Fundamentals of Organic Chemistry

CHEM 109

For Students of Health Colleges

Credit hrs.: (2+1)

King Saud University

College of Science, Chemistry Department

CHAPTER 2. ALIPHATIC HYDROCARBON

Learning Objectives

At the end of this chapter, students will able to:

- Identify the different types of aliphatic hydrocarbons (alkanes, cycloalkanes, alkenes, cycloalkenes and alkynes).
- Recognize the basic properties (structure, physical and chemical properties) of alkanes, alkenes and alkynes.
- Identify the structure of a hydrocarbon from its IUPAC and common name.
- Identify the name from the structure of hydrocarbons
- Explain the type of isomer in organic compounds and draw the different isomer structures of the compound.
- Know the different methods for the synthesis of aliphatic hydrocarbons.
- Identify the general reactions of aliphatic hydrocarbons.

Hydrocarbons

- **Hydrocarbons** are Organic Compounds, which contain only the two elements **carbon** and **hydrogen**.

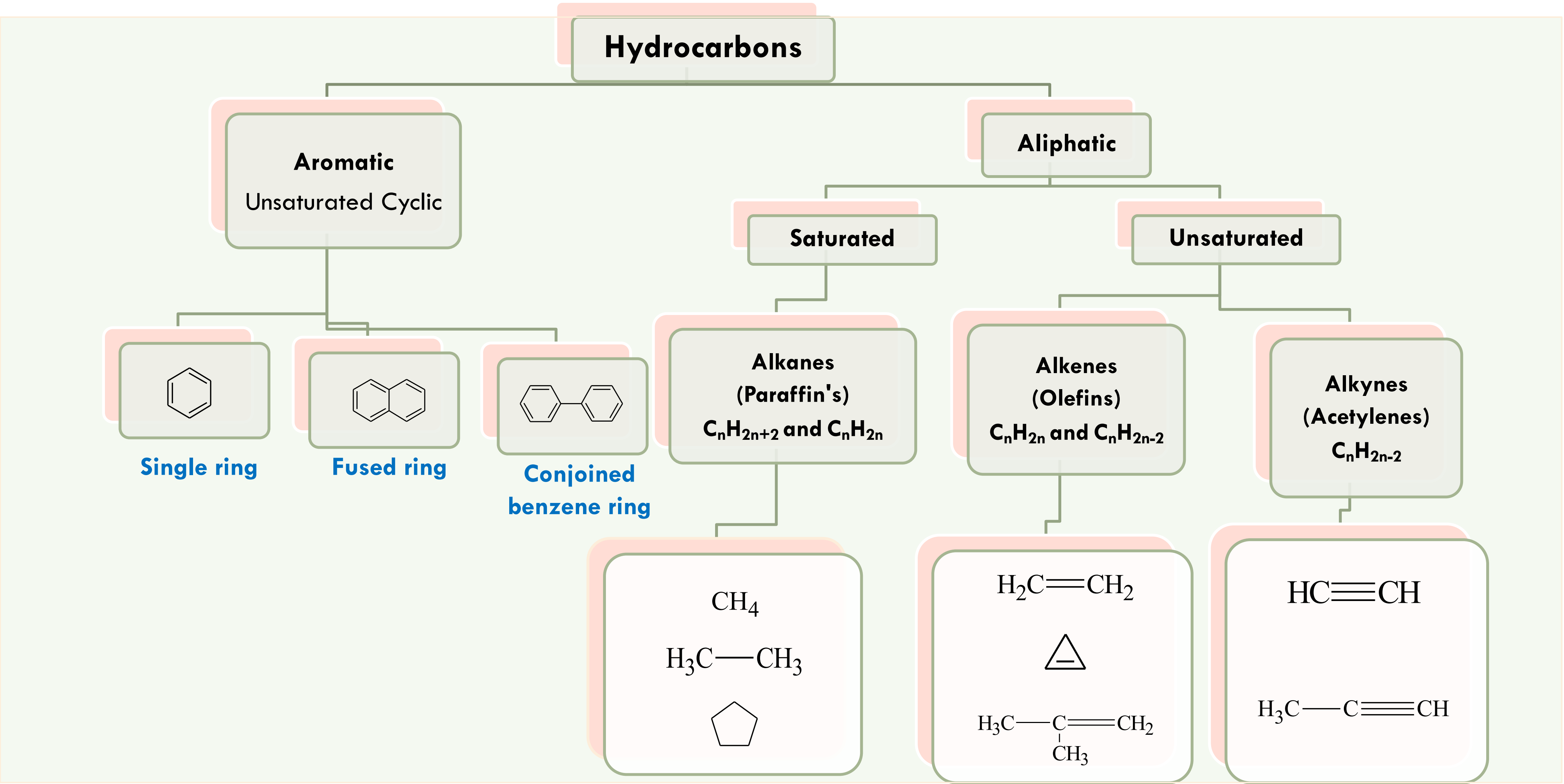
- **Aliphatic hydrocarbons** are subdivided into:

  - *Saturated hydrocarbons*
    - Alkanes; C_nH_{2n+2} (*contain carbon-carbon single bond*)
    - Cycloalkanes: C_nH_{2n} (*contain carbon-carbon single bond in a single ring*)

    Alkanes and cycloalkanes are so similar that many of their properties can be considered side by side.

  - *Unsaturated hydrocarbons*
    - Alkenes : C_nH_{2n} (contain *carbon-carbon double bond*)
    - Alkynes : $C_n H_{2n-2}$ (contain *carbon-carbon triple bond*)

Hydrocarbons



Saturated Hydrocarbons

Alkanes

Saturated Hydrocarbons

• Alkanes

- **General formula is C_nH_{2n+2}**
- In **alkanes**, the four sp^3 orbitals of carbon repel each other into a tetrahedral arrangement with bond angles of 109.5° like in CH_4.
- Each sp^3 orbital in carbon overlaps with the 1s orbital of a hydrogen atom to form a C-H bond.

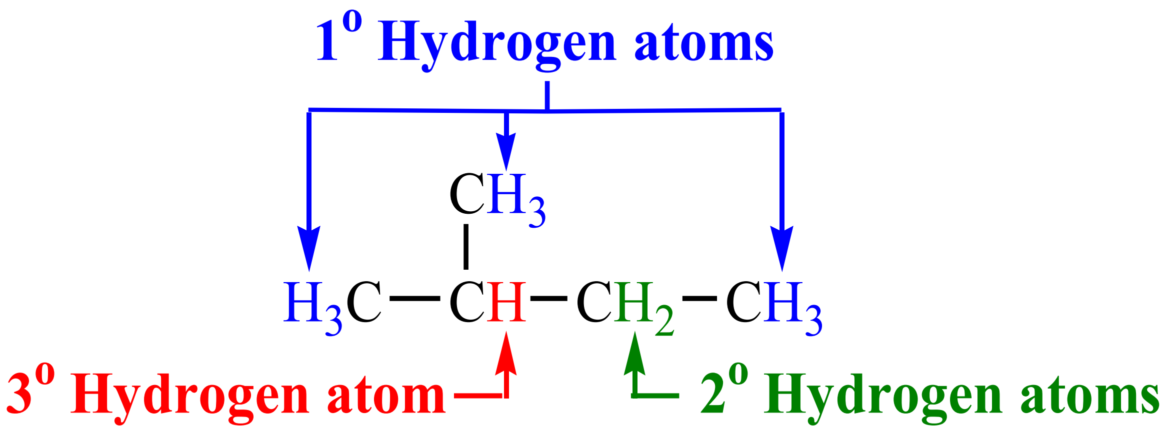
Names, Molecular formulas and Number of Isomers of the first ten Alkanes

Name	Number of carbons	Molecular formula	Structural formula	Number of structural isomers
methane	1	CH_4	CH_4	1
ethane	2	C_2H_6	CH_3CH_3	1
propane	3	C_3H_8	$CH_3CH_2CH_3$	1
butane	4	C_4H_{10}	$CH_3CH_2CH_2CH_3$	2
pentane	5	C_5H_{12}	$CH_3(CH_2)_3CH_3$	3
hexane	6	C_6H_{14}	$CH_3(CH_2)_4CH_3$	5
heptane	7	C_7H_{16}	$CH_3(CH_2)_5CH_3$	9
octane	8	C_8H_{18}	$CH_3(CH_2)_6CH_3$	18
nonane	9	C_9H_{20}	$CH_3(CH_2)_7CH_3$	35
decane	10	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$	75

Saturated Hydrocarbons

Classes of Carbons and Hydrogen

- **A primary (1°) carbon** is one that is bonded to only one other carbon.
- **A secondary (2°) carbon** is one that is bonded to two other carbons.
- **A tertiary (3°) carbon** is one that is bonded to three other carbons.



- **Hydrogens** are also referred to as 1°, 2°, or 3° according to the type of carbon they are bonded to.

Alkyl Group

- An alkyl group is formed by loss of a hydrogen atom from the corresponding alkane.
- General formula C_nH_{2n+1}.
- The letter **R** is used as a general symbol for an **alkyl group**.

Nomenclature

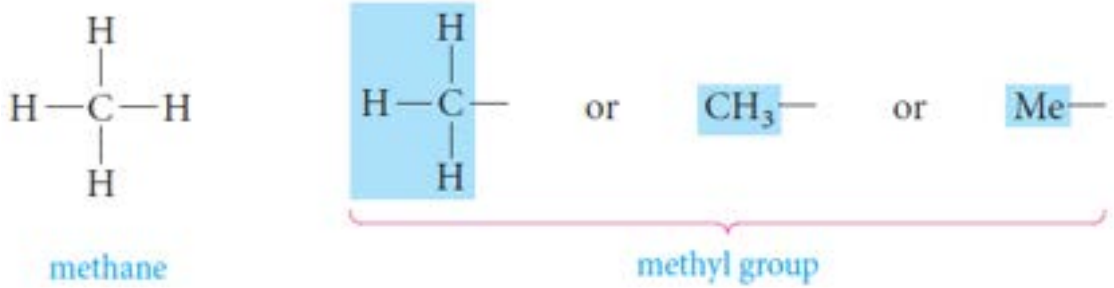
- An alkyl group is named by replacing the suffix ***–ane*** of the parent alkane by *–yl*.

i.e. Alkane – ane + yl = Alkyl

Saturated Hydrocarbons

Nomenclature

- **Examples:**
  - **Derived from methane** by removing one of the hydrogens, a one-carbon substituent is called a **methyl group**.



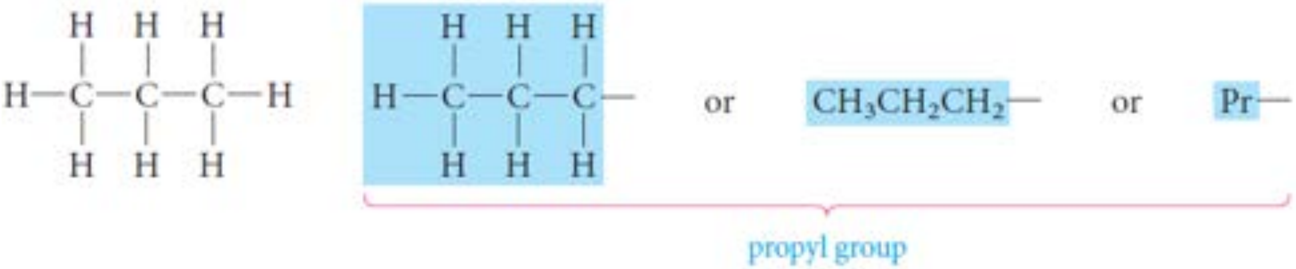
  - Thus the two-carbon alkyl group is called the **ethyl group**, **from ethane**.

CH_3CH_3 (ethane) CH_3CH_2— or C_2H_5— or Et— (ethyl group)

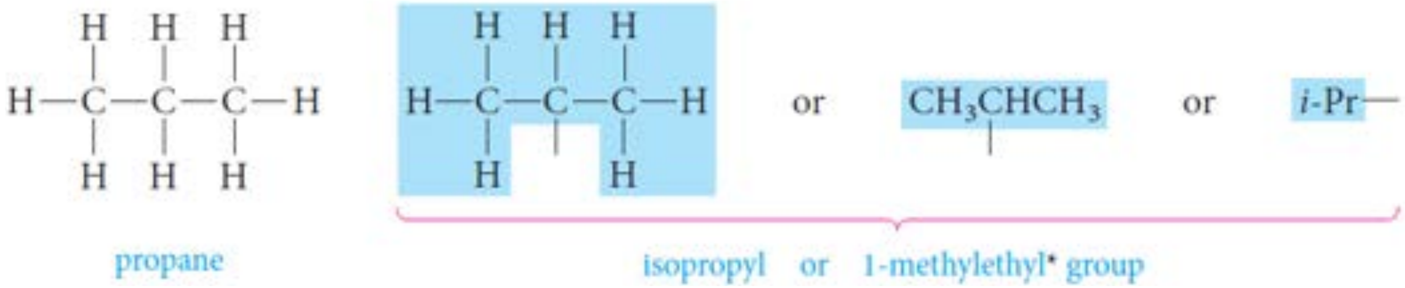
Nomenclature

- When we come to **propane**, there are two possible alkyl groups, depending on which type of hydrogen is removed.

- If a *terminal* hydrogen is removed, the group is called a **propyl group**.

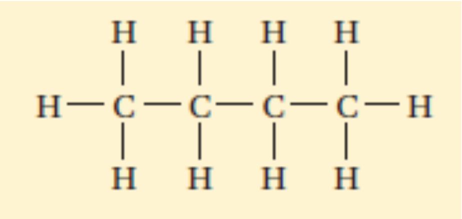


- If a hydrogen is removed from the *central* carbon atom, we get a different isomeric propyl group, called the **isopropyl group**.

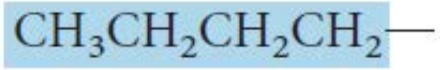


Nomenclature

- For four-carbon alkyl group, there are four different butyl groups.
  - The butyl and *sec*-butyl groups are based on ***n*-butane**.
  - The isobutyl and *tert*-butyl groups come from **isobutane**.



