III YEAR - V SEMESTER
COURSE CODE: 7BCH5C1

CORE COURSE - IX - ORGANIC CHEMISTRY – II

Unit I Organic halogen compounds:

1.1. **Alkylhalides:** classification and preparation. Reactions of alkyl halides: Substitution and elimination reactions of alkyl halides. Uses of alkyl halides as a starting material in organic syntheses, insecticides, pesticides and refrigerants. Poly halogen derivatives: Preparation and applications of chloroform, carbon tetrachloride, westron and Freon. Halogen derivatives of unsaturated hydrocarbons: Preparation and uses of vinyl chloride, allyl chloride and allyl iodide

1.2. **Aryl halides:** aryl halides and aryl alkyl halides. Preparation, properties and uses of aryl halides. Nucleophilic substitution reactions of chlorobenzene. Bimolecular and elimination – addition (benzyne) mechanisms of nucleophilic substitution reactions. Von Richter reaction of halogenonitrobenzene. Benzyl chloride and benzylidene chloride. Distinguishing aryl and aryl alkyl halogen derivatives. BHC and DDT preparation and properties.

1.3. **Organo metallic compounds:** Grignard reagent preparation properties and uses of Grignard reagent as a synthetic agent. Organo copper and organo lithium compounds and their uses as synthetic agents and catalysts. Limitations in the usage of organo metallic compounds as synthetic agents. Preparation and synthetic uses of Gilman reagent

Unit II Carbonyl Compounds:

2.1. **Carbonyl Compounds (Aldehydes and Ketones):** general methods of preparation of aliphatic and aromatic aldehydes and ketones. Conversion of an alcohol in to carbonyl compound by using N-bromosuccinimide and Oppenauer oxidation. Rosenmund's reduction, Stephen's method and Sommelet reactions. General properties of aldehydes and ketones. MPV reduction, Clemmenson reduction, Wolff – Kishner reduction. Oxidation of aldehydes and ketones. Baeyer – Villiger oxidation.

2.2. Nucleophilic addition reactions and Condensation reactions. Comparison of reactivity of aliphatic and aromatic aldehydes and ketones. Addition of hydrogen cyanide, and alcohols and protection of carbonyl groups and regeneration. Addition of amines to produce imines and enamines. Schmidt reaction, aldol condensation, Claisen condensation, Claisen Schmidt condensation, Knoevenagel, benzoin and Darzen - Glycidic condensation – Stork condensation reactions. Perkin reaction. Differences between aldehydes and ketones. Wittig reaction of carbonyl compounds and its synthetic applications. Preparation and properties of formaldehyde and acetaldehyde, polymerization, Cannizzaro reaction. Tischenko reactions. Chloral preparation and its properties.

2.3. α, β – unsaturated carbonyl compounds. Preparation and properties α, β unsaturated carbonyl compounds. Conjugated nucleophilic additions. Reactions of α, β unsaturated compounds with Grignard reagent and with Gilman reagent. Preparation and properties of acetyl acetone and acetonyl acetone. Active methylene group and generation of carbanion.

Unit III Aliphatic and aromatic carboxylic acids and their derivatives:

3.1. **Carboxylic acids:** preparation and properties of aliphatic and aromatic mono carboxylic acids. Systematic conversion of a hydrocarbon into a carboxylic acid with same and more number of carbon atoms. Comparison of acidity of aliphatic and aromatic carboxylic acids.

Effects of substituents and their position on the acidity of carboxylic acids. Ortho effects. Reactions of carboxylic acids and formation acyl halides, amides, esters, etc. Preparation, properties and estimation of urea.

3.2. **Dicarboxylic acids and substituted carboxylic acids:** preparation, properties and uses of oxalic acid, malonic acid, succinic acid and phthalic, maleic and fumaric acids. Preparation and properties of hydroxy acids, amino acids and halogen substituted acids. Action of heat on various hydroxyl acids and amino acids.

3.3. **Carboxylic acid derivatives:** carboxylic esters, carboxyl chlorides and amides: preparation and their properties. Active methylene group. Preparation of malonic ester and its synthetic uses. Acetoacetic ester and its synthetic uses.

Unit IV Organic Nitrogen derivatives.

4.1. **Organic nitro compounds:** preparation and properties of nitro methane, nitroso methane, nitrobenzene, dinitrobenzene, trinitrobenzene, trinitrotoluene, trinitrophenol and trinitroglycerine.

4.2. **Amines:** classification of amines, preparation aliphatic and aryl amines. Systematic conversion of a hydrocarbon into an amine through different intermediates. Properties of aliphatic amines and aryl amines. Comparison of basicity of aliphatic amines with aromatic amines. Effect of substituents on the basicity of amines and anilines. Alkylation and acylation of amines. Substitution reactions of amines with alkyl halides. Hoffmann elimination. Electrophilic substitutions of aryl amines. Diazotization of amines – Sandmeyer reaction. Synthetic applications of diazonium chloride.

4.3. **Heterocyclic compounds:** definition and classification heterocyclic compounds. Preparation and properties of furan, pyrrole, pyridine and thiophene. Comparison of the basicity of pyrrole and pyridine. Preparation, properties and biological importance of imidazole, pyrimidine and purine. Fischer indole synthesis and properties of indole.

Unit V Colourants

5.1. **Dyes and pigments:** Definition of dyes, pigments, chromophores and auxochromes with suitable examples. Differences between dyes and pigments. Classification of dyes based on chromophores, method of application and uses with suitable examples. Chromophores – auxochrome theory and modern theory of colour and constitution. Definitions and examples of mordents and leuco bases. Colour index of dyes and its significances. Phototropism and its importance in applications of dyes with suitable examples. Toxicity of dyes and pigments.

* * *

Unit – I

①

Alkyl halides.

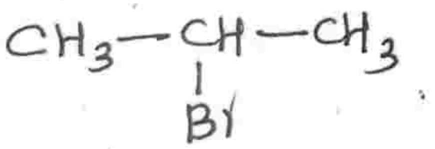
Classification

Alkyl halides are divided into mono –, di –, tri and poly – substituted products according to the number of halogen atoms in the molecule.

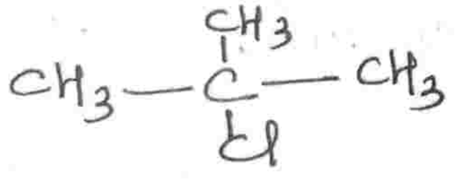
① Monohalogen derivatives.

Only one halogen atom is attached to the carbon of alkyl group.

CH_3-CH_2-Cl → ethyl chloride



$CH_3-\underset{Br}{\underset{|}{CH}}-CH_3$ → isopropyl bromide



$CH_3-\overset{CH_3}{\overset{|}{\underset{Cl}{\underset{|}{C}}}}-CH_3$ → tert-butyl chloride.

② Dihalogen derivatives.

It is classifeed as

ⓐ geminal – dihalides.

(b) Vicinal – "

inal – "

③ ~~Poly halogen derivatives.~~

~~Gem~~

ⓐ gem – dihalides.

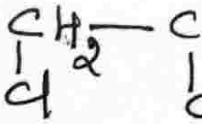
When both halogen atoms are attached to the same carbon atom. they are called as geminal (gem) position.

The loss of two ~~halo~~ hydrogen atoms from the same carbon atom gives the alkylidene group, gem-dihalides are named as the alkylidene dihalides.

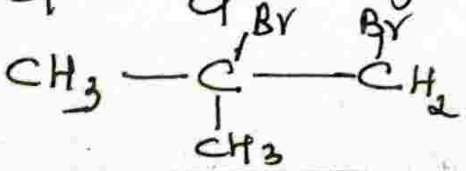
CH_3-CHBr_2 Ethylidene dibromide.

$CH_3-CCl_2-CH_3$ isopropylidene dichloride

(b) When the two halogen atoms are on adjacent carbon atoms they are called vicinal (vic-) position, and these dihalides are named as dihalides of the alkene from which they are prepared by the addition of halogen



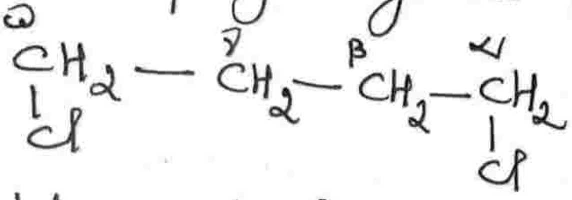
$CH_2(Cl)-CH_2(Cl)$ ethylene dichloride.



$CH_3-C(Br)(CH_3)-CH_2Br$ isobutylene dibromide

②

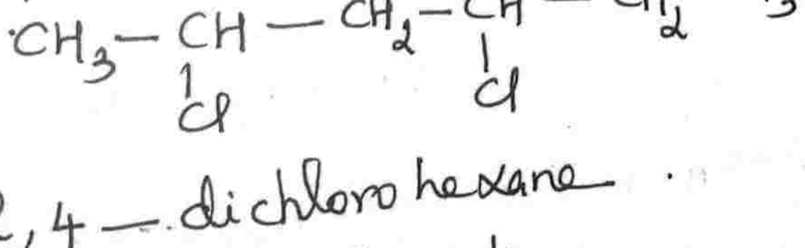
c) When the two halogen atoms on each of the termical carbon atoms of the chain i.e., in the α, ω-position, the compound is named as the polymethylene dihalide



$\overset{\omega}{C}H_2(Cl) - \overset{\gamma}{C}H_2 - \overset{\beta}{C}H_2 - \overset{\alpha}{C}H_2(Cl)$

tetramethylene dichloride.

(d) When the two halogen atoms occupy positions other than those gem-, vic-, α, ω- position, the compounds are named as dihalogen derivatives of the parent hydrocarbon, the positions of the halogen atoms being indicated by numbers (use principles of lowest numbers)

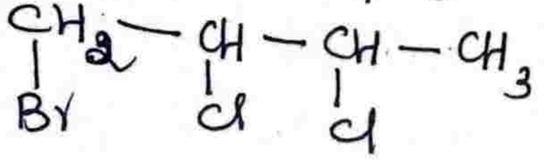


$\overset{1}{C}H_3 - \overset{2}{C}H(Cl) - \overset{3}{C}H_2 - \overset{4}{C}H(Cl) - \overset{5}{C}H_2 - \overset{6}{C}H_3$

2,4-dichlorohexane.

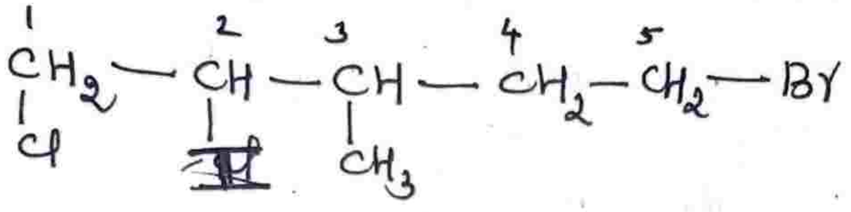
③ Poly halogen derivatives.

When more than two halogen atoms are ~~acted~~ presented in the compound called as polyhalogen derivatives.



$$CH_2(Br)-CH(Cl)-CH(Cl)-CH_3$$

1-bromo-2,3-dichlorobutane.



$$\overset{1}{C}H_2(Cl)-\overset{2}{C}H(I)-\overset{3}{C}H(CH_3)-\overset{4}{C}H_2-\overset{5}{C}H_2-Br$$

~~3~~5-bromo-1-chloro-2-Iodo-3-methylpe

Preparation

① From alcohol

Alkyl halides are prepared from alcohols by the reaction ~~of~~ HX

a) $R-OH + HX \longrightarrow R-X + H_2O$

Alcohol Alkyl halide

Example

$CH_3-CH_2-CH_2-OH + HBr \longrightarrow CH_3-CH_2-CH_2-Br + H_2O$

1-bromopropane.

$(CH_3)_3C-OH + HCl \longrightarrow (CH_3)_3C-Cl + H_2O$

tert-butyl chloride

The order of reactivity of HX is HI > HBr > HCl and that of alcohol

Tertiary > Secondary > Primary alcohol.

Primary alcohol and secondary alcohols are less reactive, therfore the reaction is carried out in the presence of ~~and~~ an acid such as ~~anhydroge~~ anhydrous $ZnCl_2$ or H_2SO_4

$$CH_3-CH_2-OH \xrightarrow[\text{anhyd. } ZnCl_2]{HCl} CH_3-CH_2-Cl + H_2O$$

A mixture of anhydrous $ZnCl_2$ & HCl known as Lucas reagent.

For bromination, hydrobromic acid (HBr) may be prepared in situ by the reaction of NaBr or KBr with Con. H_2SO_4.

The mechanism of the reaction involves the nucleophilic substitution of OH^- group with a halide ion. In acidic solution, alcohol accepts a proton to form protonated alcohol which subsequently undergoes reaction with halide ion.

Scanned by TapScanner

$$R-\ddot{\underset{\cdot\cdot}{O}}H \xrightarrow{H^+} R-\overset{\oplus}{\underset{H}{O}}-H \xrightarrow{\bar{X}} R-X +$$

Protonation converts a poor leaving group OH into a good leaving group H_2O, the function of $ZnCl_2$ is similar to that of H^+,

② <u>By the reaction of alcohols with PCl_5, PCl_3, PBr_3, PI_3 or P & I_2</u>

Alkyl chlorides are prepared by the treatment of alcohols with phosphorus halides PCl_3 or PCl_5

(b)

$$R-OH + PCl_5 \longrightarrow R-Cl + POCl_3 + HCl$$

$$3R-OH + PCl_3 \longrightarrow 3R-Cl + H_3PO_3$$

<u>Example</u>

$$\underset{\text{Ethyl alcohol}}{CH_3-CH_2-OH} + \xrightarrow{PCl_5} \underset{\text{Ethyl chloride}}{CH_3-CH_2-Cl} + POCl_3 + HCl$$

$$\xrightarrow{PCl_5} 3CH_3-CH_2-Cl + H_3PO_3$$

Alkyl bromides and alkyl ~~halides~~ Iodide are prepared by treating with PBr_3, and PI_3 generated in situ by the reaction of red P with Br_2 or I_2.

$$P_4 + 6Br_2 \longrightarrow 4PBr_3$$

c) By the reaction of thionyl chloride with alcohol.

Alcohol reacts with thionyl chloride to form alkyl chlorides.

$$R-OH + SOCl_2 \longrightarrow R-Cl + SO_2 + HCl$$

Example

~~This~~

$$CH_3-CH_2-OH + SOCl_2 \longrightarrow CH_3-CH_2-Cl + SO_2 + HCl$$

② From Olefins

Halogen acids (HCl, HBr, HI) add to alkenes to form alkyl halides

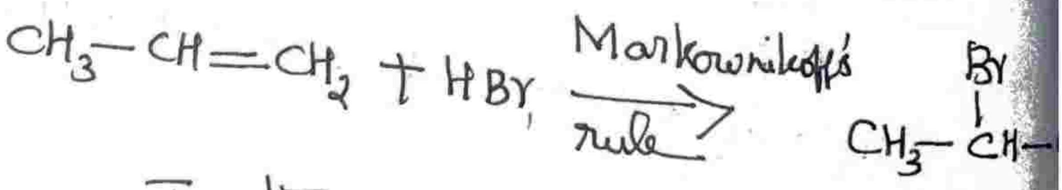
$$\underset{\text{Ethylene}}{CH_2=CH_2} + HBr \longrightarrow \underset{\text{Bromo ethane}}{CH_3-CH_2-Br}$$

The order of reactivity of halogen acids ~~as~~

HI > HBr > HCl > HF.

The strongest acid HI is the reactive, while the weakest the least reactive.

The addition of HX to unsymmetrical alkenes, takes place according to Markownikoff's rule, i.e., the negative part of the addendum (X of HX) adds ~~to~~ on to the carbon atom of the double bond that contains the least number of hydrogen.



$$CH_3-CH=CH_2 + HBr \xrightarrow[\text{rule}]{\text{Markownikoff's}} CH_3-\overset{Br}{\overset{|}{C}H}-$$

In the presence of peroxides the addition of HBr (not HCl or HI, takes place contrary to Markownikoffs' rule, i.e., the major product of addition reaction between HBr and propene is 1-bromopropane instead of ~~2-bromo propane~~

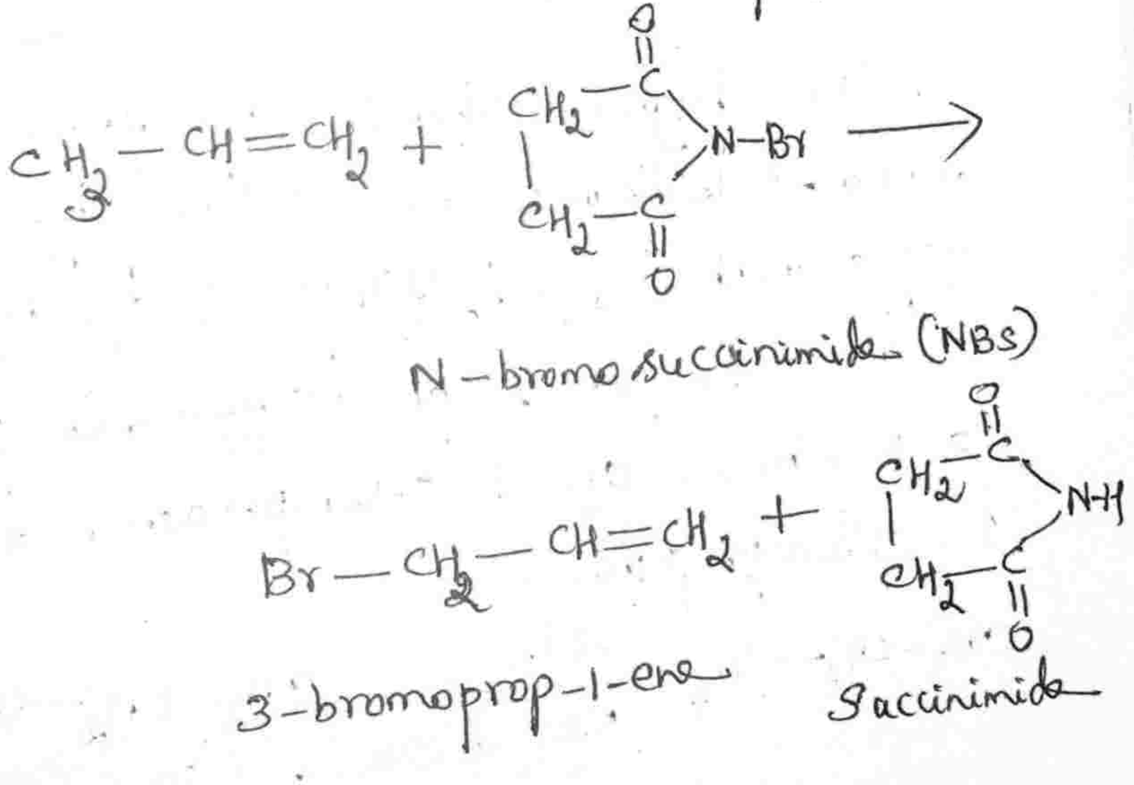
Alkenes are allowed to react with Cl_2 or Br_2 at higher temperature (773 — 873k) or with N-bromosuccinimide (NBS), allyl chlorides or bromides are obtained

$$CH_3-CH=CH_2 + Cl-Cl \xrightarrow{773k} Cl-CH_2-CH=CH_2$$

prop-1-ene 3-chloroprop-1-ene

$$\xrightarrow{Br-Br} Br-CH_2-CH=CH_2$$

3-bromoprop-1-ene



N-bromosuccinimide (NBS)

3-bromoprop-1-ene Succinimide

③ From alkanes.

By direct halogenation of
in the presence of light or cataly

Halogenation of alkanes with Cl_2 a
follows a free radical mechanism
a complex mixture of mono- an
poly-haloalkanes is obtained.

$$CH_4 \xrightarrow[520-870k]{Cl_2} CH_3Cl + CH_2Cl_2 + CHC$$

Chloro methane Dichloro methane Tri meth

CCl_4.

Tetra chloro meth

In higher alkanes, a mixture of mono-haloalkanes is obtained by the replacement of all types of hydrogen atoms. Propane on halogenation provides a mixture of 1-chloropropane and 2-chloropropane.

$$CH_3-CH_2-CH_3 \xrightarrow[520-670k]{Cl_2} CH_3-CH_2-CH_2-Cl +$$

1-chloropropane

2-chloro propane $\underset{\displaystyle Cl}{\underset{|}{CH_3-CH-CH_3}}$

It has been found that the relative rate of abstraction of 3°, 2° and 1° hydrogen atoms by Cl_2 is 5 : 3.8 : 1 at 298K.

Iodination

It is reversible, thus it is carried out in the presence of an oxidizing agent such as iodic acid (HIO_3) or conc. HNO_3 to oxidise HI formed.

$$CH_4 + I_2 \longrightarrow CH_3I + HI$$

$$5HI + HIO_3 \longrightarrow 3I_2 + 3H_2O$$

Fluorination

Fluorination of alkane with fluorine is highly exothermic and occurs explosively. This is carried out by carefully controlling the reaction conditions and performing the reaction with F_2 diluted with an inert gas such as N_2 or Ar.

Fluroalkanes are prepared b heating an alkyl chloride or brom with a metallic fluoride such as AgF, Hg_2F_2, CoF_3 or SbF_3. This ha exchange reaction is called Swarts reaction.

$$CH_3-Br + AgF \longrightarrow CH_3F + AgBr$$

$$3CH_3-CCl_2-CH_3 + SbF_3 \longrightarrow 3CH_3-CF_2-CH_3 + 2SbCl_3.$$

4 By halide exchange reactions :

Iodoalkanes are obtained from the corresponding chloro - & bromoalkanes by heating with NaI or KI dissolved in acetone or methanol solution.

$$CH_3-CH_2-Br + NaI \xrightarrow{acetone} CH_3-CH_2-I + NaBr$$

$$CH_3-CH_2-Cl + NaI \xrightarrow{acetone} \underset{\text{Iodoethane}}{CH_3-CH_2-I} + NaCl.$$

This reaction is called **Finkeistein** reaction.

5. From Silver salt of fatty acids

Bromoalkanes can be prepared by refluxing silver salt of the fatty acids with Br_2 in CCl_4 solution.

$$\cancel{CH_3}\ CH_3-CH_2-COOAg + Br_2 \xrightarrow{Reflux} CH_3-CH_2-Br + CO_2$$

Silver acetate

bromoethane

This reaction is called **Hundsdicker** reaction.

Properties

Physical Properties

① Some of the lower members of alkyl halides are gases while the rest of them are colourless, sweet smelling liquids.

② They are insoluble in water but soluble in alcohol, ether, and benzene

③ Bromides and iodides are heavier than water.

④ Their boiling points and den show a regular gradation in their properties.

Iodide > Bromide > chloride > F

It is due to the increase in the size and mass of halogen atom tha magnitude of van der Walls forces inc

Among the isomeric alkyl halides the boiling point decreases with increase in the branching. This is due to the reason that as the branching in alkyl group increases, the molecule attains spherical shape with less surface area resulting in a decrease in the ~~intermole~~ intermolecular forces.

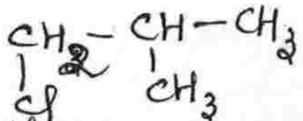
Example:

Isomeric butyl chloride, the boiling point decreases with the increase in branching:

(b-pt = 342k)

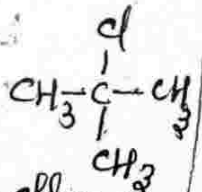
$CH_3-CH_2-CH_2-CH_2-Cl$

1-chloro butane
(b-pt = 351·2k)



$CH_2(Cl)-CH(CH_3)-CH_3$

1-chloro-2-methyl propane



$CH_3-C(Cl)(CH_3)-CH_3$

2-chloro ~~2~~ 2-methyl propane
(b-pt = 324k)

(5) Alkyl iodides are sufficiently reactive to be decomposed by light. Liberation of iodine is responsible for the darkening of alkyl iodides on standing. This is due to the instability of C—I bond.

$$2RI \longrightarrow R{-}R + I_2$$

Spectroscopic properties

In the UV region, alkyl halides show absorption bands of low intensity

C—Cl	C—Br	C—I
173 nm	240 nm	258 nm

In IR absorption region of alkyl halides (C—X stretch) depends on the nature of the halogen atom.

C—F 1100 — 1000 cm^{-1}

C—Cl 750 — 700 cm^{-1}

C—Br 600 — 500 cm^{-1}

C—I 500 cm^{-1}

Chemical Properties

The alkyl halides are h reactive, the order of reactivity iodide > bromide > chloride for a particular alkyl group and tertiary > Secondary > Primary > m

Among the primary halides the hali order of reactivity is

$CH_3X > CH_3-CH_2-X > C_2H_5-CH_2$

The order of reactivity and other important reactions of alkyl halides explained in terms of the nature of C—bond which is hig polarised covalent bond due to lar electronegativity difference between C and X atoms. In the dipole, carbon is the positive end and halogen is the negative end of the dipole.

i) The $\rangle\overset{+}{C}$ ion is susceptible to attack by nucleophiles. Leaving halides ion is substituted by the approaching nucleophile (an electron-rich species). This gives rise to nucleophilic substitution of alkyl halides

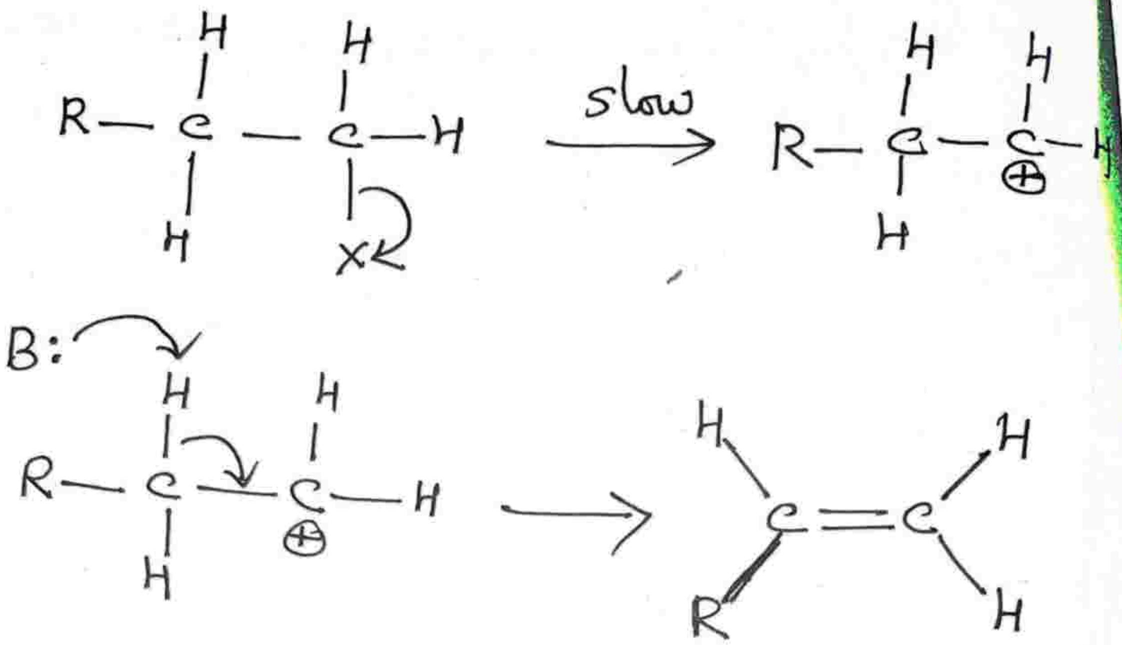
$$Nu: + R-X \longrightarrow R-Nu + \bar{X}$$

$$R-X \xrightarrow[\text{slow}]{-X^-} R^+ \xrightarrow{\bar{Nu}} R-Nu$$ (SN^1. reaction)

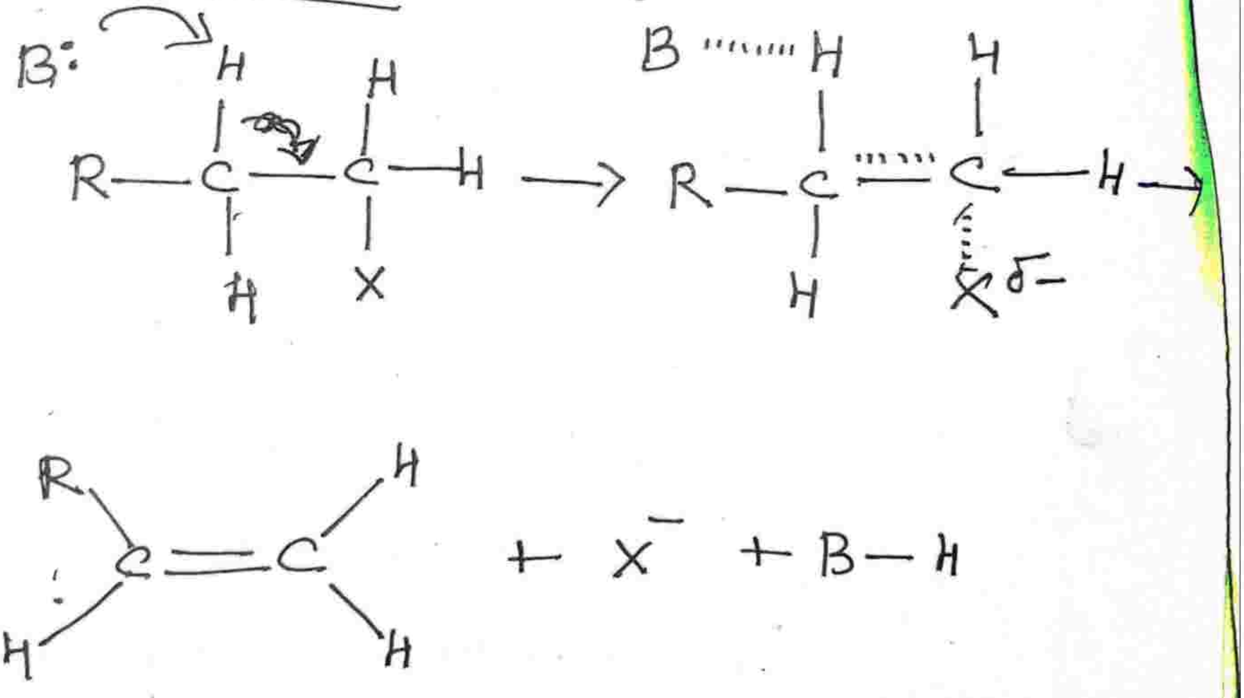
$$\bar{Nu} + R-X \longrightarrow \overset{\delta-}{Nu}-R-\overset{\delta-}{X} \longrightarrow Nu-R + \bar{X}$$ (SN^2 reaction)

(ii) The positive charge on carbon is propagated to the neighbouring carbon atom by inductive effect. When approached by a strong base, it tends to lose a proton usually from the β-carbon atom. Such reactions involving the elimination of a halogen atom along with a proton from β-position are termed elimination

a E1 reaction



b) E2 Reaction

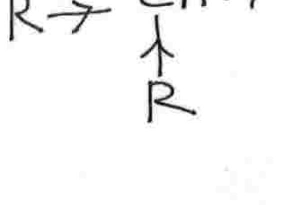


The reactions of alkyl halides involve leaving of X^-, the difference in the reactivity of various halogen should be in the order of decrease of C—X bond strength. ~~This has actually~~

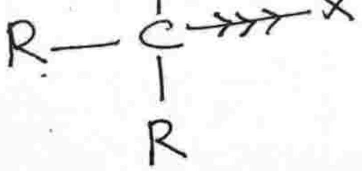
Type of bond	C—F	C—Cl	C—Br	C—I
Bond Energy	447.7	326.4	284.5	213.4.

The alkyl groups are electron repelling or electron releasing. The larger the number of alkyl groups attached to the carbon atom of the C—X, the greater ~~#~~ is the electron density on this carbon atom and hence ~~the~~ greater is the repulsion of the electron pair towards the X-atom of the C—X bond. This is represented qualitatively as follows.

$R \rightarrow CH_2 \rightarrow X$



$R \rightarrow \underset{\underset{R}{\uparrow}}{CH} \rightarrow\rightarrow X$



$R - \underset{R}{\overset{R}{\underset{|}{\overset{|}{C}}}} \rightarrow\rightarrow\rightarrow X$

The X-atom is released as an X^-

ion most readily in tertiary h
and least readily in primary h

The primary alkyl halides undergo by either S_N2 or E^2 mechanism which involves the formation of an intermediate transit state.

Bulkier group causes steric hinderance in the formation of a transition state. Hence the ease of formation of transition state decrease as we pass from ~~me~~ simple methyl group to bulky n-propyl group. Therefore the order of reactivity

$CH_3-X > C_2H_5X > n-C_3H_7X$

The tertiary alkyl halide react by either by S_N1 or E1 mechanism via the formation of carbocation as intermediate. The reaction is, therefore favoured by structural features which help stabilization of the intermediate carbo cation.

The secondary alkyl halides react by either or both these mechanisms depending on the nature of alkyl halide and the nature of reagent.

Nucleophilic substitution Reactions

① Hydrolysis

Alkyl halides are hydrolysed to alcohols very slowly by water but rapily by boiling with aqueous alkalies or with silver oxide ~~sup~~ suspended in boiling water.

$$R-X + KOH_{(aq)} \longrightarrow R-OH + KX.$$

$$R-X + OH^{-} \longrightarrow R-OH + X^{-}$$

Reaction with sodio – alkynides.

Higher alkynes are produced when alkyl halides react with sodio – alkynides.

$$\underset{\text{Sodioalkynide}}{R-C\equiv CNa} + R'I \longrightarrow \underset{\text{Higher alkyne}}{R-C\equiv C-R'} + NaI$$

Reaction is limited to the use of primary alkyl halides because secondary and tertiary alkyl halides undergo elimination in this reaction.

$$(CH_3)_2CHX + HC\equiv CNa \longrightarrow \underset{\text{Propylene}}{CH_3-CH=CH_2} + CH\equiv CH + X^-$$

The order of reactivity of alkyl halides for elimination is tertiary halides > secondary halides > Primary halides while the order of reactivity for substitution is primary halides > secondary halides > tertiary halides.

(i.e) elimination increases and substitution decreases from prim
to secondary to tertiary halides.

RX = Primary halide > Secondary halide >

$\longrightarrow$
Elimination

$\longleftarrow$
Substitution

③ **Reaction with sodium alkoxide or Dry silver oxide**

Alkyl halides react with sodium alkoxide or dry silver oxide to form ethers.

$$R-ONa + XR' \longrightarrow R-O-R' + NaX.$$

ether

$$C_2H_5-ONa + C_2H_5-I \longrightarrow C_2H_5-O-C_2H_5 + NaI$$

Sodium alkoxide ethyl iodide

$$2\,C_2H_5-I + Ag_2O \longrightarrow C_2H_5-O-C_2H_5 + 2AgI$$

Ethyliodide Dry silver oxide Diethylether

This is an example of $S_N{}^2$ reaction and takes place as under the following

$$C_2H_5-\bar{O} + CH_3-I \longrightarrow \overset{\delta-}{C_2H_5-O}\cdots\cdots\overset{\delta+}{CH_3}\cdots\cdots\overset{\delta-}{I}$$

$$\downarrow$$

$$C_2H_5-O-CH_3 + \bar{I}$$

④ Reaction with KCN

Alkyl cyanides are obtained when alkyl halides are heated with aqueous cyanide

$$R-X + KCN \longrightarrow \underset{\text{alkyl cyanide.}}{R-CN} + KX.$$

Alkyl cyanides are very important compounds, since they can be used to prepare many types of other compounds

ⓐ Acids are obtained by hydrolysis of cyanides with mineral acids or alkalis

$$R-C\equiv N \xrightarrow{H_2O} R-\underset{\underset{O}{\|}}{C}-NH_2 \xrightarrow{H_2O} \underset{\text{Acid}}{R-\underset{\underset{O}{\|}}{C}-OH} + NH_3$$

$$\underset{\text{methyl cyanide.}}{CH_3-C\equiv N} \xrightarrow{H_2O} CH_3-\overset{\overset{O}{\|}}{C}-NH_2 \xrightarrow{H_2O}$$

$$\underset{\text{Acetic acid.}}{CH_3-\overset{\overset{O}{\|}}{C}-OH} + NH_3$$

ⓑ Amides are obtained by the partial hydrolysis of cyanides with alkaline hydrogen peroxide.

$$R-C\equiv N + H_2O \xrightarrow{alk.\,H_2O_2} R-\overset{\overset{O}{\|}}{C}-NH_2$$

$$CH_3-C\equiv N + H_2O \xrightarrow{alk.\,H_2O_2} CH_3-\overset{\overset{O}{\|}}{C}-NH_2 .$$

Methyl cyanide — Acetamide

ⓒ Primary amines are obtained by the reduction of cyanides with nascent hydrogen from sodium and ethanol.

$$R-C\equiv N + 4[H] \xrightarrow{Na/C_2H_5-OH} R-CH_2-NH_2$$

Alkyl cyanide — Primary amine

$$CH_3-C\equiv N + 4[H] \xrightarrow{Na|C_2H_5-OH} CH_3-CH_2-NH_2$$

Ethyl amine

) Reaction with silver cyanide

Alkyl isocyanides are obtained when alkyl halides are heated with aqueous ethanolic silver cyanide are formed in small amounts.

$$-I + AgCN \longrightarrow C_2H_5-NC + AgI$$

de, Ag–CN, is a

covalent compound. When treated
alkyl halide, the alkyl carbo cation
driven to the nitrogen to yield main
alkyl isocyanide (of KCN which is
ionic compound and gives $R-C\equiv N$ as
explained above).

$$Ag-C\equiv N + R-I \longrightarrow \left[Ag-C\equiv N-R\right]^{+} I$$

$$\downarrow AgI$$

$$R-N\equiv C$$

⑥ Reaction with Silver salt of a Fatty Ac

Esters are obtained when alkyl halides are heated with an ethanolic of silver salt of a fatty aci

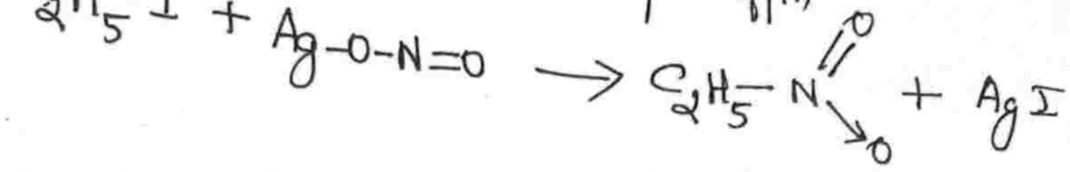
$$\underset{\text{Silver salt of Fatty acid}}{R-COOAg} + RX \xrightarrow{\Delta} \underset{\text{Ester}}{R-COOR} + AgX$$

$$CH_3-COO-Ag + I-C_2H_5 \longrightarrow \underset{\text{Ethyl acetate}}{CH_3COO-C_2H_5} + AgI$$

⑦ Reaction with silver nitrite

On heating an alkyl halide with an aqueous ethanolic solution of silver nitrite, Nitroparaffin is obtained as the main product.

$R-X + AgNO_2 \xrightarrow{\Delta} \underset{\text{nitroparaffin}}{R-NO_2} + AgX$



$C_2H_5-I + Ag-O-N=O \rightarrow C_2H_5-N\overset{O}{\overset{\|}{}}\underset{O}{\searrow} + AgI$

Nitroethane.

⑧ Reaction with potassium Nitrite

By heating an alkyl halide with potassium nitrite in an aqueous ethanolic solution, Alkyl nitrite is obtained as the product through some nitroparaffin is obtained.

$R-X + K-O-N=O \xrightarrow{\Delta} \underset{\text{alkyl nitrite}}{R-O-N=O} + KX$

$C_2H_5-I + K-O-N=O \rightarrow \underset{\text{ethyl nitrite}}{C_2H_5-O-N=O} + KI$

⑨ Reaction with sodium hydrogen sulphide

Alkyl halides from thio alcohols with aq. alcoholic sodium hydrogen sulphide.

$R-X + Na-SH \rightarrow R-SH + NaX$

⑩ Reaction with mercaptides.

Alkyl halides heated with an

alcoholic solution of a mercaptid (metallic derivative of a thioalcoho or with potassium sulphide form thio ethers

$$R-S-Na + X-R' \longrightarrow R-S-R' + Na$$

Sodio mercaptide

(II) <u>Reaction with ammonia :-</u>

When alkyl halides are heated with ethanolic solution of ammonia under pressure in a sealed tube, a mixture of amines (substituted ammonia) is obtained.

$$C_2H_5-I + H-NH_2 \xrightarrow[\text{under } P]{\Delta} C_2H_5-NH_2 + HI$$

Ethyl iodide Ammonia Ethylamine

1° amine

$$C_2H_5-\underset{\underset{H}{|}}{N}H + C_2H_5-I \longrightarrow (C_2H_5)_2NH + HI$$

Diethylamine

2° amine

$$(C_2H_5)_2NH + C_2H_5-I \longrightarrow (C_2H_5)_3N + HI$$

Triethylamine

3° amine

$$(C_2H_5)_3N + C_2H_5-I \rightarrow (C_2H_5)_4\overset{+}{N}\bar{I}$$

Tetraethylammonium iodide

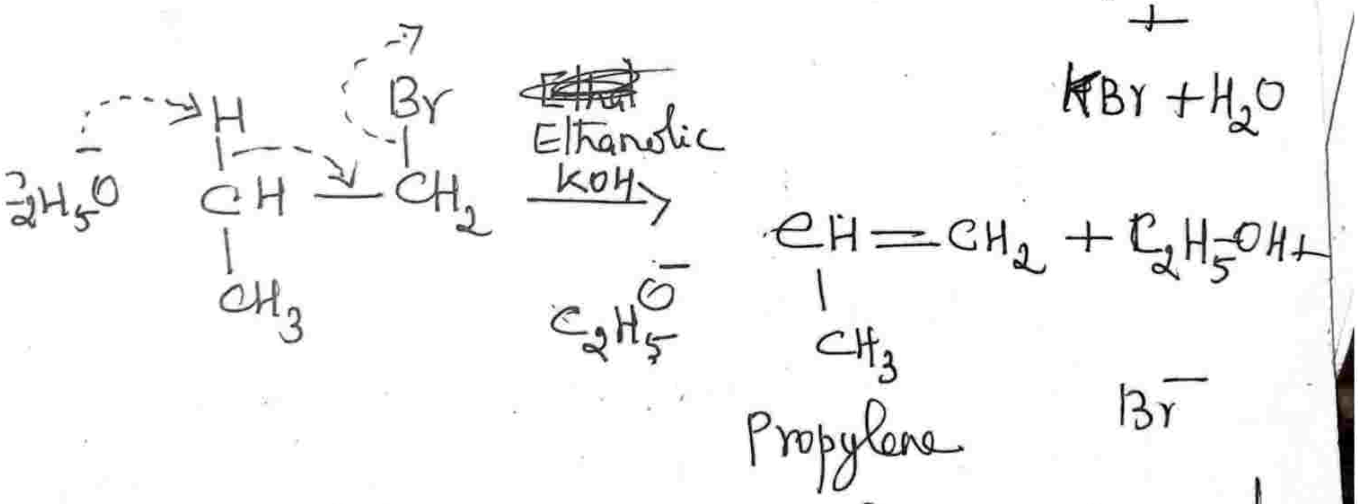
(Quarternary compound)

Elemination Reaction (or) Dehydrohalogenation

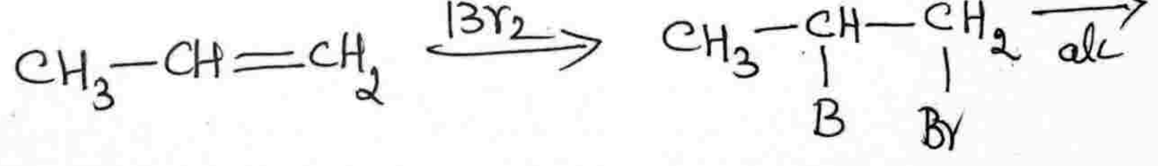
When alkyl halides are boiled with alcoholic potash, olefins are obtained

examples: propyl bromide gives propylene

$$\underset{\text{Propyl bromide}}{CH_3-CH_2-CH_2-Br} + \underset{\text{alc}}{KOH} \longrightarrow \underset{\text{Propylene}}{CH_3-CH=CH_2} + KBr + H_2O$$



Propylene obtained (olefine) is used for the preparation of alkyne.



$$CH_3-CH=CH_2 \xrightarrow{Br_2} CH_3-\underset{B}{CH}-\underset{Br}{CH_2} \xrightarrow[alc]{KOH}$$

$CH_3-C\equiv CH + 2HBr$
Propyne.

③ **Reduction**

Alkyl halides are reduced by Zn–Cu couple, sodium and ethanol or tin and hydrochloric acid, etc., to form the corresponding paraffins as a ~~ref~~ result of electron transfer from the metal to the substrate.

$$Zn \longrightarrow Zn^{2+} + 2e^-$$

From Zn/Cu couple

$$RX + e^- \longrightarrow \overset{-}{X} + \overset{+}{R} \xrightarrow{e^-} \overset{-}{R:}$$

$$\overset{-}{R:} + C_2H_5-OH \longrightarrow RH + C_2H_5-\overset{-}{O}$$

Alkyl halides reduced by heating with conc. Hydroiodic acid in the presence of red phosphorus at 430k

$$C_2H_5-I + HI \longrightarrow C_2H_6 + I_2.$$

Ethane.

4) Wurtz Reaction

An ethereal solution of an alkyl halide (bromide or iodide) gives paraffin when heated with metallic sodium.

$$R-X + 2Na + R'-X \xrightarrow{\Delta} R-R' + 2NaX$$

$$C_2H_5-I + 2Na + C_2H_5-I \rightarrow \underset{\text{Butane}}{C_2H_5-C_2H_5} +$$

I_2 .

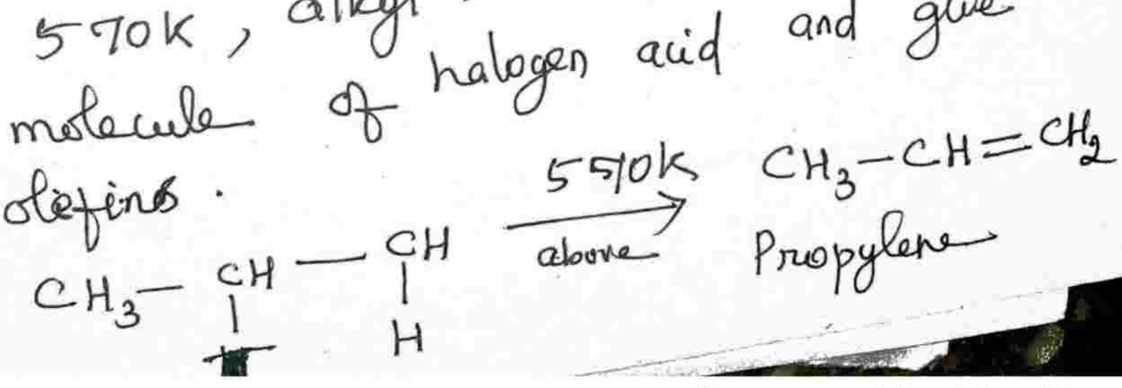
⑤ Reaction with Magnesium

Alkyl halides are used to prepare Grignard reagents by reaction with dry Magnesium powder in dry ether or dioxan.

$$C_2H_5-I + Mg \rightarrow \underset{\text{Ethyl magnesium iodide}}{C_2H_5-Mg-I}$$

⑥ Action of heat :-

ⓐ When heated at a temperature above 570K, alkyl halides tend to lose a molecule of halogen acid and give olefins.



$$CH_3-\underset{I}{\underset{|}{CH}}-\underset{H}{\underset{|}{CH}} \xrightarrow[\text{above}]{570K} \underset{\text{Propylene}}{CH_3-CH=CH_2}$$

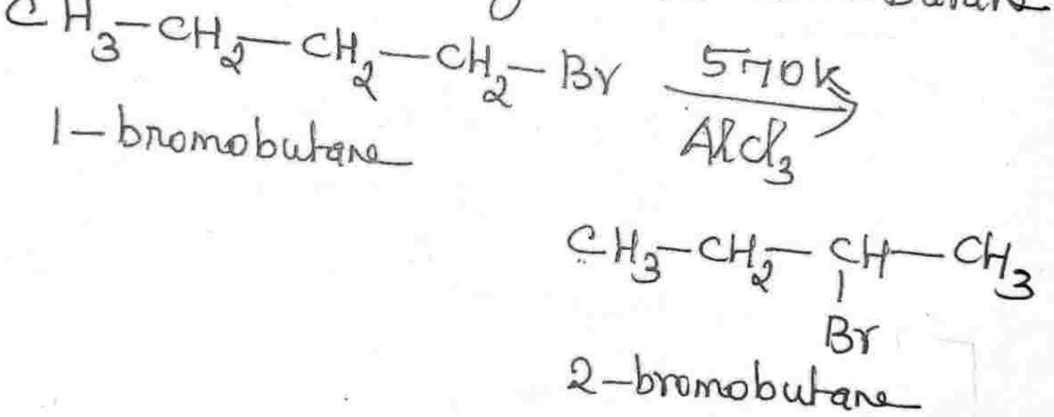
The tendency to lose a molecule halogen acid

Iodide > Bromide > chloride

Tetriary halides > Secondary halides > Prim halides

ⓑ When heated at about 570 K or lower temp. in the presence of $AlCl_3$ as catalyst, the alkyl halides undergo rearrangement. Example

1-bromobutane gives 2-bromobutane



$$CH_3-CH_2-CH_2-CH_2-Br \xrightarrow[AlCl_3]{570K} CH_3-CH_2-\underset{\displaystyle Br}{\underset{|}{CH}}-CH_3$$

1-bromobutane

2-bromobutane

Uses

I Methyl chloride used ① in the manufacture of aniline dyes.

② as a refrigerating agent

③ as a local anaesthetic

④. as a fire extinguisher.

II Ethyl chloride used in the preparation of tetraethyl lead, sulphonal

II **Ethyl bromide**

It is used in organic synthesis.

IV **Ethyl iodide**

It is a typical alkyl halide and is an important synthetic agent.

Preparation

From Ethylalcohol (or Acetone) and Bleaching Powder

By heating ethylalcohol or acetone bleaching powder, $Ca(OCl)_2$. The bleaching powder acts as source of chlorine a calcium hydroxide.

Reaction of ethylalcohol with bleac powder takes place by the following th steps.

(i) Oxidation

$$CH_3-CH_2OH + Cl_2 \longrightarrow \underset{\text{Acetaldehyde}}{CH_3-CHO} + 2HCl$$

(ii) Chlorination

$$\underset{\text{Acetaldehyde}}{CH_3-CHO} + 3Cl_2 \longrightarrow \underset{\text{Chloral}}{CCl_3-CHO} + 3HC$$

(Tri chloro acetaldehyde

(iii) Hydrolysis

$$2CCl_3-CHO + Ca(OH)_2 \longrightarrow \underset{\text{Chloroform}}{2CHCl_3} + \underset{\text{Calcium formate}}{(HCOO)_2}$$

Reaction of acetone with bleac powder takes place by the following tw steps.

(i) Chlorination

$$CH_3\text{-}CO\text{-}CH_3 + 3Cl_2 \longrightarrow CCl_3\text{-}CO\text{-}CH_3 + 3H$$

Trichloro acetone

(ii) Hydrolysis

$$CCl_3\text{-}CO\text{-}CH_3 + Ca(OH)_2 \longrightarrow 2CHCl_3 + (CH_3COO)_2Ca$$

Trichloro acetone — chloroform — calcium acetate.

(2) From Methane

By chlorination of methane at 400°c

$$CH_4 \xrightarrow[400°c]{Cl_2} CH_3Cl + CH_2Cl_2 + CHCl_3 + CCl_4$$

Chloroform is separated from the produ by fractional distillation. Today most of the chloroform is manufactured by this method

Uses

① It is used as a solvent for fats, wa and rubber

② It is used in the preparation of chloropi and chloretone.

③ In the past chloroform was extensively used general anesthetic for surgery

) It is used as a laboratory reagent ar in medicine .

) It is used as preservative for anatomical speciments .

) It is used as a flavouring agent .

carbon Tetra chloride.

Preparation

Industrial Preparation

i) By the action of chlorine on carbo disulphide in the ~~prepara~~ presence of aluminium chloride as a catalyst

$$CS_2 + 3Cl_2 \xrightarrow[AlCl_3]{} CCl_4 + S_2Cl_2$$

carbon disulphide

carbon tetra chloride

Sulpher mono chlor

(ii) By the chlorination of methane

$$CH_4 + 4Cl_2 \longrightarrow CCl_4 + 4HCl$$

Uses

① It is used as an industrial solvent

(2) " " " in dry cleaning

" " as a fire existinguisher and

a general anesthetic for surgery

④ It is used as a laboratory reagent ar in medicine.

⑤ It is used as preservative for anatomical speciments.

⑥ It is used as a flavouring agent.

Carbon Tetrachloride.

Preparation

Industrial Preparation

(i) By the action of chlorine on carbo disulphide in the ~~prepara~~ presence of aluminium chloride as a catalyst.

$$CS_2 + 3Cl_2 \xrightarrow[AlCl_3]{} CCl_4 + S_2Cl_2$$

Carbon disulphide

Carbon tetra chloride

Sulpher monochlo

(ii) By the chlorination of methane

$$CH_4 + 4Cl_2 \longrightarrow CCl_4 + 4HCl$$

Uses

① It is used as an industrial solvent

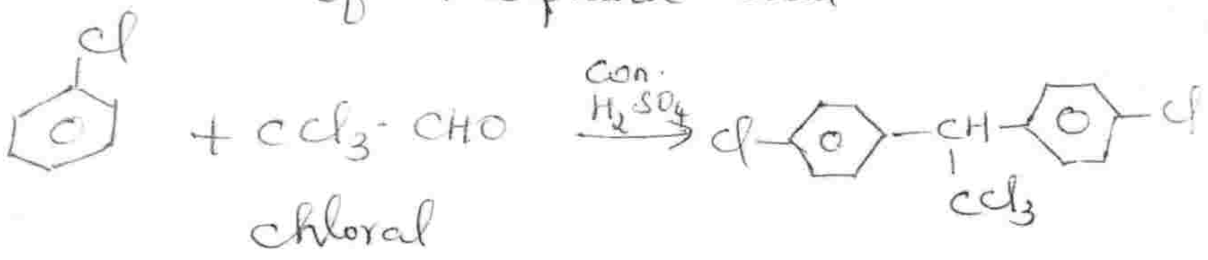
(2) " " " in dry cleaning

(3) " " " as a fire existinguisher an

the name "pyrene",

DDT – 2, 2-bis-(4-chlorophenyl)-1,1,1-trichloroethane.

It is also known as p,p'-dichloro diphenyltrichloro ethane. It is synthesized by the condensation of 1 mole of chloral with 2 moles of monochlorobenzene in the presence of sulphuric acid.



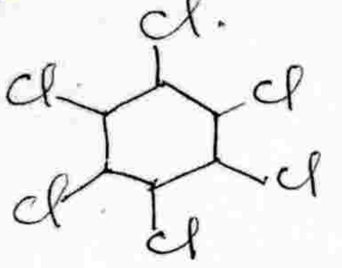
DDT.

Uses

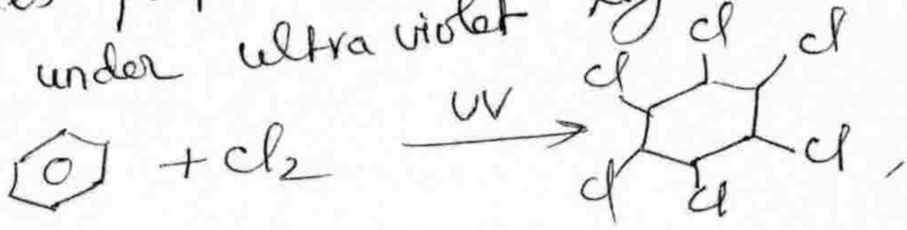
(1) It is used as insecticides.
(ii) " " " solvent.
(~~2~~)

BHC Benzene Hexa chloride

It is marketed under the trade name Gammexane or 666. chemically it is the γ-isomer of 1, 2, 3, 4, 5, 6-hexachlo cyclohexane. Gammexane contains only about 15% of the γ-isomer. Preparation containing about 99% γ-isomer is named



It is prepared by the chlorination o benzene under ultra violet light.



Uses·

Used as insecticides,

Freon – Dichlorodifluoromethane CCl_2F_2

It is prepared by the action of C with HF in presence of antimony pentaf to form Freon -12.

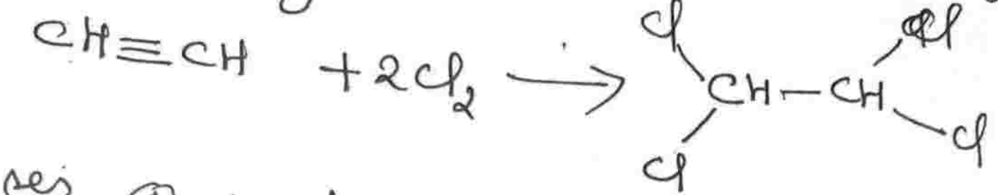
$$\underset{\text{Carbon tetra chloride}}{CCl_4} + \underset{\text{Hydrogen fluoride}}{2HF} \xrightarrow{SbF_5} \underset{\text{Freon -12}}{CCl_2F_2} + 2HCl$$

Uses

It is used as a refrigerant and propell in aerosol sprays of all kinds.

Westron → (Acetylene tetra chloride)

It is prepared by passing a mixture of acetylene and chlorine into chambers containing iron fillings and kieselgur.



$$CH \equiv CH + 2Cl_2 \longrightarrow \underset{Cl}{\overset{Cl}{CH}} - \underset{Cl}{\overset{Cl}{CH}}$$

Uses → ① Used commercially Westron as solvent for ~~②~~ oils, pains, varnishes, rubber)

Freon (or) Dichlorodifluoromethane

CCl_2F_2.

It is prepared by ~~passing~~ ~~westw~~ the action of antimony fluoride on carbon tetrachloride in presence of antimony pentachloride (catalyst)

$$3CCl_4 + 2SbF_3 \xrightarrow{SbCl_5} 3CCl_2F_2 + 2SbCl_3$$

Uses

It is widely used in electric refrigerators and air conditioning plants.

Acetylene tetrachloride (Westron)

Acetylene tetrachloride (Westron), $CHCl_2 \cdot CHCl_2$: Acetylene tetrachloride is also called as sym. tetrachloroethane. It is created by the action of chlorine on acetylene in presence of a catalyst such as aluminium chloride, iron, ferric chloride, quartz or kieselguhr.

$$CH \equiv CH + 2Cl_2 \longrightarrow \underset{\text{(1,1,2,2-Tetrachloroethane)}}{CHCl_2 \cdot CHCl_2}$$

In absence of catalyst, the reaction between chlorine and acetylene is highly explosive producing *HCl and* carbon. The reaction is less violent in occurrence of a catalyst.

It is a heavy, non-inflammable liquid. It boils at 146°C. It is highly toxic in nature. Its smell is similar to chloroform. It is not soluble with water but soluble in organic solvents.

On further chlorination, it forms hexa and pentachloroethane. On heating with Calcium hydroxide, it is converted to useful product **westrosol** ($CCl_2{=}CHCl$).

$$\underset{\text{Westron}}{2CHCl_2 - CHCl_2} + Ca(OH)_2 \longrightarrow \underset{\substack{\text{Westrosol}\\\text{(Trichloroethene)}}}{2CHCl = CCl_2} + CaCl_2 + 2H_2O$$

Both westron and westrosol are used as solvents for oils, fats, waxes, resins, varnishes and paints, etc.

Freon

Chloro fluoro - derivatives of methane and ethane are used as refrigerants and for air-conditioning under the name of Freon. which are prepared by the action of hyd fluorides on carbon tetra ~~&~~ chloride, Chloroform and hexachloro ethane

$$CHCl_3 \xrightarrow[HF]{SbF_3} CHF_2Cl \xrightarrow{800°C} C_2F_4 + 2HCl +$$

other produc

When tetrafluoroethylene is polymerised, the plastic Teflon is produced. Teflon is difficult to work, but is inert to chem reagents, even to boiling aqua ~~reagents~~. regia.

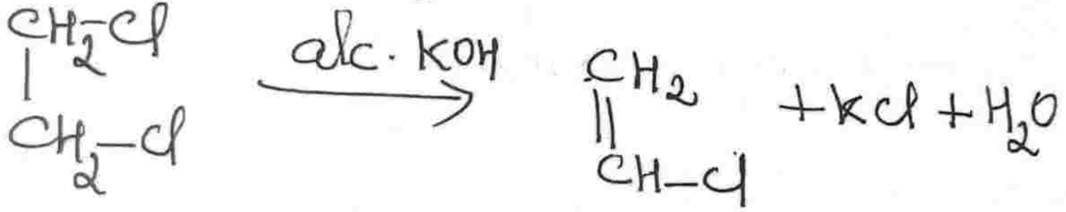
Unsaturated Halogen Compounds -

Vinyl chloride (Chloroethene):

$CH_2{=}CH-Cl$.

Preparation :

① It is prepared in the laboratory by the action of dilute ethanolic potash on ethylene chloride.

