# Organic Chemistry

## Organic Chemistry

It is the chemistry of specific carbon compounds except oxides, carbonates and carbides.

## Hydrocarbons

Organic compounds composed of carbon and hydrogen only.
Examples: Methane ($CH_4$), ethane ($C_2H_6$)

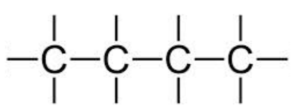
### Unique Nature of Carbon

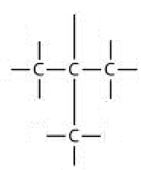
**Tetravalency of Carbon**

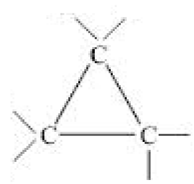
- Carbon forms four covalent bonds by mutually sharing its four electrons with other atoms.
- It is hence tetravalent or exhibits tetravalency.

**Catenation**

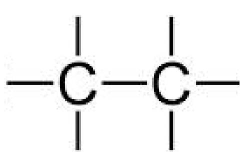
- It is the tendency of an element to form chains of identical atoms.
- Catenation is maximum in carbon because the value of the C–C bond energy is maximum.
- Carbon undergoes self-linking forming straight, branched and closed chains.

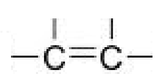

(Straight chain)

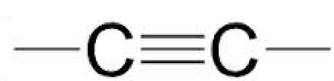

(Branch chain)


(Closed chain)

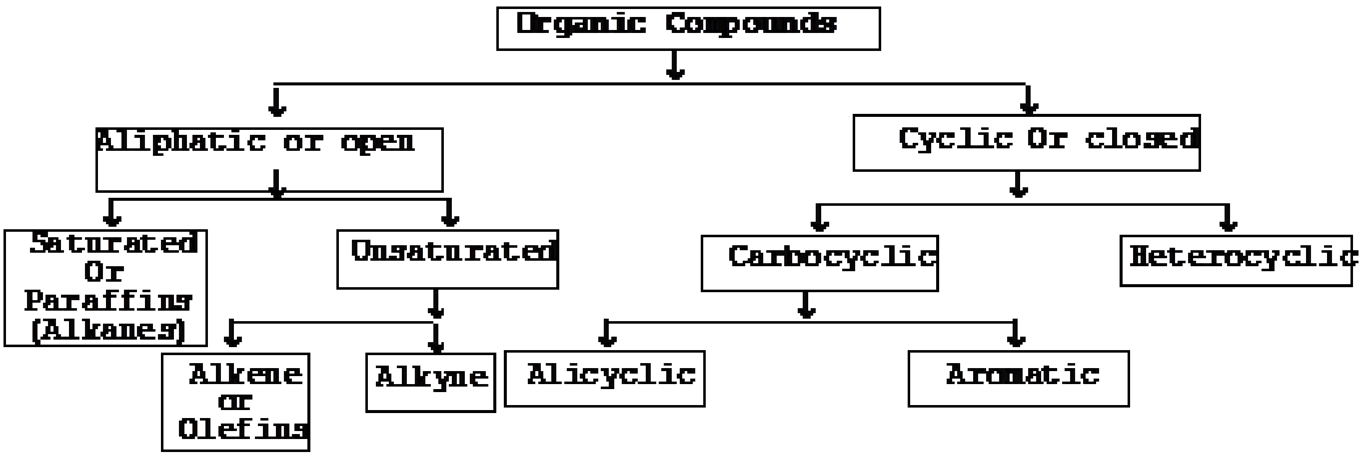
- Catenation and tetravalency also result in the formation of single, double and triple bonds.


(Single bond)


(Double bond)


(Triple bond)

## Classification of Organic Compounds




## Homologous Series

It is a group of organic compounds with a similar structure and similar chemical properties in which the successive compounds differ by a **$CH_2$** group.

