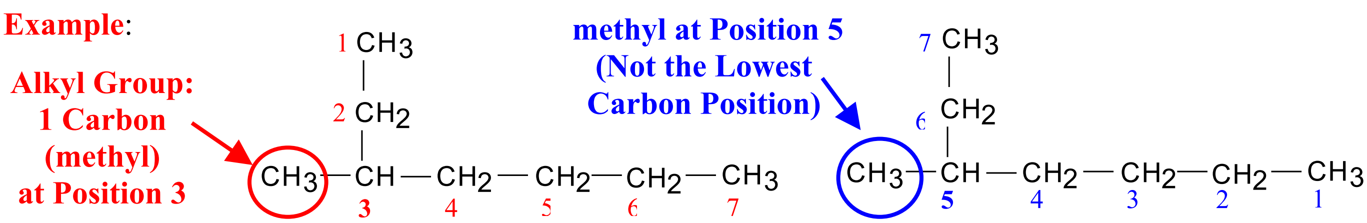
1. Identify the number of carbons in the longest chain. (It is not always the straight one. It can be bent).

Example:



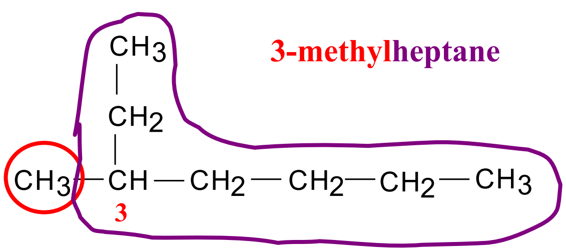
2. Number the carbons of the longest chain with the first alkyl group at the lowest carbon position possible.

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:

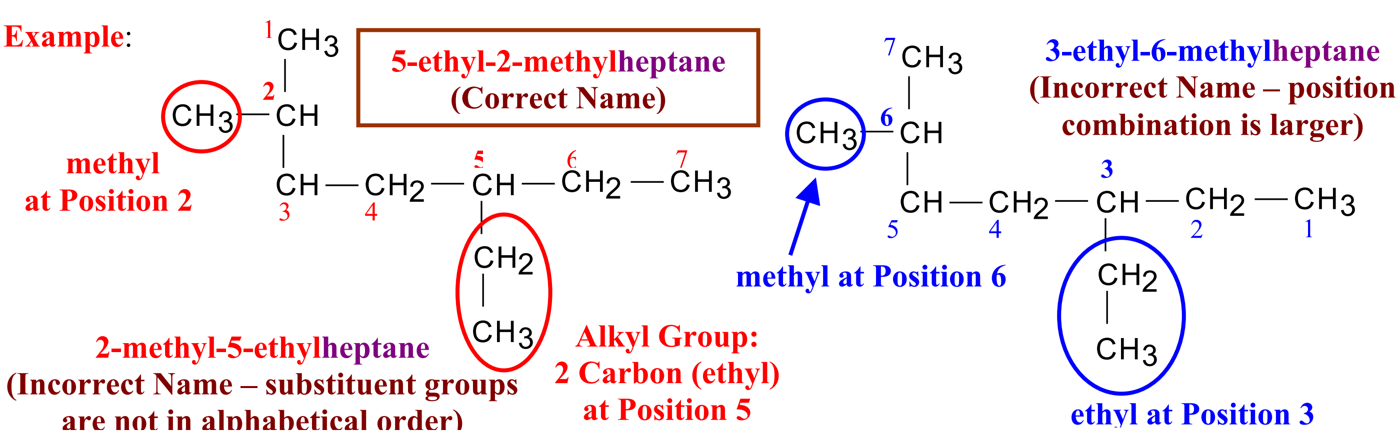


Hyphen should be added between number and alphabet.

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

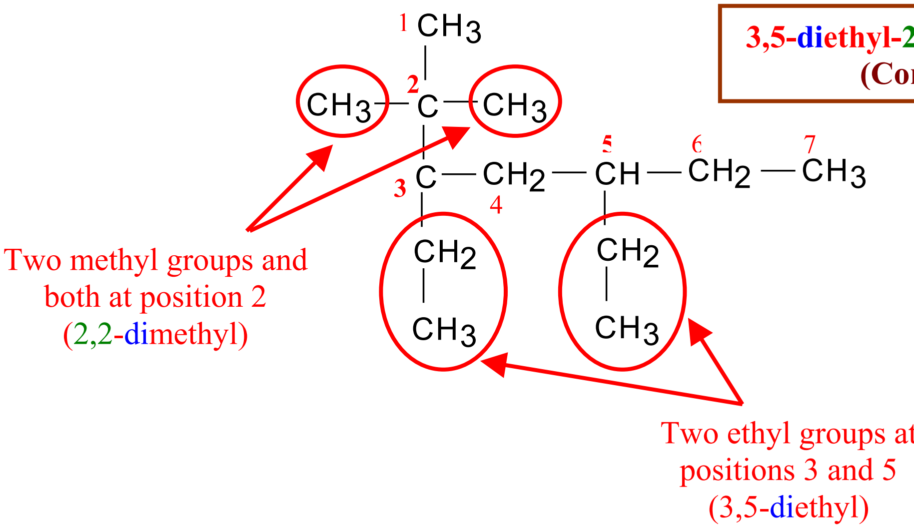
4. If there are more than one alkyl groups, and they are at the different carbon positions, the alkyl groups shall be name by their positions but their appearance in the final name has to follow alphabetical order.

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)

Properties of Alkanes

1. **All Alkanes are Non-Polar. The only intermolecular bonds they have are London Dispersion Forces.**
2. **The more carbon the alkane has, the higher the boiling point.**
3. **The smaller alkanes tend to have low melting and boiling points. They tend to be gas and liquid at room temperature (methane to butane are gases; pentane to decane are liquids).**
4. **Alkanes do NOT Dissolve in Water.**

Assignment
25.1 pg. 747 #1, 2; pg. 749 #3; pg. 750 #4, 5; pg. 751 #6 to 8, 10

25.2: Unsaturated Hydrocarbons

Saturated Hydrocarbons: - hydrocarbons that consist of **all single bonds only**.

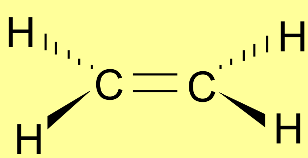
Unsaturated Bonds: - hydrocarbons that contain **double or triple bond(s)**.

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}.**

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

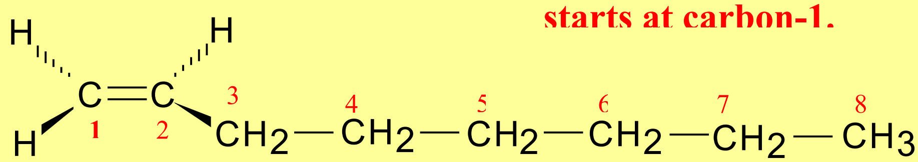
a. C_2H_4

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



b. 1-octene

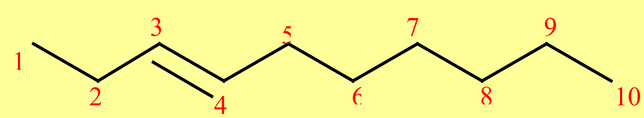
Alkene: $C_8H_{2(8)}$ **C_8H_{18}** **The double bond starts at carbon-1.**

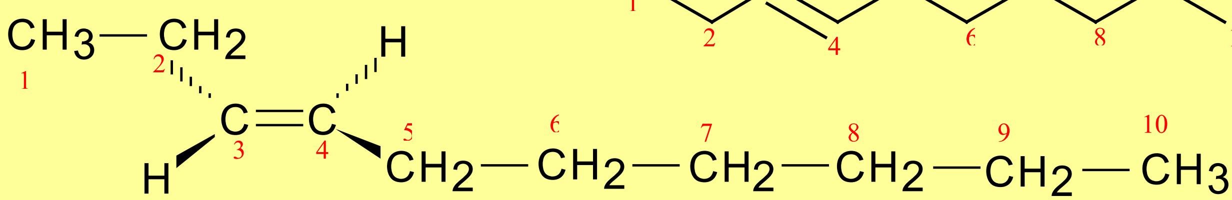


CH_2=$CHCH_2CH_2CH_2CH_2CH_2CH_3$
or $CH_2CH(CH_2)_5CH_3$

c. 3-decene

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



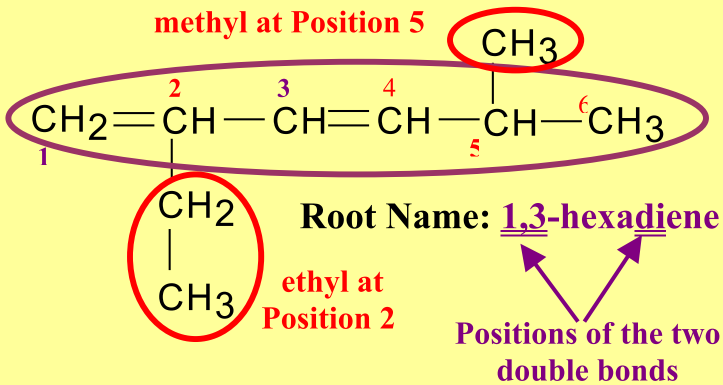


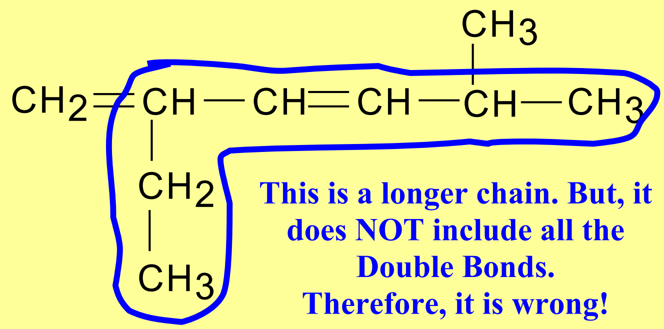
The double bond starts at carbon-3.