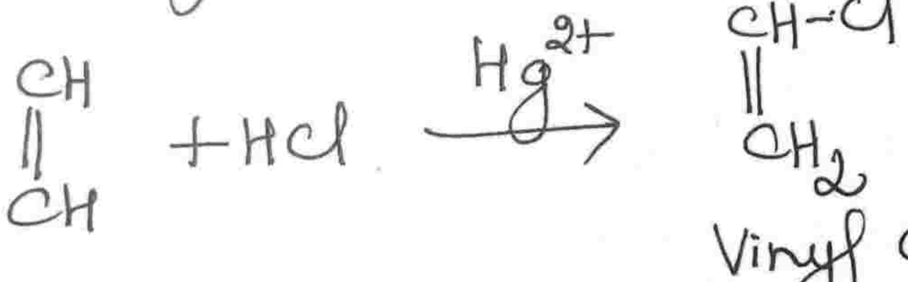


$$\begin{array}{c} CH_2-Cl \\ | \\ CH_2-Cl \end{array} \xrightarrow{alc.\,KOH} \begin{array}{c} CH_2 \\ \| \\ CH-Cl \end{array} + KCl + H_2O$$

Ethylene Chloride   Vinyl chloride

② It can be manufactured

ⓐ By passing acetylene into dil. HCl at 340K in the presence of Hg^{2+} ions (catalyst)

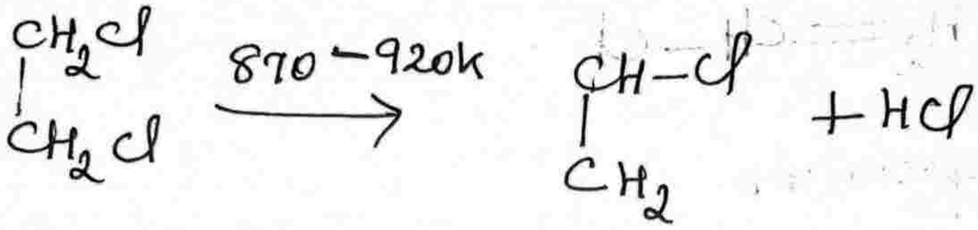


$$\begin{array}{c} CH \\ \| \\ CH \end{array} + HCl \xrightarrow{Hg^{2+}} \begin{array}{c} CH-Cl \\ \| \\ CH_2 \end{array}$$

Vinyl chloride

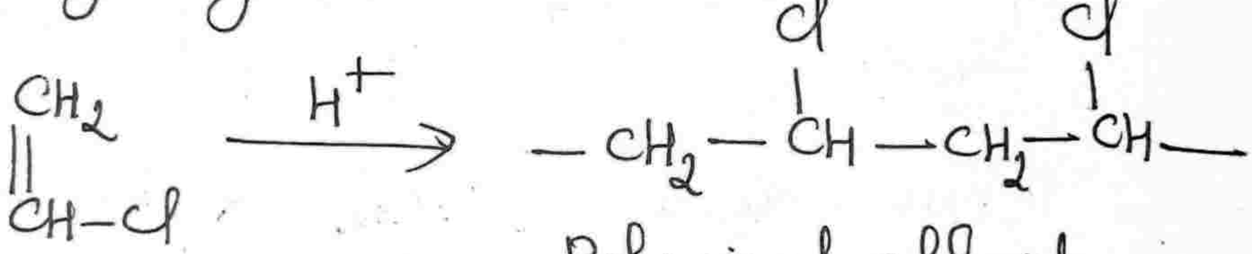
Acetylene

ⓑ By thermal decomposition of ethylene chloride at 870 — 920k



$$\begin{matrix}CH_2Cl\\|\\CH_2Cl\end{matrix} \xrightarrow{870-920k} \begin{matrix}CH-Cl\\|\\CH_2\end{matrix} + HCl$$

Uses : It is used in the manufacture of Plastics. It condenses with ~~itself~~ itself in the presence of acids to give poly vinyl chloride.



$$\begin{matrix}CH_2\\\|\\CH-Cl\end{matrix} \xrightarrow{H^+} -CH_2-\overset{\overset{Cl}{|}}{CH}-CH_2-\overset{\overset{Cl}{|}}{CH}-$$

Poly vinyl chloride

Alk

Allyl chloride

$CH_2=CH-CH_2-Cl$

It is endustrially prepared by chlorination of propene at high temperature. I,

$$CH_2=CH-CH_3 \xrightarrow{\Delta} CH_2=CH-CH_2-Cl$$

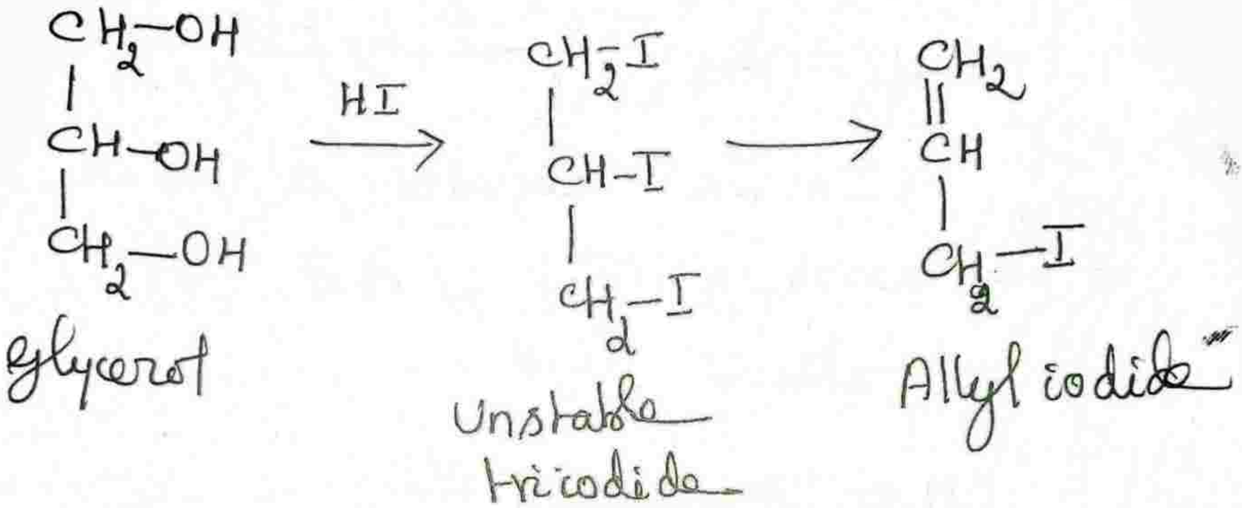
In the laboratory it may be prepared by warming allyl alcohol with hydrochloric acid

$$CH_2=CH-CH_2-OH + HCl \longrightarrow CH_2=CH-CH_2-Cl + H_2$$

Allyl Iodide

$CH_2=CH-CH_2-I$

It is prepared by heating glycerol with small amount of HI (Hydriodic acid)



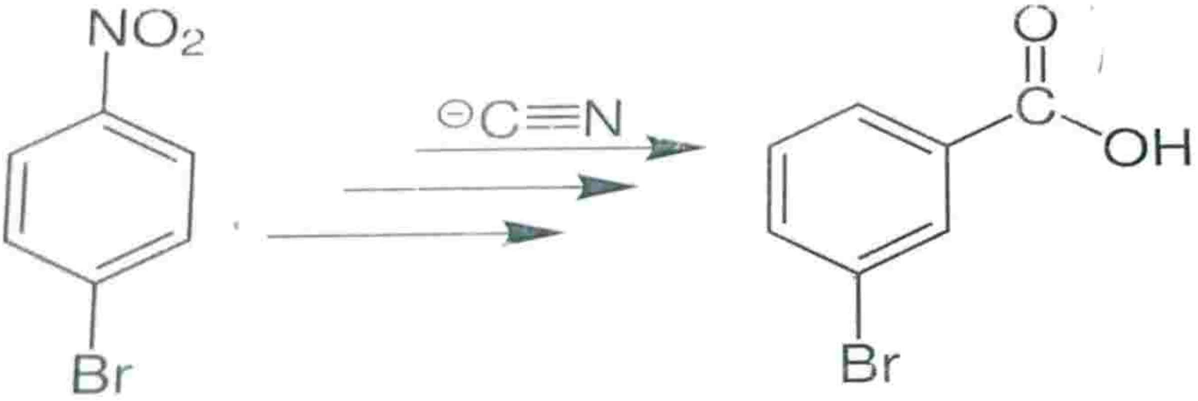
$$\begin{matrix} CH_2-OH \\ | \\ CH-OH \\ | \\ CH_2-OH \end{matrix} \xrightarrow{HI} \begin{matrix} CH_2-I \\ | \\ CH-I \\ | \\ CH_2-I \end{matrix} \longrightarrow \begin{matrix} CH_2 \\ \| \\ CH \\ | \\ CH_2-I \end{matrix}$$

Uses

Von Richter

The **von Richter reaction**, also named **von Richter rearrangement**, is a name reaction in the organic chemistry. It is named after Victor von Richter, who discovered this reaction in year 1871. It is the reaction of aromatic nitro compounds with potassium cyanide in aqueous ethanol to give the product of *cine* substitution (ring substitution resulting in the entering group positioned adjacent to the previous location of the leaving group) by a carboxyl group. Although it is not generally synthetically useful due to the low chemical yield and formation of numerous side products, its mechanism was of considerable interest, eluding chemists for almost 100 years before the currently accepted one was proposed.

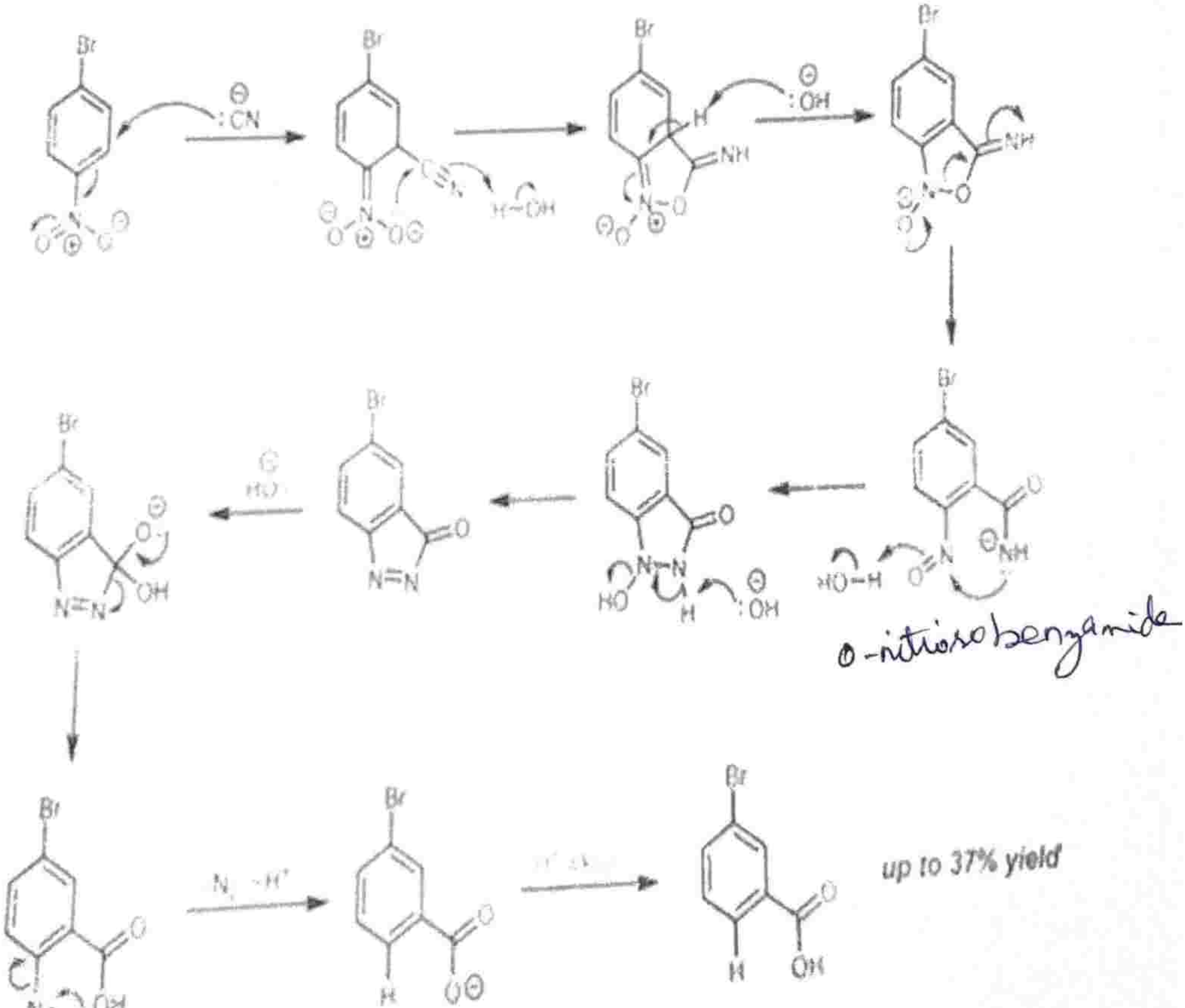
The reaction below shows the classic example of the conversion of *p*-bromonitrobenzene into *m*-bromobenzoic acid.



The reaction is a type of nucleophilic aromatic substitution. Besides the bromo derivative, chlorine- and iodine-substituted nitroarenes, as well as more highly substituted derivatives, could also be used as substrates of this reaction. However, yields are generally poor to moderate, with reported percentage yields ranging from 1% to 50%.

Reaction Mechanism

Several reasonable mechanisms were proposed and refuted by mechanistic data before the currently accepted one, shown below, was proposed in 1960 by Rosenblum on the basis of ^{15}N labeling experiments.



o-nitroso benzamide

First, the cyanide attacks the carbon *ortho* to the nitro group. This is followed by ring closing via nucleophilic attack on the cyano group, after which the imidate intermediate is rearomatized. Ring opening via nitrogen–oxygen bond cleavage gives an *ortho*-nitroso benzamide, which recyclizes to give a compound containing a nitrogen–nitrogen bond. Elimination of water gives a cyclic azoketone, which undergoes nucleophilic attack by hydroxide to give a tetrahedral intermediate. This intermediate collapses with elimination of the azo group to yield an aryldiazene with an *ortho* carboxylate group, which extrudes nitrogen gas to afford the anionic form of the observed benzoic acid product, presumably through the generation and immediate protonation of an aryl anion intermediate. The product is isolated upon acidic workup.

Subsequent mechanistic studies have shown that the subjection of independently prepared *ortho*-nitroso benzamide and azoketone intermediates to von Richter reaction conditions afforded the expected product, lending further support to this proposal

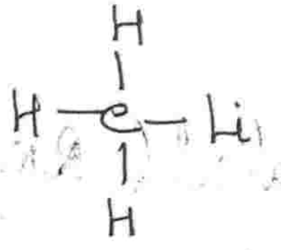
Organometallic Compounds.

An organometallic compounds is defined as a compound which conta a direct carbon-metal bond.

$-\overset{|}{\underset{|}{C}}-$ Metal or $-\overset{|}{\underset{|}{C}}-M$ $C-M$. (carbon-meta bond.)

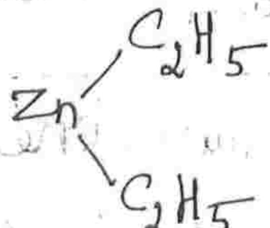
where M = K, Na, Li, Ca, Mg, Al, Zn, C Sn, Pb, Hg etc...

Organometallic compounds are name by simply adding the name of the metal (M) to that of the organic g which may be alkyl, alkenyl or a

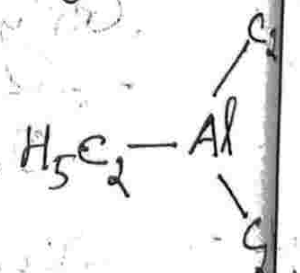


$H-\overset{H}{\underset{H}{C}}-Li$

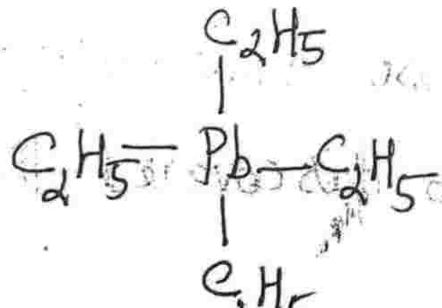
methyl lithium



diethyl zinc



triethyl alu



$C_2H_5-\overset{C_2H_5}{\underset{C_2H_5}{Pb}}-C_2H_5$

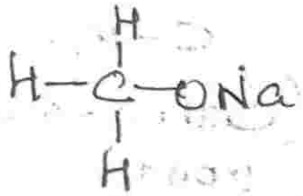
tetraethyl lead

$H-C\equiv C-K$.

Potassium acetylide

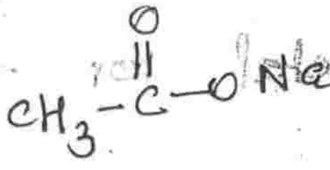
Phenylmagne chloride.

Organometallic compounds excludes substances such as sodium methoxide and sodium acetate in which the metal is not directly bonded to carbon.



$H-\underset{H}{\overset{H}{C}}-ONa$

Sodium methoxide



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

Sodium acetate

Here the metal is linked to carbon through oxygen and these compounds are not organometallic compounds

Grignard Reagent

Organomagnesium halide (RMgX) or grignard reagents are the most important organometallic compound. They are so named after Victor Grignard who discovered them and developed their use as synthetic reagents. Almost all classes of organic compounds can be prepared from them.

The general formula for Grignard reagents can be written as

$R-Mg-X$ or $R-MgX$ or $RMgX$.

where

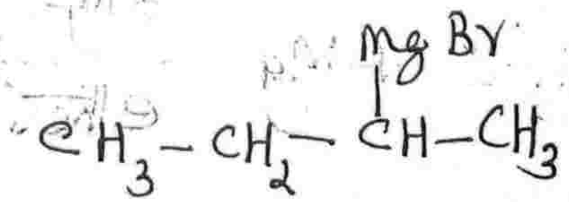
$R =$ alkyl, alkenyl, alkynyl or aryl group

$X = Cl$, Br or I.

Organometallic Organomagnesium fluoride is not known.

$C_2H_5-Mg-Br$

ethylmagnesium bromide



$CH_3-CH_2-\overset{MgBr}{CH}-CH_3$

2-butylmagnesium bromide

$CH_2=CH-Mg-Cl$

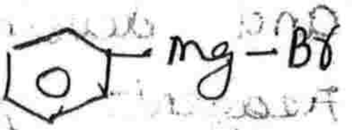
Vinylmagnesium c

$CH_2=CH-CH_2-Mg-I$

allyl iodide

$CH_3-C\equiv C-Mg-Br$

Propynylmagnesium bromide



Phenylmagnesium bromide

Preparation

Grignard reagents are prepared in the laboratory by the action of allyl halides on magnesium metal in the preparation of dry ether.

$$\underset{\text{alkyl halide}}{R-X} + Mg \xrightarrow{\text{dry ether}} \underset{\text{Grignard reagent}}{R-Mg-X}$$

$$CH_3-I + Mg \xrightarrow[\text{ether}]{\text{dry}} \underset{\text{methyl magnesium iodide}}{CH_3-Mg-I}$$

For a given alkyl group, the ease of formation of the grignard reagent is in the order RI > RBr > RCl.

In the preparation of Grignard re care must be taken that all the apparatus and reactants are abso dry. The moisture or any other impurities present will react with Grignard reagent produced. Thus e traces of moisture or impurities prevent the formation of Grignard reagent.

Magnesium ribbon cut into small pieces is suspended in dr ether placed in the three necked round-bottom flask. In the droppi funnel is placed 1:9 mixture of methyl iodide and anhydrous ether Add 2-3 ml of the solution fro the dropping funnel into the reac flask and wait till the reaction starts. When the reaction starts, ether becomes cloudy and also begins to boil gently. If the reaction does not start, drop one or two crystals of iodine into the flask. Then the reaction would start. When the reaction is complete, a clear solution of the grignard reagent in ether is obtained. This is treated in situ with various substances to get desired synthetic products.

Properties

Grignard reagents are nonvolatile, colourless solids.

Chemical Properties

The synthetic reactions of Grignard reagents may be discussed under the following heads.

(a) Reactions with active hydrogen
(b) Nucleophilic substitution reactions
(c) Nucleophilic addition reactions
and (d) Insertion reactions.

(a) Reactions with active hydrogen

The compounds like water, alcohols, carboxylic acids and amines which contain active hydrogens react with Grignard reagents to produce hydrocarbons.

$$\underset{}{R-MgX} + \underset{\text{compound having acidic hydrogen}}{H-A} \longrightarrow \underset{\text{alkane}}{R-H} + Mg\genfrac{}{}{0pt}{}{/A}{\backslash X}$$

A = OH, OR, RNH, NH_2, RCOO etc.

$$\underset{\text{methylmagnesium iodide}}{CH_3-Mg-I} + H-OH \longrightarrow \underset{\text{methane}}{CH_4} + \overset{2+}{Mg}(\overset{-}{OH})\overset{-}{I}$$

$$CH_3-MgI + \underset{\text{ethanol}}{C_2H_5-OH} \longrightarrow \underset{\text{methane}}{CH_4} + Mg(OC_2H_5)I$$

$CH_3-Mg-I + C_2H_5-NH_2 \longrightarrow CH_4 + Mg(NHC_2H_5)I.$

$CH_3-MgI + CH_3COOH \longrightarrow CH_4 + Mg(OCOCH_3)I$

This reaction not only provides a method for the synthesis of alkane but also form a bases for the Zerevitinoff determination of active hydrogens. This is done by measuring the amount of methane produced, one molecule of which indicates the presene of one active (H) atom in the original compound. This reaction can be used to distinguish primary, secondary and tertiary amines (RNH_2, R_2NH, R_3N) By measuring the volume of the g produced per mole of the amine.

B. Nucleophilic Substitution Reacti

The weak negative Charg R in $\overset{\delta-}{R}-\overset{\delta+}{Mg}X$ makes Grignard rea weak nucleophiles. They would not react with simple alkyl halides li ethyl bromide. Grignard reagents u S_N2 displacements with reactive ha

(1) Reaction with reactive halides:-

Grignard reagents react u reactive halides like benzyl ch and allyl bromide to form alkanes alkenes respectively.

$$\overset{\delta-}{CH_3}-\overset{\delta+}{Mg}I + CH_2=CH-CH_2-Br \longrightarrow$$

$$CH_2=CH-CH_2-CH_3 + \overset{2+}{Mg}I$$

1-Butene

② Reaction with Alkynes.

The terminal alkynes react with Grignard reagents to produce alkynylmagnesium halides which on subsequent treatment with alkyl halides undergo SN2 displacements to form higher alkynes.

Propynyl magnesium halide

$$\underset{\text{Propyne}}{CH_3-C\equiv C-H} + R-MgX \longrightarrow CH_3-C\equiv C-MgX + RH.$$

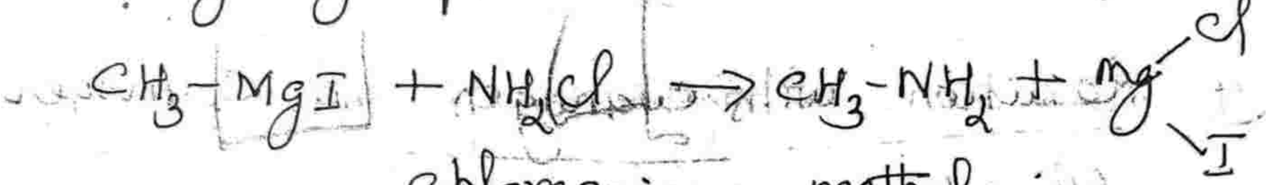
$$CH_3-C\equiv \overset{\delta-}{C}-\boxed{\overset{\delta+}{Mg}X} + CH_3-\boxed{I} \longrightarrow CH_3-C\equiv C-CH_3 + \overset{2+}{Mg}\bar{X}\bar{I}$$

2-butyne.

③ Reaction with lower halogenated Ether

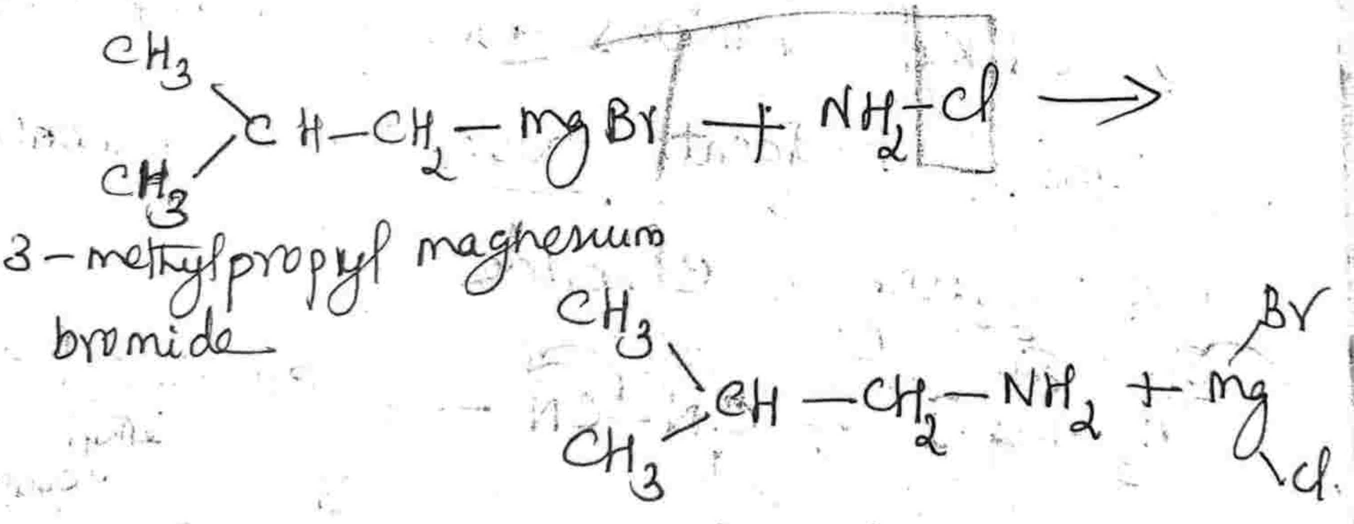
Grignard reagent react with lower halogenated ethers to produce higher ethers.

chloroamines to give primary amines. This reaction provides the best method for preparing primary amines containing tertiary alkyl groups.



$$CH_3-MgI + NH_2Cl \longrightarrow CH_3-NH_2 + Mg\begin{smallmatrix}Cl\\I\end{smallmatrix}$$

chloroamine methylamine



3-methylpropyl magnesium bromide

2-methylpropylamine.

⑥ Reaction with Inorganic halides:

Organometallic and organo-nonmetallic compounds result when Grignard reagents react with inorganic halides.

Tetraethyl lea

$4C_2H_5-\boxed{MgI} + 2Pb\boxed{Cl_2} \longrightarrow (C_2H_5)_4Pb$.

Ethylmagnesium iodide

$Pb + MgI$

diethylmercury

$2C_2H_5-\boxed{MgI} + Hg\boxed{Cl_2} \longrightarrow (C_2H_5)_2Hg +$

ethylmagnesium iodide

$2\,Mg{<}^{I}_{Cl}$.

$3CH_3-MgBr + PCl_5 \longrightarrow (CH_3)_3P + 3M$

methyl magnesium bromide

Triethyl phosphine

$CH_3-Mg\cancel{I} + SiCl_4 \longrightarrow (CH_3)_4Si +$

Tetramethylsilan

⑦ Reaction with iodine

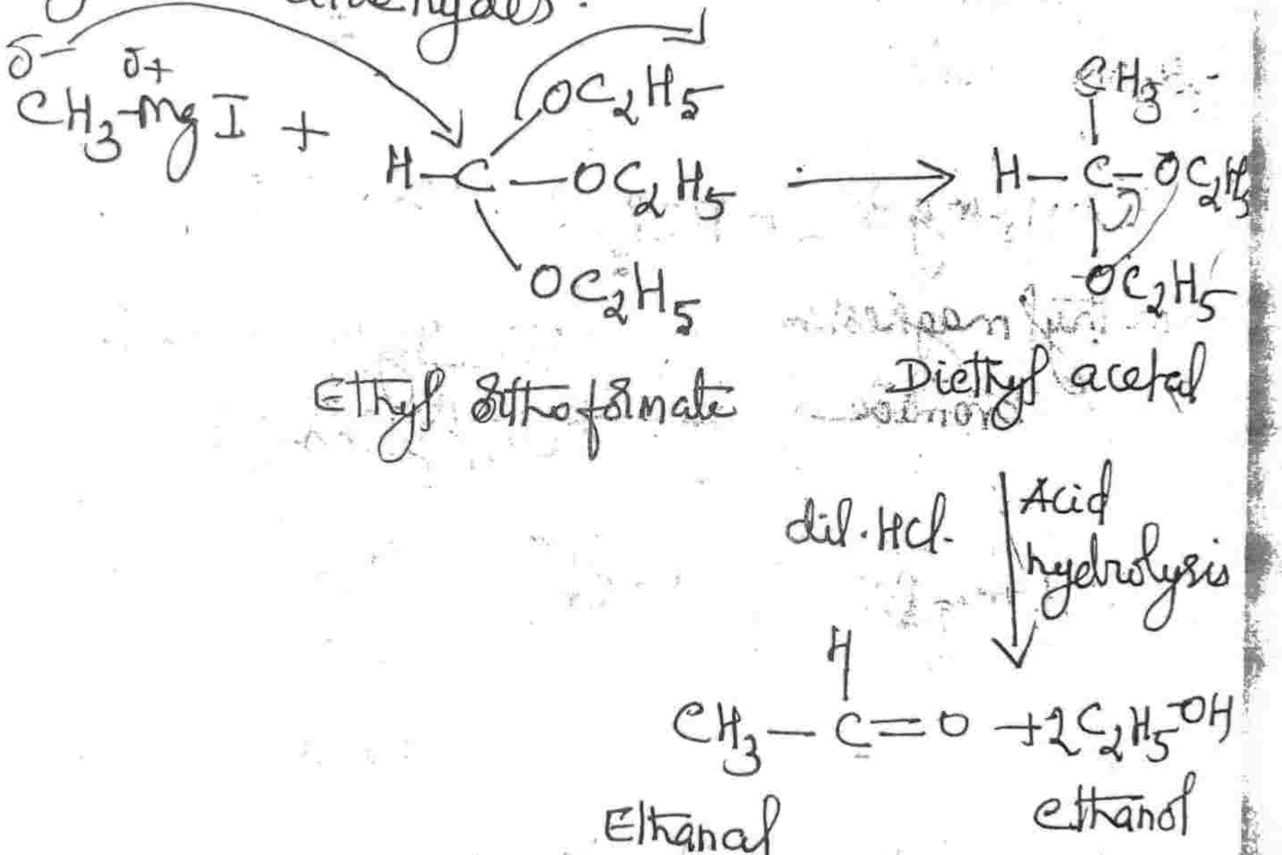
When an alkylmagnesium or bromide is treated with iodi alkyl iodides are formed.

$CH_3\boxed{MgCl} + I_2 \longrightarrow CH_3-I + Mg$

methyl iodide

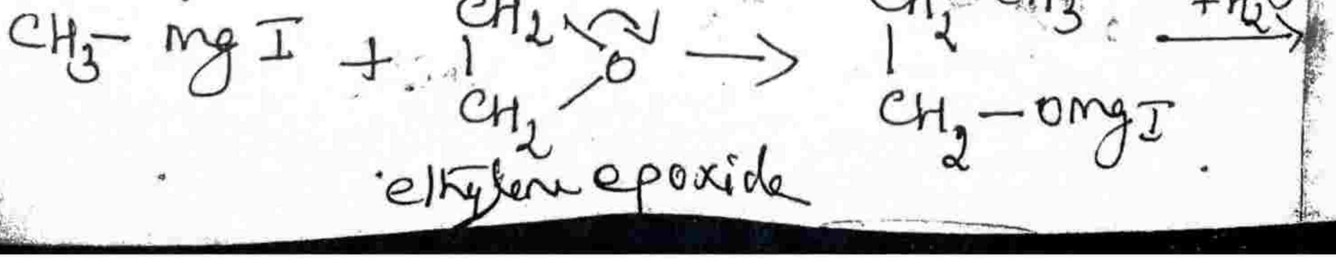
⑧ Reaction with ethyl orthoformate

Grignard reagents react with ethyl orthoformate to produce acetals which upon subsequent acid hydrolysis give aldehydes.

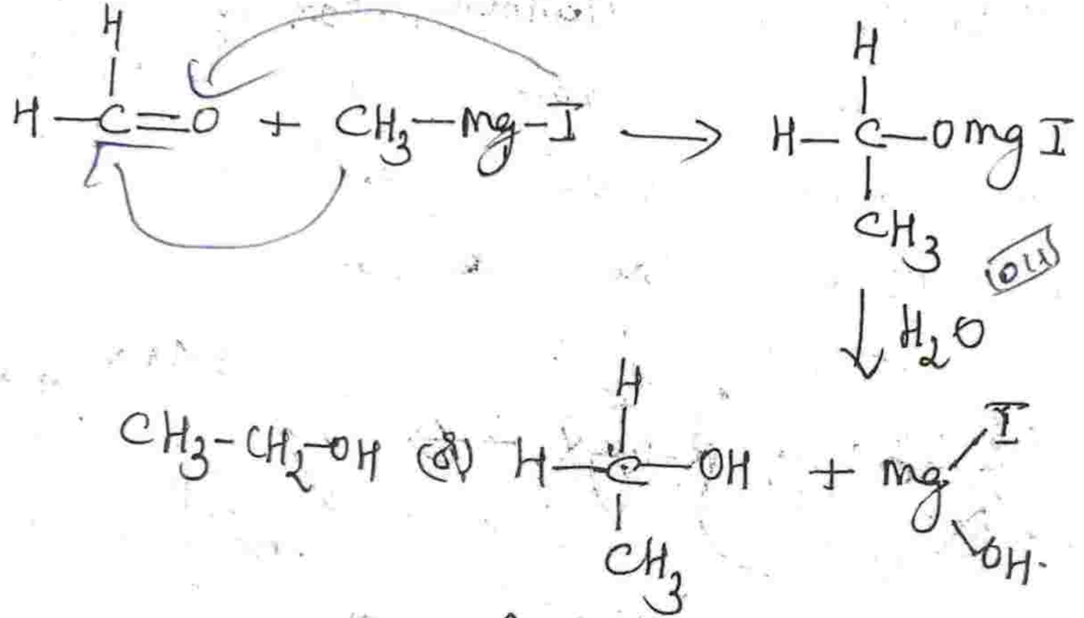


⑨ Reaction with epoxides:

Grignard reagents react with epoxide to form primary alcohols.



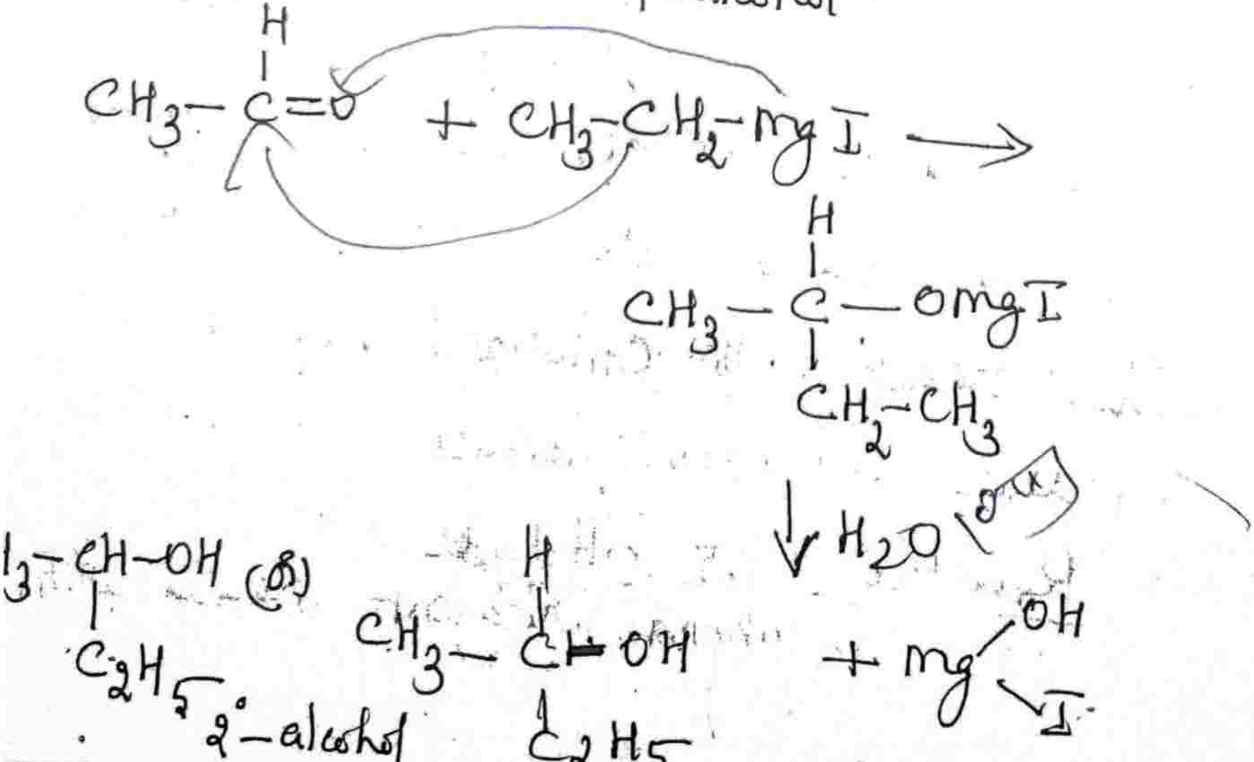
aldehydes to produce alcohols.
The reaction with formaldehyde gives primary alcohols, while with other aldehydes secondary alcohols are produced.



$H-\overset{H}{\underset{}{C}}=O + CH_3-Mg-I \longrightarrow H-\overset{H}{\underset{CH_3}{C}}-OMgI \xrightarrow{H_2O}$

CH_3-CH_2-OH (or) $H-\overset{H}{\underset{CH_3}{C}}-OH + Mg\langle^{I}_{OH}$

1°-alcohol.



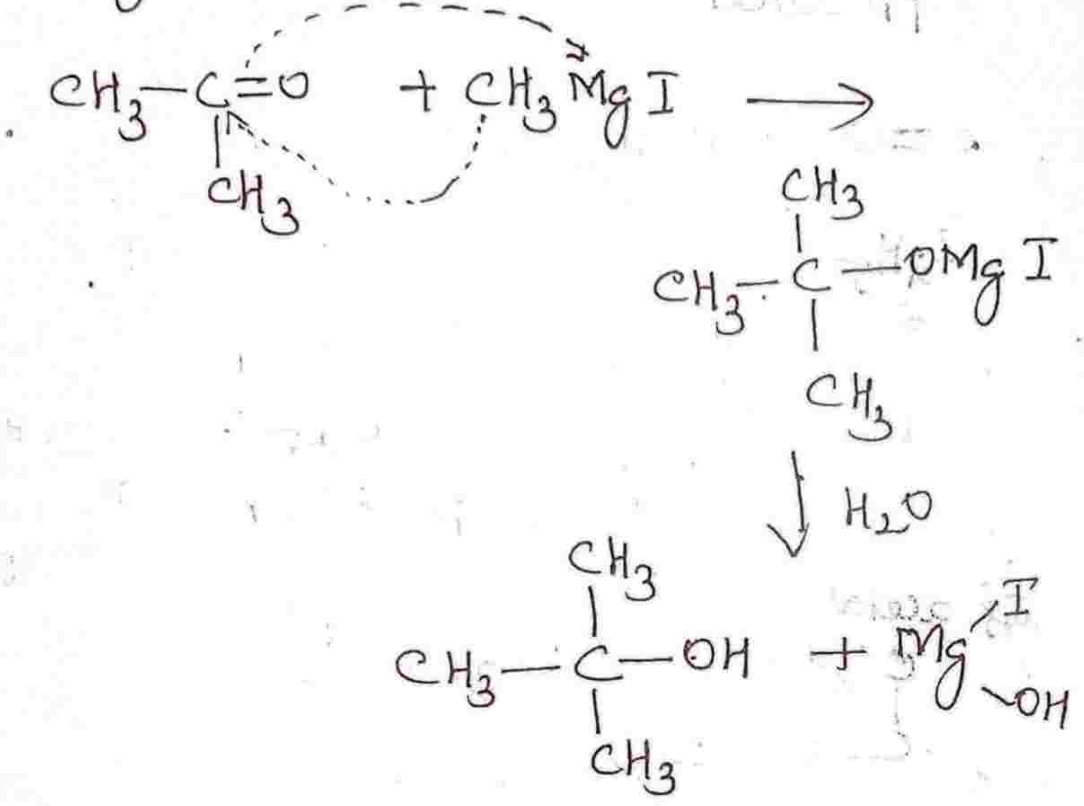
$CH_3-\overset{H}{C}=O + CH_3-CH_2-MgI \longrightarrow CH_3-\overset{H}{\underset{CH_2-CH_3}{C}}-OMgI \xrightarrow{H_2O}$

$_3-\underset{C_2H_5}{CH}-OH$ (or) $CH_3-\overset{H}{\underset{C_2H_5}{C}}-OH + Mg\langle^{OH}_{I}$

2°-alcohol

(2) Reaction with ketones :.

Ketones react with Grignar reagents to form tertiary alcohols.



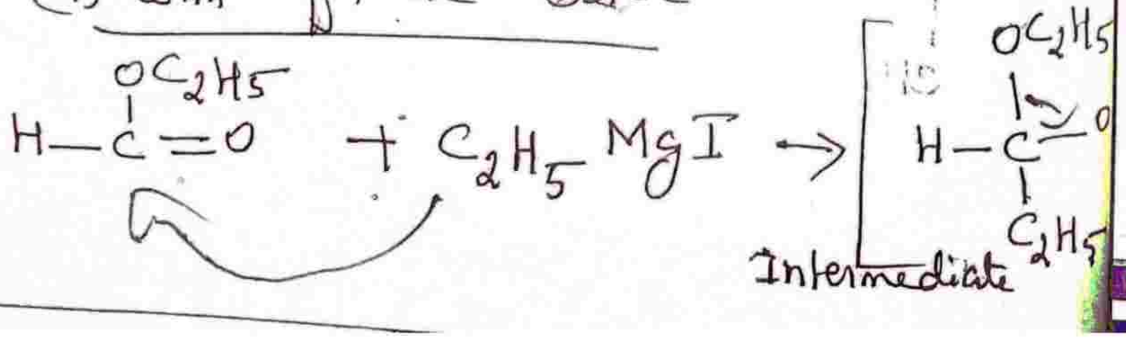
$CH_3-\underset{CH_3}{C}=O + CH_3MgI \longrightarrow CH_3-\underset{CH_3}{\overset{CH_3}{C}}-OMgI \xrightarrow{H_2O} CH_3-\underset{CH_3}{\overset{CH_3}{C}}-OH + Mg\begin{smallmatrix}I\\OH\end{smallmatrix}.$

3°-butyl alcohol.

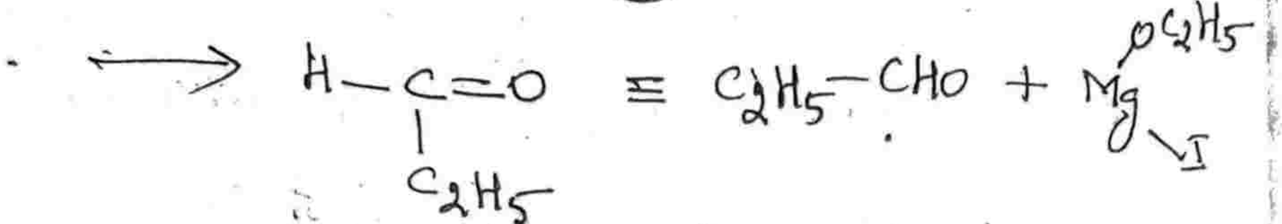
(3) Reaction with Esters.

Grignard reagents react wi formic ester to produce secondary while other esters form tertiary a

(i) with formic ester.

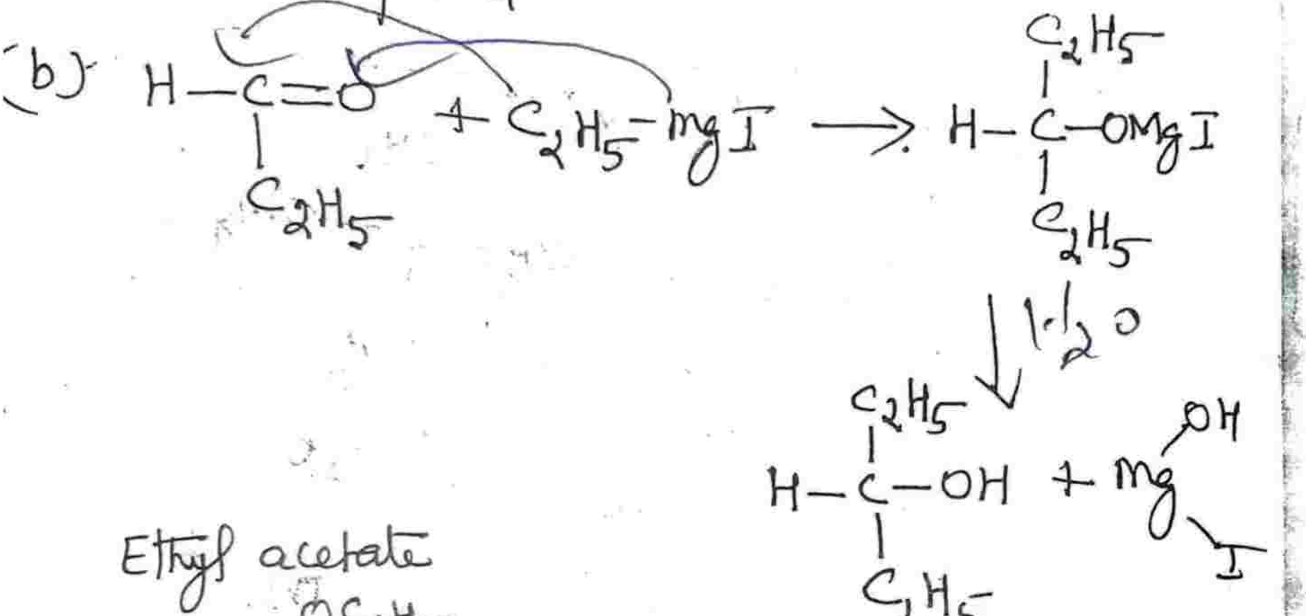


$H-\overset{OC_2H_5}{C}=O + C_2H_5MgI \rightarrow \left[H-\underset{C_2H_5}{\overset{OC_2H_5}{C}}-O \right.$



$$\longrightarrow H-\underset{C_2H_5}{\underset{|}{C}}=O \equiv C_2H_5-CHO + Mg\begin{smallmatrix}OC_2H_5\\ I\end{smallmatrix}$$

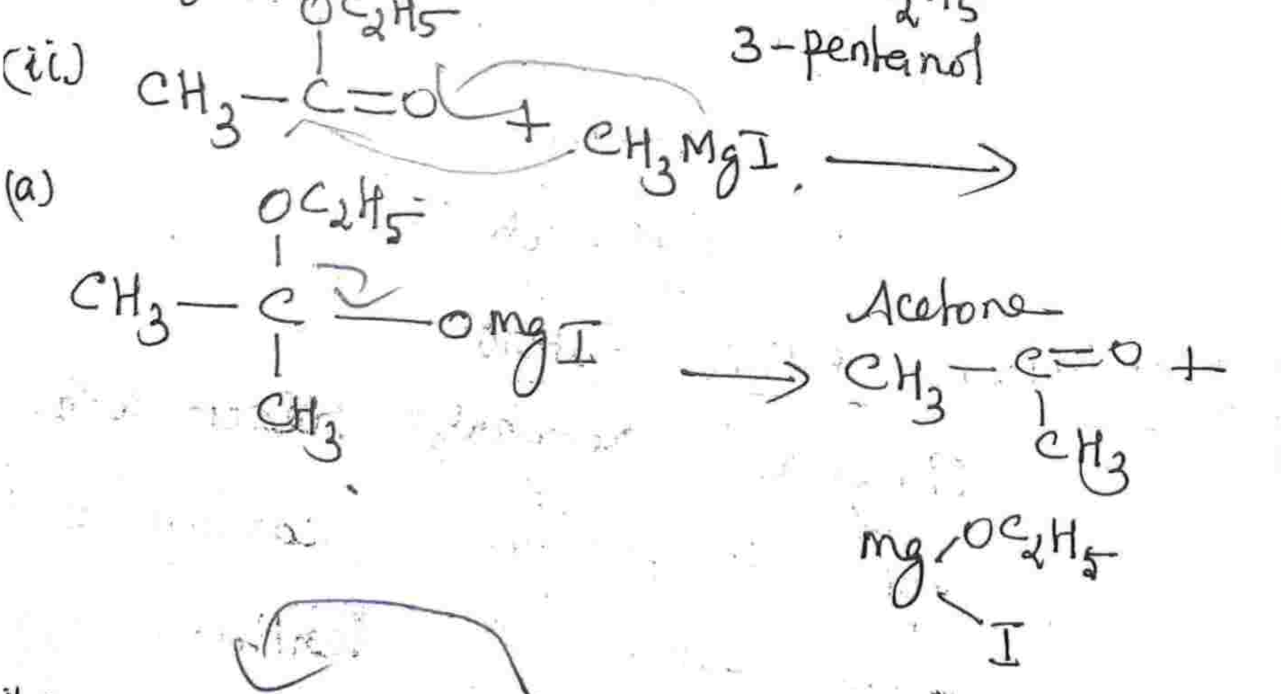
Propanal.



(b) $$H-\underset{C_2H_5}{\underset{|}{C}}=O + C_2H_5-MgI \longrightarrow H-\overset{C_2H_5}{\overset{|}{\underset{C_2H_5}{\underset{|}{C}}}}-OMgI \xrightarrow{H_2O} H-\overset{C_2H_5}{\overset{|}{\underset{C_2H_5}{\underset{|}{C}}}}-OH + Mg\begin{smallmatrix}OH\\ I\end{smallmatrix}$$

3-pentanol

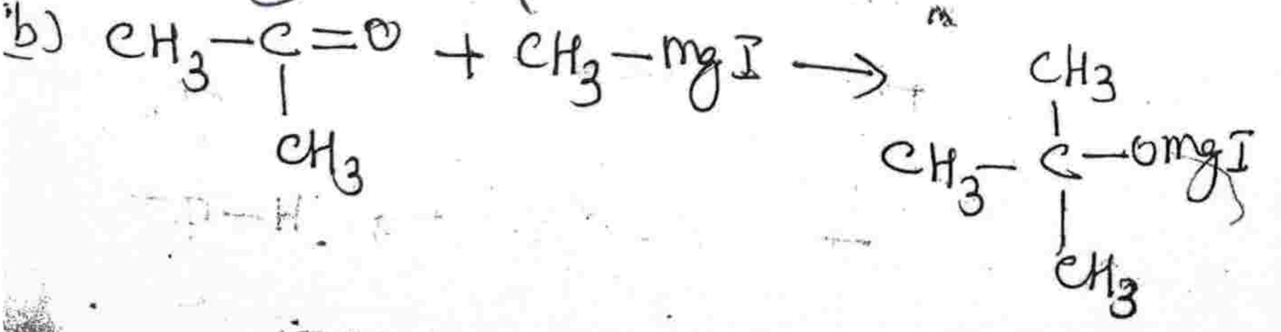
Ethyl acetate



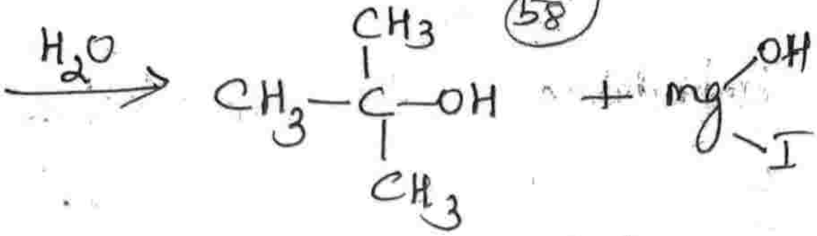
(ii) $$CH_3-\overset{OC_2H_5}{\overset{|}{C}}=O + CH_3MgI \longrightarrow$$

(a) $$CH_3-\overset{OC_2H_5}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}-OMgI \longrightarrow CH_3-\underset{CH_3}{\underset{|}{C}}=O + Mg\begin{smallmatrix}OC_2H_5\\ I\end{smallmatrix}$$

Acetone



(b) $$CH_3-\underset{CH_3}{\underset{|}{C}}=O + CH_3-MgI \longrightarrow CH_3-\overset{CH_3}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}-OMgI$$

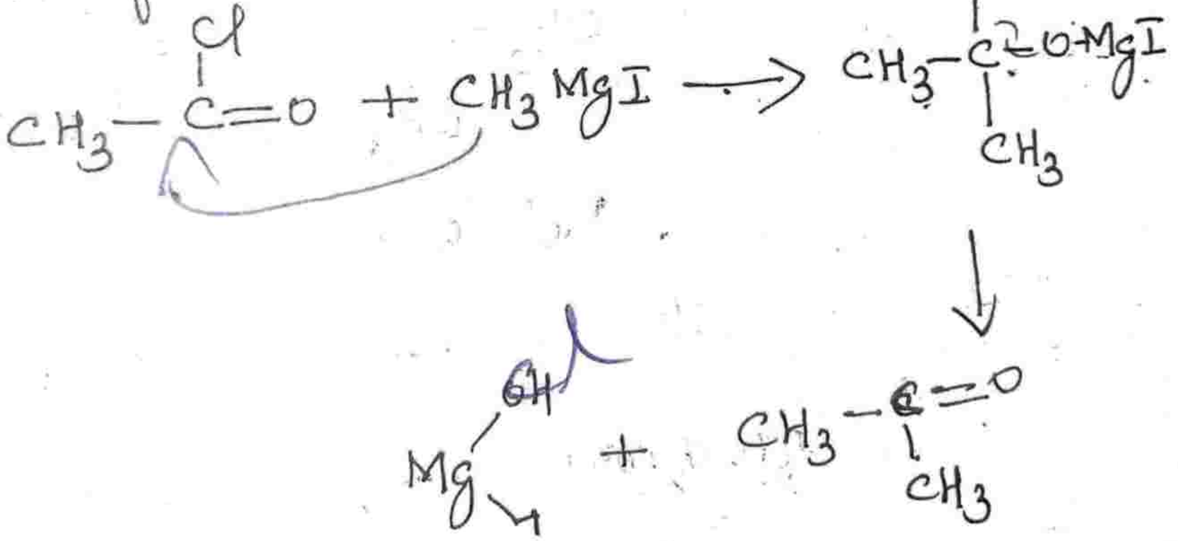


$$\xrightarrow{H_2O} CH_3-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-OH + Mg\langle^{OH}_{I}$$

tert-butyl alcohol

(4) <u>Reaction with Acid chloride and anhydride</u>.

Grignard reagent (1 mole) and an acid chloride (1 mole) react readily to form ketones.



$$CH_3-\overset{\overset{Cl}{|}}{C}=O + CH_3MgI \longrightarrow CH_3-\overset{\overset{Cl}{|}}{\underset{\underset{CH_3}{|}}{C}}-OMgI$$

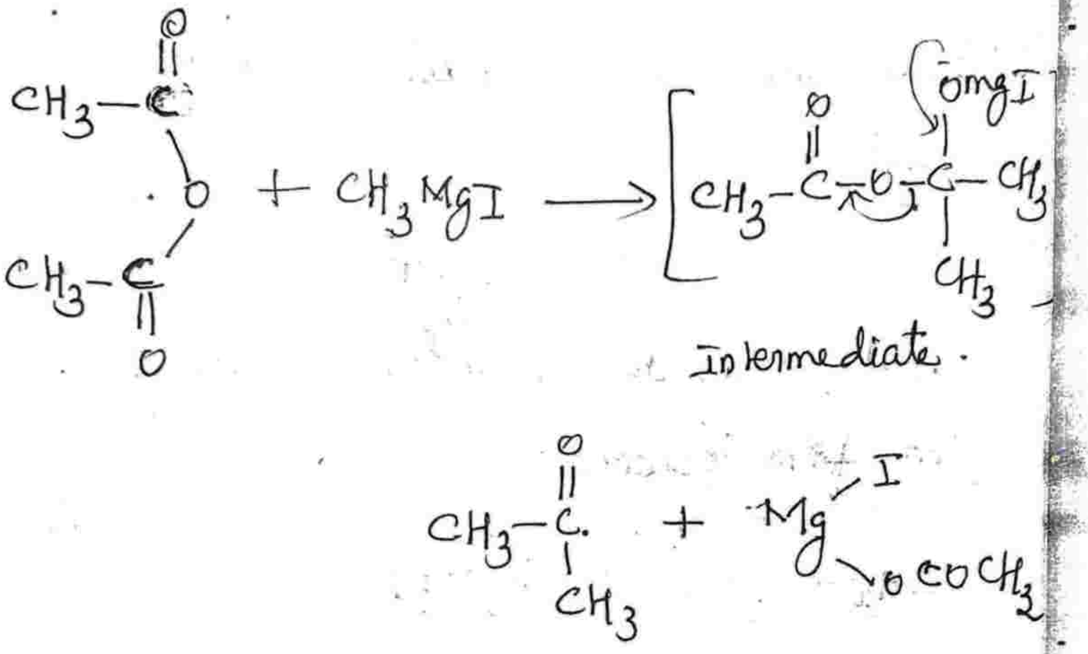
$$\downarrow$$

$$Mg\langle^{OH}_{I} + CH_3-\underset{\underset{CH_3}{|}}{C}=O$$

Acetone.

The Acetone produced will further react with another mole of Grignard reagent to form tert-butyl alcohol.

Acid anhydrides also form ketones in good yield provided the reaction is carried at −70°c

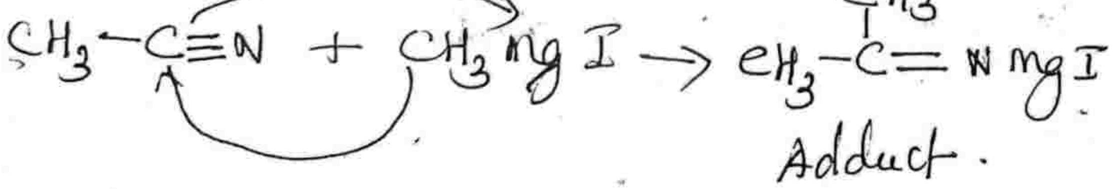


Intermediate.

Acetone.

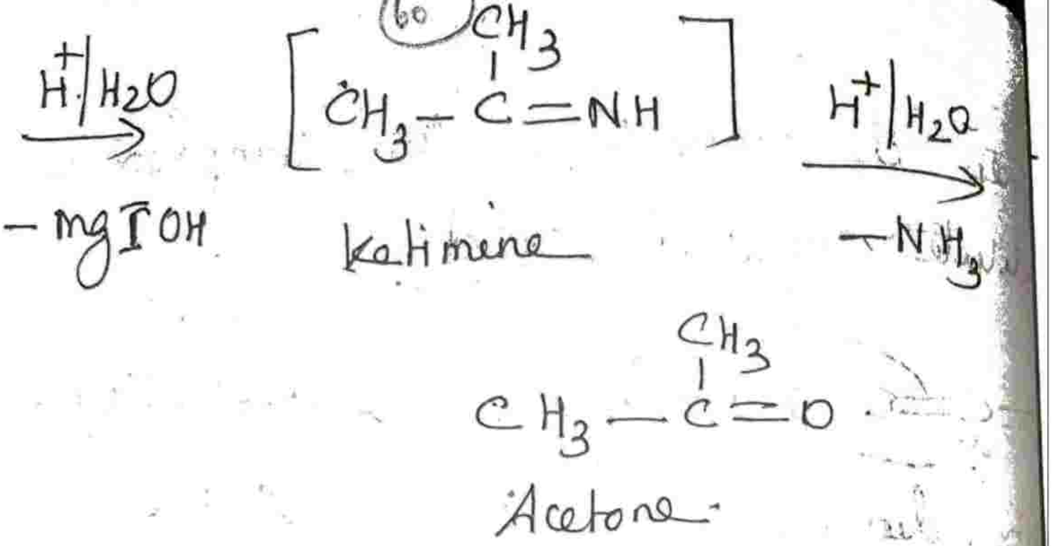
⑤ Reaction with cyanides or nitriles

Grignard reagent add on to cyanides to form addition products which on treatment with dilute mineral acid give ketones.



$$CH_3-C\equiv N + CH_3MgI \rightarrow CH_3-\overset{CH_3}{\overset{|}{C}}=NMgI$$

Adduct.