**Characteristics of a homologous series**

i. Each member of the series differs from the preceding one by the addition of a $CH_2$ group and by 14 amu.
ii. All members of a homologous series share a general formula.
For example, the general formula for alkane is $C_nH_{2n+2}$ and that for alkene is $C_nH_{2n}$.
iii. The physical properties of the members show gradation in properties as molecular mass increases.
iv. The chemical properties also show gradient similarity.
For example, methane and ethane react with chlorine to form methyl chloride and ethyl chloride, respectively.
$CH_4 + Cl_2 \rightarrow CH_3Cl$
$C_2H_6 + Cl_2 \rightarrow C_2H_5Cl$
v. All members of a homologous series can be prepared by the same general method of preparation.
For example, alcohols can be prepared from alkyl halides.

$$CH_3Br + KOH \xrightarrow{Boil} CH_3OH + KBr$$

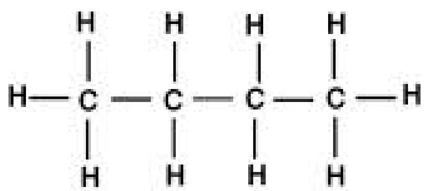
$$C_2H_5Br + KOH \xrightarrow{Boil} C_2H_5OH + KBr$$

**Significance of a Homologous Series**

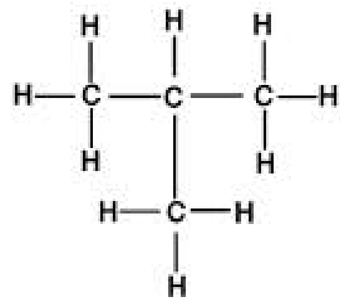
i. Helps in the systematic study of organic compounds.
ii. Predicts the properties and the nature of other elements of the series if the same is known of the first few members.

# Isomers

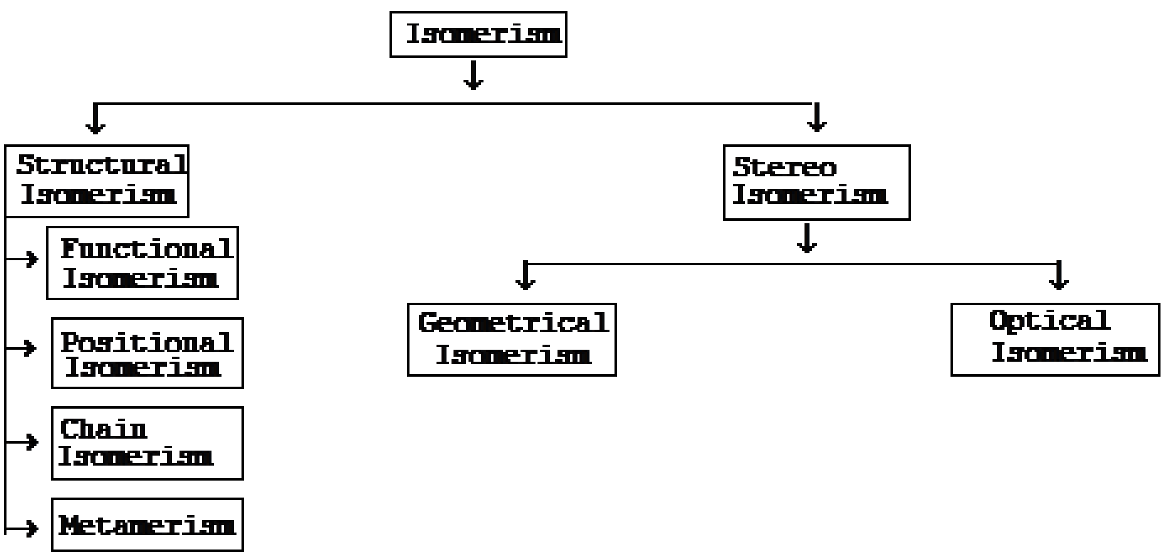
Compounds with the same molecular formula but different structural formula are known as isomers, and the phenomenon is known as isomerism.
Examples: Butane and isobutane are two different compounds with the same molecular formula $C_4H_{10}$.