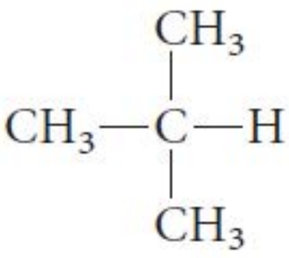
n-butane



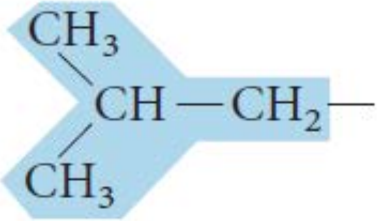
butyl

and

sec-butyl
(or 1-methylpropyl)

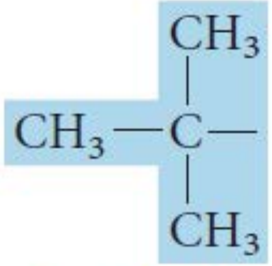


isobutane



isobutyl
(or 2-methylpropyl)

and



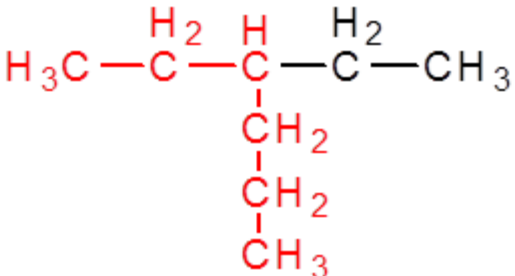
tert-butyl
(or 1,1-dimethylethyl)

Nomenclature; IUPAC Rules

- The older unsystematic names, (**Common names**).
- The **IUPAC names**. International Union of Pure & Applied Chemistry

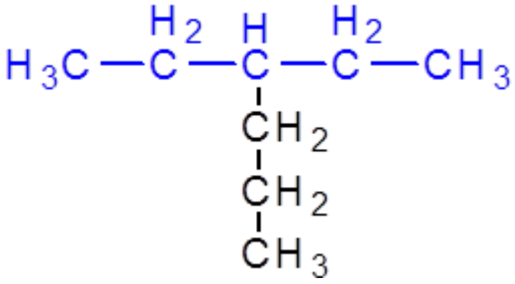
The IUPAC Rules

1) Select the parent structure; ***the longest continuous chain***



Ethylhexane

not

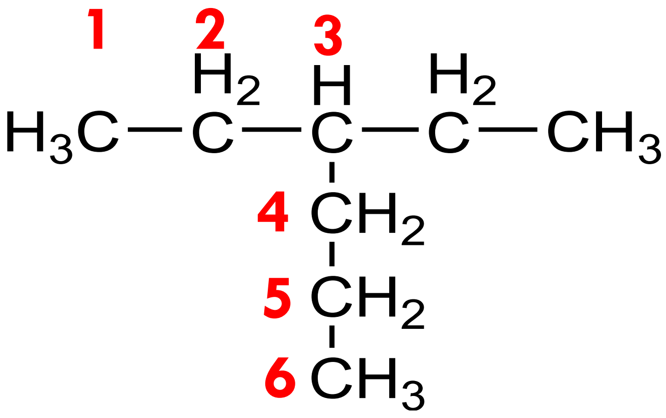


Propylpentane X

The longest continuous chain is not necessarily straight.

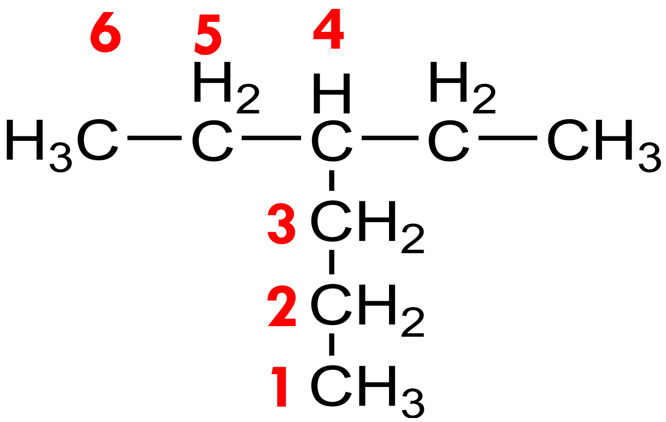
2) Number the carbons in the parent chain

starting from the carbon which gives the lowest number for the substituent



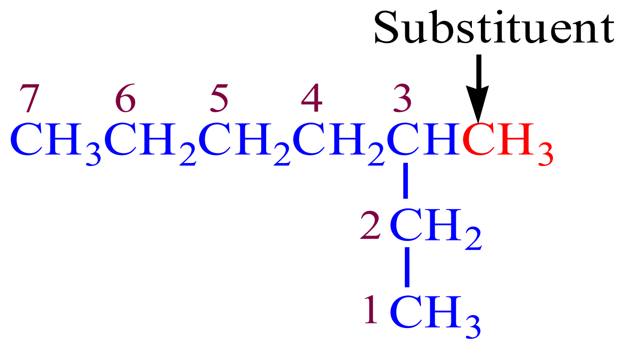
3-Ethyl hexane

not

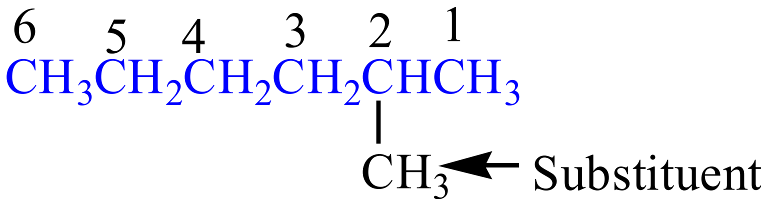


4-Ethyl hexane X

Saturated Hydrocarbons



3-**Methylheptane**



2-Methylhexane

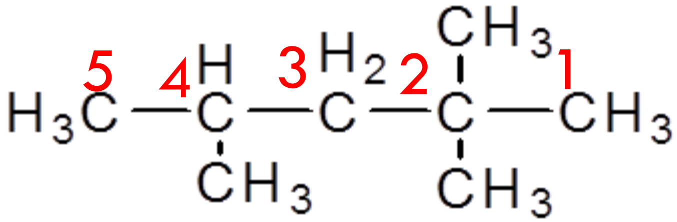
To name the compound;

1) Determine The position of the substituent on the parent carbon chain by a number.
2) The number is followed by a hyphen (-)
3) The combined name of the substituent (ethyl).
4) The parent carbon chain (hexane), So the full name will be:

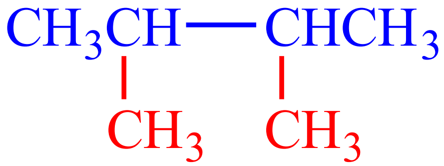
3 - Ethyl hexane

Saturated Hydrocarbons

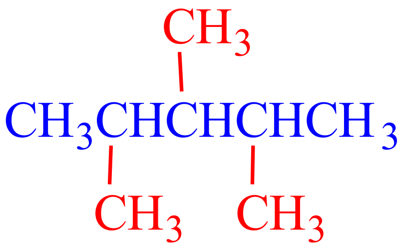
3) If the **same alkyl substituent** occurs more than once on the parent carbon chain, the prefixes **di-**, **tri-**, **tetra-**, **penta-**, and so on are used to indicate **two**, **three**, **four**, **five**, and so on.



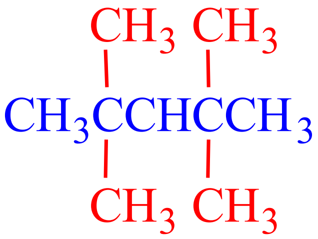
2,2,4- Tri methylpentane



2,3-Dimethylbutane



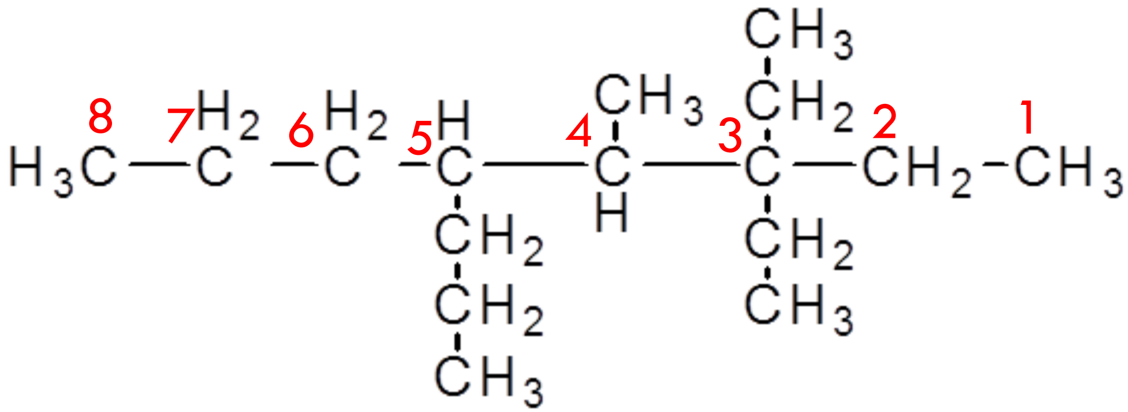
2,3,4-Trimethylpentane



2,2,4,4-Tetramethylpentane

Saturated Hydrocarbons

4) If **different alkyl substituents** are attached on the parent carbon chain, they are named in order of **alphabetical order**.



3,3-diethyl

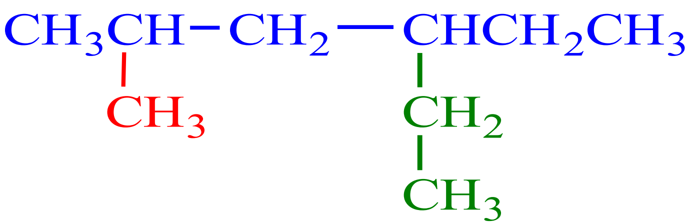
4-methyl

5-propyl

3,3-Diethyl - 4-methyl - 5 - propyl octane

Note that

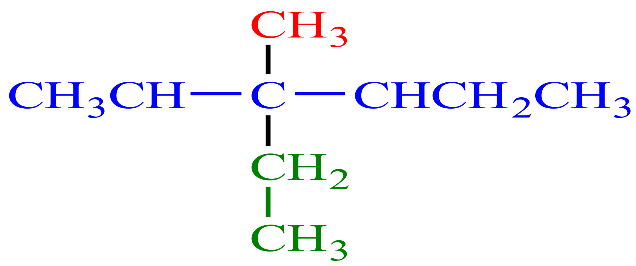
- Each substituent is given a number corresponding to its location on the longest chain.
- The substituent groups are listed alphabetically.



4-Ethyl-2-methylhexane

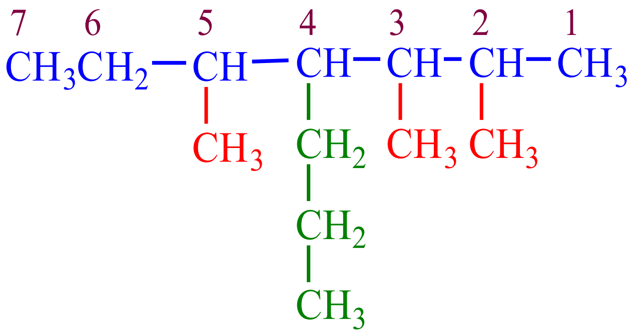
Saturated Hydrocarbons

5) When two substituent are present on the same carbon, use the number twice.



3-Ethyl-3-methylhexane

6) When two chains of equal length compete for selection as the parent chain, choose the chain with the greater number of substituents.

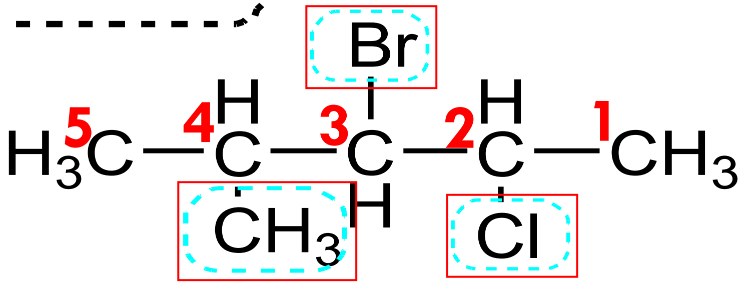


2,3,5-Trimethyl-4-*n*-propylheptane

Saturated Hydrocarbons

7) If substituents other than alky groups are also presents on the parent carbon chain;
all substituents are named alphabetically.

-F	fluoro
-Cl	chloro
-Br	bromo
-I	iodo
$-NO_2$	nitro
$-NH_2$	amino
-CN	cyano

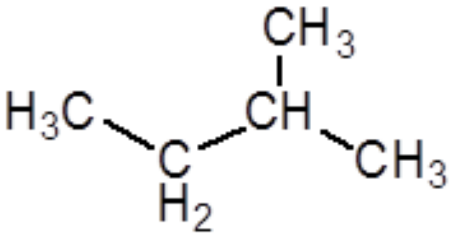
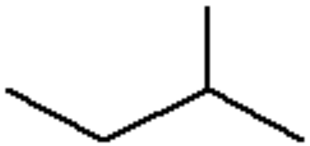
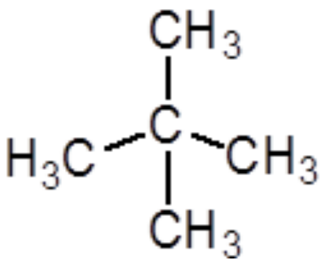
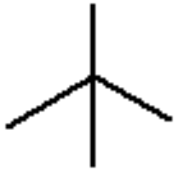


3-bromo -2-chloro -4-methyl pentane

2-chloro
3-bromo
4- methyl

Saturated Hydrocarbons

Examples

Structure	Skeletal structure	Common name:	IUPAC name:
$CH_3CH_2CH_2CH_2CH_3$		n-Pentane	Pentane
		Isopentane	2-Methylbutane
		Neopentane	2,2-Dimethylpropane

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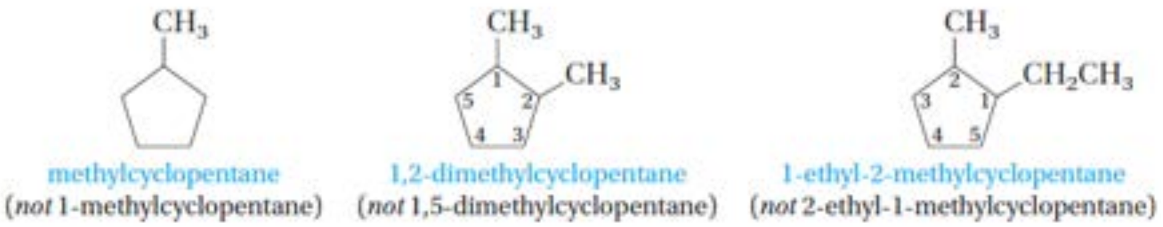
Nomenclature of Cycloalkanes

- **Cycloalkanes** are saturated hydrocarbons that have at least one ring of carbon atoms.
- **Cycloalkanes** are named by placing the prefix *cyclo-* before the alkane name that corresponds to the number of carbon atoms in the ring.