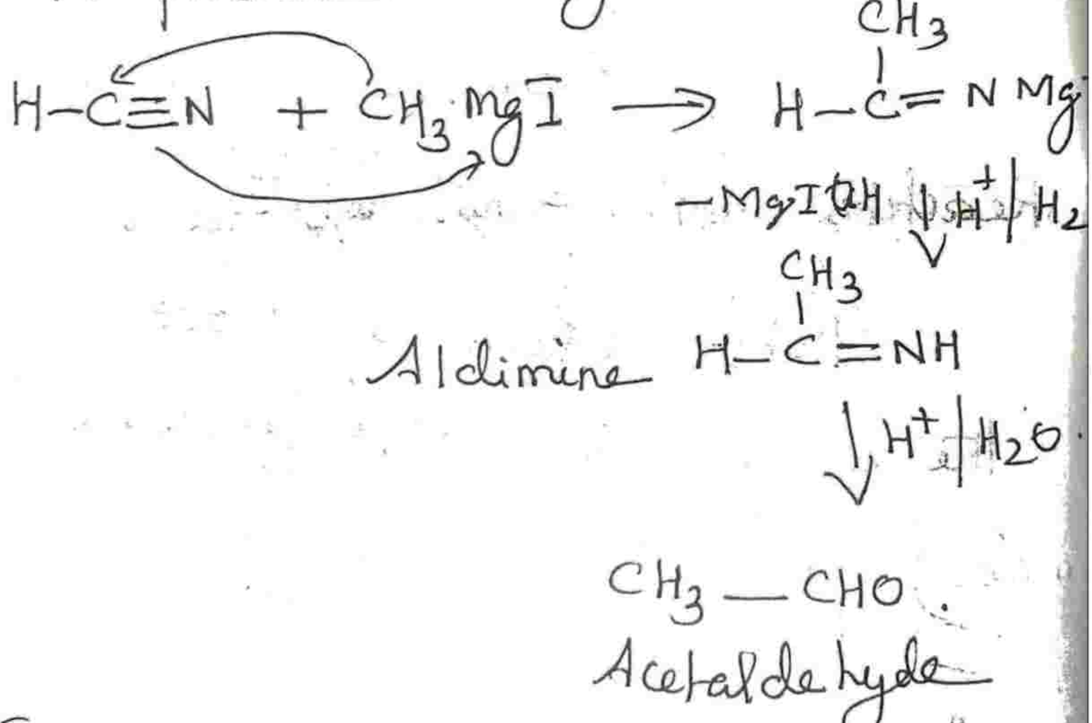
$$\xrightarrow[-MgIOH]{H^+/H_2O} \left[CH_3-\overset{CH_3}{\overset{|}{C}}=NH \right] \xrightarrow[-NH_3]{H^+/H_2O} CH_3-\overset{CH_3}{\overset{|}{C}}=O$$

Ketimine

Acetone.

Grignard reagents react with H-C

to produce aldehyde.



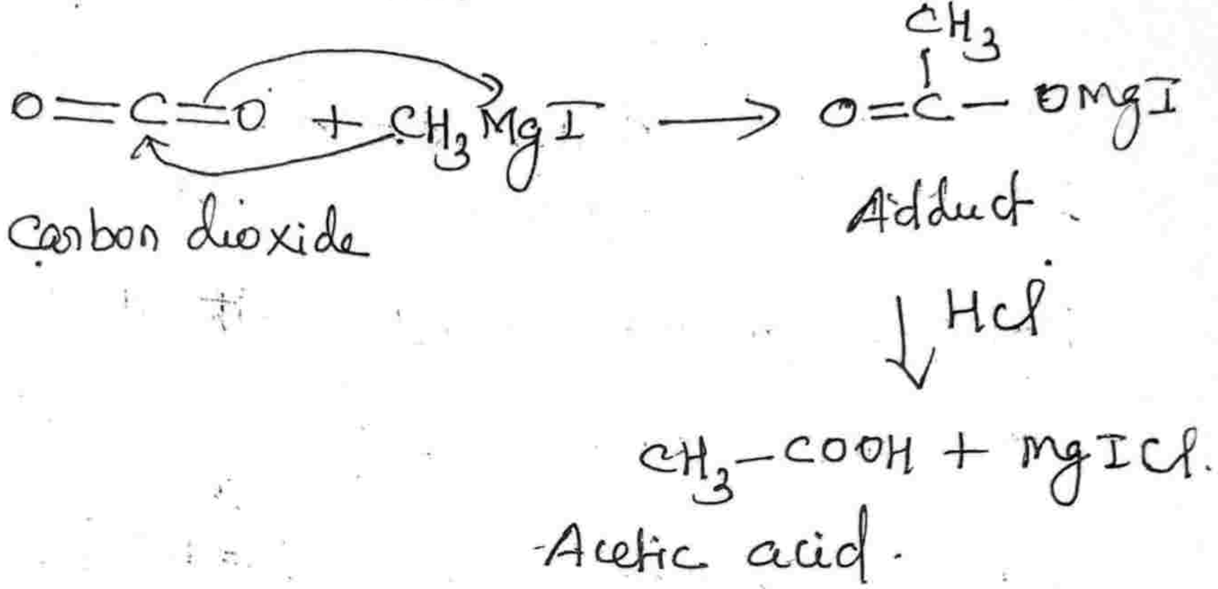
$$H-C\equiv N + CH_3MgI \rightarrow H-\overset{CH_3}{\overset{|}{C}}=NMgI \xrightarrow[-MgIOH]{H^+/H_2O} H-\overset{CH_3}{\overset{|}{C}}=NH \xrightarrow{H^+/H_2O} CH_3-CHO$$

Aldimine

Acetaldehyde

⑥ Reaction with carbon dioxide

Carboxylic acids are obtained good yeeld by pouring the solu of grignard reagent on finely powdered solid CO_2 (dry ice) and then decomposing the complex with dilute mineral acid.



$$O{=}C{=}O + CH_3MgI \longrightarrow O{=}\overset{CH_3}{\overset{|}{C}}-OMgI$$

Carbon dioxide

Adduct

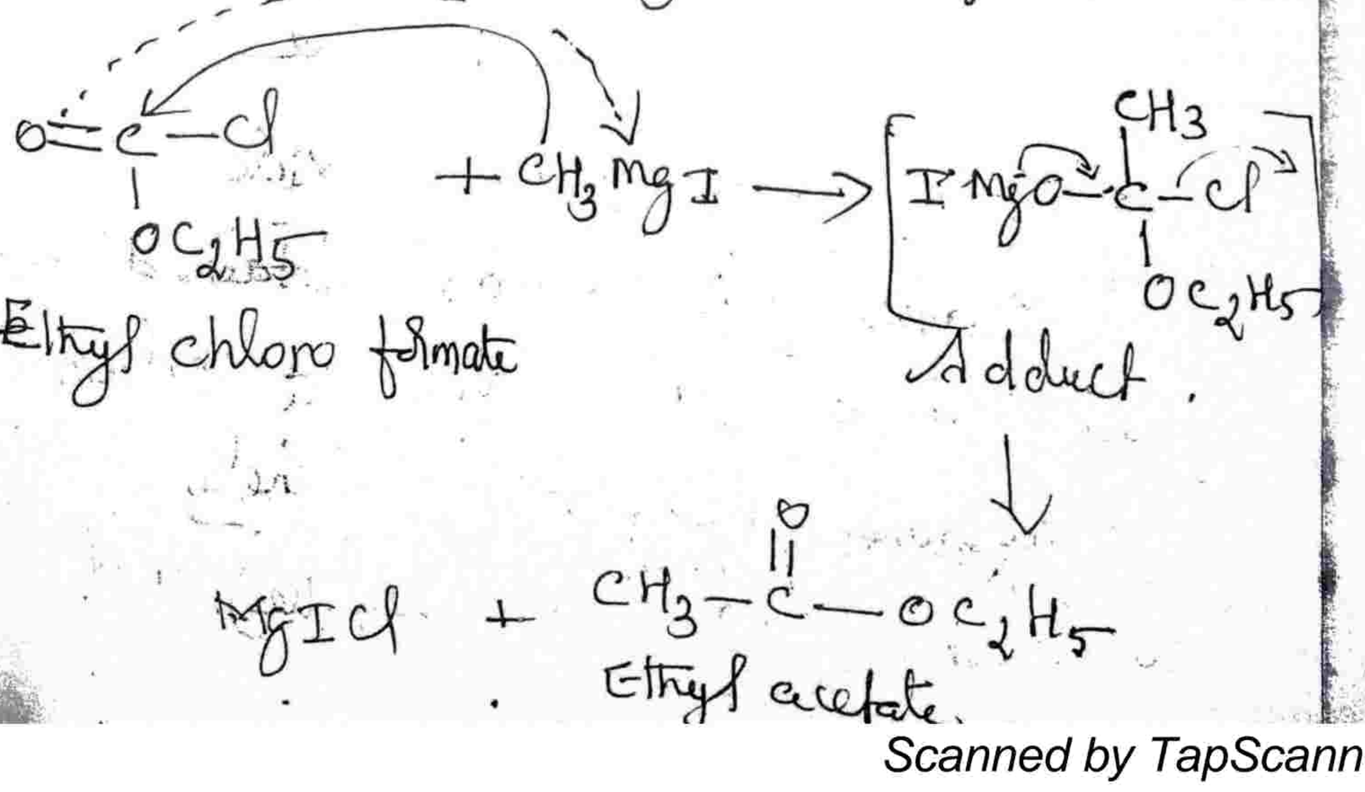
$$\downarrow HCl$$

$$CH_3-COOH + MgICl.$$

Acetic acid.

⑦ Reaction with ethyl chloro formate

Higher esters are obtained by the action of Grignard reagent (1 mole) and ethyl chloro formate (1 mole)



$$O{=}\underset{OC_2H_5}{\underset{|}{C}}-Cl + CH_3MgI \longrightarrow \left[IMgO-\overset{CH_3}{\underset{OC_2H_5}{\underset{|}{\overset{|}{C}}}}-Cl\right]$$

Ethyl chloro formate

Adduct.

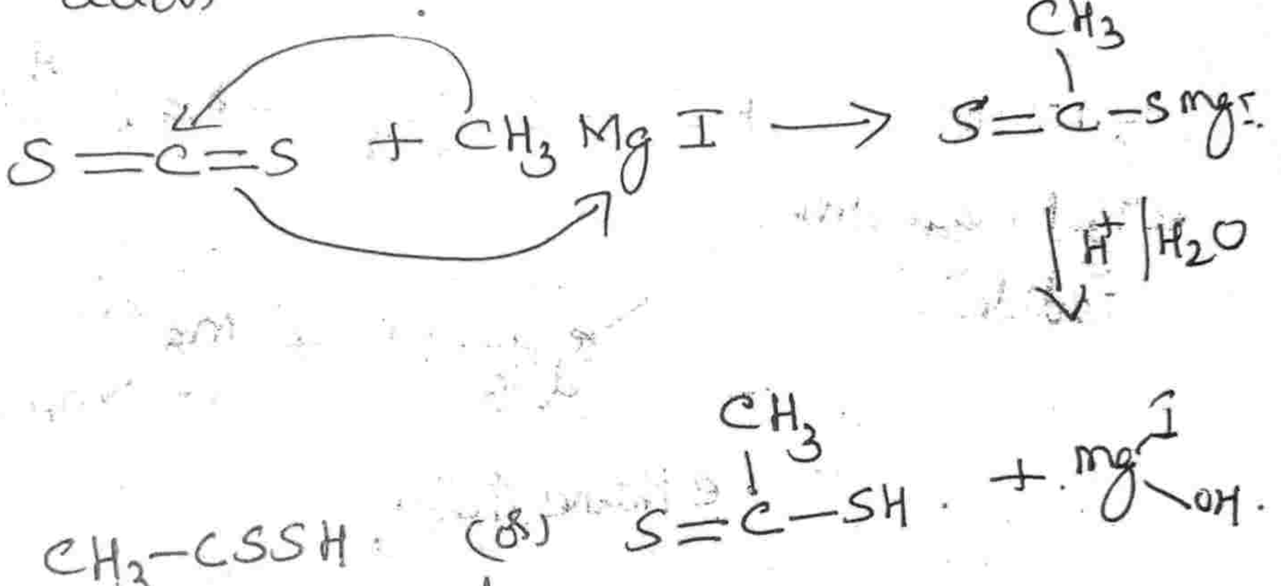
$$\downarrow$$

$$MgICl + CH_3-\overset{O}{\overset{||}{C}}-OC_2H_5$$

Ethyl acetate.

⑧ Reaction with carbon disulphide.

Grignard reagents react with carbon disulphide to form dithioic acids.



$$S=C=S + CH_3MgI \longrightarrow S=\overset{CH_3}{\overset{|}{C}}-SMgI \xrightarrow{H^+/H_2O} S=\overset{CH_3}{\overset{|}{C}}-SH + Mg\begin{smallmatrix}I\\OH\end{smallmatrix}$$

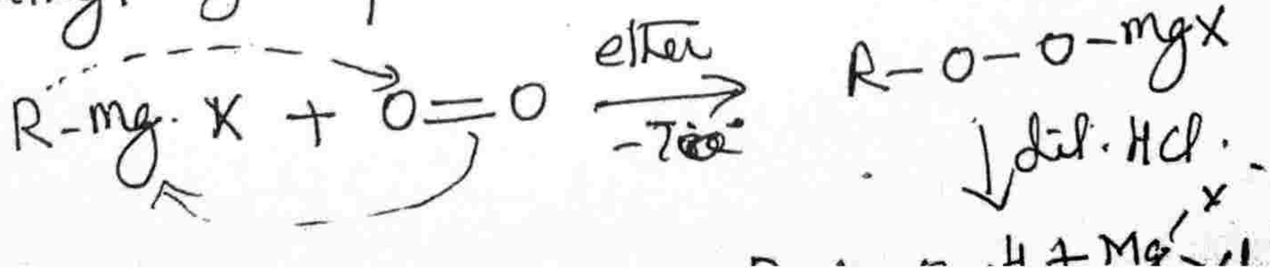
CH_3-CSSH (or)

Dithioacetic acid

Ⓓ Insertion reaction

① Reaction with oxygen:

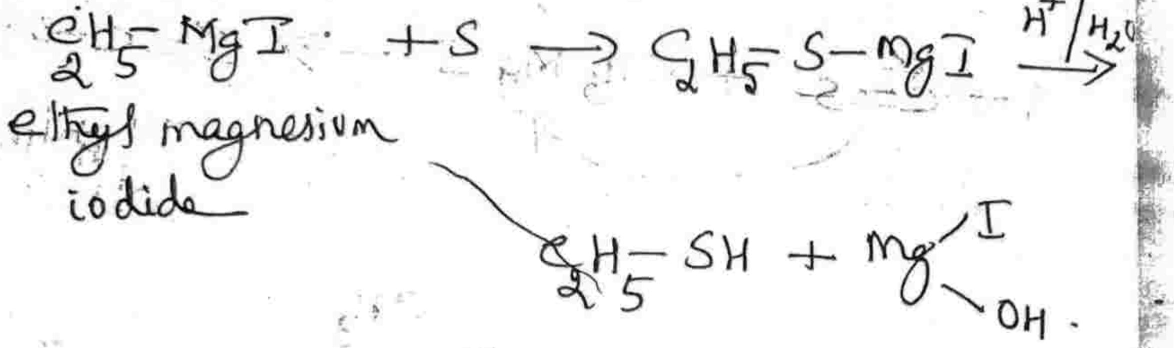
Grignard reagents react with oxygen at low temperature to form alkyl hydroperoxides.



$$R-MgX + O=O \xrightarrow[-70°C]{ether} R-O-O-MgX \xrightarrow{dil.\ HCl} R-O-O-H + Mg\begin{smallmatrix}X\\\end{smallmatrix}$$

Reaction with sulphur

Sulphur reacts with Grignard ~~CH_3~~ reagent giving the corresponding thioalcohol.



$$C_2H_5-MgI + S \rightarrow C_2H_5-S-MgI \xrightarrow{H^+/H_2O} C_2H_5-SH + Mg\begin{matrix} I \\ OH \end{matrix}$$

ethyl magnesium iodide

ethanethiol

Unit II

Carbonyl Compounds.

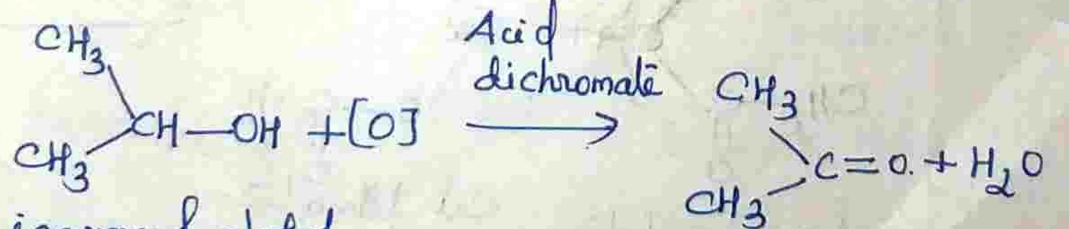
General methods of preparation of aliphatic Aldehydes and ketones.

① Oxidation of alcohols with acid dichromate

Primary alcohols give aldehydes whereas secondary alcohols give ketones

$$CH_3-CH_2-OH + [O] \xrightarrow[\text{dichromate}]{\text{Acid}} CH_3-CHO + H_2O$$

Ethanol primary alcohol — Acetaldehyde (aldehyde)



$$(CH_3)_2CH-OH + [O] \xrightarrow{\text{Acid dichromate}} (CH_3)_2C=O + H_2O$$

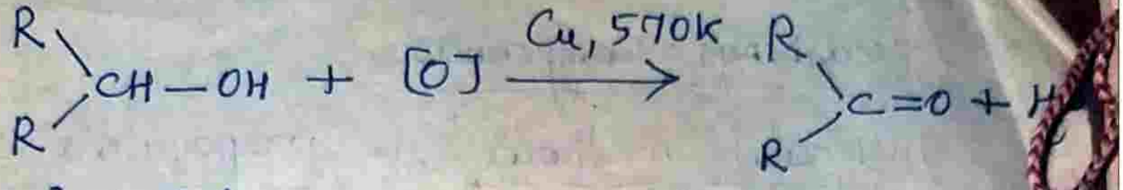
isopropyl alcohol (2° alcohol) — Acetone (ketone)

② Catalytic dehydrogenation of alcohols.

When vapours of alcohols are passed over heated copper at 570K, they yield aldehydes and ketones.

$$R-CH_2-OH + [O] \xrightarrow{Cu, 570K} R-CHO + H_2$$

1° alcohol — Aldehyde

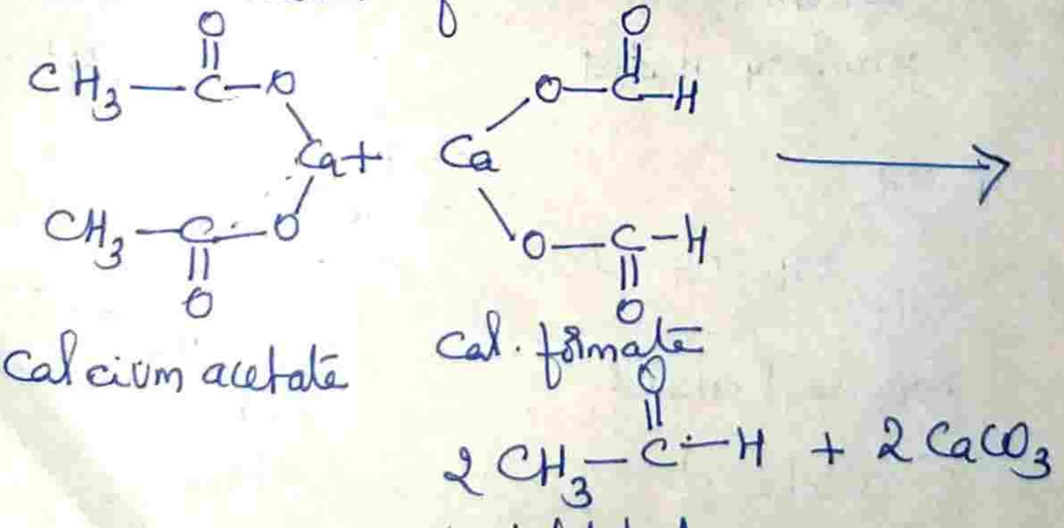


2° alcohol Ketone

In this process, there is no risk of further oxidation of the aldehyde obtained

③ Heating Calcium salts of fatty acids:

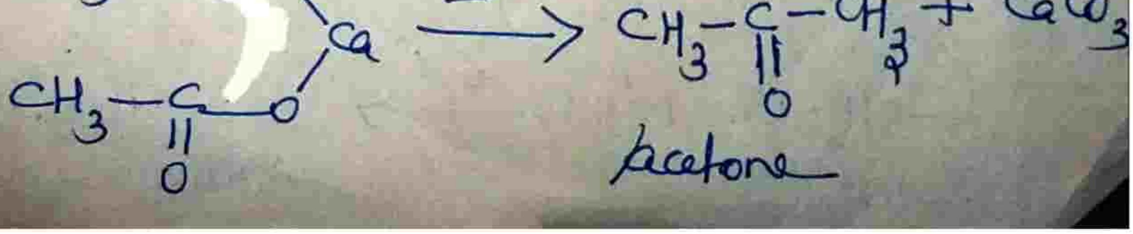
An aldehyde is obtained when calcium ~~Sa~~ acetate is heated with calcium formate. ~~A ketone is~~



Calcium acetate Cal. formate

Acetaldehyde

A ketone is obtained when calcium acetate are heated



Acetone

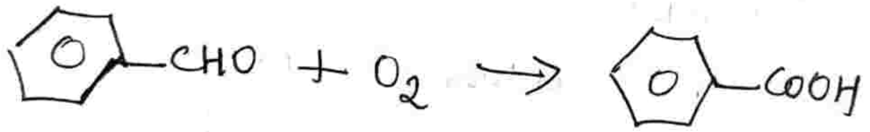
Sommelet reactions

Benzaldehyde is produced when benzyl chloride is refluxed with hexamethylenetetramine in aqueous ethanolic solution followed by acidification and steam distillation.

$C_6H_5-CH_2-Cl + (CH_2)_6N_4 \rightarrow C_6H_5-CHO$.

Oxidation of Benzaldehyde

It is oxidised to benzoic acid even on exposure to air



Benzaldehyde Benzoic acid.

Baeyer & Villiger oxidation.

He suggested that ~~this~~ oxidation of benzaldehyde to benzoic acid by air occurs via the formation of perbenzoic acid.

4 From Fatty acids.

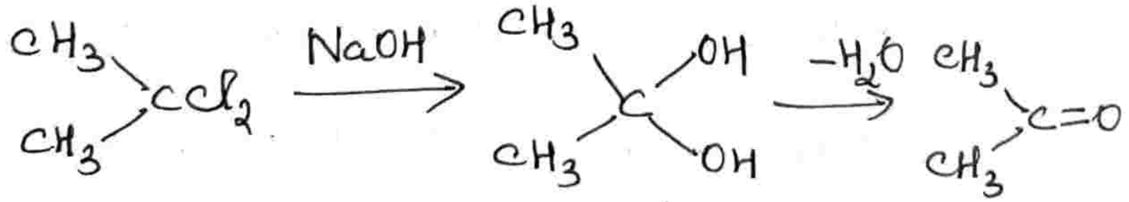
By passing the vapours of fatty acids over MnO as catalyst at 570k. An aldehyde is obtained if formic acid is one the two acids otherwise ketone is formed.

$$CH_3-COOH + HCOOH \xrightarrow{MnO} CH_3-CHO + CO_2 + H_2O$$

$$\underset{\text{Acetic acid}}{2CH_3-COOH} \xrightarrow{MnO} CH_3-CO-CH_3 + CO_2 + H_2O$$

⑤ By hydrolysis of alkylidene halide

$$CH_3-CHCl_2 \xrightarrow{NaOH} \underset{\text{unstable}}{CH_3-CH(OH)_2} \xrightarrow{-H_2O} \underset{\text{acetaldehyde}}{CH_3-CHO}$$



Dihalides are prepared from the carbonyl compounds.

⑥ Reduction of acid chloride

Aldehydes are obtained by the reduction of acid chloride with hydrogen in boiling xylene in the presence of a catalyst – Palladium suspended in barium sulphate (Rosenmund's reduction)

$CH_3-COCl + H_2 \longrightarrow CH_3-CHO + HCl$

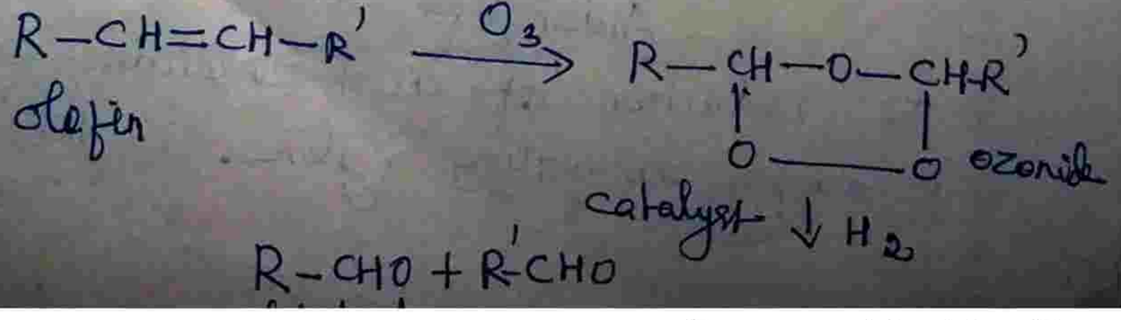
Acetyl chloride Acetaldehyde

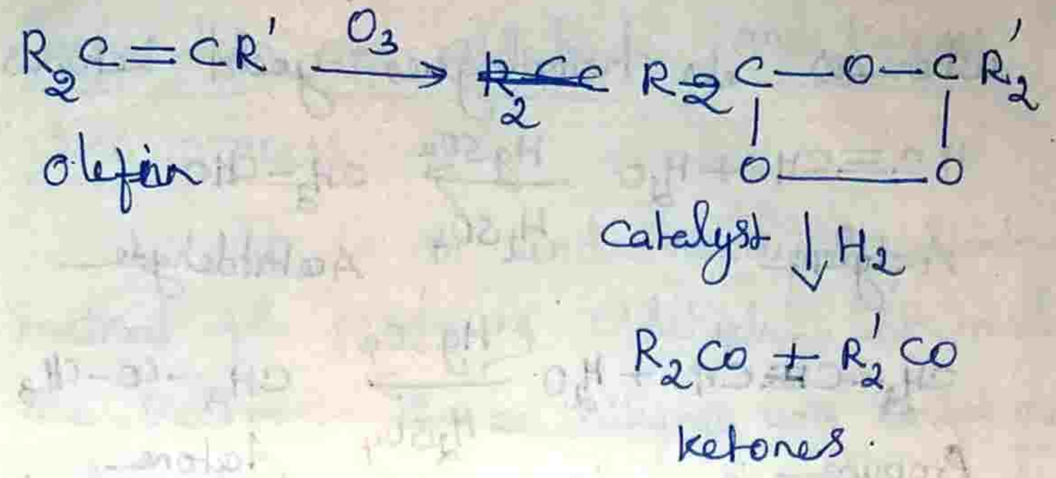
Eventhough the aldehydes are readily reduced than the acid chloride the final product is not an alcohol. This is due to barium sulphate which ~~does~~ acts as a poison for the Palladium catalyst and prevents the aldehyde reduced to alcohol. Generally small amount of quinoline and sulphur is also added. These are very effective in reducing the activity of the catalyst.

Ketones are also prepared by the action of dialkyl cadmium on acid chlorides.

$2RCOCl + R_2Cd \longrightarrow R\text{-}CO\text{-}R + CdCl_2$

⑦ Ozonolysis of olefines.



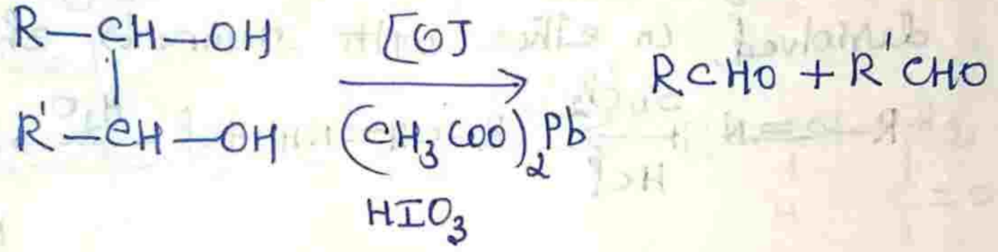


$$R_2C=CR' \xrightarrow{O_3} \cancel{R_2C}\ R_2C-O-CR'_2 \ (\text{O}—\text{O bridge}) \xrightarrow[\text{catalyst}]{H_2} R_2CO + R'_2CO$$

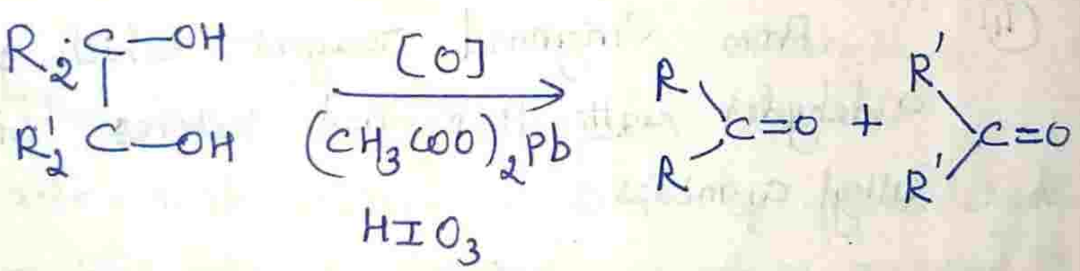
olefin

ketones.

5) Oxidation of 1,2-glycols



$$\begin{matrix} R-CH-OH \\ | \\ R'-CH-OH \end{matrix} \xrightarrow[(CH_3COO)_2Pb,\ HIO_3]{[O]} RCHO + R'CHO$$



$$\begin{matrix} R_2C-OH \\ | \\ R'_2C-OH \end{matrix} \xrightarrow[(CH_3COO)_2Pb,\ HIO_3]{[O]} R_2C=O + R'_2C=O$$

oxidation of 1,2-glycol with lead acetate and periodic acid.

7) Addition of water to acetylene (or) its derivatives

By addition of water to acetylene or its derivatives in the presence of 42% H_2SO_4 containing mercuric sulphate as catalyst. Acetylene gives acetaldehyde whereas its homologues yield ketones

$$HC\equiv CH + H_2O \xrightarrow[H_2SO_4]{HgSO_4} CH_3-CHO$$

Acetylene Acetaldehyde

$$CH_3-C\equiv CH + H_2O \xrightarrow[H_2SO_4]{HgSO_4} CH_3-CO-CH_3$$

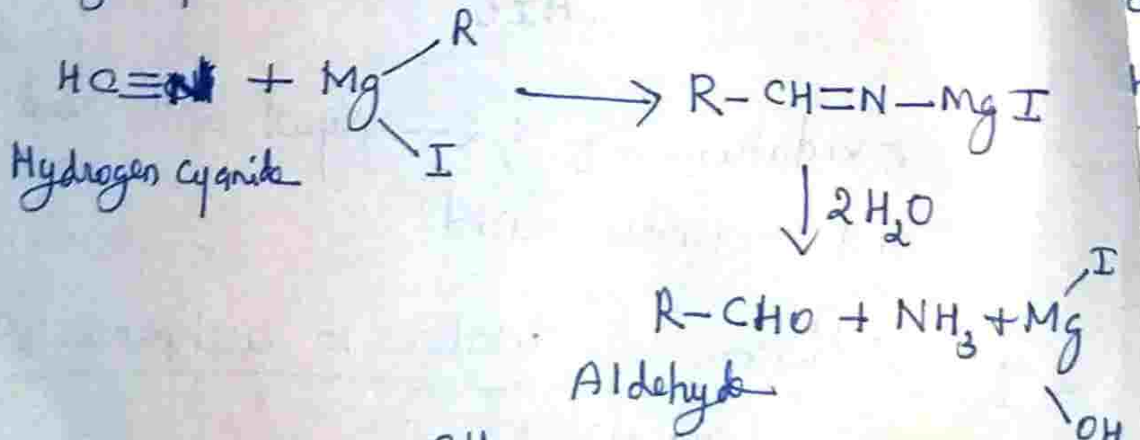
Propyne Acetone

⑩ By the reduction of an alkyl cyan dissolved in ether with stannous chlorid

$$R-C\equiv N \xrightarrow[HCl]{SnCl_2} R-CH=NH\cdot HCl \xrightarrow{H_2O} R-CH$$

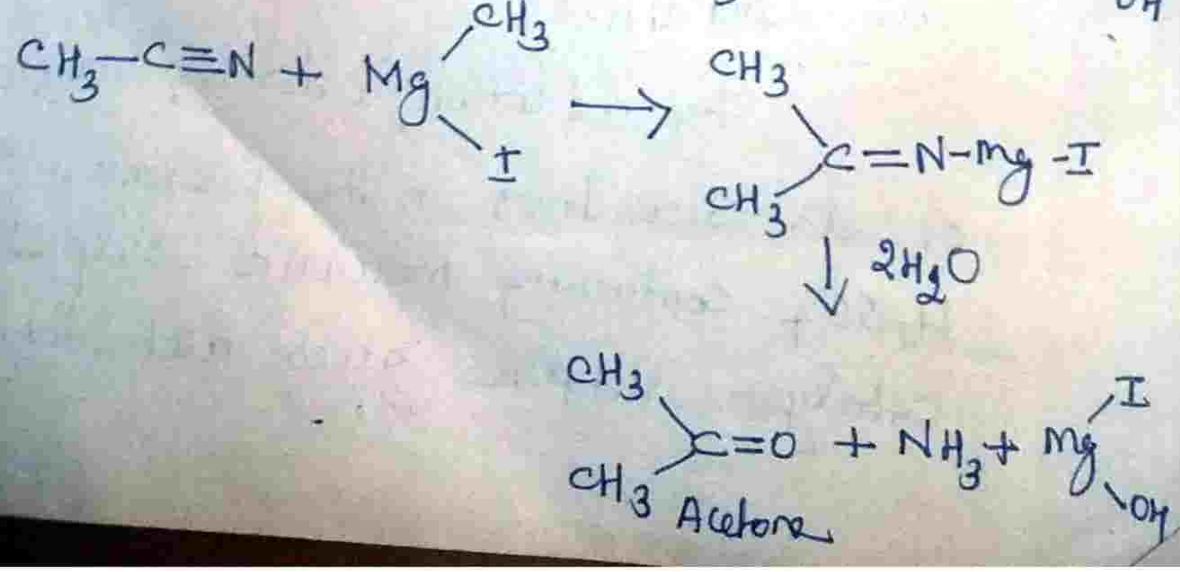
NH_4Cl

⑪ From Grignard reagent which gives aldehydes with HCN and ketones with alkyl cyanides.



$$HC\equiv N + Mg\begin{matrix} R \\ I \end{matrix} \longrightarrow R-CH=N-MgI \xrightarrow{2H_2O} R-CHO + NH_3 + Mg\begin{matrix} I \\ OH \end{matrix}$$

Hydrogen cyanide Aldehyde



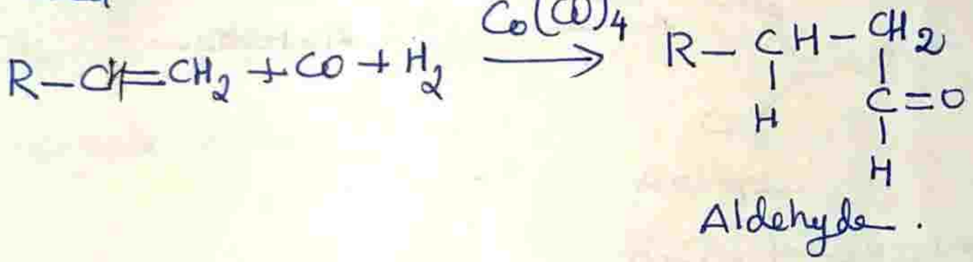
$$CH_3-C\equiv N + Mg\begin{matrix} CH_3 \\ I \end{matrix} \longrightarrow \begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>C=N-Mg-I \xrightarrow{2H_2O} \begin{matrix} CH_3 \\ CH_3 \end{matrix}\!\!>C=O + NH_3 + Mg\begin{matrix} I \\ OH \end{matrix}$$

Acetone

Preparation of aldehyde and ketones.

① Oxo process.

It is an industrially impotant method for producing aldehyde. It involves the treatment of an alkenes with carbon monoxide and hydrogen in presence of cobalt carbonyl catalyst. High temperature and pressure are used.



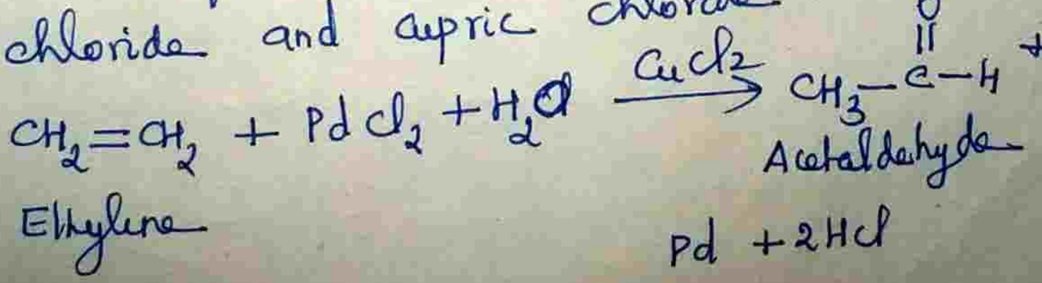
$$R-CH=CH_2 + CO + H_2 \xrightarrow{Co(CO)_4} R-\underset{H}{CH}-\underset{\underset{H}{C=O}}{CH_2}$$

Aldehyde.

This net reaction appears to be an anti-Markowrikoff addition of formaldehyde to the alkene. Ketone cannot be prepared by this method

② Wacker Process

Both aldehyde and ketones can be prepared by this method. This process involves the treatment of an alkene with an acidified aqueous solution of palladium chloride and cupric chloride.



$$CH_2=CH_2 + PdCl_2 + H_2O \xrightarrow{CuCl_2} CH_3-\overset{O}{\overset{\|}{C}}-H + Pd + 2HCl$$

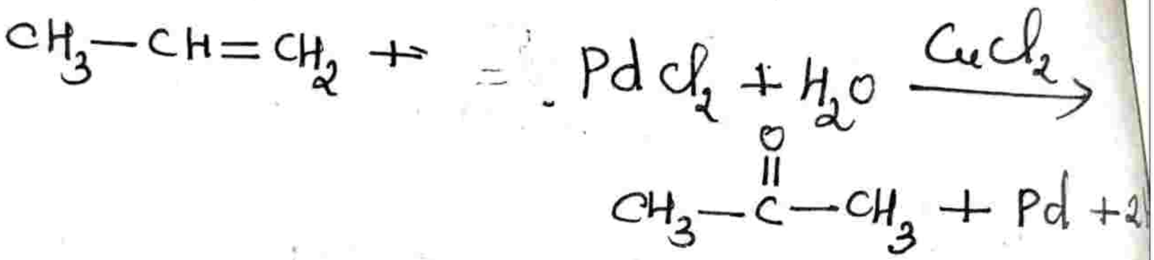
Ethylene

Acetaldehyde

The Cupric chloride promotes the second reaction, enhancing the reconvers The palladium back into palladium chlor

$Pd + 2CuCl_2 \longrightarrow PdCl_2 + 2CuCl$.

Acetone is prepared from propene.

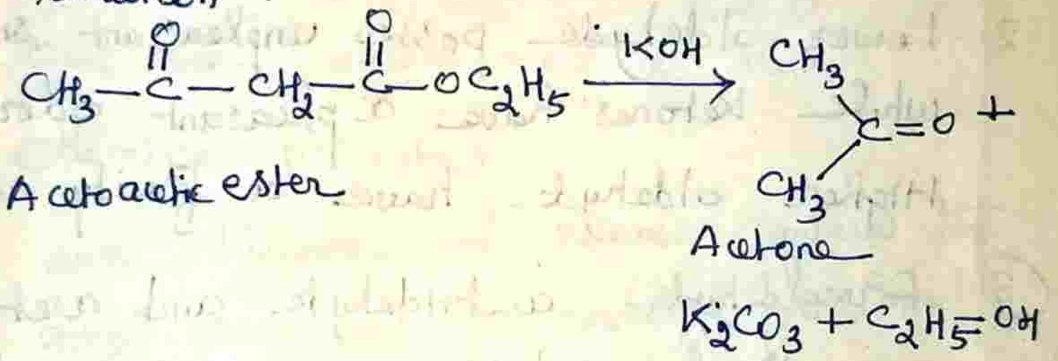


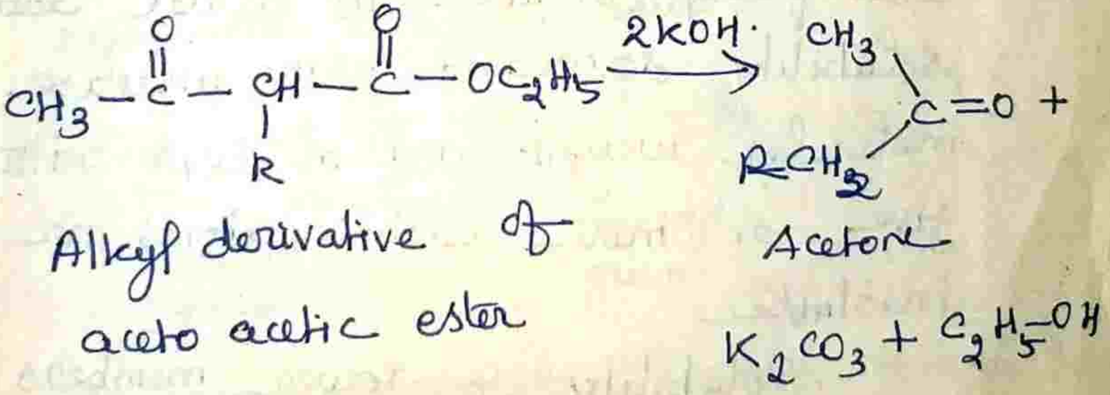
$$CH_3-CH=CH_2 + PdCl_2 + H_2O \xrightarrow{CuCl_2} CH_3-\overset{\overset{O}{\parallel}}{C}-CH_3 + Pd + 2$$

Acetone.

③ Hydrolysis of alkyl derivative of acetoacetic ester.

Ketones are prepared by the ketonic hydrolysis of the alkyl derivative of acetoacetic ester by boiling with dilute acid or dilute alkali, preferably acid solution.





There is no analogous method for the preparation of aldehyde.

General Properties of Aldehyde and ke

R.

Physical Properties

R

1. Except formaldehyde which is a gas, lower aldehydes and ketones are colourles Volatile liquids. Higher aldehyde and keto are solids.
2. Lower aldehyde posses unpleasant small while ketones have a pleasant odour. Higher aldehyde have a fruity odour
3. Formaldehyde, acetaldehyde and acetone are freely soluble in water. ~~Solubility~~ Solubility decreases with increase in molecular weight and members with five or more carbon atoms are insoluble.

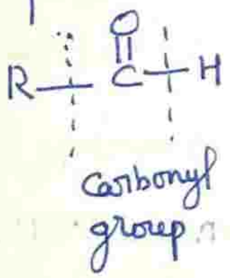
Solubility of lower members in H_2O is due to H-bonding between $>C=O$ group and the H_2O molecule and smaller size of alkyl group. Solubility decreases as the size of alkyl group increases.

4) Aldehyde and ketones are polar compounds because of the $>C=O$ group. intermolecular forces in them are stronger than those in hydrocarbon molecules but They are weaker than those in alcohols having Hydrogen bonds.

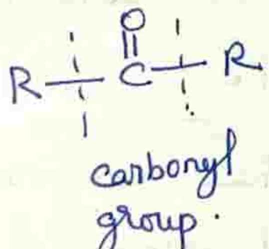
5) Acetone and other ketones are very good solvents and are widely used as such.

Chemical properties

Both aldehyde and ketones contain the alkyl group and the carbonyl group and represented as given below.

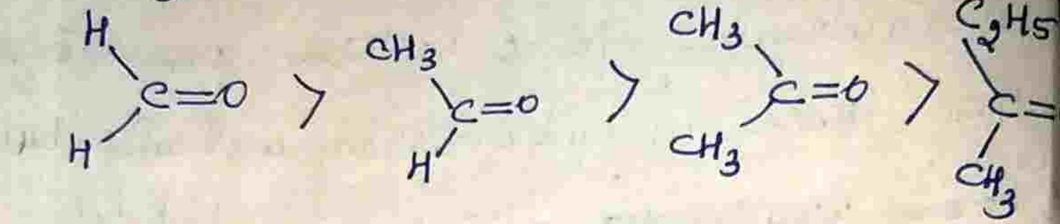


$R-\overset{O}{\overset{\|}{C}}-H$



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

A large number of reactions common to both aldehyde and ketones. The reactivity of carbonyl group depends on the nature of alkyl groups attached to it. The smaller alkyl group, more ~~reati~~ reactive is the carbonyl group. The order of reactivity of various carbonyl compoun is given below.

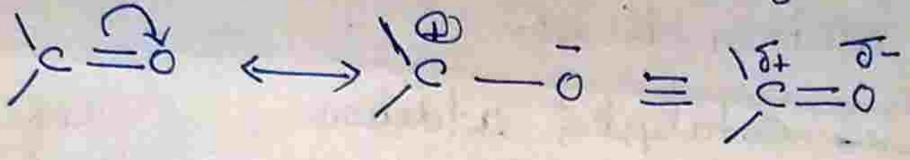


This is because the alkyl group inc the electron density on the carbonyl carb due to inductive effect and also becau the larger groups protect the carbon of th carbonyl group from the attacking nucleoph

The hydrogen in aldehydes is very reactive and hence aldehydes are readily oxidised to carboxylic acids.

① Nucleophilic Addition to the carbonyl grou

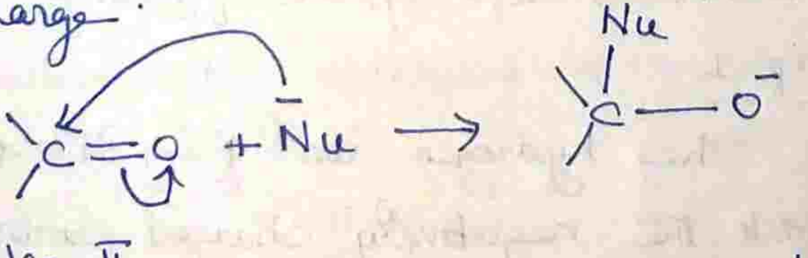
The compound containing the carbonyl group is plannar with π-electrons above and below this group in a direction perpendicular to the plane of carbonyl group; the nucleophilic reagents attack at this group of molecule. The oxygen acquires a negative charge and carbon a slightly positive charge. Therefore nucleophile will add to, the carbon of carbonyl group. This reaction is termed the nucleophilic addition at the carbonyl carbon. As a result of addition the carbonyl carbon



Aldehyde and ketones undergo nucleophilic addition reaction by the following mechanism.

Step-I

The nucleophile ($\bar{Nu}$) attacks the positively charged carbonyl carbon to form a new bond. As the new bond is formed, π-bond between the carbon and oxygen is broken. The electron pair goes to oxygen, which acquires a negative charge.



Step-II

The electrophile (H^+) attacks the negatively charged oxygen to form the

This addition reaction may be cataly by acid or bases.

Base catalysed addition

Bases convert a weak neutral nucleophile to a strong one by removing a proton. The strong nucleophile then adds to the carbonyl groups as shown abov

$$Nu-H + \bar{B} \longrightarrow \bar{Nu} + BH$$

neutral nucleophile (weak)

Base

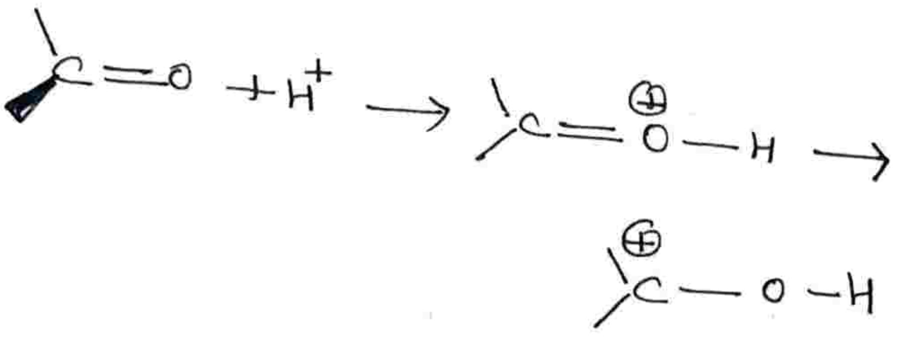
Anionic nucleophile (Strong)

Acid catalysed addition

The acid catalysed nucleophilic addition occurs by. the following mechanism.

Step : I

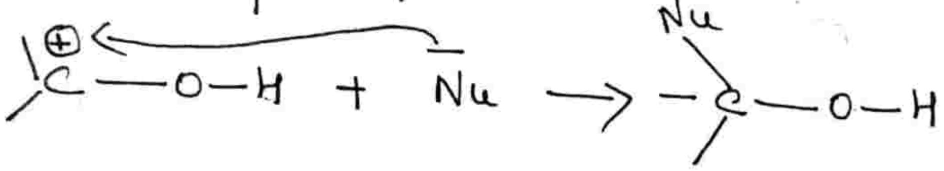
The hydrogen ion from the acid attack the negatively charged carbonyl oxygen to give protonated carbonyl group. The protonated carbonyl group is resonance stabilised.



Protonated carbonyl group.

Step - 2

The nucleophile attacks the protonated carbonyl group to form the addition product.

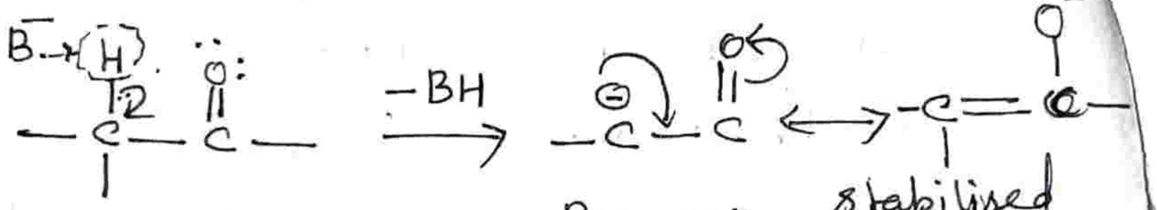


Addition product.

The addition product is same whether the reaction is acid-catalysed or base - catalysed. The nucleophile always adds to the carbonyl carbon and the proton to the oxygen. Generally ketones are less reactive than aldehydes in nucleophilic addition reactions.

Acidity of α-Hydrogen

A carbon atom next to the carbonyl group is called an α- carbon. A hydrogen attached to an α-carbon is referred to as an α-hydrogen. The α-hydrogen of alde and ketones are acidic in nature. The acidity is due to the anion, which result from the removal of an α-hydrog by ~~a~~ base B^-, is stabilised by resona The resonance stabilised anion is called Enolate ion.



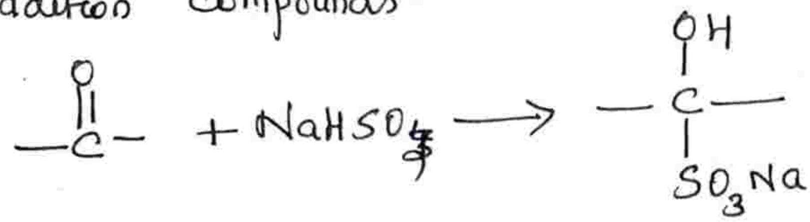
Resonance stabilised Enolate ion.

The α-carbon of enolate ion is negatively charged. It can acts as a nucleophile. The formation of the enolate ion followed by the addition ~~of~~ to the carbonyl group in the process involved in all the condensation reaction of aldehyde and ketones.

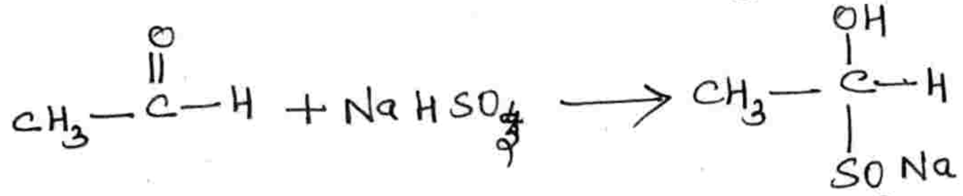
(A) Addition reaction.

① Addition of Sodium Bisulphate:

Aldehydes and methyl ketones react with a saturated aqueous solution of sodium bisulphate ($NaHSO_4$) to form solid addition compounds.

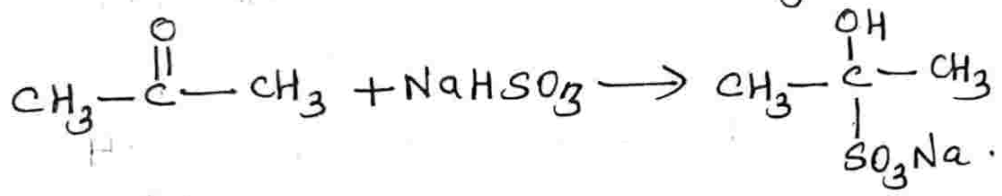


$$-\overset{O}{\overset{\|}{C}}- + NaHSO_3 \longrightarrow -\overset{OH}{\underset{SO_3Na}{C}}-$$



$$CH_3-\overset{O}{\overset{\|}{C}}-H + NaHSO_3 \longrightarrow CH_3-\overset{OH}{\underset{SO_3Na}{C}}-H.$$

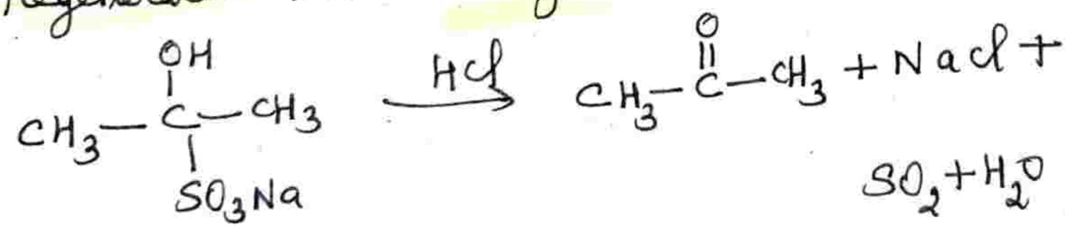
Acetaldehyde bisulphite



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + NaHSO_3 \longrightarrow CH_3-\overset{OH}{\underset{SO_3Na}{C}}-CH_3.$$

Acetone bisulphate

The bisulphate addition compounds can be decomposed with dilute acids or bases to regenerate the carbonyl compound.

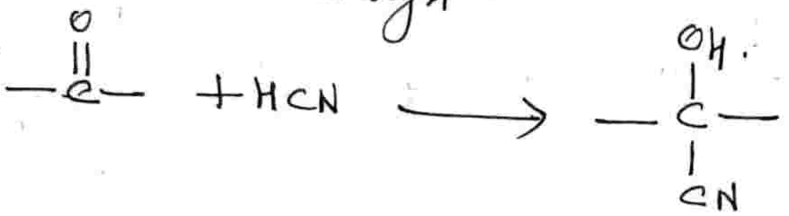


$$CH_3-\overset{OH}{\underset{SO_3Na}{C}}-CH_3 \xrightarrow{HCl} CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + NaCl + SO_2 + H_2O$$

The formation and decomposition of bisulphite addition compound is used for the purification and separation of carbonyl compounds from mixture.

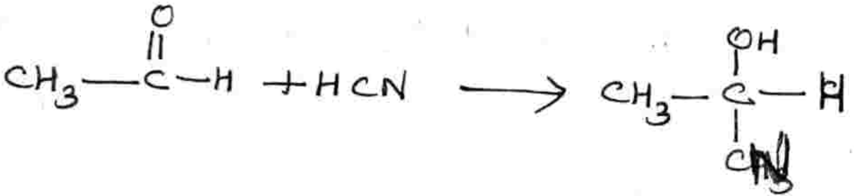
② Addition of Hydrogen Cyanide.

Aldehydes and ketones react wi hydrogen cyanide to form cyanohydrins. The reaction is carried in the presence o a basic catalyst.



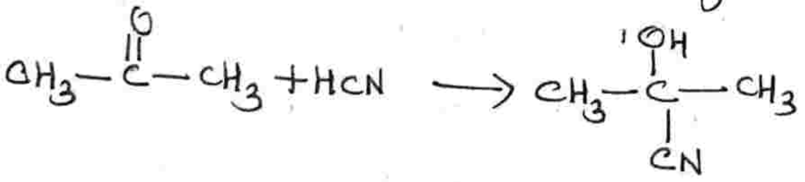
$$-\overset{O}{\overset{\|}{C}}- + HCN \longrightarrow -\underset{CN}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-$$

cyanohydrin.



$$CH_3-\overset{O}{\overset{\|}{C}}-H + HCN \longrightarrow CH_3-\underset{CN}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-H$$

Acetaldehyde cyanohydrin



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + HCN \longrightarrow CH_3-\underset{CN}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-CH_3$$

Acetone cyanohydrin.

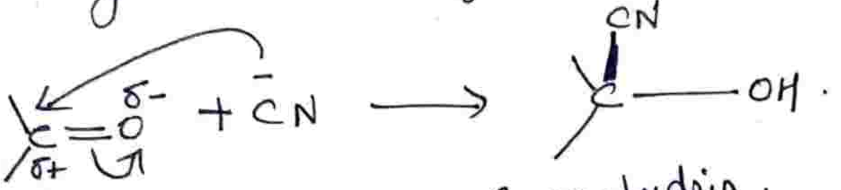
HCN is very poisonous gas. It is prepared in situ by the action of dil. H_2SO_4 on KCN.

Mechanism

Step - I : The base removes a proton from hydrogen cyanide to produce cyanide ion.

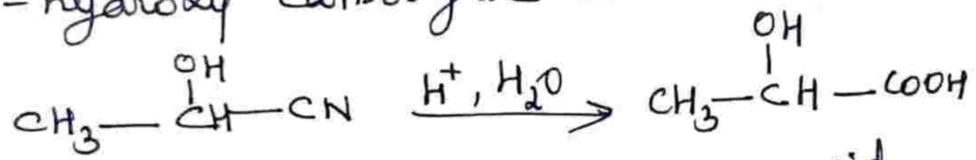
$$HCN + \bar{O}H \longrightarrow H_2O + \underset{\text{Nucleophile}}{\bar{CN}}$$

Step-2 The cyanide ion attacks the carbonyl carbon to form an anion.



cyanohydrin.

cyanohydrin can be hydrolysed to give α-hydroxy carboxylic acids.

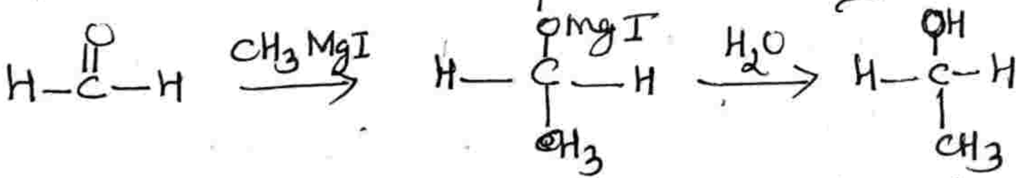


$$CH_3-\overset{OH}{\overset{|}{C}H}-CN \xrightarrow{H^+,\,H_2O} CH_3-\overset{OH}{\overset{|}{C}H}-COOH$$

Lactic acid

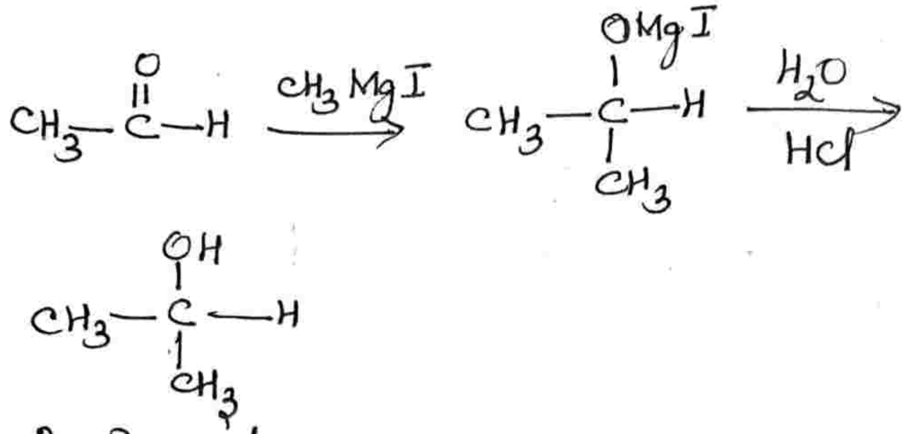
③ <u>Addition of Grignard reagent</u>.

The carbonyl group adds on grignard reagent to yield an addition product which on hydrolysis, gives an alcohol. For example, formaldehyde reacts with Grignard reagents to produce primary alcohols. Other aldehydes give secondary alcohols. Ketones to produce tertiary alcohol.