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)

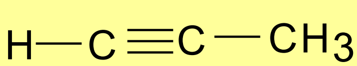
Alkynes: - hydrocarbons that contain a C ≡ C (triple bond)

- 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}.**

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

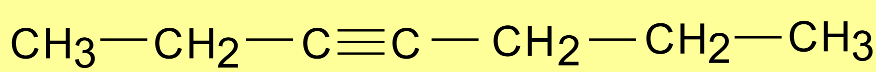
a. C_3H_4

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



b. 3-heptyne

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



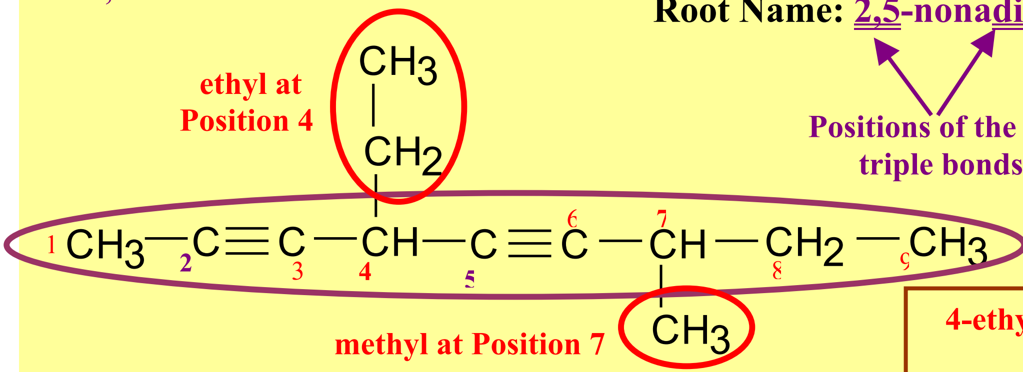
$CH_3CH_2CCCH_2CH_2CH_3$
or $CH_3CH_2CC(CH_2)_2CH_3$

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

First, we draw the structural formula.

Root Name: 2,5-nonadiyne

Positions of the two triple bonds



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

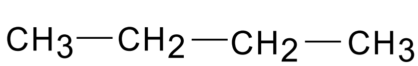
Properties of Alkenes and Alkynes

1. **Most Alkenes and Alkynes are Non-Polar. They only have London Dispersion Forces.**
2. **Their boiling points are comparable to alkanes. The double bonds and triple bonds do NOT have any effect on their physical properties.**
3. **They do give off more heat (more exothermic) when burned (combusted) compare to alkanes. This is because there are more energy stored in the double and triple bonds. When this energy is released during a chemical reaction, more heat is given off. Combustion is a chemical property.**
4. **Because of the non-polar nature of alkenes and alkynes, they do NOT Dissolve in Water.**

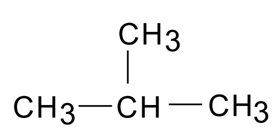
25.3: Isomerism

Structural Isomers: - hydrocarbons with the same molecular formula that can have other structural formulas.
- all have very different chemical and physical properties.

Example: C_4H_{10} has two structural formulas.

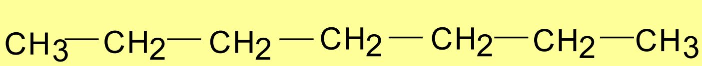


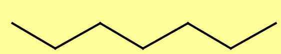
butane (bp –0.5°C)



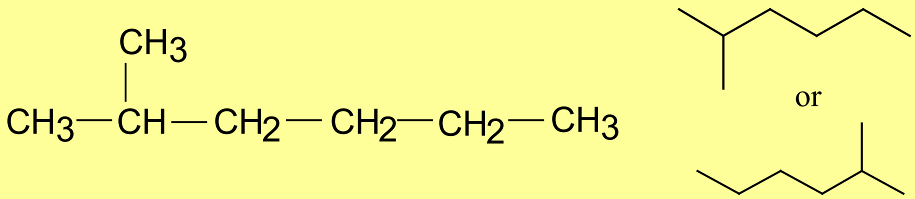
2-methylpropane or methylpropane (bp –10.2°C)

Example 1: Provide the names and structural formulas for all the isomers of heptane.
(Hint: there are 9 isomers)

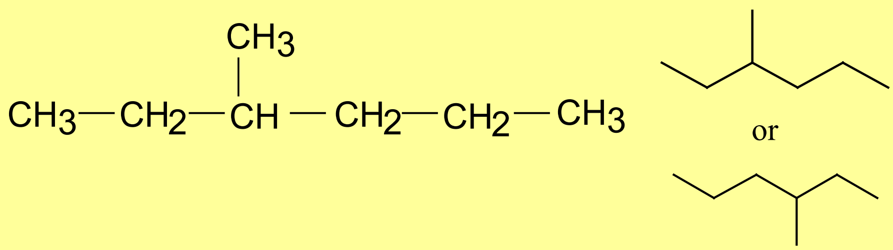




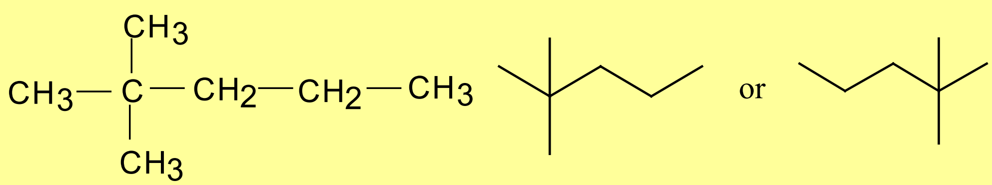
heptane
$CH_3(CH_2)_5CH_3$



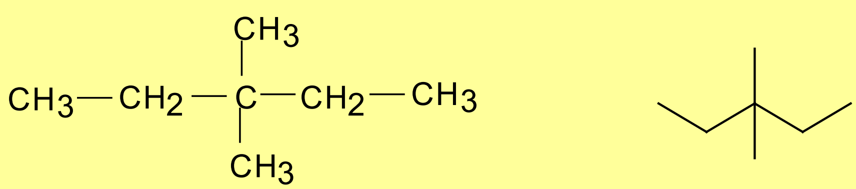
2-methylhexane
$CH_3CHCH_3(CH_2)_3CH_3$



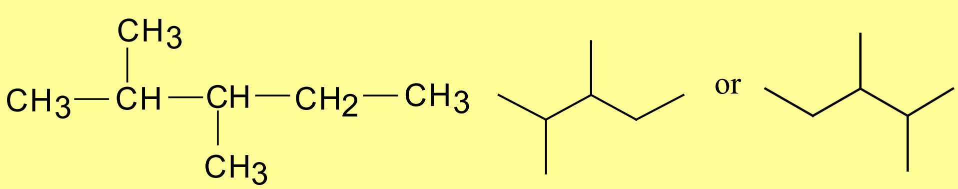
3-methylhexane
$CH_3CH_2CHCH_3(CH_2)_2CH_3$



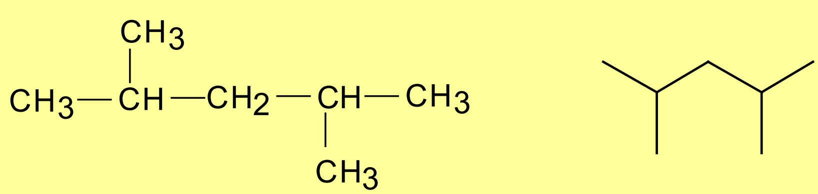
2,2-dimethylpentane
$CH_3C(CH_3)_2(CH_2)_2CH_3$



