GENERAL ORGANIC CHEMISTRY

1. GENERAL ORGANIC CHEMISTRY

1.1 Introduction

In 1807, Berzelius proposed the term 'Organic Chemistry' for the study of compounds derived from natural sources. This was based on the theory of **vitalism** which said that all living systems possessed a 'vital force' which was absent in non-living systems. Compounds derived from living natural sources (organic) were thought to be fundamentally different from inorganic compounds.

Vital Force	No Vital Force
Living Systems	Non-living Systems

The vital force could be philosophically thought as the mysterious force God instilled in the living systems.

In 1823, Friedrich Wohler joined Berzelius as his student. In 1828, Wohler made a discovery which changed the definition of organic chemistry. Wohler conducted the following experiment.

$$\overset{\oplus}{NH_4}\,\overset{\ominus}{\ddot{O}}CN(aq) \xrightarrow{\text{evaporation}} O{=}C(NH_2)_2(s)$$

Ammonium Cyanate (Inorganic) — Urea Crystals (Organic)

Wohler successfully synthesized an organic compound starting from an inorganic compound. Following this, many others synthesized organic compounds starting from inorganic compounds. Thus, the theory of vitalism and the definition of organic chemistry lost its meaning.

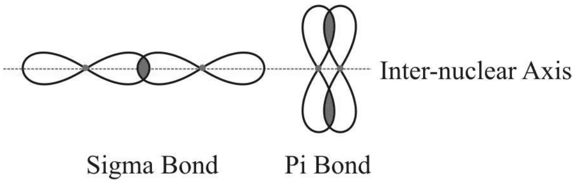
But what was common in all the above compounds synthesized was the presence of carbon. Carbon shows a special property **catenation**. Carbon can connect with other carbon atoms to form long chains and rings (self-catenation) and can connect with atoms of many other elements in the periodic table (cross-catenation). Because of this reason, carbon can form a wide variety of compounds. Therefore, **the modern definition of organic chemistry is the study of carbon compounds.**

Probably, the vital force can be explained by the fact that most of the life-giving and life-sustaining functions are performed by carbon compounds, for example, the human tissues and skin are formed by proteins, respiration is possible due to haemoglobin, the information in our genes is carried out in the form of DNA/RNA etc.

General Organic Chemistry is the detailed study of the basic concepts and factors that govern the progress and outcome of reactions.

> *Note..* The making and breaking of bonds usually occurs in several discrete steps before transforming transforming into products. The detailed sequential description of all the steps is called the **mechanism** of the reaction.

2.1 Sigma and Pi Bonds - Comparison



Property	Sigma (σ) Bond	Pi (π) Bond
Overlap	Axial/Head-on	Parallel/Lateral/ Side-ways
Electron Cloud	Along the inter-nuclear axis	Perpendicular to the inter-nuclear axis
Bond Strength	Stronger	Weaker

2.2 Structural Formulas

Several kinds of formulas are used by organic chemists to represent organic compounds.

2.2.1 Complete Formulas

Complete formulas are lewis structures which shows all bond pair of electrons as a dash (–). Lone pair of electrons are shown as a pair of dots.

2.2.2 Condensed Formulas

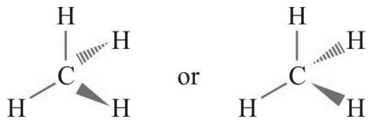
Condensed formulas are written without showing all the individual bonds. Each central atom is shown together with the atoms that are bonded to it.

2.2.3 Line-Angle Formulas

These are also called **skeletal structures** or a **stick figure**. Line-angle formulas are often used for cyclic compounds and occasionally for non-cyclic ones. Bonds are represented by lines, and carbon atoms are assumed to be present where two lines meet or a line begins or ends. Hydrogens are generally implicit in these drawings.

2.2.4 Tetrahedral Representation

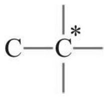
This is generally the three-dimensional (3-D) representation of molecules. Dashed Wedge (⫶⫶⫶) or solid wedge (◀) are used to indicate bonds projecting behind the plane (away from the observer) and out of the plane (towards the observer) respectively. Bonds lying in the plane of paper are depicted by using a normal line (—).



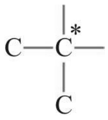
2.3 Degrees of Carbon

It is defined as the number of carbons attached to carbon under observation.

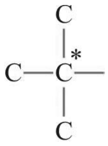
Methyl



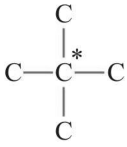
1° (Primary)



2° (Secondary)



3° (Tertiary)



4° (Quaternary)

2.4 Hybridization

Hybridisation is a process in which two or more atomic orbitals of comparable energy of the valence-shell of an atom (**central atom** of the molecule or ion) either in its ground state or in its excited state mix together and give rise to the formation of new degenerate orbitals which are called **hybrid orbitals**.

2.5 Applications of Hybridization

Hybridization	% s-character
sp^3	25.0
sp^2	33.3
sp	50.0

2.5.1 Size of Hybrid Orbitals

As % s-character increases, size of hybrid orbital decreases. Therefore

Size of Hybrid Orbital : $sp^3 > sp^2 > sp$

2.5.2 Electronegativity of Hybrid Orbitals

As % s-character increases, electronegativity of hybrid orbital increases. Therefore

EN of Hybrid Orbital : $sp > sp^2 > sp^3$

2.6 Dienes

Dienes are organic compounds containing two double bonds. There are three types of dienes :

(a) Isolated (b) Conjugated (c) Cumulated

2.6.1 Isolated Diene

In this case, double bonds are separated by atleast one sp^3 carbon.

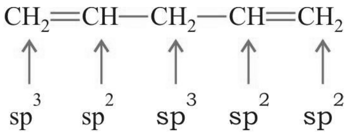
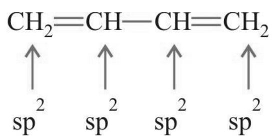


Table : Hybridization of Common Molecules.

Molecule	σ	π	LP	Hybridization	Geometry	Shape
$*CH_4$	4	0	0	sp^3	Tetrahedral	Tetrahedral
$*\ddot{N}H_3$	3	0	1	sp^3	Tetrahedral	Trigonal Pyramidal
$H_2\ddot{\underset{..}{O}}*$	2	0	2	sp^3	Tetrahedral	V-shape or Bent
$*CH_2{=}CH_2$	3	1	0	sp^2	Trigonal Planar	Trigonal Planar
$*CH{\equiv}CH$	2	2	0	sp	Linear	Linear

2.6.2 Conjugated Diene

Double bonds are separated by only one single bond (or 4 sp^2 carbons in a row).



$$\underset{sp^2}{CH_2}=\underset{sp^2}{CH}-\underset{sp^2}{CH}=\underset{sp^2}{CH_2}$$

2.6.3 Cumulated Diene

Both sets of double bonds are at the same carbon.

$$CH_3-CH=C=CH-CH_3$$

A substituted **allene**

An allene is $CH_2=C=CH_2$

2.6.4 Stability of Dienes

The relative stabilities of dienes follows the order

Conjugated > Isolated > Cumulated

Important: Stability $\propto \dfrac{1}{\text{Energy Content of the molecule}}$

2.7 Commonly Occuring Forms of Carbon

The commonly occuring forms of carbon are

(a) Diamond (b) Graphite (c) Carbides

(d) Fullerenes (e) Charcoal

Note...

Diamond - Each C is sp^3. Tetrahedral solid.

Graphite - Each C is sp^2. Layered solid with weak van der Waal's forces between layers.

Calcium Carbide - Each C is sp.

Fullerene - Each C is sp^2.

3. BREAKING OF BONDS

In organic chemistry, the bond that is important for the study of reactions is covalent bond. We, therefore, study ways in which a covalent bond can be broken.

(a) Homolytic Fission (b) Heterolytic Fission

3.1 Homolytic Fission or Homolytic Cleavage

In this kind of bond breaking, each atom separates with one electron, leading to the formation of highly reactive species known as radicals (or free radicals).

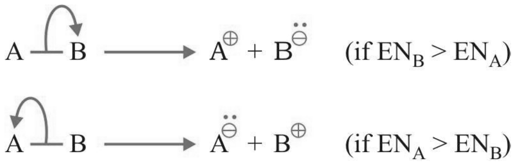
$$A-B \longrightarrow A^\bullet + B^\bullet$$

The bond breaking is shown by two **half-headed or fish-hook** arrows. A half-headed arrow shows the movement of one electron.

Radicals are **neutral** and are **odd electron** species.

3.2 Heterolytic Fission or Heterolytic Cleavage

In this type of covalent bond breaking, the shared pair of electrons are transferred to the more electronegative part. Therefore, this fission leads to the formation of **a cation and an anion (ion-pair).**



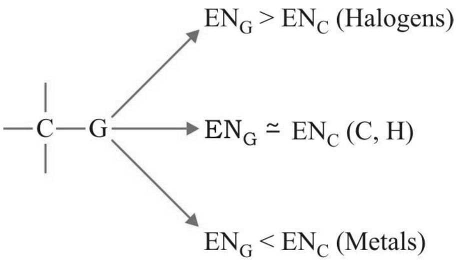
$$A-B \longrightarrow A^{\oplus} + \ddot{B}^{\ominus} \quad (\text{if } EN_B > EN_A)$$

$$A-B \longrightarrow \ddot{A}^{\ominus} + B^{\oplus} \quad (\text{if } EN_A > EN_B)$$

The bond breaking is shown by a **full-headed** arrow. A full headed arrow shows the movement of a pair of electrons. In organic chemistry, the movement of electrons is always shown by curved arrows - half-headed or full-headed arrows.

4. INDUCTIVE EFFECT

When two unlike atoms form covalent bond, the electron-pair forming the sigma bond is never shared equally between the two atoms but is shifted slightly towards the more electronegative species.



There are broadly three types of groups/atoms that may be attached to carbon as illustrated. Although C is more electronegative than H, the electronegativity difference is small and the bond is generally consider non-polar.

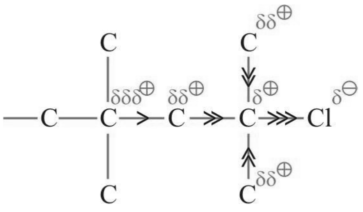
4.1 Nature of Inductive Effect

Inductive effect is a **permanent effect** and can be directly correlated to its dipole moment.

It is a weak effect as the shifting of electrons takes place only through sigma bonds.

4.2 Effect of branched carbon chain

An illustration has been marked for operation of inductive effect which is self-explanatory.



More the number of δ, lesser the effect

4.3 Electron Donating and Electron withdrawing Groups

Inductive effect may be due to single atom or a group of atoms. Relative inductive effects are measured with reference to hydrogen. Those which donate electrons to carbon chain are called **electron-donating groups (EDG)** or **electron-releasing groups (ERG)** and are said to exert **+I effect**. Those which withdraw electrons from carbon chain are called **electron-withdrawing groups (EWG)** and are said to exert **–I effect**.

Important :

1. I.E. of alkyl groups : 3° > 2° > 1° > CH_3–
2. In general, greater is the number of carbons in an alkyl group, greater is its +I effect.
3. For problem-solving, we take electronegativity of sp-hybridized carbon to be more than sp^3 hybridized nitrogen.

4.4 Applications of Inductive Effect

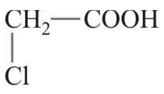
4.4.1 Effect on Acidic/Basic Strength

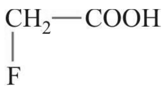
EWG increases acidic strength and decreases basic strength. ERG decreases acidic strength and increases basic strength.

Example - 1

Compare the acidic strength :

(I) $CH_3—COOH$

(II)

$\underset{Cl}{\underset{|}{CH_2}}—COOH$

(III)

$\underset{F}{\underset{|}{CH_2}}—COOH$

Solution :

An alkyl group is donating only if no other EWG is present on it. Therefore, groups like $–CH_2Cl$ and $–CH_2F$ become electron withdrawing groups.

Order of Acidic Strength : III > II > I

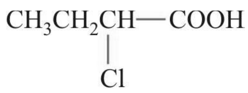
4.4.2 Effect of Distance

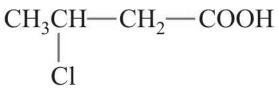
If the ERG/EWG moves away, the inductive effect diminishes.

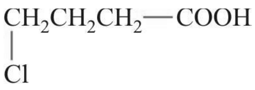
Example - 2

(a) Compare the acidic strength of :

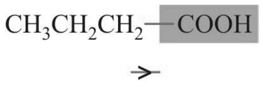
(I) $CH_3CH_2CH_2—COOH$

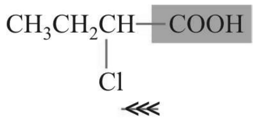
(II)

$CH_3CH_2\underset{Cl}{\underset{|}{CH}}—COOH$

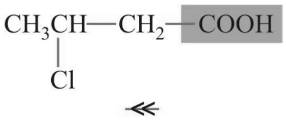
(III)

$CH_3\underset{Cl}{\underset{|}{CH}}—CH_2—COOH$

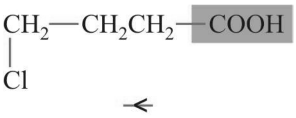
(IV)

$\underset{Cl}{\underset{|}{CH_2}}CH_2CH_2—COOH$

Solution :

(a) (I)

$CH_3CH_2CH_2—COOH$

(II)

$CH_3CH_2\underset{Cl}{\underset{|}{CH}}—COOH$

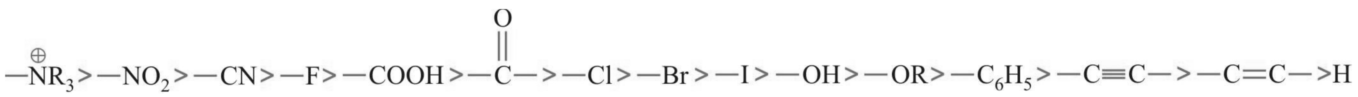
(III)

$CH_3\underset{Cl}{\underset{|}{CH}}—CH_2—COOH$

(IV)

$\underset{Cl}{\underset{|}{CH_2}}—CH_2CH_2—COOH$

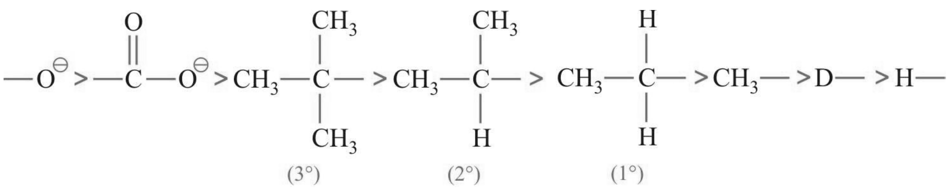
Order of acidic strength : II > III > IV > I

Series of +I and –I groups in order of their strength

–I Series (EWG)


$\overset{\oplus}{—NR_3} > —NO_2 > —CN > —F > —COOH > —\overset{O}{\overset{\|}{C}}— > —Cl > —Br > —I > —OH > —OR > —C_6H_5 > —C\equiv C— > —C=C— > H$

+I Series (ERG)


$—O^{\ominus} > —\overset{O}{\overset{\|}{C}}—O^{\ominus} > CH_3—\underset{CH_3}{\overset{CH_3}{C}}— > CH_3—\underset{H}{\overset{CH_3}{C}}— > CH_3—\underset{H}{\overset{H}{C}}— > CH_3— > D— > H—$

4.4.3 Basicity of Amines

The order in **gaseous or liquid phase** is :

$$3° > 2° > 1° > NH_3$$

To determine the basic strength of amines in **aqueous phase**. We have to consider **inductive effect, solvation effect and steric hinderance**. The order of basic strength is therefore experimental in aqueous state as we can't give priority to stability provided by any one factor. Two results are important for aqueous phase :

(a) $(CH_3)_2NH > CH_3NH_2 > (CH_3)_3N > NH_3$

i.e. $2° > 1° > 3° > NH_3$ $(R = CH_3)$

(b) $(C_2H_5)_2NH > (C_2H_5)_3N > C_2H_5NH_2 > NH_3$

i.e. $2° > 3° > 1° > NH_3$ $(R = C_2H_5)$

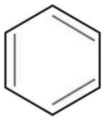
5. RESONANCE

Molecules are generally represented by simple lewis structures but some molecules can not be represented by just one Lewis structure. This led to the discovery of resonance. Resonance refers to the delocalization of electrons (generally π-electrons).