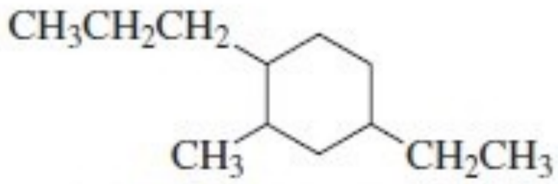
- If only one substituent is present, no number is needed to locate it.
- **If there are several substituents, numbers are required.**

With different substituents, the one with highest alphabetic priority is located at carbon 1.

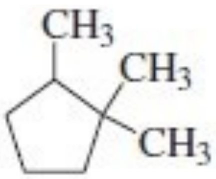


Saturated Hydrocarbons

- If there are more than two substituents on the ring, they are cited in alphabetical order.
- The substituent given the number 1 position is the one that results in a second substituent getting as low a number as possible.
- If two substituents have the same low number, the ring is numbered in the direction that gives the third substituent the lowest possible number.
- **Examples,**



4-ethyl-2-methyl-1-propylcyclohexane
not
1-ethyl-3-methyl-4-propylcyclohexane
because 2 < 3
not
5-ethyl-1-methyl-2-propylcyclohexane
because 4 < 5



1,1,2-trimethylcyclopentane
not
1,2,2-trimethylcyclopentane
because 1 < 2
not
1,1,5-trimethylcyclopentane
because 2 < 5

Physical Properties of Hydrocarbons

Those properties that can be observed without the compound undergoing a chemical reaction such as its physical states, density, color, Boiling and melting points and solubility.

A. Physical States

C1 to C4 are gases,

C5 to C17 are liquids,

C18 and larger alkanes are wax –like solids.

B. Solubility

- Alkanes, Alkenes and Alkynes are nonpolar compounds.
- Their solubility " Like dissolve like"
- Alkanes, Alkenes and Alkynes are soluble in the nonpolar solvents;
  carbon tetrachloride, CCl_4 and benzene,
- Alkanes, Alkenes and Alkynes are insoluble in polar solvents like water.

Physical Properties of Hydrocarbons

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○ Boiling Points & Melting Points

▪ Effect of Molecular Weight

The boiling points and melting points of normal hydrocarbons increase with increasing molecular weight.

As the molecules become larger, there are more forces of attraction between them, and more energy is needed.

▪ Effect of Branching

- Among isomers, straight chain compound has the highest boiling point.

- The greater the number of branches, the lower the boiling point.

Name	Formula	Boiling point, °C
pentane	$CH_3CH_2CH_2CH_2CH_3$	36
2-methylbutane (isopentane)	$CH_3CH(CH_3)CH_2CH_3$	28
2,2-dimethylpropane (neopentane)	$CH_3C(CH_3)_2CH_3$	10

Preparation of Alkanes

1. Hydrogenation of unsaturated hydrocarbon:

$$\underset{\text{Propene}}{H_3C-\overset{H}{C}=CH_2} \xrightarrow[\text{Pt}]{H_2} \underset{\text{Propane}}{H_3C-\overset{H_2}{C}-CH_3}$$

$$\underset{\text{Propyne}}{H_3C-C\equiv CH} \xrightarrow[\text{Pt}]{2H_2} \underset{\text{Propane}}{H_3C-\overset{H_2}{C}-CH_3}$$

2. Hydrolysis of Grignard reagent

$$CH_3CH_2Br + Mg^{2+} \xrightarrow{\text{Dry ether}} \underset{\text{Grignard reagent}}{CH_3CH_2MgBr}$$

$$CH_3CH_2MgBr \xrightarrow{H_3O^+} CH_3CH_3 + Mg(OH)Br$$

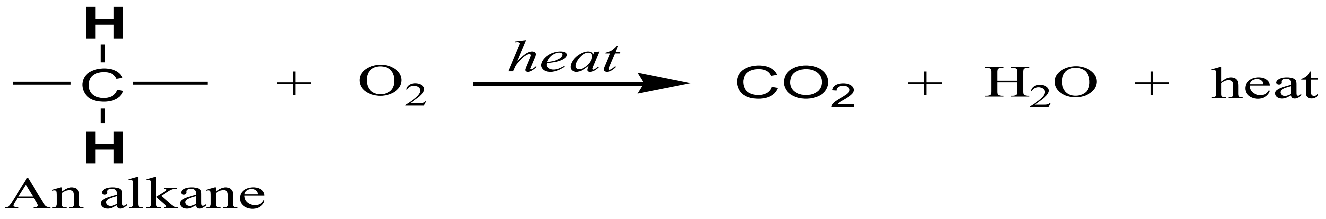
3. Reduction of Alkyl halides By lithium dialkyl cuprate

$$(CH_3CH_2)_2CuLi + CH_3Br \longrightarrow CH_3CH_2CH_3$$

Reactions of Alkanes

Saturated hydrocarbons undergo very few reactions, so they are called Paraffinic hydrocarbons. (Latin *parum*, little; *affinis*, affinity)

Combustion



Halogenation

The halogenation of an alkane appears to be a simple free radical substitution in which a C-H bond is broken and a new C-X bond is formed

$$RH + X_2 \xrightarrow[\text{or UV light}]{\text{Heat}} \underset{\text{Alkyl halide}}{RX} + HX \quad X = Cl \text{ or } Br$$

Reactivity X_2: $Cl_2 > Br_2$

$H: 3^0 > 2^0 > 1^0 > CH_3\text{-}H$

Reactions of Alkanes

Halogenation

- **Substitution reaction of alkanes,**

  i.e. replacement of hydrogen by halogen,
  usually chlorine or bromine, giving alkyl chloride or alkyl bromide.

- **Fluorine reacts explosively with alkanes**

  It is unsuitable reagent for the preparation of the alkyl fluorides.

- **Iodine is too unreactive**

  It is not used in the halogenation of alkanes.

- **Halogenation of alkanes take place at**

  high temperatures or under the influence of ultraviolet light

Reactions of Alkanes

- **Chlorination of an alkane usually gives a mixture of products**

$$\underset{\text{methane}}{CH_4} + Cl{-}Cl \xrightarrow[\text{or heat}]{\text{sunlight}} \underset{\substack{\text{chloromethane}\\ \text{(methyl chloride)}}}{CH_3Cl} + HCl$$

$$CH_3Cl \xrightarrow{Cl_2} \underset{\substack{\text{dichloromethane}\\ \text{(methylene chloride)}}}{CH_2Cl_2} \xrightarrow{Cl_2} \underset{\substack{\text{trichloromethane}\\ \text{(chloroform)}}}{CHCl_3} \xrightarrow{Cl_2} \underset{\substack{\text{tetrachloromethane}\\ \text{(carbon tetrachloride)}}}{CCl_4}$$

- With longer chain alkanes, mixtures of products may be obtained even at the first step. For example, with propane,

$$\underset{\text{propane}}{CH_3CH_2CH_3} + Cl_2 \xrightarrow[\text{or heat}]{\text{light}} \underset{\substack{\text{1-chloropropane}\\ (n\text{-propyl chloride})}}{CH_3CH_2CH_2Cl} + \underset{\substack{\text{2-chloropropane}\\ \text{(isopropyl chloride)}}}{CH_3\underset{\substack{|\\ Cl}}{C}HCH_3} + HCl$$

Use of Alkanes

- **Alkanes** are unreactive compounds and mainly used as a source of energy;

  Examples:

  - Natural gas is composed mostly of methane, but it also contains small amounts of ethane, propane, butane, and pentane.
  - Diesel itself is a mixture of hydrocarbons, ranging from $C_{10}H_{20}$, (decane) to $C_{15}H_{28}$.

- **Petroleum jelly (Vaseline)** is petrolatum, a hydrocarbon, $C_{15}H_{15}N$ (1,1,2 Trimethylbenzeindole).
- Most petroleum jelly today is used as an ingredient in skin lotions and cosmetics.
- **Paraffin wax (or petroleum wax)** is a soft colorless solid, derived from petroleum, that consists of a mixture of hydrocarbon molecules containing between twenty and forty carbon atoms.
- Common applications for paraffin wax include lubrication, electrical insulation, and candles
- **Cyclopropane** is used as an anaesthetic
- **General uses;**

- Making organic compounds and used as Organic solvents

Unsaturated Hydrocarbons

Alkenes

The Structure of Alkenes

- **Alkenes** are hydrocarbons that contain a ***carbon–carbon double bond***.
- **Alkenes are also *Olefins*.**
- **General formula is C_nH_{2n}**
- The simplest members of the **Alkenes** series are **C_2 & C_3**

	$CH_2{=}CH_2$	$H_3C{-}CH{=}CH_2$
Common name:	Ethylene	Propylene
IUPAC name:	Ethene	Propene

- Hybridization; ***sp*^{2}-hybridized orbitals**
- The angle between them is 120° and bond length C=C (1.34 Å).
- A **trigonal planar.**

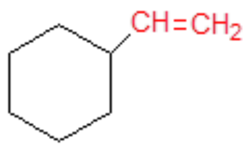
Nomenclature; Common Names

- The simplest members of the alkene and alkyne series are frequently referred to by their older common names, ethylene, acetylene, and propylene.

$CH_2{=}CH_2$	$HC{\equiv}CH$	$CH_3CH{=}CH_2$
ethylene	acetylene	propylene
(ethene)	(ethyne)	(propene)

- Two important groups also have common names; They are the **vinyl** and **allyl** groups.
- These groups are used in common names.

$CH_2{=}CH{-}$	$CH_2{=}CHCl$
vinyl	vinyl chloride
(ethenyl)	(chloroethene)
$CH_2{=}CH{-}CH_2{-}$	$CH_2{=}CH{-}CH_2Cl$
allyl	allyl chloride
(2-propenyl)	(3-chloropropene)



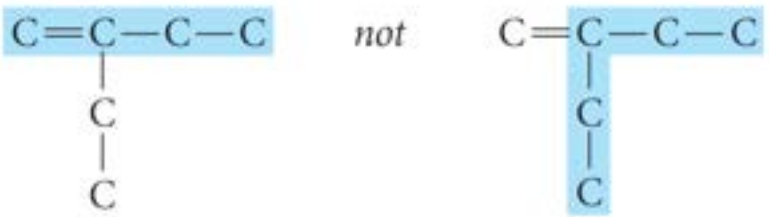
Common name: Vinyl cyclohexane
IUPAC name: Cyclohexylethene

Nomenclature; IUPAC Rules

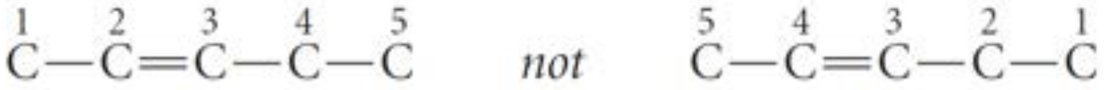
The IUPAC rules for naming alkenes are similar to those for alkanes, but a few rules must be added for naming and locating the multiple bonds.

1. The ending ***-ene*** is used to designate a carbon–carbon double bond.

2. Select the **longest chain that includes *both <u>carbons of the double bond</u>***.

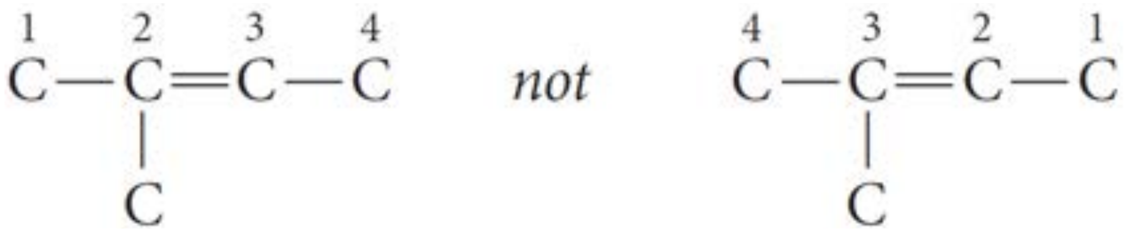


3. **Number the chain from the end nearest the double bond** so that the carbon atoms in that bond have the lowest possible numbers.



Unsaturated Hydrocarbons

If the multiple bond is equidistant from both ends of the chain, number the chain from the end nearest the first branch point.



4. Indicate the **position of the multiple bond using the *lower numbered carbon atom*** of that bond.

$\overset{1}{C}H_2{=}\overset{2}{C}H\overset{3}{C}H_2\overset{4}{C}H_3$ 1-butene, *not* 2-butene

Unsaturated Hydrocarbons

NOTES

The root of the name (*eth-* or *prop-*) tells us the number of carbons, and the ending (-*ane*, -*ene*, or -*yne*) tells us whether the bonds are single, double, or triple.

No number is necessary in these cases, because in each instance, only one structure is possible.

CH_3CH_3 ethane	$CH_2{=}CH_2$ ethene	$HC{\equiv}CH$ ethyne
$CH_3CH_2CH_3$ propane	$CH_2{=}CHCH_3$ propene	$HC{\equiv}CCH_3$ propyne

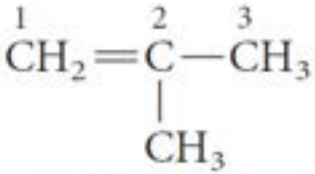
With four carbons, a number is necessary to locate the double bond.

$$\overset{1}{C}H_2{=}\overset{2}{C}H\overset{3}{C}H_2\overset{4}{C}H_3 \quad \text{1-butene}$$

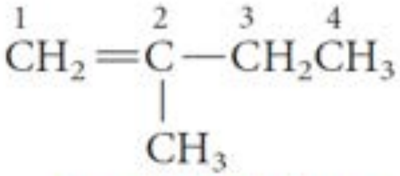
$$\overset{1}{C}H_3\overset{2}{C}H{=}\overset{3}{C}H\overset{4}{C}H_3 \quad \text{2-butene}$$

Unsaturated Hydrocarbons

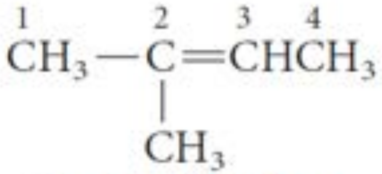
- Branches are named in the usual way.



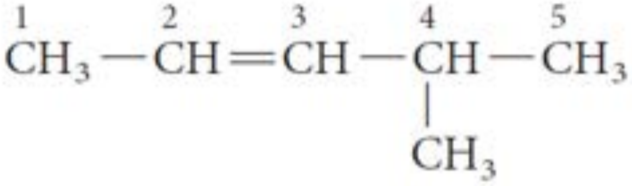
methylpropene
(isobutylene)



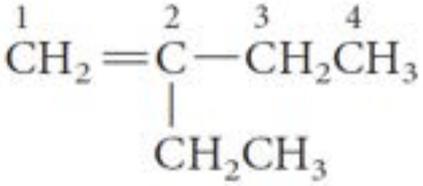
2-methyl-1-butene



2-methyl-2-butene



4-methyl-2-pentene
(*Not* 2-methyl-3-pentene; the chain is numbered so that the double bond gets the lower number.)