Butane



Isobutane




**Causes of Isomerism**

i. Difference in the mode of linking of atoms.
ii. Difference in the arrangement of atoms or groups in space.

**Different Types of Structural Isomerism**

**i. Chain isomerism**

Two or more compounds which have a similar molecular formula but different arrangement of carbon atoms in straight or branched chains are referred to as chain isomers, and the phenomenon is known as chain isomerism.

**ii. Position isomerism**

When two or more compounds with the same molecular formula differ in the position of the substituent atom or functional group on the carbon atom, they are called position isomers, and the phenomenon is known as position isomerism.

**iii. Functional isomerism**

Two or more compounds with the same molecular formula but different functional groups are called functional isomers, and the phenomenon is known as functional isomerism.

**iv. Metamerism**

It arises because of unequal distribution of alkyl groups on either side of the functional groups in the molecules.

## Nomenclature

It is the system of assigning names to organic compounds.

**The Systems of Nomenclature Are**

**i.** Trivial system
**ii.** IUPAC (International Union of Pure and Applied Chemistry) system

According to the IUPAC system, the name of an organic compound consists of three parts:
**i.** Root word
**ii.** Suffix
**iii.** Prefix

**i. Root word**

It depends on the number of carbon atoms present in the longest carbon chain selected.

| Number of carbon atoms | Root word |
|---|---|
| One carbon atom $C_1$ | Meth |
| Two carbon atoms $C_2$ | Eth |
| Three carbon atoms $C_3$ | Prop |
| Four carbon atoms $C_4$ | But |
| Five carbon atoms $C_5$ | Pent |
| Six carbon atoms $C_6$ | Hex |
| Seven carbon atoms $C_7$ | Hept |
| Eight carbon atoms $C_8$ | Oct |
| Nine carbon atoms $C_9$ | Non |
| Ten carbon atoms $C_{10}$ | Dec |

**ii. Suffix**

The root word is followed by an appropriate suffix, which represents the nature of the bond in a carbon–carbon atom.

| Nature of bond | Suffix | General name | General formula |
|---|---|---|---|
| Single bond (C–C) | -ane | Alkane | $C_nH_{2n+2}$ |
| Double bond (C=C) | -ene | Alkene | $C_nH_{2n}$ |
| Triple bond ( $C\equiv C$ ) | -yne | Alkyne | $C_nH_{2n-2}$ |
| Group (R-) | -yl | Alkyl | $C_nH_{2n+1}$ |

**iii. Prefix**

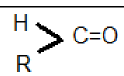
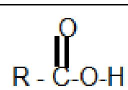
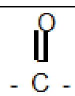
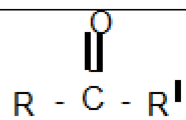
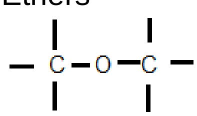
It denotes the substituent, alkyl or functional group and its position in the carbon chain.
Di-, tri- and tetra- are used for two, three and four groups of the same type, respectively.

# Functional Group

It is an atom or a group of atoms which defines the structure (or the properties of a particular family) of organic compounds.

**Characteristics of a Functional Group**

i. Compounds of the same functional group are identified using the same types of tests.
ii. The physical and chemical properties of the compounds of different functional groups are different.
iii. There exists a homologous series of compounds containing a particular type of functional group.