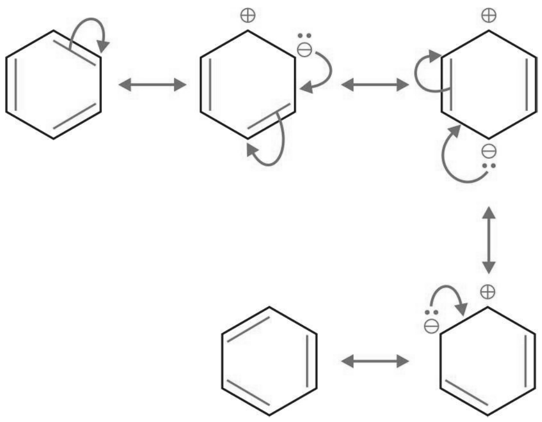
5.1 Conjugated Systems

5.1.1 Pi alternate Pi

Example - 3

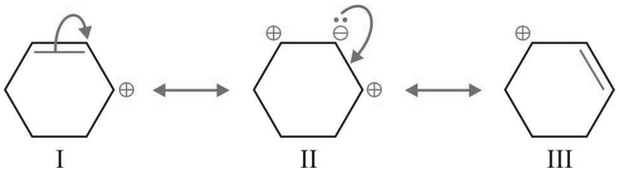


Benzene



5.1.2 Pi alternate Positive Charge

Example - 4



5.1.3 Pi alternate Negative Charge

Example - 5

$$CH_2=CH-\overset{\ominus}{\ddot{C}}H_2 \longleftrightarrow \overset{\ominus}{\ddot{C}}H_2-CH=CH_2$$

5.1.4 Pi alternate Odd Electron

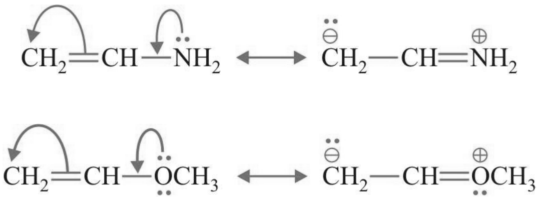
Example - 6

$$CH_2=CH-\dot{C}H_2 \longleftrightarrow \dot{C}H_2-CH=CH_2$$

5.1.5 Pi alternate Lone Pair

This case is similar to 'pi alternate negative charge' as lone pair and negative charge are treated similarly.

Example - 7



$$CH_2=CH-\ddot{N}H_2 \longleftrightarrow \overset{\ominus}{\ddot{C}}H_2-CH=\overset{\oplus}{N}H_2$$

$$CH_2=CH-\underset{\cdot\cdot}{\ddot{O}}CH_3 \longleftrightarrow \overset{\ominus}{\ddot{C}}H_2-CH=\underset{\cdot\cdot}{\overset{\oplus}{O}}CH_3$$

5.1.6 Lone Pair and Positive Charge on Adjacent Atoms

Example - 8

$$\overset{\oplus}{C}H_2-\ddot{N}H_2 \longleftrightarrow CH_2=\overset{\oplus}{N}H_2$$

5.2 Rules for Validity of Lewis Structures

Rule-1 :

All the lewis structures must conform to lewis octet rule.

Rule-2 :

Position of atoms in all resonating structures must be the same. Only the electrons move.

Rule-3 :

All the resonating structures must have the same number of paired and unpaired electrons, i.e. sum of bond pairs and lone pairs must be constant.

Rule-4 :

All the atoms participating in resonance in a molecule must be coplanar. This is required for the effective overlap of p orbitals and the delocalization of electrons, for eg, buta-1,3-diene.

5.3 Criteria for Major/Minor Contributors

Resonance forms can be compared using the following criteria in the following order :

1. As many octets as possible (a neutral molecule is always more stable in which its octet is complete).
2. As many π bonds as possible.
3. Negative charge on more electronegative atom is stable.
4. Charge separation.

(a) Similar charges - Keep them as FAR as possible to minimize repulsion and instability.

(b) Opposite charges - Keep them as NEAR as possible to maximize attraction and stability.

Example - 9

Which of the following structures is more stable ?

$$\overset{\oplus}{C}H_2-\ddot{N}H_2 \longleftrightarrow CH_2=\overset{\oplus}{N}H_2$$

(I) (II)

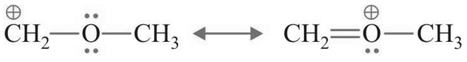
Solution :

II is more stable as all the octets are complete.

Example - 10

Which of the following is more stable in the following pairs ?

(a)



$$\overset{\oplus}{C}H_2-\ddot{\underset{\cdot\cdot}{O}}-CH_3 \longleftrightarrow CH_2=\overset{\oplus}{\underset{\cdot\cdot}{O}}-CH_3$$

(I) (II)

(b)

$$\overset{\ominus}{\ddot{C}}H_2-\overset{O}{\overset{\|}{C}}-H \longleftrightarrow CH_2=\overset{\ddot{O}^{\ominus}}{\overset{|}{C}}-H$$

(I) (II)

Solution :

(a) In II, all octets are complete. Therefore, II is more stable.

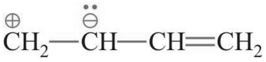
(b) I and II are tied on octets and number of π bonds but negative charge is more stable on more electronegative atom. Hence, II is more stable.

Example - 11

Give the order of stability of following resonating structures

(I) $CH_2=CH-CH=CH_2$

(II)

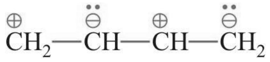


$$\overset{\oplus}{C}H_2-\overset{\ominus}{\ddot{C}}H-CH=CH_2$$

(III)

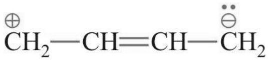
$$\overset{\oplus}{C}H_2-\overset{\ominus}{\ddot{C}}H-\overset{\ominus}{\ddot{C}}H-\overset{\oplus}{C}H_2$$

(IV)



$$\overset{\oplus}{C}H_2-\overset{\ominus}{\ddot{C}}H-\overset{\oplus}{C}H-\overset{\ominus}{\ddot{C}}H_2$$

(V)



$$\overset{\oplus}{C}H_2-CH=CH-\overset{\ominus}{\ddot{C}}H_2$$

Solution :

In (I), there are maximum number of pi bonds. Therefore, it is most stable. In (II) and (V), the number of pi bonds is equal but charge separation is greater in (V). Therefore, (II) is more stable than (V). In (III) and (IV), there is maximum charge separation but (III) is highly unstable due to electrostatic repulsion. Hence, the order of stability is :

I > II > V > IV > III

6. MESOMERIC EFFECT

The permanent polarization, due to a group conjugated with a π bond or a set of alternate π bonds, is transmitted through the π electrons of the system-resulting in a different distribution of electrons in the unsaturated chain.

This kind of electron redistribution in unsaturated compounds conjugated with electron-releasing or electron-withdrawing groups (or atoms) is called **Mesomeric Effect or Resonance Effect**.

This effect is **permanent** and is indicated by the dipole moment.

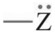
6.1 Electron-Releasing and Electron-Withdrawing Groups

Groups which release or withdraw electrons by resonance are said to exert M or R effect.

6.1.1 Electron-Releasing Groups (+R or +M effect)

$$-\ddot{\underset{\cdot\cdot}{O}}H, -\ddot{\underset{\cdot\cdot}{O}}R, -\ddot{N}H_2, -\ddot{N}HR, -\ddot{N}R_2, -\ddot{\underset{\cdot\cdot}{S}}H, -\ddot{\underset{\cdot\cdot}{S}}R, -\ddot{\underset{\cdot\cdot}{X}}:$$

The common thing about all the groups listed is that the atom connected with the conjugated system has a lone pair to donate. Therefore, a generic representation can be



$$-\ddot{Z}$$

6.1.2 Electron-Withdrawing Groups (–R or –M effect)

$-NO_2, -CN, -CHO, -COR, -COOH, -SO_3H, -\overset{\oplus}{N}R_3, -\overset{\oplus}{N}H_3$

The common thing about all the groups listed is that the atom connected with the conjugated system has a π bond with another more electronegative atom which withdraws the electrons or directly has a positive charge on them. Therefore, a generic representation can be

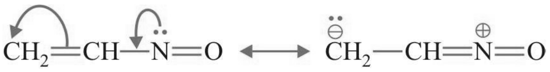
$-Y{=}Z \ (EN_Z > EN_Y)$

6.1.3 Dual Behaviour

Groups such as $-N{=}O$ are both electron-releasing and electron-withdrawing as illustrated.

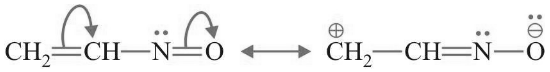
Example - 12

As electron releasing group



$CH_2{=}CH{-}\ddot{N}{=}O \longleftrightarrow \overset{\ominus}{\ddot{C}}H_2{-}CH{=}\overset{\oplus}{N}{=}O$

As electron withdrawing group



$CH_2{=}CH{-}\ddot{N}{=}O \longleftrightarrow \overset{\oplus}{C}H_2{-}CH{=}\ddot{N}{-}\overset{\ominus}{\ddot{O}}$

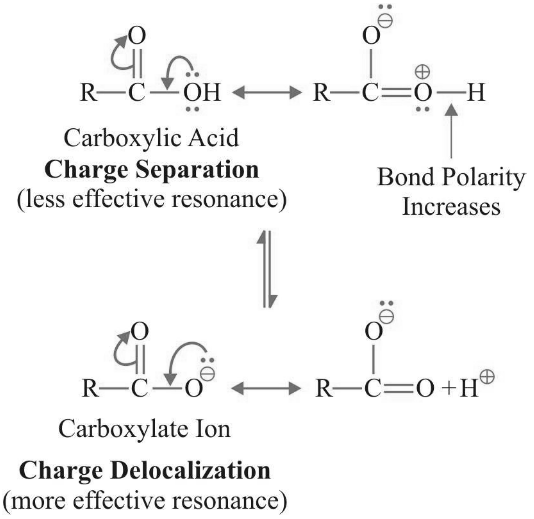
Which behaviour dominates and which is used in a particular context will be discussed later in **Electrophilic Aromatic Substitution** later.

Resonance Effect does NOT depend upon distance unlike inductive effect.

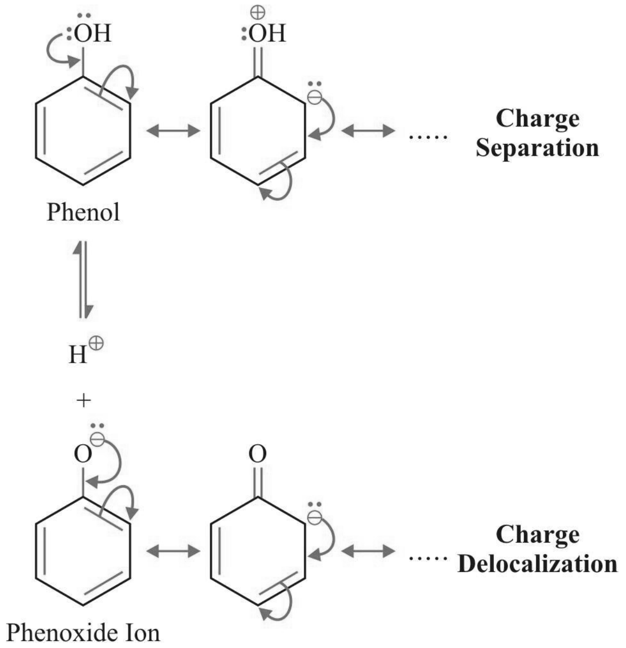
6.2 Applications of Mesomeric Effect

6.2.1 Effect on Acidic Strength of Carboxylic Acids and Phenols

The resonating structure of carboxylic acid leads to charge-separated structure which is less stable than the carboxylate ion in which charge is delocalized. Therefore, carboxylic acid readily loses proton ($H^{\oplus}$) to form a carboxylate ion.



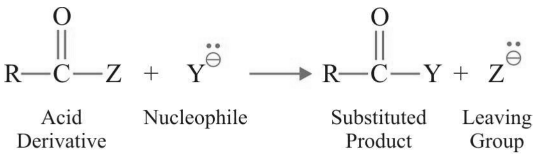
Similarly, in phenol, resonance leads to charge separation which increases the rate of ionization and forms phenoxide ion which is stabilized by charge delocalization.



> **Note..** Order of acidic strength
>
> $RSO_3H > RCOOH > H_2CO_3 > PhOH > CH_3OH > H_2O > ROH > HC{\equiv}CH > NH_3 > CH_4$

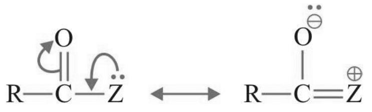
6.2.2 Effect on Reactivity of Carboxylic Acid Derivatives

A typical nucleophilic reaction is represented as :



$$\underset{\text{Acid Derivative}}{R{-}\overset{O}{\overset{\|}{C}}{-}Z} + \underset{\text{Nucleophile}}{\ddot{Y}^{\ominus}} \longrightarrow \underset{\text{Substituted Product}}{R{-}\overset{O}{\overset{\|}{C}}{-}Y} + \underset{\text{Leaving Group}}{\ddot{Z}^{\ominus}}$$

The stronger is the bond between C and Z, the difficult it is for a nucleophile to break a bond and therefore, lower reactivity.



$$R{-}\overset{O}{\overset{\|}{C}}{-}\ddot{Z} \longleftrightarrow R{-}\overset{\overset{\ominus}{\ddot{O}}}{\overset{|}{C}}{=}\overset{\oplus}{Z}$$

Reactivity order of carboxylic acid derivatives towards nucleophilic acyl substitution is :

Acyl Chloride > Acid Anhydride > Ester > Amide

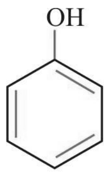
6.2.3 Effect of ERG/EWG on Acidic/Basic Strength

EWG increases the acidic strength and decreases the basic strength.

ERG decreases the acidic strength and increases the acidic strength.

Example - 13

Arrange the following in the order of decreasing acidic strength :


(I)

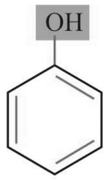

(II)


(III)


(IV)

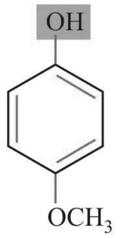

(V)

Solution :


(I)


(II)
–I
–M ✓

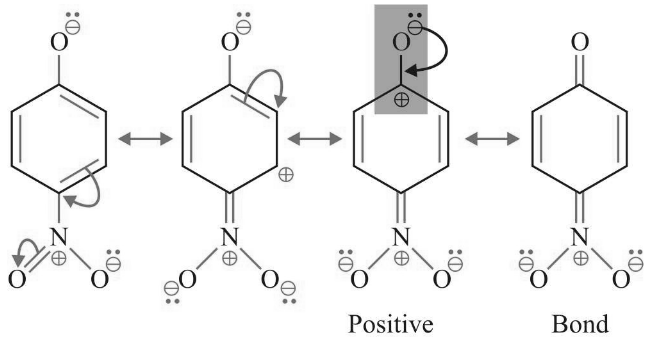

(III)
+I


(IV)
–I
+M ✓

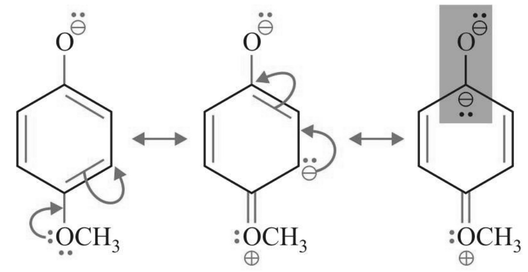

(V)
–I ✓
+M

The order of acidic strength is : II > V > I > III > IV

In the previous example, let's also discuss the stability of phenoxide ions corresponding to (II) and (IV).

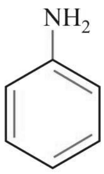

Positive and Negative Charge in Vicinity.
Attractive Forces
STABLE

Bond Formation leads to Stability.