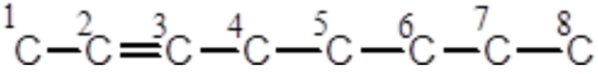
2-ethyl-1-butene
(Named this way, even though there is a five-carbon chain present, because that chain does not include both carbons of the double bond.)

Unsaturated Hydrocarbons

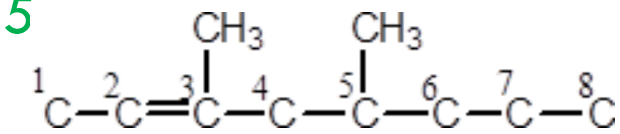
Example: Write the structural formula of 4-Isopropyl-3,5-dimethyl-2-octene.

1) The parent carbon chain is an **Octene**.

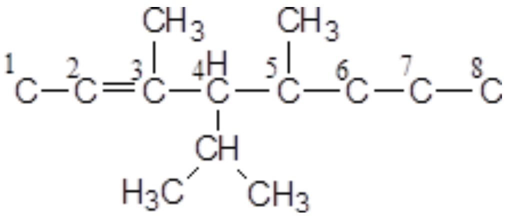
The double bond is located between the 2nd and 3rd carbons.



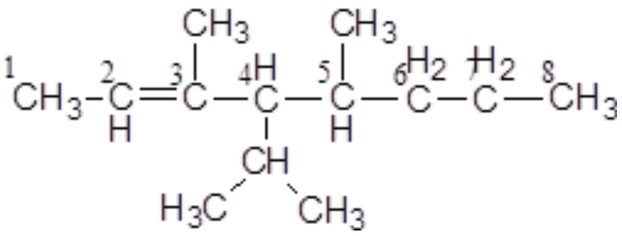
2) Two methyl groups are attached on the parent carbon chain, one on carbon 3 and the other on carbon 5



3) An isopropyl group is attached on carbon 4.

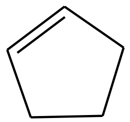


4) Put the missing hydrogens to get the correct structure.



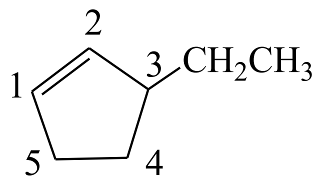
Nomenclature of Cycloalkenes

- We start numbering the ring with the carbons of the double bond.
- A number is not needed to denote the position of the functional group, because the ring is always numbered so that the double bond is between carbons 1 and 2.
- Put the lowest substituent number into the name not in the direction that gives the lowest sum of the substituent numbers.



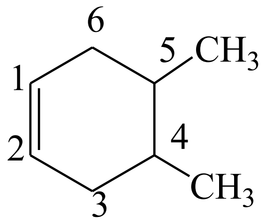
Cyclopentene

2-Cyclopentene X

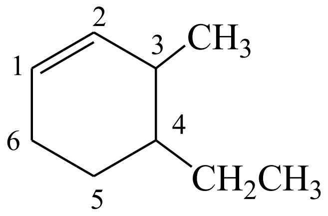


3-Ethylcyclopentene

5-Ethylcyclopentene X



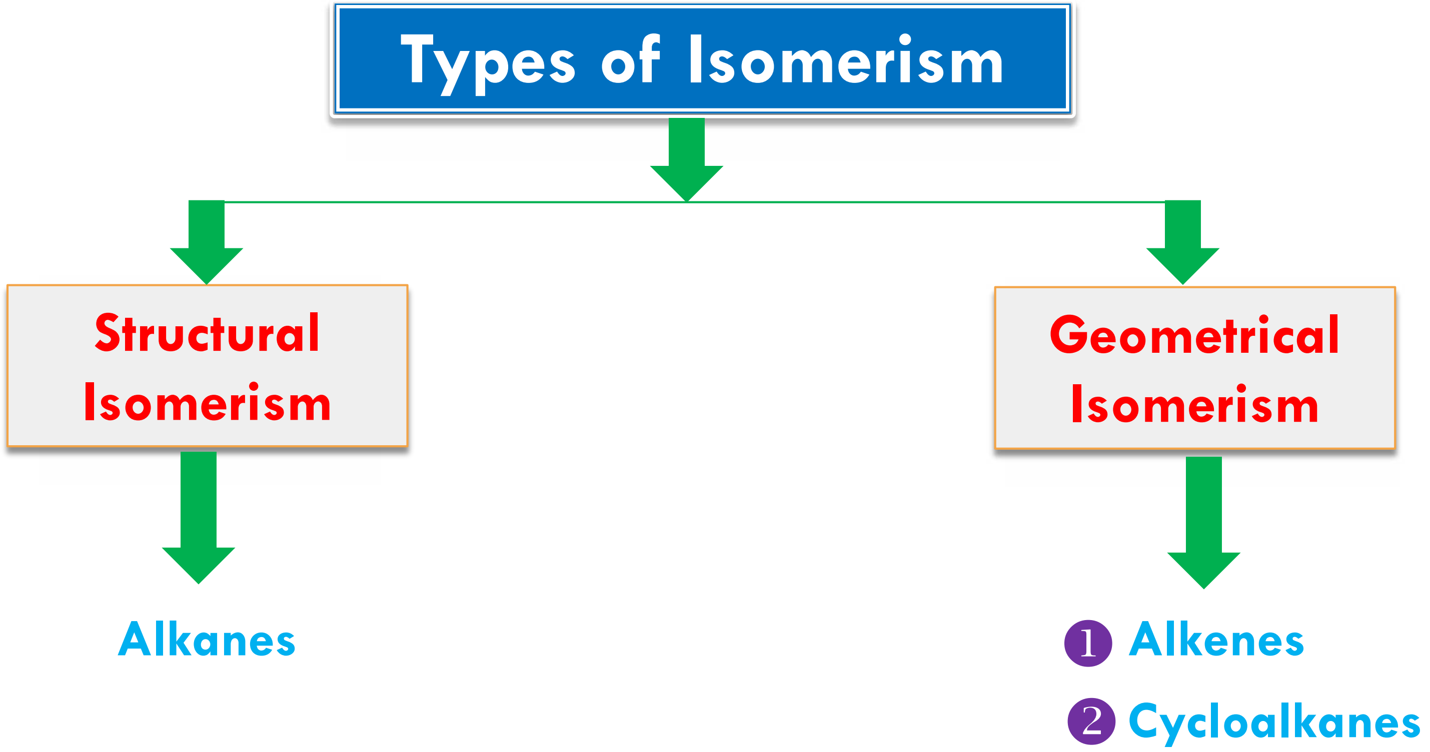
4,5-Dimethylcyclohexene



4-Ethyl-3-methylcyclohexene

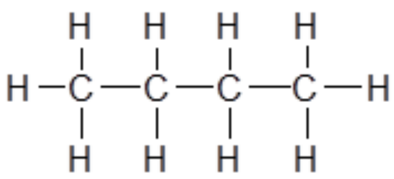
Isomerism

- **Isomers** are different compounds with identical molecular formulas.
- The phenomenon is called ***isomerism***.

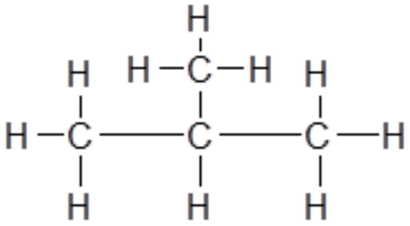


Structural Isomerism in Alkanes

- **Structural** or **constitutional isomers** are isomers which differ in the sequence of atoms bonded to each other.
  - **Examples:**
    - **Butanes, C_4H_{10}**

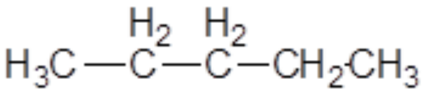


n-Butane

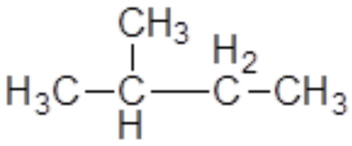


Isobutane

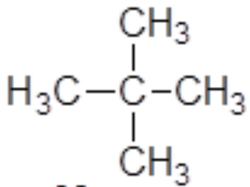
    - **Pentanes, C_5H_{12}**



n-Pentane



Isopentane



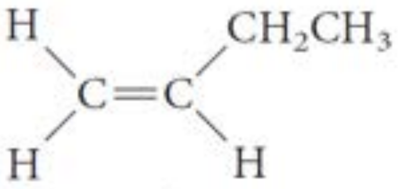
Neopentane

Geometric Isomerism in Alkenes

- In alkenes, geometric isomerism is due to restricted rotation about the carbon - carbon double bond.

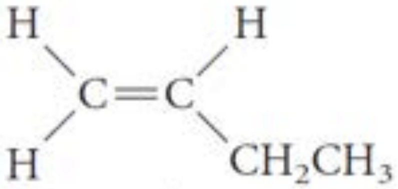
A) If (W = X or Y = Z), geometric isomerism is not possible.

Geometric isomers

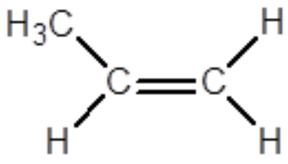


1-butene

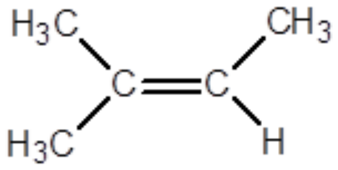
is identical to



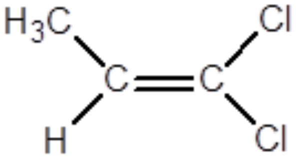
1-butene



Propene



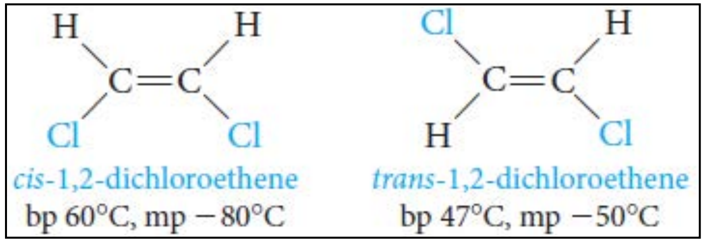
2-Methyl-2-butene

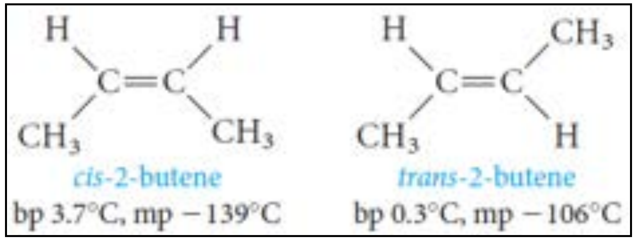


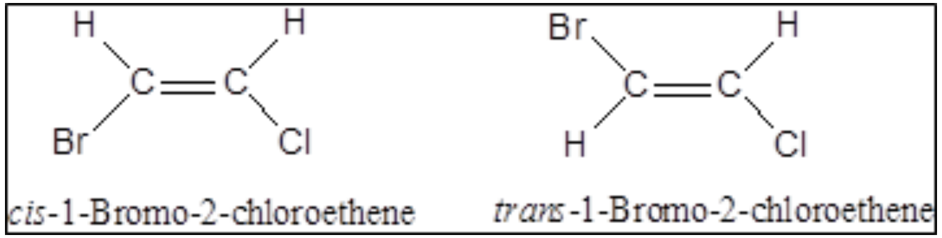
1,1-Dichloropropene

B) when W differs from X and Y from Z, Alkenes exist as geometric isomers

Geometric isomers



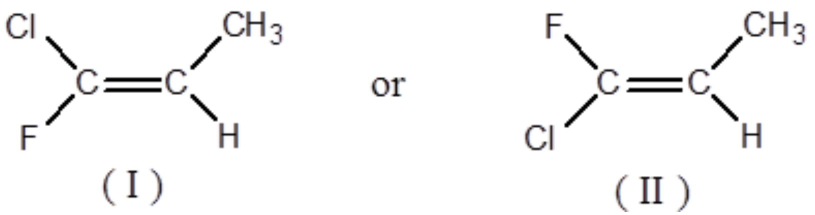




- ***cis* isomer;** when two similar groups are on the same side or same side of the double bond.
- ***trans* isomer;** when two similar groups are on the opposite direction or opposite sides of the double bond.

- *They have different physical properties and can be separated by fractional crystallization or distillation.*

- For alkenes with four different substituent such as



Another system, the *E, Z* system,

- **Basically, the E,Z system works as follows;**

Arrange the groups on each carbon of the C=C bond in order of priority

- **The priority depends on atomic number:**

The higher the atomic number of the atom directly attached to the double-bonded carbon, the higher the priority.

Thus, in structure (I), Cl > F, and CH_3 > H.

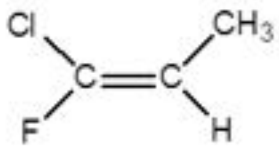
- If the two groups of **higher priority** are on the **same side** of the C=C plane,

  <u>*The* isomer is labeled *Z;*</u> (from the German *zusammen*, together).