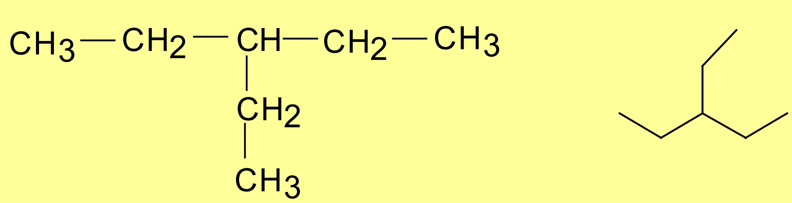
3,3-dimethylpentane
$CH_3CH_2C(CH_3)_2CH_2CH_3$



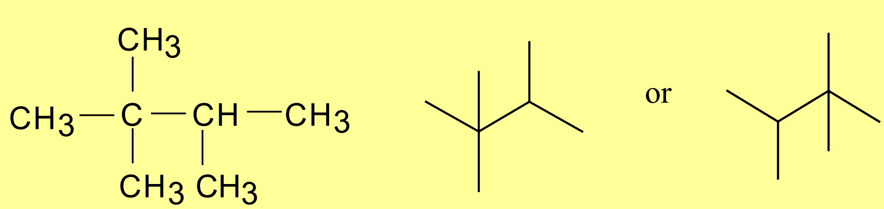
2,3-dimethylpentane
$CH_3CHCH_3CHCH_3CH_2CH_3$



2,4-dimethylpentane
$CH_3CHCH_3CH_2CHCH_3CH_3$



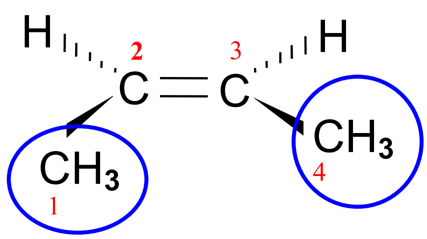
3-ethylpentane
$CH_3CH_2CH(C_2H_5)CH_2CH_3$



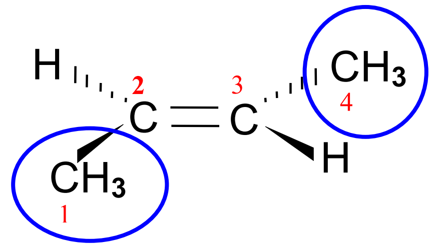
2,2,3-trimethylbutane
$CH_3C(CH_3)_2CHCH_3CH_3$

Geometrical isomers: - hydrocarbons or which differ in the positions of atoms (or groups) relative to a reference plane. Also refer to as ***cis-trans* isomers**.
- in the ***cis*-isomer** the atoms are **on the same side**.
- in the ***trans*-isomer** they **are on opposite sides**.
- all have different chemical and physical properties.

Examples:



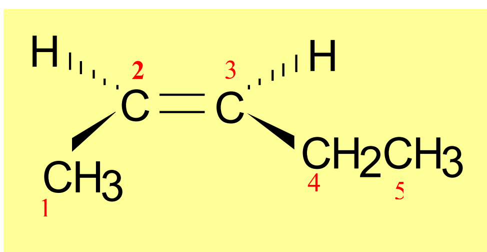
***cis*-2-butene (bp 3.7°C)**



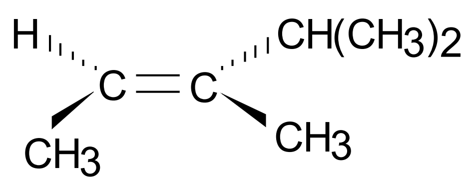
***trans*-2-butene (bp 0.9°C)**

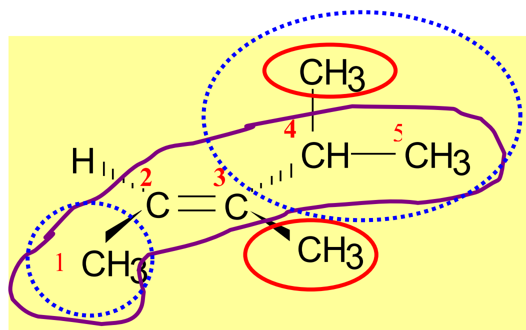
Example 2: Draw the structural formula and state the name for the following organic compounds.

a. *cis*-2-pentene



b.





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

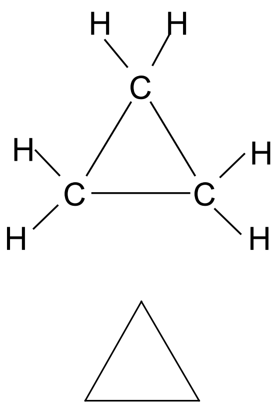
(*trans* are on the main chain)

Assignment
25.2 pg. 753 #11 to 13
25.3 pg. 757 #16, 18

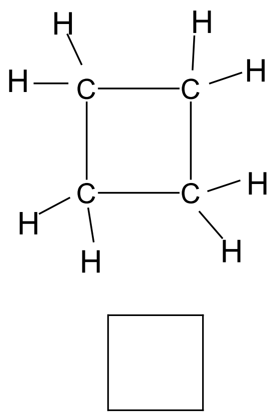
25.4: Hydrocarbon Rings

Cyclic Hydrocarbons: - hydrocarbons where carbons form a ring of some geometrical shape.

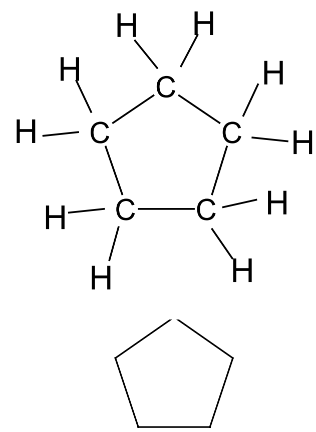
Cyclic Alkane: - where the ends of an alkane chain are connected to each other in a cyclical shape.
- the molecular formula has a form of C_nH_{2n}.
- naming contains the prefix ***cyclo~*** before the root name.
- substituents are named the same way as branched alkanes (pick any corner as carbon 1).



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

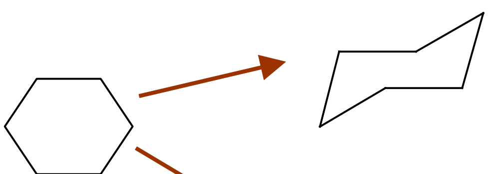


Cyclobutane (C_4H_8)
(bond angle 90°)
(still tight – unstable)

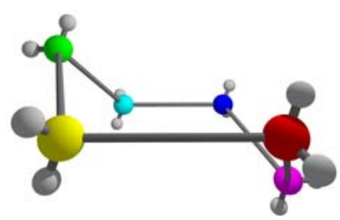


Cyclopentane (C_5H_{10})
(bond angle 108° - close to tetrahedral - stable)

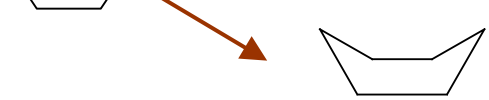
3-D (use molecular model to demonstrate)



"Chair" Conformation



"Boat" Conformation

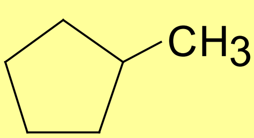


Cyclohexane (C_6H_{12})
(bond angle 109.5° - same as tetrahedral)
(very stable)

The Chair formation is slightly more stable

Example 1: Provide a structural formula for these organic compounds below.

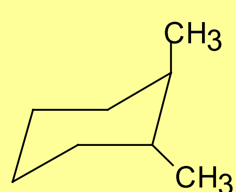
a. methylcyclopentane



$CHCH_3(CH_2)_4$

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

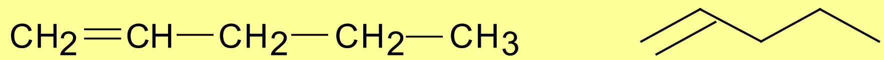
b. 1,2-dimethylcyclohexane



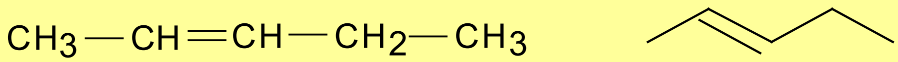
$CHCH_3CHCH_3(CH_2)_4$

Example 2: Provide the names and structural formulas for all the isomers (non-cyclic and cyclic) of C_5H_{10}.

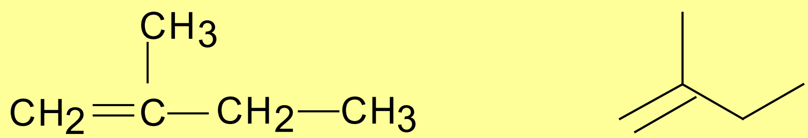
There are 9 isomers to C_5H_{10}.