Same Charges in Vicinity.
Repulsive Forces
UNSTABLE

Example - 14

Arrange the following in decreasing order of basic strength


(I)

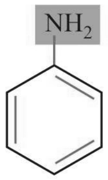

(II)


(III)


(IV)


(V)

Solution :


(I)


(II)
–I
–M ✓

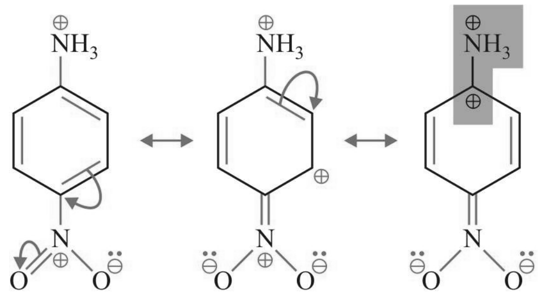

(III)
+I


(IV)
–I
+M ✓


(V)
–I ✓
+M

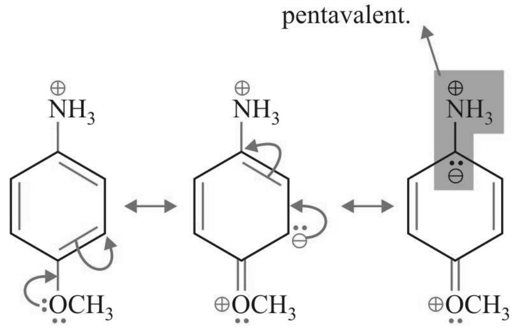
Therefore, order of basic strength is : IV > III > I > V > II

Let's also discuss the stability of anilinium ions corresponding to (II) and (IV).



Same Charges in Vicinity.
Repulsive Forces
UNSTABLE

Do NOT form a bond between N & C which renders nitrogen pentavalent.



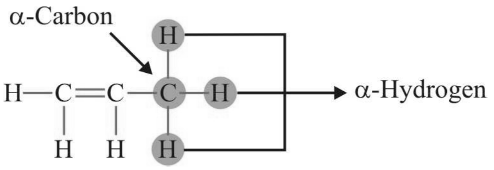
Opposite Charges in Vicinity.
Attractive Forces
STABLE

7. HYPERCONJUGATION

Hyperconjugation is the ability of the σ bond electrons of an α C—H bond to undergo conjugation with the adjacent π electrons. It is also known as **Baker-Nathan Effect**, **No-Bond Resonance** and **σ-π Effect**.

7.1 α-Carbon and α-Hydrogen

We have already discussed the α, β, γ nomenclature. Let's take an example :



α-Carbon is the carbon attached to a functional group such as C═C. The hydrogen attached to α-carbon is called α-hydrogen. **For an α C—H bond to be eligible for hyperconjugation, α C must be sp^3 hybridized**.

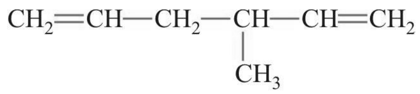
Example - 15

Mark the number of α-C and α-H in the given compounds

(a) $(CH_3)_2C{=}C(CH_3)_2$

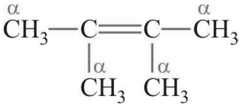
(b) $[((CH_3)_3C)_3C]_2C{=}C[C(C(CH_3)_3)_3]_2$

(c) $CH_2{=}CH{-}CH{=}CH_2$

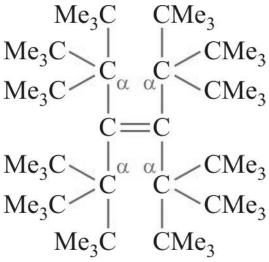
(d)


$CH_2{=}CH{-}CH_2{-}CH(CH_3){-}CH{=}CH_2$

Solution :

(a)


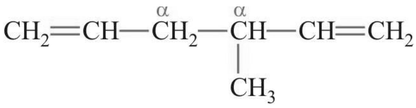
$\overset{\alpha}{C}H_3{-}C(\overset{\alpha}{C}H_3){=}C(\overset{\alpha}{C}H_3){-}\overset{\alpha}{C}H_3$

(b)


α C = 4, α H = 0

(c) $CH_2{=}CH{-}\overset{\alpha}{C}H{=}CH_2$

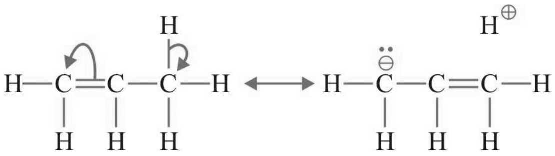
α C = 1, α H = 1 but since α C is sp^2 hybridized, therefore, it won't participate in hyperconjugation. Therefore, α H = 0 that will participate in hyperconjugation.

(d)


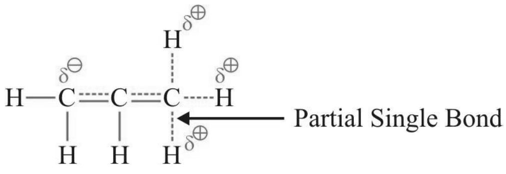
$CH_2{=}CH{-}\overset{\alpha}{C}H_2{-}\overset{\alpha}{C}H(CH_3){-}CH{=}CH_2$

α C = 2, α H = 3

7.2 Mechanism of Electron Donation in Hyperconjugation

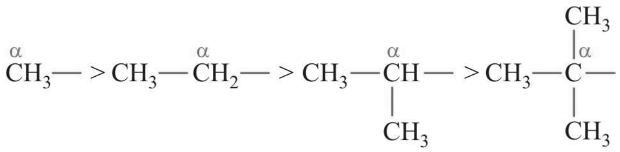


The hybrid formed by these resonating structures better known as hyperconjugating structures is :



Now, greater the number of α-H, greater the number of hyperconjugating structures and more is the electron donation of alkyl group to π bond.

The order of electron-donation of alkyl groups based on hyperconjugation is :



$$\overset{\alpha}{CH_3}— > CH_3—\overset{\alpha}{CH_2}— > CH_3—\underset{CH_3}{\overset{\alpha}{CH}}— > CH_3—\underset{CH_3}{\overset{CH_3}{C}}—$$

Methyl > 1° > 2° > 3°

More is the number of α-H, more is the π bond delocalized. This implies that more will be the stability of alkene and less will be the heat of hydrogenation and more is the **no-bond resonance energy**.

7.3 Applications of Hyperconjugation

7.3.1 Stability of Alkenes

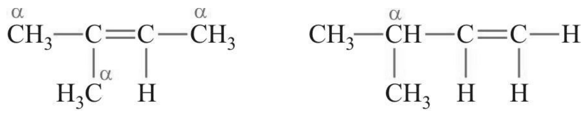
More is the number of α-hydrogen, more is the number of hyperconjugating structure and therefore more stability and greater no bond resonance.

Example - 16

Which alkene is more stable ?

$(CH_3)_2C{=}CH—CH_3$ (I) $(CH_3)_2CH—CH{=}CH_2$ (II)

Solution :



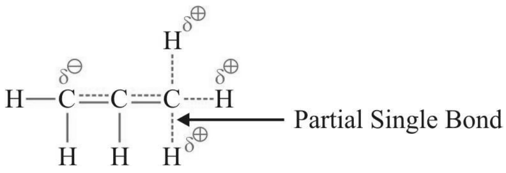
(I) (II)

αC = 3, αH = 9 αC = 1, αH = 1

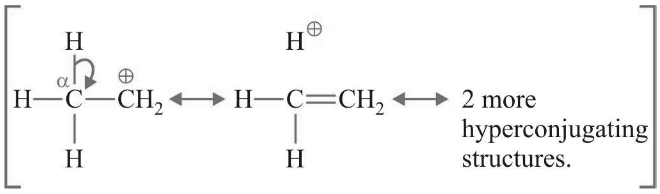
I is more stable than II.

7.3.2 Acidic Character of Alkenes

Hyperconjugation weakens the αC-H bond in hyperconjugation hybrid (partial single bond) and therefore αH can be lost easily.

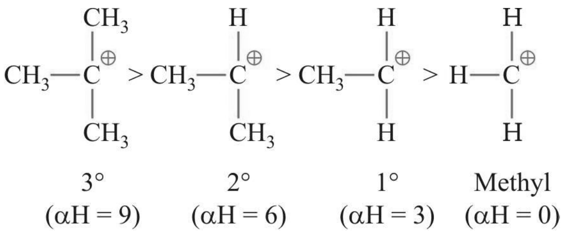


7.3.3 Stability of Carbocations



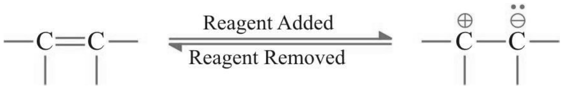
The positive charge on C is delocalized over αH to give stability to the carbocation. More is the number of αH, more is the stability of carbocations.

Stability of Carbocations



8. ELECTROMERIC EFFECT

Electromeric effect is observed only in the presence of a reagent and is therefore, a temporary effect. When a reagent approaches a molecule, the multiple bond such as $C{=}C$ or $C{=}O$ is polarized by the complete transfer of π electrons.



When the multiple bond is between two unlike atoms, the shift of electrons takes place towards more electronegative atom.

9. COMPARISON OF INDUCTIVE, HYPERCONJUGATION AND RESONANCE EFFECTS

Inductive Effect is a **σ-σ** interaction and acts through **strong sigma bonds**.

Resonance/Mesomeric Effect is a **π-π** interaction and acts through **weak pi bonds**.

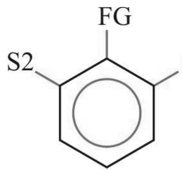
Hyperconjugation is a **σ-π** interaction and acts through a **strong sigma and a weak pi bond**.

Therefore, the order of importance is :

Resonance > Hyperconjugation > Inductive

10. STERIC INHIBITION OF RESONANCE (SIR)

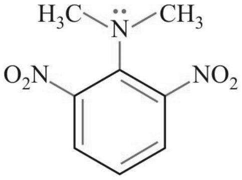
When both the **ortho positions** of a **bulky functional group** are occupied by **bulky substituents**, all the three groups are out of plane of the benzene ring.



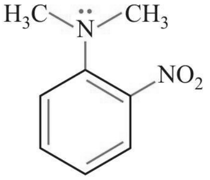
FG, S1, S2 - Bulky Groups

Example - 17

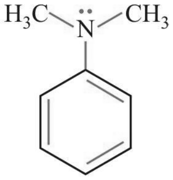
Mark the order of basic strength :



(I)



(II)



(III)

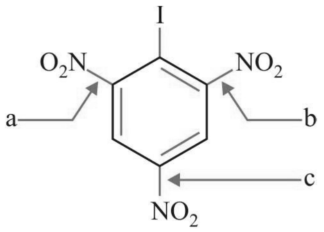
Solution :

In (II) and (III), the lone pair of N is in conjugation with the benzene ring and is not available for donation. (II) is less basic than (III) due to –I and –M of $-NO_2$ group. It may seem that (I) is least basic due to presence of 2 $-NO_2$ groups but $-NO_2$ and $-N(CH_3)_2$ are all bulky groups. This is a case of steric inhibition of resonance due to which the lone pair of N is not in conjugation and is readily available for electron donation. Hence, the order of basic strength is :

(I) > (III) > (II)

Example - 18

Mark the order of bond lengths in the given molecule.



Solution :

–I, $-NO_2$ are bulky groups and is case of steric inhibition of resonance. Therefore, the $-NO_2$ groups ortho to –I are out of conjugation while the $-NO_2$ group para to –I will be in conjugation with the benzene ring. Therefore, bonds 'a' and 'b' will always have single bond character while 'c' has double bond character. Therefore :

c < a = b

11. CARBOCATION

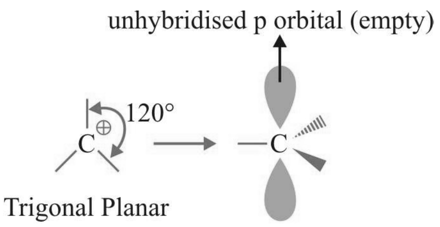
11.1 Definition

Carbocation is the intermediate of carbon containing positive charge. It has six electrons in the valence shell.

11.2 Geometry and Hybridization

Hybridization of $C^{\oplus}$ = sp^2

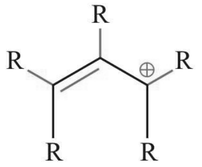
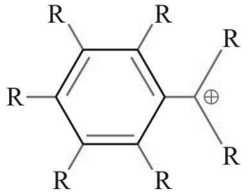
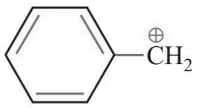
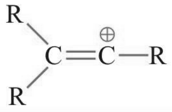
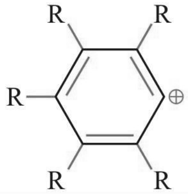
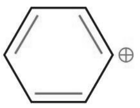
Geometry of $C^{\oplus}$ = Trigonal Planar



11.3 Classification of Carbocations

This classification will also be used for carbanions and carbon free radical and will be studied only in this section.

$\oplus CH_3$	Methyl Carbocation
$R-\overset{\oplus}{C}H_2$	1° Primary Carbocation
$R_2-\overset{\oplus}{C}H$	2° Secondary Carbocation
$R_3C\oplus$	3° Tertiary Carbocation

Type	Generic	Example
Allylic Carbocation		$CH_2=CH-\overset{\oplus}{C}H_2$ Allyl Carbocation
Benzylic Carbocation		 Benzyl Carbocation
Vinylic Carbocation		$CH_2=\overset{\oplus}{C}H$ Vinyl Carbocation
Aryl Carbocation		 Phenyl Carbocation

11.4 Stability of Carbocations

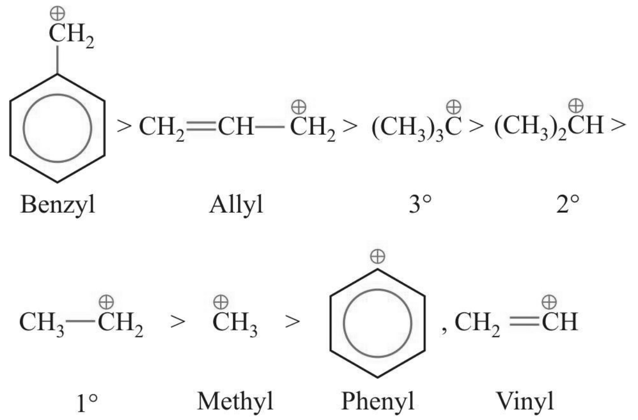
There are three factors contributing to the stability of carbocations :

(a) Inductive Effect

(b) Hyperconjugation

(c) Resonance

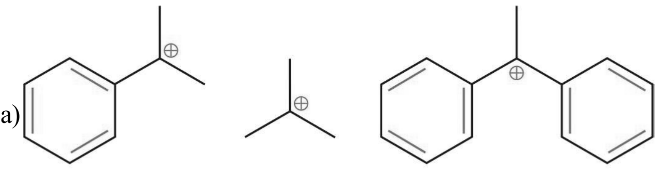
Order of stability :



Example - 19

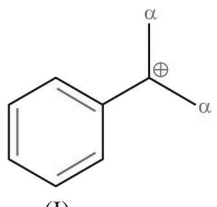
Rank the stability of carbocations in each case :

(a)



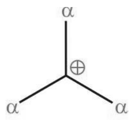
(I) (II) (III)

Solution :



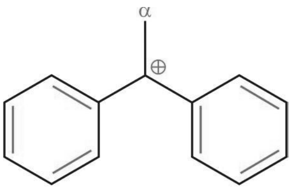
(I)

(a) Resonance Stabilization (Positive charge is delocalized over 4 atoms) and 6αH and +I.E.



(II)

9αH and +I.E.



(III)

Resonance Stabilization (Positive charge is delocalized over 7 atoms) and 3αH and +I.E.

Order of stability : III > I > II

11.5 Formation of Carbocations

11.5.1 Ionization of Carbon-Leaving Group Bond

In this method :

(a) Bond between carbon and leaving group ionizes.