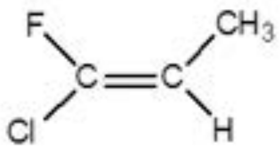
- **If the two groups of higher priority are on opposite sides of the C=C plane,**

  <u>*The isomer is labeled E;*</u> *(from the German entgegen, opposite).*

Priority: Cl > F, CH_3 > H

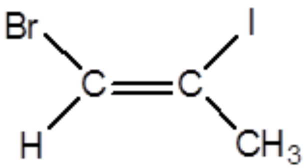


Z-1-Chloro-1-fluoropropene
(Cl and CH_3 on same side)



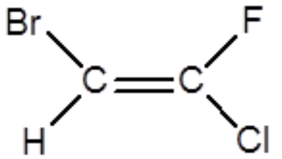
E-1-Chloro-1-fluoropropene
(Cl and CH_3 on opposite side)

Priority: Br > H, I > CH_3



Z-1-Bromo-2-iodopropene

Priority: Br > H, Cl > F

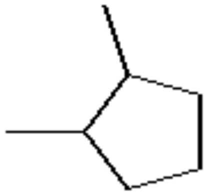


E-1-Brfomo-2-chloro-2-fluoroethene

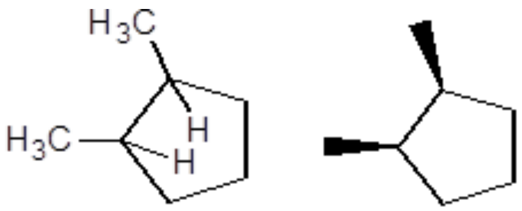
Geometric Isomerism in Cycloalkanes

cis-trans Isomerism in Cycloalkanes

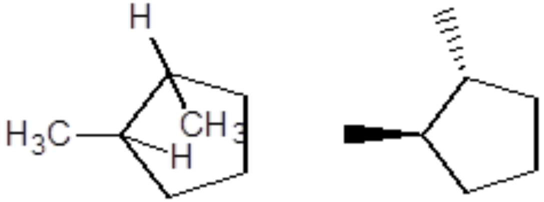
cis–trans **isomerism (sometimes called geometric isomerism) is one kind of stereoisomerism.**



1,2-Dimethylcyclopentane



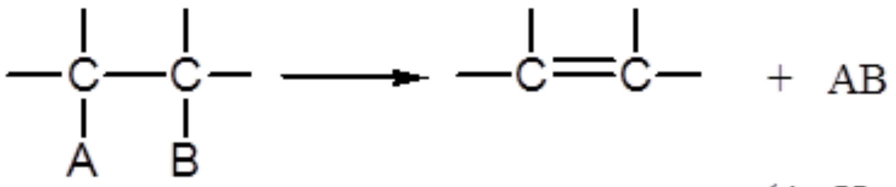
cis-1,2-Dimethylcyclopentane



trans-1,2-Dimethylcyclopentane

Preparation of Alkenes

- Unsaturated hydrocarbons are prepared by ***Elimination*** of an atom or group of atoms from adjacent carbons to form *carbon-carbon double or triple bond.*



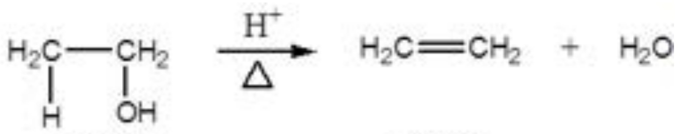
(A=H or halogen;
B=OH or halogen)

Preparation of Alkenes

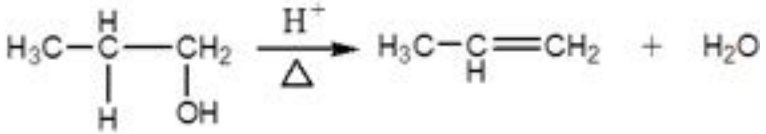
King Saud University

1. Dehydration of Alcohols

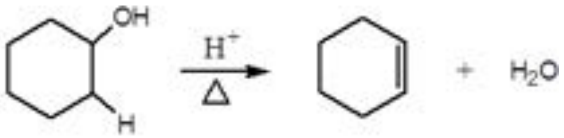
- *When an alcohol is heated in the presence of a mineral acid catalyst, It readily loses a molecule of water to give an alkene.*
- Removal of OH group and a proton from two adjacent carbon atoms using mineral acids such as HCl, H_2SO_4 and H_3PO_4



IUPAC name: Ethanol — Ethene
Common name: Ethyl alcohol — Ethylene



IUPAC name: 1-Propanol — Propene
Common name: *n*-Propyl alcohol — Propylene

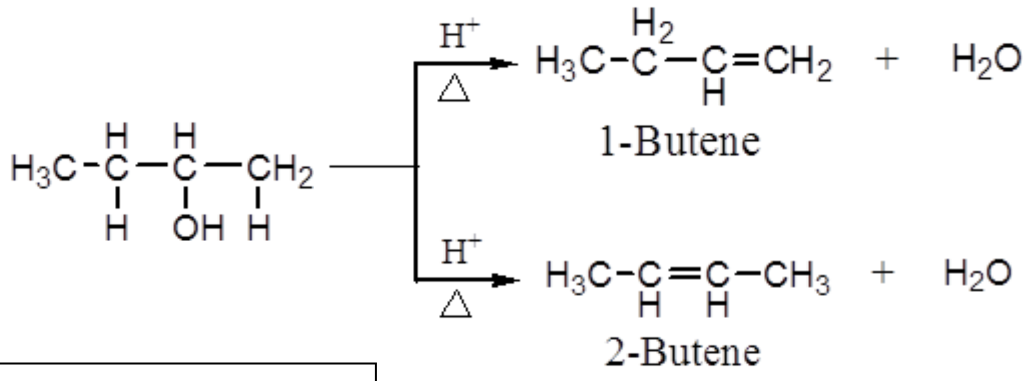


IUPAC name: Cyclohexanol — Cyclohexene
Common name: Cyclohexyl alcohol

Which Alkene Predominates?; Saytzeff's Rule

The loss of water from adjacent carbon atoms, can give rise to more than one alkene.

Example: the dehydration of 2-butanol.



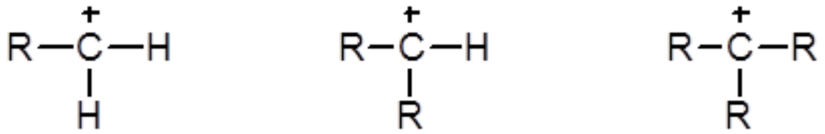
2-butene is the major (with two alkyl substituents attached to C=C)

Saytzeff's Rule applies

In every instance in which more than one Alkene can be formed

The major product is always the alkene with the most alkyl substituents attached on the double-bonded carbons.

Classes of Carbocations



1° carbocation   2° carbocation   3° carbocation

according to the number of carbon atoms attached to the positively charged carbon.

The ease of formation and the stabilities of carbocations follow the order

$3^\circ > 2^\circ > 1^\circ$

← Ease of formation and stabilities of carbocations

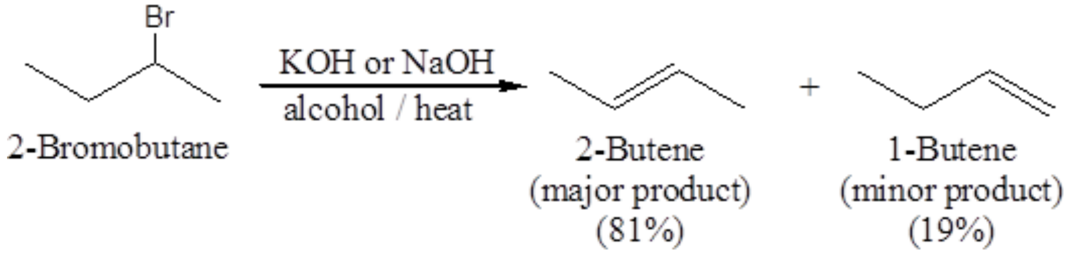
Generally

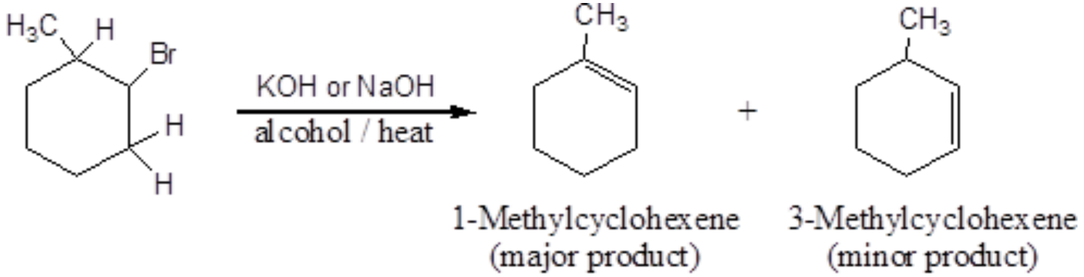
1. The dehydration of alcohols requires an acid catalyst.
2. The predominant alkene formed follows Saytzeffs rule.
3. The reaction proceeds *via* a carbocation intermediate.
4. The stabilities of carbocations and the ease of dehydration of alcohols follows the order $3^\circ > 2^\circ > 1^\circ$.

2. Dehydrohalogenation of Alkyl Halides

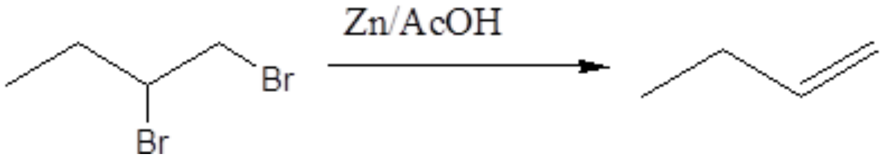
- Alkenes can also be prepared under alkaline conditions.

  heating an alkyl halide with a solution of KOH or NaOH in alcohol, yields an alkene.





3. Dehalogenation of Vicinal Dibromides



Type of Reagents

- Any electron-deficient species is called an electrophile.
- Any electron-rich species is called a nucleophile.

Examples of Electrophile:

a) Positive reagents: protons (H^+), alkyl group R^+ , nitronium ion (NO_2^+), etc.…

b) Neutral reagents having positively polarized centers: HCl, bromine (because it can be polarized so that one end is positive).

c) Lewis acids: molecules or ions that can accept an electron pair $\Rightarrow$ BF_3 and $AlCl_3$.

Examples of Nucleophile:

a) Negative ions

e.g. $H\ddot{\underset{..}{O}}{:}^-$ Hydroxide ion, $H\ddot{\underset{..}{S}}{:}^-$ Hydrosulphide ion, $R\ddot{\underset{..}{O}}{:}^-$ Alkoxide ions,

${:}N{\equiv}C{:}^-$ Cyanide ion, ${:}\ddot{\underset{..}{X}}{:}^-$ Halide ions, ...etc.

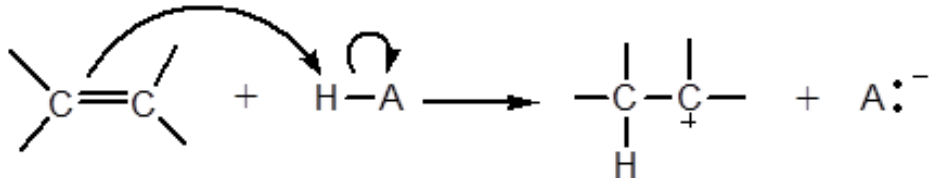
b) Neutral molecules

e.g. $H_2\ddot{\underset{..}{O}}$, $R{-}\ddot{\underset{..}{O}}{-}H$, $R{-}\ddot{\underset{..}{O}}{-}R$, $H_3\ddot{N}$, $R_3\ddot{N}$, ...etc.

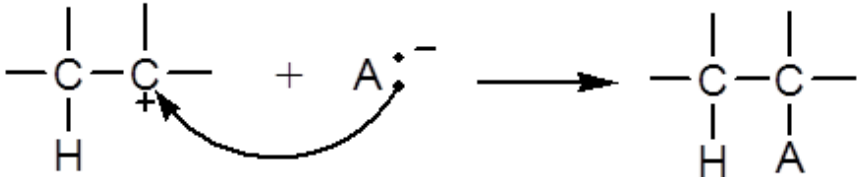
Electrophilic Addition Reaction Mechanism

- **The addition of H—A to an alkene is believed to be a two-step process.**

  Step 1. The hydrogen ion (the electrophile) attacks the ∏-electrons of the alkene, forming a C—H bond and a carbocation.



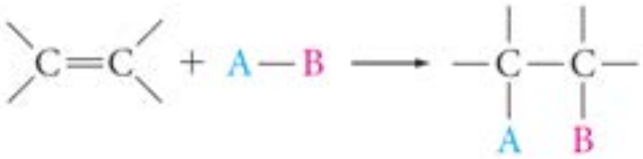
  Step 2. The negatively charged species A: - (a nucleophile) attacks the carbocation and forms a new C—A bond.



- The attack by an electrophilic reagent on the ∏-electrons, falls in a general category called **electrophilic addition reactions.**

Reactions of Alkene

1. Electrophilic Addition Reactions



Addition of Symmetric and Unsymmetric Reagents to symmetric Alkenes.

1. Addition of Hydrogen: Catalytic Hydrogenation
2. Addition of Halogens: Halogenation

Addition of Unsymmetric Reagents to Unsymmetric Alkenes; Markovnikov's Rule.

1. Addition of Hydrogen Halides
2. Addition of Sulfuric Acid
3. Addition of Water: Hydration
4. Addition of HOX: Halohydrin Formation

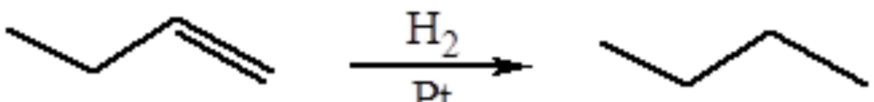
2. Oxidation Reactions

1. Ozonolysis
2. Oxidation Using $KMnO_4$

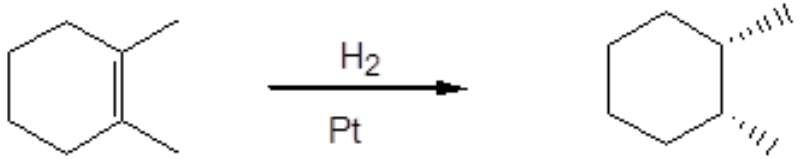
1. Electrophilic Addition Reactions

a. Addition of Hydrogen: Hydrogenation

Addition of a mole of hydrogen to carbon-carbon double bond of Alkenes in the presence of suitable catalysts to give an Alkane.



1-Butene → Butane



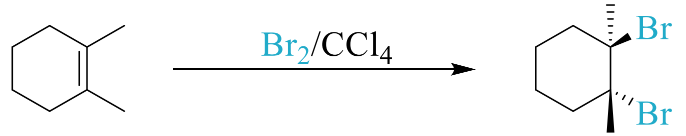
1,2-Dimethylcyclohexene → *cis*-1,2-Dimethylcyclohexane

b. Addition of Halogen: Halogenation

*When an **alkene** is treated at room temperature with a solution of bromine or chlorine in carbon tetrachloride to give the corresponding vicinal dihalide (two halogens attached to adjacent carbons)*

$$CH_3CH{=}CHCH_3 + Cl_2 \longrightarrow CH_3\underset{\displaystyle Cl}{\underset{|}{C}H}{-}\underset{\displaystyle Cl}{\underset{|}{C}H}CH_3$$

2-butene → 2,3-dichlorobutane

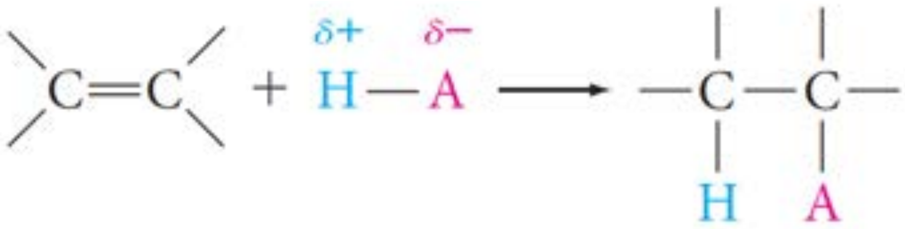


1,2-Dimethyl-cyclohexene → *trans*-1,2-Dibromo-1,2-dimethyl-cyclohexane

c. Addition of Acids

- **A variety of acids add to the double bond of alkenes.**

  The hydrogen ion (or proton) adds to one carbon of the double bond, and the remainder of the acid becomes connected to the other carbon.