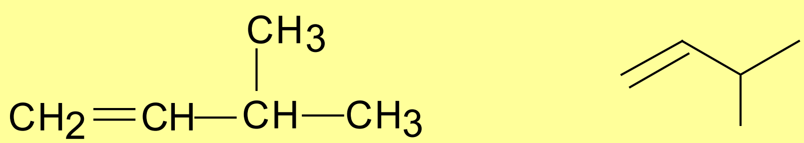
1-pentene
$CH_2CHCH_2CH_2CH_3$



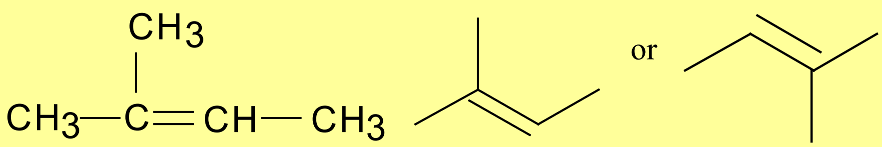
2-pentene
$CH_3CHCHCH_2CH_3$



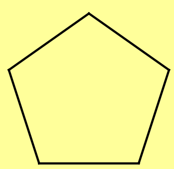
2-methyl-1-butene
$CH_2C(CH_3)CH_2CH_3$



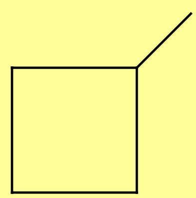
3-methyl-1-butene
$CH_2CHCH(CH_3)CH_3$



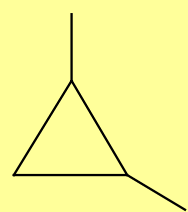
2-methyl-2-butene
$CH_3C(CH_3)CHCH_3$



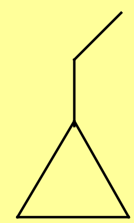
cyclopentane
$(CH_2)_5$



methylcyclobutane
$CH(CH_3)CH_2CH_2CH_2$



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

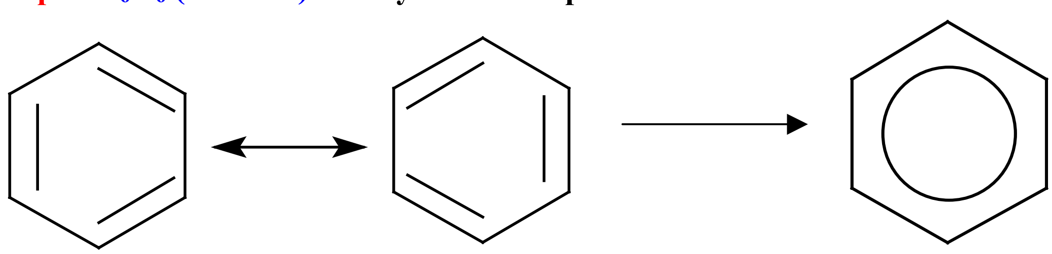


ethylcycloproane
$CH(C_2H_5)CH_2CH_2$

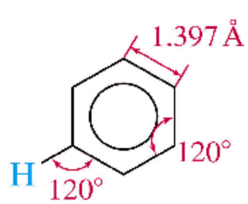
Aliphatic Hydrocarbons: - alkanes, alkenes, alkynes, and cyclic alkanes.

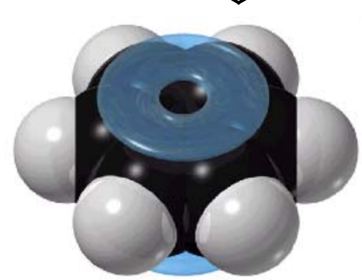
Aromatic Hydrocarbons: - cyclic hydrocarbons characterize by alternating double bonds in a ring.

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



Resonance structures for benzene



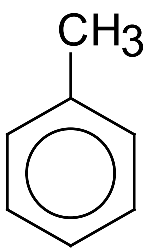


Naming Aromatic Compounds:

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.

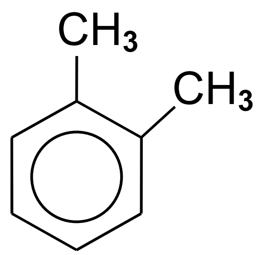
Example 6: Name the following aromatic compounds

a.



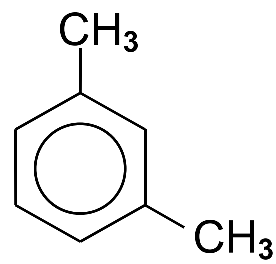
methylbenzene
Common name: Toluene

b.



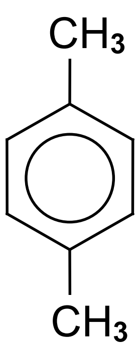
1,2-dimethylbenzene
(*ortho*-dimethylbenzene)
Common name: (*o*-xylene)

c.



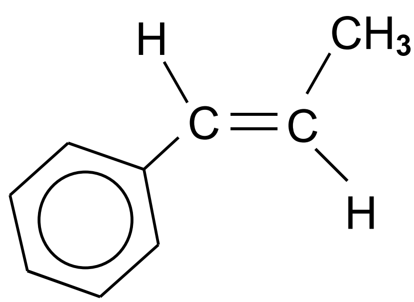
1,3-dimethylbenzene
(*meta*-dimethylbenzene)
Common name: (*m*-xylene)

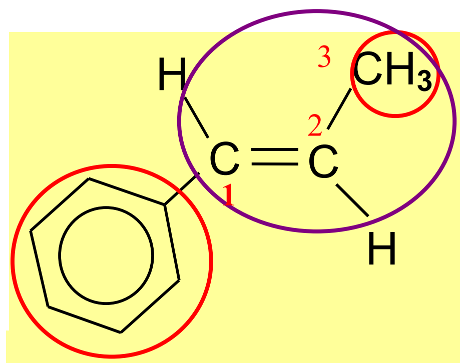
d.



1,4-dimethylbenzene
(*para*-dimethylbenzene)
Common name: (*p*-xylene)

e.





***trans*-1-phenylpropene**

25.5: Hydrocarbons from Earth

Fossil Fuel: - hydrocarbon fuels that came from fossils of decayed organisms.

1. **Natural Gas**: - fossil fuel that consists of mainly small alkanes (80% methane, 10% ethane, 4% propane, 2% butane, 4% nitrogen).
   - usually burns efficiently (complete combustion).

   Complete Combustion: - where the products of combustion are carbon dioxide and water vapour only.
   -characterized by a blue flame.

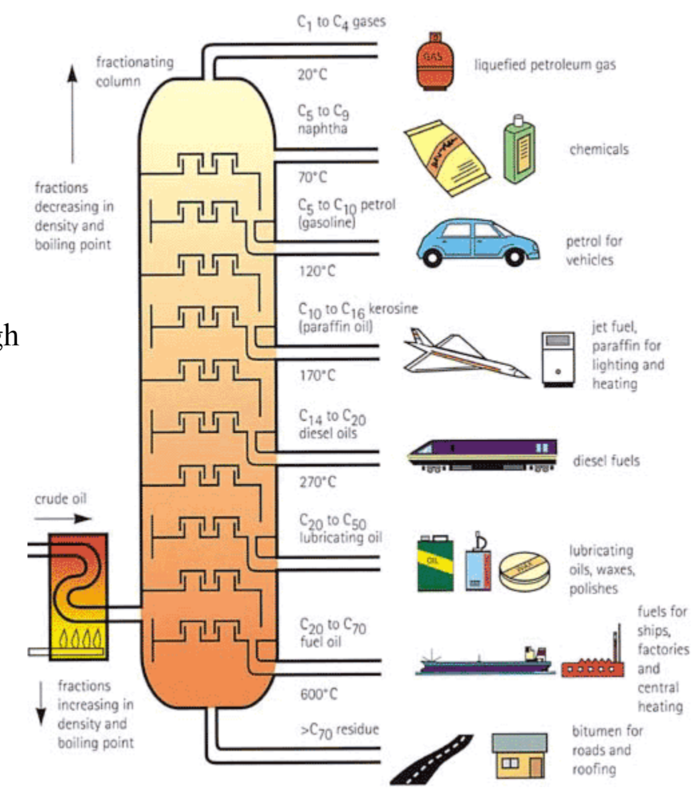
   Example: Propane burns completely. $C_3H_{8\,(g)} + 5\,O_{2\,(g)} \rightarrow 3\,CO_{2\,(g)} + 4\,H_2O_{\,(g)}$

   Incomplete Combustion: - where the main product of combustion is carbon monoxide, along with carbon dioxide and water vapour.
   - happens when carbon particles started to form during combustion and deposited as soot as they cooled, or when there is insufficient oxygen.
   - characterized by a yellow flame.

   Example: Incomplete combustion of Propane. $C_3H_{8\,(g)} + 4\,O_{2\,(g)} \rightarrow 2\,CO_{\,(g)} + CO_{2\,(g)} + 4\,H_2O_{\,(g)}$

2. **Petroleum (Crude Oil)**: - fossil fuels that consist mainly of heavier alkanes along with small amounts of aromatic hydrocarbons, and organic compounds that contain sulfur, oxygen and nitrogen.
   - gasoline is composed of 40% of crude oil, whereas natural gas is composed of only 10%.