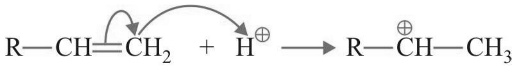
(b) Leaving group accepts the pair of electrons that were shared in the covalent bond.

Rate of formation of carbocation depends on :

(a) The stability of carbocation formed.

(b) The nature of the leaving group. **Weaker the base better the leaving group**. This is because weaker leaving group implies a stable compound and its formation will therefore be favoured.

11.5.2 Addition of Proton to a π bond



$$R{-}CH{=}CH_2 + H^{\oplus} \longrightarrow R{-}\overset{\oplus}{C}H{-}CH_3$$

Rate of carbocation formation depends on :

(a) Stability of carbocation formed.

(b) Strength of the electrophile.

11.6 Reactions of Carbocations

There are three important reactions of carbocations :

(a) Capture a Nucleophile

(b) Lose a proton to form a π bond.

(c) Rearrangement

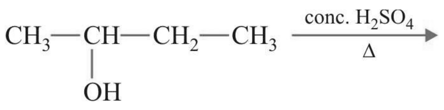
11.6.1 Capture a Nucleophile

$$R^{\oplus} + \ddot{N}u^{\ominus} \longrightarrow R{-}Nu$$

11.6.2 Loose a proton to form a π bond

Example - 20

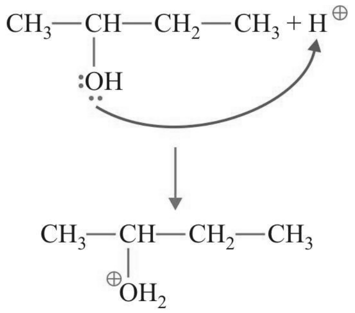
Form the products from the following reaction :



$$CH_3-\underset{OH}{\underset{|}{CH}}-CH_2-CH_3 \xrightarrow[\Delta]{conc.\ H_2SO_4}$$

Solution :

Step-1 : Protonation

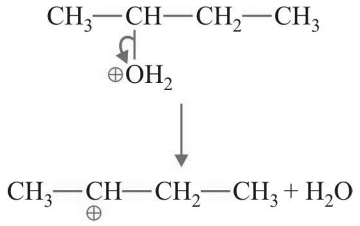


$$CH_3-\underset{:\ddot{O}H}{\underset{|}{CH}}-CH_2-CH_3 + H^{\oplus}$$

$$\downarrow$$

$$CH_3-\underset{\overset{\oplus}{O}H_2}{\underset{|}{CH}}-CH_2-CH_3$$

Step-2 : Formation of Carbocation

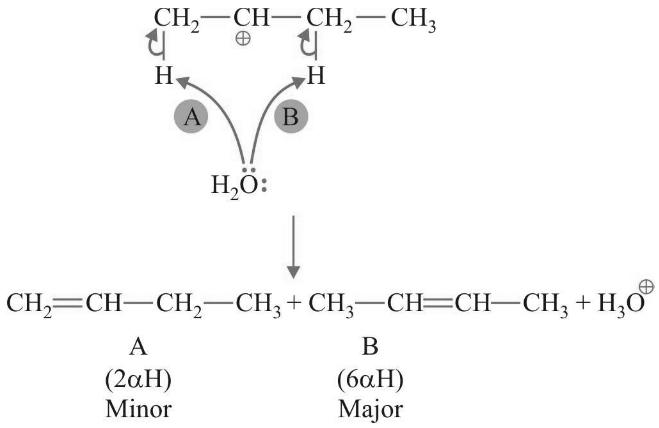


$$CH_3-\underset{\oplus OH_2}{\underset{|}{CH}}-CH_2-CH_3$$

$$\downarrow$$

$$CH_3-\underset{\oplus}{CH}-CH_2-CH_3 + H_2O$$

Step-3 : Deprotonation



$$\underset{H}{CH_2}-\underset{\oplus}{CH}-\underset{H}{CH_2}-CH_3$$

$$H_2\ddot{O}:$$

$$\downarrow$$

$$CH_2{=}CH-CH_2-CH_3 + CH_3-CH{=}CH-CH_3 + H_3O^{\oplus}$$

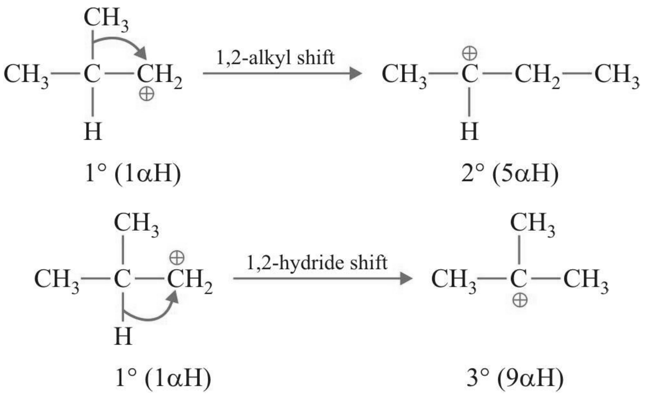
When carbocation deprotonation can lead to more than one product, all products are formed and the most stable product is the major product.

11.6.3 Carbocation Rearrangement

A carbocation can become more stable by rearrangement. Bonding electrons of carbocation may shift between adjacent atoms to form more stable carbocation. There are two kinds of shifts that take place in order to gain stability.

(a) Hydride Shift (b) Alkyl Shift

Example - 21



$$CH_3-\underset{H}{\overset{CH_3}{C}}-\overset{}{C}H_2^{\oplus} \xrightarrow{1,2\text{-alkyl shift}} CH_3-\underset{H}{\overset{\oplus}{C}}-CH_2-CH_3$$

$$CH_3-\underset{H}{\overset{CH_3}{C}}-\overset{\oplus}{C}H_2 \xrightarrow{1,2\text{-hydride shift}} CH_3-\underset{\oplus}{\overset{CH_3}{C}}-CH_3$$

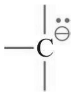
In the above example, both hydride and methyl shifts are possible leading to more stable carbocation but **only that shift is preferred which leads to more stable carbocation**. In this example, hydride shift will take place.

Important : The shift takes place in the form of $\ddot{H}^{\ominus}$ or $\ddot{C}H_3^{\ominus}$.

12. CARBANIONS

12.1 Definition

Carbanion is the intermediate of carbon containing negative charge. It has eight electrons in the valence shell.

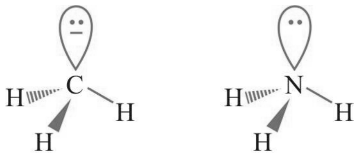


12.2 Geometry and Hybridization

Hybridization of $\ddot{C}^{\ominus}$: sp^3

Geometry : Trigonal Pyramidal

Carbanion and ammonia are isoelectronic species having same structure

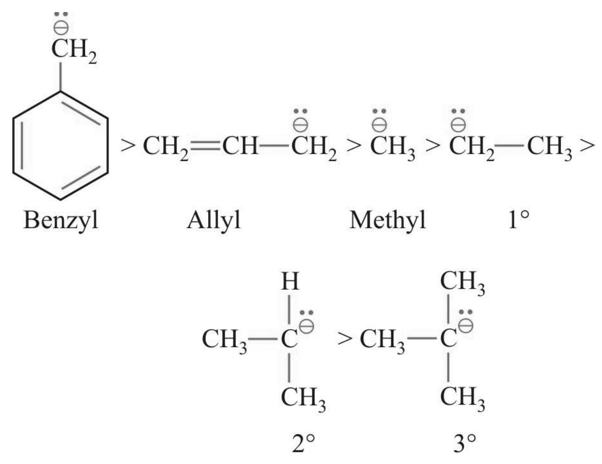


Carbanion Ammonia

12.3 Stability

ERG will increase the electron density at carbon and will make it unstable. EWG will decrease the electro density at carbon and will make it stable.

Order of Stability :



Example - 22

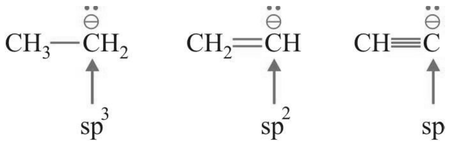
Give the order of stability of :

$CH_3-\overset{\ominus}{C}H_2$ (I) $\quad CH_2=\overset{\ominus}{C}H$ (II) $\quad CH\equiv\overset{\ominus}{C}$ (III)

Solution :

As s-character increases, electronegativity of C increases and therefore negative charge will become more stable. Therefore, order of stability is :

III > II > I



12.4 Formation of Carbanion

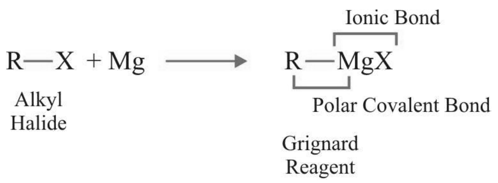
There are two methods for the formation of carbanion :

(A) Partial formation via Grignard Reagent

(B) Formation from Carbonyl Compounds

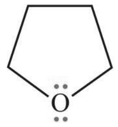
We will discuss these methods in the subsequent section

12.4.1 Formation via Grignard Reagent



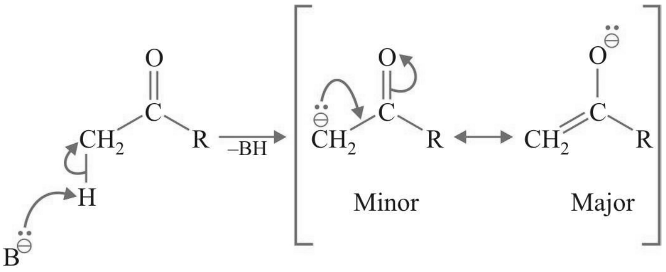
$\overset{\delta\ominus}{R}-\overset{\delta\oplus}{MgX}$ Development of partial charges in polar covalent bond.

1. Carbanion is never formed as an intermediate that can be isolated in the case of Grignard Reagent. It directly participates in the reaction.
2. Dry ether is used in this formation as it is inert to Grignard reagent. For the formation of Grignard reagent from aryl halides, we use tetrahedrofuran (THF) as solvent.



Tetrahydrofuran (THF)

12.4.2 Formation from Carbonyl Compounds



There are three reasons for the easy formation of carbanion from carbonyl compounds

(a) Resonance - stabilization of carbanion which is the conjugate base of carbonyl compound.

(b) Hyperconjugation makes the αC-H bond acidic.

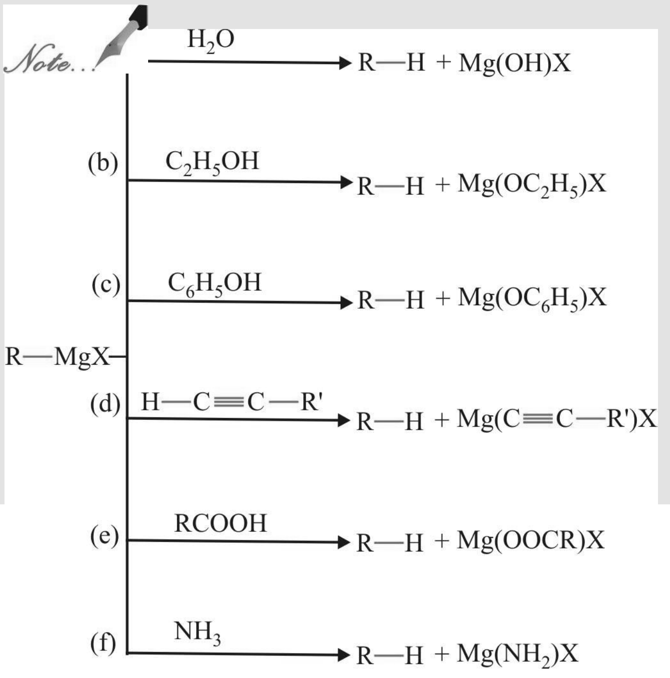
(c) –I of increases the acidic strength of C–H bond.

12.5 Reactions of Carbanion

The reactions of carbanion are very fast as electropositive carbon carries negative charge.

12.5.1 Grignard Reagent as a Base

In this reaction it captures acidic hydrogen.

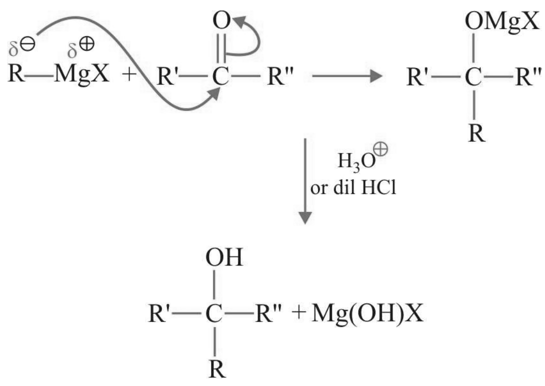


In (d), the reaction with terminal alkyne also takes place as sp-hydridized carbon is highly electronegative and therefore H attached to it is fairly acidic.

12.5.2 Grignard Reagent as a Nucleophile

Grignard Reagent reacts with carbonyl compounds to form alcohols. This is a very important method for the synthesis of alcohols.

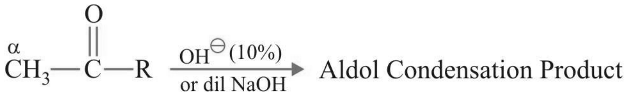
Mechanism :



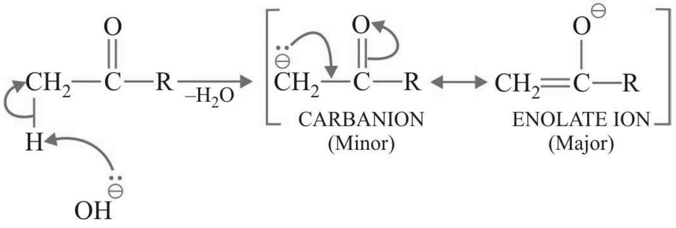
$H_3O^{\oplus}$ is never added along with the first step as Grignard Reagent will react with $H^{\oplus}$ to give R—H as in previous reaction.

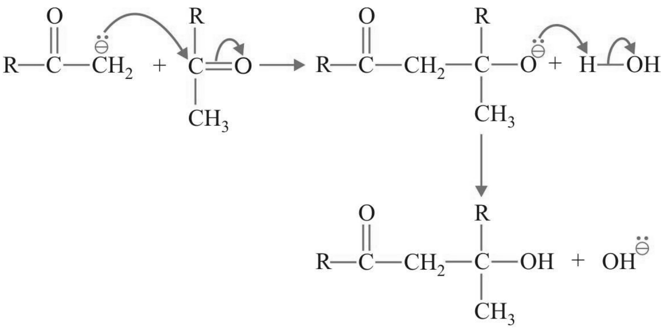
12.5.3 Aldol Condensation

This reaction is shown by carbonyl compounds containing atleast one αH in presence of dilute base such as dilute NaOH.



Mechanism :



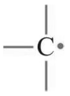


Aldol product

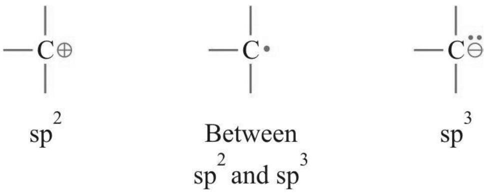
13. CARBON FREE RADICALS

13.1 Definition

Carbon Free Radical is the intermediate of carbon having an odd electron. It is neutral and has seven electrons in the valence shell. It is highly reactive as it requires only one electron to complete its octet and therefore, is short-lived.



13.2 Geometry and Hybridization



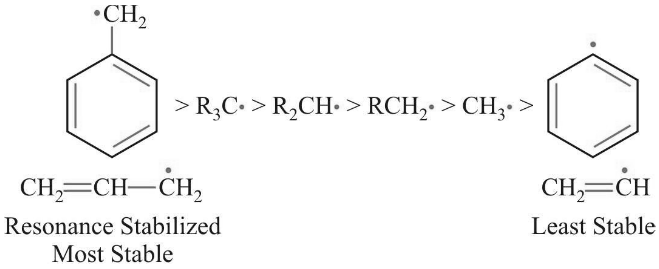
The hybridization of carbon free radical was proposed after experimental verification of structure of different radicals.