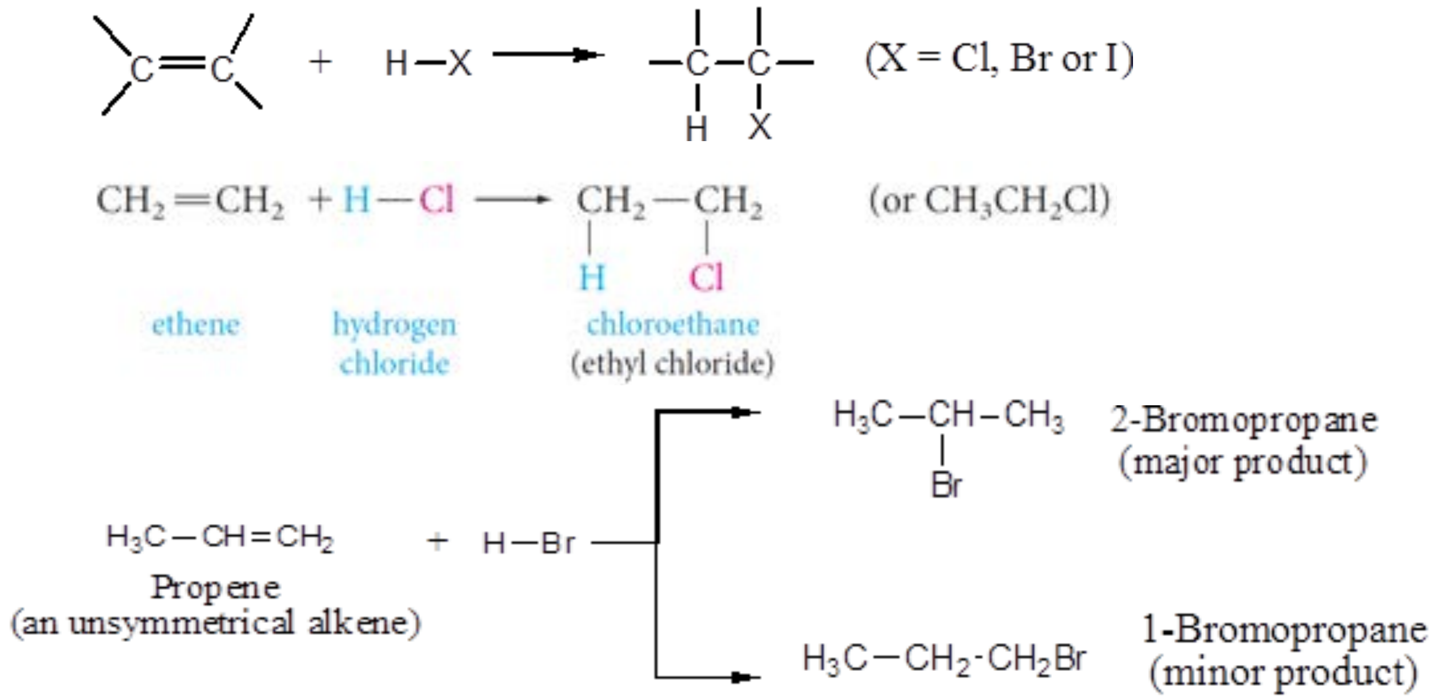
- Acids that add in this way are the **hydrogen halides** (H-F, H-Cl, H-Br, H-I), and **water** (H-OH).

d. Addition of Hydrogen Halide

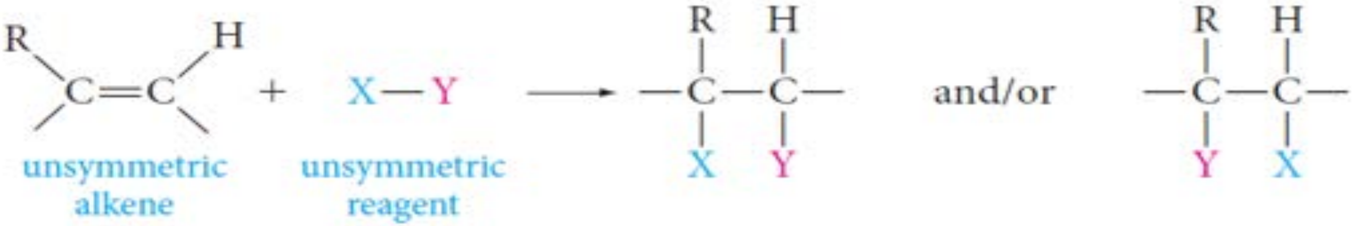
Alkenes react with hydrogen chloride, HC1, hydrogen bromide, HBr and hydrogen iodide, HI, *to form alkyl halides, RX.*

Examples;

General equation



- **Reagents and alkenes can be classified as either symmetric or unsymmetric** with respect to addition reactions.
  - If a reagent and/or an alkene is symmetric, only one addition product is possible.
  - But if *both* the reagent *and* the alkene are *unsymmetric*, two products are, in principle, possible.



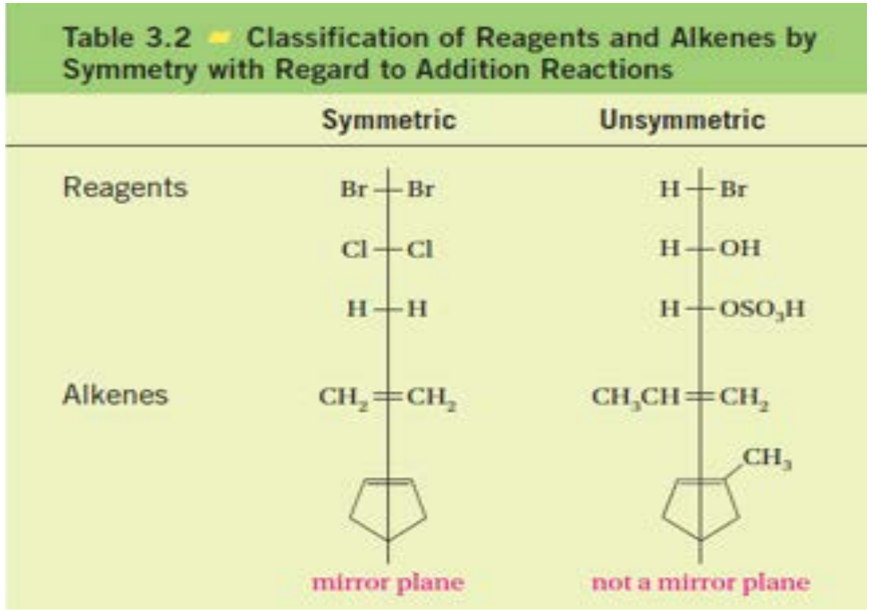
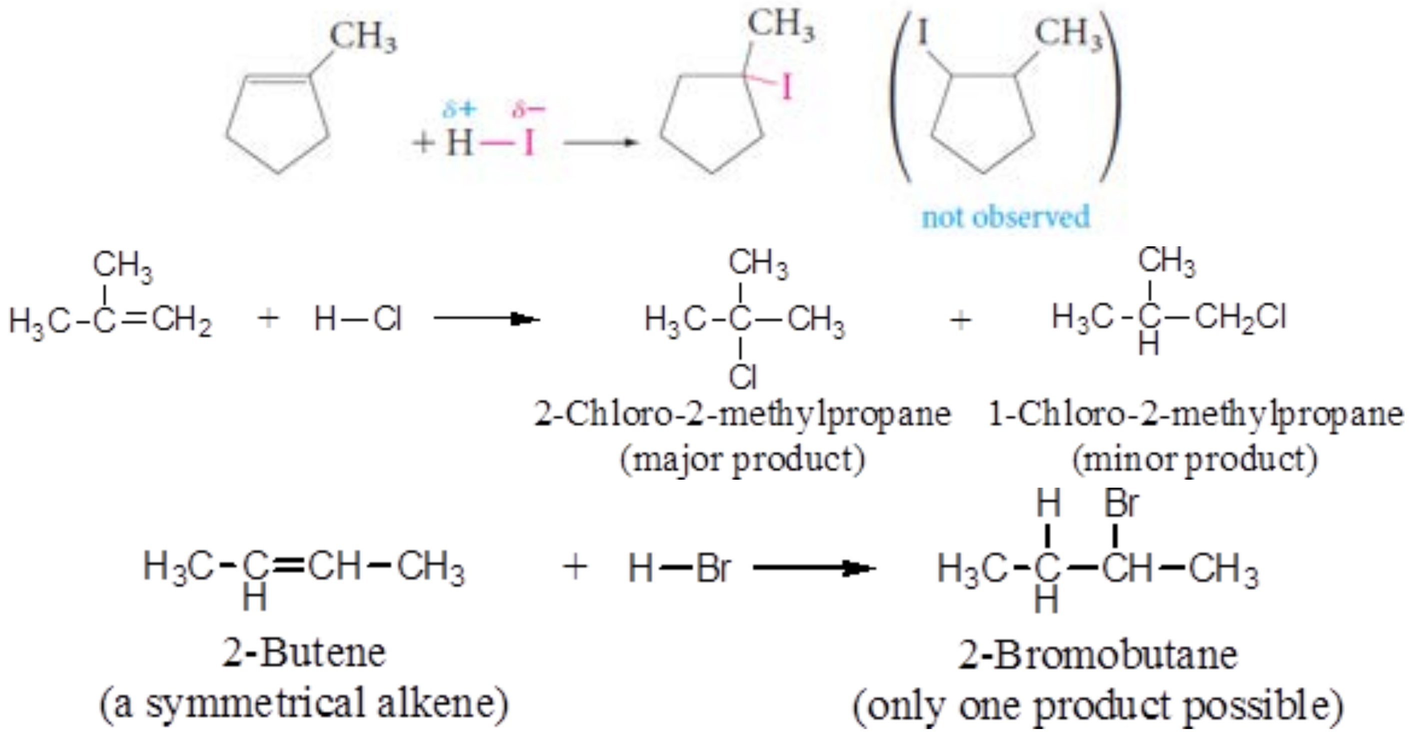


Table 3.2 Classification of Reagents and Alkenes by Symmetry with Regard to Addition Reactions

	Symmetric	Unsymmetric
Reagents	Br–Br	H–Br
	Cl–Cl	H–OH
	H–H	H–OSO_3H
Alkenes	$CH_2=CH_2$	$CH_3CH=CH_2$
	cyclopentene	methylcyclopentene
	mirror plane	not a mirror plane

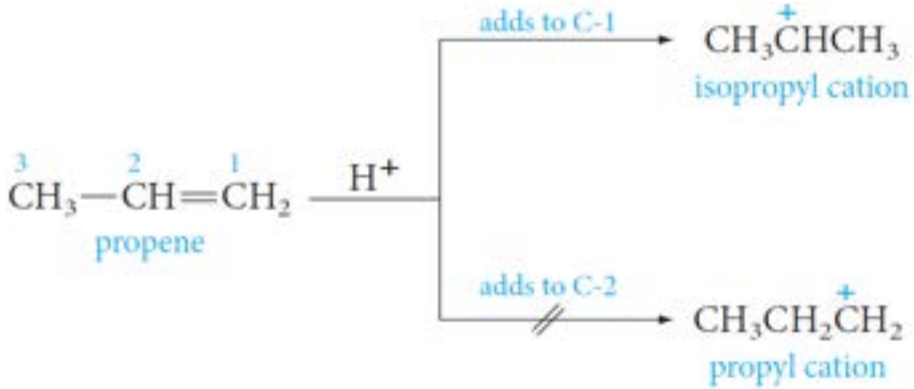
Markovnikov's Rule

In electrophilic addition of H—X to ***Unsymmetrical Alkenes*** *the hydrogen of the hydrogen halide adds to the double-bonded carbon that bears the greater number of hydrogen atoms and the negative halide ion adds to the other double-bonded carbon.*



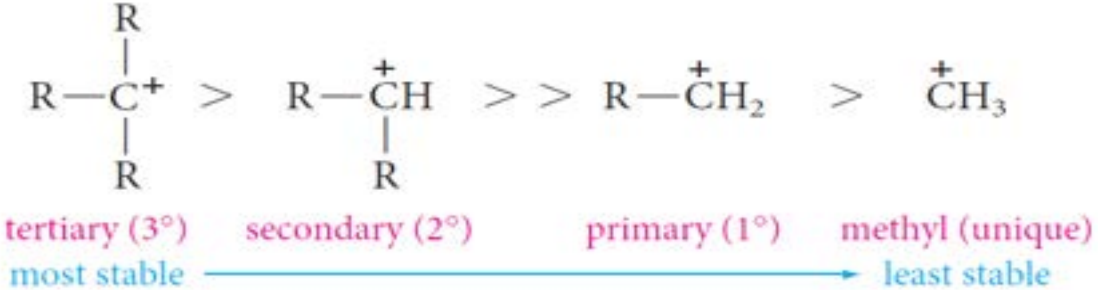
Explanation for Markovnikov's Rule

Example; *Addition of HBr to propene*



- **In modern terms Markovnikov's rule can be restated:**

  The addition of an unsymmetrical reagent HX *to an unsymmetrical alkene proceeds in such a direction as to produce the more stable carbocation.*