   Fractional Distillation: - a method of heating crude oil in a tall column to separate its different components by their different boiling points.
   - lighter alkanes in the natural gas will rise up to the top of the column because of their low boiling points.
   - the heavier, fuel and lubricating oils will boil off at the bottom of the column due to their high boiling points.



Petroleum Refining: - a process to isolate different types of fuel from crude oil using fractional distillation or cracking.

Cracking: - a chemical process whereby bigger alkanes are broken up into smaller ones using a catalyst and heat.
- since gasoline and natural gas only consists of 50% of crude oil, cracking is necessary to convert heavier fuel to more common fuel used in today's world.

Example: The Cracking of Hexadecane. $C_{16}H_{34} + 2\ H_2 \xrightarrow{\text{catalyst and heat}} C_8H_{18} + C_8H_{18}$

Reforming: - a chemical process where smaller alkanes are combined together and hydrogen is removed to form heavier alkanes or changed unbranched alkanes into branched alkanes.
- branched alkanes are easier to burn and has a higher octane value in gasoline. (isooctane or 2,2,4-trimethylpentane has the best octane rating – assigned as 100)

3. **Coal**: - a carbon-based mineral consists of very dense hydrocarbon ring compounds with high molar masses.
- leaves a lot of soot and burns incompletely.
- usually contains 7% sulfur and when combusted with oxygen gives off SO_2 and SO_3, which is the main source of air pollution and acid rain.

Assignment

25.4 pg. 761 #20 to 23
25.5 pg. 765 #24 to 27
Chapter 25 Review: pg. 768–769 #28 to 45, 49 to 50, 53, 55; pg. 771 #68, 69

Chapter 26: Functional Groups and Organic Reactions

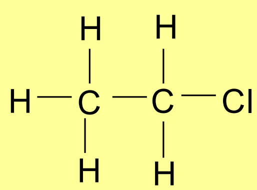
26.1: Introduction to Functional Groups

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

Halocarbons (RX): - hydrocarbons that contain **halogen substituent(s) – (also known as alkyl halides)**.
- **R symbolizes the rest of the carbon chain.**
- uses the same rules as naming branched alkanes.
- F (fluoro), Cl (chloro), Br (bromo), I (iodo).

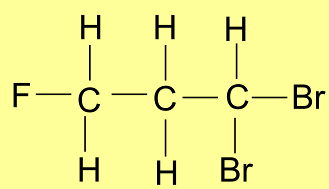
Example 1: Name the following halogen derivates or give the molecular formula. Provide a structural formula for these compounds.

a. CH_3CH_2Cl



chloroethane

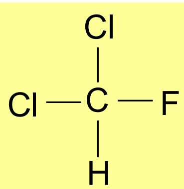
b. $CH_2FCH_2CHBr_2$



1,1-dibromo-3-fluoropropane

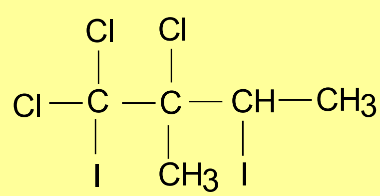
3,3-dibromo-1-fluoropropane (Incorrect Naming – number sequence could be better)

c. dichlorofluoromethane



$CHCl_2F$

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



$CCl_2ICCH_3ClCHICH_3$

Properties of Halocarbons:

1. **Depending on the number of alkyl halides, some halocarbons can be polar; some are non-polar.**
2. **The Polar Halocarbons are soluble in water while the Non-polar ones do not.**
3. **In general, the more alkyl halides groups a halocarbon have, the higher its boiling point. This is because halogens are heavier atoms that are governed by van der Waals Forces (London Dispersion and sometimes Dipole-Dipole Interactions).**

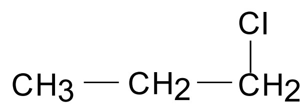
Halogen Substitution Reaction: - a reaction where a halogen element (X_2) is reacting with alkane (R–H) to form halocarbon (RX) and a hydrogen halide (HX) under the presence of light energy or a catalyst.

Alkane (R–H) + Halogen (X_2) $\xrightarrow{h\nu}$ Halogen Derivate (RX) + HX **$h\nu$ = 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

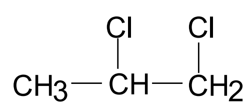
Halogenation Addition: - when a halogen element (X_2) or hydrogen halide (HX) is added across a double bond or triple bond to form halocarbons.

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

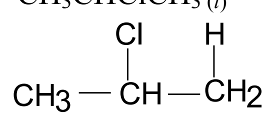
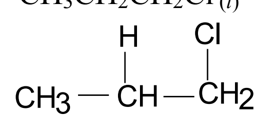
$C_3H_{6\,(g)}$ + $Cl_{2\,(g)}$ → $CH_3CHClCH_2Cl_{(l)}$

$CH_3 - CH = CH_2$ + Cl–Cl → 

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

Example: Propene + Hydrogen Chloride → 2-chloropropane + 1-chloropropane

$C_3H_{6\,(g)}$ + $HCl_{(g)}$ → $CH_3CHClCH_{3\,(l)}$ + $CH_3CH_2CH_2Cl_{(l)}$

$CH_3 - CH = CH_2$ + H–Cl →  

Assignment

26.1 pg. 777 #1 to 4, 6; pg. 784 #12a, b.

26.2: Alcohols and Ethers

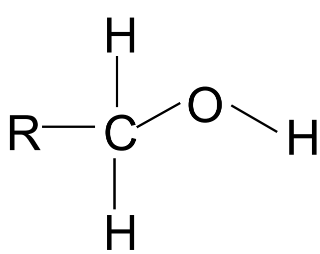
Alcohols: - organic compounds containing a **hydroxyl functional group**, (***R*-OH**), substituted for a hydrogen atom. **(*R* – represent the rest of the carbon main chain.)**

- 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).***

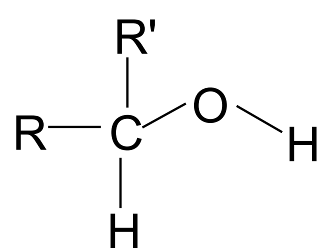
a. **Primary Alcohol**: - **–OH group attaches to a carbon with one alkyl group**.
 - can react to form functional group like **aldehydes** (will be explain later).

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).

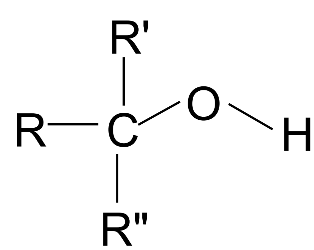
c. **Tertiary Alcohol**: - **–OH group attaches to a carbon with three alkyl groups**.
 - do not usually react to form other functional groups (**chemically stable**).



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)

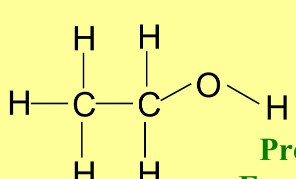


Tertiary Alcohol
(three alkyl groups R, R', and R" attached to C which attached to –OH group)

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

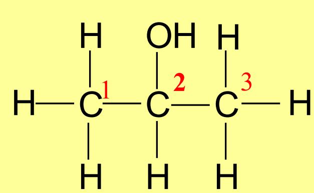


Ethanol

Primary Alcohol

Product of Fermentation

b. 2-propanol



The –OH group is at carbon-2.

Rubbing Alcohol

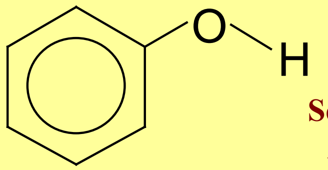
$CH_3CH(OH)CH_3$

Secondary Alcohol

c. C_6H_5OH

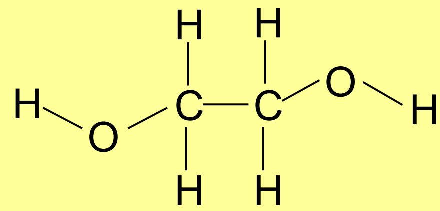
Alcohol with Benzene

Benzenol (or Phenol)



Secondary Alcohol

d. ethandiol



The –OH groups are at both carbons.