It was proposed that when ERG are placed on $\dot{C}$, it has sp^2 hybridization and when EWG are placed on C•, it has sp^3 hybridization.

Molecule	Hybridization	Location of odd electron
$\cdot CH_3$	sp^2	p
$\cdot CF_3$	sp^3	sp^3

13.3 Stability

ERG increase stability while EWG decrease stability.



13.4 Formation of Carbon Free Radical

Carbon Free Radicals are formed by homolytic cleavage of bonds. They are formed :

(a) at high temperature in the gas phase

(b) in non-polar solvents

(c) by ultraviolet light

(d) by addition of other radicals

13.5 Reactions of Carbon Free Radical

The most common reactions in which free radical is involved are :

(a) Halogenation of alkanes.

(b) Addition of HBr in the presence of peroxides to alkenes. (Anti-Markonikov Rule)

(c) α-Halogenation of alkenes.

(d) Wurtz Reaction

(e) Decarboxylation reaction

13.5.1 Free Radical Halogenation of Alkanes

The typical reactions of free radical are chain reaction mechanisms. There are three steps in a chain reaction mechanism : initiation, propagation and termination.

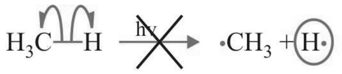
$$CH_4 + X_2 \xrightarrow[\text{or } \Delta]{h\nu} CH_3X + HX$$

Mechanism

(I) Chain Initiation

There are two choices :

(a)



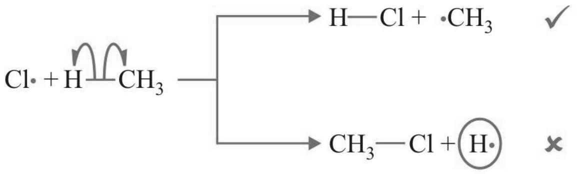
Hydrogen free radical is highly unstable.

(b) $Cl-Cl \xrightarrow{h\nu} 2Cl\cdot$

(I) (b) will take place as it is energetically feasible.

(II) Chain Propagation

(a)



Highly Unstable

(b)

This will again participate in II(a) to propagate the reaction.

(III) Chain Termination

The various free radicals in the progress of reaction are : Cl•, CH_3•. There are ways in which free radicals from different chains may combine to terminate the reaction.

$$CH_3\cdot + Cl\cdot \longrightarrow CH_3-Cl$$

$$CH_3\cdot + CH_3\cdot \longrightarrow CH_3-CH_3$$

$$Cl\cdot + Cl\cdot \longrightarrow Cl_2$$

There is a side-product CH_3-CH_3 that is formed in this reaction. Besides these, a number of other side-products such as CH_2Cl_2, $CHCl_3$ and CCl_4 have also been observed. These get formed since carbon free radical is highly reactive. It randomly reacts with other species that make it stabler.

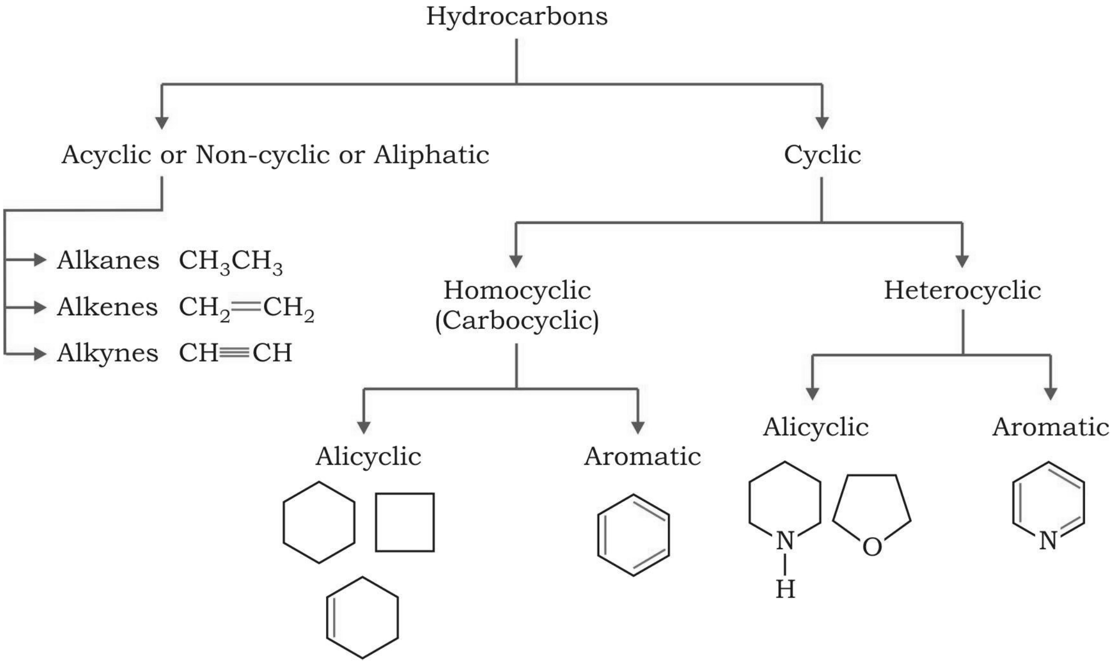
14. NOMENCLACTURE-I

14.1 INTRODUCTION

In 1949, an organization was set up to formulate the rules for naming organic compounds. This organization is **IUPAC - International Union for Pure and Applied Chemistry**. Prior to this, the organic compounds were known by their **trivial/common names** which generally indicated their source. For example, formic acid gets its name from *formica (Latin, red ants)* and acetic acid gets its name from *acetum (Latin, vinegar).*

Important : Systematic nomenclature is required in order to have unambigous names for all compounds.

14.2 CLASSIFICATION OF HYDROCARBONS



Important :

1. **Aliphatic Compounds** do not have rings and exist as a chain of carbon atoms.
2. **Alicyclic Compounds** have similar properties as aliphatic compounds except that the carbon chain exists in the form of ring.
3. **Aromatic Compounds** are based on the structure of benzene. These compounds are also called **arenes**.

14.3 HOMOLOGOUS SERIES

A homologous series *(Greek homos = "the same as")* is a family of compounds in which each member differs from the next by one **methylene (CH_2)** group. The members of the homologous series are called **homologues**. Example :

(a) Alkanes C_nH_{2n+2} (b) Alkenes C_nH_{2n} (c) Alkynes C_nH_{2n-2}

14.4 NOMENCLATURE OF UNBRANCHED ALKANES

Name	No. of Carbon Atoms	Structure	Substituent Name
Methane	1	CH_4	Methyl
Ethane	2	CH_3CH_3	Ethyl
Propane	3	$CH_3CH_2CH_3$	Propyl
Butane	4	$CH_3(CH_2)_2CH_3$	Butyl
Pentane	5	$CH_3(CH_2)_3CH_3$	Pentyl
Hexane	6	$CH_3(CH_2)_4CH_3$	Hexyl
Heptane	7	$CH_3(CH_2)_5CH_3$	Heptyl
Octane	8	$CH_3(CH_2)_6CH_3$	Octyl
Nonane	9	$CH_3(CH_2)_7CH_3$	Nonyl
Decane	10	$CH_3(CH_2)_8CH_3$	Decyl
Undecane	11	$CH_3(CH_2)_9CH_3$	
Dodecane	12	$CH_3(CH_2)_{10}CH_3$	
Tridecane	13	$CH_3(CH_2)_{11}CH_3$	
Tetradecane	14	$CH_3(CH_2)_{12}CH_3$	
Pentadecane	15	$CH_3(CH_2)_{13}CH_3$	
Eicosane	20	$CH_3(CH_2)_{18}CH_3$	

Meth, Eth, Prop, But, etc. are called compound roots. Compound roots represent the number of carbon atoms.

14.5 IUPAC NAME TEMPLATE

Prefix	Compound Root	Suffix	
Substituents	***No. of C in the Parent Chain***	***Unsaturation Index***	***+ Functional Group Suffix (optional)***
eg. Methyl	eg. Meth	eg. ane	eg. ol
Ethyl	Eth	ene	al
Propyl	Prop	yne	oic acid
Bromo			

This template will be used to give the name for any organic compound.

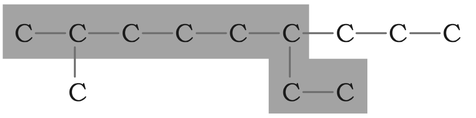
14.6 RULES FOR NOMENCLATURE OF SIMPLE HYDROCARBONS

Rule-1 :

Determine the **longest carbon chain in the molecule (parent chain).** Where a double/triple bond is present, choose the chain which includes these bonds. If there is a cyclic structure present, the longest chain starts and stops within the cyclic structure.

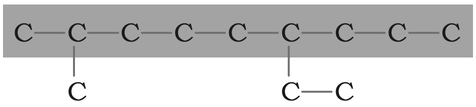
EXAMPLE

(I)



Longest chain = 8

(II)



Longest chain = 9

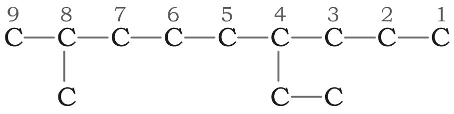
(II) is the correct chain selection.

Rule-2 :

Assign numbers to each carbon of the parent chain. Numbering is done to identify the parent alkane (compound root) and to locate the positions of the carbon atoms at which branching takes place. The numbering is done in such a way that **the branched atoms get the lowest possible number.**

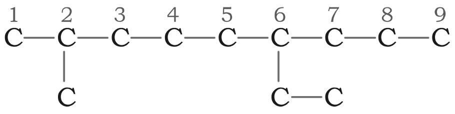
EXAMPLE

(I)



4, 8-INCORRECT

(II)

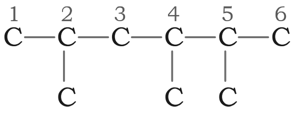


2, 6-CORRECT

If there is a tie for the first branch, then go to the second and so on until a difference is observed.

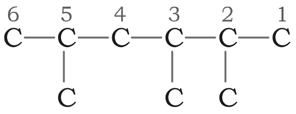
EXAMPLE

(I)



2, 4, 5-INCORRECT

(II)



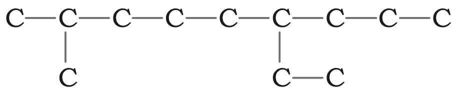
2, 3, 5-CORRECT

Rule-3 :

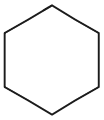
Determine the compound root and the unsaturation index. **Compound root corresponds to the number of carbon atoms in parent chain.** Add prefix cyclo if the parent chain is cyclic.

Unsaturation Index	**Suffix**
C—C	—ane
C=C	—ene
C≡C	—yne

EXAMPLE



$$\mathrm{C-\underset{\substack{|\\ C}}{C}-C-C-C-\underset{\substack{|\\ C-C}}{C}-C-C-C}$$



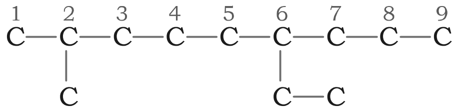
$\mathrm{C{=}C-C-C}$ [but] [ene]

∴ Butene

Rule-4 :

Determine the correct name for each branch for example, alkyl groups such as methyl, ethyl, etc. Attach the name of the branches alphabetically along with their positions to the parent chain as prefix. Separate numbers from letters with hyphens.

EXAMPLE



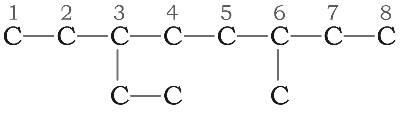
$$\mathrm{\overset{1}{C}-\underset{\substack{|\\ C}}{\overset{2}{C}}-\overset{3}{C}-\overset{4}{C}-\overset{5}{C}-\underset{\substack{|\\ C-C}}{\overset{6}{C}}-\overset{7}{C}-\overset{8}{C}-\overset{9}{C}}$$

6-Ethyl-2-methylnonane

If two substituents are in equivalent positions, the lower number is given to the one coming first in the alphabetical listing.

EXAMPLE

(I)

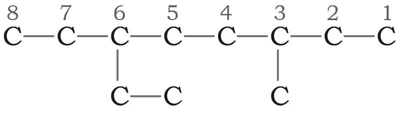


$$\mathrm{\overset{1}{C}-\overset{2}{C}-\underset{\substack{|\\ C-C}}{\overset{3}{C}}-\overset{4}{C}-\overset{5}{C}-\underset{\substack{|\\ C}}{\overset{6}{C}}-\overset{7}{C}-\overset{8}{C}}$$

CORRECT

3-Ethyl-6-methyloctane

(II)



$$\mathrm{\overset{8}{C}-\overset{7}{C}-\underset{\substack{|\\ C-C}}{\overset{6}{C}}-\overset{5}{C}-\overset{4}{C}-\underset{\substack{|\\ C}}{\overset{3}{C}}-\overset{2}{C}-\overset{1}{C}}$$

INCORRECT

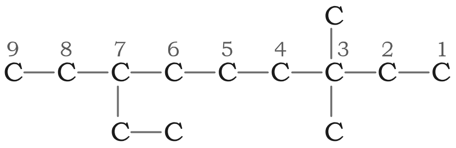
6-Ethyl-3-methyloctane

Rule-5 :

When two or more branches are identical, use prefixes di-, tri-, tetra-, etc. Numbers are separated with commas and prefixes are ignored while determining alphabetical order.

EXAMPLE

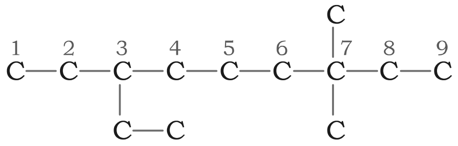
(I)



$$\mathrm{\overset{9}{C}-\overset{8}{C}-\underset{\substack{|\\ C-C}}{\overset{7}{C}}-\overset{6}{C}-\overset{5}{C}-\overset{4}{C}-\underset{\substack{|\\ C}}{\overset{\substack{C\\ |3}}{C}}-\overset{2}{C}-\overset{1}{C}}$$

3, 3-Dimethyl-7-ethylnonane INCORRECT

7-Ethyl-3, 3-dimethylnonane CORRECT

(II) 

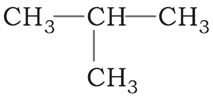
$$\begin{array}{ccccccccccccccccc}
 & & & & & & & & & & & & C & & & & \\
 & & & & & & & & & & & & | & & & & \\
\overset{1}{C} & - & \overset{2}{C} & - & \overset{3}{C} & - & \overset{4}{C} & - & \overset{5}{C} & - & \overset{6}{C} & - & \overset{7}{C} & - & \overset{8}{C} & - & \overset{9}{C}\\
 & & & & | & & & & & & & & | & & & & \\
 & & & & C-C & & & & & & & & C & & & &
\end{array}$$

INCORRECT

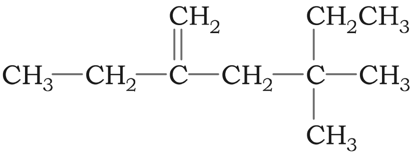
This is an incorrect selection as lowest number rule is violated.

EXERCISE

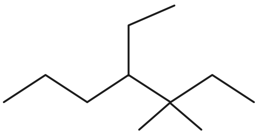
Give the IUPAC names of :

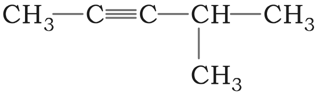
1. 

$CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_3$

2. 

$CH_3-CH_2-\overset{\displaystyle CH_2}{\overset{\|}{C}}-CH_2-\overset{\displaystyle CH_2CH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}-CH_3$

3. 

4. 

$CH_3-C\equiv C-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_3$

Solution :

14.7 ALKYL SUBSTITUENTS - COMMON AND SYSTEMATIC NAMES

CH_3 – Methyl
CH_3CH_2 – Ethyl

From three carbon onwards, alkyl substituents can be complicated for which common as well as systematic names are possible.

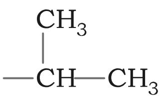
Rules for Systematic and Common Names

Rule-1 : For systematic names, the carbon atom of the branch that attaches to the parent chain is numbered one.