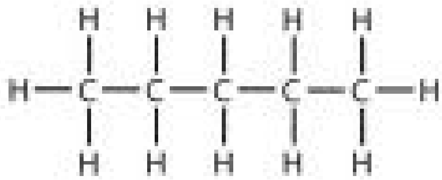
| Functional group | General formulae | Organic compound | Suffix | Examples with common and IUPAC name |
|---|---|---|---|---|
| Halide<br>–X<br>(F, Cl, Br, I) | R–X | Haloalkanes | ane | $CH_3Cl$<br>Common name: Methyl chloride<br>IUPAC name: Chloromethane |
| Hydroxyl<br>–OH | R–OH | Alcohols | ol | $C_2H_5OH$<br>Common name: Ethyl alcohol<br>IUPAC name: Ethanol |
| Aldehyde<br>–CHO |  | Aldehydes | al | $CH_3CHO$<br>Common name: Acetaldehyde<br>IUPAC name: Ethanal |
| Carboxyl<br>–COOH |  | Carboxylic acids | oic acid | $CH_3CH_2COOH$<br>Common name: Propionic acid<br>IUPAC name: Propanoic acid |
| Keto  |  | Ketones | one | $CH_3COC_2H_5$<br>Common name: Diethyl ketone<br>IUPAC name: Pentanone |
| Ethers<br> | R–O–R′ | Ethers | oxy | $CH_3–O–C_2H_5$<br>Common name: Ethyl methyl ether<br>IUPAC name: Methoxy ethane |

# Alkanes

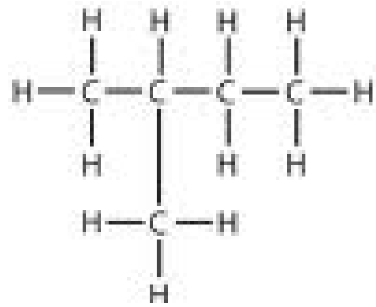
- Alkanes are hydrocarbons in which all the linkages between the carbon atoms are single covalent bonds.
- Compounds are known as saturated hydrocarbons because all the four valencies of carbon are fully satisfied.
- General formula : $C_nH_{2n+2}$
- These hydrocarbons are relatively unreactive under ordinary conditions so they are also called paraffins.

## Isomerism in Alkanes

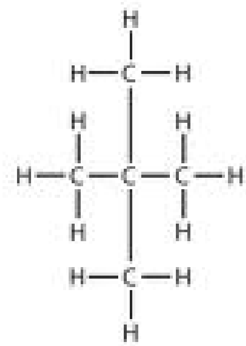
- Alkanes with more than three carbon atoms form isomers.
- The various isomers differ in the framework of the carbon chains.
  Example:
  **Isomers of Pentane ($C_5H_{12}$)**



n-pentane



isopropane



neo-pentane

### Laboratory Preparation of Methane and Ethane

$$CH_3COONa + NaOH \xrightarrow[300^0C]{CaO} Na_2CO_3 + CH_4$$

$$C_2H_5COONa + NaOH \xrightarrow[300^0C]{CaO} Na_2CO_3 + C_2H_6$$

### Methods of Preparation of Methane and Ethane

1. From iodomethane or bromoethane:
   $CH_3I + 2[H] \rightarrow CH_4 + HI$
   $C_2H_5I + 2[H] \rightarrow C_2H_6 + HI$

2. Methane is produced on addition of water to aluminium carbide at room temperature.
   $Al_4C_3 + 12H_2O \rightarrow 3CH_4 + 4Al\,(OH)_3$

3. Ethane from alkyl halides:
   $2CH_3I + 2Na \xrightarrow{\text{dry ether}} CH_3\text{–}CH_3 + 2NaI$

This reaction is known as the Wurtz reaction.

### Chemical Properties

**1. Substitution reaction**

**(i) Reaction with halogens**

$CH_4 + Cl_2 \xrightarrow{\text{Diffused sunlight}} CH_3Cl + HCl$
$CH_3Cl + Cl_2 \rightarrow CH_2Cl_2 + HCl$
$CH_2Cl_2 + Cl_2 \rightarrow CHCl_3 + HCl$
$CHCl_3 + Cl_2 \rightarrow CCl_4 + HCl$
(Carbon tetrachloride)