Commonly known as ethylene glycol (Automobile Antifreeze)

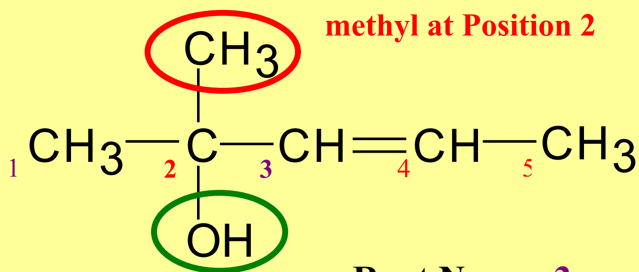
Primary Alcohol

$CH_2(OH)CH_2(OH)$

e. $CH_3C(CH_3)OHCHCHCH_3$

First, we draw the structural formula.

methyl at Position 2



hydroxyl at Position 2

Root Name: 3-penten-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

Properties of Alcohol:

1. **All Alcohols are Polar. Because of the –OH group, they all have hydrogen bonding.**
2. **Alcohols that have four carbons or less are very soluble in water (*R*-OH compares to H–OH).**
3. **Alcohols that have more than four carbons are not as soluble in water due to the long carbon chain, which is non-polar.**
4. **Most alcohols have high boiling points due to the hydrogen bonds. This is especially true for alcohol molecules that have more than one –OH group.**
5. **Primary Alcohols has the Highest Boiling Point, whereas Tertiary Alcohol has the Lowest Boiling Point. This is because primary alcohols have the –OH group at the carbon atom that is the least crowded Thus, hydrogen bonds are stronger and boiling points are higher.**

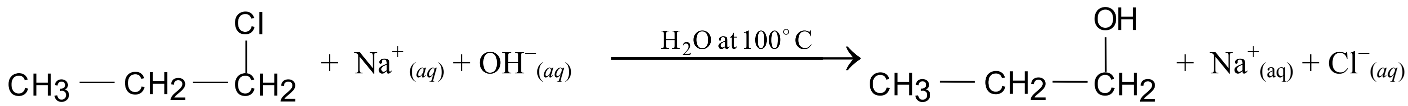
Alcohol Substitution Reaction: - a reaction where a base (AOH) is reacting with a halocarbon (R–X) to form alcohol (ROH) and an alkali halide (AX) under the aqueous condition of water at high temperature.

$$\textbf{Halocarbon (R–X) + Alkali Halide (AOH)} \xrightarrow{H_2O \text{ at } 100^\circ C} \textbf{Alcohol (ROH) + Alkali Halide AX}$$

Example:

1-chloropropane + Sodium Hydroxide $\xrightarrow{H_2O \text{ at } 100^\circ C}$ 1-propanol + Sodium Chloride

$CH_3CH_2CH_2Cl_{(l)}$ + $NaOH_{(aq)}$ $\xrightarrow{H_2O \text{ at } 100^\circ C}$ $CH_3CH_2CH_2OH_{(l)}$ + $NaCl_{(aq)}$

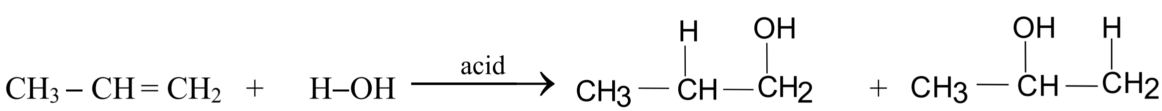


Hydration Addition: - when water (H–OH) is added across a double bond to form an alcohol under acidic condition.

$$\textbf{Alkene } (C_nH_{2n}) + \textbf{Water (H–OH)} \xrightarrow{\text{acid}} \textbf{Alcohol } (C_nH_{2n+1}OH)$$

Example: Propene + Water $\xrightarrow{\text{acid}}$ 1-propanol + 2-propanol

$C_3H_{6\,(g)}$ + $HOH_{(l)}$ $\xrightarrow{\text{acid}}$ $CH_3CH_2CH_2OH_{(l)}$ + $CH_3CH(OH)CH_{3\,(l)}$



Hydrogenation Addition: - when hydrogen is added across a double bond or triple bond alkanes with the aid of a catalyst.

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

$C_3H_{6\,(g)}$ + $H_{2\,(g)}$ $\xrightarrow{\text{catalyst}}$ $C_3H_{8\,(g)}$

$CH_2 = CH - CH_3$ + $H - H$ $\xrightarrow{\text{catalyst}}$ $CH_3 - CH_2 - CH_3$

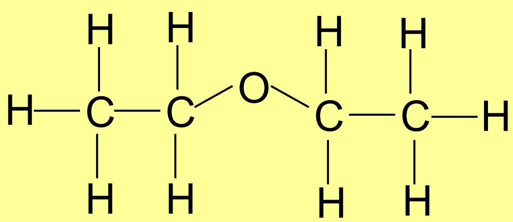
(*Note*: From Propyne to Propane Hydrogenation, it is stepwise.)

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

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

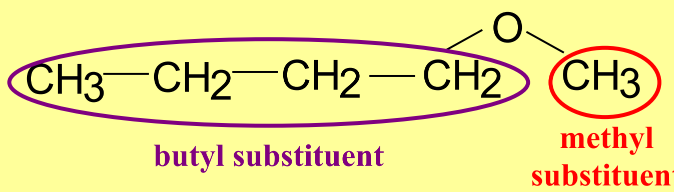
a. diethyl ether

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



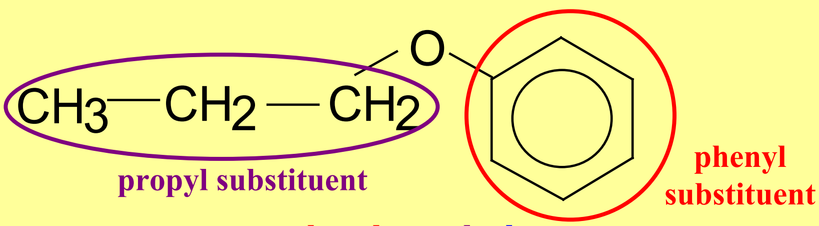
Used as anaesthetic in the past.
Now it is an industrial solvent.

b. $C_4H_9OCH_3$



butylmethyl ether

c. $C_3H_7OC_6H_5$



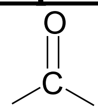
phenylpropyl ether

Properties of Ethers:

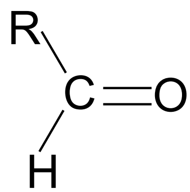
1. **Ethers are Polar. This is due to the bent shape and the two lone pairs around the oxygen atom.**
2. **Ethers have Higher Boiling Points than Alkanes with the same molar mass. However, they have Lower Boiling Points than comparable Alcohols. This is because even though ethers are polar, they do not have hydrogen bonds like alcohols do.**
3. **Ethers are very Soluble in Water.**

Assignment
26.2 pg. 784 #7 to 11, 12c; pg. 777 #5

26.3: Carbonyl Compounds

Carbonyl Group: - a  group.

1. **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.***

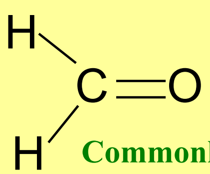


- **polar molecules** (due to oxygen's two lone pairs); **very soluble in water** (hydrogen bonding between water and carbonyl group).
- **Aromatic aldehydes are commonly used as artificial flavours.**
- naming of aldehydes starts with the prefix of the number of carbon in the longest chain including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

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

a. methanal

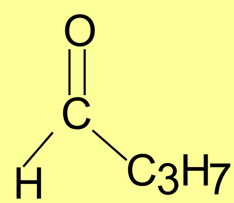
Aldehyde: Methanal (1-Carbon) **HCHO**



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

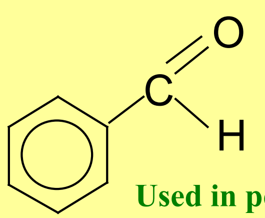
b. C_3H_7CHO

Aldehyde: 4-Carbons **Butanal**



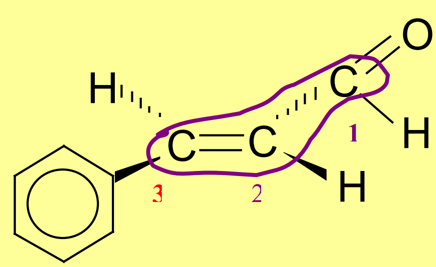
c. C_6H_5CHO

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



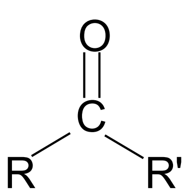
Used in peaches, cherries and almond flavours.

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



Used as cinnamon flavour.

2. **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.***



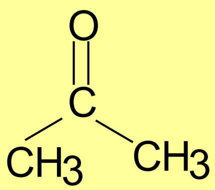
- **polar molecules** (due to oxygen's two lone pairs); **very soluble in water** (hydrogen bonding between water and carbonyl group).
- **Aromatic ketones are commonly used as artificial flavours.**
- naming of ketones starts with the prefix of the number of carbon in the longest chain including the –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 aldehyde and ketone carbonyl groups take precedent in the root naming over any substituents (alcohol, ether, alkyl, and halogen substituents).