Rule-2 : Substituents which have branching at the first carbon can be classified as secondary *(sec-)* or tertiary *(tert-)* depending upon the number of carbons attached to it. *‘sec-’* and *‘tert–* are italicized and can also be abbreviated as *‘s-’* or *‘t-’* respectively.

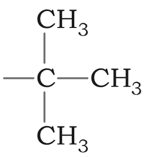
Rule-3 : Substituents which have a CH_3– group on second last carbon are called **iso** and which have two methyl groups on second last carbon are called **neo**.

Rule-4 : Iso and **neo** are considered while determining alphabetical order of substituents. ***‘sec-’*** and ***‘tert-’*** are not considered.



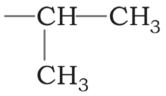
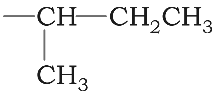
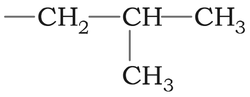
$$-\overset{\overset{CH_3}{|}}{CH}-CH_3$$

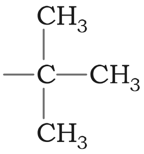
iso



$$-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_3$$

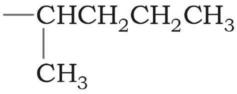
neo

	Alkyl Substituent	Systematic Name	Common Name
1.	$—CH_2CH_2CH_3$	propyl	propyl
2.	 $-\underset{\underset{CH_3}{\vert}}{CH}-CH_3$	1-methyl ethyl	isopropyl (not s-propyl)
3.	$—CH_2CH_2CH_2CH_3$		
4.	 $-\underset{\underset{CH_3}{\vert}}{CH}-CH_2CH_3$		
5.	 $-CH_2-\underset{\underset{CH_3}{\vert}}{CH}-CH_3$		

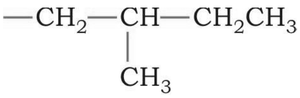
6. 

$-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_3$

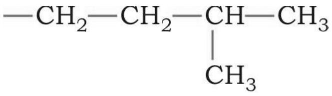
7. $-CH_2CH_2CH_2CH_2CH_3$

8. 

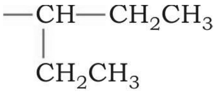
$-\underset{\underset{CH_3}{|}}{CH}CH_2CH_2CH_3$

9. 

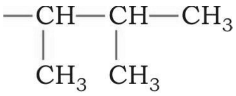
$-CH_2-\underset{\underset{CH_3}{|}}{CH}-CH_2CH_3$

10. 

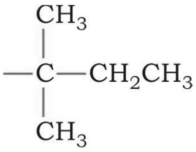
$-CH_2-CH_2-\underset{\underset{CH_3}{|}}{CH}-CH_3$

11. 

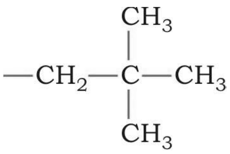
$-\underset{\underset{CH_2CH_3}{|}}{CH}-CH_2CH_3$

12. 

$-\underset{\underset{CH_3}{|}}{CH}-\underset{\underset{CH_3}{|}}{CH}-CH_3$

13. 

$-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_2CH_3$

14. 

$-CH_2-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_3$

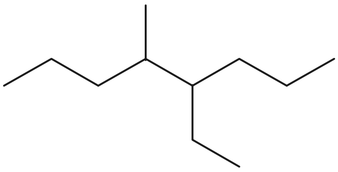
15. NOMENCLATURE–II

15.1 ALKYL SUBSTITUENTS – COMMON AND SYSTEMATIC NAMES

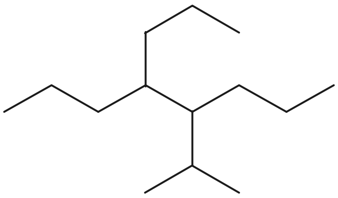
EXERCISE

Give IUPAC names for :

(a)



(b)



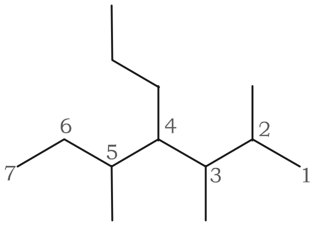
Solution :

15.1.1 Corollory to Longest Chain Rule

If there happen to be two chains of equal length, then that chain is selected which contains more number of side chains

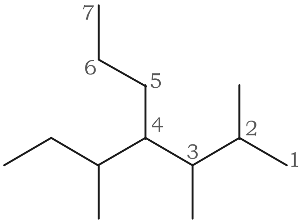
EXAMPLE

(I)



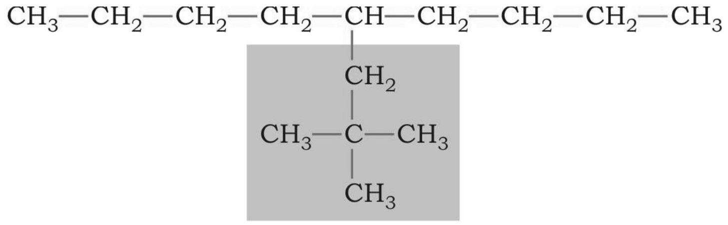
CORRECT (4 side chains)

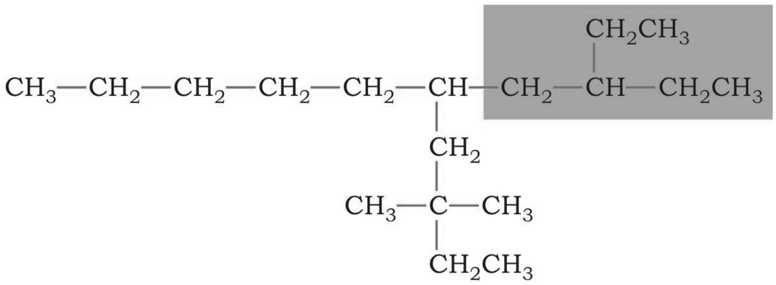
(II)

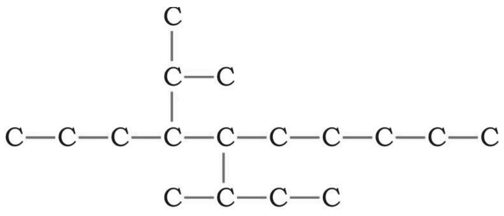


INCORRECT (3 side chains)

IUPAC Name : 2,3,5-Trimethyl-4-propyloctane







15.2 FUNCTIONAL GROUPS

A functional group is an atom or a group of atoms which characterizes the chemical reactivity of a molecule. The longest chain of atoms containing the functional group is numbered in such a way that the carbon to which functional group is attached is assigned the lowest number. In case of polyfunctional compounds, one of the functional groups is chosen as the principal functional group and the compound is named treating other functional groups as substituents.

Class	**Formula**	**Prefix**	**Suffix**
Acid Halide	$-COX$	Halocarbonyl	– carbonyl halide
	$-(C)OX$	–	– oyl halide
Alcohols	$-OH$	Hydroxy	– ol
Aldehydes	$-CHO$	Formyl	– carbaldehyde
	$-(C)HO$	Oxo	– al
Amides	$-CONH_2$	Carbamoyl	– carboxamide
	$-(C)ONH_2$	–	– amide
Amines	$-NH_2$	Amino	– amine
Carboxylates	$-COO^{\ominus}$	Carboxylato	– carboxylate
	$-(C)OO^{\ominus}$	–	– oate
Carboxylic Acid	$-COOH$	Carboxy–	– carboxylic acid
	$-(C)OOH$	–	– oic acid
Ethers	$-OR$	Alkoxy–	–
Esters of	$-COOR$	Alkoxy carbonyl	Alkyl .. carboxylate
Carboxylic Acid	$-(C)OOR$	–	Alkyl … oate
Ketones	$>C=O$	Oxo–	– one
cyanides (Nitriles)	$-C\equiv N$	Cyano	– carbonitrile
	$-(C)\equiv N$	–	– nitrile
Salts of Carboxylic	$-COO^{\ominus}M^{\oplus}$	–	Cation … carboxylate
Acids	$-(C)OO^{\ominus}M^{\oplus}$	–	Cation … oate
Sulphonic Acids	$-SO_2-OH$	Sulfo–	– sulfonic acid
Thiols	$-SH$	Sulfanyl	– thiol

The order of decreasing priority for functional groups is :

$$-COOH,\ -SO_3H,\ -COOR,\ -COCl,\ -CONH_2,\ -CN,\ -CHO,\ >C=O,\ -OH,\ -SH,\ -NH_2,$$

$$>C=C<,\ -C\equiv C-$$

Important :

(a) The $-R$, $-C_6H_5$, halogens, nitro and alkoxy groups are always treated as substituents.

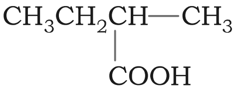
(b) If more than one functional group of same type is present, its number is indicated by adding di-, tri- etc.

(c) When C is marked in parenthesis, the carbon of the functional group is counted as part of the parent chain and the numbering will always begin from this carbon and its position need not be marked in the name.

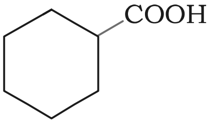
EXERCISE

Write IUPAC names of :

(a) $CH_3CH_2CH_2CH_2COOH$

(b) 

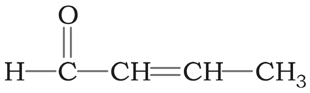
$CH_3CH_2\underset{\underset{COOH}{|}}{CH}-CH_3$

(c) 

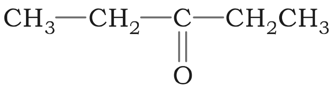
Solution :

EXERCISE

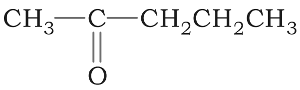
Give IUPAC names for :

(a) 

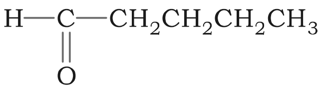
$H-\overset{\overset{O}{\|}}{C}-CH{=}CH-CH_3$

(b) 

$CH_3-CH_2-\underset{\underset{O}{\|}}{C}-CH_2CH_3$

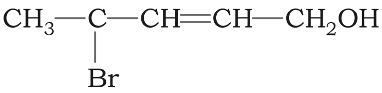
(c) 

$CH_3-\underset{\underset{O}{\|}}{C}-CH_2CH_2CH_3$

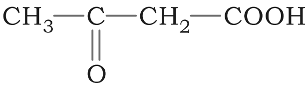
(d) 

$H-\underset{\underset{O}{\|}}{C}-CH_2CH_2CH_2CH_3$

(e) $CH_3{-}C{\equiv}C{-}CH_2CH_2{-}OH$

(f) 

$CH_3{-}\underset{\displaystyle Br}{\underset{|}{C}}{-}CH{=}CH{-}CH_2OH$

(g) 

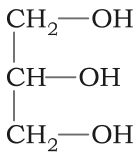
$CH_3{-}\underset{\displaystyle O}{\underset{\|}{C}}{-}CH_2{-}COOH$

Solution :

EXERCISE

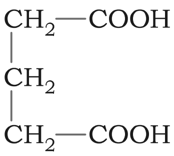
Give IUPAC names for :

(a)



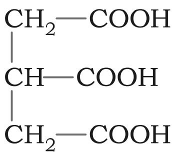
$$\begin{array}{l} CH_2-OH \\ | \\ CH-OH \\ | \\ CH_2-OH \end{array}$$

(b)



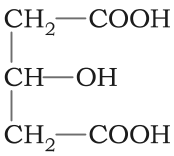
$$\begin{array}{l} CH_2-COOH \\ | \\ CH_2 \\ | \\ CH_2-COOH \end{array}$$

(c)



$$\begin{array}{l} CH_2-COOH \\ | \\ CH-COOH \\ | \\ CH_2-COOH \end{array}$$

(d)



$$\begin{array}{l} CH_2-COOH \\ | \\ CH-OH \\ | \\ CH_2-COOH \end{array}$$

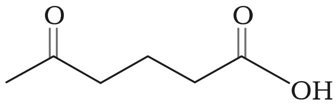
Solution :

Important : Pentane-1, 5-dioic acid is incorrect name. There is no need to give positions of COOH because if we include their carbons in the parent chain, they will always be present at the end of the chain.

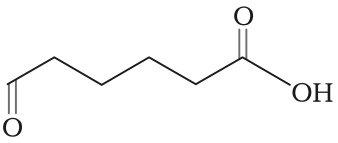
EXERCISE

Give IUPAC names of :

(a)



(b)



Solution :

15.3 PRIORITY BETWEEN ALKENE AND ALKYNE

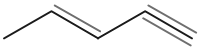
When there is a choice between alkene and alkyne, alkene is given lower number.

EXERCISE

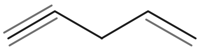
Give IUPAC names of :

(a)

(b)



(c)



Solution :

Important : 'e' of 'ene' is dropped as 'yne' sounds like starting from 'i' (vowel).

15.3.1 Common Alkenyl/Alkynyl Substituents

Structure	Common Name	Systematic Name
$CH_2{=}CH{-}$	Vinyl	Ethenyl
$CH_2{=}CH{-}CH_2{-}$	Allyl	Prop-2-enyl
$CH{\equiv}C{-}$	–	Ethynyl

15.3.2 Chain selection Rules for Alkene and Alkyne Priority

Rule-1 :

Select that chain which contains maximum number of double and triple bonds.

Rule-2 :

If two chains are competing for selection as the chain with maximum number of unsaturated bonds, then the choice goes to

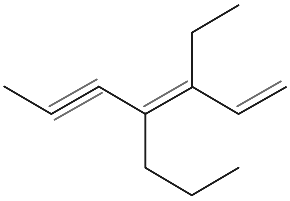
(a) The one with the greatest number of carbon atoms.

(b) The number of carbon atoms being equal, the one containing maximum number of double bonds.

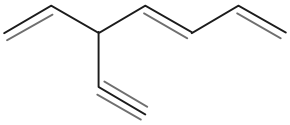
EXERCISE

Give IUPAC names for :

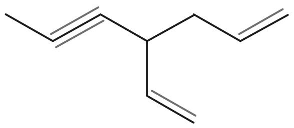
(a)



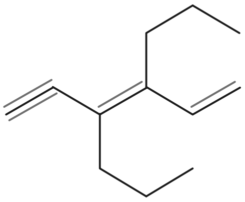
(b)



(c)



(d)



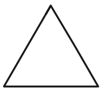
Solution :

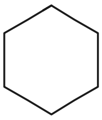
15.4 CYCLIC COMPOUNDS

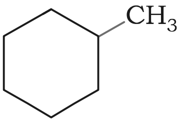
Corollory to Longest Chain Rule

A ring is treated as a substituent only when the number of carbon atoms are less in the ring than in the chain.