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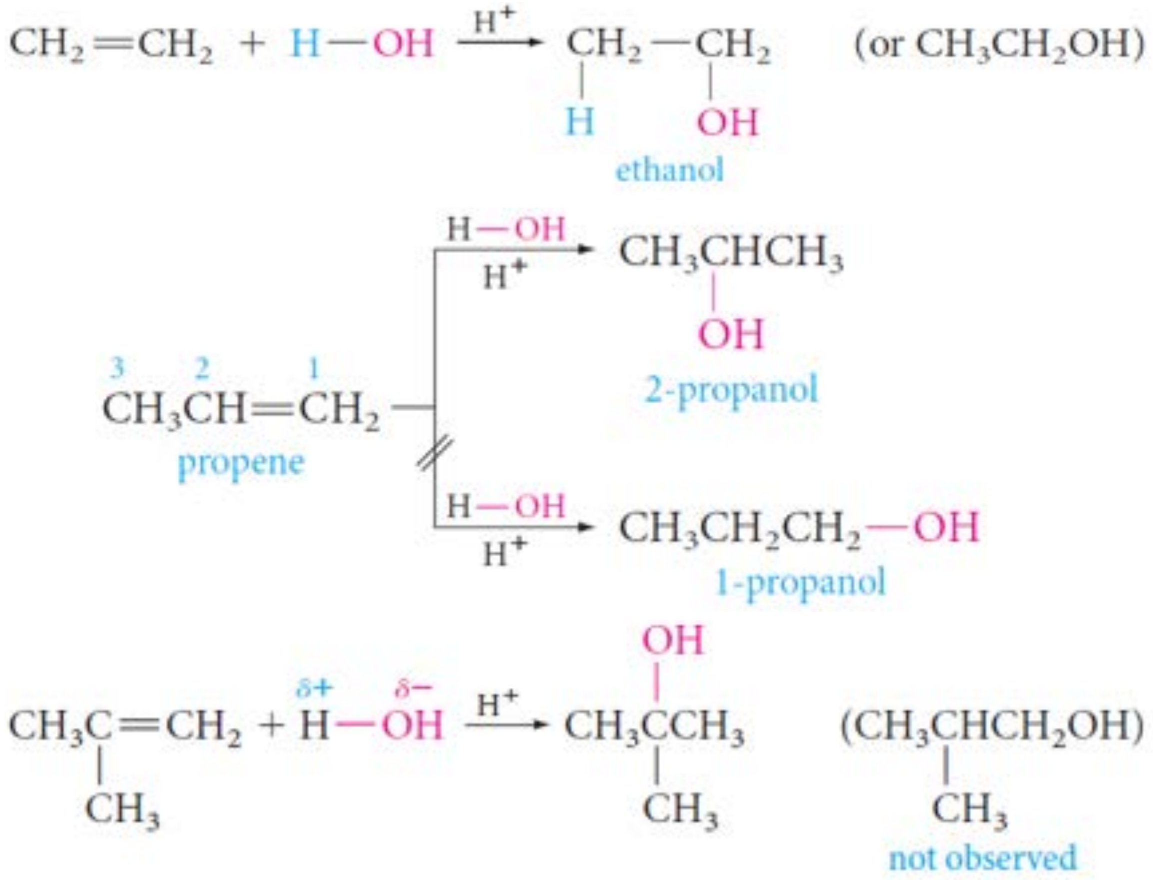
e. Addition of Water: Hydration

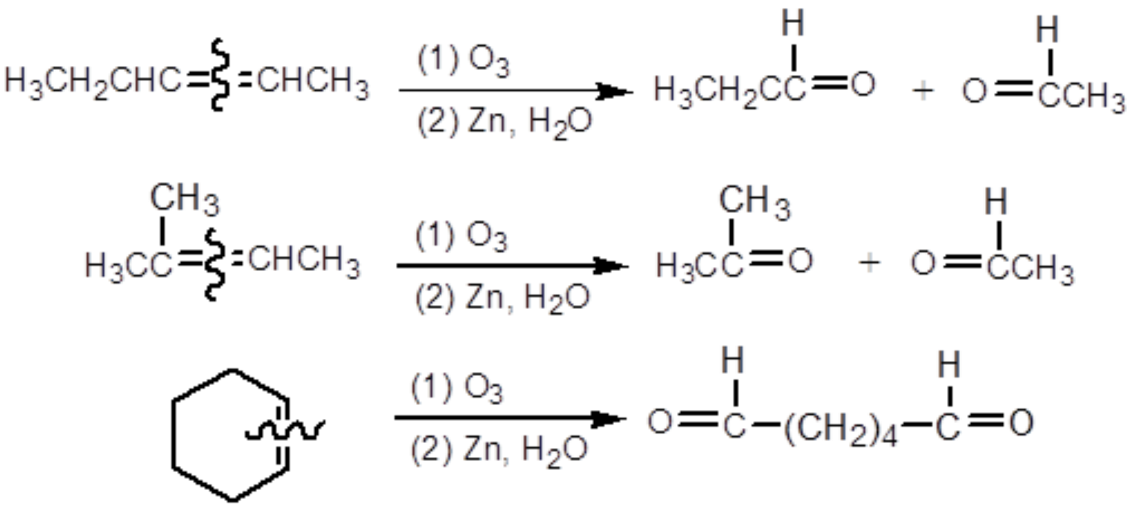
If an acid catalyst is present, water (as H-OH) adds to alkenes and the product is alcohol.



2. Oxidation Reactions

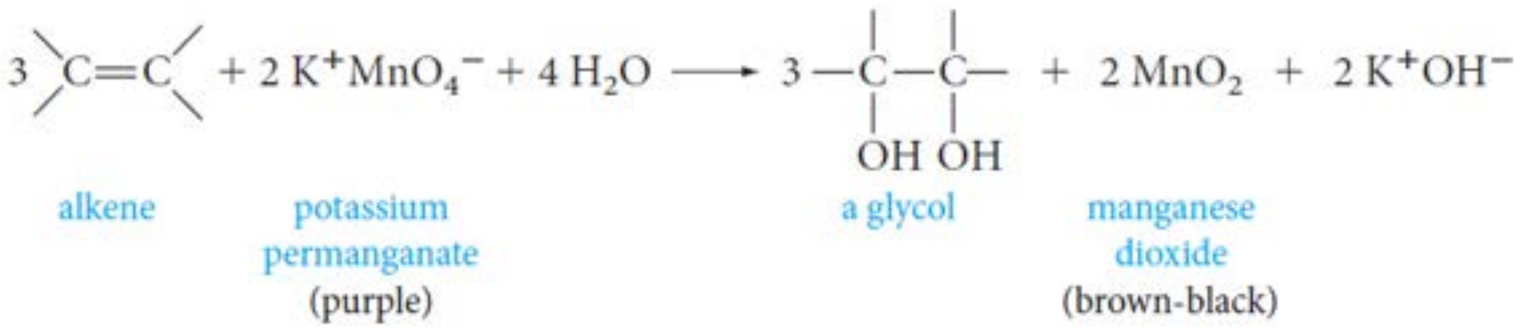
a. Ozonolysis

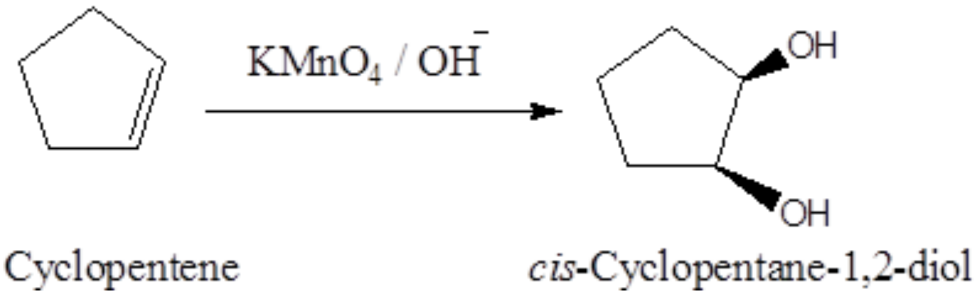
- Ozonolysis can be used to locate the position of a double bond.
- **Example**, ozonolysis of 1-butene gives two different aldehydes, whereas 2-butene gives a single aldehyde.



b. Oxidation Using $KMnO_4$

Alkenes react with alkaline potassium permanganate to form glycols (compounds with two adjacent hydroxyl groups).





Hexane does not react with purple $KMnO_4$ (left); cyclohexene (right) reacts, producing a brown-black precipitate of MnO_2.

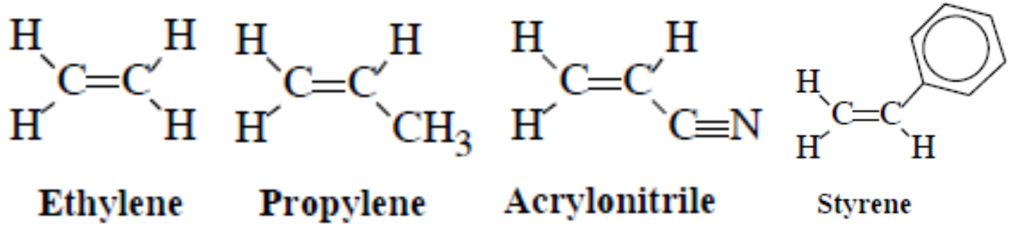
Use of Alkenes

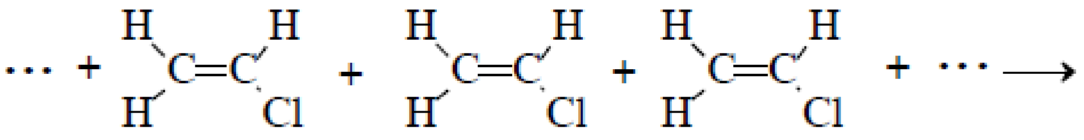
- SYNTHETIC POLYMERS

Synthetic polymers are produced when small molecules called monomers bond together to form a much smaller number of very large molecules.

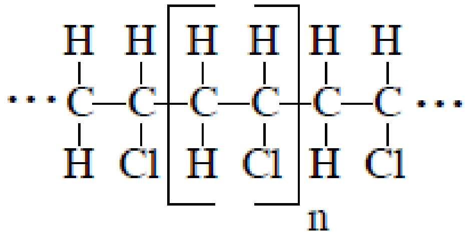
An important example:

- Polyvinylchloride; manufacture of water and sewer pipe.
- Polyethylene (plastic bags, milk cartons),
- Polypropylene, (impact-resistant plastics, indoor-outdoor carpeting),
- Polyacrylonitrile (Orlon, carpets),
- Polystyrene (foam insulation)





"n" vinyl chloride monomers



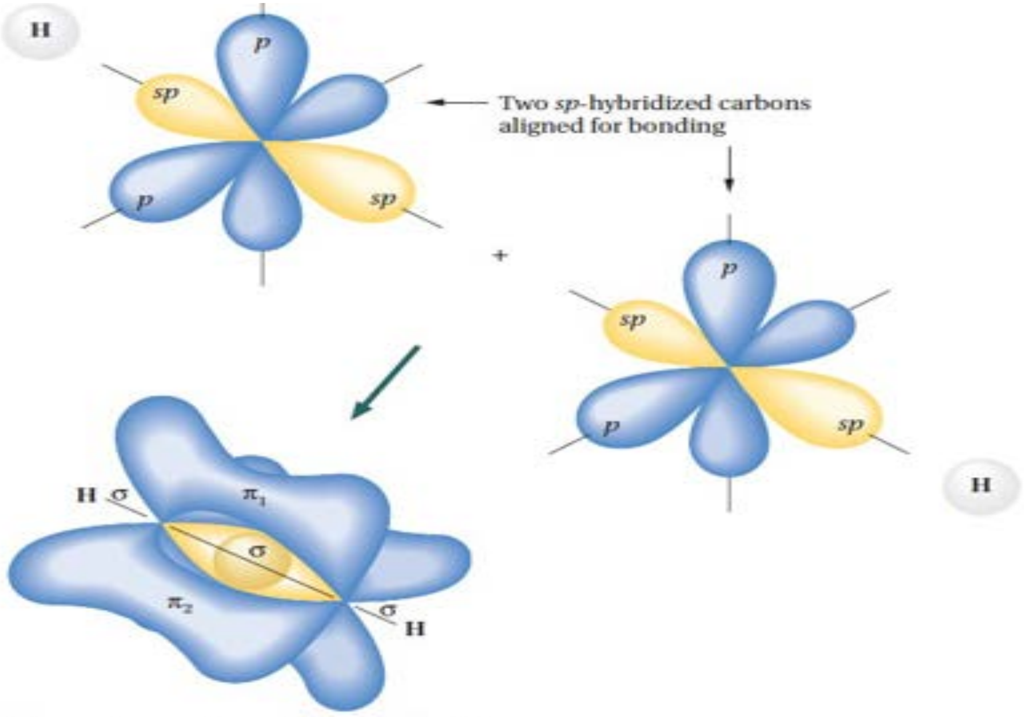
Polyvinylchloride polymer containing a large number, "n," monomer units per molecule

Unsaturated Hydrocarbons

Alkynes

The Structure of Alkynes

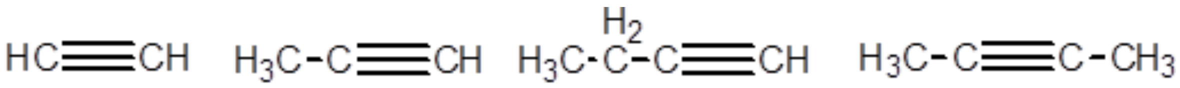
- **Alkynes** are hydrocarbons that contain a ***carbon–carbon triple bond***.
- **Alkynes** are also known as *Acetylenes*.
- General formula is C_nH_{2n-2}
- Hybridization; ***sp*-hybridized orbitals**
- The angle between them is **180°** and the bond length **1.20 A°**
- The geometry is **Linear.**



The resulting carbon-carbon triple bond, with a hydrogen atom attached to each remaining *sp* bond. (The orbitals involved in the C—H bonds are omitted for clarity.)

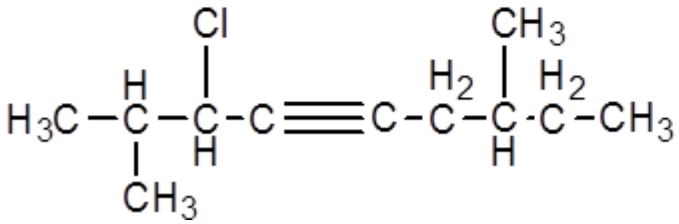
Unsaturated Hydrocarbons

- The simplest members of the Alkynes series are C_2 & C_3
- The IUPAC names are derived from the corresponding alkanes by replacing the –ane ending by –yne.
- IUPAC rules as discussed for Alkenes .