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

a. CH_3COCH_3

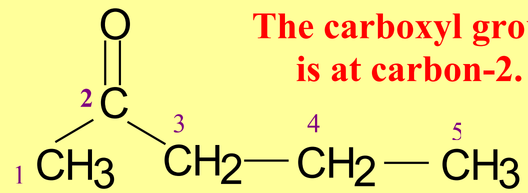
Ketone: (3-Carbons) **Propanone**



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) **$CH_3CO(CH_2)_2CH_3$**



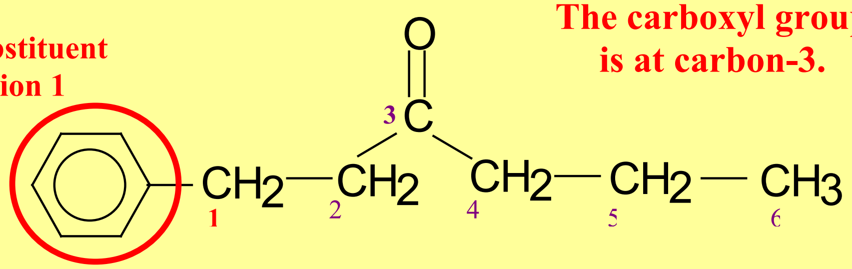
The carboxyl group is at carbon-2.

c. 1-phenyl-3-hexanone

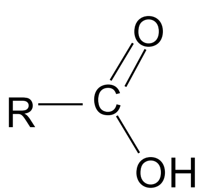
Ketone: (6-Carbons Main Chain) **$C_6H_5CH_2CO(CH_2)_2CH_3$**

phenyl substituent at Position 1

The carboxyl group is at carbon-3.



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



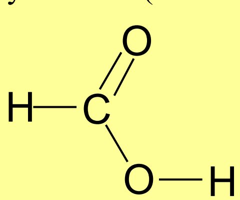
- **polar molecules** (due to oxygens' four lone pairs); **very soluble in water** (hydrogen bonding between water and carbonyl group).
- naming of carboxylic acid starts with the prefix of the number of carbon in the longest chain including the –COOH group but end with the suffix *~oic acid* (like in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

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

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

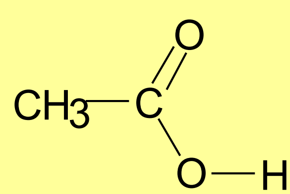
a. methanoic acid

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



b. CH_3COOH

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

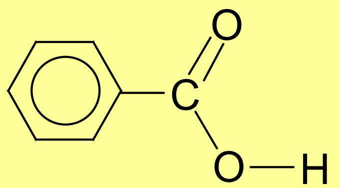


Commonly known as Acetic Acid (Vinegar)

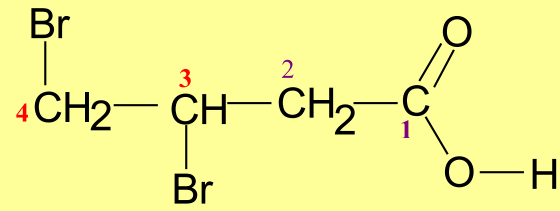
c. C_6H_5COOH

Carboxylic Acid with Benzene

Benzenoic Acid

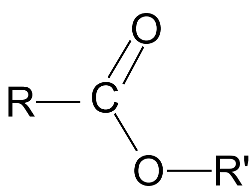


d. 3,4-dibromo-butanoic acid



$CH_2BrCHBrCH_2COOH$

4. **Ester**: - compound containing a carbonyl group **(RCOOR')**.

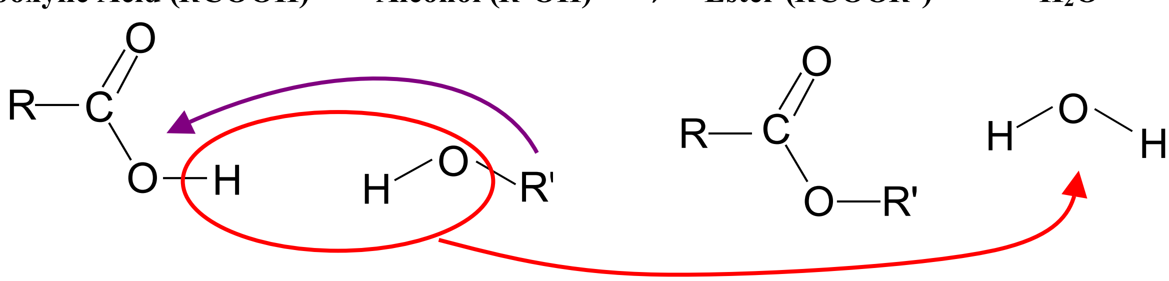


- **polar molecules** (due to oxygens' four lone pairs); **very soluble in water** (hydrogen bonding between water and carbonyl group).
- commonly use as artifical flavorings.
- **form when alcohol is reacted with carboxylic acid.**
- naming of ester starts with the **alkyl group –R'**, then the prefix of the number of carbon in the longest chain 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).

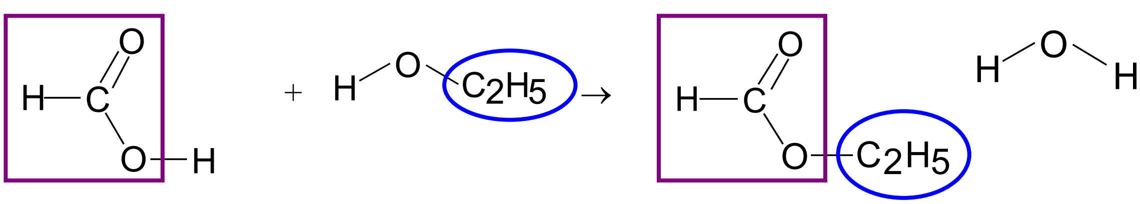
Esterification (Ester Condensation): - **when alcohol reacts with carboxylic acid to form ester and water (condensation because water is produced)**.
- the alcohol chain becomes the alkyl group of the ester (R').
- the carboxylic acid chain becomes main carbon chain for the ester functional group.

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



Example: **Methanoic Acid** + **Ethanol** → **ethyl methanoate** + water

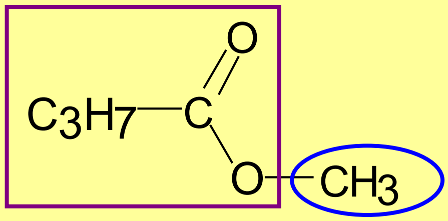
$HCOOH_{(l)}$ + $C_2H_5OH_{(l)}$ → $HCOOC_2H_5\ _{(l)}$ + $H_2O_{(l)}$



Used as Rum flavouring

Example 4: 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.

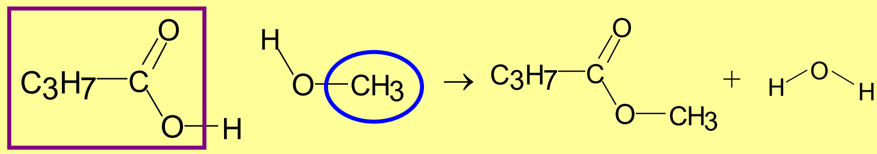
a. methyl butanoate



butanoate main chain including carboxyl group | **methyl substituent at single bond O**

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

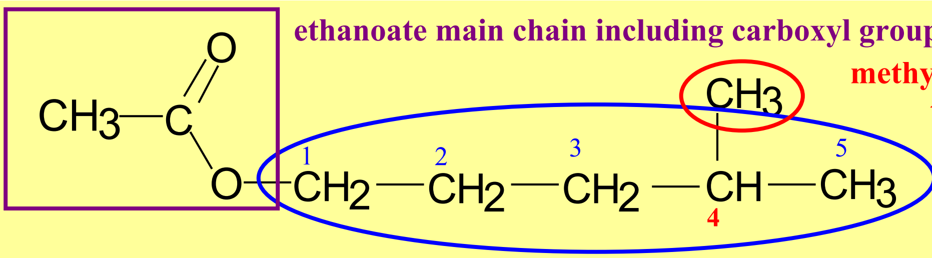
$C_3H_7COOH_{(l)}$ + $CH_3OH_{(l)}$ → $C_3H_7COOCH_{3\,(l)}$ + $H_2O_{(l)}$



Used as Apple flavouring

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

ethanoate main chain including carboxyl group

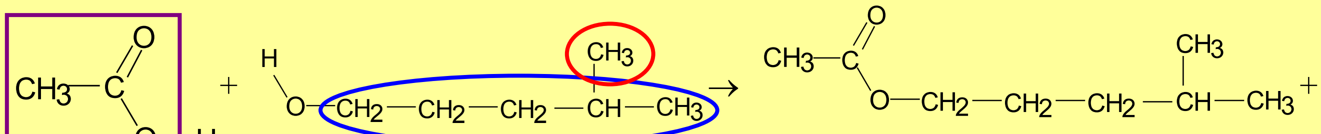


methyl substituent at Position 4 of the pentyl substitutent

4-methylpentyl substituent at single bond O

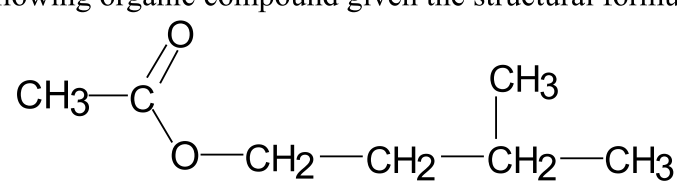
Ethanoic Acid + **4-methyl-1-pentanol** → **4-methylpentylethanoate** + water