**(ii) Reaction with oxygen**

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

**Insufficient supply of air**

$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$

$2C_2H_6 + 5O_2 \rightarrow 4CO + 6H_2O$

**2. Cracking or Pyrolysis**

$2CH_4 \xrightarrow{1500^0C} CH \equiv CH + 3H_2$

$CH_3–CH_3 \xrightarrow[Al_2O_3]{500^0C} CH_2=CH_2 + H_2$

**3. Catalytic oxidation of alkanes**

$2CH_4 + O_2 \xrightarrow[120atm.]{475K\ Cu\ tube} 2CH_3OH$

$2C_2H_6 + O_2 \xrightarrow[120atm.]{475K\ Cu\ tube} 2C_2H_5OH$

$CH_4 + O_2 \xrightarrow{MoO} HCHO + H_2O$

$C_2H_6 + O_2 \xrightarrow{MoO} CH_3CHO + H_2O$

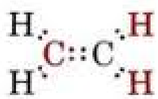
**4. Slow combustion**

$CH_4 \xrightarrow[K_2Cr_2O_7]{[O]} CH_3OH \xrightarrow[K_2Cr_2O_7]{[O]} HCHO \xrightarrow[K_2Cr_2O_7]{[O]} HCOOH$

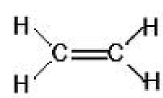
## Alkenes

- Alkenes are unsaturated aliphatic hydrocarbons containing a carbon–carbon double bond.
- They are also called olefins because of their tendency to form oily products.
- The general formula of alkenes is $C_nH_{2n}$.

**Structure of Ethene**



Electronic structure

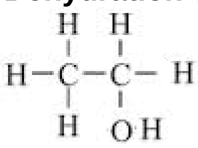


Structural formula ($C_2H_4$)

- Two carbon atoms linked by a double covalent bond.
- A double covalent bond is formed by sharing of two pairs of electrons between the two carbon atoms.
- Four C–H single covalent bonds and one C=C double covalent bond.
- It is a planar molecule and all bond angles (H–C–H and H–C=C) are of 120°.

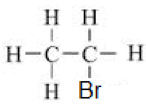
# Preparation of Ethene

**i. Dehydration of ethyl alcohol**




$\xrightarrow[170^0C]{\text{Conc. } H_2SO_4,}$ $CH_2=CH_2 + H_2O$

ii. **Dehydrohalogenation of ethyl bromide**




\+ KOH (alcoholic) $\xrightarrow{\text{Boil}}$ $CH_2=CH_2 + KBr + H_2O$

**iii. Cracking of methane**

$CH_3–CH_3 \xrightarrow[SiO_2\text{-}Al_2O_3]{500^0C} CH_2=CH_2 + H_2$

## Chemical properties

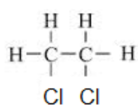
### 1. Addition Reactions

**(i) Catalytic hydrogenation**

$CH_2=CH_2 + H_2 \xrightarrow[300^0C]{\text{Nickel}} C_2H_6$

**(ii) Halogenation**

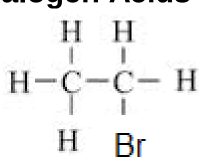
$CH_2=CH_2 + Cl_2 \xrightarrow[\text{[Inert solvent]}]{CCl_4}$




(1,2-dichlorethane)

**(iii) Reaction with Halogen Acids**

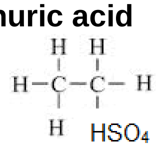
$CH_2=CH_2 + HBr \rightarrow$




(bromoethane)

**(iv) Reaction with Sulphuric acid**

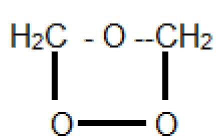
$CH_2=CH_2 + H.\ HSO_4 \rightarrow$




(ethyl hydrogen sulphate)

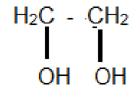
**(v) Ozone**

$CH_2=CH_2 + O_3 \xrightarrow{\text{Ether}}$




(ethylene ozonide)

**(vi) Oxidation**

$CH_2{=}CH_2$ + H–O–H + [O] →  (1,2-ethanediol)


Cold alkaline $KMnO_4$ solution

$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$ + Heat

**(vii) Polymerisation**

n $CH_2{=}CH_2$ $\xrightarrow[\text{(polymerization)}]{\text{High temp. \& pressure catalyst}}$ $[H_2C - CH_2]n$ (polyethylene)

# Alkynes

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- Alkynes are unsaturated aliphatic hydrocarbons containing a carbon–carbon triple bond in their molecule.
- The general formula of alkynes is $C_nH_{2n-2}$.
- They are more reactive than alkenes because of the presence of a triple bond, often referred to as an acetylenic linkage.