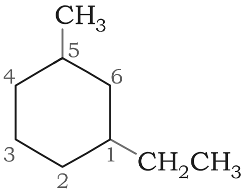
EXAMPLE

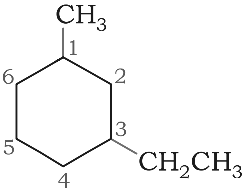
(a)  Cyclopropane

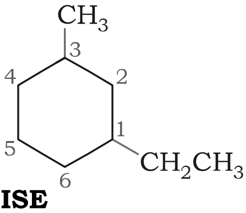
(b)  Cyclohexane

(c) 

Methylcyclohexane

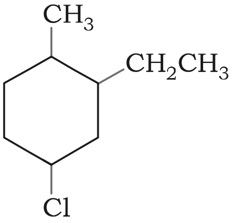
(d) (i) 

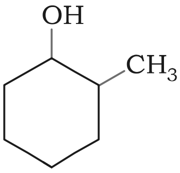
(ii) 

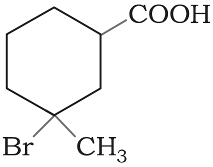
(iii) 

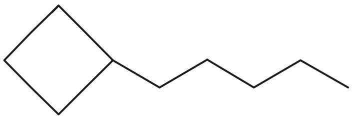
EXERCISE

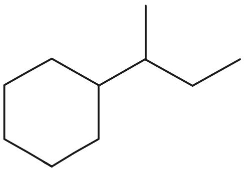
Give IUPAC names for :

(a) 

(b) 

(c) 

(d) 

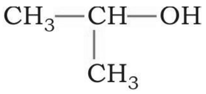
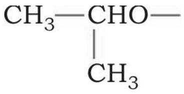
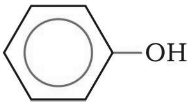
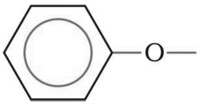
(e) 

Solution :

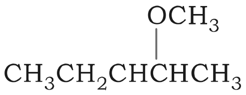
15. NOMENCLATURE–III

15.1 SUBSTITUENTS – ALKOXY, NITRO AND HALOGEN GROUPS

Alkoxy, nitro and halogen groups are always treated as substituents

Alcohol	Alkoxy Group	Substituent Name
CH_3OH	CH_3O-	Methoxy
CH_3CH_2OH	CH_3CH_2O-	Ethoxy
$CH_3CH_2CH_2OH$	$CH_3CH_2CH_2O-$	Propoxy
 $CH_3-\underset{CH_3}{\underset{\vert}{CH}}-OH$	 $CH_3-\underset{CH_3}{\underset{\vert}{CH}}O-$	Isopropoxy
		Phenoxy

EXAMPLE



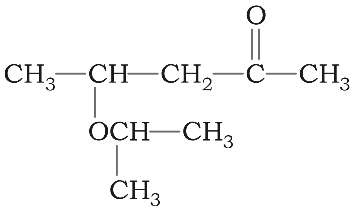
$CH_3CH_2\overset{OCH_3}{\overset{\vert}{CH}}CHCH_3$

2-Methoxypentane

EXAMPLE

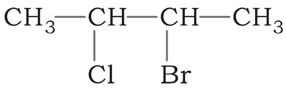
Give IUPAC names of :

(a)



$CH_3-\underset{\underset{\underset{CH_3}{\vert}}{OCH-CH_3}}{\underset{\vert}{CH}}-CH_2-\overset{\overset{O}{\Vert}}{C}-CH_3$

(b)



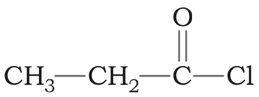
$CH_3-\underset{Cl}{\underset{\vert}{CH}}-\underset{Br}{\underset{\vert}{CH}}-CH_3$

Solution :

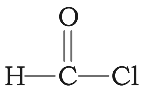
15.2 CARBOXYLIC ACID DERIVATIVES

Nomenclature of acid halides and amides is very straight forward.

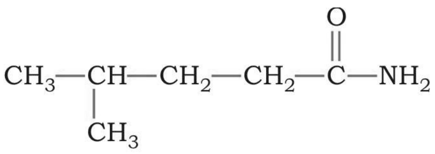
EXAMPLE

(I) 

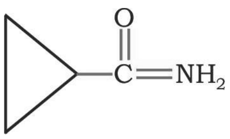
$\mathrm{CH_3-CH_2-\overset{O}{\overset{\|}{C}}-Cl}$

(II) 

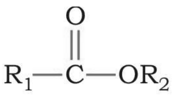
$\mathrm{H-\overset{O}{\overset{\|}{C}}-Cl}$

(III) 

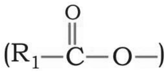
$\mathrm{CH_3-\underset{CH_3}{\underset{|}{CH}}-CH_2-CH_2-\overset{O}{\overset{\|}{C}}-NH_2}$

(IV) 

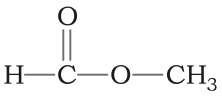
Esters nomenclature is done in the following manner :



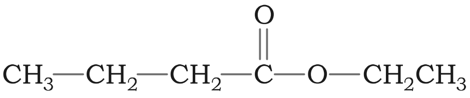
$\mathrm{R_1-\overset{O}{\overset{\|}{C}}-OR_2}$

Alkyl (R_2) Alkanoate 

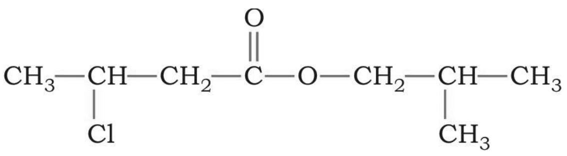
$\mathrm{(R_1-\overset{O}{\overset{\|}{C}}-O-)}$

(I) 

$\mathrm{H-\overset{O}{\overset{\|}{C}}-O-CH_3}$

(II) 

$\mathrm{CH_3-CH_2-CH_2-\overset{O}{\overset{\|}{C}}-O-CH_2CH_3}$

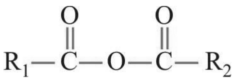
(III) 

$\mathrm{CH_3-\underset{Cl}{\underset{|}{CH}}-CH_2-\overset{O}{\overset{\|}{C}}-O-CH_2-\underset{CH_3}{\underset{|}{CH}}-CH_3}$

Solution :

2-Methylpropyl-3-chlorobutanoate

Acid Anhydrides



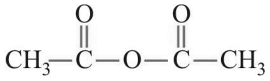
$$R_1-\overset{\overset{O}{\|}}{C}-O-\overset{\overset{O}{\|}}{C}-R_2$$

Alkanoic (R_1) + alkanoic (R_2) anhydride

If R_1 = R_2, then name is Alkanoic anhydride

EXAMPLE :

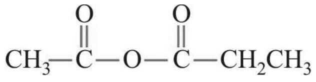
(I)



$$CH_3-\overset{\overset{O}{\|}}{C}-O-\overset{\overset{O}{\|}}{C}-CH_3$$

Ethanoic anhydride

(II)

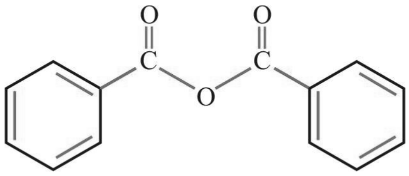


$$CH_3-\overset{\overset{O}{\|}}{C}-O-\overset{\overset{O}{\|}}{C}-CH_2CH_3$$

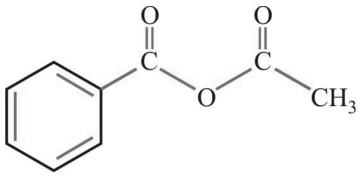
Ethanoic Propanoic anhydride

EXERCISE :

(I)



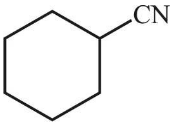
(II)



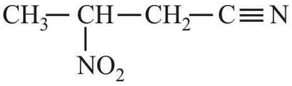
Cyanides/Nitriles

$R-(C)\equiv N$	Alkane nitrile (C is counted as part of parent chain)
$R-C\equiv N$	Alkane carbonitrile (C is not counted as part of parent chain)

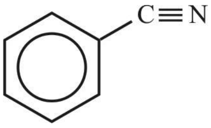
EXAMPLE :

(I)	$CH_3-CH_2-C\equiv N$	Propanenitrile
(II)		Cyclohexane Carbonitrile

EXERCISE :

(I) 

$CH_3-\underset{NO_2}{\underset{|}{CH}}-CH_2-C\equiv N$

(II) 

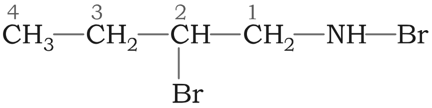
(III) 

$CH_3-\underset{CN}{\underset{|}{CH}}-CH_2-CH_3$

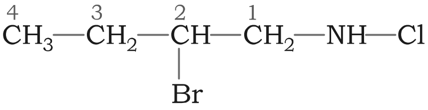
15.3 N-SUBSTITUTED AMINES/AMIDES

The substituents on nitrogen atom is written as *N*-<substituent name>. Here, '*N*'(italic) indicates the position of substituent.

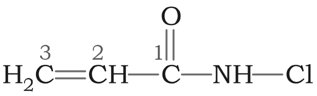
EXAMPLE

(I) 

$\overset{4}{CH_3}-\overset{3}{CH_2}-\underset{Br}{\underset{|}{\overset{2}{CH}}}-\overset{1}{CH_2}-NH-Br$

(II) 

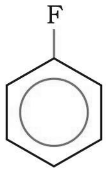
$\overset{4}{CH_3}-\overset{3}{CH_2}-\underset{Br}{\underset{|}{\overset{2}{CH}}}-\overset{1}{CH_2}-NH-Cl$

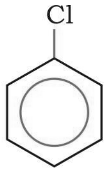
(III) 

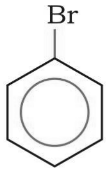
$H_2\overset{3}{C}=\overset{2}{CH}-\overset{\overset{O}{\|}}{\overset{1}{C}}-NH-Cl$

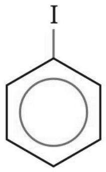
15.4 NOMENCLATURE OF BENZENE DERIVATIVES

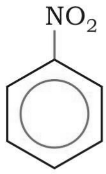
15.4.1 Common Names and IUPAC names of Important Compounds

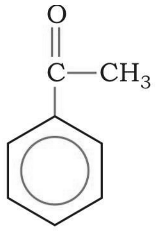

Fluorobenzene

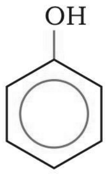

Chlorobenzene

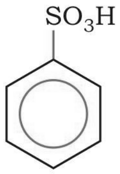

Bromobenzene

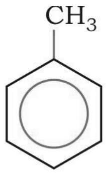

Iodobenzene

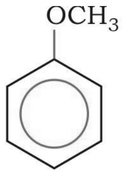

Nitrobenzene

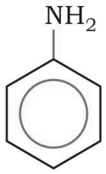

Acetophenone

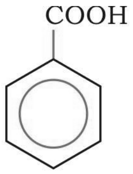

Phenol


Benzenesulphonic acid

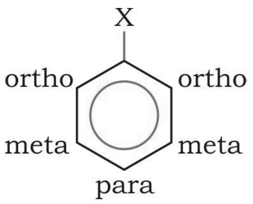

Methylbenzene
(Toluene)


Methoxybenzene
(Anisole)


Benzenamine
(Aniline)


Benzene carboxylic acid
(Benzoic Acid)

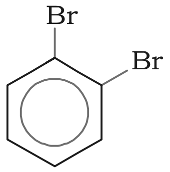
15.4.2 Ortho, Meta and Para Positions



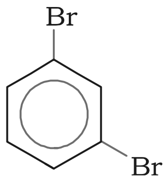
With respect to substituent X, we define three positions on the benzene ring as shown in the figure. Ortho, meta, para positions are used for writing common names of disubstituted benzenes. The positions are also abbreviated as o-, m-, p-.

EXAMPLE

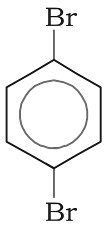
(I)


o-Dibromobenzene
1,2-Dibromobenzene

(II)

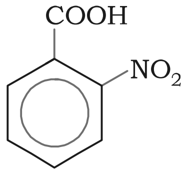

m-Dibromobenzene
1,3-Dibromobenzene

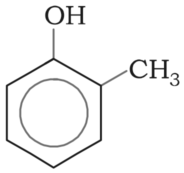
(III)

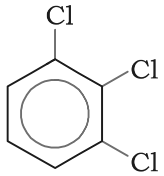

p-Dibromobenzene
1,4-Dibromobenzene

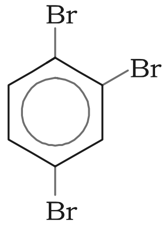
EXERCISE

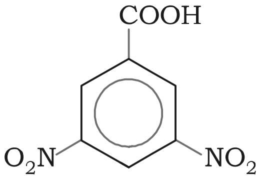
Give the IUPAC and common name (o/m/p wherever possible).

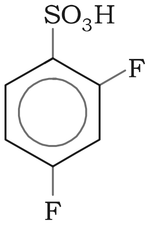
(a) 

(b) 

(c) 

(d) 

(e) 

(f) 

Solution :

15.4.3 Benzene as substituent-Phenyl Group

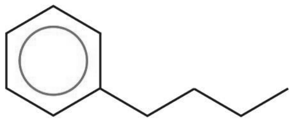
When C_6H_5– group is treated as substituent, it's called phenyl group.

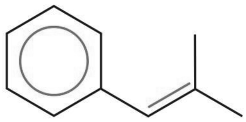
Important :

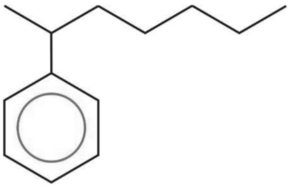
(a) A saturated chain containing benzene ring is named as derivative of the larger structural unit. (Use corollory for longest chain selection for cyclic compounds).

(b) If the chain is unsaturated, the compound is always named as a derivative of that chain.

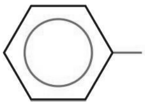
EXAMPLE

(I) 

(II) 

(III) 

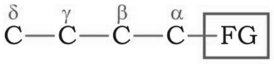
There is another special group in which C_6H_5– is present.



CH$_2$— or $C_6H_5CH_2$— Benzyl

15.5 Alpha (α), Beta (β), Gamma (δ) Nomenclature

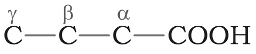
Prior to IUPAC, greek symbols were used to indicate positions of the substituents or functional groups. The carbons attached to the principal functional group are numbered as illustrated.



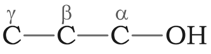
$\overset{\delta}{C}-\overset{\gamma}{C}-\overset{\beta}{C}-\overset{\alpha}{C}-\boxed{FG}$

Principal Functional Group

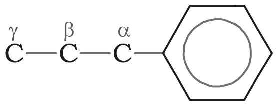
EXAMPLE

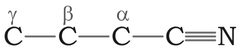
(I) 

$\overset{\gamma}{C}-\overset{\beta}{C}-\overset{\alpha}{C}-COOH$

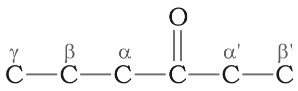
(II) 

$\overset{\gamma}{C}-\overset{\beta}{C}-\overset{\alpha}{C}-OH$

(III) 

(IV) 

$\overset{\gamma}{C}-\overset{\beta}{C}-\overset{\alpha}{C}-C\equiv N$

(V) 

$\overset{\gamma}{C}-\overset{\beta}{C}-\overset{\alpha}{C}-\overset{O}{\overset{\|}{C}}-\overset{\alpha'}{C}-\overset{\beta'}{C}$

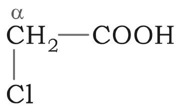
EXERCISE

Draw the structure of

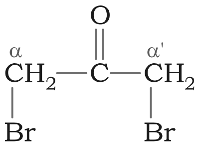
(a) α-chloroacetic acid

(b) α, α'-Dibromoacetone

Solution :

(a) 

$\underset{Cl}{\underset{|}{\overset{\alpha}{CH_2}}}-COOH$

(b) 

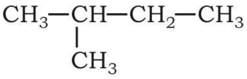
$\underset{Br}{\underset{|}{\overset{\alpha}{CH_2}}}-\overset{O}{\overset{\|}{C}}-\underset{Br}{\underset{|}{\overset{\alpha'}{CH_2}}}$

16. COMMON NAMES IN ORGANIC CHEMISTRY

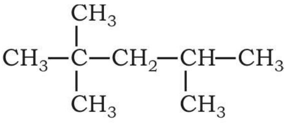
A. ALKANES

CH_4

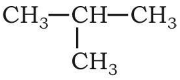
Methane
(*Marsh Gas*)


$CH_3-\underset{CH_3}{CH}-CH_2-CH_3$

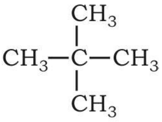
Isopentane


$CH_3-\overset{CH_3}{\underset{CH_3}{C}}-CH_2-\underset{CH_3}{CH}-CH_3$

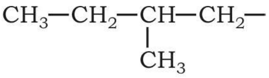
Isooctane
(Used in octane rating)