IUPAC name:	Ethyne	Propyne	1-Butyne	2-Butyne
Common name:	Acetylene			

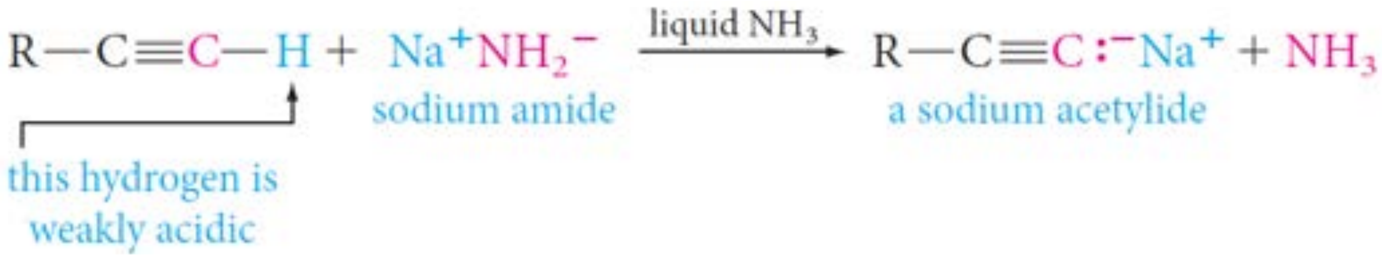
- **Example:**



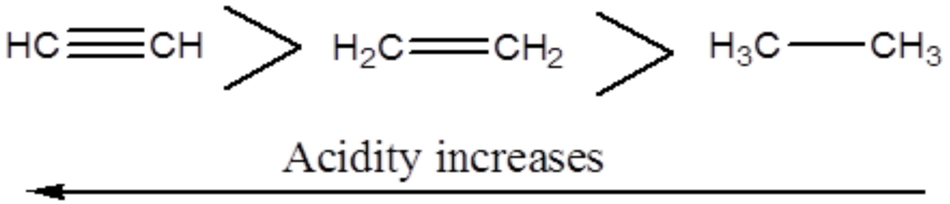
3-Chloro-2,7-dimethyl-4-nonyne

Acidity of Alkynes

- A hydrogen atom on a triply bonded carbon (**Terminal Alkyne**) is weakly acidic and can be removed by a very strong base (as Sodium amide).



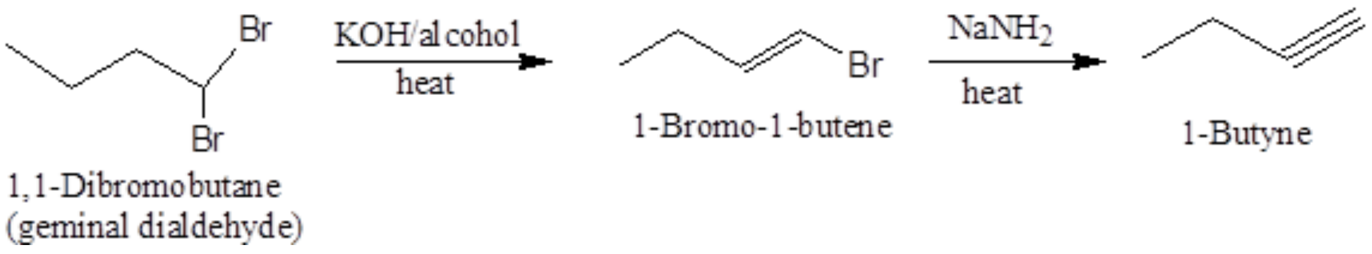
- Internal alkynes (**Non-Terminal Alkyne**) have no exceptionally acidic hydrogens.
  - Relative Acidity of the Hydrocarbon.
    Terminal alkynes, are more acidic than other hydrocarbons

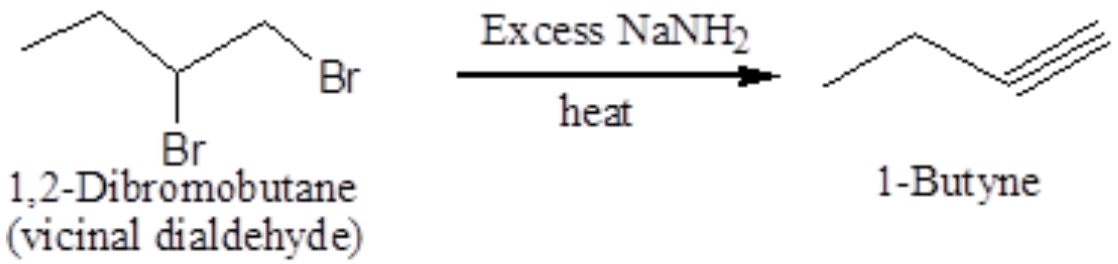


Preparation of Alkynes

1. Dehydrohalogenation of Alkyl dihalides

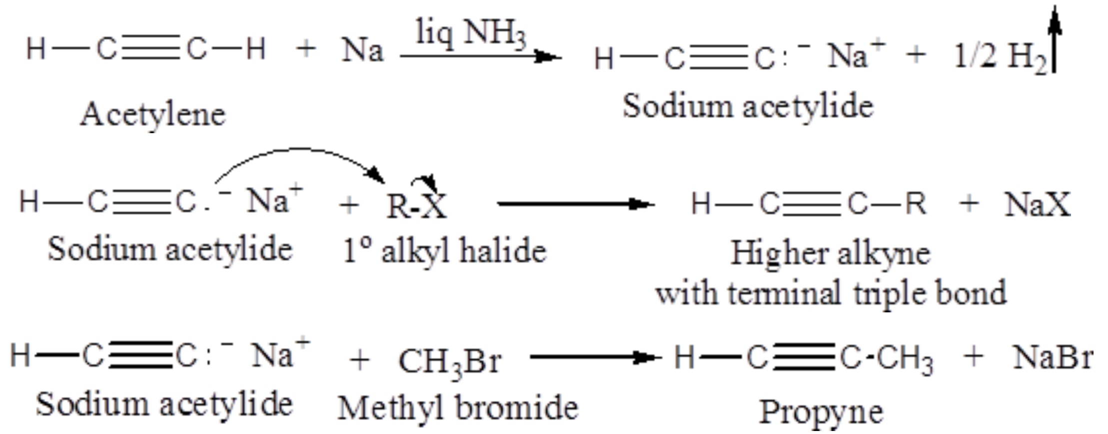
Alkynes can be prepared under alkaline conditions via deydrohalogenation of alkyl dihalides



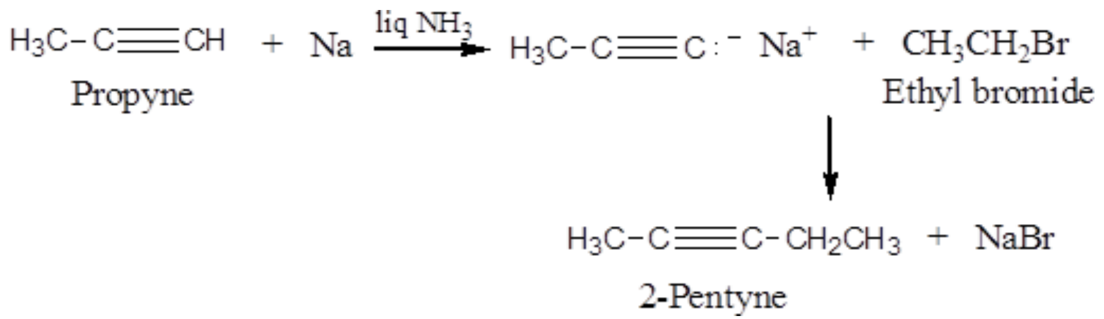


2. Reaction of Sodium Acetylide with Primary Alkyl Halides

- **Acetylene**



- **Monosubstituted Acetylenes**

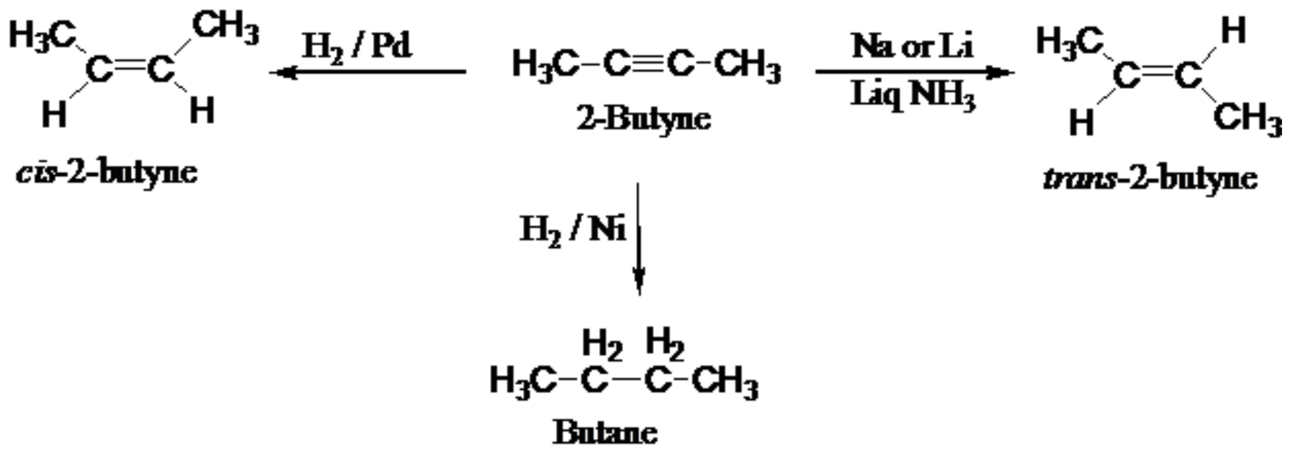


Reactions of Alkyne

Electrophilic Addition Reactions

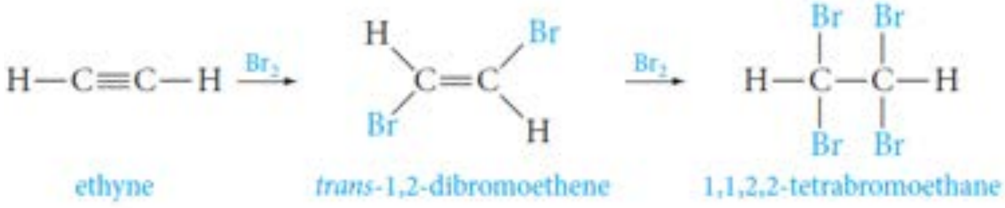
a. Addition of Hydrogen: Hydrogenation

- With an ordinary nickel or platinum catalyst, alkynes are hydrogenated all the way to alkanes.
- However, a special palladium catalyst (called Lindlar's catalyst) can control hydrogen addition so that only one mole of hydrogen adds. In this case, the product is a *cis* alkene.
- On the other hand, reduction using metals such a s sodium or lithium in liquid ammonia results in formation of trans alkenes.



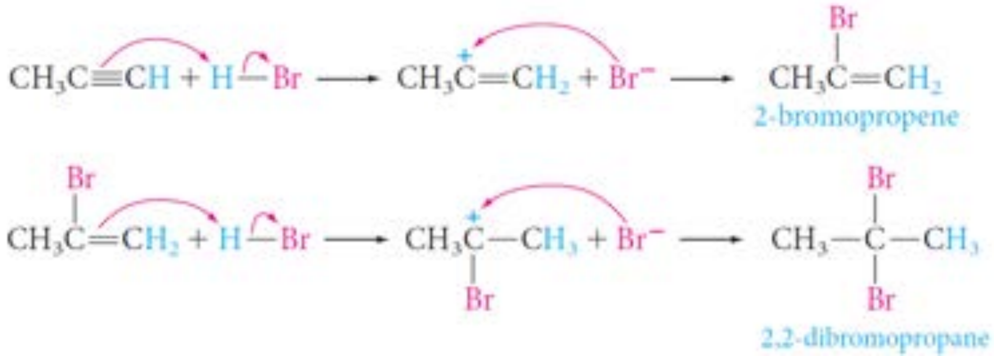
b. Addition of Halogen: Halogenation

Bromine adds as follows; In the first step, the addition occurs mainly *trans*.



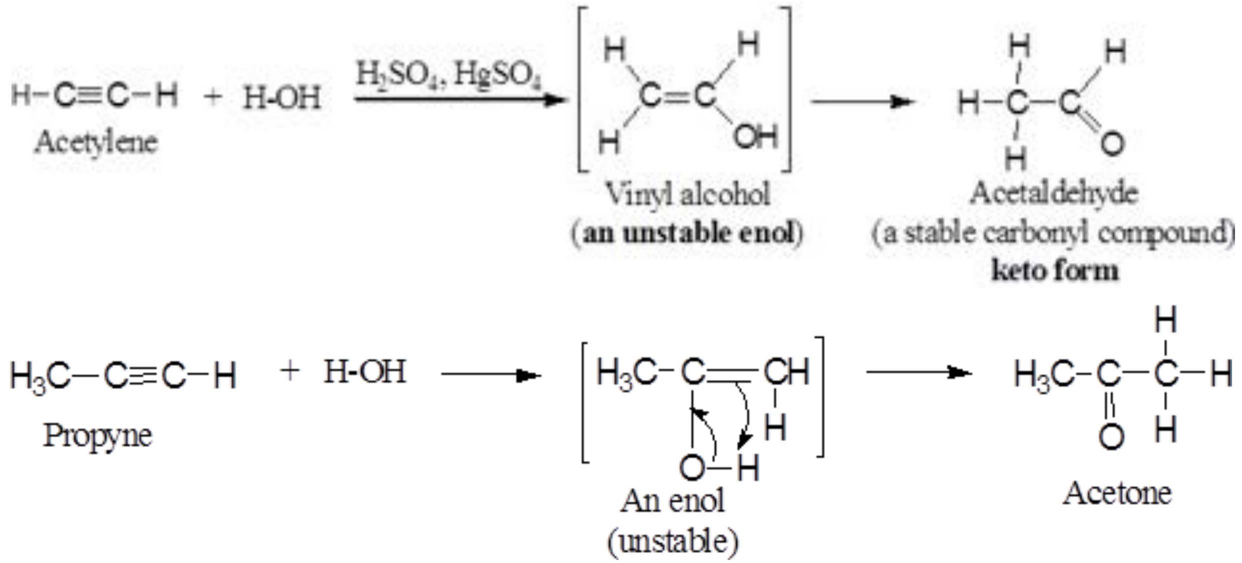
c. Addition of Hydrogen Halide

With unsymmetrical triple bonds and unsymmetrical reagents, Markovnikov's Rule is followed in each step, as shown in the following example:



d. Addition of Water: Hydration

- **Addition of water to alkynes** requires not only an acid catalyst but mercuric ion as well.
- The mercuric ion forms a complex with the triple bond and activates it for addition.
- Although the reaction is similar to that of alkenes, the initial product - a vinyl alcohol or enol - rearranges to a carbonyl compound (keto form).



Use of Alkenes

- Ethyne or acetylene reacts with oxygen to produce enough heat to weld metals.
- Anti-tumor agent

  Many alkynes are dangerous for humans when used in pharmaceuticals. However, specific alkynes, known as ene-diynes, hold a very strong and aggressive anti-tumor compound. Calicheamicin is an example of an anti-tumor working agent
- Drug production

  Alkynes are used in the manufacture of many drugs on the market, such as antiretroviral efavirenz and the antifungal terbinafine.
- General uses;
  - Making organic compounds
  - Organic solvents