**Structural formula of Ethyne**

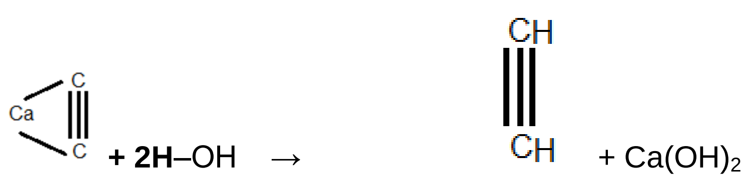

Electronic structure

H—C≡C—H

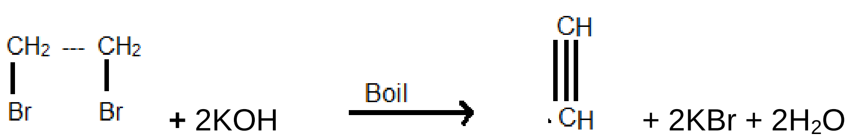
Structural formula ($CH_2{=}CH_2$)

## Preparation of Ethyne

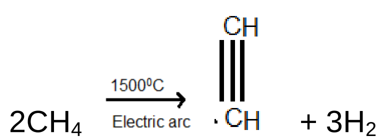
**i. Laboratory preparation from calcium carbide**




**ii. From 1,2-dibromoethane**



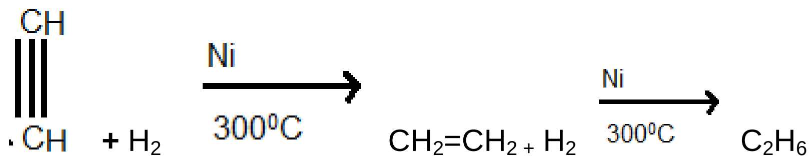

**iii. From methane**



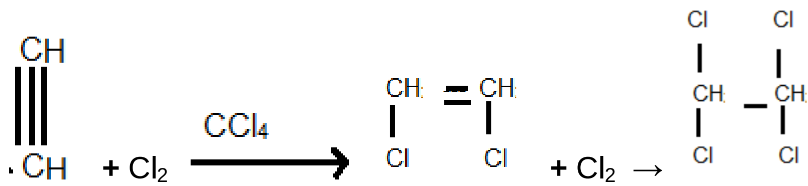
## Chemical Properties

### 1. Addition Reactions

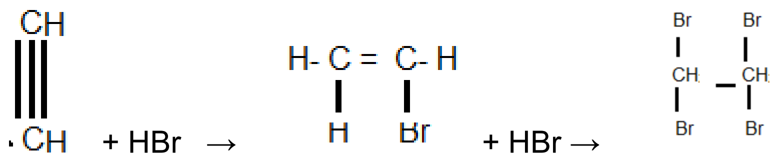
**a] Catalytic Hydrogenation**



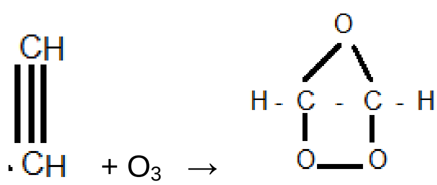

**b] Halogenation**




**c] Reaction with Halogen Acids**

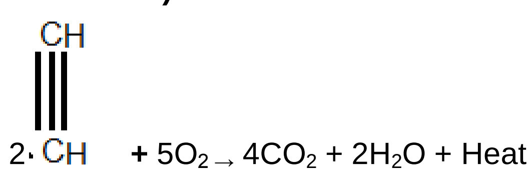



**d] Ozone**




(acetylene ozonide)

**e] Oxidation of ethyne (Combustion)**



# Alcohols

- Alcohols are hydroxyl derivatives of alkanes obtained by replacement of one, two or three hydrogen atoms of alkanes by the corresponding number of –OH groups.
- The hydroxyl group is the functional group of alcohols.
- The general molecular formula of alcohols is $\mathbf{C_nH_{2n+1}OH}$.