$CH_3COOH_{(l)}$ + $CH_3CH(CH_3)(CH_2)_3OH_{(l)}$ → $CH_3COO(CH_2)_3CH(CH_3)_{2\,(l)}$ + $H_2O_{(l)}$

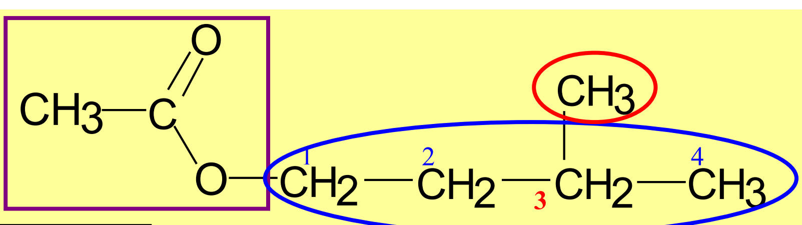


Used as Banana flavouring

Example 5: Name the following organic compound given the structural formula below.



ethanoate main chain including carboxyl group



3-methylbutylethanoate

3-methylbutyl substituent at single bond O

Used as Pear flavouring

Elimination Reactions: - reactions that turn saturated hydrocarbons into unsaturated ones using oxidizing agent like $KMnO_4$ or $K_2Cr_2O_7$ in an acidic environment.

Dehydrogenation: - an elimination reaction where alkanes is turned into alkenes or alkynes by removing hydrogen.

$$\textbf{Alkane} \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} \textbf{Alkene + Hydrogen}$$

$$\textbf{Alkene} \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} \textbf{Alkyne + Hydrogen}$$

Example:

$$\text{Propane} \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} \text{Propene} + \text{Hydrogen}$$

$$C_3H_8 \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} C_3H_6 + H_{2\,(g)}$$

$$CH_3 - CH_2 - CH_3 \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} CH_2 = CH - CH_3 + H - H$$

Example:

$$\text{Propene} \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} \text{Propyne} + \text{Hydrogen}$$

$$C_3H_6 \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} C_3H_4 + H_{2\,(g)}$$

$$CH_2 = CH - CH_3 \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} CH \equiv C - CH_3 + H - H$$

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

Dehydrations: - elimination reactions where primary alcohols are turned into aldehydes or secondary alcohols are converted to ketones by removing hydrogen.

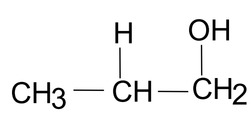
$$\textbf{Primary Alcohol} \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} \textbf{Aldehyde + Hydrogen}$$

$$\textbf{Secondary Alcohol} \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} \textbf{Ketone + Hydrogen}$$

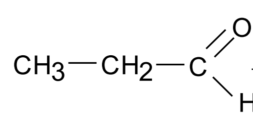
Example:

$$\text{1-Propanol} \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} \text{Propanal} + \text{Hydrogen}$$

$$CH_3CH_2CH_2OH \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} CH_3CH_2CHO + H_{2\,(g)}$$



$$\xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4}$$

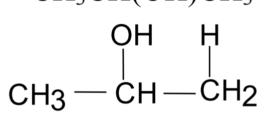


$+ \quad H - H$

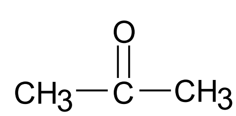
Example:

$$\text{2-Propanol} \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} \text{Propanone} + \text{Hydrogen}$$

$$CH_3CH(OH)CH_3 \xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4} CH_3COCH_3 + H_{2\,(g)}$$



$$\xrightarrow{KMnO_4 \text{ or } K_2Cr_2O_7 \text{ and } H_2SO_4}$$



$+ \quad H - H$

Assignment
26.3 pg. 794 #13 to 16

26.4: Polymerization

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.

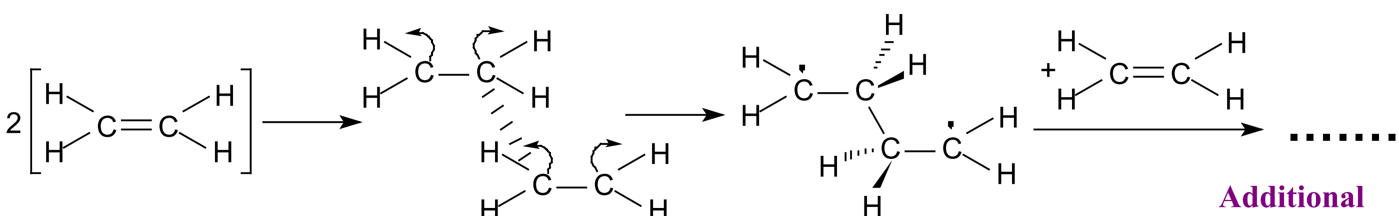
Polymerization: - molecules react with one another much like train carts hooking up to form a long train.

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)**

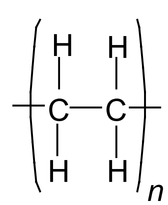


2 monomers start the polymerization **Double bonds open up** **Dimer results (with two free radical sites)** **Additional polymerizations**

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

Condensed Notation for Polymerization of Ethene into Polyethylene:

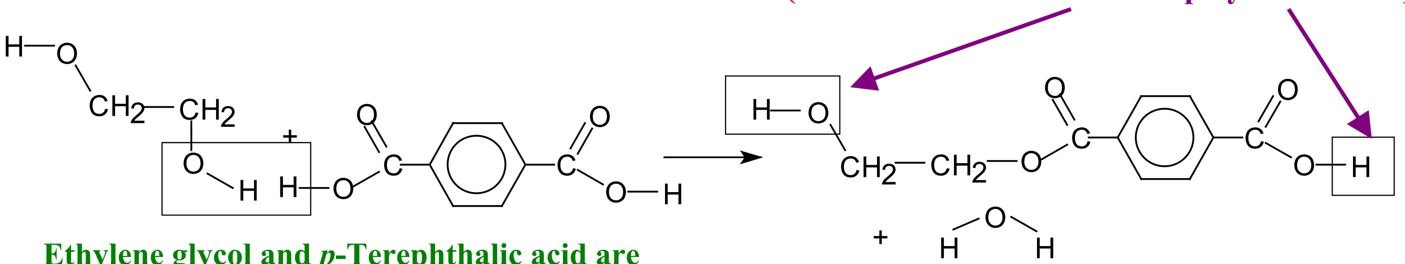
***n* represents many monomer molecules**

$n\ CH_2=CH_2 \rightarrow$ 

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

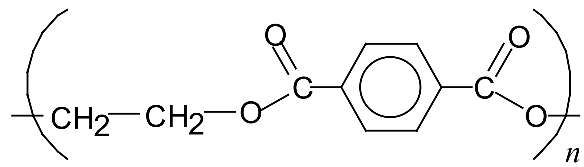
Example: The Polymerization of **Ethylene glycol** and ***p*-Terephthalic acid** into ***Polyester***. **(Condensation Polymerization)**

Dimer results (with two sites for additional polymerizations)

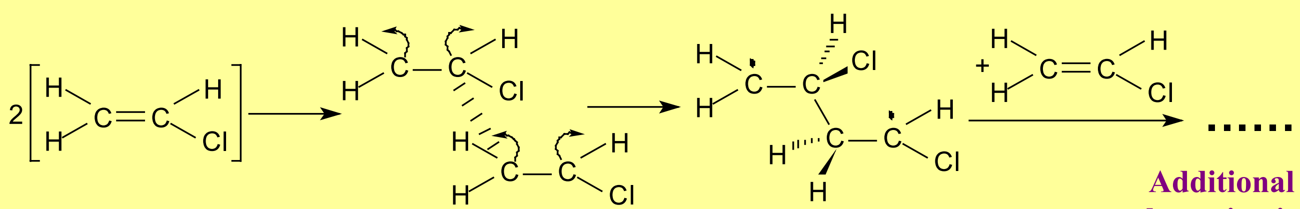


Ethylene glycol and *p*-Terephthalic acid are the monomers of the polymerization

Condensation of Water

$n\ CH_2(OH)CH_2OH\ + n\ p\text{-}\ C_6H_4(COOH)_2 \rightarrow n\ H_2O +$ 

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

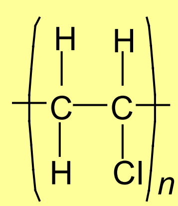


2 monomers start the polymerization

Double bonds open up

Dimer results (with two free radical sites)

Additional polymerizations

$n\ CH_2 = CHCl \rightarrow$ 

Assignment

26.4 pg. 800 #17 to 19

Chapter 26 Review: pg. 804–805 #20 to 36, 41 to 43, 48 to 50