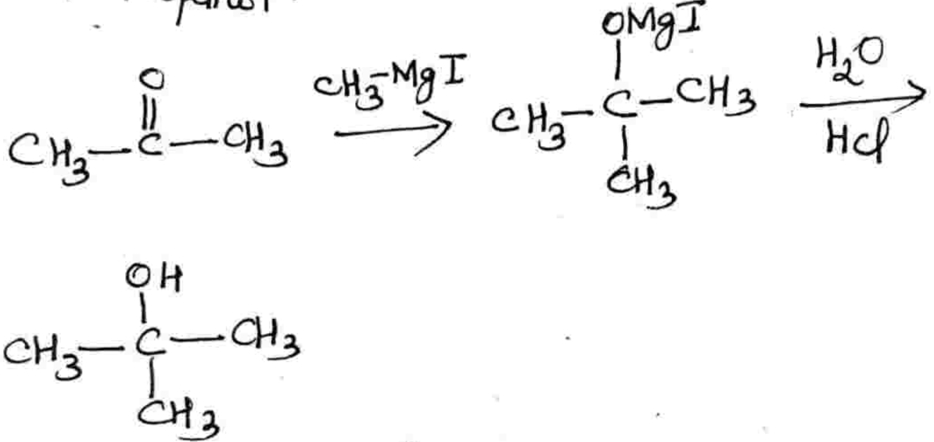
$$H-\overset{O}{\overset{||}{C}}-H \xrightarrow{CH_3MgI} H-\underset{CH_3}{\underset{|}{\overset{OMgI}{\overset{|}{C}}}}-H \xrightarrow{H_2O} H-\underset{CH_3}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-H$$

Ethanol.



$$CH_3-\overset{O}{\overset{\|}{C}}-H \xrightarrow{CH_3MgI} CH_3-\underset{CH_3}{\underset{|}{\overset{OMgI}{\overset{|}{C}}}}-H \xrightarrow[HCl]{H_2O} CH_3-\underset{CH_3}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-H$$

2-Propanol.

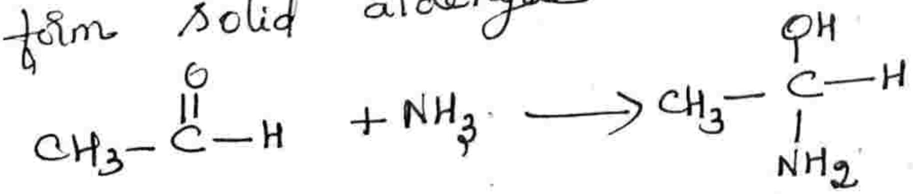


$$CH_3-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow{CH_3-MgI} CH_3-\underset{CH_3}{\underset{|}{\overset{OMgI}{\overset{|}{C}}}}-CH_3 \xrightarrow[HCl]{H_2O} CH_3-\underset{CH_3}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-CH_3$$

2-methyl-2-propanol.

④ Addition of Ammonia.

Aldehyde react with ammonia to form solid aldehyde ammonia.



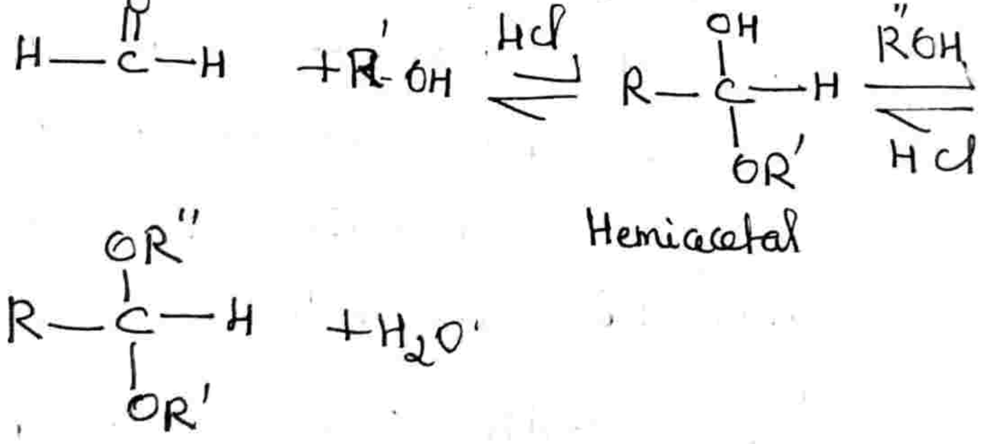
$$CH_3-\overset{O}{\overset{\|}{C}}-H + NH_3 \longrightarrow CH_3-\underset{NH_2}{\underset{|}{\overset{OH}{\overset{|}{C}}}}-H$$

The aldehyde ammonia when heated with dilute acids, regenerate the aldehydes. Thus the formation ~~of~~ and decomposition of these compounds is used for purification of aldehyde.

1) Addition Reactions followed by Loss of water

5) Addition of Alcohols.

Alcohols react with aldehyde in the presence of anhyd. HCl to form unstable addition products known as Hemiacetals. These hemiacetals react further with alcohol to form stable compounds known as Acetals. These ~~acetals~~ acetals are gem-diethers.



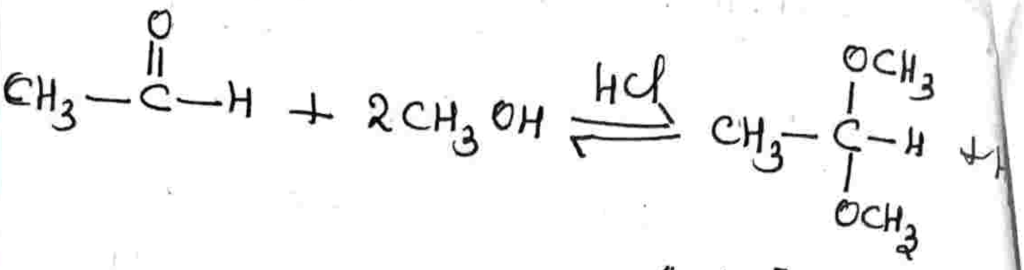
$$H-\overset{\overset{O}{\|}}{C}-H + R'-OH \underset{}{\overset{HCl}{\rightleftharpoons}} R-\underset{\underset{OR'}{|}}{\overset{\overset{OH}{|}}{C}}-H \underset{HCl}{\overset{R''OH}{\rightleftharpoons}} R-\underset{\underset{OR'}{|}}{\overset{\overset{OR''}{|}}{C}}-H + H_2O$$

Hemiacetal

Acetal

(gem-diether

The reaction is reversible. A large excess of alcohol is used to shift the equilibrium in favour of acetal formation. The reaction of acetaldehyde with methyl alcohol results the formation of acetaldehyde dimethyl ~~ate~~ acetal.



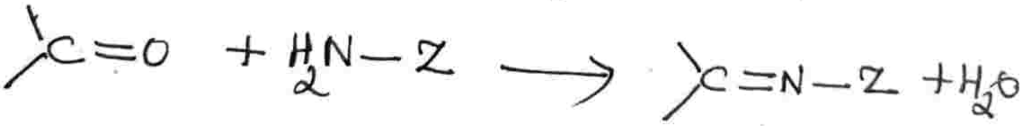
$$CH_3-\overset{\overset{O}{\|}}{C}-H + 2CH_3OH \xrightleftharpoons{HCl} CH_3-\underset{\underset{OCH_3}{|}}{\overset{\overset{OCH_3}{|}}{C}}-H + H$$

Acetal.

Ketones do not react with alcohols to form the corresponding hemiacetals and ketals.

⑥ Reaction with Ammonia derivatives.

Ammonia derivatives (NH_2-Z) react with aldehydes and ketones to form compounds containing carbon-nitrogen double bonds together with the elimination of a H_2O molecule.

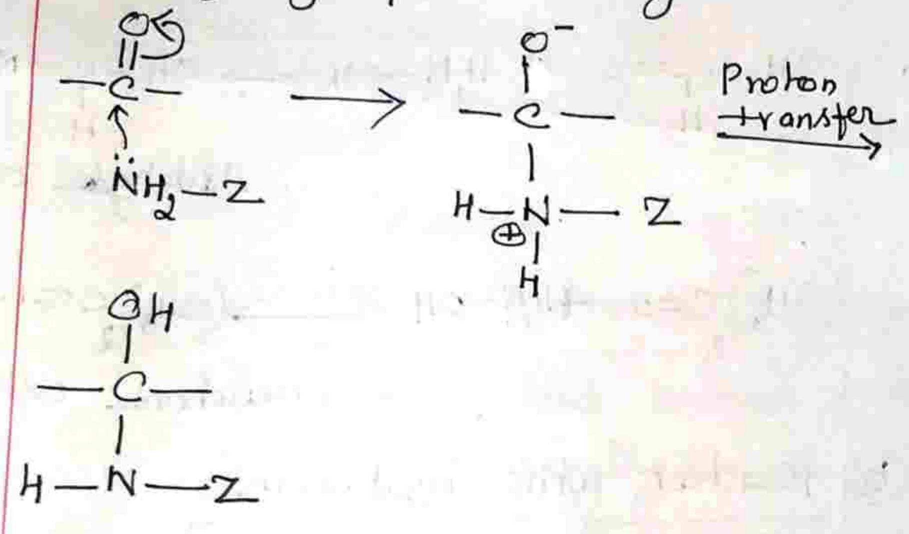


$$>C=O + H_2N-Z \longrightarrow >C=N-Z + H_2O$$

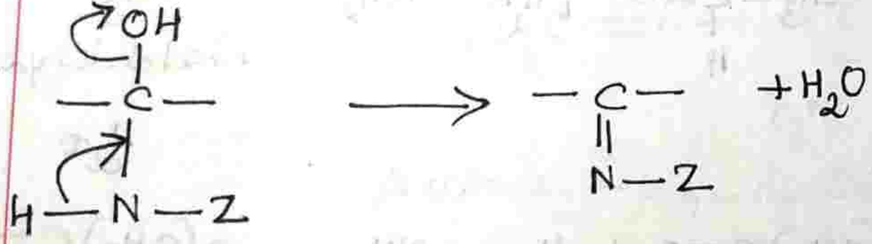
The reaction products are usually crystalline solids whose melting points can be used to identify aldehyde and ketones, most of which are liquids.

Mechanism

Step-I Ammonia derivatives (NH_2-Z) behave as nucleophilic reagents since they have an unshared electron pair on nitrogen. They add to the carbonyl group in aldehyde and ketones.



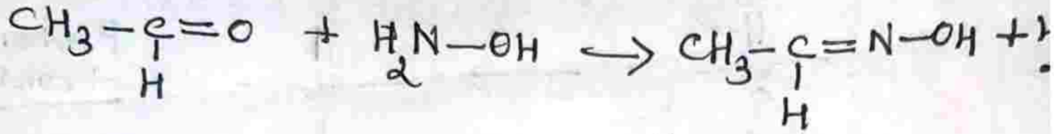
Step-2 : Addition product rapidly loses a molecule of water to give the final product.



Hydroxylamine, hydrazine, phenylhydrazine, 2,4-dinitrophenylhydrazine and semicarbazine react in this way.

(a) Reaction with hydroxylamine :

Aldehyde and ketones react with hydroxylamine (NH_2-OH) to form oximes



$$CH_3-\underset{H}{\underset{|}{C}}=O + H_2N-OH \rightarrow CH_3-\underset{H}{\underset{|}{C}}=N-OH +$$

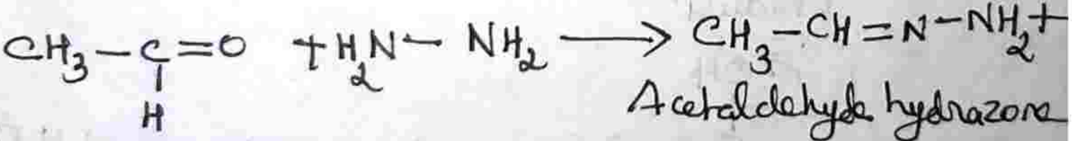
Aldehyde oxime

$$(CH_3)_2C=O + H_2N-OH \longrightarrow (CH_3)_2C=N-OH + H_2$$

acetone oxime.

(b) Reaction with Hydrazine

Aldehyde and ketones reacts with hydrazine (NH_2-NH_2) to form hydrazones.



$$CH_3-\underset{H}{\underset{|}{C}}=O + H_2N-NH_2 \longrightarrow CH_3-CH=N-NH_2 +$$

Acetaldehyde hydrazone

H_2O

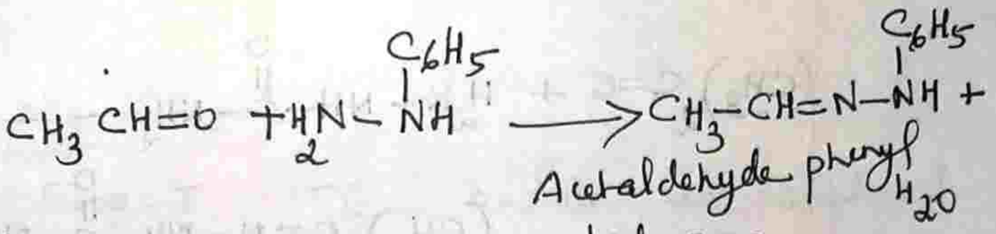
$$(CH_3)_2C=O + H_2N-NH_2 \longrightarrow (CH_3)_2C=N-NH_2 +$$

Acetone hydrazone

$+ H_2O$

(c) Reaction with Phenylhydrazine

Aldehyde and ketones react with phenylhydrazine $C_6H_5-NH-NH_2$ to form phenylhydrazone.



$$CH_3CH{=}O + H_2N{-}NH(C_6H_5) \longrightarrow CH_3{-}CH{=}N{-}NH(C_6H_5) + H_2O$$

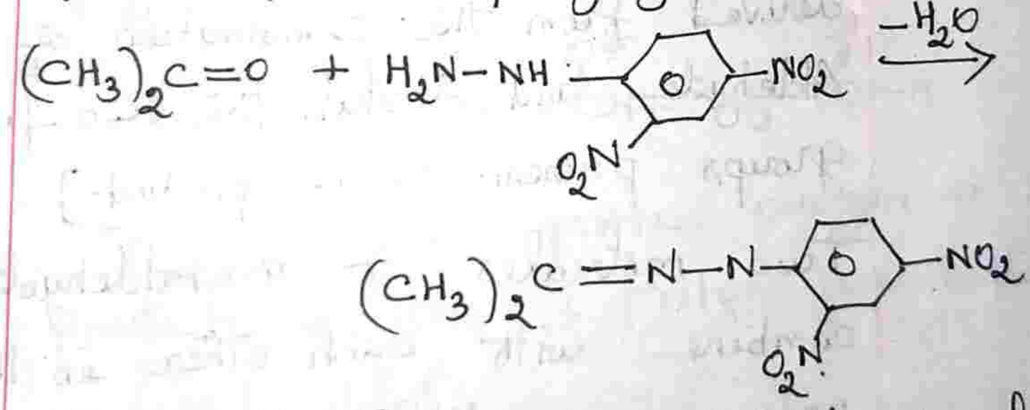
Acetaldehyde phenyl hydrazone

$$(CH_3)_2C{=}O + H_2N{-}NH{-}C_6H_5 \longrightarrow (CH_3)_2C{=}N{-}NH{-}C_6H_5 + H_2O$$

Acetone phenylhydrazone

(d) Reaction with 2,4-Dinitrophenylhydrazine

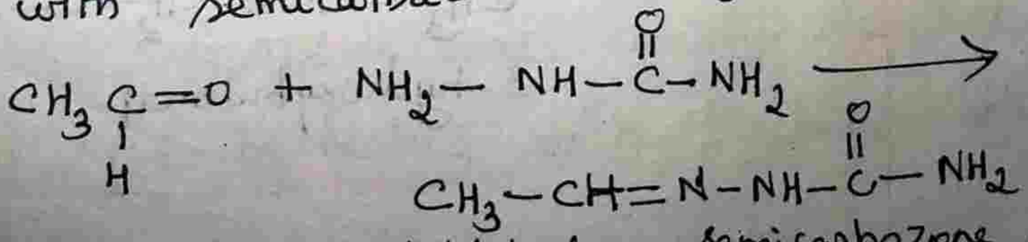
Aldehydes and ketones react with 2,4-dinitrophenylhydrazine to form 2,4-dinitrophenylhydrazone.



Acetone - 2,4-dinitrophenyl hydrazone.

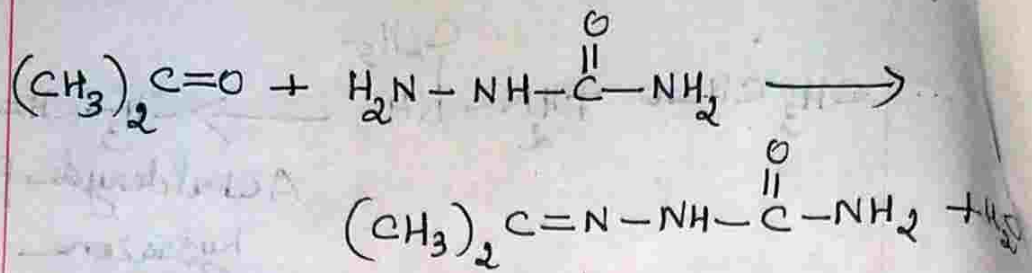
(e) Reaction with Semicarbazide:

Aldehyde and ketones react with semicarbazides to form semicarbazone



$$CH_3CH{=}O + NH_2{-}NH{-}\overset{O}{\overset{\|}{C}}{-}NH_2 \longrightarrow CH_3{-}CH{=}N{-}NH{-}\overset{O}{\overset{\|}{C}}{-}NH_2$$

Acetaldehyde semicarbazone



$$(CH_3)_2C{=}O + H_2N-NH-\overset{\overset{O}{\|}}{C}-NH_2 \longrightarrow (CH_3)_2C{=}N-NH-\overset{\overset{O}{\|}}{C}-NH_2 + H_2O$$

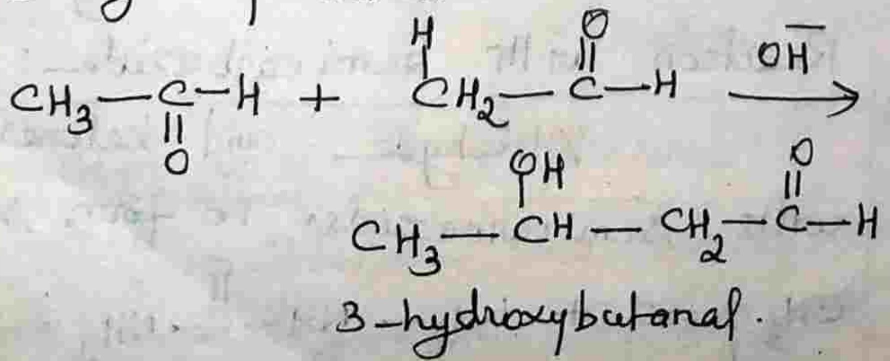
Acetone semicarbazone

III Reactions involving alkyl groups.

Aldol condensation

Aldehyde containing α-hydrogen undergo self addition in the presence of a base to form products called Aldols. The reaction is called Aldol condensation. [The term aldol is derived from the combination of the words Aldehyde and Alcohol, the two functional groups present in the product].

Two molecules of acetaldehyde combine with each other in the presence of dil. NaOH to form 3-hydroxybutanal.

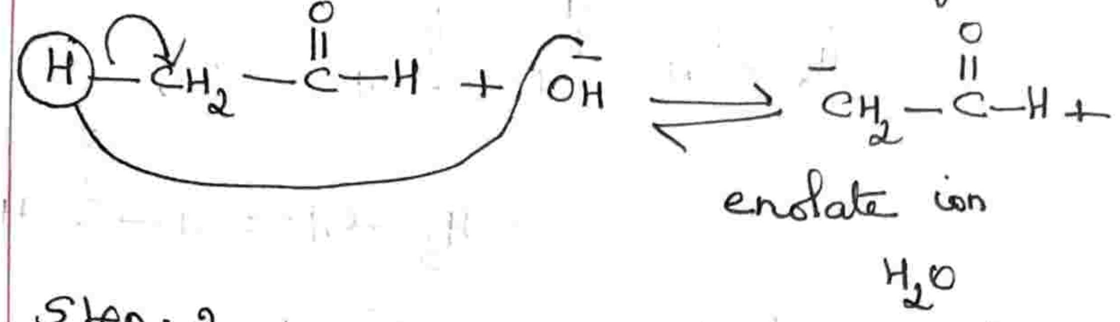


$$CH_3-\underset{\underset{O}{\|}}{C}-H + \overset{H}{\overset{|}{C}}H_2-\overset{\overset{O}{\|}}{C}-H \xrightarrow{\overline{OH}} CH_3-\overset{OH}{\overset{|}{C}}H-CH_2-\overset{\overset{O}{\|}}{C}-H.$$

3-hydroxybutanal.

Mechanism

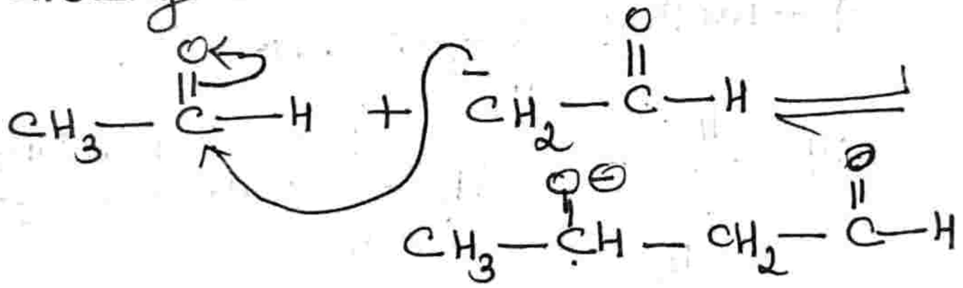
Step - I : The enolate ion is formed.



$$H-CH_2-\overset{O}{\overset{\|}{C}}-H + \overline{O}H \rightleftharpoons {}^{-}CH_2-\overset{O}{\overset{\|}{C}}-H + H_2O$$

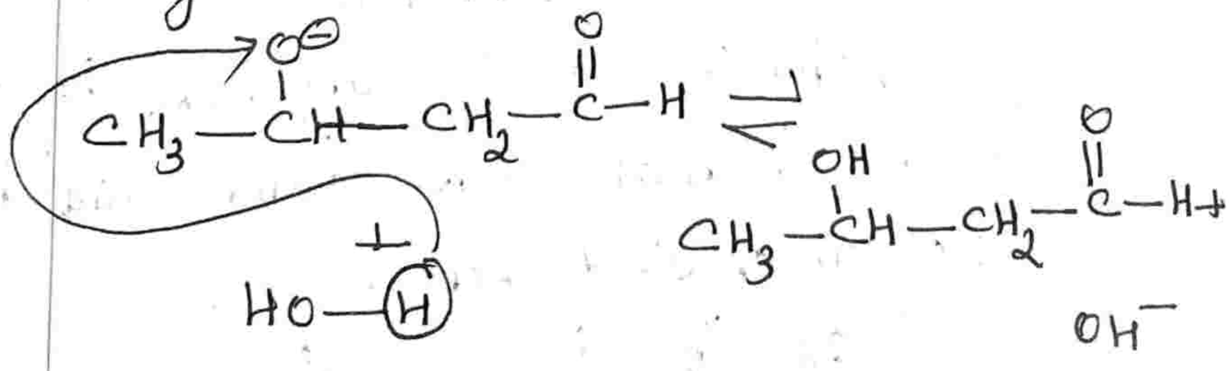
Step : 2

The enolate ion attacks the carbonyl carbon of another un-ionised aldehyde molecule.



$$CH_3-\overset{O}{\overset{\|}{C}}-H + {}^{-}CH_2-\overset{O}{\overset{\|}{C}}-H \rightleftharpoons CH_3-\overset{O^{\ominus}}{\overset{|}{C}}H-CH_2-\overset{O}{\overset{\|}{C}}-H$$

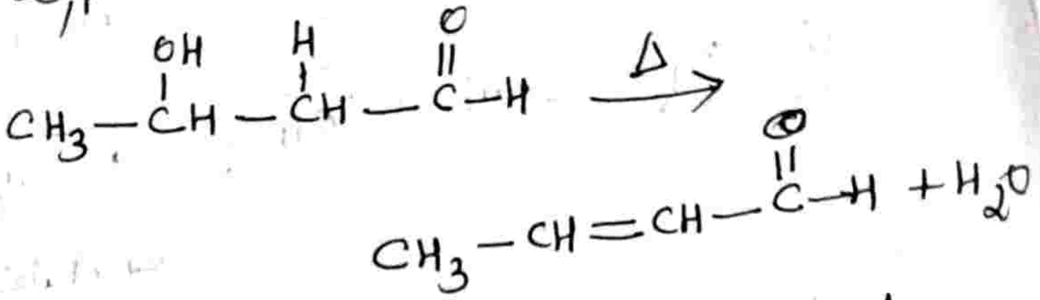
Step - 3 : The negative oxygen in the product accepts a proton from Water to give aldol.



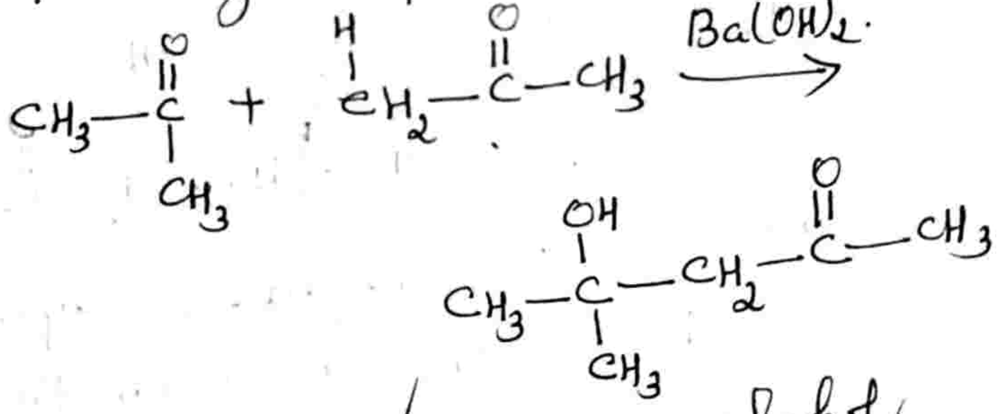
$$CH_3-\overset{O^{\ominus}}{\overset{|}{C}}H-CH_2-\overset{O}{\overset{\|}{C}}-H + HO-H \rightleftharpoons CH_3-\overset{OH}{\overset{|}{C}}H-CH_2-\overset{O}{\overset{\|}{C}}-H + OH^{-}$$

Aldols are easily dehydrated either by heating or by treatment with xidation There eton

dilute acid to form ~~α,β~~ ~~α,β un~~ α,β-unsaturated aldehyde.

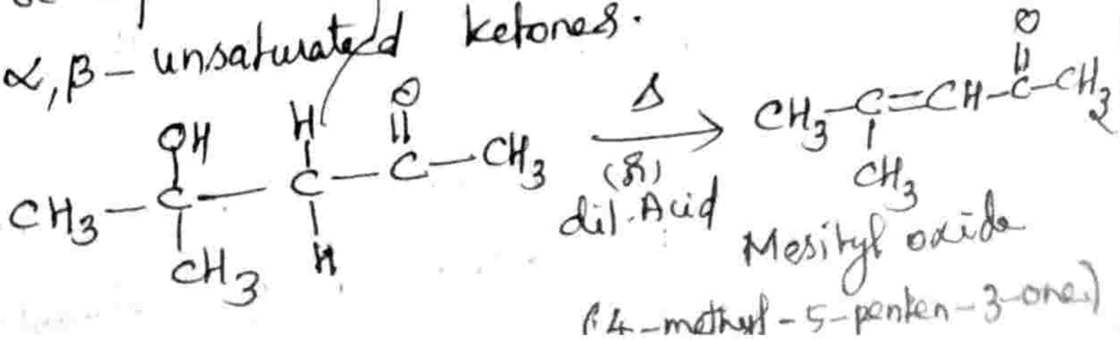

$CH_3-\overset{OH}{CH}-\overset{H}{CH}-\overset{O}{\overset{\|}{C}}-H \xrightarrow{\Delta} CH_3-CH=CH-\overset{O}{\overset{\|}{C}}-H + H_2O$

Ketones containing α-hydrogen also undergo condensation to form ketols. Acetone gives 4-hydroxy-4-methyl-2-pentanone.


$CH_3-\underset{CH_3}{\overset{O}{\overset{\|}{C}}} + \overset{H}{CH_2}-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow{Ba(OH)_2} CH_3-\underset{CH_3}{\overset{OH}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-CH_3$

Diacetone alcohol.

ketones are dehydrated by heating & by treatment with dilute acid to form α,β-unsaturated ketones.


$CH_3-\underset{CH_3}{\overset{OH}{C}}-\underset{H}{\overset{H}{C}}-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow[\text{(&) dil. Acid}]{\Delta} CH_3-\underset{CH_3}{C}=CH-\overset{O}{\overset{\|}{C}}-CH_3$

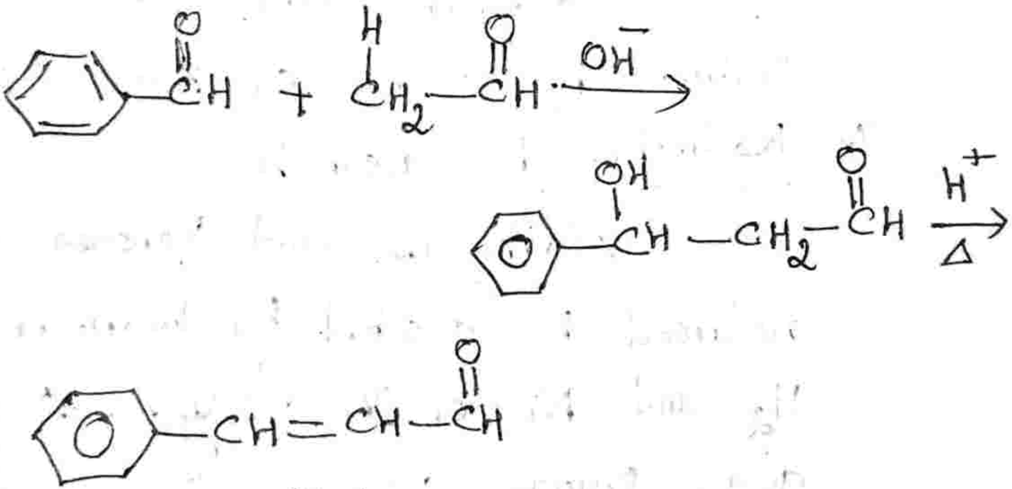
Mesityl oxide

(4-methyl-5-penten-3-one)

Mixed aldol condensation.

The reaction of two different carbonyl compounds (one of which must have an α-H) in the presence of a base is known as mixed aldol condensation.

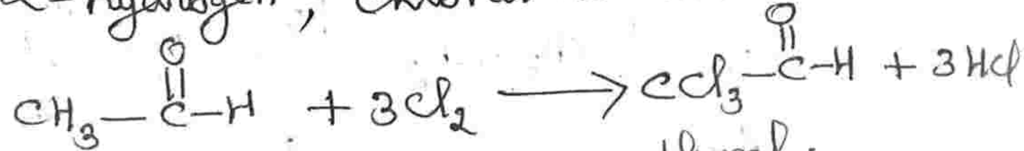
Acetaldehyde reacts with benzaldehyde (which has no α-H) in the presence of a base to form cinnamaldehyde.



cinnamaldehyde

⑧ Chlorination :

Chlorine is bubbled through acetaldehyde, chlorine replace the α-hydrogen, chloral is obtained.

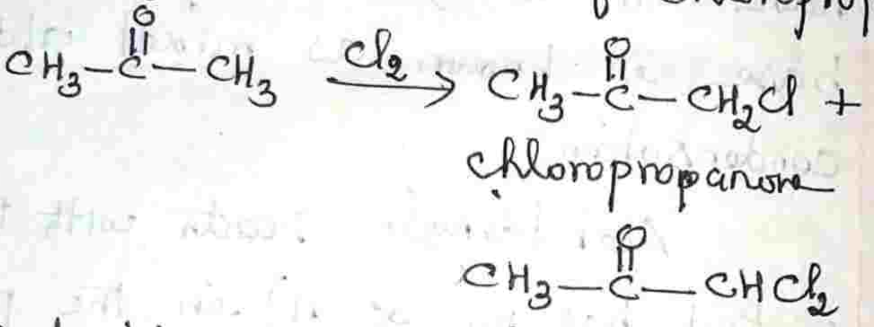


$$CH_3-\overset{O}{\overset{\parallel}{C}}-H + 3Cl_2 \longrightarrow CCl_3-\overset{O}{\overset{\parallel}{C}}-H + 3HCl$$

Acetaldehyde

chloral.

If chlorine is bubbled through warm acetone, successive replacement of the methyl hydrogen takes place, yielding a mixture of chloropropanones.



$$CH_3-\overset{O}{\overset{||}{C}}-CH_3 \xrightarrow{Cl_2} CH_3-\overset{O}{\overset{||}{C}}-CH_2Cl +$$

chloropropanone

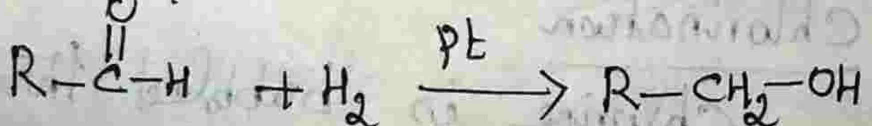
$$CH_3-\overset{O}{\overset{||}{C}}-CHCl_2$$

D **Reduction Reactions.**

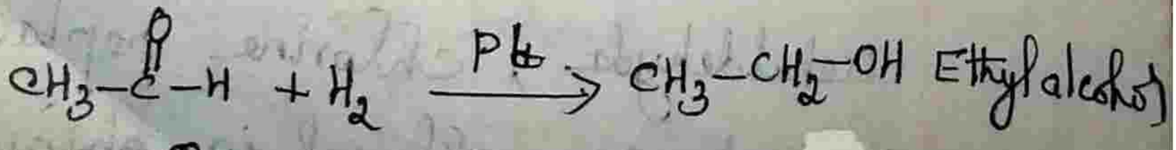
Aldehyde and ketones are reduced to alcohol or alkanes.

(i) **Reduction to alcohols.**

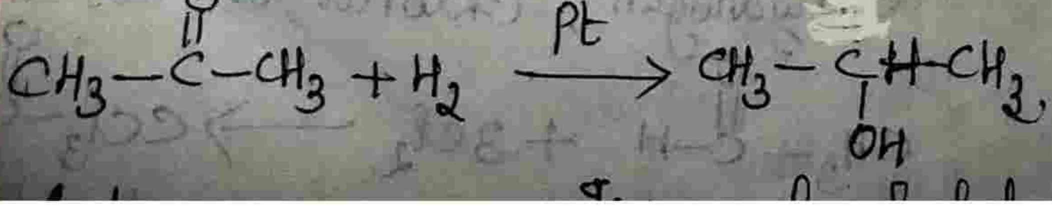
Aldehydes and ketones can be reduced to alcohol by treatment with H_2 and Ni or Pt catalyst. Aldehyde gives primary alcohols, ketones give secondary alcohols.



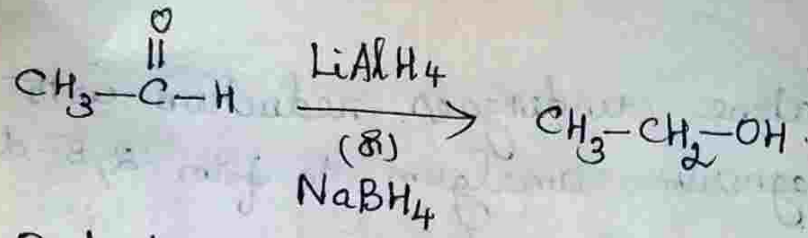
$$R-\overset{O}{\overset{||}{C}}-H + H_2 \xrightarrow{Pt} R-CH_2-OH$$



$$CH_3-\overset{O}{\overset{||}{C}}-H + H_2 \xrightarrow{Pt} CH_3-CH_2-OH$$ Ethyl alcohol



$$CH_3-\overset{O}{\overset{||}{C}}-CH_3 + H_2 \xrightarrow{Pt} CH_3-\underset{OH}{\underset{|}{CH}}-CH_3$$



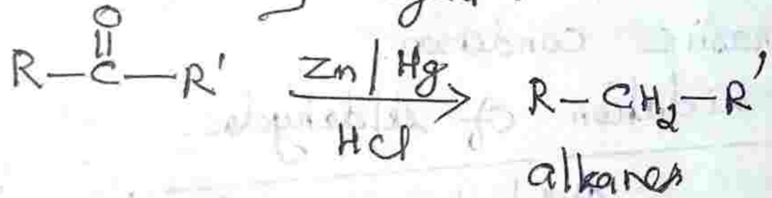
$$CH_3-\overset{\overset{O}{\parallel}}{C}-H \xrightarrow[\substack{(\text{or}) \\ NaBH_4}]{LiAlH_4} CH_3-CH_2-OH.$$

0) Reduction to Alkanes :

Aldehydes and ketones can be reduced to alkanes by either the Clemmensen reduction or the Wolf-kishner reduction.

Clemmensen reduction

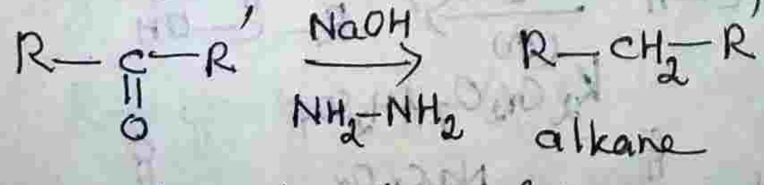
This involves the use of zinc-mercury amalgam in HCl acid as the reducing agent.



$$R-\overset{\overset{O}{\parallel}}{C}-R' \xrightarrow[HCl]{Zn/Hg} \underset{\text{alkanes}}{R-CH_2-R'}$$

Wolf-kishner reduction

This involves the use of basic solution of hydrazine as the reducing agent.

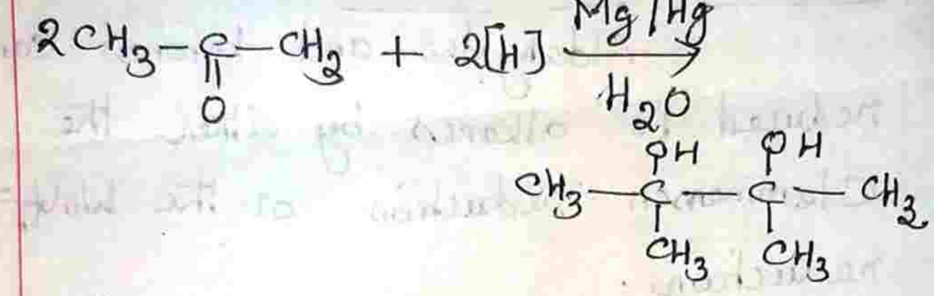


$$R-\underset{\underset{O}{\parallel}}{C}-R' \xrightarrow[NH_2-NH_2]{NaOH} \underset{\text{alkane}}{R-CH_2-R'}$$

ii) Reduction to Pinacols.

Ketones when reduced in neutral or alkaline medium, form pinacols

Acetone undergoes reduction with magnesium amalgam to form 2,3-dimethyl butane-2,3-diol.



$$2CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + 2[H] \xrightarrow[H_2O]{Mg/Hg} CH_3-\underset{CH_3}{\overset{OH}{C}}-\underset{CH_3}{\overset{OH}{C}}-CH_3$$

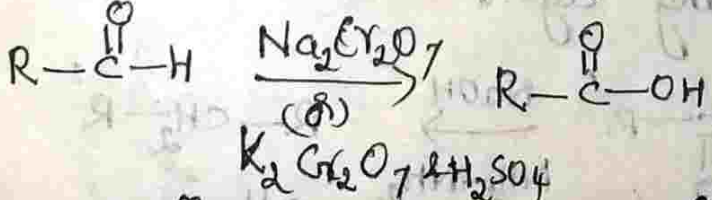
Aldehyde do not give this reaction.

Ⓔ Oxidation reaction

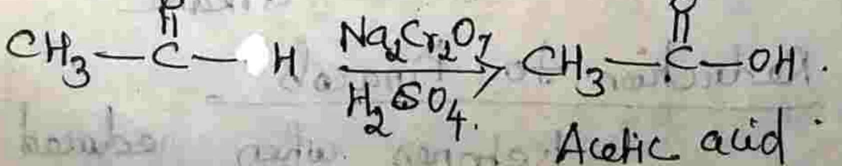
Aldehydes are easily oxidised. ketones are oxidised only under drastic condition.

① Oxidation of Aldehyde

Aldehyde oxidised with $K_2Cr_2O_7$ (or) $Na_2Cr_2O_7$ in acidic medium to form carboxylic acids containing the same number of carbon atoms.



$$R-\overset{O}{\overset{\|}{C}}-H \xrightarrow[(or)\ K_2Cr_2O_7 + H_2SO_4]{Na_2Cr_2O_7} R-\overset{O}{\overset{\|}{C}}-OH$$



$$CH_3-\overset{O}{\overset{\|}{C}}-H \xrightarrow[H_2SO_4]{Na_2Cr_2O_7} CH_3-\overset{O}{\overset{\|}{C}}-OH$$

Acetic acid

Potassium permanganate used in place of sodium dichromate. Aldehyde can be oxidised by much milder oxidising agents such as Tollen's reagent, fehling's solution and Benedict's solution

Tollen's Reagent.

[Ammoniacal solution of silver oxide is Tollen's Regent. It is obtained by adding ammonia to a ~~prep~~ precipitate of silver oxide present in a solution of silver nitrate and NaOH.]

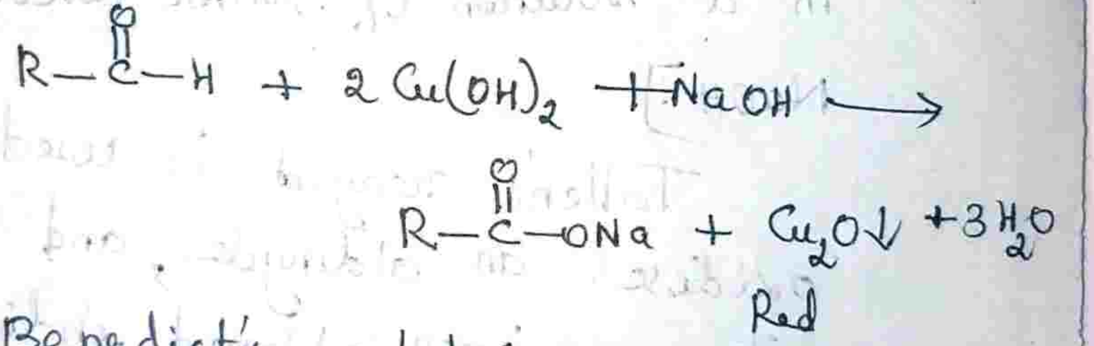
Tollen's reagent is used to oxidise an aldehyde, and the silver mirror formed indicates the presence of an aldehyde group in a molecules:

$$R-\underset{\underset{O}{\|}}{C}-H + \underset{\text{ammoniacal}}{Ag_2O} \longrightarrow R-\underset{\underset{O}{\|}}{C}-OH + \underset{\text{mirror}}{Ag\downarrow}$$

Fehling's Solution

Fehling's solution is an alkaline solution of cupric ion complexed with sodium potassium tartarate ion.

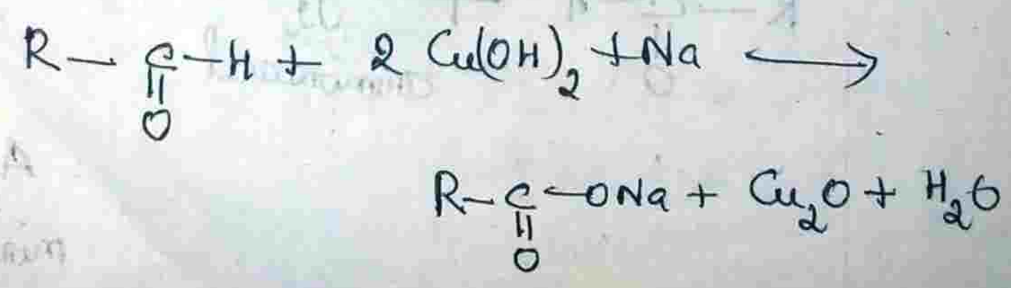
Fehling's solution is used to oxidise an aldehyde, cupric ion reduced to red cuprous oxide. The presence of red cuprous oxide serves as an indication of an aldehyde group in a molecule.



$$R-\overset{O}{\overset{\|}{C}}-H + 2\,Cu(OH)_2 + NaOH \longrightarrow R-\overset{O}{\overset{\|}{C}}-ONa + \underset{Red}{Cu_2O\downarrow} + 3H_2O$$

Benedict's solution

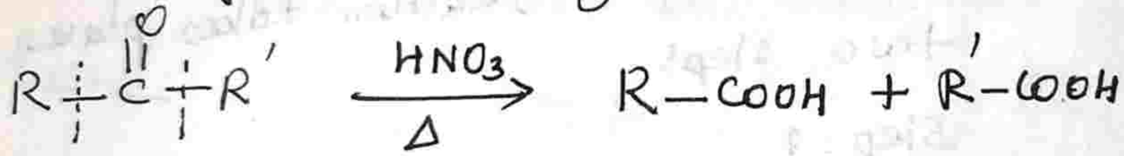
[It is an alkaline solution of cupric ion complexed with citrate.



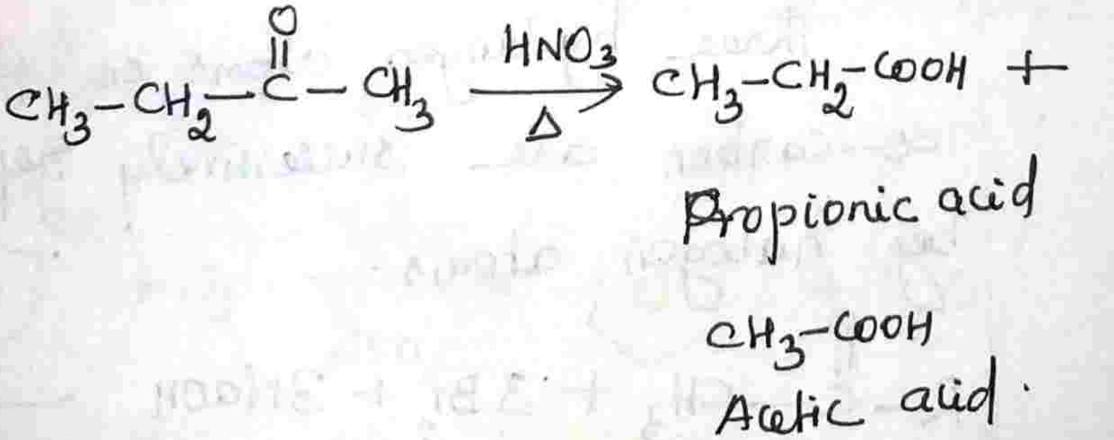
$$R-\underset{O}{\underset{\|}{C}}-H + 2\,Cu(OH)_2 + Na \longrightarrow R-\underset{O}{\underset{\|}{C}}-ONa + Cu_2O + H_2O$$

oxidation of ketones:

Ketones are oxidised by strong oxidising agents like alkaline $KMnO_4$ or hot concentriated HNO_3 to form two carboxylic acids with fewer carbon atoms than the original ketones. This is because the ketone is broken into two fragments by attack on either side of the carbonyl group.



$$R-\overset{O}{\overset{\|}{C}}-R' \xrightarrow[\Delta]{HNO_3} R-COOH + R'-COOH$$



$$CH_3-CH_2-\overset{O}{\overset{\|}{C}}-CH_3 \xrightarrow[\Delta]{HNO_3} CH_3-CH_2-COOH + CH_3-COOH$$

Propionic acid

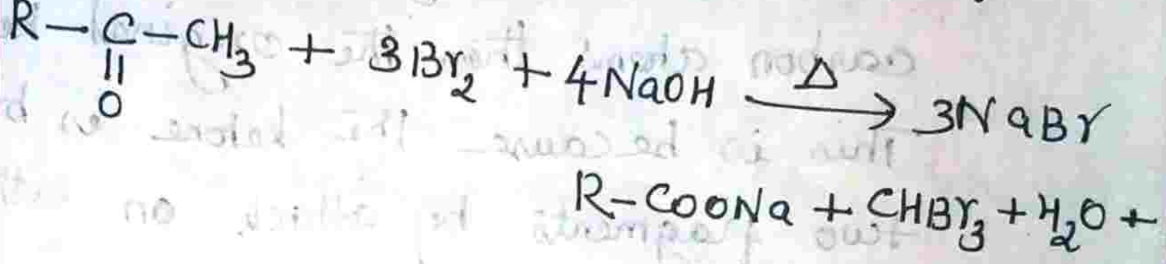
Acetic acid.

Ketones do not react with Tollen's reagent, Fehling's solution or Benedict's solution:

E. Some other important reactions :

(14) Haloform Reactions :

Acetaldehyde and methyl ketones react with halogen (Cl_2, Br_2, I_2) rapidly in presence of alkali to form haloform.



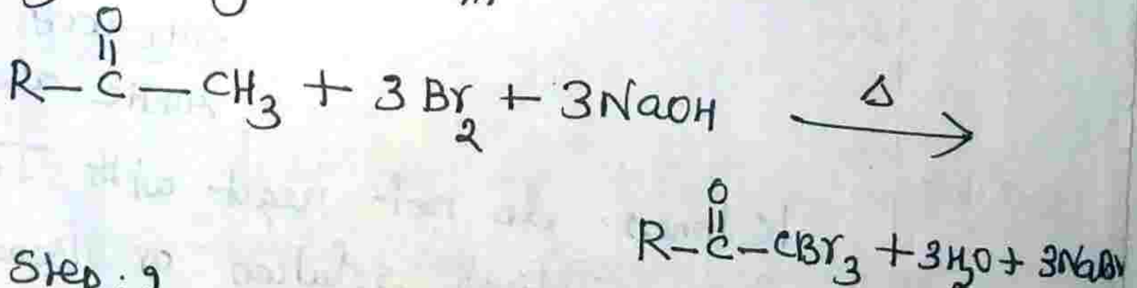
$$R-\underset{\underset{O}{\|}}{C}-CH_3 + 3Br_2 + 4NaOH \xrightarrow{\Delta} 3NaBr + R-COONa + CHBr_3 + H_2O +$$

Bromoform.

This haloform reaction takes place in two steps.

Step : 1

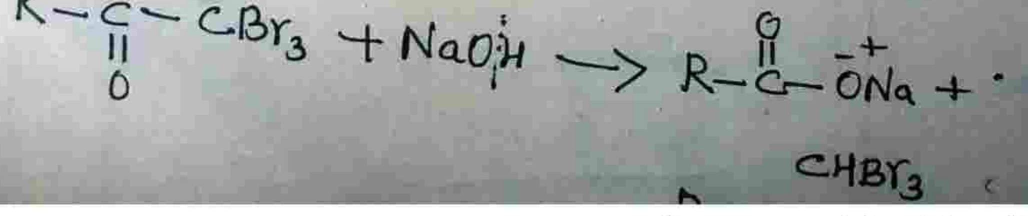
Three hydrogen atoms on the α-carbon are successively replaced by halogen atoms.



$$R-\overset{\overset{O}{\|}}{C}-CH_3 + 3Br_2 + 3NaOH \xrightarrow{\Delta} R-\overset{\overset{O}{\|}}{C}-CBr_3 + 3H_2O + 3NaBr$$

Step : 2

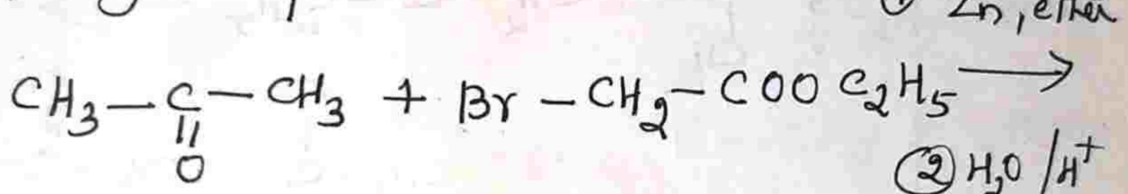
The 1,1,1-trihaloketone molecule is cleaved to give a trihalo methane



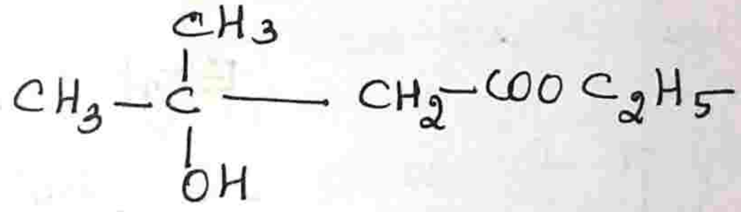
$$R-\underset{\underset{O}{\|}}{C}-CBr_3 + NaO\vdots H \longrightarrow R-\overset{\overset{O}{\|}}{C}-\overset{-}{O}\overset{+}{Na} + CHBr_3$$

16 Reformatsky Reaction

This involves the treatment of an aldehyde or ketone with α-bromo ester in presence of Zinc. The product (after hydrolysis) is β-hydroxy ester.



$$CH_3-\underset{\underset{O}{\|}}{C}-CH_3 + Br-CH_2-COOC_2H_5 \xrightarrow[\text{② } H_2O/H^+]{\text{① Zn, ether}}$$

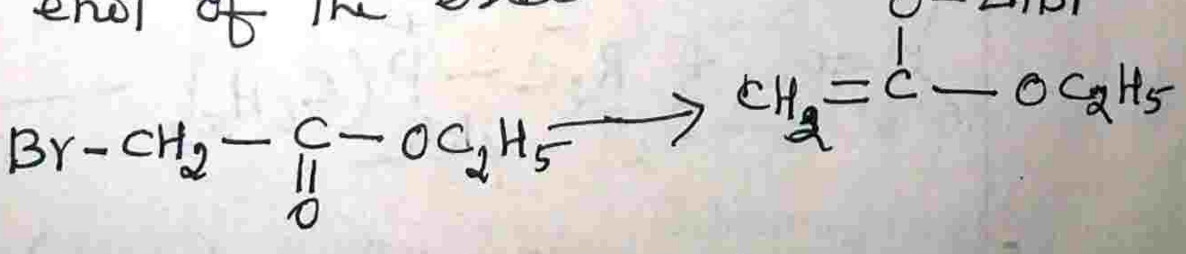


$$CH_3-\underset{\underset{OH}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_2-COOC_2H_5$$

Ethyl ~~3~~-hydroxy-3-methyl butanoate.

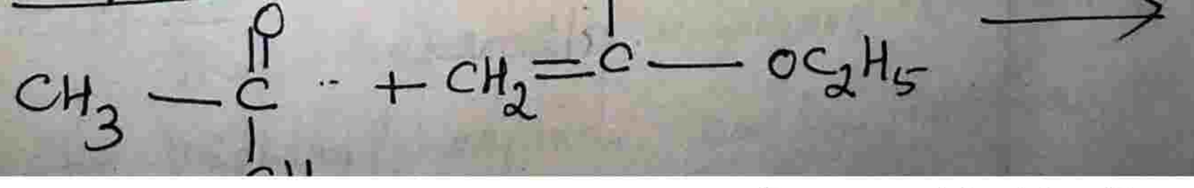
mech. 3 steps.

Step-I Formation of Zinc salt of enol of the ester

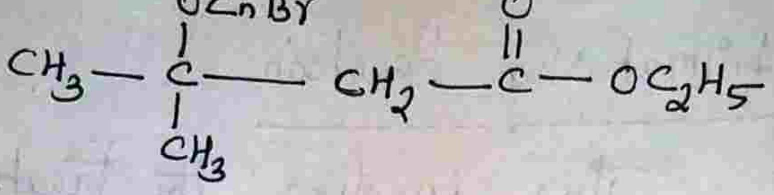


$$Br-CH_2-\underset{\underset{O}{\|}}{C}-OC_2H_5 \longrightarrow CH_2=\overset{\overset{O-ZnBr}{|}}{C}-OC_2H_5$$

Step-2



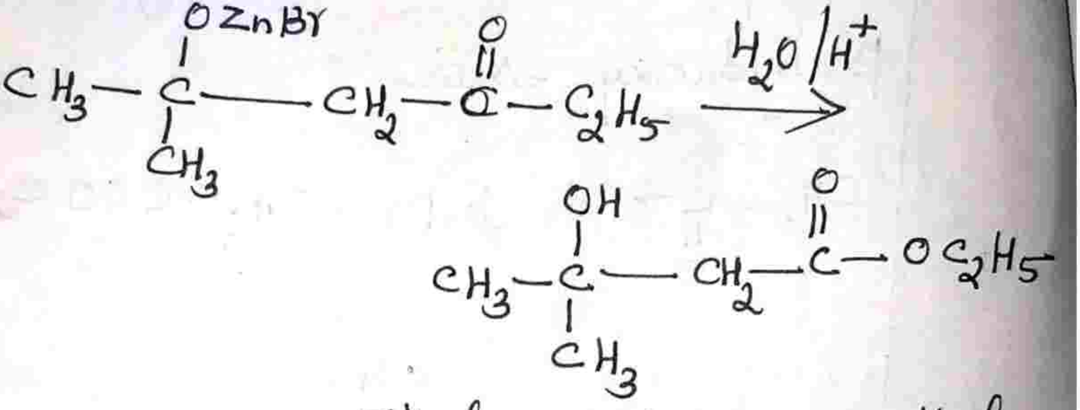
$$CH_3-\overset{\overset{O}{\|}}{C} + CH_2=\overset{\overset{O-ZnBr}{|}}{C}-OC_2H_5 \longrightarrow$$



$$CH_3-\underset{CH_3}{\overset{OZnBr}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5$$

Step-3
$\longrightarrow$

Acid hydrolysis gives the β-hydroxy ester.

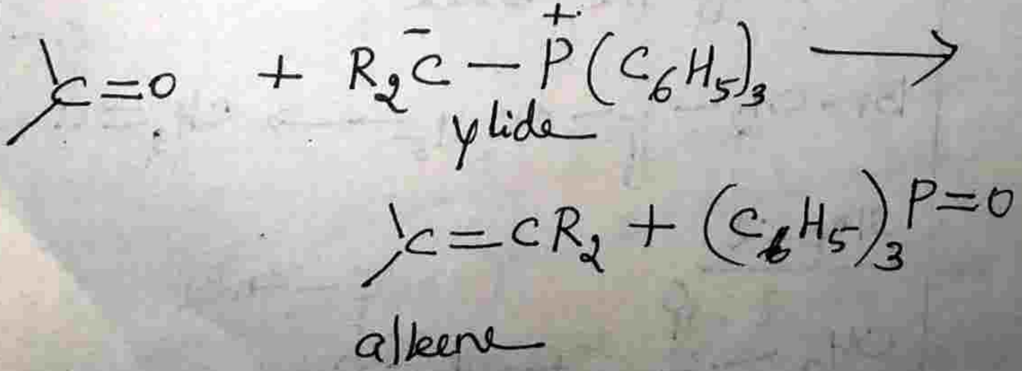


$$CH_3-\underset{CH_3}{\overset{OZnBr}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-C_2H_5 \xrightarrow{H_2O/H^+} CH_3-\underset{CH_3}{\overset{OH}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5$$

Ethyl 3-hydroxy-3-methyl-butanoate.

⑰ Witting Reaction

This involves the treatment of aldehyde and ketones with phosphorus ylide to form alkenes.



$$>C=O + \underset{\text{ylide}}{R_2\bar{C}-\overset{+}{P}(C_6H_5)_3} \longrightarrow \underset{\text{alkene}}{>C=CR_2} + (C_6H_5)_3P=O$$

An ylide is a molecule with adjacent opposite charges. Phosphorus ylides are prepared from primary alkyl halides and triphenyl phosphine.

$$(C_6H_5)_3\ddot{P} + R_2CH-Br \longrightarrow (C_6H_5)_3P-\overset{H}{\overset{|}{C}}$$

$$\downarrow C_2H_5-\overset{-}{O}\overset{+}{Na}$$

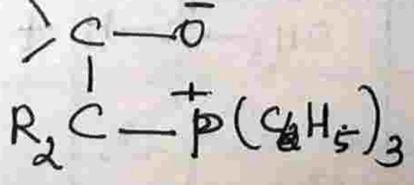
$$(C_6H_5)_3\overset{+}{P}-\overset{-}{C}R_2 + C_2H_5OH$$

Mechanism Two steps are involved.