### Preparation of Ethanol

**(i) Laboratory preparation by hydrolysis of alkyl halides**

$$C_2H_5Cl + NaOH_{(aq)} \xrightarrow{\text{Boil}} C_2H_5OH + NaCl$$

**(ii) Industrial Method**

**(a) Hydration of Ethene**

$$C_2H_4 + H_2SO_4 \xrightarrow[\text{30 atm}]{80^0C} C_2H_5HSO_4$$

$$C_2H_5HSO_4 + H_2O \rightarrow C_2H_5OH + H_2SO_4$$

**(b) Fermentation of Carbohydrates**

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow[\text{Fermentation}]{\text{Invertase}} C_6H_{12}O_6 + C_6H_{12}O_6$$

$$C_6H_{12}O_6 \xrightarrow[\text{Fermentation}]{\text{Zymase}} 2C_2H_5OH + 2CO_2$$

### Chemical properties

**1. Combustion**

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

**2. Oxidation with $K_2Cr_2O_7$**

$$C_2H_5OH \xrightarrow[K_2Cr_2O_7]{[O]} CH_3CHO \xrightarrow[K_2Cr_2O_7]{[O]} CH_3COOH \text{ (acetic acid)}$$

**3. Reaction with Sodium**

$$2C_2H_5OH + 2Na \rightarrow 2C_2H_5ONa + H_2$$

**4. Reaction with Acetic acid**

$$C_2H_5OH + CH_3COOH \rightarrow CH_3COOC_2H_5 + H_2O$$

**5. Reaction with Sulphuric acid**

$$C_2H_5OH \xrightarrow[170^0C]{\text{Conc.}H_2SO_4} CH_2{=}CH_2 + H_2O$$

$$2C_2H_5OH \xrightarrow[140^0C]{\text{Conc.}H_2SO_4} C_2H_5{-}O{-}C_2H_5 + H_2O$$

**6. Reaction with $PCl_3$**

$$3C_2H_5OH + PCl_3 \rightarrow 3C_2H_5Cl + H_3PO_3$$

# Carboxylic Acids

- Carboxylic acids are organic compounds containing a carboxylic group (–COOH) attached to an alkyl group or to a hydrogen atom.
- Representation of carboxylic acids: R-COOH (R is either –H or alkyl)
- The functional group of carboxylic acids: –COOH (carboxylic)
- The acidic character in carboxylic acids is because of the presence of the replaceable hydrogen atom in the carboxylic group.

**Preparation of Acetic Acid**
**A] By oxidation of ethyl alcohol**

$$C_2H_5OH + [O] \xrightarrow[\text{acidified}]{K_2Cr_2O_7} CH_3CHO + H_2O$$

$$CH_3CHO + [O] \xrightarrow[\text{acidified}]{K_2Cr_2O_7} CH_3COOH$$

**B] By hydrolysis of ethyl acetate**

$$CH_3COOC_2H_5 + H_2O \xrightarrow[\text{Conc.} H_2SO_4]{\text{Hydrolysis}} CH_3COOH + C_2H_5OH$$

## Chemical Properties

1. It is a weak acid and turns blue litmus red.

2. **Reaction with Alkalis**
$CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$
$CH_3COOH + NH_4OH \rightarrow CH_3COONH_4 + H_2O$

**3. Reaction with Carbonates**
$2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + H_2O + CO_2$
$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$

**4. Reaction with Alcohols**

$$CH_3COOH + C_2H_5OH \xrightarrow{H_2SO_4} CH_3COOC_2H_5 + H_2O$$

**5. Reaction with $PCl_3$**
$CH_3COOH + PCl_5 \rightarrow CH_3COCl + POCl_3 + HCl$

**6. Reduction**
$CH_3COOH + 4[H] \rightarrow C_2H_5OH + H_2O$