$CH_3-\underset{CH_3}{CH}-CH_3$

Isobutane


$CH_3-\overset{CH_3}{\underset{CH_3}{C}}-CH_3$

Neopentane


$CH_3-CH_2-\underset{CH_3}{CH}-CH_2-$

Active Amyl Group

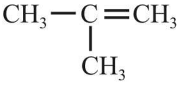
B. ALKENES

$CH_3-CH_2-CH=CH_2$

α-Butylene

$CH_3-CH=CH-CH_3$

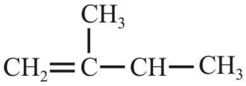
β-Butylene


$CH_3-\underset{CH_3}{C}=CH_3$

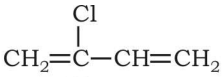
Isobutylene

$CH_2=C=CH_2$

Allene


$CH_2=\overset{CH_3}{C}-CH-CH_3$

Isoprene
(Monomer of Natural Rubber)


$CH_2=\overset{Cl}{C}-CH=CH_2$

Chloroprene
(Monomer of Synthetic Rubber)

C. ALKYNES

$CH\equiv CH$

Acetylene

$CH_2=CH-C\equiv CH$

Vinylacetylene

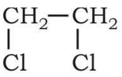
$CH_3-C\equiv CH$

Allylene

D. ALKYL HALIDES

CH_3CHCl_2

Ethylidene Chloride
(Gem Dihalide)


$\underset{Cl}{CH_2}-\underset{Cl}{CH_2}$

Ethylene Dichloride
(Vicinal Dihalide)


$\begin{matrix} CHCl_2 \\ | \\ CHCl_2 \end{matrix}$

Acetylene Tetrachloride
(Westron)
(Solvent)

$ClCH=CCl_2$

Westrosol
(*Solvent for paints, oils, varnishes and rubber*)

$Cl_2C=CCl_2$

Perclean
(Solvent for Dry Washing)

$CF_2=CF_2$

Tetrafluoroethene
(Monomer of Teflon)


$\begin{matrix} CHCl \\ || \\ CHAsCl_2 \end{matrix}$

Lewisite
(Poisonous Gas)

CCl_3-NO_2

Chloropicrin
(*Tear Gas*)

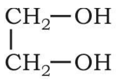
$CHCl_3$

Chloroform
(*Solvent in Organic Synthesis, Anaesthetic*)

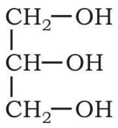
CH_2Cl_2

Dichloromethane
(DCM)
(*Solvent in Organic Synthesis*)

E. ALCOHOL


$$\begin{array}{l} CH_2-OH \\ | \\ CH_2-OH \end{array}$$

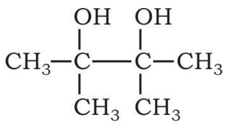
Glycol
(*Anti Freeze*)


$$\begin{array}{l} CH_2-OH \\ | \\ CH-OH \\ | \\ CH_2-OH \end{array}$$

Glycerol/Glycerine
(*Anti Freeze,*
used in Soaps)

$CH_2=CH-CH_2-OH$

Allyl Alcohol

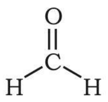

$$CH_3-\underset{CH_3}{\overset{OH}{C}}-\underset{CH_3}{\overset{OH}{C}}-CH_3$$

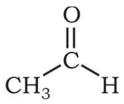
Pinacol

$CH_2=CH-OH$

Vinyl Alcohol

F. ALDEHYDE


Formaldehyde


Acetaldehyde

$CH_3-CH=CH-CHO$

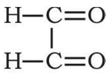
Crotonaldehyde

$(CH_3)_2CHCHO$

Isobutyraldehyde

$CH_2=CH-CHO$

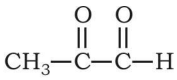
Acrolein
(*Acraldehyde*)


$$\begin{array}{l} H-C=O \\ \quad | \\ H-C=O \end{array}$$

Glyoxal


$$\begin{array}{l} CHO \\ | \\ COOH \end{array}$$

Glyoxalic Acid


$$CH_3-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-H$$

Methyl Glyoxal or
Pyurvic Aldehyde

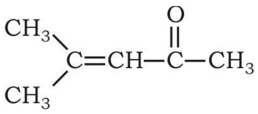
G. KETONE

CH_3COCH_3

Acetone

$CH_2=C=O$

Ketene


Mesityl Oxide

H. CARBOXYLIC ACID

$HCOOH$

Formic acid

CH_3COOH

Acetic acid

$CH_3CH_2CH_2CH_2COOH$

Valeric acid
(*n-Pentanoic acid*)

$CH_3CH_2CH_2COOH$

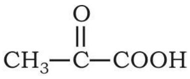
Butyric acid
(*Butter is triglyceride*
of butyric acid)

$CH_3(CH_2)_4COOH$

Caproic acid
(*n-Hexanoic acid*)

$CH_2=CH-COOH$

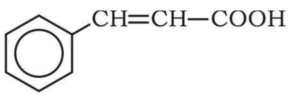
Acrylic Acid

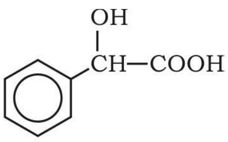

$$CH_3-\overset{O}{\overset{\|}{C}}-COOH$$

Pyurvic acid
(*Produced during*
metabolism)

$CH_3-CH=CH-COOH$

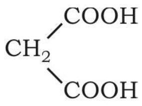
Crotonic Acid

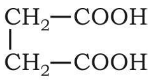

Cinnamic Acid


Mandelic Acid

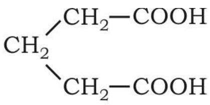

$$\begin{array}{l} COOH \\ | \\ COOH \end{array}$$

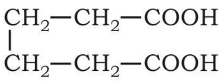
Oxalic Acid


Malonic Acid

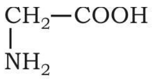

$$\begin{array}{l} CH_2-COOH \\ | \\ CH_2-COOH \end{array}$$

Succinic Acid

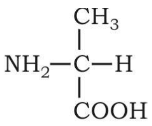

Glutaric Acid


$$\begin{array}{l} CH_2-CH_2-COOH \\ | \\ CH_2-CH_2-COOH \end{array}$$

Adipic Acid


$$\begin{array}{l} CH_2-COOH \\ | \\ NH_2 \end{array}$$

Glycine
(Amino Acetic Acid)
Only Achiral Amino Acid


$$NH_2-\underset{COOH}{\overset{CH_3}{C}}-H$$

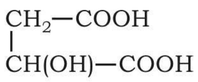
Alanine

NH_2COOH

Carbamic Acid
(*Amino formic acid*)

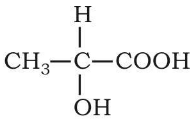
$HO-CH_2COOH$

Glycolic Acid



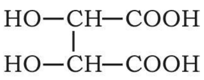
$$\begin{array}{l} CH_2-COOH \\ \mid \\ CH(OH)-COOH \end{array}$$

Malic Acid



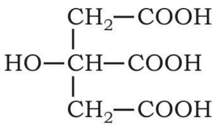
$$CH_3-\overset{H}{\underset{OH}{C}}-COOH$$

Lactic Acid
(*Present in Milk*)



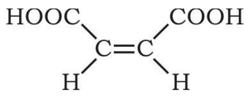
$$\begin{array}{l} HO-CH-COOH \\ \quad\;\; \mid \\ HO-CH-COOH \end{array}$$

Tartaric Acid

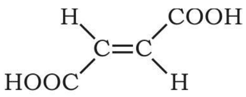


$$\begin{array}{l} \qquad\;\; CH_2-COOH \\ \qquad\;\; \mid \\ HO-CH-COOH \\ \qquad\;\; \mid \\ \qquad\;\; CH_2-COOH \end{array}$$

Citric Acid
(*Present in Lemon*)



Maleic Acid
(*cis*)



Fumaric Acid
(*trans*)

$CH_3(CH_2)_{14}COOH$

Palmitic Acid
(hexa decanoic acid)
(*sodium salts of stearic and palmitic acid is used as soaps*)

$CH_3(CH_2)_{16}COOH$

Stearic Acid
(*octadecanoic acid*)

I. ACID DERIVATIVES

$HCOOCH_3$

Methylformate

$HCOOC_2H_5$

Ethylformate

$CH_3COOC_2H_5$

Ethyl acetate

$CH_3COCH_2COOC_2H_5$

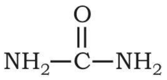
Ethylacetoacetate

CH_3CONH_2

Acetamide

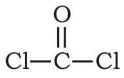
NH_2COONH_4

Ammonium carbamate



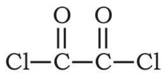
$$NH_2-\overset{O}{\overset{\|}{C}}-NH_2$$

Urea
(*Fertilizer*)



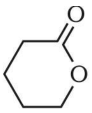
$$Cl-\overset{O}{\overset{\|}{C}}-Cl$$

Phosgene
(*Poisonous gas used in World War-I*)

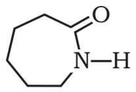


$$Cl-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-Cl$$

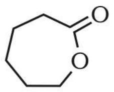
Oxalyl chloride



δ-Nalerolactone



∈-Caprolactam



∈-Caprolactone

J. N–DERIVATIVES

CH_3CN

Acetonitrile

$CH_3-\overset{\oplus}{N}\equiv\overset{\ominus}{C}$

Methyl isocyanide
(*Foul smelling and poisonous*)

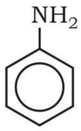
CH_3NCO

Methyl Isocyanate
(*Leaked in Bhopal gas tragedy*)

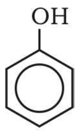
$CH_2=CH-C\equiv N$

Acrylonitrile or Vinyl Cyanide
(*Monomer of Orlon*)

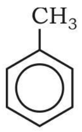
K. AROMATIC COMPOUNDS



Aniline

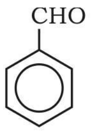


Phenol

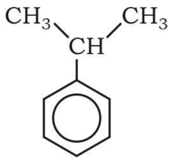


Toluene
(*Light Oil*)

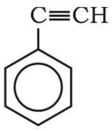
Benzoic Acid



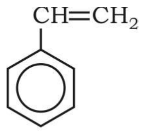
Benzaldehyde
(*Bitter Almond Oil*)



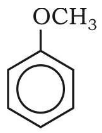
Cumene
(*Isopropyl Benzene*)



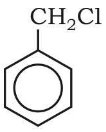
Phenyl Acetylene



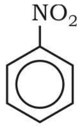
Styrene
(*Monomer of Polystyrene*)



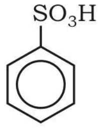
Anisole



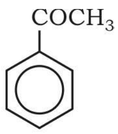
Benzyl chloride



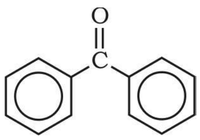
Nitrobenzene
(*Oil of Morbane*)



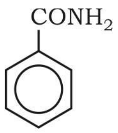
Benzene sulphonic acid



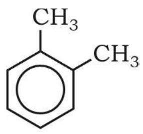
Acetophenone



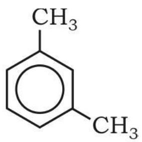
Benzophenone



Benzamide

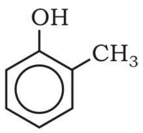


o-Xylene

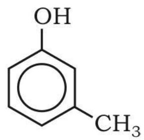


m-Xylene

p-Xylene

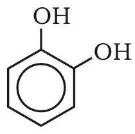


o-Cresol

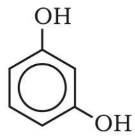


m-Cresol

p-Cresol

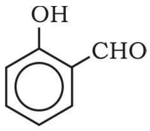


Catechol

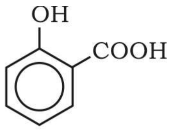


Resorcinol

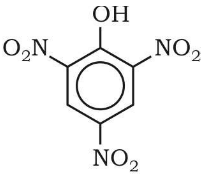
Quinol



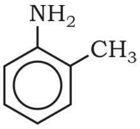
Salicylaldehyde



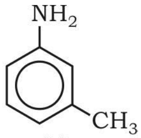
Salicycic Acid



Picric Acid

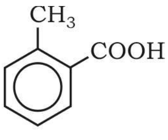


o-toulidine

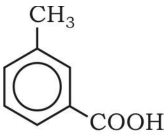


m-toulidine

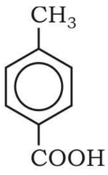
p-toulidine



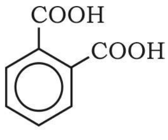
o-toluic acid



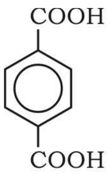
m-toluic acid



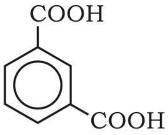
p-toluic acid



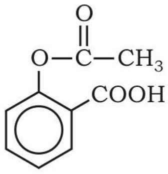
Phthalic Acid



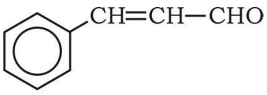
Terephthalic Acid



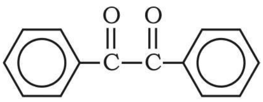
Isophthalic Acid



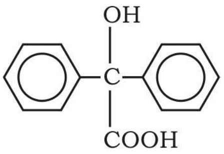
Acetyl Salicyclic Acid
(*Aspirin*)



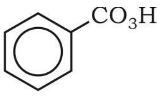
Cinnamaldehyde
(*Cinnamon*)



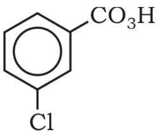
Benzil



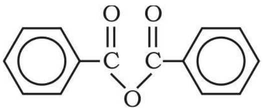
Benzilic Acid



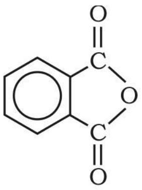
Perbenzoic Acid



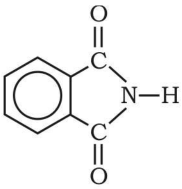
m-chloroperbenzoic acid
(m-CPBA)
(*Used for Epoxidation of Alkene*)



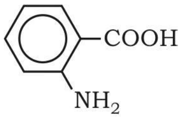
Benzoic anhydride



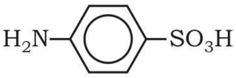
Phthalic anhydride



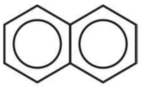
Phthalamide
(*Used in Gabriel's Phthalamide Reaction*)



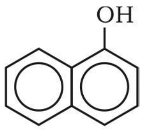
Anthranilic acid



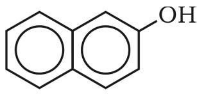
Sulphanilic Acid
(*used in S-drugs*)



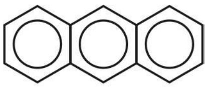
Napthalene
(*Middle or Carbolic Oil*)



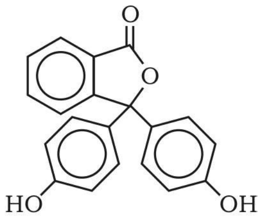
α-napthol



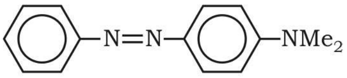
β-napthol



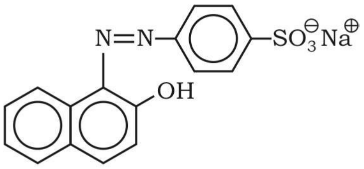
Anthracene
(Green Oil)



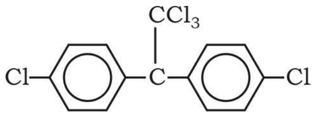
Phenolpthalein
(*Indicator*)



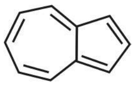
Butter Yellow
(*Dye*)



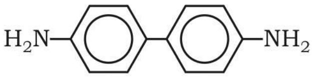
Orange-II
(*Dye*)



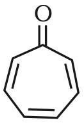
DDT (Dichlorodiphenyl
trichloroethane)
(*Used as fertilizers*)



Azulene



Benzidine



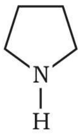
Tropone
(cycloheptatrienone)

K. HETEROCYCLIC COMPOUNDS

Pyrrole

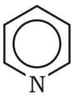
Furan

Thiophene

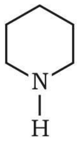


Pyrrolidine

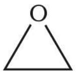
THF
(Tetrahydrofuran)
(*Solvent in
organic reactions*)



Pyridine

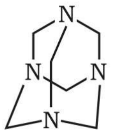


Piperidine



Oxirane or
ethylene oxide

Aziridine



Hexa-methylenetetramine
(Urotropine)
(*Polymer of* NH_3 *and HCHO*)