Step-I

The negative carbon of the ylide attacks the carbonyl carbon to form a betaine. A betaine is a molecule having non-adjacent opposite charges.

$$>C=O + R_2\overset{-}{C}-\overset{+}{P}(C_6H_5)_3 \longrightarrow$$



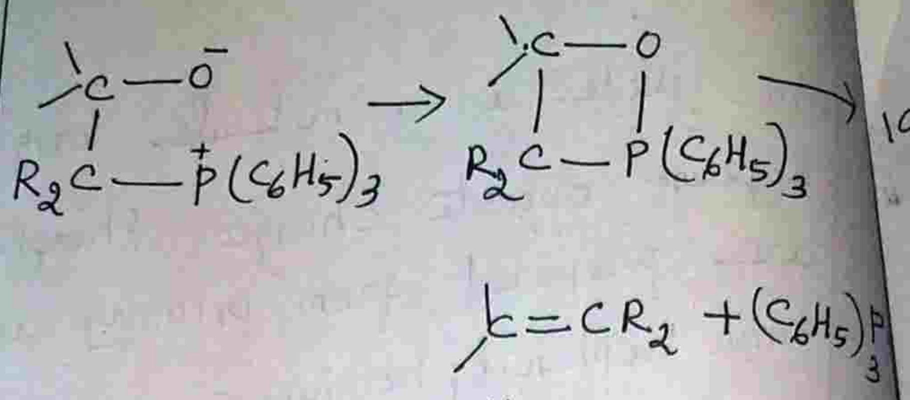
$$\begin{array}{l} >C-\overset{-}{O} \\ \quad | \\ R_2C-\overset{+}{P}(C_6H_5)_3 \end{array}$$

Betaine

Step-2

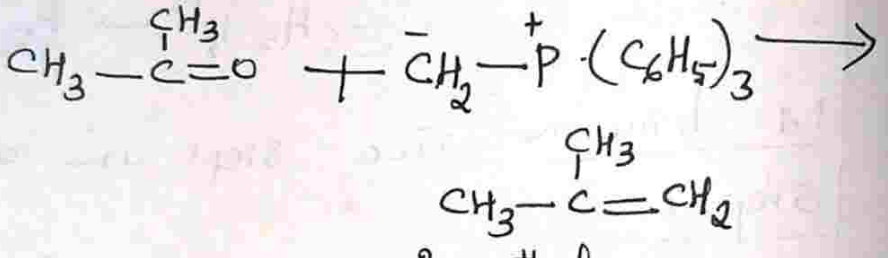
The betaine undergoes elimination of triphenylphosphine oxide to give the alkene

E.



alkene.

The Wittig reaction is an excellen method of making alkene from aldehyd and ketones.



$$CH_3-\overset{CH_3}{\overset{|}{C}}=O + \overset{-}{C}H_2-\overset{+}{P}(C_6H_5)_3 \longrightarrow CH_3-\overset{CH_3}{\overset{|}{C}}=CH_2$$

2-methyl propene.

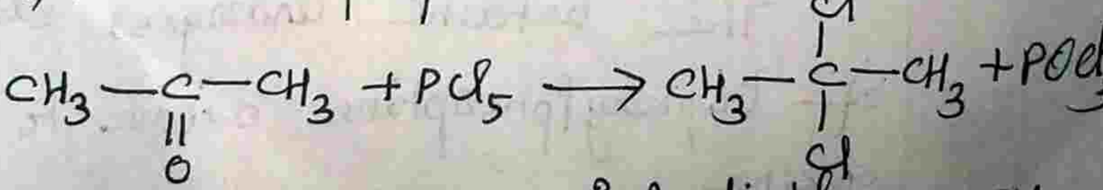
18 **Reaction with Phosphorus pentachloride**

Both aldehydes & ketones react with PCl_5 to form gem-dihalides. Acetaldehyde gives 1,1-dichloroethane

$$CH_3-\overset{O}{\overset{\|}{C}}-H + PCl_5 \longrightarrow CH_3-\underset{Cl}{\underset{|}{\overset{Cl}{\overset{|}{C}}}}-H + POCl_3$$

1,1-dichloroethane.

Acetone reacts with PCl_5 to form 2,2-dichloropropane



$$CH_3-\underset{O}{\underset{\|}{C}}-CH_3 + PCl_5 \longrightarrow CH_3-\underset{Cl}{\underset{|}{\overset{Cl}{\overset{|}{C}}}}-CH_3 + POCl_3$$

2,2-dichloropropane

19. **Schiff's Test**

Dilute solution of aldehyde when added to schiff's reagent (Rosaniline hydrochloride dissolved in water and its red colour discolourised by passing sulphur dioxide) restores its red colour. This is known as schiff's test for aldehyde. Ketones do not give this test.

⑳ **Polymerisation**

The aldehyde undergo polymerisation to give variety of products :

Comparison of the reaction of Aromatic aldehyde and aliphatic aldehyde.

	Aromatic aldehyde	Aliphatic aldehyde
①	It gives addition products with HCN, $NaHSO_3$, & RMgX.	It also gives addition products with same reagents.

2.	It reacts with NH_2OH, NH_2-NH_2 and $NH_2-NH-C_6H_5$	It also reacts w these reagents
3	It oxidised with $K_2Cr_2O_7$ and $KMnO_4$	It does the sam
4	It reduced with $LiAlH_4$.	It also reduced w $LiAlH_4$.
5.	It reacts with Tollen's reagent	It also reacts wi Tollen's reagent
6	It does not give iodoform with I_2 & NaOH	But It gives iodof with I_2 & NaOH.
⑦	It does not ~~involves~~ involve in ~~aldo~~ aldol condensation ~~to~~ in presence of base (NaOH)	It involves aldol condensation in presence of base
⑧	It ~~involv~~ undergoes Cannizzaro reaction in presence of NaOH.	It does not undergo such type of reaction

aldehyde and ketones

9	It condenses with benzaldehyde	It gives addition products.
10	It does not react with Fehlings' solution.	It reacts with Fehlings' reagent.

oxidation of ketones.

On oxidation with cold $KMnO_4$, acetophenone gives phenyl glyoxlic acid (benzoyl formic acid) which on further oxidation yields benzoic acid.

$$C_6H_5-COCH_3 \xrightarrow{[O]} C_6H_5-CO-COOH \xrightarrow{[O]}$$

Acetophenone. phenylglyoxylic acid

C_6H_5-COOH
benzoic acid.

Acetone gives acetic acid.

$$CH_3-COCH_3 \xrightarrow{[O]} CH_3COOH$$

Acetic acid

On oxidation with selenium oxide, it gives phenylglyoxal

$C_6H_5-CO-CH_3 \xrightarrow{SeO_2} C_6H_5-CO-CHO + Se + H_2O$

phenylglyoxal

Addition with amines.

Benzaldehyde gives anils or schiffs' bases with primary aromatic amines.

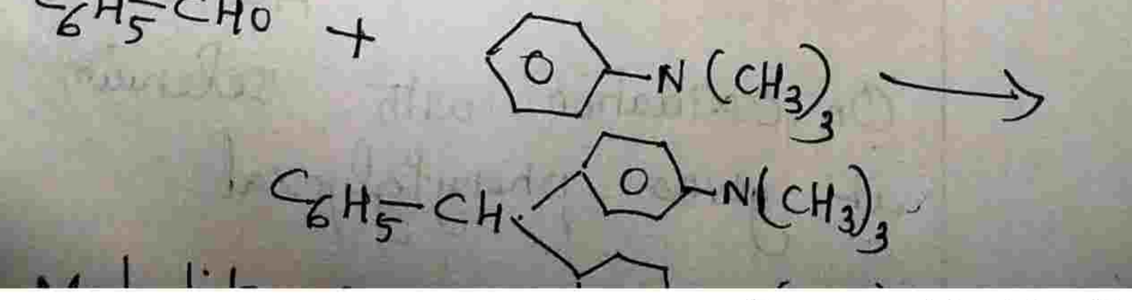
$C_6H_5-\overset{H}{C}=O + H_2N-C_6H_5 \xrightarrow{H^+} C_6H_5-CH=N-C_6H_5$

benzylidene aniline (imine)

Aliphatic aldehyde tends to produce compounds of the type $RCH(NHC_6H_5)_2$

$R-CHO + H_2N-C_6H_5 \longrightarrow R-CH\begin{matrix} NHC_6H_5 \\ NHC_6H_5 \end{matrix}$

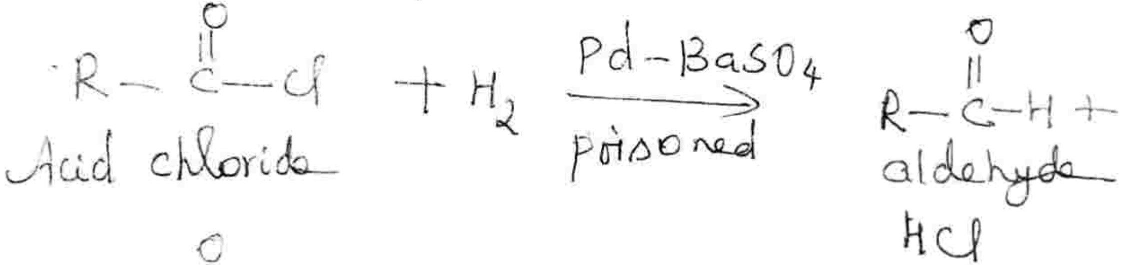
Benzaldehyde reacts with ~~tert-amine~~ tert-aromatic amines in presence of $ZnCl_2$ and H_2SO_4, it condenses to give triphenylmethane derivatives.



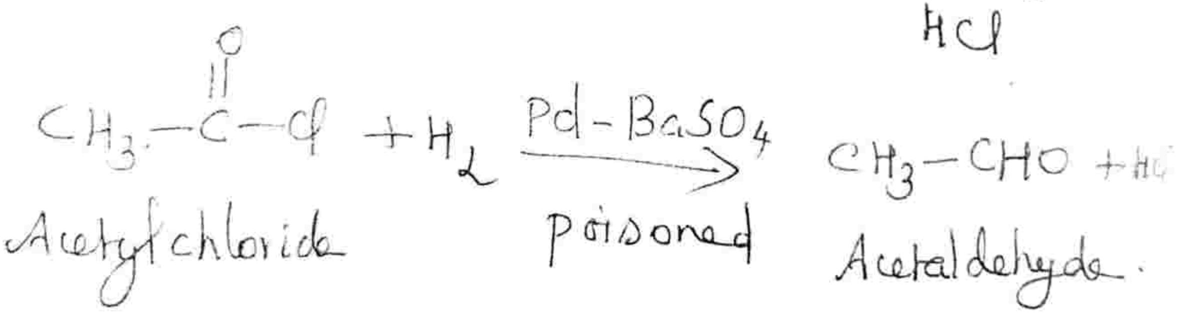
Aldehydes and ketones

Rosenmund reduction.

Aldehyde is prepared by the reduction of acid chlorides with H_2 gas in the presence of a palladium catalyst supported over barium sulphate at 140°c



$$\underset{\text{Acid chloride}}{R-\overset{O}{\overset{\|}{C}}-Cl} + H_2 \xrightarrow[\text{poisoned}]{Pd-BaSO_4} \underset{\text{aldehyde}}{R-\overset{O}{\overset{\|}{C}}-H} + HCl$$



$$\underset{\text{Acetyl chloride}}{CH_3-\overset{O}{\overset{\|}{C}}-Cl} + H_2 \xrightarrow[\text{poisoned}]{Pd-BaSO_4} \underset{\text{Acetaldehyde.}}{CH_3-CHO} + HCl$$

Normally the aldehyde formed is further reduced to primary alcohol. But the barium sulphate poisons the palladium catalyst which is deactivated so as not to permit the further reduction of the aldehyde product. This is called Rosenmund reduction

~~Formalde ea~~

Formaldehyde can not be made by this method because formyl chloride HCOCl is very unstable at ordinary temperatures.

Stephen's reduction of Nitriles

It is a useful procedure to prepare aldehyde. Alkane nitriles are first reduced in ether solution by hydrogen chloride gas and stannous chloride at room temperature. The aldimine hydrochloride produced is filtered off and subsequently hydrolysed with warm water.

$$R-C\equiv N + 2H + \underset{\text{gas}}{HCl} \xrightarrow[\text{ether}]{SnCl_2-HCl}$$

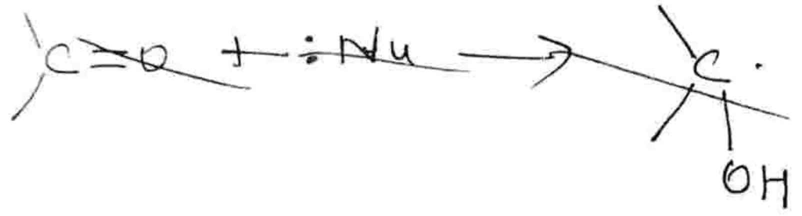
$$R-\overset{H}{\overset{|}{C}}=NH\cdot HCl$$

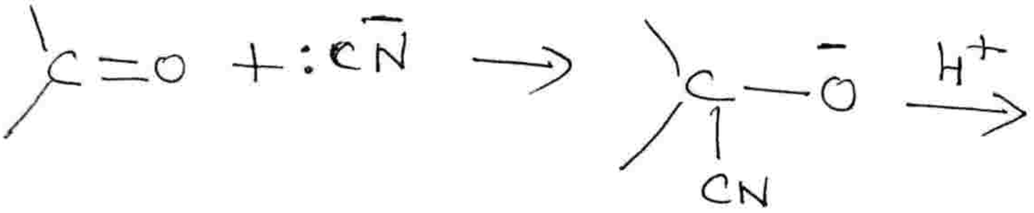
aldimine hydrochloride
(precipitate)

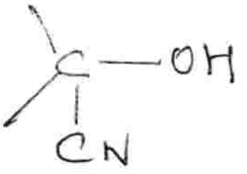
$$\Big\downarrow \text{Hydrolysis} \; H_2O$$

$$R-\overset{H}{\overset{|}{C}}=O + NH_4Cl$$

This method is not applicable to the synthesis of ketones.





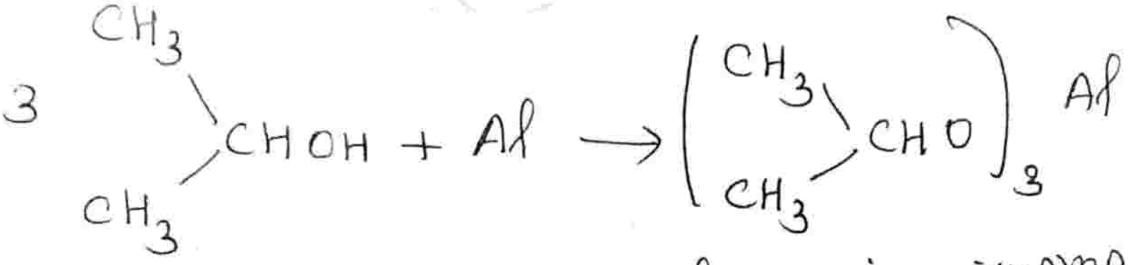


Cyanohydrin.

Meerwein - Poundorf - Varley - reduction

The reduction of carbonyl compounds to alcohol by the reagent aluminium isopropoxide is known as Meerwein - Poundorf - Varley reduction.

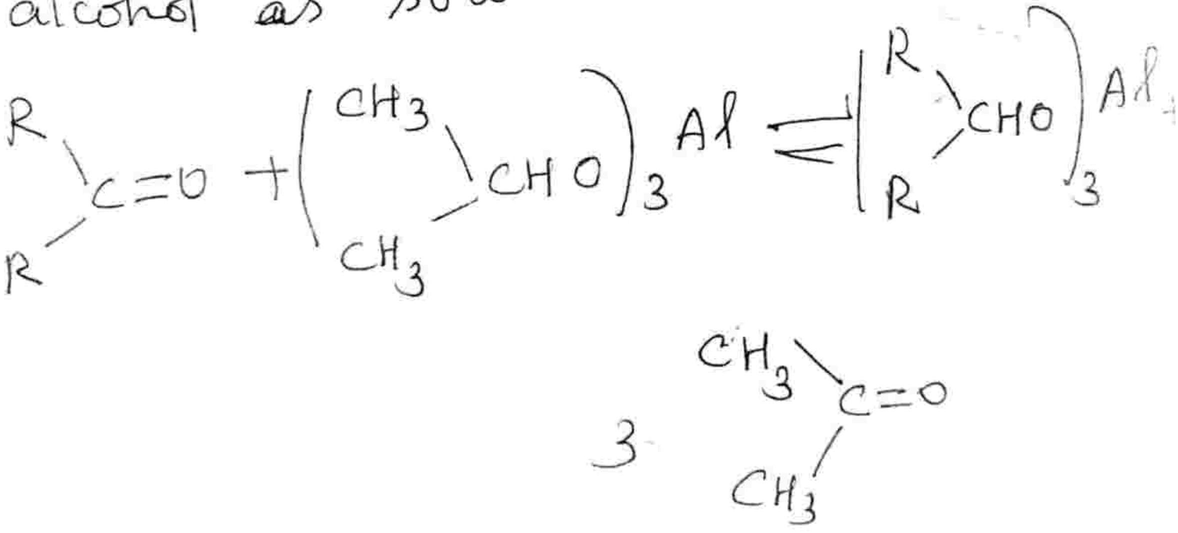
Aluminium isopropoxide is prepared from aluminium and isopropyl alcohol.



$$3\,(CH_3)_2CHOH + Al \rightarrow \left((CH_3)_2CHO\right)_3Al$$

aluminium isopropoxid

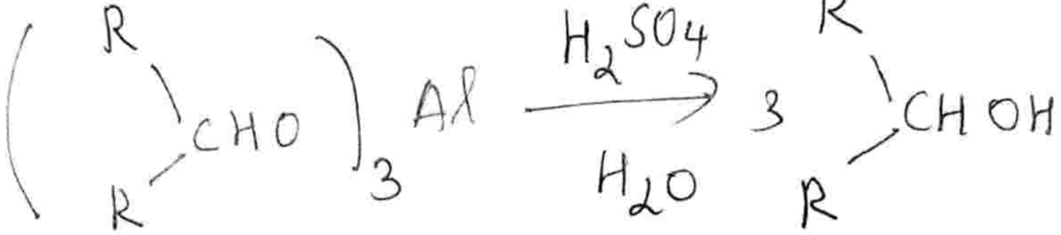
Aldehyde or ketone reacts with aluminium isopropoxide in isopropyl alcohol as solvent.



$$R_2C=O + \left((CH_3)_2CHO\right)_3Al \rightleftharpoons \left(R_2CHO\right)_3Al + 3\,(CH_3)_2C=O$$

acetone.

Acetone is distilled and the equilibriu is pushed to the right hand side. The resulting aluminate is then treated with dilute acid to yield the alcohol.

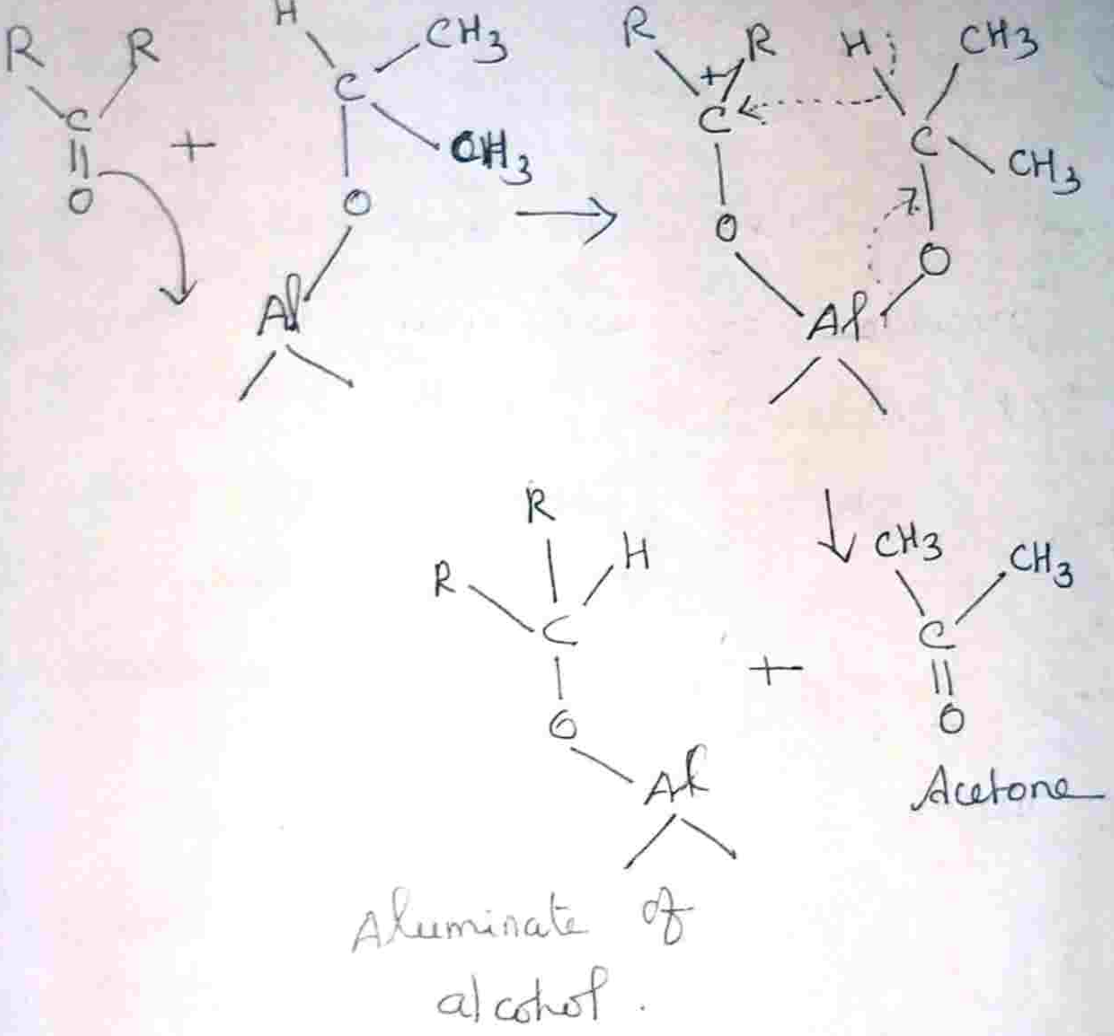


$$\left(\begin{matrix}R\\ \quad\rangle CHO\\ R\end{matrix}\right)_3 Al \xrightarrow[H_2O]{H_2SO_4} 3\ \begin{matrix}R\\ \quad\rangle CHOH\\ R\end{matrix}$$

Meerwein - Poundorf - Varley reduc is useful because other reducible groups like double bond, nitro groups etc, present in the carbonyl compound remain unaffected.

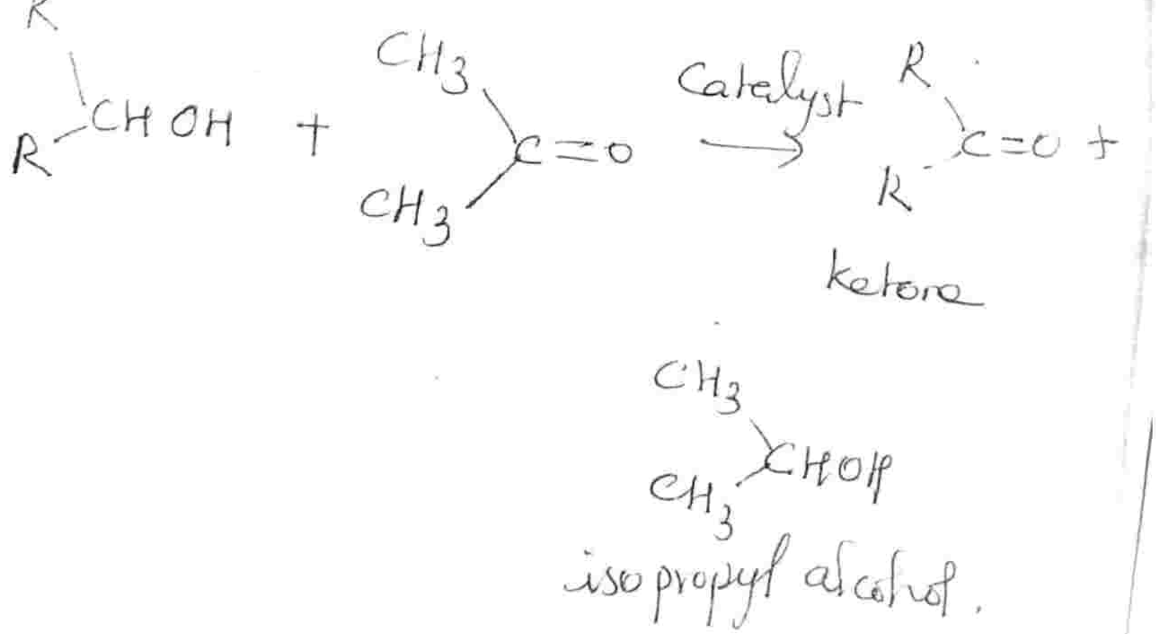
Mechanism.

The reaction is initiated by donation of a pair of electron from the carbonyl double bond to the incomplete shell of aluminium. This is followed by direct hydride (H^-) transfer to the carbonyl carbon to give aluminate of the alcohol product


R
R
C
O
+
H
C
CH3
CH3
O
Al
R
R
C
H
C
CH3
CH3
O
O
Al
R
R
H
C
O
Al
+
CH3
CH3
C
O
Acetone
Aluminate of alcohol.

Oppenauer oxidation

The Oxidation of alcohols is by refluxing with acetone in the presence of aluminium tert-butoxide $Al(O\text{-tert-}Bu)_3$ as catalyst. This is called Oppenauer oxidation. Here the alcohol is oxidised at the expense of acetone which is reduced.



This method is more commonly used for the preparation of ketone which contain oxidative function. (carbon — carbon double bond). This reaction cannot be ordinarily employed for the synthesis of aldehydes because most of them undergo al condensation in the presence of aluminium tert-butoxide.

Sommelet reactions

Benzaldehyde is produced when benzyl chloride is refluxed with hexamethylenetetramine in aqueous ethanolic solution followed by acidification and steam distillation.

$$C_6H_5-CH_2-Cl + (CH_2)_6N_4 \rightarrow C_6H_5-CHO.$$

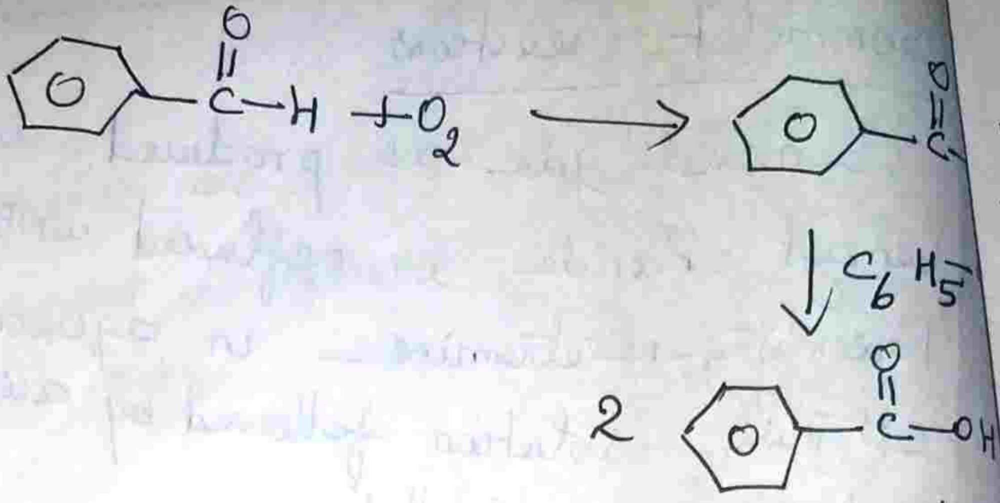
Oxidation of Benzaldehyde

It is oxidised to benzoic acid even on exposure to air

Benzaldehyde Benzoic acid.

Baeyer & Villiger oxidation.

He suggested that ~~this~~ oxidation of benzaldehyde to benzoic acid by air occurs via the formation of perbenzoic acid.



benzoic acid

Tischenko reaction

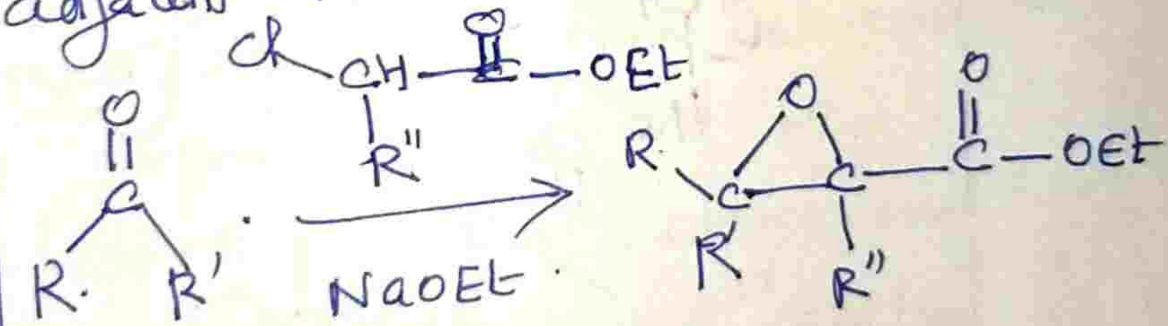
Benzaldehyde on heating with aluminium alkoxide (ethoxide or isopropoxide) and anhydrous $AlCl_3$ & $ZnCl_2$, undergoes an intermolecular oxidation and reduction similar to Cannizzaro reaction but the alcohol and acid instead of appearing as such, react to produce benzylbenzoate

$$2C_6H_5{-}CHO \xrightarrow[(C_2H_5O)_3Al]{\Delta} C_6H_5{-}CH_2{-}O\,CO\,C_6H_5$$

Benzylbenzoate

Darzens reaction (or) Glycidic condensation

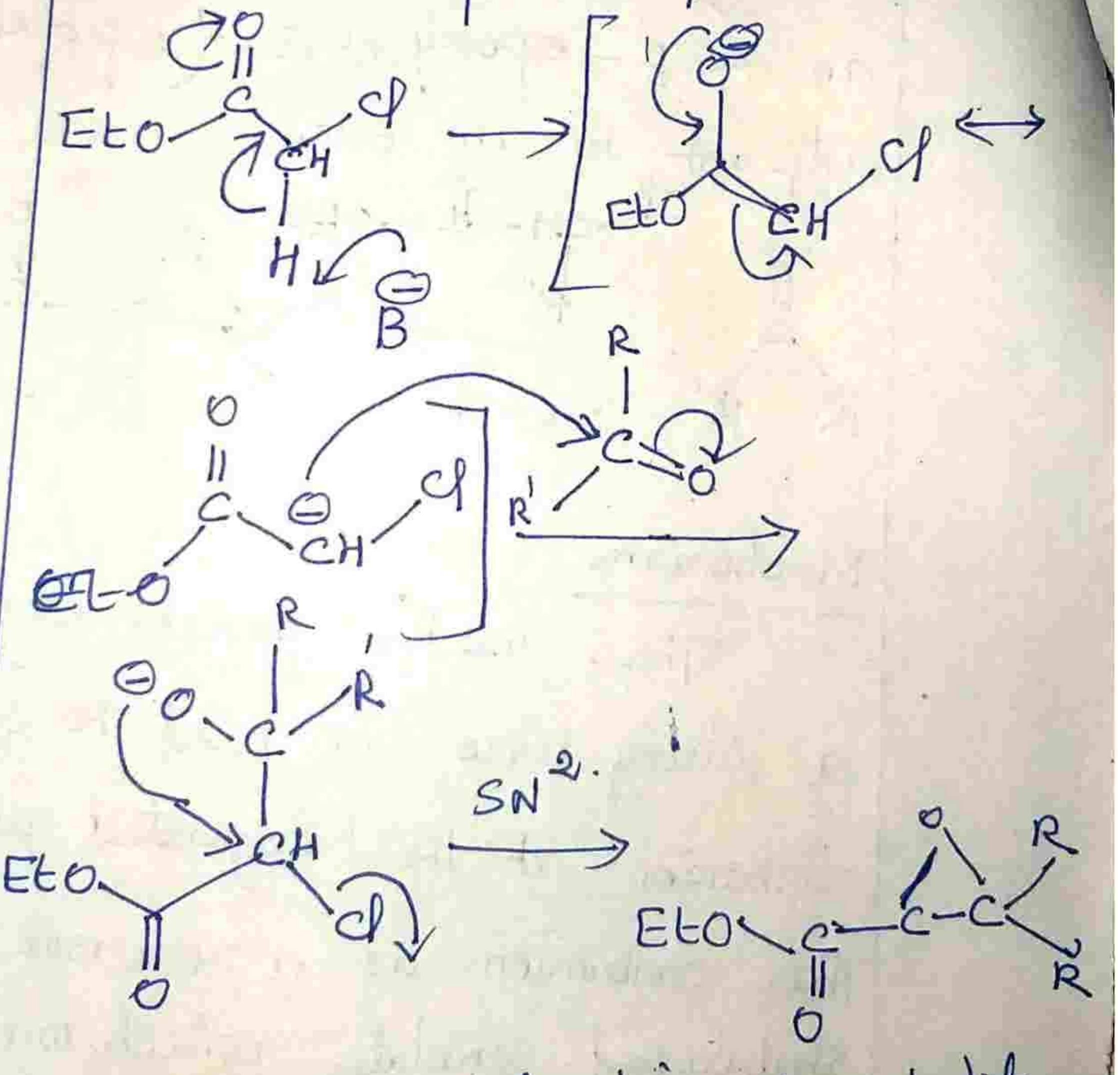
The Darzens reaction is the reaction of a ketone or aldehyde with an α-haloester in the presence of a base to form an α,β-epoxy ester (epoxide adjacent to an ester.



Mechanism

The reaction process begins when a strong base is used to form a carbanion at the halogenated position. This carbanion is a resonance stabilised enolate which makes it relatively easy to form. This nucleophi

~~forming~~ forming C—C bond. First two steps are similar to a bas catalysed aldol reaction. The oxyge anion in this aldol like product the does an intramolecular S_N2 attack on the formerly nucleophilic halide



bearing position, displacing the halide to form an epoxide. This reaction sequence is a condensation reaction, since there is a net loss of HCl when the two reactant molecules join.

Stork condensation.

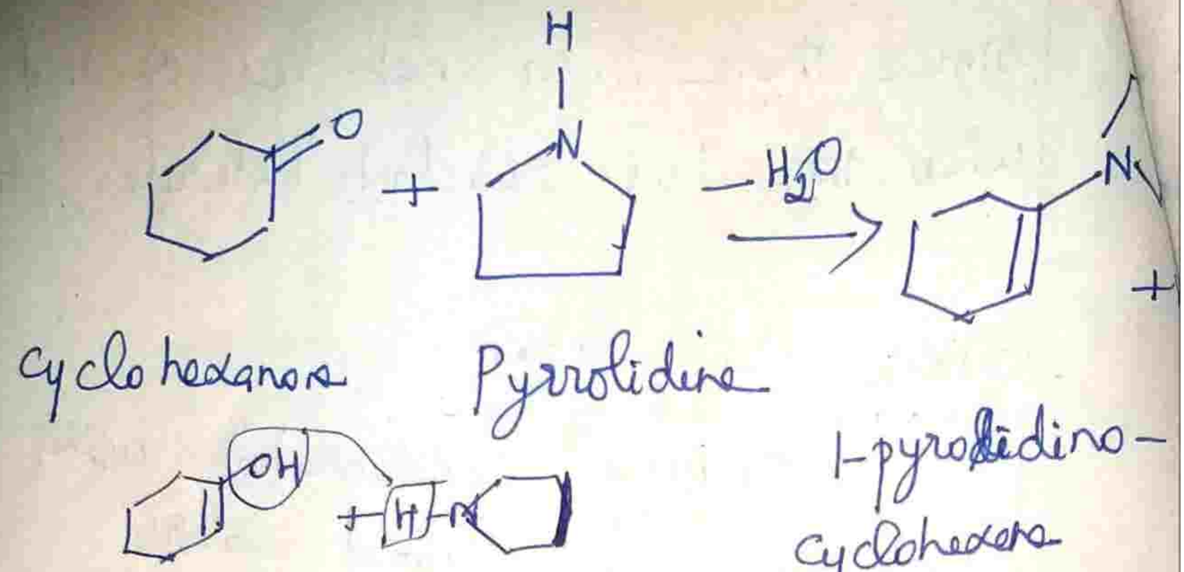
carbonyl condensation with enamines are called Stork Condensation.

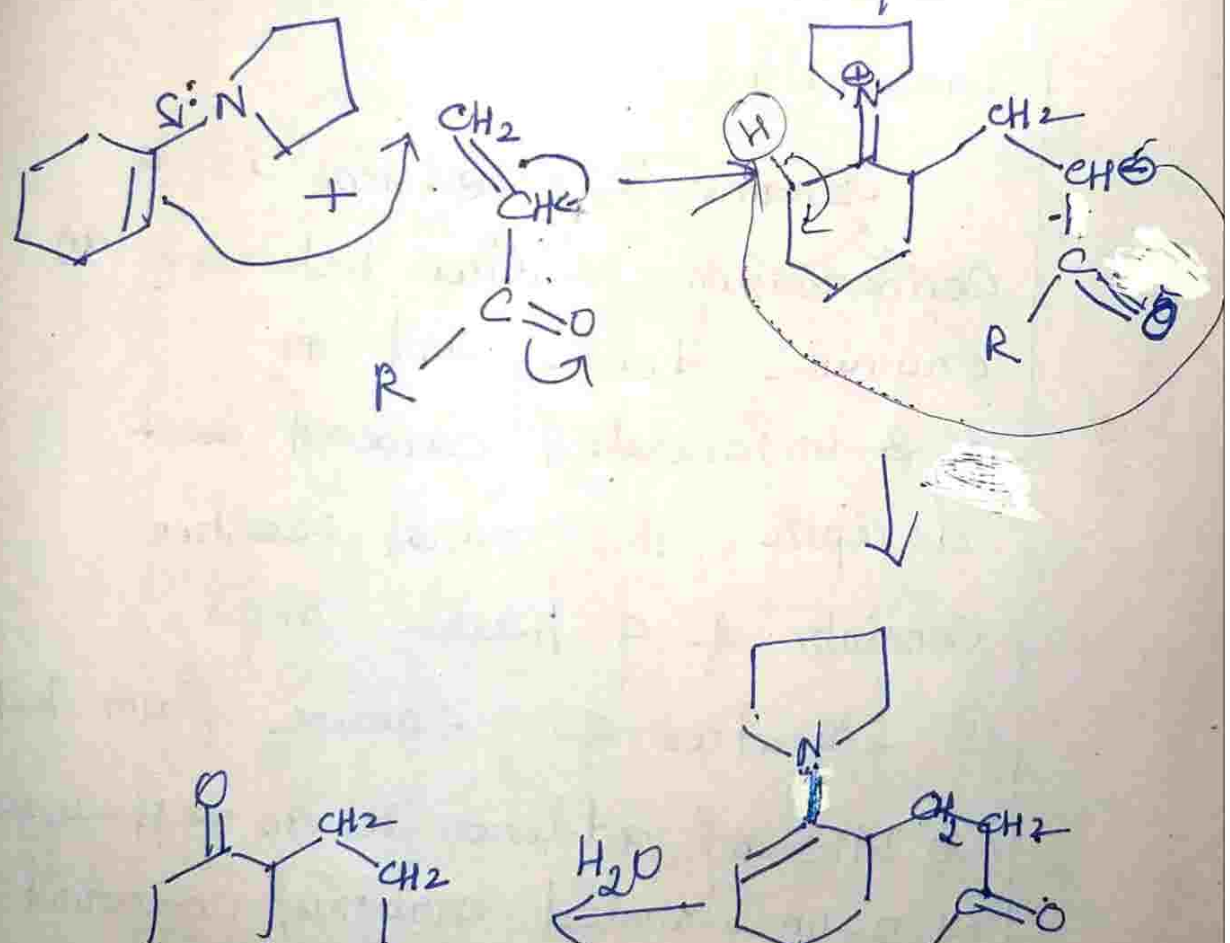
~~Enami~~ This reaction is a Condensation reaction between an enamine donor and an α,β-unsaturated carbonyl ~~acet~~ acceptor. The overall reaction Consists of a three steps.

① formation of eamine from ketone

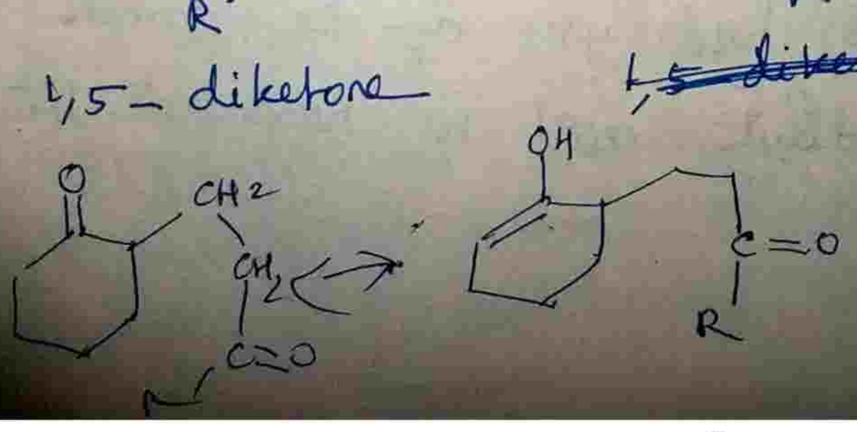
② Michael addition to an ~~α,β-unsaturated~~ α,β-unsaturated carbonyl compound

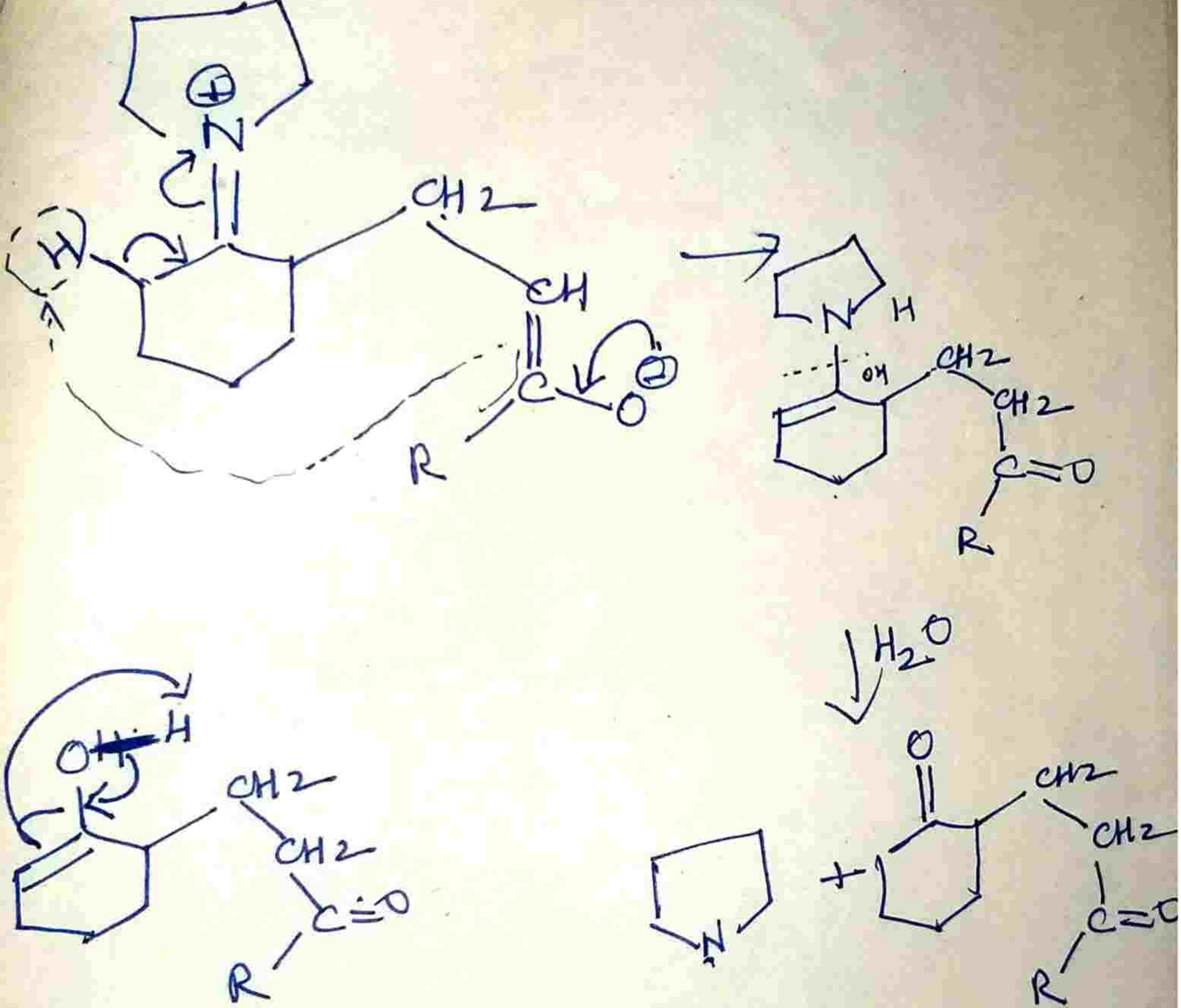
③ hydrolysis of the eamine in dilute acid to regenerate the ketone.





1,5 - diketone ~~1,5 diketone~~



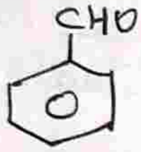


N
H
CH2
CH
C
O
R
N
H
OH
CH2
CH2
C=O
R
H_2O
OH
H
CH2
CH2
C=O
R
N
+
O
CH2
CH2
C=O
R

Aromatic aldehyde and ketones

Aromatic aldehyde

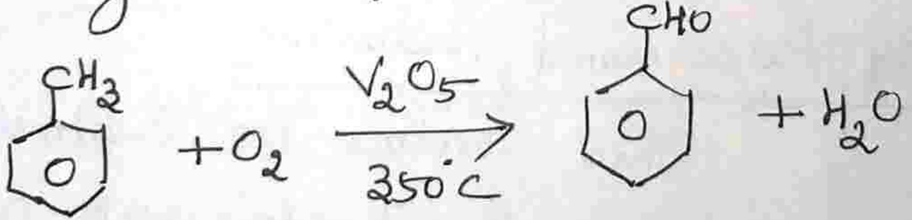
Aromatic aldehydes are compounds in which the —CHO group is attached directly to an aromatic ring.



Benzaldehyde

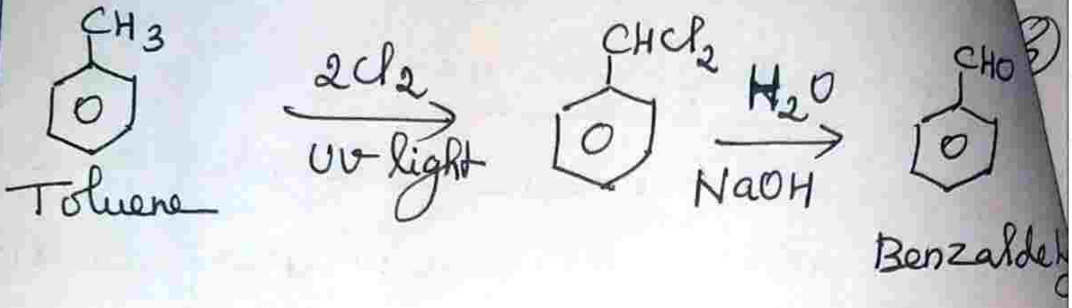
a) By oxidising of Toluene

This involves the treatment of toluene with oxygen / air in the presence of vanadium pentaoxide catalyst at 350°C



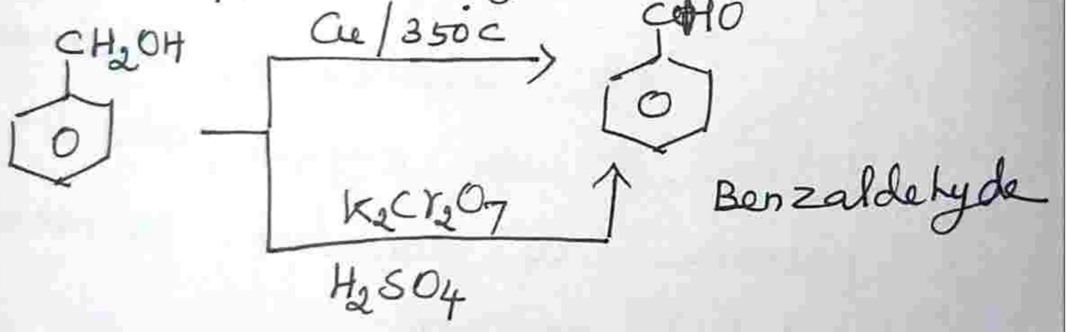
b) By hydrolysis of Benzal chloride

Toluene is ~~treatment~~ treated with chlorine in the presence of UV light to give benzal chloride. This on on basic hydrolysis yields benzald



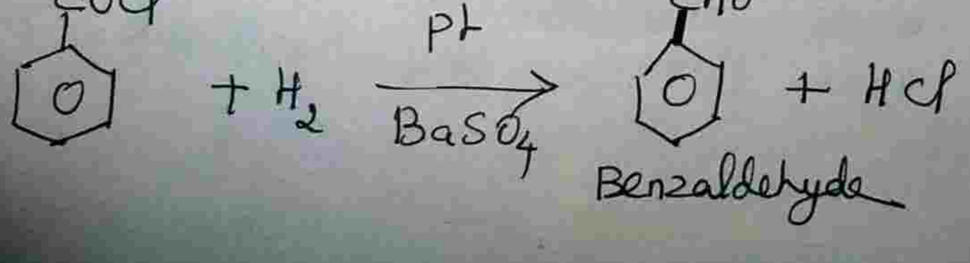
③ By oxidation of Benzyl alcohol.

This involves the treatment of benzyl ~~eth~~ alcohol with acidic K_2Cr_2O with copper catalyst at 350°C



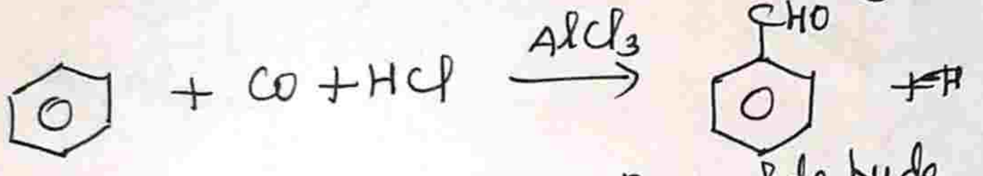
By Rosenmund Reduction

This involves the treatment of ~~benzyl~~ benzoyl chloride with hydrogen in the presence of Palladium catalyst poisoned with $BaSO_4$.



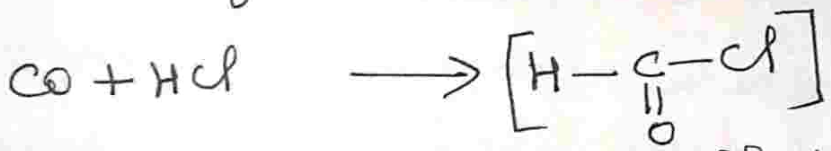
⑤ **By Gattermann – Koch Synthesis**

This involves the treatment of benzene with carbon monoxide and hydrogen chloride in the presence of $AlCl_3$ catalyst.



Benzaldehyde

Mechanism step-I: carbon monoxide and HCl react to form unstable formyl chloride

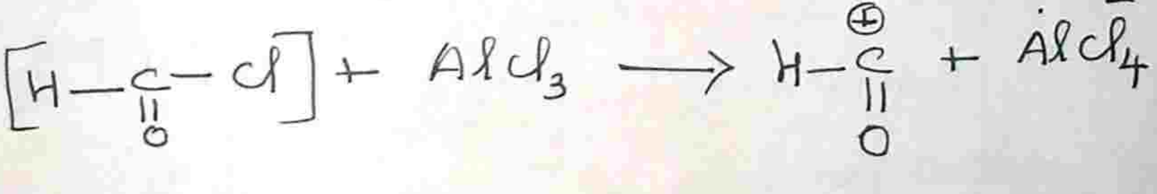


$$CO + HCl \longrightarrow \left[H-\underset{\underset{O}{\|}}{C}-Cl\right]$$

Formyl chloride.

Step-II

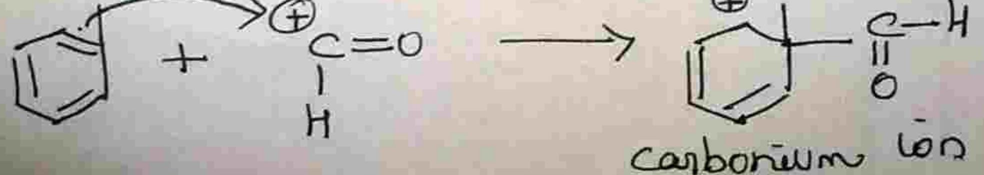
Formation of the electrophile $H-\overset{+}{C}=O$



$$\left[H-\underset{\underset{O}{\|}}{C}-Cl\right] + AlCl_3 \longrightarrow H-\underset{\underset{O}{\|}}{\overset{\oplus}{C}} + \bar{A}lCl_4$$

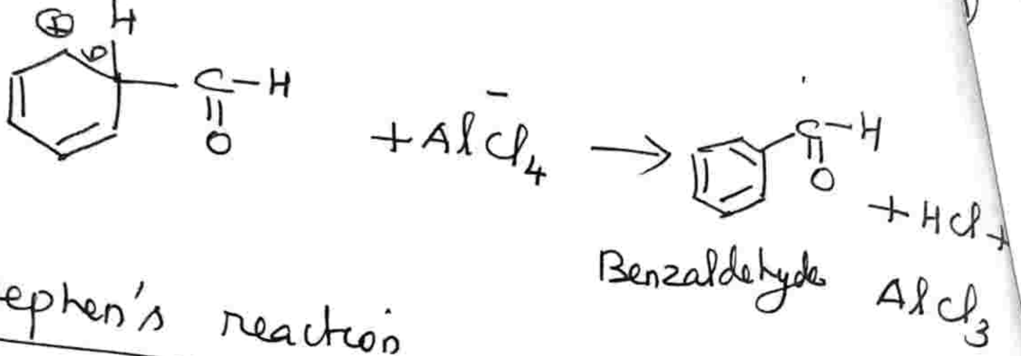
Step III:

The electrophile attack the benzene ring to give a carbonium ion



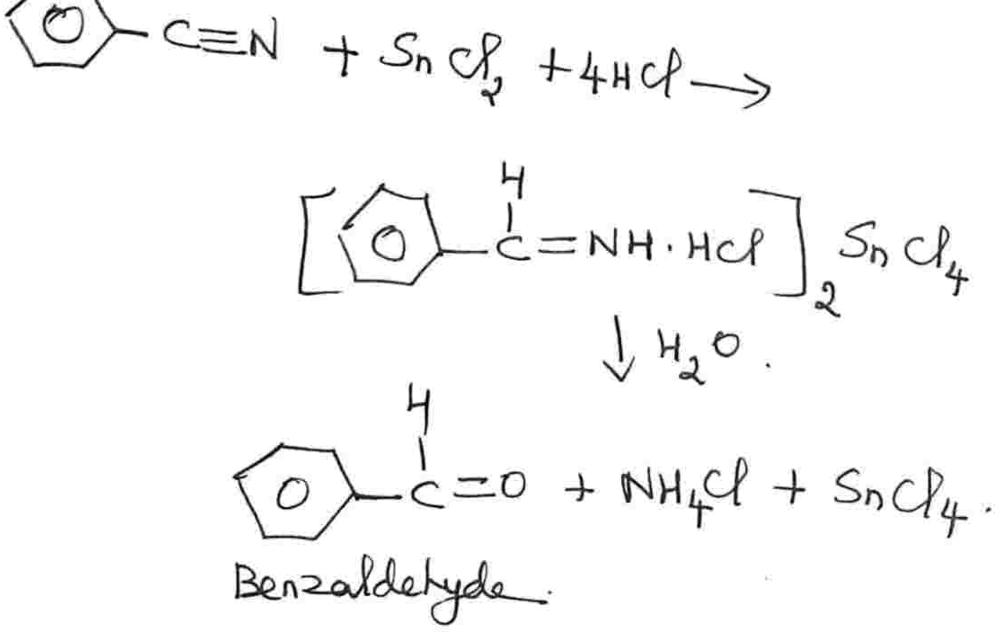
carbonium ion

Step IV : Removal of proton gives benzaldehyde.



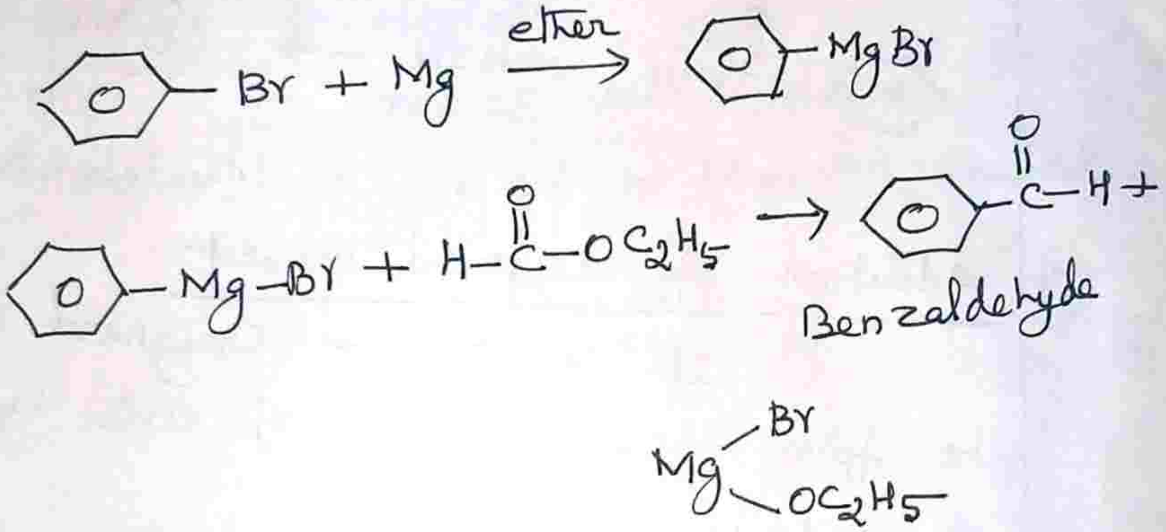
⑥ Stephen's reaction

Benzonitrile on reduction with stannous chloride and HCl form aldimine complex. This complex on hydrolysis yield benzaldehyde.



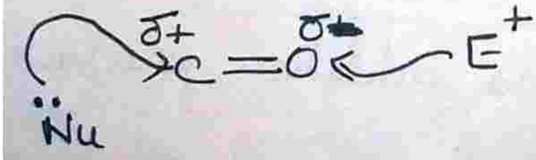
Grignard Reaction

Phenyl magnesium bromide reacts with ethyl formate to form benzaldehyde.



Properties

Benzaldehyde undergoes addition reaction. This is because the carbonyl group is polar. Electrophilic reagents attack the negative oxygen while nucleophile attack the carbonyl carbon.



COMPARISON OF REACTIVITY OF AROMATIC AND ALIPHATIC ALDEHYDE

AROMATIC ALDEHYDES

The π electrons in the carbonyl group in an ***aromatic*** aldehyde have the nice nearness to those in the aromatic ring, which I would say promotes some **π orbital overlap** between the orbital of the carbonyl carbon and an orbital on the aromatic ring.

As a result, it *extends* the delocalization of the π electrons by **redistributing** the effects of the electron-withdrawing nature of oxygen in the carbonyl group to *incorporate* the aromatic ring. (In fact, you could draw two more resonance structures showing the distribution of the electropositivity onto the other two aromatic carbons, each one meta to the previous.)

Thus, the presence of the aromatic ring makes the carbonyl carbon **less electrophilic** through the redistribution of the electropositivity throughout the aromatic ring instead of just on the carbonyl carbon.

ALIPHATIC ALDEHYDES

An ***aliphatic*** aldehyde *doesn't* have that adjacency to an aromatic ring, so it doesn't have some resonance stabilization that **makes the carbonyl carbon less acidic/electrophilic**.

Therefore, the greater electrophilicity of the aliphatic aldehyde's carbonyl carbon makes it more reactive.

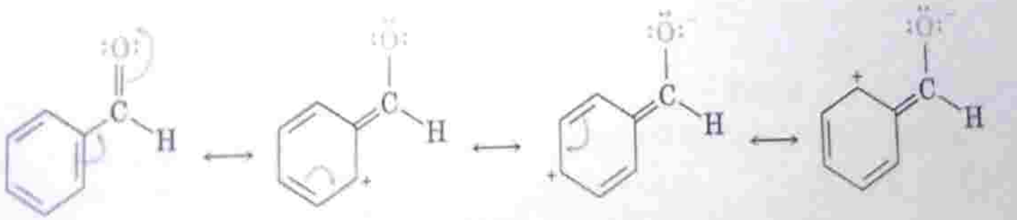
COMPARISON OF REACTIVITY OF ALIPHATIC ALDEHYDE AND ALIPHATIC KETONES

Aldehydes are typically more reactive than ketones due to the following factors.

1. Aldehydes are less hindered than ketones (a hydrogen atom is smaller than any other organic group).
2. The carbonyl carbon in aldehydes generally has more partial positive charge than in ketones due to the electron-donating nature of alkyl groups. Aldehydes only have one e^- donor group while ketones have two.

Reactivity of Aromatic Aldehydes

- Less reactive in nucleophilic addition reactions than aliphatic aldehydes
- Electron-donating resonance effect of aromatic ring makes C=O less reactive electrophilic than the carbonyl group of an aliphatic aldehyde

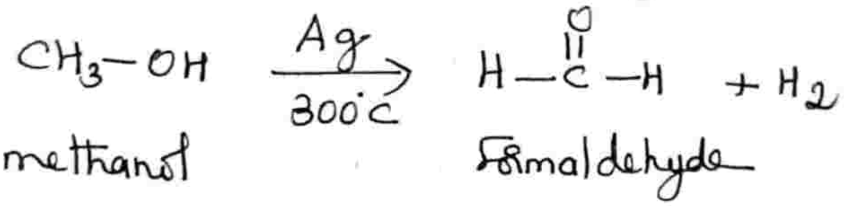


Formaldehyde

Preparation

① By dehydrogenation of methanol

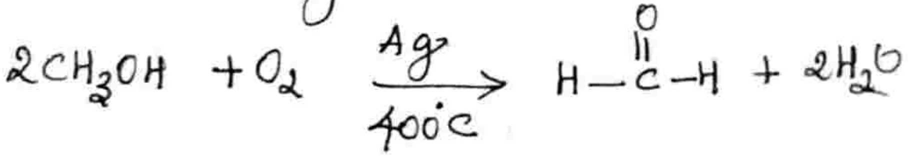
Methanol vapours are passed over heated silver catalyst at 300°C



$$\underset{\text{methanol}}{CH_3-OH} \xrightarrow[300^\circ C]{Ag} \underset{\text{Formaldehyde}}{H-\overset{\overset{O}{\|}}{C}-H} + H_2$$

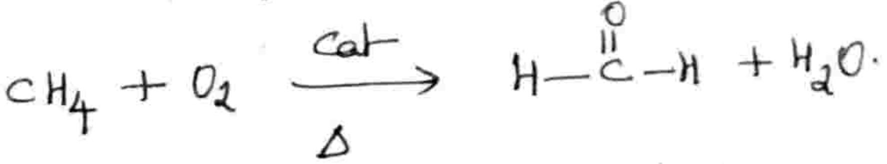
② By air-oxidation of methanol :

Methanol vapours and limited amount of air are passed over silver catalyst at 400°C.



$$2CH_3OH + O_2 \xrightarrow[400^\circ C]{Ag} H-\overset{\overset{O}{\|}}{C}-H + 2H_2O$$

3 By air oxidation of methane in the presence of various metallic oxide.



$$CH_4 + O_2 \xrightarrow[\Delta]{Cat} H-\overset{\overset{O}{\|}}{C}-H + H_2O.$$

It is a gas, the product is marketed as 40% aqueous solution under the name Formalin.

Properties

It is a colourless gas.

It's boiling point is −21C

It has an irritating odour.

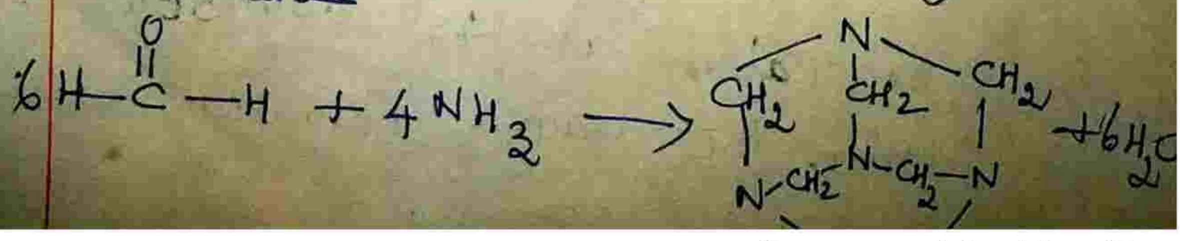
It is extremely soluble in H_2O.

Chemical properties

It is different from other aldehyde. It contains no alkyl group in the molecule. Both hydrogen atoms may be regarded as being part of an aldehyde group. As a result several reactions of formaldehyde are different from those of other aldehyde.

① Reaction with ammonia :-

When heated with ammonia, it does not give an aldehyde ammonia, but forms hexamethylene tetramine.



Hexamethylene tetramine is used as a urinary ~~att~~ antiseptic and has been given the trade name of ~~the~~ Urotropine.

2 **Reaction with Sodium hydroxide**

Cannizzaro reaction.

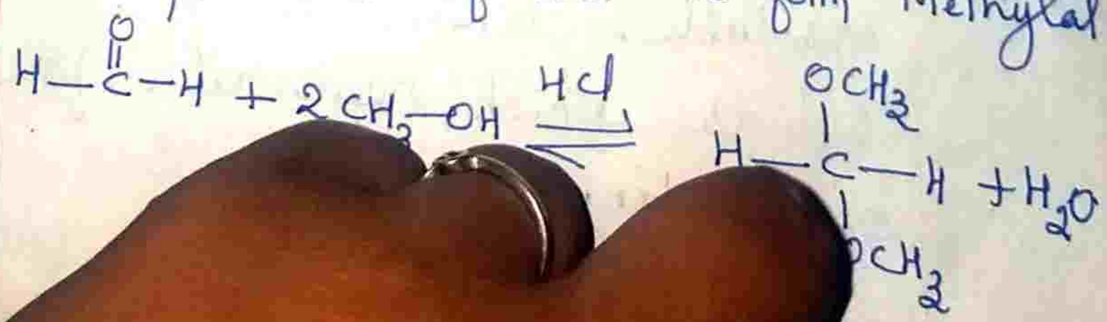
Formaldehyde reacts with concentrated NaOH solution to form methanol and sodium formate.

$2HCHO + NaOH \longrightarrow CH_3-OH + HCOONa$.

methanol   sodium formate.

③ **Reaction with Alcohols.**

Like other aldehyde, it reacts with alcohol to form acetals. Formaldehyde reacts with methanol in the presence of HCl to form Methylal.



$$H-\overset{\overset{O}{\|}}{C}-H + 2CH_3-OH \xrightleftharpoons{HCl} H-\underset{\underset{OCH_3}{|}}{\overset{\overset{OCH_3}{|}}{C}}-H + H_2O$$

④ Polymerization

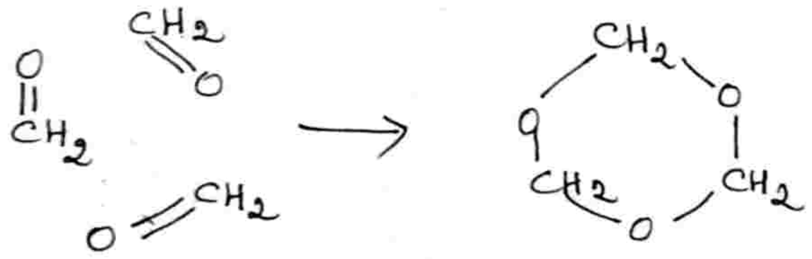
ⓐ When aqueous solution of formaldehyde (formalin) is evaporat to dryness; Paraformaldehyde is form

$HO-CH_2-(CH_2-O)_n-CH_2OH$.

It is crystalline solid. It regenerates formaldehyde on heating. Because paraformaldehyde is readily ~~re covere~~ re converted to formaldehyde upon gentle heating. It serves as a convenient storage of formaldehyde.

ⓑ Formaldehyde on treatment with concentrated H_2SO_4, gives polyoxymethylene $(CH_2O)_n \cdot 2H_2O$, where $n > 100$. ~~Polyoxyl~~ Polyoxymethylene are insoluble while solids white solids which regenerate formaldehyde on heating.

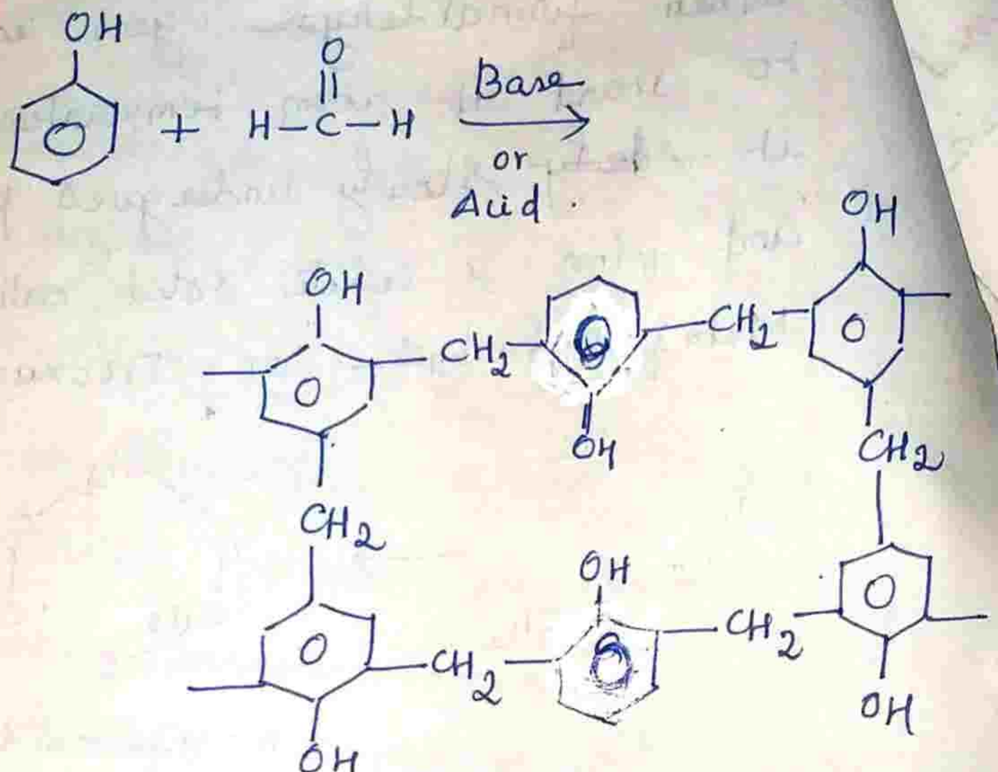
(c) When formaldehyde gas is allowed to stand at room temperature, it ~~slowly~~ slowly undergoes polymerisation and forms a white solid called Metaformaldehyde or Trioxane



metaformaldehyde.

) Condensation with phenol.

Formaldehyde condenses with phenol to give a synthetic plastic Bakelite. Phenol is refluxed with formalin and 0.88 ammonia (catalyst) when an oil separates. The oily liquid is transferred to an open vessel and heated until a test sample, on cooling in water, is formed to be [illegible] and brittle. It is [illegible] to cool to give [illegible]



Bakelite

Uses

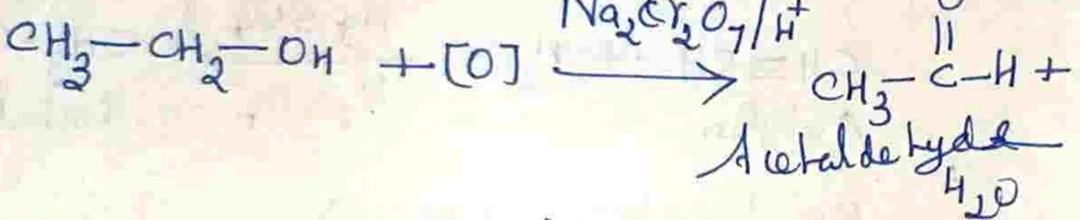
Formaldehyde is sold as 40% aqueous solution under the name Formalin.

Formalin is used ① as a general antiseptic ② in the manufacture of urinary antiseptic Urotropine ③ in the ~~preparation~~ preservation of biological specimens. ④ in the manufacture of synthetic dyes like para rosanilines and Indigo and ⑤ synthetic plastics such as Bakelite

Acetaldehyde.

Preparation

In laboratory acetaldehyde is prepared by oxidation of ethanol with acidified sodium dichromate solution. It contains impurities ethanol, acetic acid



$$CH_3-CH_2-OH + [O] \xrightarrow{Na_2Cr_2O_7/H^+} \underset{\text{Acetaldehyde}}{CH_3-\overset{\overset{O}{\|}}{C}-H} + H_2O$$

The impure acetaldehyde is purified by converting it into acetaldehyde ammonia by treatment with ammonia. This crystals are dried and distilled with dilute sulphuric acid and the regenarated aldehyde is collected in an ice-cooled receiver.

Manufacture :

① By air-oxidation of ethanol.

Ethanol vapours and limited amount of air are pa over heated silver cat

$CH_3-CH_2-OH + ($

② By dehydrogenation of ethanol:

Ethanol vapours are pa over heated copper catalyst at

$$CH_3-CH_2-OH \xrightarrow[500^\circ c]{Cu} CH_3-CHO + H_2O$$

③ By hydration of acetylene.

$$\underset{\text{Acetylene}}{CH\equiv CH} + H_2O \xrightarrow[H_2SO_4]{HgSO_4} \underset{\text{Acetaldehyde}}{CH_3-CHO}$$

⑤ By Wacker process

This involves the treatment on ethylene with an acidefied aqueous solution of Palladium chlorides and cupric chloride.

$$\underset{\text{Ethylene}}{CH_2=CH_2} + PdCl_2 + H_2O \xrightarrow[H^+]{CuCl_2} \underset{\text{acetaldehyde}}{CH_3-\overset{O}{\overset{\|}{C}}-H} +$$

Pd + HCl.

Properties

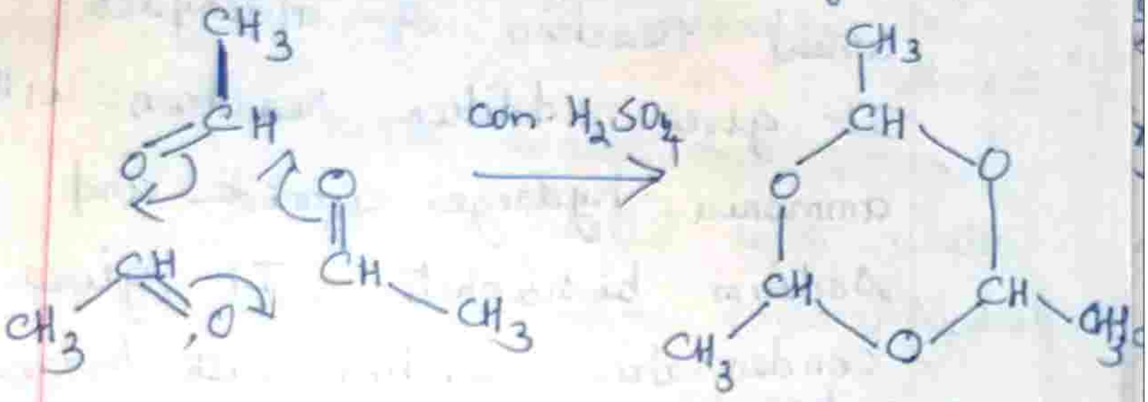
It is a colourless volatile liquid. Boiling point 21°c.

It has a characteristic pungent smell.

It is soluble in H_2O, $CHCl_3$ C_2H_5-OH and diethyl ether

Chemical properties

① When acetaldehyde is treated with a small amount of conc. H_2SO_4 at room temperature, a cyclic trimer paraldehyde is formed.

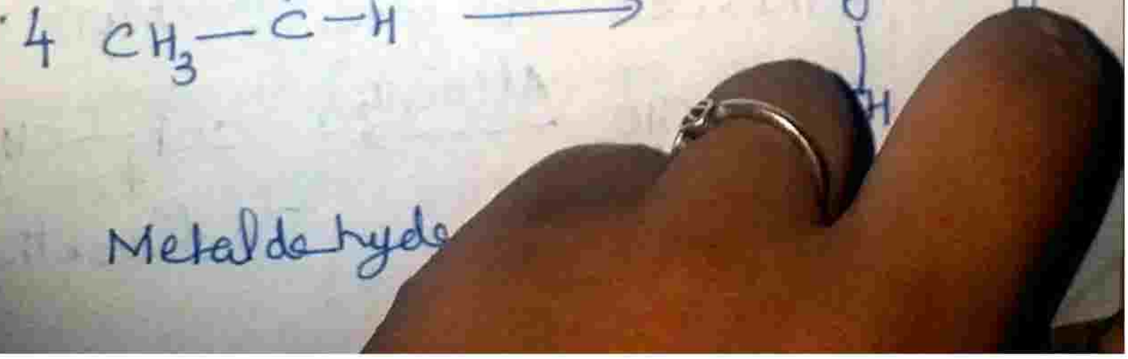


Paraldehyde

Paraldehyde is a liquid.

It regenerates acetaldehyde on distilling with conc. H_2SO_4.

② It is treated with small amount of conc. H_2SO_4 at 0°C, a cyclic tetramer metaldehyde is formed.



Metaldehyde

[illegible]

slug and snails

chloral

Properties

It shows most of the usual reaction of aldehydes. It gives addition reaction with ammonia, hydrogen cyanide and sodium bisulphite. It gives condensation reaction with hydroxylamine, hydrazine, and phenyl hydrazine.

① **Oxidation**

It is oxidised by conc. HNO_3 to give trichloro acetic acid.

$$\underset{\text{chloral}}{CCl_3-CHO} + [O] \xrightarrow{\text{Con. } HNO_3} \underset{\text{trichloro acetic acid}}{CCl_3-COOH}$$

② **Reduction**

It is reduced by aluminium ethoxide to give trichloro ethanol.

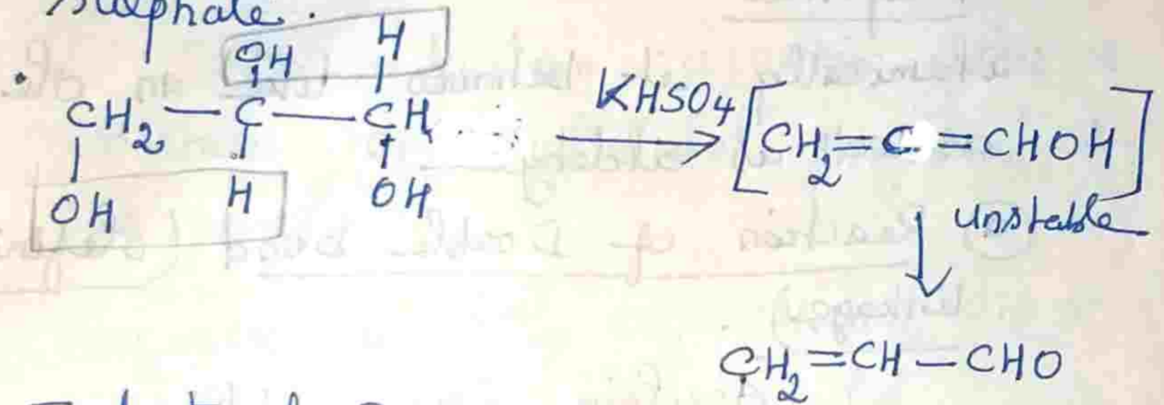
$$CCl_3-CHO \xrightarrow{Al(OC_2H_5)_3} \underset{\text{Trichloroethanol}}{CCl_3-CH_2-OH}$$

α, β – unsaturated aldehyde.

Acrolein $CH_2=CH-CHO$

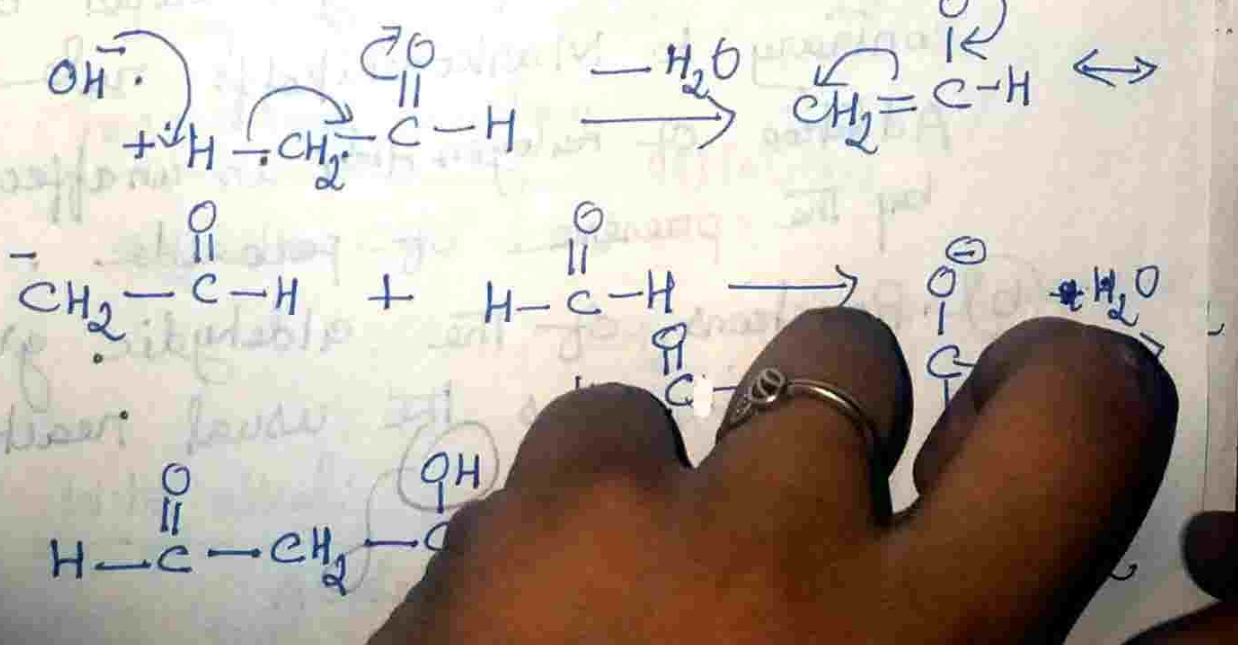
Preparation

It is prepared by the dehydration of glycerol with potassium hydrogen sulphate.



Industrial Preparation

Reaction of acetaldehyde and formaldehyde in the presence of a base or by passing their combined vapours over sodium silicate.



It can be prepared by direct o
of propylene over copper oxide

$$CH_2=CH-CH_3 + O_2 \xrightarrow[\text{Oxide}]{\text{Copper}} \underset{\text{acrolein}}{CH_2=CH-}$$

H_2O.

Properties

Chemically it behaves like an olefin as well as aldehyde :

ⓐ Reaction of Double bond (olefinic linkage).

Acrolein gives addition products with halogens and halogen acids.

$$CH_2=CH-CHO + Br_2 \longrightarrow Br-CH_2-CHBr-$$

$$\xrightarrow{HCl} ClCH_2-CH_2-CHO$$

Addition of halogen acids occurs contrary to Markownikoff's rule. Addition of ~~halogen~~ HBr is unaffected by the presence of peroxide.

ⓑ. Reactions of the aldehydic group. Acrolein gives the usual reactions of aldehydes oxidation

Ammonical silver nitrate oxidises acrolein to acrylic acid.

$CH_2=CH-CHO \longrightarrow CH_2=CH-COOH$

acrylic acid.

Reduction

On reduction, acrolein gives a mixture of allyl alcohol, propanal & propanol.

$CH_2=CH-CHO \xrightarrow{[H]} CH_2=CH-CH_2-OH +$

Acrolein — Allyl alcohol

$CH_3-CH_2-CHO + CH_3-CH_2-CH_2-OH$

propanal — propanol

Polymerisation

Acrolein polymerises to give Disacryl a white solid.

Tischenko reaction

$\longrightarrow Al(OC_2H_5)_3$

$CH_2=CH-CHO + HCl \longrightarrow$

condensation with alkalis. The ch
breaks at the double bond to
a mixture of methanal and et

$$CH_2=CH-CHO + H_2O \longrightarrow HCHO + CH_3-CHO$$

Uses

Acrolein used as a tear gas and as a warning agent to find out leakage. If any, when methyl chloride used as a refrigerant.

Crotonaldehyde → $CH_3-CH=CH-CHO$.

It is prepared by heating aldol alone or with anhydrous zinc chloride or still better with acetic acid as the catalyst.

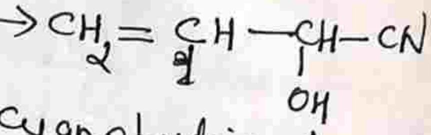
$$CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_2-CHO \xrightarrow[-H_2O]{\text{anhyd. } ZnCl_2} CH_3-CH=CH-CHO$$

It resembles acrolein in chemical properties. It exhibits geometrical isomerism and exists in cis and trans isomer.

Acrolein reduces ammoniacal si nitrate, forms a cyanohydrin wi hydrogen cyanide, and phenyl hydraz with phenyl hydrazine.

$$CH_2=CH-CHO + Ag_2O \xrightarrow{[O]} CH_2=CH-COOH$$

acrylic acid.



$$CH_2=CH-CHO + HCN \longrightarrow CH_2=CH-\underset{OH}{CH}-CN$$

cyanohydrin of acrolein.

Many of the reaction of α,β-unsaturated aldehyde are 1,2-addition but, α,β-unsaturated ketones tends to undergo 1,4-addition. Aldehyde are more reactive than ketones towards nucleophiles and kinetically controlled product with aldehyde is 1,2-addition

Acrolein undergoes the Tischenko reaction to form allyl acrylate

It is reduced by aluminium isopropoxide (MPV) to allyl alcohol.

$$CH_2=CH-CHO \xrightarrow[\text{isopropoxide}]{\text{Aluminium}} \underset{\text{allyl alcohol}}{CH_2=CH-CH_2-OH}$$

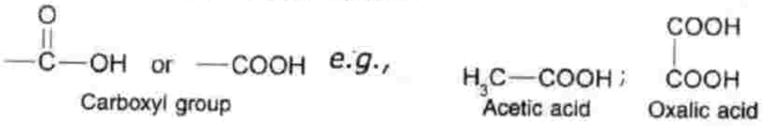
α, β-unsaturated carbonyl compound reduced to unsaturated alcohol by LiAlH4. (or) NaBH4.

$$CH_2=CH-CHO \xrightarrow{LiAlH_4} CH_2=CH-CH_2OH.$$

UNIT - III

CARBOXYLIC ACIDS

Organic compounds which contain one or more carboxyl groups, —COOH, are called carboxylic acids. The word carboxyl is a contraction of the words carbonyl (C=O) and hydroxyl (OH) because in the carboxyl group, both the (C=O) and the (OH) groups are combined as shown below:



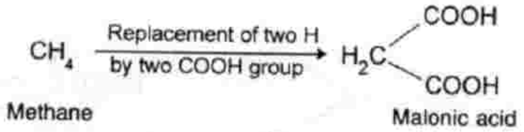
$$-\overset{\overset{\displaystyle O}{\|}}{C}-OH \quad \text{or} \quad -COOH \quad e.g., \quad H_3C-COOH; \quad \begin{array}{c} COOH \\ | \\ COOH \end{array}$$

Carboxyl group   Acetic acid   Oxalic acid

The carboxylic acids can also be considered as the carboxyl derivatives of hydrocarbons in which one or more hydrogen atoms are replaced by carboxyl groups. *e.g.*,

$$CH_4 \xrightarrow[\text{by one COOH group}]{\text{Replacement of one H}} H_3C-COOH$$

Methane   Acetic acid



Acids containing *one* COOH group are termed *mono*-carboxylic acid while others containing *two* and *three* COOH groups are called *di*-and *tri*-carboxylic acids respectively.

Fatty Acids

The monocarboxylic acids are called *fatty acids*. The name fatty acid has been derived from the fact that some of the higher members of the series, *e.g.*, palmitic acid ($C_{15}H_{31}COOH$) and stearic acid ($C_{17}H_{35}COOH$), were first obtained from fats. The general formula of the carboxyl homologous series is $C_nH_{2n+1}COOH$ or RCOOH whereas the functional group is the carboxyl group, —COOH. As only hydrogen atom of the carboxyl group is replaceable by a metal, the fatty acids are all monobasic acids.

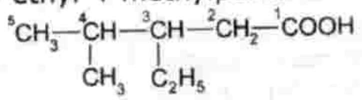
C_4H_9COOH	Valeric acid	Pentanoic acid
$C_5H_{11}COOH$	Caproic acid	Hexanoic acid
$C_6H_{13}COOH$	Heptanoic acid	Heptanoic acid
$C_{15}H_{31}COOH$	Palmitic acid	Hexadecanoic acid
$C_{17}H_{35}COOH$	Stearic acid	Octadecanoic acid

Sometimes acids are named as alkyl derivatives of acetic acid. For example,

$CH_3CH_2CH_2COOH$ $(CH_3)_2CHCOOH$

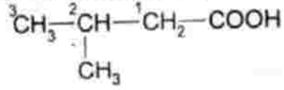
Ethylacetic acid   Dimethylacetic acid

Complicated members are always named according to the *IUPAC* system and the substituents are indicated by numbers. Here the carboxyl group is always given number 1. For example, is 3-ethyl-4-methylpentanoic acid.



$${}^{5}CH_3-\underset{\displaystyle CH_3}{\underset{|}{{}^{4}CH}}-\underset{\displaystyle C_2H_5}{\underset{|}{{}^{3}CH}}-{}^{2}CH_2-{}^{1}COOH$$

Alternatively, the carboxyl group is regarded as a substituent and is denoted by adding the suffix carboxylic acid to alkane. For example,



$${}^{3}CH_3-\underset{\displaystyle CH_3}{\underset{|}{{}^{2}CH}}-{}^{1}CH_2-COOH$$

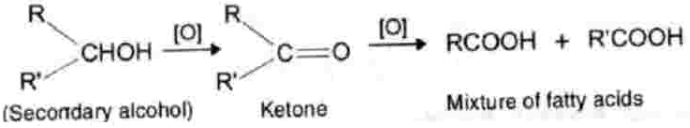
is 2-methylpropane-1-carboxylic acid or 3-methylbutanoic acid.

General Methods of Preparation of Fatty Acids

(*i*) ***By the oxidation of alcohols, aldehydes or ketones with dichromate solution.*** Primary alcohols are oxidised with oxidising agents acid as potassium permanganate or chromic acid first to aldehydes and then to carboxylic acids.

$$\underset{\substack{\text{Ethyl alcohol}\\\text{(Primary alcohol)}}}{C_2H_5OH} \xrightarrow{[O]} \underset{\text{Acetaldehyde}}{CH_3CHO} \xrightarrow{[O]} \underset{\text{Acetic acid}}{CH_3COOH}$$

Secondly alcohols are oxidised first to ketones and then to a mixture of carboxylic acids


$$\underset{\text{(Secondary alcohol)}}{RR'CHOH} \xrightarrow{[O]} \underset{\text{Ketone}}{RR'C{=}O} \xrightarrow{[O]} \underset{\text{Mixture of fatty acids}}{RCOOH + R'COOH}$$

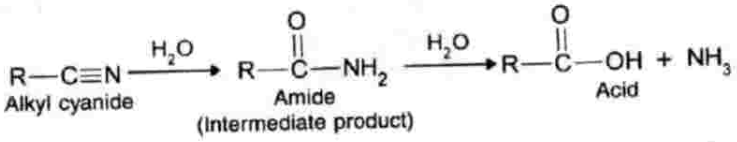
(Secondary alcohol) Ketone

In some cases an ester is obtained in place of the acid because a part of the alcohol gets oxidised to the acid which can form an ester with the remaining part of the alcohol.

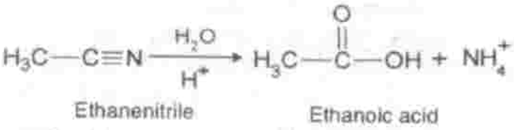
Since aldehydes are more easily oxidised than ketones, even mild oxidising agents such as Tollen's reagent, $[Ag(NH_3)_2]^+OH^-$ oxidise aldehydes to carboxylic acids

$$R{-}CHO \xrightarrow[\text{(ii) } H_3O^+]{\text{(i) } Ag(NH_3)_2OH} R{-}COOH$$

(*ii*) ***By the hydrolysis of cyanides with acid or alkali.*** This constitutes a very good synthetic method for carboxylic acids as cyanides can be easily obtained from alkyl halides.


$$\underset{\text{Alkyl cyanide}}{R{-}C{\equiv}N} \xrightarrow{H_2O} \underset{\substack{\text{Amide}\\\text{(Intermediate product)}}}{R{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}NH_2} \xrightarrow{H_2O} \underset{\text{Acid}}{R{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}OH} + NH_3$$

For example,


$$\underset{\text{Ethanenitrile}}{H_3C{-}C{\equiv}N} \xrightarrow[H^+]{H_2O} \underset{\text{Ethanoic acid}}{H_3C{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}OH} + NH_4^+$$

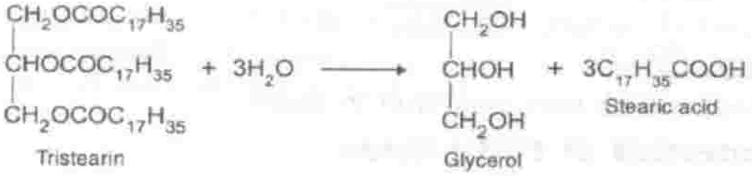
(*iii*) ***By the oxidation of alkenes.*** Alkenes can be oxidized to carboxylic acids with hot alkaline $KMnO_4$.

$$R{-}CH{=}CH{-}R' \xrightarrow[\text{Heat}]{MnO_4^-} \underset{\text{Mixture of fatty acids}}{RCOOH + R'COOH}$$

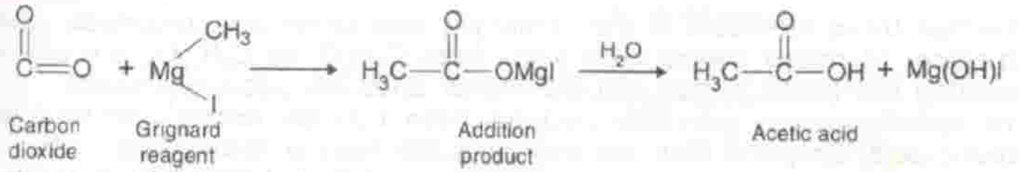
For example,

$$\underset{\text{Pent-2-ene}}{H_3C{-}CH{=}CH{-}CH_2CH_3} \xrightarrow[\text{Heat}]{MnO_4^-} \underset{\text{Ethanoic acid}}{CH_3COOH} + \underset{\text{Propanoic acid}}{CH_3CH_2COOH}$$

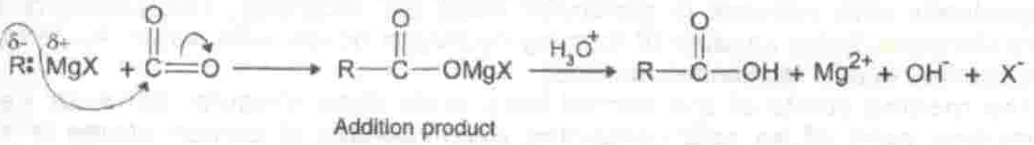
(*iv*) ***By the hydrolysis of natural fats.*** Higher farry acids are commonly obtained by the *hydrolysis of natural fats.* For example, stearic acid is obtained from triglyceride of stearic acid.


$$\underset{\text{Tristearin}}{\begin{array}{l}CH_2OCOC_{17}H_{35}\\ |\\ CHOCOC_{17}H_{35}\\ |\\ CH_2OCOC_{17}H_{35}\end{array}} + 3H_2O \longrightarrow \underset{\text{Glycerol}}{\begin{array}{l}CH_2OH\\ |\\ CHOH\\ |\\ CH_2OH\end{array}} + \underset{\text{Stearic acid}}{3C_{17}H_{35}COOH}$$

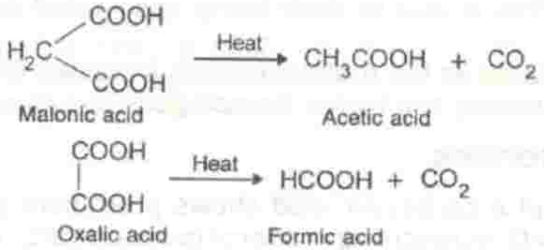
(v) ***By treating Grignard reagent with carbon dioxide followed by hydrolysis vith an acid, e.g.,***



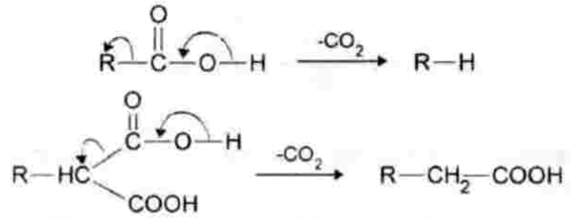
Mechanism of the reaction is as given below:



(vi) ***By heating a dicarboxylic acid having two —COOH groups attached o the same carbon atom,*** when a molecule of carbon dioxide is eliminated to ield a monocarboxylic acid.



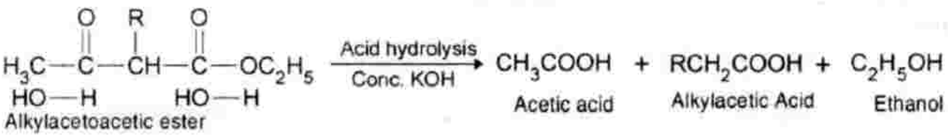
The mechanism of the reaction can be represented as follows



(vii) ***By heating sodium alkoxide with carbon monoxide under pressure*** followed by acid hydrolysis of the sodium salt of the fatty acid formed.

$$\underset{\text{Sodium alkoxide}}{R{-}ONa} + CO \xrightarrow[\text{Pressure}]{\text{High}} \underset{\text{Sodium salt of acid}}{RCOONa} \xrightarrow{HCl} \underset{\text{Fatty acid}}{RCOOH}$$

(viii) ***From Malonic or Acetoacetic ester.*** Many fatty acids are conveniently synthesised from malonic or acetoacetic ester. For example, alkyl-substituted acetoacetic ester on hydrolysis with conc. KOH yields the corresponding alkyl acetic acid.



$$H_3C{-}\overset{O}{\overset{\|}{C}}{-}\overset{R}{\overset{|}{CH}}{-}\overset{O}{\overset{\|}{C}}{-}OC_2H_5 \xrightarrow[\text{Conc. KOH}]{\text{Acid hydrolysis}} \underset{\text{Acetic acid}}{CH_3COOH} + \underset{\text{Alkylacetic Acid}}{RCH_2COOH} + \underset{\text{Ethanol}}{C_2H_5OH}$$

HO—H HO—H

Alkylacetoacetic ester

General Properties of Fatty Acids

(A) Physical Properties

(i) The first three members of the carboxylic acid series are colourless, pungent-smelling, corrosive liquids. The acids from $C_4H_8O_2$ to $C_9H_{18}O_2$ are oily liquids smelling like goat's butter and the higher ones are odourless solids.

(ii) The specific gravity gradually declines from 1.22 for formic acid to 0.845 for stearic acid. Only the first two members are heavier than water.

(iii) The first four members are very soluble in water and the solubility decreases gradually with increase in molecular mass (*cf.* alcohols). *This solubility is due to the acids being capable of forming hydrogen bonds with water.* All fatty acids dissolve readily in alcohol or ether.

(iv) The melting points of the normal fatty acids show irregular behavior *i.e.,* the melting point of an acid containing even number of carbon atoms is always higher than that of the acids containing odd number of carbon atoms immediately below and above it. The boiling points, however, have a regular gradation.

(v) The lower members are far less volatile than that can be expected of their molecular mass. This is due to their being associated as a result of hydrogen bonding.

(vi) Their acidity decreases as the molecular mass increases the faint acidic character, however, persists among the higher homologues and they give salts and esters.

(C) Chemical Properties

The molecule of a fatty acid (RCOOH) consists of (*i*) an alkyl group, R, and (*ii* the carboxyl group (—COOH). The properpties of fatty acids, therefore, are the properties of these groups as examplified below:

Reactions of the Alkyl Group

(i) Halogenation

Fatty acids may be readily halogenated in the α-position, *i.e.*, the hydrogen attached to the carbon adjacent to the carboxyl group is readily displaced. The reaction is best carried out in diffused sunlight or in the presence of halogen carrier (iodine, red phosphorus). This reaction is known as the **Hell-Volhard-Zelinsky reaction.**

$$RCH_2COOH \xrightarrow{P + I} R{-}CHI{-}COOH \xrightarrow{P + I} R{-}CI_2{-}COOH$$

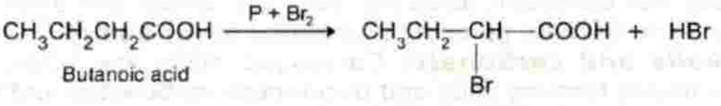
Similarly in acetic acid the three hydrogen atoms of the alkyl group are successively replaced by halogen atoms (chlorine or bromine).

$$CH_3COOH + Cl_2 \longrightarrow \underset{\text{Monochloroacetic acid}}{ClCH_2COOH} + HCl$$

$$ClCH_2COOH + Cl_2 \longrightarrow \underset{\text{Dichloroacetic acid}}{Cl_2CHCOOH} + HCl$$

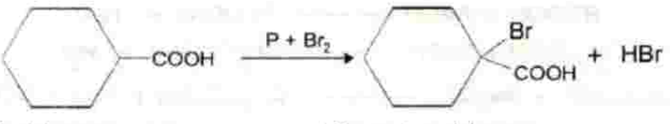
$$Cl_2CHCOOH + Cl_2 \longrightarrow \underset{\text{Trichloroacetic acid}}{Cl_3CCOOH} + HCl$$

Some other examples are



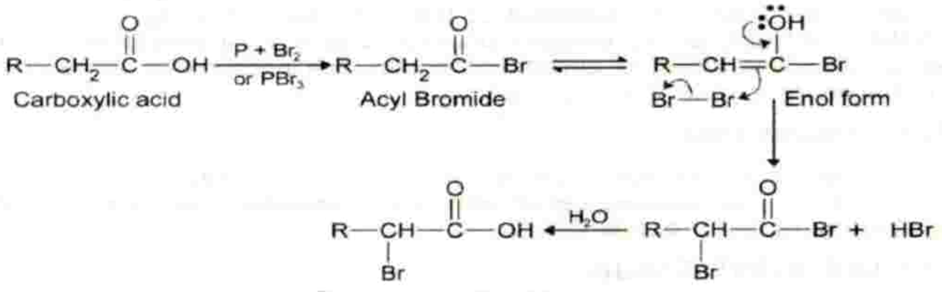
$$\underset{\text{Butanoic acid}}{CH_3CH_2CH_2COOH} \xrightarrow{P + Br_2} CH_3CH_2{-}\underset{\underset{Br}{|}}{CH}{-}COOH + HBr$$

2-Bromobutanoic acid



Cyclohexane-
Carboxylic acid

1-Bromo-1-cyclohexane
Carboxylic acid



α-Bromocarboxylic acid

(ii) Oxidation

When acids are treated with mild oxidising agents (*e.g.,* hydrogen peroxide), the alkyl group is oxidised at the β-position. For example, butyric acid gives β-hydroxybutyric acid.

$$\underset{\text{Butyric acid}}{H_3C-\overset{\beta}{C}H_2-\overset{\alpha}{C}H_2-COOH} \xrightarrow{[O]} \underset{\beta\text{-Hydroxybutyric acid}}{H_3C-\overset{\beta}{C}HOH-\overset{\alpha}{C}H_2-COOH}$$

Reactions of the Carboxyl Group

(i) Reactions Involving Replaceable Hydrogen Atom

The fatty acids ionize in polar media to give hydrogen ions (H^+) responsible for their acidic nature.

$$RCOOH \rightleftharpoons RCOO^- + H^+$$
$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$

This indicates that carboxylic acids will react with alkalis and alkali metal carbonates and with metals themselves as described below in *(a)* and *(b)*:

(a) ***With alkalis and carbonate.*** Carboxylic acids are acidic towards litmus, neutralize alkalis forming salts and decompose carbonates and bicarbonate when carbon dioxide gas is evolved with effervescence.

$$RCOOH + NaOH \longrightarrow RCOONa + H_2O$$
$$CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$$
$$2CH_3COOH + Na_2CO_3 \longrightarrow \underset{\text{Sodium acetate}}{2CH_3COONa} + H_2O + CO_2$$

(b) ***With metals.*** With strongly electropositive metals like sodium and zinc, the fatty acids give salts with the liberation of hydrogen.

$$2RCOOH + Zn \longrightarrow (RCOO)_2Zn + H_2$$
$$2CH_3COOH + 2Na \longrightarrow \underset{\text{Sodium acetate}}{2CH_3COONa} + H_2$$

Reactions involving the hydroxyl group

(a) ***With alcohols.*** Fatty acids react with alcohols in the presence of dehydrating agents like anhydrous zinc chloride or concentrated sulphuric acid, to form *esters (Esterification)*.

$$\underset{\text{Acetic acid}}{CH_3COOH} + \underset{\text{Ethyl alcohol}}{C_2H_5OH} \rightleftharpoons \underset{\text{Ethyl acetate (Ester)}}{CH_3COOC_2H_5} + H_2O$$

Esterification becomes difficult when both the carboxylic acid and the alcohol have bulky groups. The order of relativity of carboxylic acids and alcohols towards esterification is:

$$HCOOH > CH_3COOH > RCH_2COOH > R_2CHCOOH > R_3CCOOH$$
$$CH_3OH > 1^0\text{-alcohol} > 2^0\text{-alcohol} > 3^0\text{-alcohol}$$

(b) ***With phosphorus halides or thionyl chloride.*** Phosphorus trichloride, phosphorus pentachloride and thionyl chloride react with fatty acids to give acid chlorides.

$$\underset{\text{Acid}}{3RCOOH} + PCl_3 \longrightarrow \underset{\text{Acid chloride}}{3RCOCl} + H_3PO_3$$
$$\underset{\text{Acetic acid}}{CH_3COOH} + \underset{\text{Phosphorus pentachloride}}{PCl_5} \longrightarrow \underset{\text{Acetyl chloride}}{CH_3COCl} + POCl_3 + HCl$$
$$\underset{\text{Propanoic acid}}{C_2H_5COOH} + \underset{\text{Thionyl chloride}}{SOCl_2} \longrightarrow \underset{\text{Propanoyl chloride}}{C_2H_5COCl} + HCl + SO_2$$

(c) **Dehydration.** Acetic anhydride is obtained by passing acetic acid vapours over a heated catalyst $Na(NH_4)HPO_4 + BPO_4$ at 875—895 K.

$$2CH_3COOH \xrightarrow{-H_2O} (CH_3CO)_2O$$

Anhydrides of higher fatty acids may be prepared by heating with acetic anhydride.

$$2RCOOH + \underset{\text{Acetic anhydride}}{(CH_3CO)_2O} \rightleftharpoons \underset{\text{Acid anhydride}}{(RCO)_2O} + 2CH_3COOH$$

(d) **With ammonia.** Carboxylic acids react with ammonia to form ammonium salts which upon heating lose a molecule of water to form acid amides

$$\underset{\text{Carboxylic acid}}{RCOOH} + NH_3 \longrightarrow \underset{\text{Ammonium salt}}{RCOONH_4} \xrightarrow{\text{Heat}} \underset{\text{Acid amide}}{RCONH_2} + H_2O$$

Carboxylic acids are, however, less reactive towards nucleophilic substitution reaction with ammonia. A better method to prepare amides is to treat acid chlorides with ammonia.

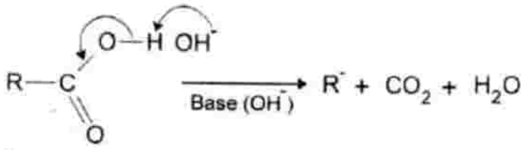
Reactions involving Carboxyl Group as a whole

(i) **Decarboxylation.** *Dry distillation of the anhydrous alkali salts of fatty acids with soda-lime yields paraffins.*

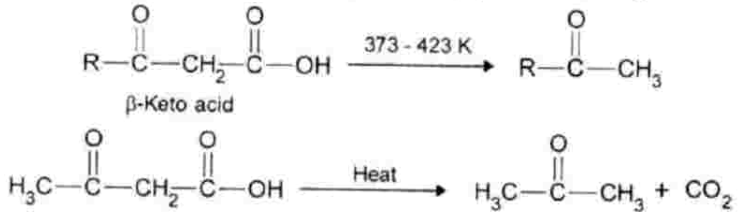
$$RCOONa + NaOH \longrightarrow RH + Na_2CO_3$$

$$\underset{\text{Sodium acetate}}{CH_3COONa} + NaOH \longrightarrow \underset{\text{Methane}}{CH_4} + Na_2CO_3$$

The mechanism of the above base-induced decarboxylation is uncertain but it is believed that salts decompose by S_E1 reaction.



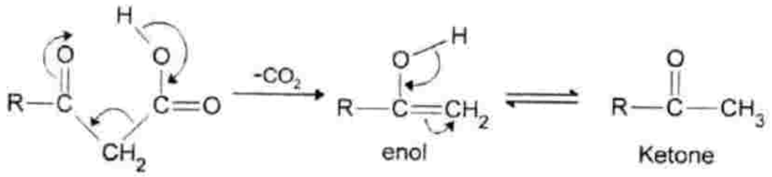
Decarboxylation is favoured by the presence of an electron-withdrawing group. The presence of a β- carbonyl group, for example, facilitates decarboxylation and thus β-keto acids undergo decarboxylation simiply on heating.



$$\underset{\beta\text{-Keto acid}}{R-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OH} \xrightarrow{373-423\ K} R-\overset{O}{\overset{\|}{C}}-CH_3$$

$$H_3C-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OH \xrightarrow{\text{Heat}} H_3C-\overset{O}{\overset{\|}{C}}-CH_3 + CO_2$$

Decarboxylation of β–keto acids proceeds through a cyclic transition state.



(ii) ***Kolbe's electrolytic reaction.*** Electrolysis of the concentrated aqueous solution of alkali metal salts of fatty acids gives paraffins (Kolbe's reaction). For example,

At anode: $2CH_3COO^- \longrightarrow \underset{\text{Ethane}}{CH_3CH_3} + 2CO_2 + 2e^-$

At cathode: $2H_2O + 2e^- \longrightarrow 2OH^- + H_2$

(*iii*) ***Action of heat on ammonium salt of fatty acids.*** Strong heating of the ammonium salt of fatty acids results in the formation of acid amides:

$$\underset{\text{Acid}}{RCOOH} + \underset{\text{Ammonia}}{NH_3} \longrightarrow \underset{\text{Ammonium salt}}{RCOONH_4}$$

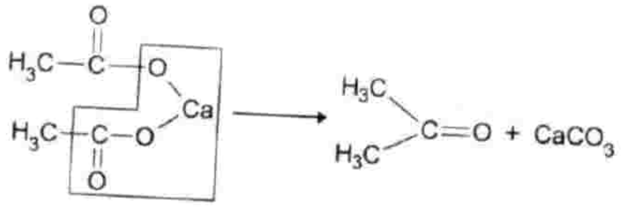
$$\underset{\substack{\text{Ammonium salt}\\\text{of fatty acid}}}{RCOONH_4} \longrightarrow \underset{\text{Acid amide}}{RCONH_2} + H_2O$$

$$\underset{\text{Ammonium acetate}}{CH_3COONH_4} \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + H_2O$$

(*iv*) ***Dehydration of ammonium salts*** with phosphorus pentoxide results in the formation of a *cyanide, e.g.,*

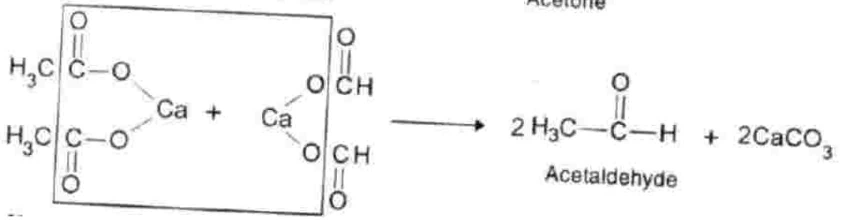
$$\underset{\text{Ammonium acetate}}{CH_3COONH_4} \xrightarrow{P_4H_{10}} \underset{\text{Methyl cyanide}}{H_3C{-}C{\equiv}N} + 2H_2O$$

(*v*) ***Action of heat on calcium salt of acids.*** Calcium salt of a fatty acid other than formic acid, when heated strongly, gives a ketone. If, however, the calcium salt is heated with calcium formate, an aldehyde is obtained.



Calcium acetate

Acetone



Acetaldehyde

(*vi*) ***Hundsdiecker reaction.*** When silver salt of the fatty acid is heated with a halogen, it gives an alkyl halide. With an alkyl halide it gives an ester. This reaction is called Hundsdiecker reaction.

$$\underset{\substack{\text{Silver salt of}\\\text{the fatty acid}}}{RCOOAg} + X_2 \xrightarrow{\text{Heat}} \underset{\text{Alkyl halide}}{R{-}X} + CO_2 + AgX$$

$$RCOOAg + R'X \xrightarrow{\text{Heat}} \underset{\text{Ester}}{RCOOR'} + AgX$$

(*vii*) ***Reduction.*** All fatty acids are very resistant to reduction but prolonged heating of the fatty acid under pressure with concentrated hydriodic acid and small amount of red phosphorus results in its reduction to a *paraffin*. Reduction may also be effected by heating with hydrogen at high temperature and under pressure in the presence of a nickel catalyst.

$$\underset{\text{Fatty acid}}{RCOOH} + 3H_2 \xrightarrow{\text{Ni}} \underset{\text{Paraffin}}{RCH_3} + 2H_2O$$

Carboxylic acids can be

Fatty acid Paraffin

Carboxylic acids can be easily reduced to the corresponding alcohols by $LiAlH_4$. Primary alcohols are also produced by hydrogenation in presence of ruthenium or copper-chromium oxide catalyst.

$$RCOOH \xrightarrow{LiAlH_4} RCH_2OH$$

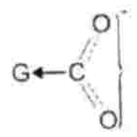
(viii) **Oxidation.** All the fatty acids, except formic acid, are extremely resistant to oxidation. These are, however, oxidised to carbon dioxide and water on prolonged heating with strong oxidising agents.
Mild oxidising agents oxidise them to β-hydroxy acids.

DETECTION OF THE

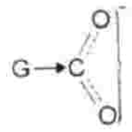
Effect of Substituents on Acidity

From the above discussion it is clear that any factor that stabilizes the anion more than it stabilizes the acid, should increase the acidity and any factor that makes the anion less stable should decrease the acidity of the carboxylic acid.

An electron-withdrawing substituent stabilizes the anion by dispersing the negative charge and, therefore, increases the acidity. On the other hand, electron-releasing substituents intensify the negative charge on the anion resulting in decrease of stability of the carboxylate anion and therefore decrease the acidity of the acid.



An electron-withdrawing substituent G withdraws electrons and stabilizes the anion
(Acidity increases)



An electron-releasing substituent G releases electrons and destabilizes the anion
(Acidity decreases)

(*a*) **Effect of electron releasing groups.** The presence of an electron releasing group decreases the acid strength of the carboxylic acid. For example, CH_3COOH (acetic acid) in about one tenth as strong as HCOOH (formic acid) and C_2H_5COOH (propionic acid) containing a larger alkyl group is weaker still. *i.e,*

$$HCOOH > CH_3COOH > C_2H_5COOH$$

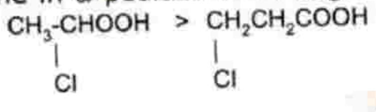
(*b*) **Effect of electron withdrawing groups.** Introduction of electron withdrawing groups result in the increase in the acidic strength of carboxylic acids. For example, chloroacetic acid; ($ClCH_2COOH$) is 100 times as strong as acetic acid; dichloroacetic acid ($Cl_2CHCOOH$) is 10,000 times as strong as acetic acid (CH_3COOH), *i.e.,*

$$Cl_3C.COOH > Cl_2CH.COOH > ClCH_2.COOH > CH_3COOH$$

(*c*) **Effect of nature of electron withdrawing group.** The acidic strength of carboxylic acids increases with the increase in electronegativity or electron withdrawing nature of the substituent. For example, strength of halogen substituted acids follows the following order because electron withdrawing nature of various halogens is in the same order

$$FCH_2COOH > ClCH_2COOH > BrCH_2COOH > ICH_2COOH$$
$$F > Cl > Br > I$$

(*d*) **Effect of position of electron withdrawing group.** The acidic strength decreases with the increasing distance between electron withdrawing substituent and the COOH group. For example, 2-chloropropanoic acid ($CH_3CHCl.COOH$) is a stronger acid than 3-chloropropanoic acid ($ClCH_2CH_2.COOH$) since electron withdrawing effect of chlorine in α-position is stronger than in β-position. *i.e.,*

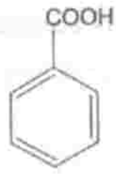


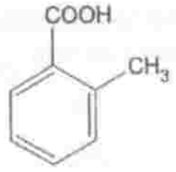
$$\underset{\displaystyle Cl}{CH_3\text{-}\underset{|}{C}HOOH} > \underset{\displaystyle Cl}{\underset{|}{C}H_2CH_2COOH}$$

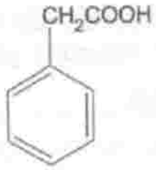
AROMATIC ACIDS

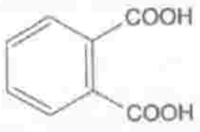
INTRODUCTION

The aromatic acids are obtained from aromatic hydrocarbons by the replacement of one or more hydrogen atoms by carboxyl groups (—COOH). The carboxyl group may be directly attached to the benzene nucleus or may be present in the side chain. The acids containing the carboxyl group in the side chain can be regarded as aryl-substituted aliphatic acids and are also classified as aromatic acids due to the presence of a benzene ring. Some typical aromatic acids are:


Benzoic acid


o-Toluic acid


Phenyl-
acetic acid

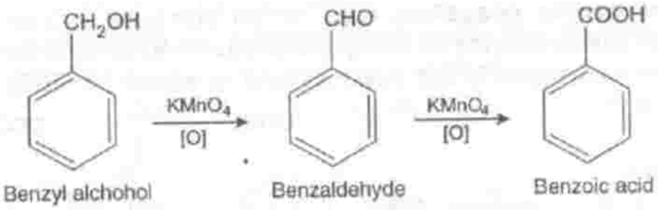

Phthalic acid

MONOBASIC ACIDS WITH CARBOXYL GROUP ATTACHED TO THE NUCLEUS

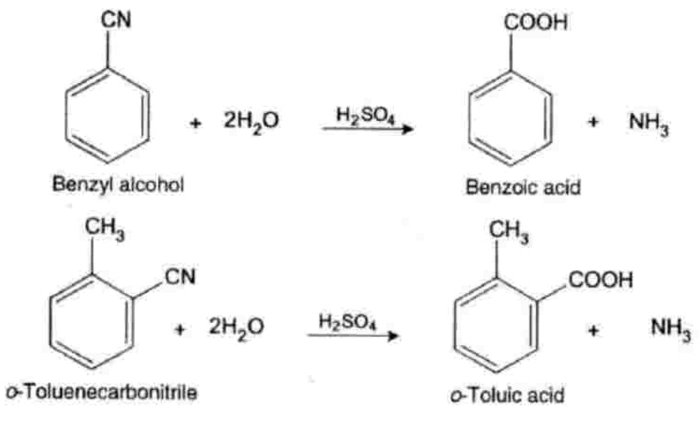
General Methods of Preparation

General methods for the preparation of aromatic acids are given below. Aromatic ariels are prepared :

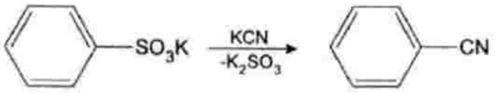
(*i*) ***By the oxidation of corresponding alcohol or aldehyde, e.g.,*** benzyl alcohol or benzaldehyde gives benzoic acid.



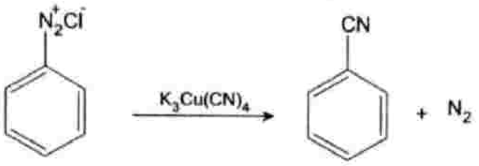
(*ii*) ***By the hydrolysis of aromatic nitriles, e.g.,*** benzonitrile on hydrolysis gives benzoic acid and *o*–toluenecarbonitrile gives *o*–toluic acid.



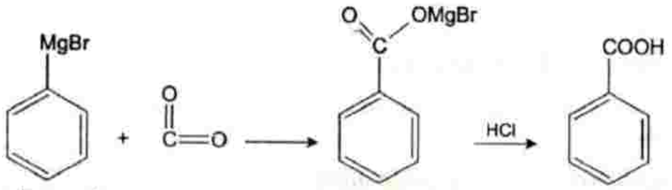
The nitriles may be obtained by fusing the alkali salt of sulphonic acid with potassium cyanide or



By Sandmeyer's reaction, *i.e.*, by treating a diazotized amino compound with cuprous cyanide dissolved in aqueous potassium cyanide.

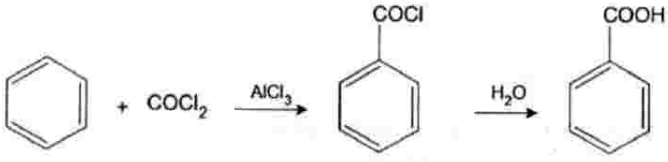


(*iii*) ***By means of a Grignard reagent,*** *e.g.*, phenylmangnesium bromide on treatment with CO_2, yields benzoic acid.



Phenylmagnesium bromide
Addition product
Benzoic acid

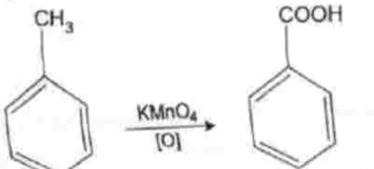
(*iv*) ***By Friedel–crafts reaction,*** *e.g.*, when benzene is treated with excess of carbonyl chloride in the presence of anhydrous aluminium chloride, benzoyl chloride is produced. This on hydrolysis gives benzoic acid in about 55-58% yield.



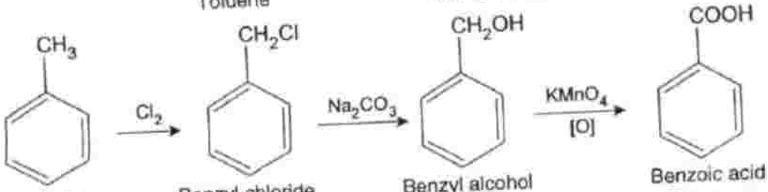
Benzoyl chloride
Benzoic acid

Excess of carbonyl chloride is necessary as otherwise benzophenone may be obtained as the main product.

(*v*) ***By the oxidation of homologues of benzene*** with dilute nitric acid, dichromate+sulphuric acid, alkaline permanganate, etc.Sometimes it may be more convenient to chlorinate the hydrocarbon and then oxidise the chloro derivative.



Toluene
Benzoic acid



Toluene
Benzyl chloride
Benzyl alcohol
Benzoic acid

Oxidation of side chain *via* chlorination is very easy since the intermediate alcohol is comparatively more readily oxidised than the original hydrocarbon.

General Properties

When compared with aliphatic acids, the aromatic acids are generally less volatile, less soluble in water and are slightly stronger acids. This is because phenyl group, like a double bond, exerts an electron-withdrawing effect on the carboxyl group. When heated with soda-lime aromatic acids are readily decarboxylated. Their more important reactions are given under benzoic acid.

Benzoic acid (Benzenecarboxylic acid, C_6H_5COOH)

Benzoic acid is found in balsams and resins particularly gum benzoin. It is also present as hippuric acid (*benzylglycine*) in the urine of horses.

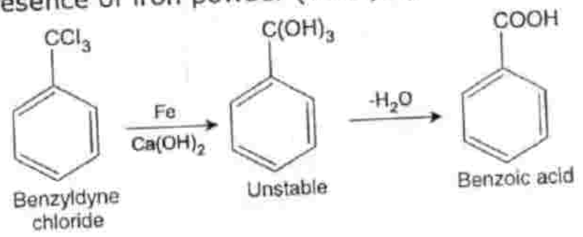
Preparation

Benzoic acid can be prepared in the laboratory by any of the general methods of preparation of aromatic carboxylic acids as given above.

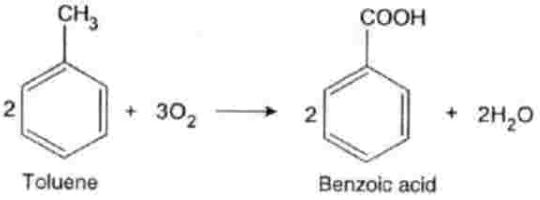
Manufacture

Commercially benzoic acid is prepared:

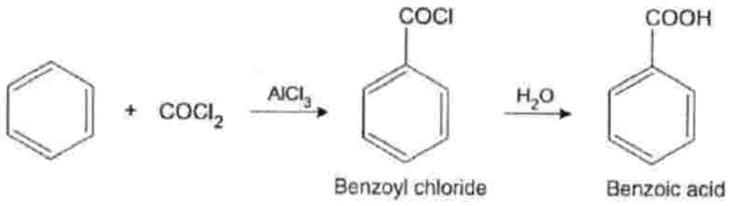
(*i*) ***By the hydrolysis of benzylidyne chloride (or benzotrichloride)*** with milk of lime in the presence of iron powder (catalyst).



(*ii*) ***By the catalytic oxidation of toluene with air.***



(*iii*) ***By means of Friedel Crafts reaction between benzene and carbonyl chloride* and hydrolysis of benzoyl chloride obtained.**



Physical Properties

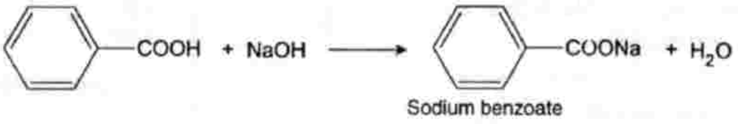
Benzoic acid forms white, pearly flakes (m.p. 395 K), sparingly soluble in cold water but is readily soluble in hot water, alcohol and ether. It is volatile in steam, and sublimes when heated at about 370 K. Its vapours are irritating in smell and provoke coughing and sneezing.

Chemical Properties

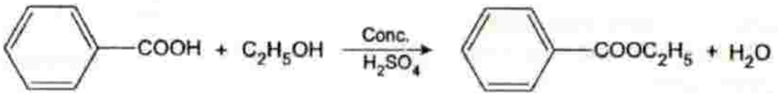
Chemically benzoic acid resemble aliphatic acids and gives similar reactions. It is, however, a stronger acid than acetic acid.

(*a*) *Reactions of Carboxyl group*

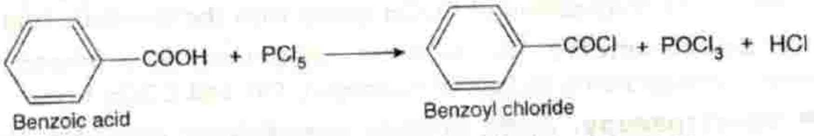
(*i*) When benzoic acid reacts with an alkali metal hydroxide or carbonate, it gives the corresponding salt:



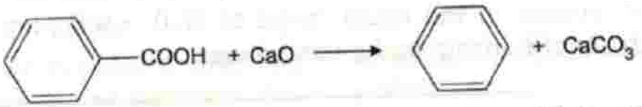
(*ii*) Benzoic acid readily forms esters when it is refluxed with alcohol in the presence of small quantity of concentrated sulphuric acid or hydrogen chloride.



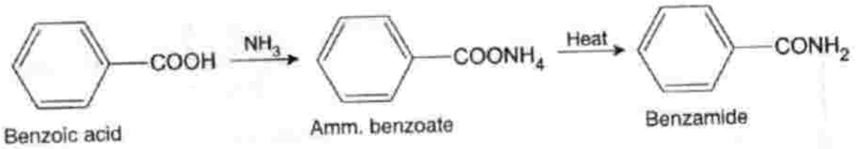
(*iii*) When phosphorus pentachloride, benzoic acid gives benzoyl chloride,



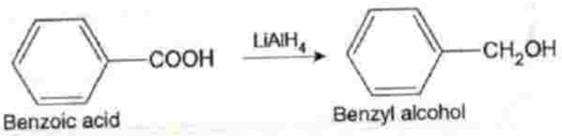
(*iv*) When heated with soda-lime, benzoic acid gives benzene.



(*v*) With ammonia it gives ammonium benzoate which on heating gives benzamide.

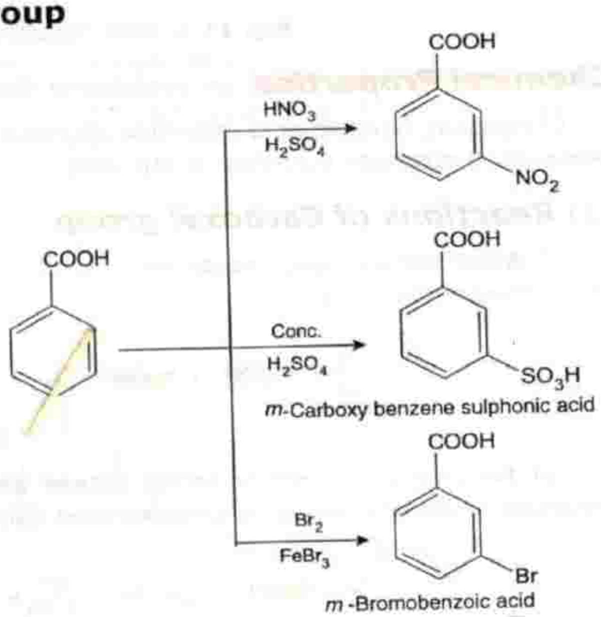


(*vi*) On reduction with lithium aluminium hydride benzoic acid gives benzyl alcohol.



(*b*) Reactions of the Phenyl group

Benzoic acid gives the usual substitution reaction of the benzene nucleus, *e.g.*, nitration, sulphonation and halogenation, and meta derivatives are obtained in each case.



Uses

(*i*) Benzoic acid and some of its salts are used in medicine as urinary antiseptics.

(*ii*) Sodium benzoate finds use as a food preservative.

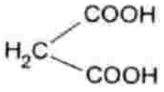
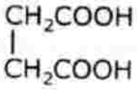
(*iii*) This acid is also used in the manufacture of dyestuffs such as aniline blue.

(*iv*) Its vapours mixed with steam are inhaled for disinfecting bronchial tubes.

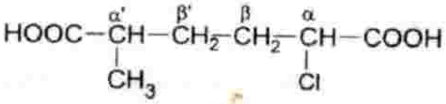
DICARBOXYLIC ACID

Nomenclature

Saturated dicarboxylic acids are represented by the general formula $C_nH_{2n}(COOH)_2$ (n=0 for oxalic acid). Their common names generally indicate the source from which these have been obtained, *e.g.*, oxalic acid is named so because it occurs in plants of the *oxalis* group. According to *IUPAC* system, their class suffix is dioic acid or dicarboxylic acid as exemplified below:

Formula	*Common name*	*IUPAC name*
	Oxalic acid	Ethanedioic acid
	Malonic acid	Propanedioic acid
	Succinic acid	Butanedioic acid
$(CH_2)_3(COOH)_2$	Glutaric acid	Pentanedioic acid
$(CH_2)_4(COOH)_2$	Adipic acid	Hexanedioic acid
$(CH_2)_5(COOH)_2$	Pimelic acid	Heptanedioic acid
$(CH_2)_6(COOH)_2$	Suberic acid	Octanedioic acid
$(CH_2)_7(COOH)_2$	Azelaic acid	Nonanedioic acid
$(CH_2)_8(COOH)_2$	Sebacic acid	Decanedioic acid

In the trivial system positions of side-chains are indicated by Greek letters and in the *IUPAC* system by numbers, *e.g.*,



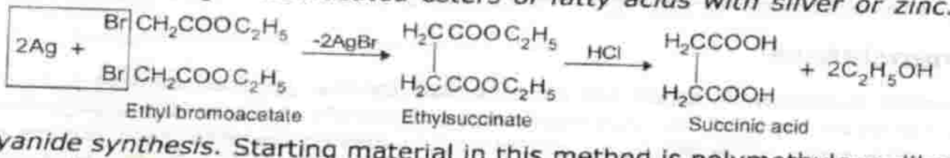
α-Chloro-α'-methyladipic acid (*Common name*) or
2-Chloro-5-methylhexanedioic acid (*IUPAC name*)

General Methods of Preparation

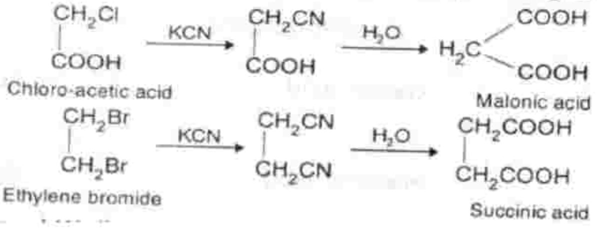
(*i*) *By oxidation of Glycols, e.g.,* ethyleneglycol gives oxalic acid.

Since higher polymethylene glycols are relatively inaccessible this method is of very limited synthetic utility.

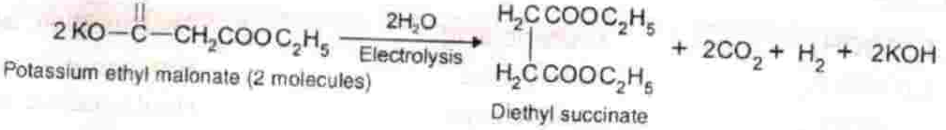
(*ii*) *By treating halogen substituted esters of fatty acids with silver or zinc.*



(*iii*) *Cyanide synthesis.* Starting material in this method is polymethylene dibromide or a halogen-substituted acid which is converted to its cyanide derivative which in turn can be readily hydrolysed to the corresponding carboxylic acids.



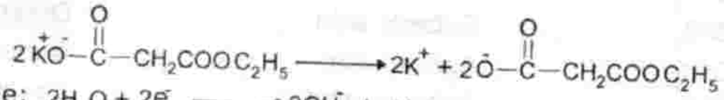
(IV) *Crum-Brown and Walker Electrolytic method.* Electrolysis of an aqueous solution of the potassium alkyl ester of a dibasic acid gives higher dicarboxylic acid.



$$2\,KO-\overset{O}{\overset{\|}{C}}-CH_2COOC_2H_5 \xrightarrow[\text{Electrolysis}]{2H_2O} \begin{array}{l} H_2C\,COOC_2H_5 \\ | \\ H_2C\,COOC_2H_5 \end{array} + 2CO_2 + H_2 + 2KOH$$

Potassium ethyl malonate (2 molecules)

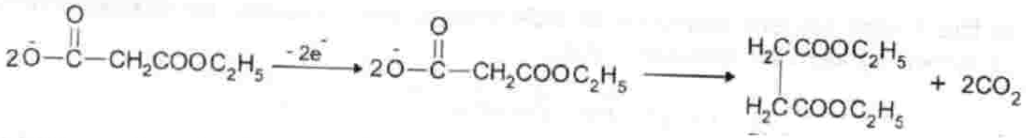
Diethyl succinate



$$2\,\overset{+}{K}\overset{-}{O}-\overset{O}{\overset{\|}{C}}-CH_2COOC_2H_5 \longrightarrow 2K^+ + 2\bar{O}-\overset{O}{\overset{\|}{C}}-CH_2COOC_2H_5$$

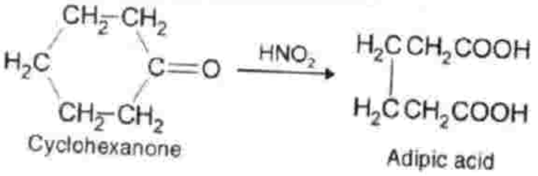
At cathode: $2H_2O + 2e^- \longrightarrow 2OH^- + H_2$

At anode:



$$2\bar{O}-\overset{O}{\overset{\|}{C}}-CH_2COOC_2H_5 \xrightarrow{-2e^-} 2\dot{O}-\overset{O}{\overset{\|}{C}}-CH_2COOC_2H_5 \longrightarrow \begin{array}{l} H_2C\,COOC_2H_5 \\ | \\ H_2C\,COOC_2H_5 \end{array} + 2CO_2$$

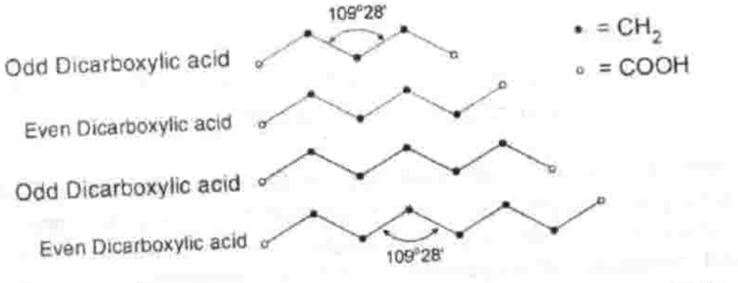
By oxidation of cyclic ketones.



Physical Properties

Dicarboxylic acids are crystalline solids which are soluble in water. Solubility decreases with increase in molcular weights. Their solubilities and melting points show alternation or oscillation from one member to the next. Odd acids (with odd number of carbon atoms) are more soluble in water than even acids (with even number of carbon atoms) immediately above and below them. Similarly even acids have higher melting points than the odd acids.

This phenomenon of alternation is probably due to the fact that the carbon chains of dicarboxylic acids are arranged in the zig-zag fashion. As a result of this zig-zag orientation (shown below) the carboxyl groups of an 'odd acid' lie on the same side of the carbon chain while of an 'even acid' lie on the opposite sides of the chain.



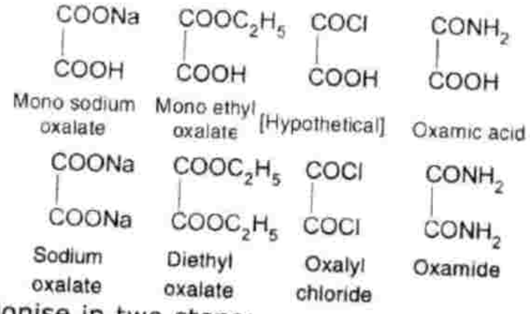
Arrangement of carbon chains in 'odd' and 'even' acids.

Chemical Properties

Chemical reactions of dibasic acids are mainly the reactions of the two carboxyl groups as given below:

(i) Acidic Nature

The acid strength of the dicarboxylic acids decreases as the series is ascended. They dissociate in two steps, the dissociation constant of the first being much greater than that of the second. They give two series of derivatives depending upon whether one or both the carboxylic acid groups react. For example, possible derivatives of oxalic acid are:



Dicarboxylic acid ionise in two steps:

$$\begin{array}{c}COOH\\ |\\ COOH\end{array} + H_2O \rightleftharpoons \begin{array}{c}COO^-\\ |\\ COOH\end{array} + H_3O^+ \qquad \ldots(1)$$

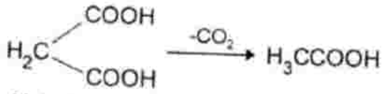
$$\begin{array}{c}COO^-\\ |\\ COOH\end{array} + H_2O \rightleftharpoons \begin{array}{c}COO^-\\ |\\ COO^-\end{array} + H_3O^+ \qquad \ldots(2)$$

Since in the second ionization, a proton has to be removed from a negatively charged species containing an electron-donating substituent *i.e.*, $-COO^-$, the equilibrium lies to the left. As a result of this equilibrium, oxalic, malonic and succinic acids are weaker in their second ionisation than formic, acetic and propionic acids respectively.

The dicarboxylic acids are much stronger than the monocarboxylic acids. This is expected since a carboxyl group being electron-attracting its presence close to another carboxyl group facilitates the release of the first proton. Since inductive effect falls off sharply as soon as the carboxyl groups are separated by more than one carbon atom ($-CH_2-$), oxalic acid ($K_a=5400\times10^{-5}$) is stronger than malonic acid ($K_a=140 \times 10^{-5}$). When two or more methylene groups intervene, the two carboxyl groups have little effect on each other. For example, succinic acid ($K_a=6.4\times10^{-5}$) is only slightly stronger than acetic acid ($K_a=1.76\times10^{-5}$).

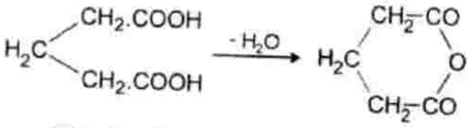
(ii) Action of Heat

(*i*) Acids with two carboxyl groups attached to the same carbon atom eliminate a molecule of carbon oxide on heating.



Malonic acid Acetic acid

(*ii*) Succinic and glutaric acids on heating form cyclic anhydrides.

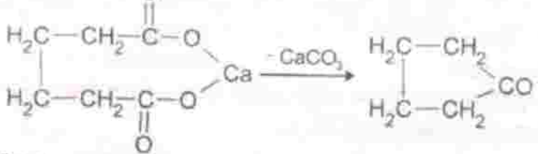


Glutaric acid Glutaric anhydride

(*iii*) Adipic acid and higher members are stable towards heat.

(iii) Action of Heat on Calcium Salts

Calcium salts of higher dicarboxylic acid form cyclic ketones when heated.



Calcium adipate Cyclopentanone

(iv) Oxidation

Except for oxalic acid, dicarboxylic acids are stable towards oxidising agents. This difference in behaviour is due to the fact that oxalic molecule has no hydrocarbon chain.

INDIVIDUAL MEMBERS

(*i*) Oxalic acid (*Ethanedioic acid*), $(COOH)_2$

Oxalic acid is one of the most important dicarboxylic acids and it occurs in rhubarb, sorrel and other plants of the *oxalis* group (hence the name). As calcium oxalate, it is present in spinach, sweet potatoes, cabbage, grapes and tomatoes.

Preparation

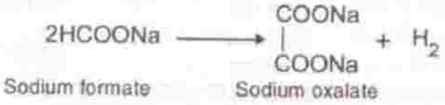
(*i*) *Laboratory Method.* Oxalic acid is prepared in the laboratory by oxidation of sucrose (cane-sugar) with concentrated nitric acid in the presence of vanadium pentoxide as catalyst. The Product is concentrated and crystallized when oxalic acid crystals, $(COOH)_2 2H_2O$ separate which can be purified by recrystallization from water.

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + 18[O] \xrightarrow[V_2O_5]{HNO_3} \underset{\text{Oxalic acid}}{6(COOH)_2} + 5H_2O$$

(*ii*) *Manufacture.* An industrial method for the preparation of oxalic acid, which is now almost obsolete, is by strongly heating (470–490 K) a paste of sawdust with caustic soda when sodium oxalate is obtained. The fused mass is treated with water when sodium oxalate dissolves. The solution is treated with milk of lime when calcium oxalate is precipitated out which is filtered, washed and decomposed with sulphuric acid to recover oxalic acid. The precipitated calcium sulphate is filtered off and the filtrate evaporated be crystallization when oxalic acid dihydrate crystallizes out

$$\underset{\text{Calcium oxalate}}{Ca(OOC)_2} + H_2SO_4 \longrightarrow \underset{\text{ppt.}}{CaSO_4} + \underset{\text{Oxalic acid}}{(COOH)_2}$$

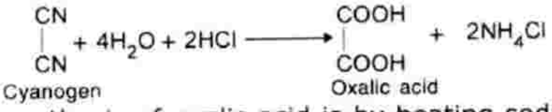
(*iii*) The modern method for the industrial preparation of oxalic acid is by heating sodium formate rapidly to 633 K.



$$\underset{\text{Sodium formate}}{2HCOONa} \longrightarrow \underset{\text{Sodium oxalate}}{\begin{matrix} COONa \\ | \\ COONa \end{matrix}} + H_2$$

Sodium oxalate obtained is treated as described in method (*ii*) for obtaining free acid.

(*iv*) Oxalic acid can also be obtained by the hydrolysis of cyanogen with concentrated hydrochloric acid. The method is, however, of theoretical importance only.



$$\underset{\text{Cyanogen}}{\begin{matrix} CN \\ | \\ CN \end{matrix}} + 4H_2O + 2HCl \longrightarrow \underset{\text{Oxalic acid}}{\begin{matrix} COOH \\ | \\ COOH \end{matrix}} + 2NH_4Cl$$

(*v*) An interesting synthesis of oxalic acid is by heating sodium or potassium in a current of carbon dioxide at 633 K.

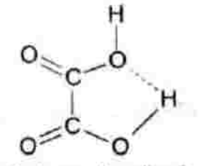
$$2Na + 2CO_2 \xrightarrow{633\ k} \underset{\text{Sodium oxalate}}{(COONa)_2} \longrightarrow \underset{\text{oxalic acid}}{(COOH)_2}$$

Properties of Oxalic acid

Physical Properties

Oxalic acid is a colourless, crystalline solid with two molecules of water of crystallization. The hydrated acid melts at 374 K whereas the anhydrous acid melts at 462.5 K. It is poisonous in nature, soluble in water and alcohol but almost insoluble in ether.

Chemical Properties

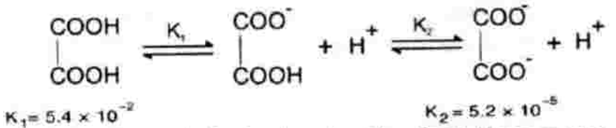


Hydrogen bonding in oxalate mono anion

Oxalic acid contains two carboxyl groups and gives the reactions of fatty acids.

Some important reactions of oxalic acid are:

(*i*) ***Acidic nature.*** Since there are two ionizable hydrogen atoms, it ionizes in two steps. First hydrogen atom ionizes about 1000 times more readily than the second hydrogen atom.

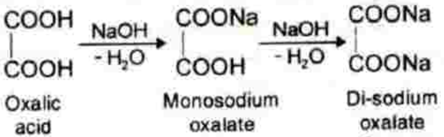


$$\begin{matrix}COOH\\|\\COOH\end{matrix} \overset{K_1}{\rightleftharpoons} \begin{matrix}COO^-\\|\\COOH\end{matrix} + H^+ \overset{K_2}{\rightleftharpoons} \begin{matrix}COO^-\\|\\COO^-\end{matrix} + H^+$$

$K_1 = 5.4 \times 10^{-2}$ $K_2 = 5.2 \times 10^{-5}$

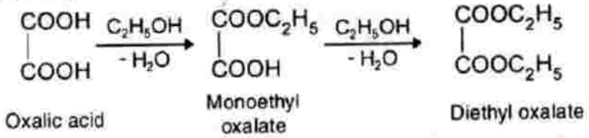
This difference in K_1 and K_2 is due to the fact that more energy is needed in the second step when H^+ (proton) is being pulled away from the negatively charged $HOOC-COO^-$ ion than from the neutral molecule (in the first step) due to hydrogen bonding as shown in the margin.

(*ii*) ***Neutralization.*** With alkalis or carbonates it gives two series of salts.



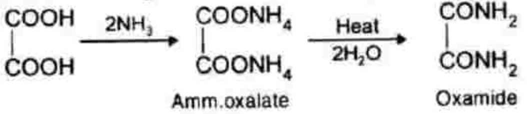
$$\begin{matrix}COOH\\|\\COOH\end{matrix} \xrightarrow[-H_2O]{NaOH} \begin{matrix}COONa\\|\\COOH\end{matrix} \xrightarrow[-H_2O]{NaOH} \begin{matrix}COONa\\|\\COONa\end{matrix}$$

(*iii*) ***Esterification.*** With alcohols in the presence of conc. H_2SO_4, oxalic acid gives two series of esters.



$$\begin{matrix}COOH\\|\\COOH\end{matrix} \xrightarrow[-H_2O]{C_2H_5OH} \begin{matrix}COOC_2H_5\\|\\COOH\end{matrix} \xrightarrow[-H_2O]{C_2H_5OH} \begin{matrix}COOC_2H_5\\|\\COOC_2H_5\end{matrix}$$

(*iv*) ***With ammonia.*** When oxalic acid is treated with ammonia, ammonium oxalate is obtained which on heating loses water to give oxamide:



$$\begin{matrix}COOH\\|\\COOH\end{matrix} \xrightarrow{2NH_3} \begin{matrix}COONH_4\\|\\COONH_4\end{matrix} \xrightarrow[2H_2O]{Heat} \begin{matrix}CONH_2\\|\\CONH_2\end{matrix}$$

(*v*) ***Action of Heat.*** Oxalic acid dihydrate when heated loses water at 370-378 K. On further heating to 470 K, Oxalic acid decomposes into carbon dioxide, carbon monoxide, formic acid and water.

$$HOOC.COOH.2H_2O \xrightarrow{370\text{-}378\ K} (COOH)_2 \xrightarrow{470\ K} HCOOH + CO_2 + CO + H_2O$$

(*vi*) ***With glycerol.*** When oxalic acid is heated with glycerol, formic acid or allyl alcohol is obtained depending upon the conditions of reactions.

(*vii*) ***Dehydration.*** On heating with concentrated sulphuric acid at 360 K, oxalic acid loses water giving carbon monoxide and carbon dioxide.

$$(COOH)_2 \xrightarrow{H_2SO_4\ 360\ K} CO + CO_2 + H_2O$$

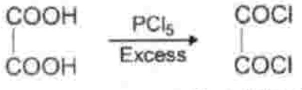
(*viii*) ***Oxidation.*** With oxidising agents like acidified potassium permanganate, potassium dichromate or chlorine, oxalic acid is oxidised to carbon dioxide.

$$(COOH)_2 + O \longrightarrow 2CO_2 + H_2O$$

$$(COOH)_2 + Cl_2 \longrightarrow 2CO_2 + 2HCl$$

With concentrated nitric acid, it is only very slowly oxidised.

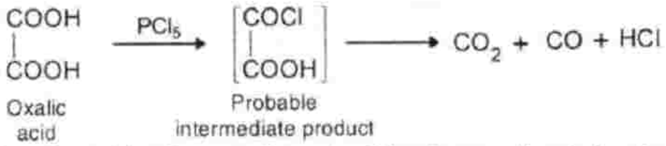
(*ix*) ***With phosphorus pentachloride.*** If oxalic acid is treated with excess of phosphorus pentachloride, the two —OH groups are replaced by two —Cl atoms and oxalyl chloride (b.p. 337 K) is formed.



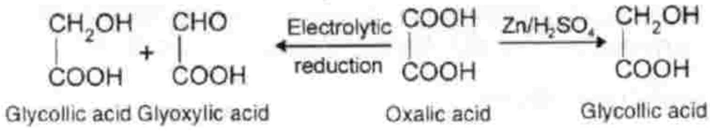
$$\begin{matrix}COOH\\|\\COOH\end{matrix} \xrightarrow[Excess]{PCl_5} \begin{matrix}COCl\\|\\COCl\end{matrix}$$

Oxalyl chloride

If an excess of phosphorus pentachloride is not used, instead of giving oxalyl chloride, oxalic acid decomposes to yield carbon dioxide and carbon monoxide.



(*x*) **Reduction.** Oxalic acid when reduced with zinc and sulphuric acid gives glycollic acid. When subjected to electrolytic reduction with lead cathode, it yields glycollic and glyoxylic acids.



Uses

(*i*) Oxalic acid is used in volumetric analysis and is a constituent of most metal polishes.
(*ii*) It is used to remove ink stains from cloth and to bleach straw (for hats).
(*iii*) Its antimony salts are used as mordants in printing and dyeing.
(*iv*) Potassium ferrous oxalate is used in photography as a developer.
(*v*) For the laboratory preparation of allyl alcohol and formic acid.

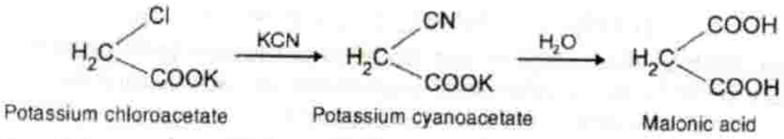
Analytical Tests

(*i*) Oxalic acid and its salts yield a mixture of carbon monoxide and carbon dioxide when heated with concentrated sulphuric acid.

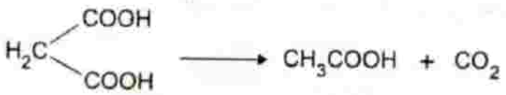
(*ii*) A neutral solution of oxalic acid when treated with calcium chloride, yields a white precipitate of calcium oxalate which is insoluble in acetic acid.
(*iii*) Oxalic acid and its salts decolorise acidified potassium permanganate solution on warming.

2. Malonic Acid (*Propanedioic acid*), $CH_2(COOH)_2$

Malonic acid is commonly prepared by heating potassium chloroacetate with aqueous potassium cyanide followed by hydrolysis of the product (Potassium cyanoacetate) with hydrochloric acid.

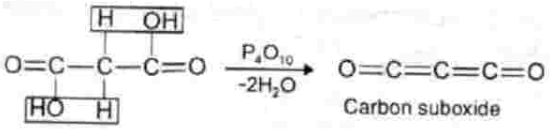


Malonic acid is a colourless, crystalline solid (m.p. 318.5 K) soluble in water and alcohol but is sparingly soluble in ether. It gives the usual reactions of a dicarboxylic acid, *e.g.*, on heating to 413-423 K, it eliminates a molecule of carbon dioxide to yield acetic acid.



$$H_2C(COOH)_2 \longrightarrow CH_3COOH + CO_2$$

When malonic acid is heated with phosphorus pentoxide, a small amount of carbon suboxide is produced.

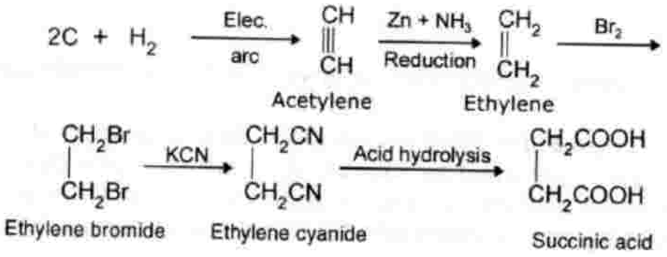


Its diethyl ester (*diethylmalonate*) is a valuable synthetic reagent in organic chemistry.

3. Succinic Acid (*Butanedioic acid*), $HOOC.CH_2CH_2.COOH$

It was originally obtained by distillation of amber called *succinum* in Latin (hence the name). It is also formed during the fermentation of sugar, etc.

Synthesis of Succinic Acid



Preparation

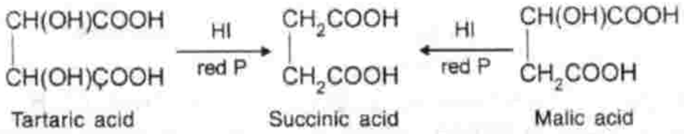
(*i*) *From ethylene bromide as given above.*

(*ii*) *By the reaction between malonic ester and ethyl chloroacetate or iodine*

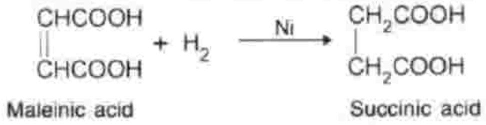
Manufacture

(*i*) It is prepared on a large scale as a by-product during the distillation of amber. The distillate is evaporated to dryness and crystallized from hot dil. HNO_3.

(*ii*) *Tartaric acid and malic acid get reduced to succinic acid when heated with hydriodic acid and red phosphorus in a sealed tube.*



(*iii*) *By the catalytic or electrolytic reduction of maleic acid.*

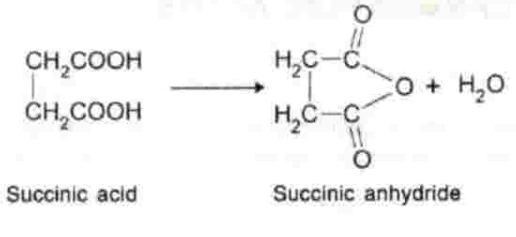


Properties of Succinic Acid

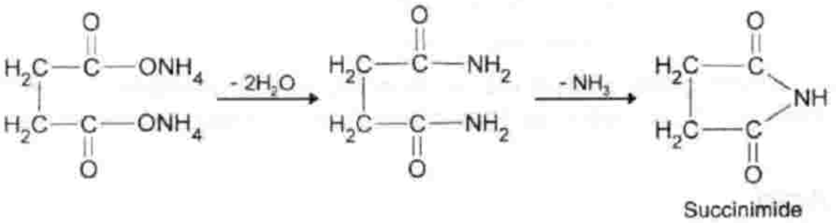
(*a*) **Physical Properties.** It is a crystalline solid (m.p. 458 K) which is moderately soluble in water and alcohol but is sparingly soluble in ether.

(*b*) **Chemical Properties.** Succinic acid gives the normal reactions of dicarboxylic acid. A few more important reactions are:

(*i*) Succinic acid generally sublimes on heating. However, a small amount of succinic anhydride is also obtained on strong heating.



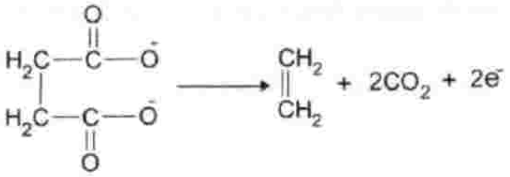
(*ii*) On heating ammonium succinate, succinimide is formed which on further heating loses a molecule of ammonia to give succinimide.



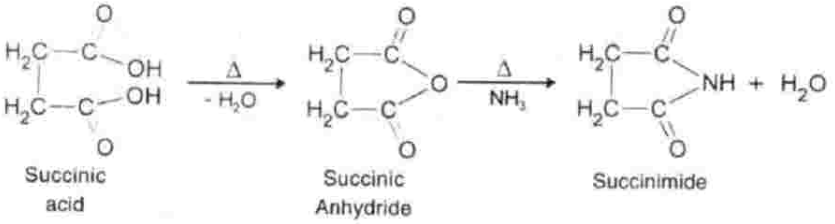
(*iii*) On electrolysis of an aqueous solution of sodium or potassium succinate ethylene is obtained.

At cathode: $2H_2O + 2e^- \longrightarrow 2OH^- + H_2$

At anode:

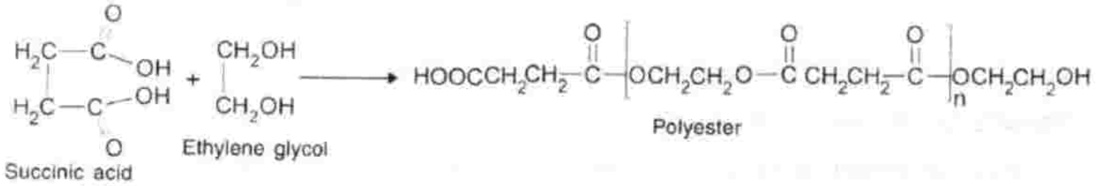


(*iv*) On heating with dry ammonia, succinimide is obtained.



Succinimide on reaction with alkaline solution of Br_2 at 273K forms N-bromosuccinimide (NBS), which is a useful reagent for allylic bromination.

(*v*) Succinic acid on heating with an excess of ethylene glycol forms a polyester, known as Alkyd. esters.



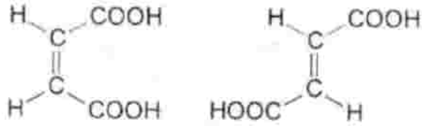
Uses

Succinic acid finds use in volumetric analysis, medicine and in the manufacture of dyes and perfumes.

UNSATURATED DICARBOXYLIC ACIDS

Introduction

The formula of the simplest unsaturated dibasic acid is HOOC.CH=CH.COOH. In fact this formula represents two important isomers, *viz.*, maleic acid and fumaric acid



cis (Maleic acid) *trans* (Fumaric acid)

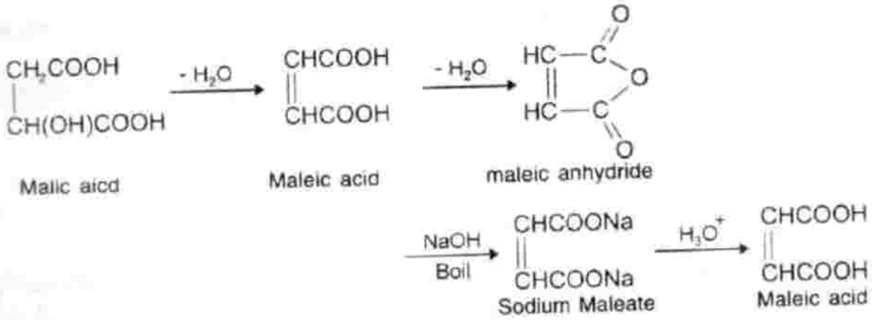
Maleic acid which gives anhydride on heating is the cis-variety and fumaric acid is the trans variety. Thus, we find that maleic and fumaric acids show *geometrical isomerism*.

1. Maleic Acid

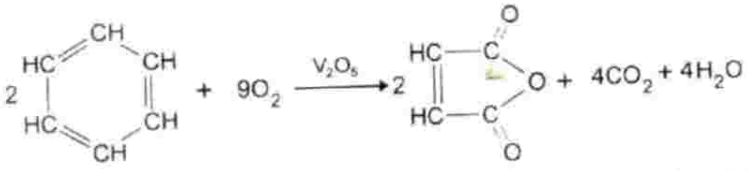
Preparation

Maleic acid is a synthetic compound and does not occur in nature. It may be prepared:

(*i*) *By heating malic acid at about 520 K. The maleic anhydride formed is converted into the acid by boiling with alkali followed by acidification.*



(*ii*) *By oxidation of benzene with air in the presence of vanadium pentoxide at 680 – 700K.*



The anhydride so obtained is hydrolysed as given above and acidified to yield the maleic acid.

Properties

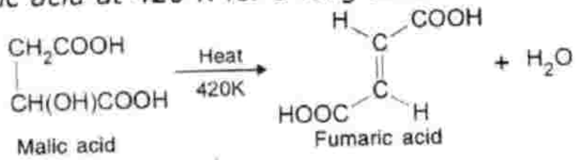
It is a colourless, crystalline solid (m.p. 403 K) which is soluble in water. On heating a part of the acid distils unchanged and the rest changes into maleic anhydride. The anhydride is also obtained when the acid is heated with acetic anhydride. When heated for some time at 423 K, it changes into fumaric acid. Its chemical properties have been described under fumaric acid.

2. *Fumaric Acid*

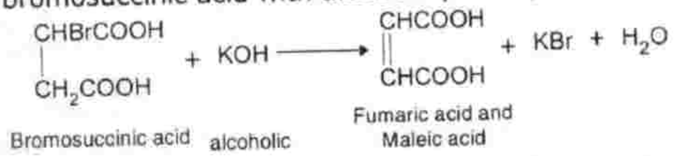
Fumaric acid occurs in nature in many plants.

Preparation

(*i*) *By heating malic acid at 420 K for a long time.*



(*ii*) By heating bromosuccinic acid with alcoholic potash, maleic acid is also obtained.

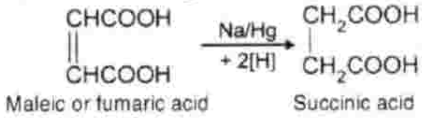


Properties

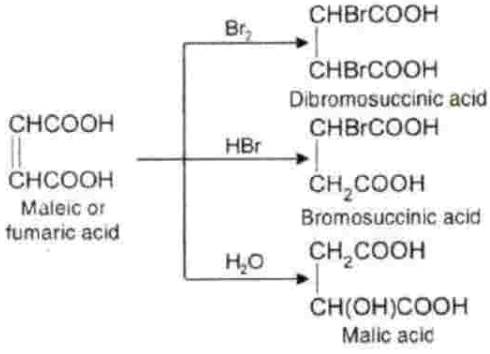
It is a colourless, crystalline solid (m.p. 560 K) which is slightly soluble in water. It does not give the anhydride of its own but gives maleic anhydride when heated at 500 K.

Chemically both fumaric and maleic acids give the reactions of alkenes as well as dibasic acids. For example,

(*i*) **Reduction.** Both fumaric acid and maleic acid give succinic acid when reduced catalytically or with sodium amalgam.

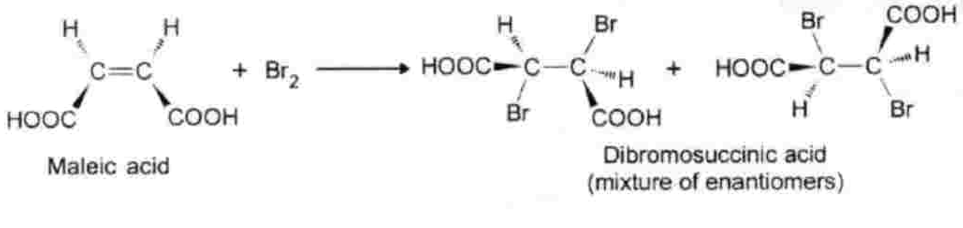


(*ii*) **Addition reactions.** Maleic acid and fumaric acid both form addition products with bromine and hydrobromic acid. A molecule of water is added on boiling maleic acid with dilute sulphuric acid under pressure to yield malic acid.

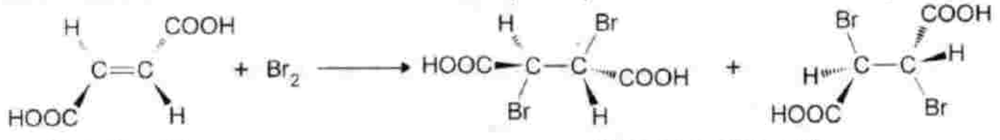


Addition of bromine to maleic acid or fumaric acid takes place in a stereospecific manner, *i.e.*, one particular stereoisomer form of the starting material reacts in such a way that it gives a specific stereoisomeric form of the product.

When maleic acid reacts with bromine in CCl_4 or acetic acid, the product is a mixture of enantiomers of dibromosuccinic acids (*i.e.*, a racemic mixture).



When fumaric acid reacts with bromine, the product is a meso compound.



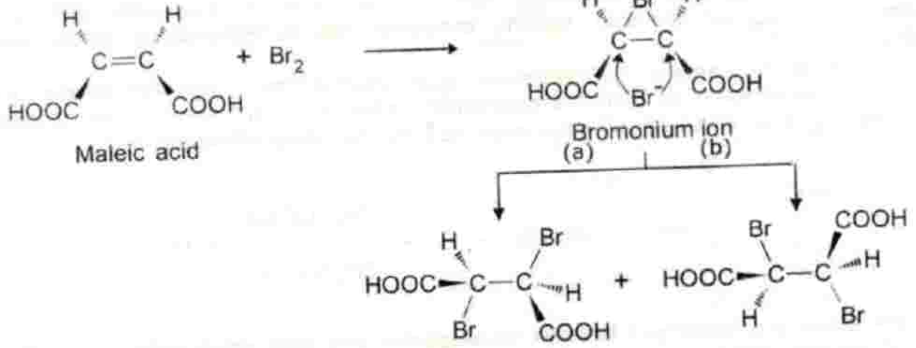
Fumeric acid

Dibromosuccinic acid
(meso compound)

Since both maleic acid and fumaric acid are stereoisomers of each other and the products of their reaction with bromine, racemic or meso dibromosuccinic acid are different stereoisomeric forms of product, both the reactions are stereospecific.

The formation of these products is explained below.

Maleic acid adds bromine to form an intermediate bromonium ion, which can then react with bromide ion in two possible ways (a or b) to yield enantiomers of dibromosuccinic acid.

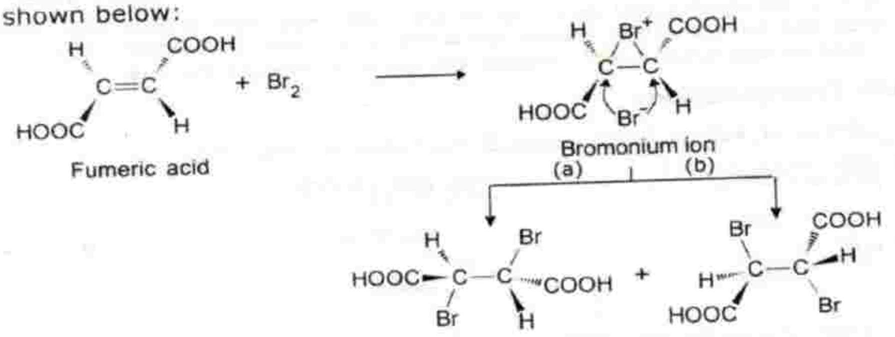


Maleic acid

Bromonium ion

Dibromosuccinic acid
(mixture of enantiomers)

Fumaric acid adds bromine in a similar manner to form meso-dibromosuccinic acid as shown below:



Fumeric acid

Bromonium ion

Dibromosuccinic acid
(meso compound)

(*iii*) **Oxidation.** Fumaric and maleic acids both get oxidised by alkaline permanganate to tartaric acid.

$$\begin{array}{l}\text{CHCOOH}\\ \|\\ \text{CHCOOH}\end{array} + H_2O + O \longrightarrow \begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array}$$

Maleic or fumaric acid (alkaline permanganate) Tartaric acid

(*iv*) ***Formation of salts and esters.*** Both of them form salt when treated with alkalis and esters when treated with alcohols.

$$\begin{array}{l}\text{CHCOONa}\\ \|\\ \text{CHCOONa}\end{array} \qquad \begin{array}{l}\text{CHCOOC}_2\text{H}_5\\ \|\\ \text{CHCOOC}_2\text{H}_5\end{array}$$

Sod. salt of maleic or fumaric acid

Dietyl maleate or fumerate

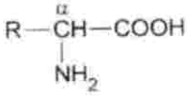
AMINO SUBSTITUTED CARBOXYLIC ACIDS

Amino Acids

Proteins are complex nitrogenous substances which occur in plants and in most cells of animal body. Proteins on hydrolysis with strong inorganic acids or by enzymes yield a mixture of amino acids. In all about twenty-five amino acids are known to occur in nature, ten of which are essential, *i.e.*, a deficiency of any of these can prevent growth in young animals, and may even cause death.

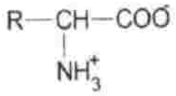
Structure of α-Amino Acids

α-Amino acids are the compounds containing an amino group and a carboxylic acid group within the same molecule. They are represented as follow:



$$R-\overset{\alpha}{C}H(NH_2)-COOH$$

However, their properties such as high melting points, solubility in polar solvents, large dipole moments and the low values of acidity constant (K_a) and basicity constant (K_b) cannot be explained by the above structure. Since amino acids contain both a basic group ($-NH_2$) and an acidic group ($-COOH$), an amino acid undergoes an internal acid-base reaction to form a *dipolar ion* called *Zwitterion* as shown below:



$$R-CH(NH_3^+)-CO\overset{-}{O}$$

General Methods of Preparation of Amino Acids.

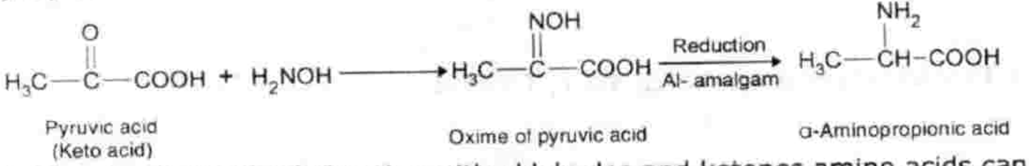
(*i*) ***By treating halogen-substituted acids with ammonia or potassiophthalimide (Gabriel phthalimide reactions)***.

$$ClCH_2COOH + H_2O \xrightarrow{NH_3} H_2NCH_2COOH \xrightarrow[\text{reactions}]{\text{Secondary}} NH(CH_2COOH)_2 + N(CH_2COOH)_3$$

Chloroacetic acid — Aminoacetic acid — Secondary amino acid — Tertiary amino acid

To avoid secondary reactions, the Gabriel's phthalimide synthesis is generally used (*see under Glycine*)

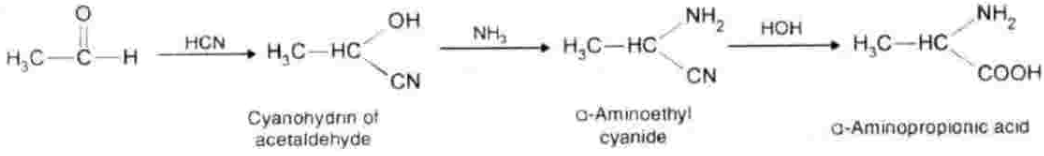
(*ii*) ***By reduction of the oximes of aldehydic and ketonic acids.***



$$H_3C-\overset{O}{\overset{\|}{C}}-COOH + H_2NOH \longrightarrow H_3C-\overset{NOH}{\overset{\|}{C}}-COOH \xrightarrow[\text{Al- amalgam}]{\text{Reduction}} H_3C-\overset{NH_2}{\overset{|}{C}H}-COOH$$

Pyruvic acid (Keto acid) — Oxime of pyruvic acid — α-Aminopropionic acid

(*iii*) ***Strecker's Method***. Starting with aldehydes and ketones amino acids can be synthesised as follows:



Cyanohydrin of acetaldehyde — α-Aminoethyl cyanide — α-Aminopropionic acid

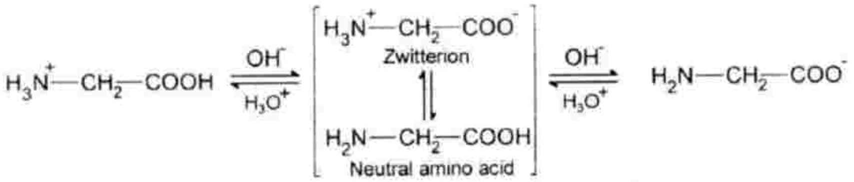
(*iv*) ***From Proteins.*** Proteins on heating with $Ba(OH)_2$ at 473 K in an autoclave, get hydrolysed to give a mixture of amino acids. This mixture on esterification gives a mixture of esters which can be separated by fractional distillation. The esters on hydrolysis give the corresponding amino acids.

Physical Properties

Most of the amino acids are crystalline substances with high melting points and are sweet in taste. Simpler acids are readily soluble in water, whereas higher members are less soluble. They are insoluble in alcohol and ether. Except glycine, all are optically active; and therefore some amino acids are dextrorotatory while others are laevorotatory. They give a deep red colour with ferric chloride.

Chemical Properties

The structure of the amino acids suggests that these compounds should behave both as acids and bases (amphoteric in nature). For example in an aqueous solution of glycine we have the following equilibria:



$$H_3\overset{+}{N}-CH_2-COOH \underset{H_3O^+}{\overset{OH^-}{\rightleftharpoons}} \left[\begin{array}{c} H_3\overset{+}{N}-CH_2-COO^- \\ \text{Zwitterion} \\ \updownarrow \\ H_2N-CH_2-COOH \\ \text{Neutral amino acid} \end{array}\right] \underset{H_3O^+}{\overset{OH^-}{\rightleftharpoons}} H_2N-CH_2-COO^-$$

The position of the equilibrium, however, depends on the *p*H of the solution. The dipolar ion is termed as a zwitterion. The existence of α-amino acids as zwitterions is confirmed by the following facts.

(*i*) Most of the amino acids are crystaline substances with high melting points. The high melting point of amino acids can be explained by strong interparticle forces arising from the electrostatic interactions of dipolar structure.

(*ii*) The amino acids are insoluble in non-polar organic solvents such as benzene, ether etc., but are soluble in water.

(*iii*) Their aqueous solutions behave like solutions of substances having high dipole moments. This shows that they have considerable ionic or dipolar structure.

(*iv*) Spectroscopic studies of these compounds do not show the presence of free amino or carboxylic groups.

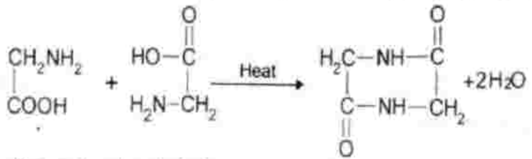
(*v*) Amino acids show low values of acidity constant (K_a) and basicity constant (K_b) than the usual values for aliphatic carboxylic acids and amines.

The acidic portion in the zwitterion is the ammonium ion ($-NH_3^+$) rather than the free $-COOH$ group. Similarly the basic centre is the carboxylate ion ($-COO^-$) rather than the free $-NH_2$ group. Acidity constant, K_a for glycine $= 1.6 \times 10^{-10}$ while its

(c) Distinctive Properties of α-, β-, and γ-Amino Acids.

Intramolecular reactions of the amino acids on heating depend upon the positions of the amino group in the molecule with respect to carboxyl group, as will be clear from the following examples:

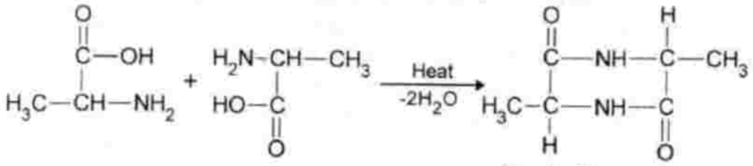
(*i*) α-***amino acids*** lose water to give cyclic anhydrides called diketopiperazines.



Two molecules of glycine

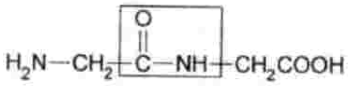
Diketopiperazine

Similarly $CH_3CH(NH_2)CO_2H$ will yield dimethyldiketo piperazine.



Dimethyldiketo piperazine

Diketopiperazine on partial hydrolysis gives a dipeptide of glycine.

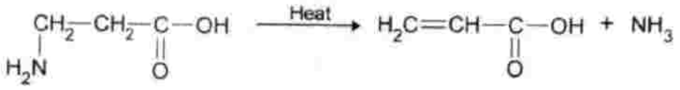


$H_2N-CH_2-\boxed{\overset{O}{\overset{\|}{C}}-NH}-CH_2COOH$

Peptide linkage

Peptides are compounds obtained by linking COOH group of one amino acid molecule with NH_2 group of the other amino acid molecule. The CONH group linking the two molecules is termed the ***peptide linkage***.

(*ii*) β-***amino acids*** readily produce unsaturated acids with the loss of ammonia.

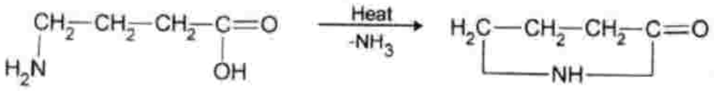


$H_2N-CH_2-CH_2-\underset{\overset{\|}{O}}{C}-OH \xrightarrow{\text{Heat}} H_2C=CH-\underset{\overset{\|}{O}}{C}-OH + NH_3$

β-Amino propionic acid

Acrylic acid

(*iii*) γ-***amino acids*** readily give rise to inner anhydrides known as lactams with the loss of one molecule of water.



γ-Aminobutyric acid

γ-Butyro-lactam

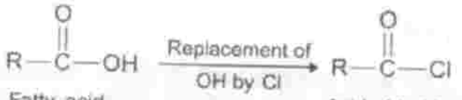
δ-amino acids and others having longer chains behave similar to γ-amino acids.

CARBOXYLIC ACID DERIVATIVES

(A) ACID OR ACYL CHLORIDES

Nomenclature

Acid chlorides are obtained by the replacement of the hydroxyl by chlorine in the carboxyl group. These are also known as *acyl chlorides* because they contain the acyl group RCO—



$$\underset{\text{Fatty acid}}{R-\overset{O}{\overset{\|}{C}}-OH} \xrightarrow[\text{OH by Cl}]{\text{Replacement of}} \underset{\text{Acid chloride or Acylchloride}}{R-\overset{O}{\overset{\|}{C}}-Cl}$$

The common names of acid chlorides are obtained by changing the suffix *-ic* acid of the trivial or IUPAC names of the acids into *-yl* chloride, *e.g.*,

Formula	*Parent acid*	*Common names*	*IUPAC names*
$HCOCl$	Formic acid	Formyl chloride	Methanoyl chloride
CH_3COCl	Acetic acid	Acetyl chloride	Ethanoyl chloride
C_2H_5COCl	Propionic acid	Propionyl chloride	Propanoyl chloride
C_3H_7COCl	Butyric acid	Butyryl chloride	Butanoyl chloride

General Methods of Preparation

Acid chlorides may be prepared by the following general methods:

(*i*) *By heating the acid with phosphorus trichloride or pentachloride e.g.,*

$$3CH_3COOH + PCl_3 \longrightarrow 3CH_3COCl + H_3PO_3$$

$$\underset{\text{Propanoic acid}}{C_2H_5COOH} + PCl_5 \longrightarrow \underset{\text{Propanoyl chloride}}{C_2H_5COCl} + POCl_3 + HCl$$

(*ii*) *By the action of thionyl chloride on the acid.*

$$\underset{\text{Acetic acid}}{CH_3COOH} + \underset{\text{Thionyl chloride}}{SOCl_2} \longrightarrow \underset{\text{Acetyl chloride}}{CH_3COCl} + SO_2 + HCl$$

(*iii*) *Acid chlorides are prepared industrially by distilling sodium salts of the acids with phosphorus trichloride, phosphoryl chloride or sulphuryl chloride, e.g., acetyl chloride is prepared from sodium acetate.*

$$2\,CH_3COONa + POCl_3 \longrightarrow 2CH_3COCl + NaCl + NaPO_3$$

$$\underset{\text{Sodium acetate}}{2\,CH_3COONa} + SO_2Cl_2 \longrightarrow \underset{\text{Acetyl chloride}}{2CH_3COCl} + Na_2SO_4$$

General Properties of Acid Chlorides

Physical Properties

Lower members are colourless, pungent-smelling liquids, while the higher homologues are colourless solids. They fume in moist air. These are insoluble in water but slowly dissolve on account of hydrolysis.

IR spectra. The IR spectrum of an acid chloride shows a prominent C=O stretching band at 1780-1850 cm^{-1} and a C—Cl stretching band at 650-800 cm^{-1}.

Chemical Properties

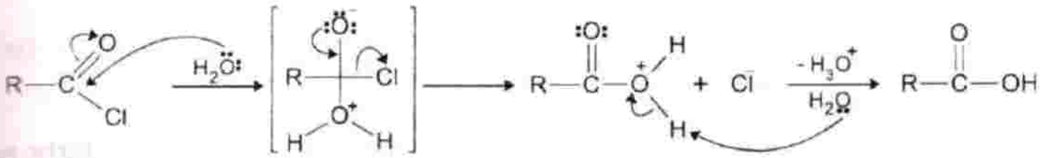
The chlorine atom in acid chlorides is very reactive. This makes acid chlorides very important reagents. Various chemical reactions shown by them are:

(*i*) *Hydrolysis.* Acid chlorides are readily hydrolysed to form the corresponding acids. For example,

$$\underset{\text{Acid chloride}}{RCOCl} + H_2O \longrightarrow \underset{\text{Carboxylic acid}}{RCOOH} + HCl$$

$$\underset{\text{Acetyl chloride}}{CH_3COCl} + H_2O \longrightarrow \underset{\text{Acetic acid}}{CH_3COOH} + HCl$$

The rate of hydrolysis decreases with increase in the size of the alkyl portion of the acid chlorides. The mechanism of the reaction is as follows.



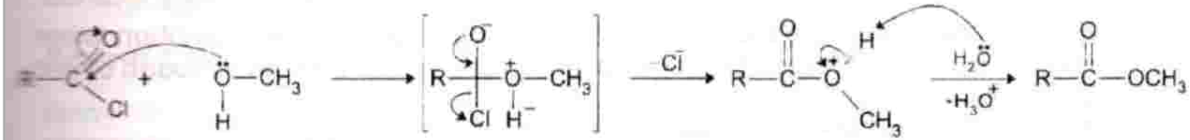
(*ii*) *Alcoholysis.* Acid chlorides react with alcohols and phenols to form esters. The reaction of an organic compound with an alcohol is known as alcoholysis.

$$\underset{\text{Acid chloride}}{R-\overset{O}{\overset{\|}{C}}-Cl} + \underset{\text{Alcohol}}{R'OH} \longrightarrow \underset{\text{Ester}}{R-\overset{O}{\overset{\|}{C}}-OR'} + H_2O$$

$$\underset{\text{Acetyl chloride}}{R-\overset{O}{\overset{\|}{C}}-Cl} + \underset{\text{Methanol}}{CH_3OH} \longrightarrow \underset{\text{Methyl acetate}}{R-\overset{O}{\overset{\|}{C}}-OCH_3} + H_2O$$

The reaction of an acid chloride with alcohol is usually carried out in the presence of a weak base such as pyridine. The role of pyridine apart from a catalyst, is to help in the removal of HCl.

The mechanism of alcoholysis is similar to that of hydrolysis of an acyl halide as shown below.

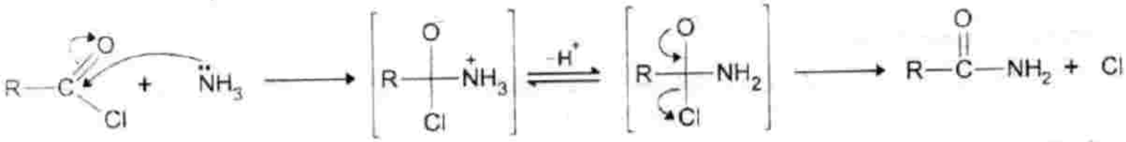


(*iii*) *With amino compounds.* Acylation occurs when acid chlorides react with amino compounds. During acylation H-atom of the amino group (—NH$_2$ or>NH) is replaced by an acyl (—COR) group.

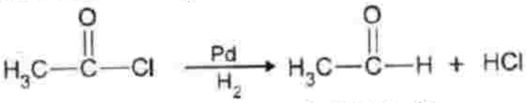
$$\underset{\text{Acetyl chloride}}{CH_3COCl} + \underset{\text{Ammonia}}{NH_3} \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + HCl$$

$$\underset{\text{Acetyl chloride}}{CH_3COCl} + \underset{\text{Amine}}{CH_3NH_2} \longrightarrow \underset{\text{Acetyl derivative of the amine}}{CH_3CONHCH_3} + HCl$$

The mechanism of the reaction is as follows:



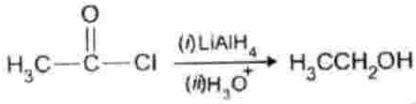
(*iv*) *Reduction*. Acid chlorides on reduction with hydrogen in presence of palladium suspended in $BaSO_4$ yield aldehydes (*Rosenmund's reaction*). For example, acetyl chloride on reduction gives acetaldehyde.



$$H_3C-\overset{\overset{\large O}{\|}}{C}-Cl \xrightarrow[H_2]{Pd} H_3C-\overset{\overset{\large O}{\|}}{C}-H + HCl$$

Acetaldehyde

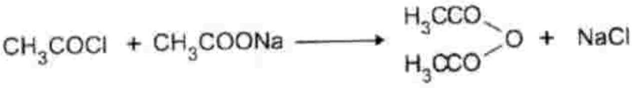
Acid chlorides are, however, reduced to alcohols on reaction with lithium aluminium hydride



$$H_3C-\overset{\overset{O}{\|}}{C}-Cl \xrightarrow[(ii)H_3\overset{+}{O}]{(i)LiAlH_4} H_3CCH_2OH$$

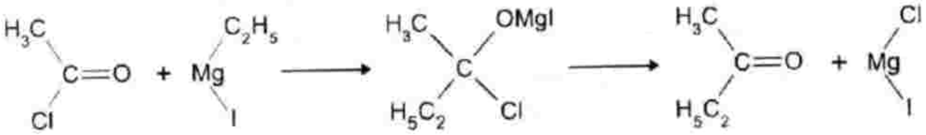
Acetal chloride Ethyl alcohol

(*v*) *Formation of Acid anhydrides.* When heated with sodium salt of a fatty acid, they give acid anhydride, *e.g.*, acetyl chloride with sodium acetate gives acetic anhydride.



Acetic anhydride

(*vi*) *With Grignard reagents.* Acid chlorides react with Grignard reagents to produce ketones, *e.g.*,



Acetyl chloride Ethyl magnesium iodide Ethyl methyl ketone

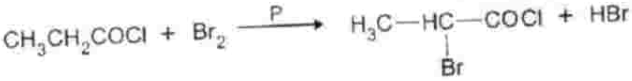
Grignard reagents however react further with ketones to give tertiary alcohols.

(*vii*) *Halogenation.* Acyl chlorides are readily halogenated in the α-position when treated with chlorine or bromine in the presence of a small amount of red phosphorus.

This reaction is called Hell Volhard Zelinsky (HVZ) reaction

$$CH_3COCl + Cl_2 \xrightarrow{P} ClCH_2COCl + HCl$$

Acetyl chloride α-chloro acetyl chloride



$$CH_3CH_2COCl + Br_2 \xrightarrow{P} H_3C-\underset{\underset{Br}{|}}{HC}-COCl + HBr$$

Propionyl chloride α-Bromopropionyl chloride

(*viii*) *With carboxylic acids.* The acyl chlorides react with carboxylic acids as indicated below:

$$RCOCl + R'COOH \longrightarrow R'COCl + RCOOH$$

In case R'COCl has lowest boiling point, whole of R'COOH may be converted to R'COCl.

(*ix*) *With Ethers.* Acetyl chloride reacts with ethers in the presence of zine chloride to form alkyl acetate and alkyl chloride.

$$CH_3COCl + C_2H_5OC_2H_5 \longrightarrow CH_3COOC_2H_5 + C_2H_5Cl$$

Acetyl chloride Ether Ethyl acetate Ethyl chloride

(*x*) *With potassium cyanide.* Acetyl chloride reacts with potassium cyanide to give acetyl cyanide which on hydrolysis yields pyruvic acid.

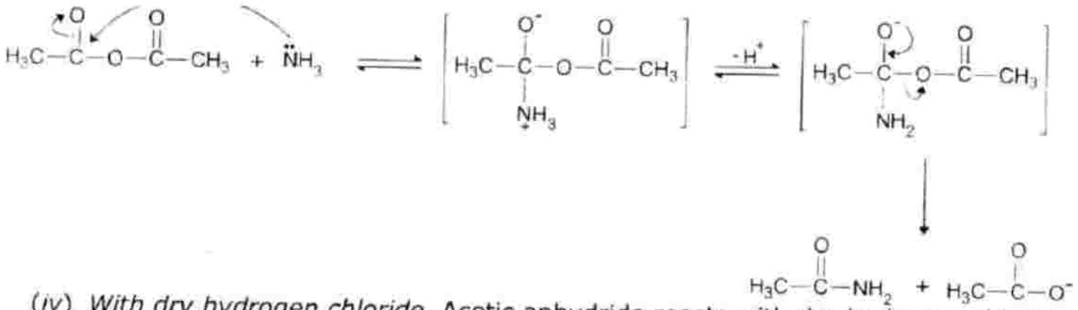
$$CH_3COCl \xrightarrow{KCN} CH_3COCN \xrightarrow{H_2O} CH_3COCOOH$$

Acetyl chloride Acetyl cyanide Pyruvic acid

(*xi*) *With organo cadmium compounds.* Acid chlorides react with organo cadmium compounds to form ketones.

$$2CH_3COCl + (CH_3)_2Cd \longrightarrow 2CH_3COCH_3 + CdCl_2$$

Acetyl Chloride Dimethyl Cadmium Acetone



(*iv*) *With dry hydrogen chloride.* Acetic anhydride reacts with dry hydrogen chloride to give acetyl chloride.

$$CH_3COOCOCH_3 + HCl \longrightarrow CH_3COCl + CH_3COOH$$

Acetic anhydride　　Acetyl chloride　　Acetic acid

(*iv*) *With phosphorus pentachloride.* Acetic anhydride reacts with phosphorus pentachloride to give acetyl chloride.

$$(CH_3CO)_2O + PCl_5 \longrightarrow 2\,CH_3COCl + POCl_3$$

Uses

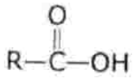
Acetic anhydride is largely used:

(*i*) As an acetylating agent.
(*ii*) For the detection of hydroxy and amino groups.
(*iii*) In the manufacture of dyes and acetate rayon from cellulose.
(*iv*) In the manufacture of aspirin and some other pharmaceuticals.

(*C*) ACID AMIDES

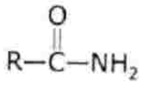
Nomenclature

Acid amides are compounds in which the hydroxyl group present in the carboxyl group of an acid had been replaced by the amino group ($-NH_2$).



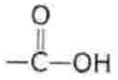
$R-COOH$

Carboxylic acid



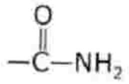
$R-CONH_2$

Acid amide



$-COOH$

Carboxyl group



$-CONH_2$

Amide group

Their common names have been obtained by replacing the suffix *-ic acid* of the corresponding acid by amide. According to the **IUPAC** system, the final *e* of the parent alkane is replaced by *amide.*

Formula	*Parent acid*	*Common name*	*Parent alkane*	*IUPAC name*
$HCONH_2$	$HCOOH$ Formic acid	Formamide	Methane	Methanamide
CH_3CONH_2	CH_3COOH Acetic acid	Acetamide	Ethane	Ethanamide
$C_2H_5CONH_2$	C_2H_5COOH Propionic acid	Propionamide	Propane	Propanamide
$C_3H_7CONH_2$	C_3H_7COOH Butyric acid	Butyramide	Butane	Butanamide

Formamide, $HCONH_2$

Formamide is prepared by heating ammonium formate in an atmosphere of ammonia.

$$\underset{\text{Ammonium formate}}{HCOONH_4} \longrightarrow \underset{\text{Formamide}}{HCONH_2} + H_2O$$

It is manufactured by the catalytic combination of ammonia and carbon monoxide under high pressure.

$$CO + \underset{\text{Ammonia}}{HNH_2} \longrightarrow \underset{\text{Formamide}}{HCONH_2}$$

Formamide is a hygroscopic liquid readily soluble in water and alcohol. It is unstable and readily decomposes at its boiling point. In this respect it differs from other amides.

$$\underset{\text{Formamide}}{HCONH_2} \longrightarrow CO + NH_3$$

It is an ionising solvent and dissolves many organic compounds. In industry formamide is used as solvent as well as a plasticizer.

Acetamide, Ethanamide, CH_3CONH_2

Preparation

Acetamide is obtained

(*i*) *By heating ammonium acetate*

$$\underset{\text{Ammonium acetate}}{CH_3COONH_4} \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + H_2O$$

Since ammonium acetate tends to dissociate on heating, the reaction is carried out in the presence of some free acetic acid which suppresses dissociation and hydrolysis of the salt. Acetamide is conveniently prepared in the laboratory by this method.

$$CH_3COONH_4 \rightleftharpoons CH_3COOH + NH_3$$

Expt. A mixture of ammonium acetate crystals and glacial acetic acid (equal weights) is taken in a round-bottom flask fitted with a long upright air condenser and refluxed for about 4 hours. Partial dehydration of ammonium acetate occurs to give acetamide and the water vapours escape through the condenser. The contents are transferred, while still hot, to a distillation flask and distilled using an air condenser. Acetamide distils over above 487 K and the distillate solidifies on cooling. It may be further purified by recrystallization from alcohol and benzene.

(*ii*) *By the action of concentrated solution of ammonia on acetyl chloride, acetic anhydride or ethyl acetate (ester).*

$$\underset{\text{Acetyl chloride}}{CH_3COCl} + 2\,NH_3 \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + NH_4Cl$$

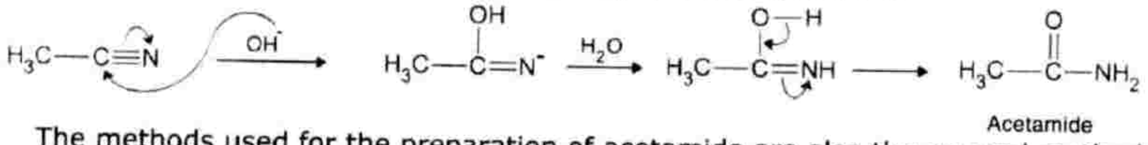
$$\underset{\text{Acetic anhydride}}{(CH_3CO)_2O} + 2\,NH_3 \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + CH_3COONH_4$$

$$\underset{\text{Ethyl acetate}}{H_3C-\overset{\overset{\displaystyle O}{\|}}{C}-OC_2H_5} + NH_3 \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + C_2H_5OH$$

(*iii*) *By the partial hydrolysis of methyl cyanide* effected by means of (*a*) alkaline hydrogen peroxide, or (*b*) by dissolving it in concentrated sulphuric acid and pouring the solution in cold water.

$$H_3C—C\equiv N \;+\; H_2O \xrightarrow[\text{or } H_2SO_4]{\text{Alk. } H_2O_2} CH_3CONH_2$$

The mechanism of the reaction can be represented as under:



The methods used for the preparation of acetamide are also the general methods used for the preparation of other amides.

Properties : Physical Properties

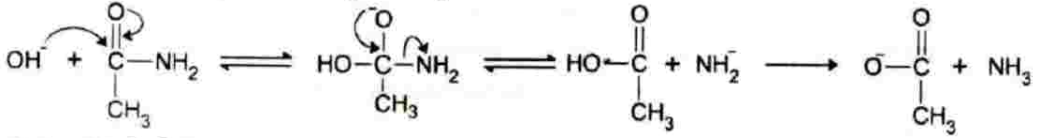
Acetamide is a colourless crystalline (m.p. 335 K; b.p. 495 K). It is practically odourless when pure. It is readily soluble in water, alcohol and ether.

(*i*) *Hydrolysis.* Acetamide is hydrolysed slowly by water, rapidly by acids and far more rapidly by alkalis.
Reflece hally by

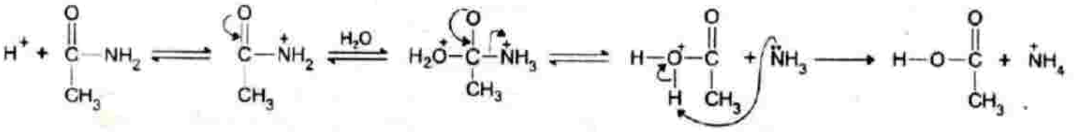
$$CH_3CONH_2 \xrightarrow[-\,NH_3]{H_2O} CH_3COOH$$

Mechanism of the reactions involved is given below:

(*a*) Basic hydrolysis of CH_3CONH_2:



(*b*) Acid hydrolysis of CH_3CONH_2:

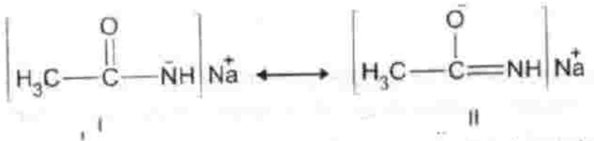


(*ii*) *Feebly Basic and Acidic Nature.* The presence of acetyl group not only reduces the basic character of the amino group but also makes the molecule feebly acidic. Acetamide is thus both feebly basic as well as acidic, e.g., it forms unstable salts with strong inorganic acids (*feebly basic character*) and dissolves mercuric oxide to form covalent mercury compounds in which mercury is probably linked to the nitrogen (*feebly acidic character*).

$$CH_3CONH_2 \;+\; HCl \longrightarrow CH_3CONH_2HCl$$

$$2\,CH_3CONH_2 \;+\; HgO \longrightarrow (CH_3CONH)_2Hg \;+\; H_2O$$

When treated with sodium or sodamide in ethereal solution, the sodium salt $[CH_3CONH]^-Na^+$ is formed. The structure of the sodium salt may be I or II.



I II

(*iii*) **Reduction.** Acetamide is reduced by sodium and ethanol or catalytically to ethylamine.

$$\underset{\text{Acetamide}}{CH_3CONH_2} \;+\; 4\,[H] \xrightarrow{Na\,/\,C_2H_5OH} \underset{\text{Ethylamine}}{CH_3CH_2NH_2} \;+\; H_2O$$

(*iv*) **Dehydration.** Acetamide is dehydrated to methyl cyanide when heated with phosphorus pentoxide.

$$\underset{\text{Acetamide}}{CH_3CONH_2} \xrightarrow[-H_2O]{P_4O_{10}} \underset{\text{Methyl cyanide}}{H_3C{-}C{\equiv}N}$$

(*v*) ***Action of Nitrous acid.*** When acetamide is treated with nitrous acid, nitrogen is evolved and acetic acid is formed.

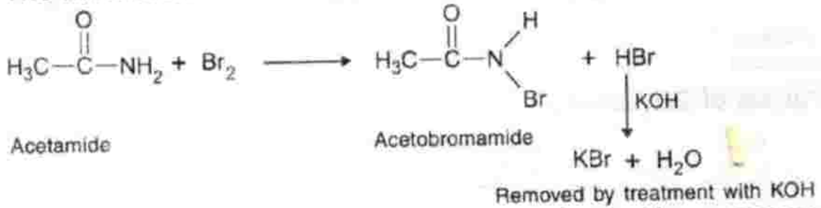
$$\underset{\text{Acetamide}}{CH_3CONH_2} + \underset{\text{Nitrous acid}}{HONO} \longrightarrow \underset{\text{Acetic acid}}{CH_3COOH} + H_2O + N_2$$

(*vi*) ***Hofmann Bromamide Reaction or Hofmann Degradation.*** On treatment with bromine and alkali, the amide gives a primary amine which has one carbon atom less than the amide. For example, acetamide gives methylamine. This reaction is known as *Holfmann reaction or Hofmann degradation.*

$$\underset{\text{Acetamide}}{CH_3CONH_2} + Br_2 + 4KOH \longrightarrow \underset{\text{Methylamine}}{CH_3NH_2} + 2KBr + K_2CO_3 + 2H_2O$$

The mechanism of the reaction is explained as follows:

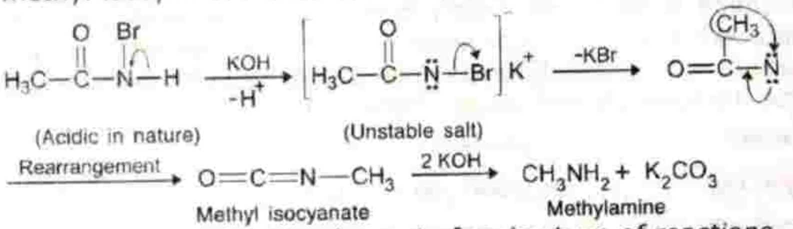
(*a*)



$$\underset{\text{Acetamide}}{H_3C{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}NH_2} + Br_2 \longrightarrow \underset{\text{Acetobromamide}}{H_3C{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}N(H)(Br)} + HBr \xrightarrow{KOH} KBr + H_2O$$

Removed by treatment with KOH

(*b*) Acetobromamide has acidic properties owing to the presence of the carbonyl group and the bromine atom. With KOH, it forms a salt which is unstable and loses a molecule of KBr and then undergoes molecular rearrangement to give methyl isocyanate. It is an example of 1, 2-alkyl shift.



$$H_3C{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}\overset{Br}{N}{-}H \xrightarrow[-H^+]{KOH} \left[H_3C{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}\ddot{N}{-}Br\right]K^+ \xrightarrow{-KBr} O{=}\overset{CH_3}{C}{-}\ddot{N} \xrightarrow{\text{Rearrangement}} O{=}C{=}N{-}CH_3 \xrightarrow{2\,KOH} CH_3NH_2 + K_2CO_3$$

This reaction is used in the *descent of series type of reactions, i.e.,* for preparing a lower homologue from a higher one.

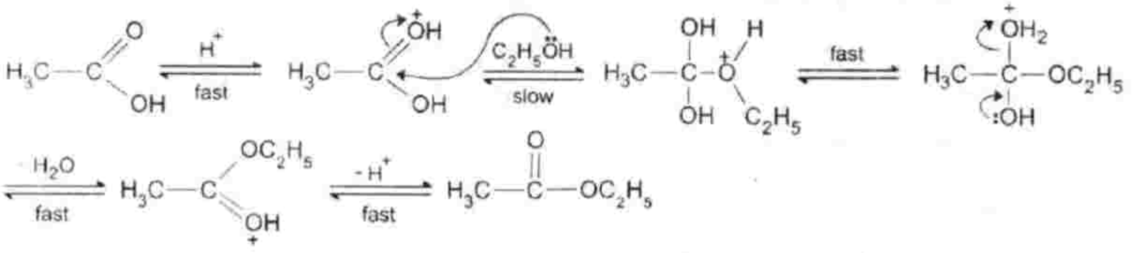
In the amides, the keto form behaves as a week base. The enol form, which is capable of giving metallic derivatives, behaves as a weak acid.

General Methods of Preparation of Esters

(1) **From carboxylic acids**. Esters are generally prepared by refluxing the acid with alcohol in the presence of small amounts of mineral acids as catalysts, *e.g.*, 5–10% concentrated sulphuric acid. The reaction is reversible and is known as esterification.

$$\mathrm{RCOOH} + \mathrm{R'OH} \xrightleftharpoons{H_2SO_4} \mathrm{RCOOR'} + \mathrm{H_2O}$$

Mechanism of the reaction is as follows:



Rate-determining step for esterification of acids is addition of alcohol. Alternatively, dry hydrogen chloride gas is passed into the acid-alcohol mixture till there is 3% increase in weight and the mixture is refluxed to yield an ester. Esterification may also be brought about by passing a mixture of the vapours of an acid and an alcohol over a metallic oxide catalyst (Thoria, ThO_2) at 575 K.

(2) **From silver salts of carboxylic acids**. By refluxing silver salt of an acid with an alkyl halide in ethanolic solution.

$$\underset{\substack{\text{Silver}\\\text{acetate}}}{\mathrm{CH_3COOAg}} + \underset{\substack{\text{Ethyl}\\\text{iodide}}}{\mathrm{C_2H_5I}} \longrightarrow \underset{\substack{\text{Ethyl acetate}\\(\textit{Ester})}}{\mathrm{CH_3COOC_2H_5}} + \mathrm{AgI}$$

This method is very useful in cases where direct esterification is difficult, *e.g.*, tertiary alcohols.

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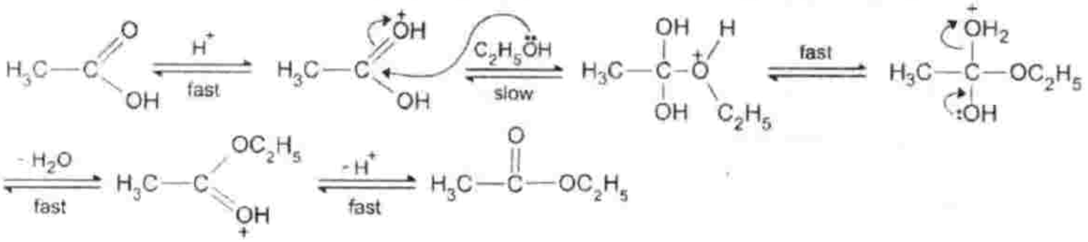

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This method is very useful in cases where direct esterification is difficult, *e.g.*, tertiary alcohols.

(3) **From acid chlorides or acid anhydrides.** By the action of an acid chloride or acid anhydride of an alcohol.

$$\underset{\text{Acetyl chloride}}{CH_3COCl} + \underset{\text{Ethanol}}{C_2H_5OH} \longrightarrow \underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + HCl$$

$$\underset{\text{Acid anhydride}}{(RCO)_2O} + \underset{\text{An alcohol}}{R'OH} \longrightarrow \underset{\text{Ester}}{RCOOR'} + RCOOH$$

The reaction with tertiary alcohols is very slow. With acid anhydrides there is tendency for dehydration of alcohol to olefin. With acid chlorides tertiary chlorides are also formed.

(4) **By reaction of carboxylic acids with diazomethane.** Methyl esters can very conveniently be obtained by treating an acid with an ethereal solution of diazomethane.

$$\underset{\text{Acid}}{RCOOH} + \underset{\text{Diazomethane}}{CH_2N_2} \longrightarrow \underset{\text{Ester}}{RCOOCH_3} + N_2$$

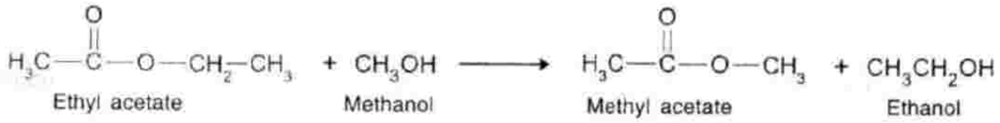
(5) **From aldehydes.** Ester may also be obtained by condensation of aldehydes in the presence of aluminium ethoxide (***Tischenko reaction***).

$$H_3C-\underset{\underset{O}{\|}}{\overset{\overset{H}{|}}{C}} + O=\underset{\underset{H}{|}}{C}-CH_3 \xrightarrow{Al(OC_2H_5)_3} H_3C-\underset{\underset{O}{\|}}{C}-O-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-CH_3$$

Acetaldehyde (Two molecules)

Ethyl acetate

(6) **Transesterification**. The reaction of an ester with alcohol in the presence of an acid or a base as the catalyst yields a new ester, the reaction is known as **transesterification**. For example,



$$\underset{\text{Ethyl acetate}}{H_3C-\overset{\overset{O}{\|}}{C}-O-CH_2-CH_3} + \underset{\text{Methanol}}{CH_3OH} \longrightarrow \underset{\text{Methyl acetate}}{H_3C-\overset{\overset{O}{\|}}{C}-O-CH_3} + \underset{\text{Ethanol}}{CH_3CH_2OH}$$

General Properties of Esters

Physical Properties

(*i*) Esters are colourless neutral liquids or solids with characteristic pleasant odours.

(*ii*) Boiling points of methyl and ethyl esters are lower than those of the corresponding acids. Straight-chain esters have higher boiling points than their branched-chain isomers.

(*iii*) Esters with low molecular weight are fairly soluble in water. The solubility decreases as the molecular weight increases. All esters are soluble in most of the organic solvents. Many of them are good solvents for other substances as well.

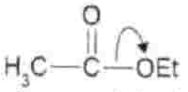
Chemical Properties

(*i*) ***Hydrolysis.*** Esters are hydrolysed by acids or alkalies to form alcohols and acids or their sodium salts. For example, ethyl acetate is hydrolysed as under:

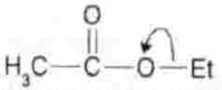
$$\underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + HOH \xrightarrow{\text{acid}} \underset{\text{Acetic acid}}{CH_3COOH} + \underset{\text{Ethanol}}{C_2H_5OH}$$

$$\underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + NaOH \longrightarrow \underset{\text{Sodium acetate}}{CH_3COONa} + \underset{\text{Ethanol}}{C_2H_5OH}$$

The hydrolysis of carboxylic esters may be represented in two ways:

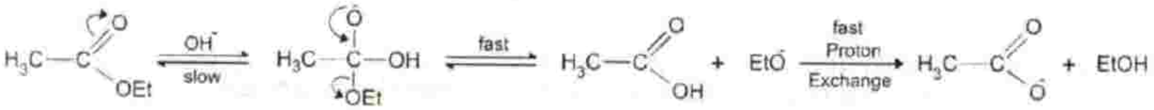


Acyl-oxygen heterolysis

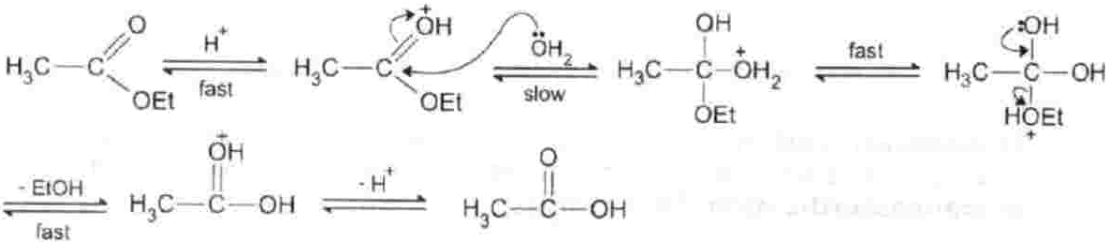


Alkyl-oxygen heterolysis

It has been observed that alkaline hydrolysis of esters proceeds with acyl-oxygen heterolysis and it is a bimolecular reaction. For example, base catalysed hydrolysis of ethyl acetate is formulated as under:



On the other hand acid catalysed hydrolysis proceeds with alkyl-oxygen heterolysis. This is also a bimolecular reaction and is formulated as under:



In the above reactions Et means the ethyl group, C_2H_5.

Experimental studies indicate that the rate determining step for acid hydrolysis is the addition of water.

During alkaline hydrolysis of an ester, sodium or potassium salt of the acid is obtained. Since alkali salts of the higher fatty acids are soaps, alkaline hydrolysis of an ester is also known as ***saponification***. Saponification of an ester is more rapid than its acid hydrolysis.

(*ii*) ***Reaction with Ammonia.*** Esters react with ammonia on heating to form amides. This reaction is an example of *ammonolysis* (*splitting by ammonia*).

$$\underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + NH_3 \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + C_2H_5OH$$

(*iii*) ***Reaction with Phosphorus Pentachloride.*** Phosphorus pentachloride reacts with esters to produce acid chloride and alkyl chlorides.

$$\underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + PCl_5 \longrightarrow \underset{\text{Acetyl chloride}}{CH_3COCl} + \underset{\text{Ethyl chloride}}{C_2H_5Cl} + POCl_3$$

(*iv*) ***Reduction.*** Reduction of an ester by means of excess of sodium and ethanol gives alcohols.

$$\underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + 4[H] \xrightarrow{C_2H_5OH/Na} \underset{\text{Ethanol}}{CH_3CH_2OH} + \underset{\text{Ethanol}}{C_2H_5OH}$$

$$RCOOR' + 4[H] \xrightarrow{C_2H_5OH/Na} RCH_2OH + R'OH$$

Other reducing agents used are: (*i*) lithium-aluminium hydride and (*ii*) hydrogen under pressure (100–300 atmospheres) in the presence of copper chromate (*catalyst*) at 570 K.

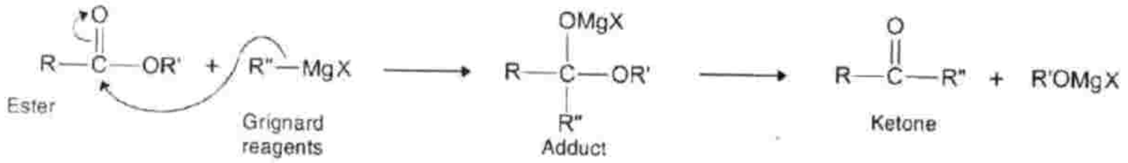
(*v*) ***Alcoholysis (splitting by alcohol).*** When an ester is refluxed with a large excess of alcohol in presence of a little acid or sodium alkoxide (*catalyst*), the alcohol residue present is replaced by another (a lower one). This method is called trans esterification.

$$\underset{\text{Butyl Acetate}}{CH_3COOC_4H_9} + C_2H_5OH \xrightleftharpoons{C_2H_5ONa} \underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + C_4H_9OH$$

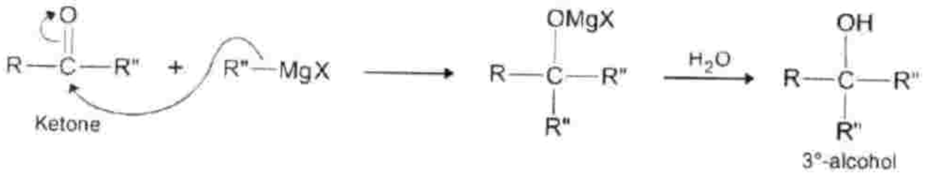
(*vi*) ***Acidolysis (splitting by acid).*** In acidolysis, the acid residue present is replaced by another acid residue.

$$\underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + \underset{\text{Valeric acid}}{C_4H_9COOH} \rightleftharpoons \underset{\text{Ethyl valerate}}{C_4H_9COOC_2H_5} + \underset{\text{Acetic acid}}{CH_3COOH}$$

(*vii*) ***Reaction with Grignard Reagents.*** Esters react with Grignard reagents to form addition products which undergo decomposition to give ketones.



Under the reaction conditions, ketone reacts further with Grignard reagent to form a tertiary alcohol



(*viii*) ***Claisen Ester Condensation.*** Two molecules of ethyl acetate in the presence of sodium ethoxide undergo condensation to form ethyl acetoacetate.

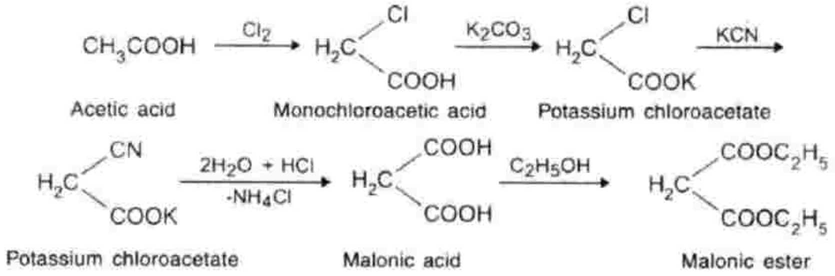
$$\underset{\text{Ethyl acetate}}{2CH_3COOC_2H_5} \xrightarrow[\text{Claisen ester condensation}]{C_2H_5ONa/C_2H_5OH} \underset{\text{Ethyl acetoacetate}}{CH_3COCH_2COOC_2H_5} + C_2H_5OH$$

MALONIC ESTER, DIETHYL MALONATE OR MALONIC ESTER, $CH_2(COOC_2H_5)_2$

Malonic ester is the diethyl ester of malonic acid. It is a colourless liquid (b.p. 472 K) with a pleasant odour. Like acetoacetic ester, it contains a reactive methylene group and exists as a tautomeric mixture of *keto* and *enol* forms.

Preparation

It is obtained from monochloroacetic acid. The monochloroacetic acid is neutralized with aqueous solution of K_2CO_3 and the resulting potassium salt solution is heated with KCN till the vigorous reaction that has set in, subsides. The solution of the potassium cyano-acetate so obtained is evaporated to dryness on a sand bath with constant stirring to give a residue which is powered and heated with an equal amount of absolute alcohol in a flask through which dry hydrogen chloride gas is passed to saturate the mixture. The product is cooled and poured in ice-cold water. The malonic ester so obtained is extracted with ether. The ethereal solution is washed, dried and distilled to recover ether. The oily residue left is further purified by fractional distillation and the fraction distilling between 468 K and 478 K is collected, which is pure malonic ester.



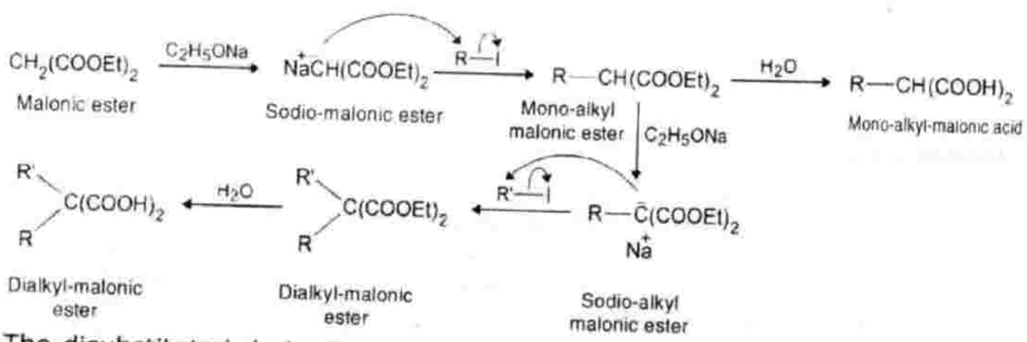
Synthetic uses of Malonic ester

Malonic ester is one of the few important synthetic tools in the hands of an organic chemist. Its wide applications in organic synthesis are due to the presence of a reactive methylene group. The hydrogen atoms in this methylene group are reactive due to their position between two electron attracting groups. One of these active hydrogen atoms is readily replaced by sodium when treated with alcoholic solution of sodium ethoxide. The following examples will show the importance of malonic ester in organic synthesis:

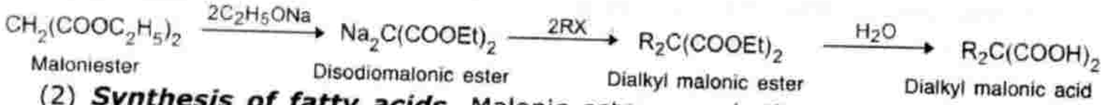
(1) ***Synthesis of substituted malonic acids.*** Malonic ester gives its sodio-derivative when boiled with alcoholic solution of sodium ethoxide or metallic sodium in alcohol. The sodio-derivative forms with alkyl iodide monosubstituted. The second hydrogen atom may similarly be replaced to obtain substituted ester.

It is the enolic form of the acid that gives sodio-derivative which is a resonance hybrid of two structures. On reacting the sodio-derivative with alkyl halide, the alkyl group attaches with the carbon atom. In the following discussion, however, simple formulae have been used for the sake of convenience.

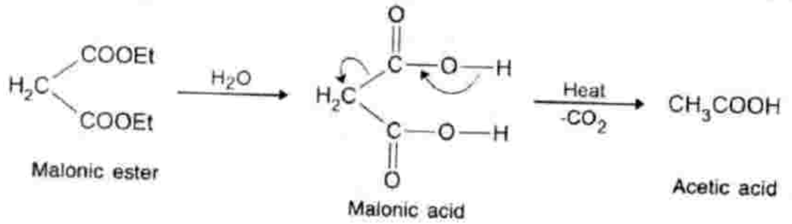
The ester on hydrolysis will produce the corresponding acids.

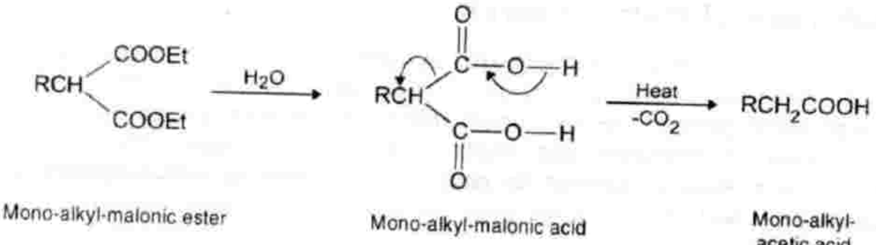


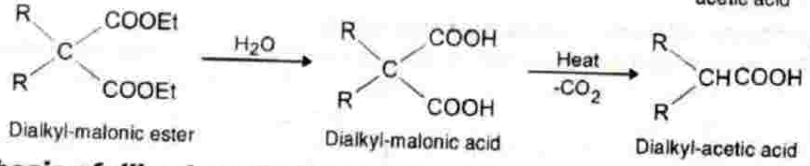
The disubstituted derivative can be prepared *in one step* by treating the ester with two equivalents of C_2H_5ONa and then with two equivalents of alkyl halide (*cf.* acetoacetic ester).



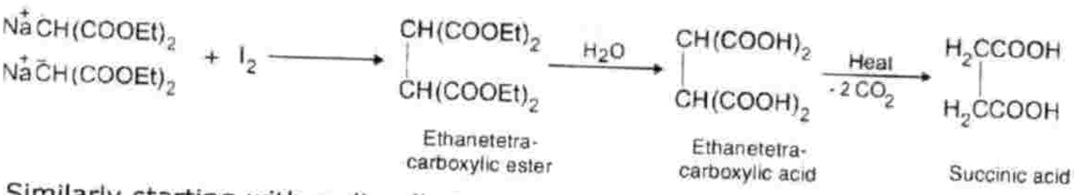
(2) ***Synthesis of fatty acids.*** Malonic ester or substituted malonic ester on hydrolysis and subsequent heating gives a fatty acid with loss of carbon dioxide.





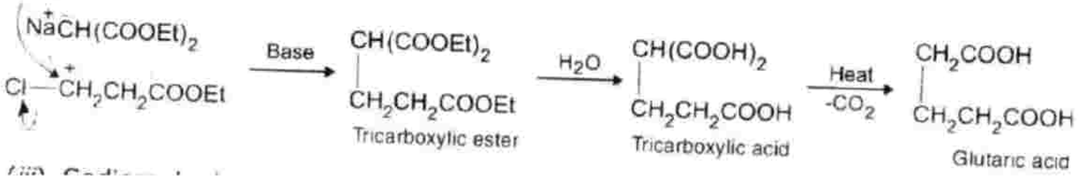


(3) ***Synthesis of dibasic and other polybasic acids.*** (*i*) Two molecules of sodio-malonic ester with iodine yield a tetracarboxylic ester which on hydrolysis and subsequent heating yields succinic acid.



Similarly starting with sodio-alkylmalonic ester, we get dialkyl succinic acid.

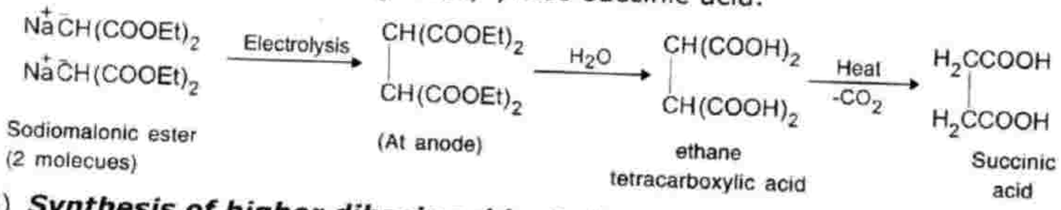
(*ii*) Sodimalonic ester may also be treated with a halogen substituted fatty acid to get a dibasic acid.



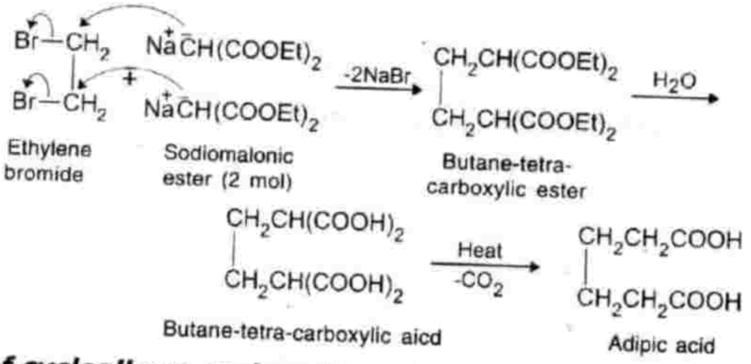
(*iii*) Sodi

Glutaric acid

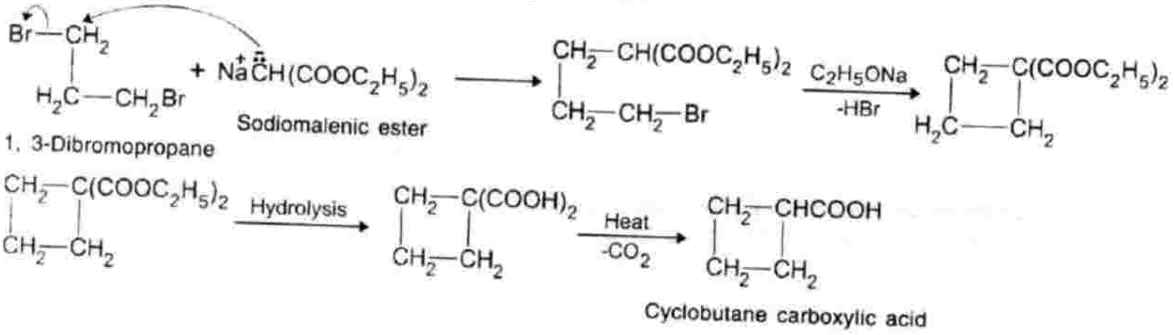
(*iii*) Sodiomalonic ester on electrolysis gives tetracarboxylic ester which on hydrolysis and subsequent heating finally yields succinic acid.



(4) ***Synthesis of higher dibasic acids.*** Sodiomalonic ester when treated with an alkylene halide with two halogen atoms in the end positions yields higher dibasic acids.

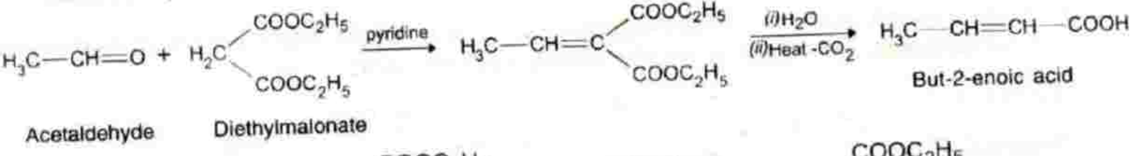


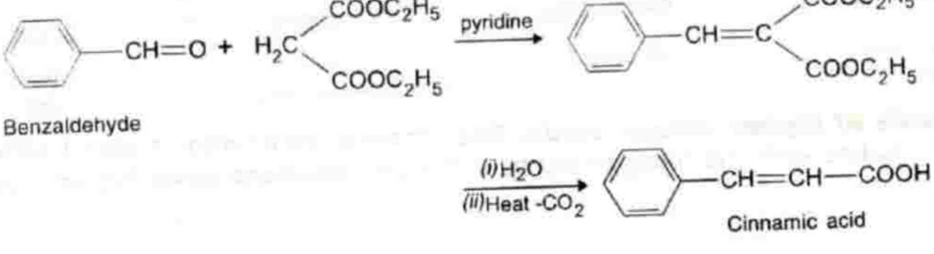
(5) ***Synthesis of cycloalkane carboxylic acid***



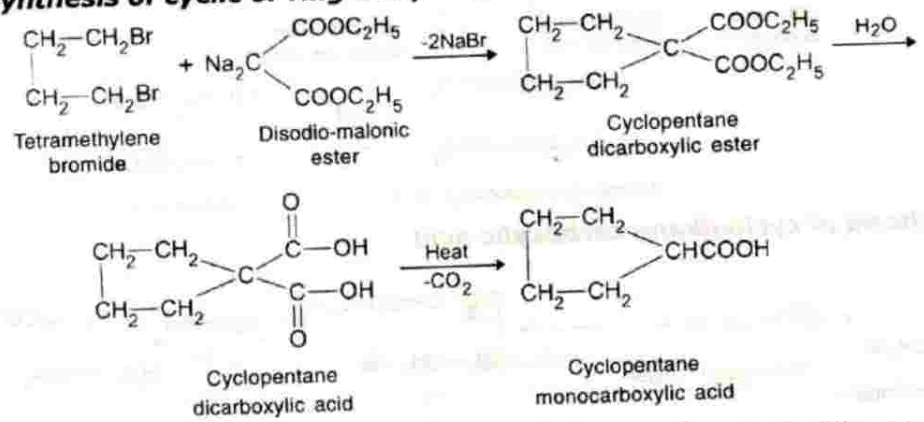
(6) ***Synthesis of α, β-unsaturated acid.*** Malonic ester undergoes Knoevenagel reaction with aldehydes in the presence of organic bases (*e.g.*, pyridine) and gives an unsaturated ester and finally an unsaturated acid as given below:

For example,

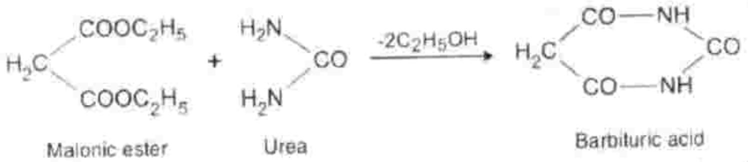




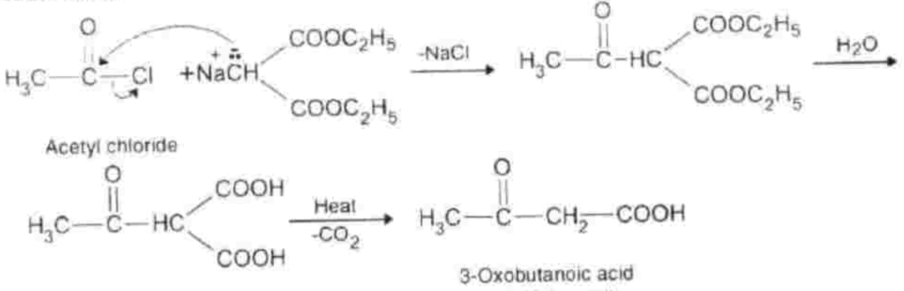
(7) ***Synthesis of cyclic or ring compounds***



(8) ***Synthesis of Heterocyclic compounds.*** Urea and malonic ester combine to form malonylurea or barbituric acid and alcohol.



(9) ***Synthesis of β-ketoacids (3-oxobutanoic acid).*** Sodium salt of malonic ester on treatment with acyl chloride followed by hydrolysis and decarboxylation yields β-keto acid.



(10) ***Synthesis of amino acids.*** Amino acid, glycine can be synthesized from malonic ester by the following sequence of reactions.

$$\underset{\text{Nitrous acid}}{HO-N=O} + \underset{\text{Malonic ester}}{CH_2(COOC_2H_5)_2} \longrightarrow \underset{\text{Oximino malonic ester}}{HO-N=C(COOC_2H_5)_2} \xrightarrow[\text{Acetic acid}]{\text{Zn}}$$

$$\underset{\text{Amino malonic ester}}{H_2N-CH(COOC_2H_5)_2} \xrightarrow{\text{Hydrolysis}} H_2N-CH(COOH)_2 \xrightarrow[-CO_2]{\text{Heat}} \underset{\text{(Glycine)}}{\underset{\text{Aminoacetic acid}}{H_2N-CH_2COOH}}$$

ACETOACETIC ESTER

Acetoacetic Ester or Ethyl Acetoacetate

It is the ethyl ester of acetoacetic acid, CH_3COCH_2COOH, a β-ketonic acid. The name acetoacetic ester is given to it since it could also be regarded as an acetyl derivative of acetic ester (ethyl acetate). It is an extremely valuable synthetic reagent.

Preparation

Acetoacetic ester is prepared by the action of sodium on ethyl acetate in the presence of ethyl alcohol.

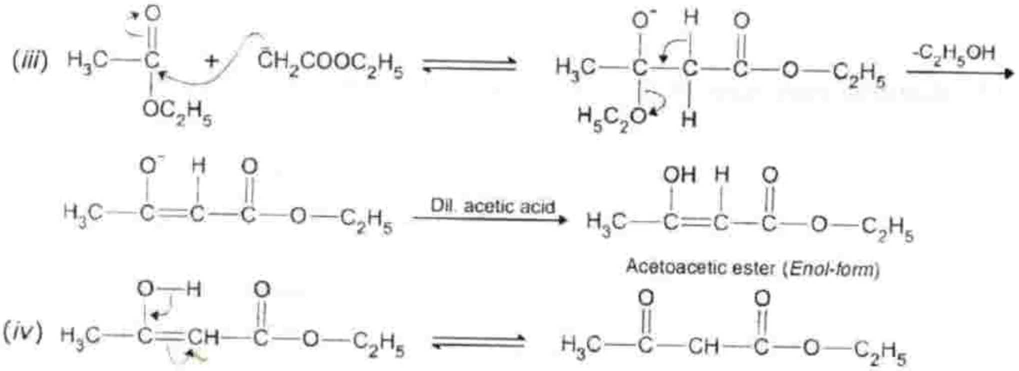
Acetoacetic ester is produced as a result of condensation between two molecules of ethyl acetate in the presence of sodium ethoxide.

$$2CH_3COOC_2H_5 \longrightarrow \underset{\text{Acetoacetic ester}}{CH_3COCH_2COOC_2H_5} + C_2H_5OH$$

The above condensation between two molecules of ethyl acetate is called **Claisen ester condensation**. It is a rather complex reaction and many mechanisms have been proposed for it. The most widely accepted mechanism at the moment consists of the following steps:

(*i*) $\underset{\text{Ethanol}}{C_2H_5OH} \xrightarrow{Na} \underset{\text{Sodium ethoxide}}{C_2H_5ONa} \rightleftharpoons |\overline{C_2H_5O}| + \overset{+}{Na}$

(*ii*) $CH_3COOC_2H_5 + |\overline{C_2H_5O}| \rightleftharpoons \overset{-}{C}H_2COOC_2H_5 + C_2H_5OH$



Acetoacetic ester (*Enol-form*)

Acetoacetic ester (*Enol-form*)

Acetoacetic ester (*Keto form*)

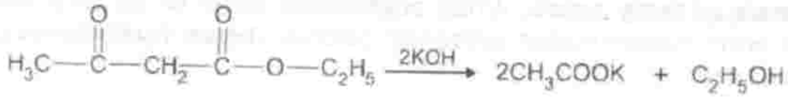
Pure ethyl acetate (10 parts) with a little alcohol is taken in a flask and to this is added a clean sodium wire (1 part). A slow reaction sets in which becomes gradually vigorous with the evolution of hydrogen and boiling of the liquid. The flask is heated on a water bath after the reaction subsides till whole of sodium disappears.

The product of the above reaction is the sodium derivative of acetoacetic ester which forms a brown semi-solid mass with sodium ethoxide and unused ethyl acetate. This is acidified with dilute acetic acid (1 : 1) to decompose the sodium derivative when acetoacetic ester separates out as an oily layer at the top. The oily product is distilled and fraction passing between 448-453 K consists of almost pure ester and is further purified by distilling under reduced pressure.

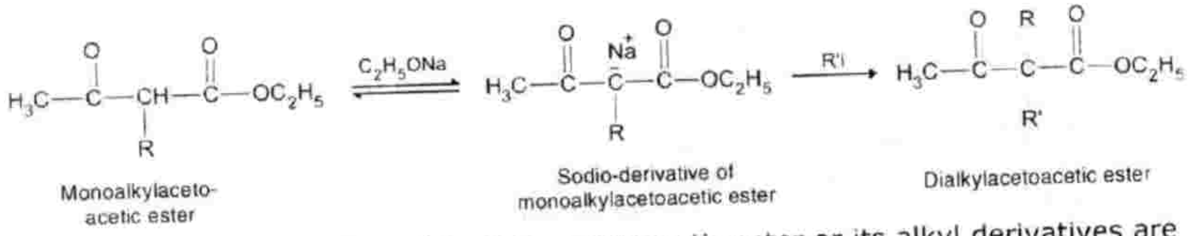
$$H_3C-\overset{\overset{\displaystyle O-H}{|}}{C}=CH_2 \rightleftharpoons H_3C-\overset{\overset{\displaystyle O}{\|}}{C}-CH_3$$

It is the electron-attracting property of the carbonyl group which facilitates the elimination of one CO_2 molecule.

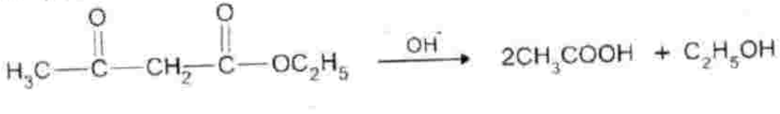
(8) ***Acid Hydrolysis.*** This is called acid hydrolysis because an acid is the chief product of hydrolysis though it is generally carried out by boiling acetoacetic ester with concentrated alcoholic potash.



$$H_3C-\overset{\overset{\displaystyle O}{\|}}{C}-CH_2-\overset{\overset{\displaystyle O}{\|}}{C}-O-C_2H_5 \xrightarrow{2KOH} 2CH_3COOK + C_2H_5OH$$



(2) ***Synthesis of fatty acids.*** When acetoacetic ester or its alkyl derivatives are *heated with concentrated alcoholic potash* (**base hydrolysis**), fatty acids are produced.

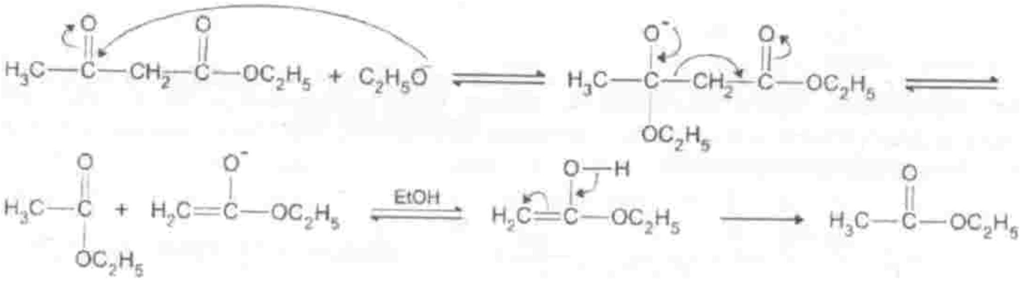


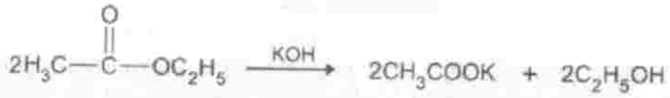
$$H_3C-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5 \xrightarrow{OH^-} 2CH_3COOH + C_2H_5OH$$

The possible mechanism of the reaction is given below:

(*i*) $C_2H_5OH + KOH \longrightarrow C_2H_5O^-K^+ + H_2O$

(*ii*)





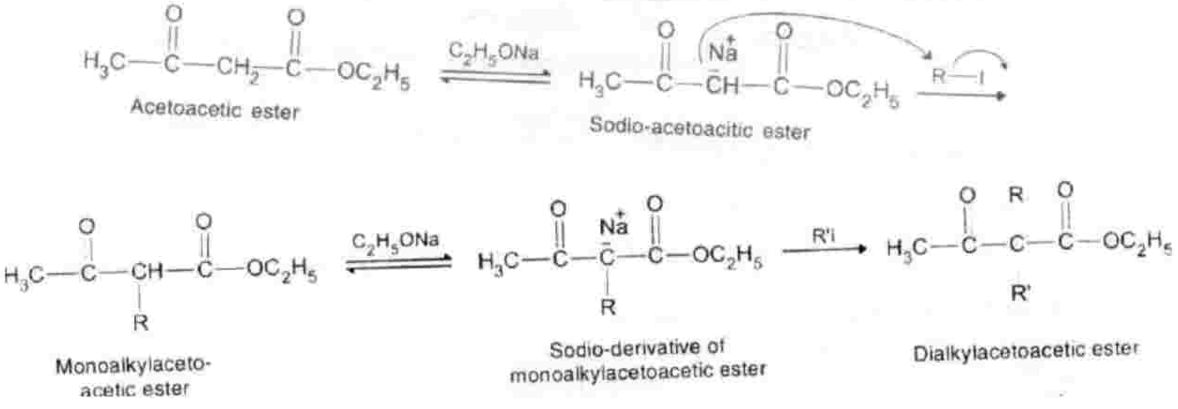
$$(iii)\ 2H_3C-\overset{O}{\overset{\|}{C}}-OC_2H_5 \xrightarrow{KOH} 2CH_3COOK + 2C_2H_5OH$$

(*iv*) $CH_3COOK \xrightarrow{H^+} CH_3COOH$

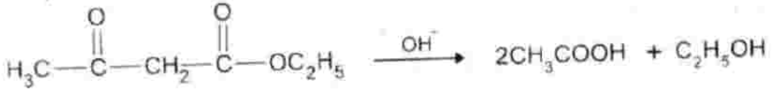
Use of Acetoacetic Ester in Organic Synthesis

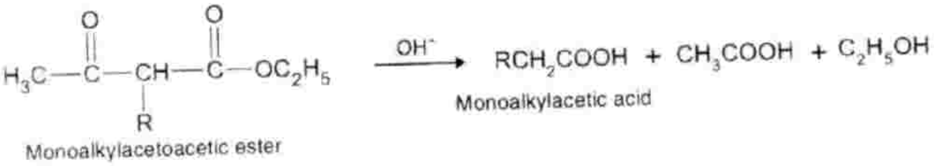
Acetoacetic ester is an important reagent. Some of the important reactions of acetoacetic ester exploited for synthetic purposes are given below:

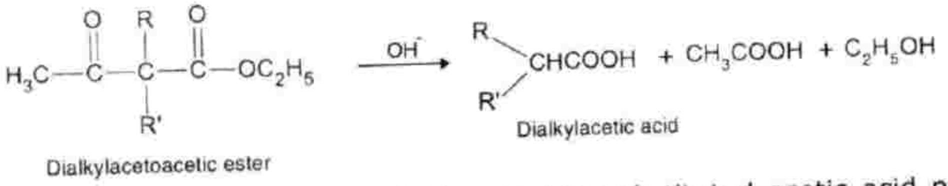
(1) ***Synthesis of alkyl acetoacetic ester.*** Acetoacetic ester is treated with sodium ethoxide and the sodio-derivative so obtained is further treated with alkyl iodide when we get monoalkyl acetoacetic ester. The monoalkyl derivative may again be treated with C_2H_5ONa and then with alkyl iodide to get dialkyl derivative.



(2) ***Synthesis of fatty acids.*** When acetoacetic ester or its alkyl derivatives are *heated with concentrated alcoholic potash* (**base hydrolysis**), fatty acids are produced.

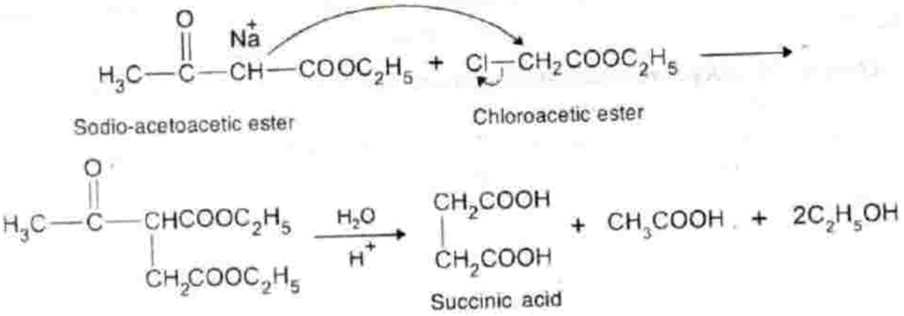




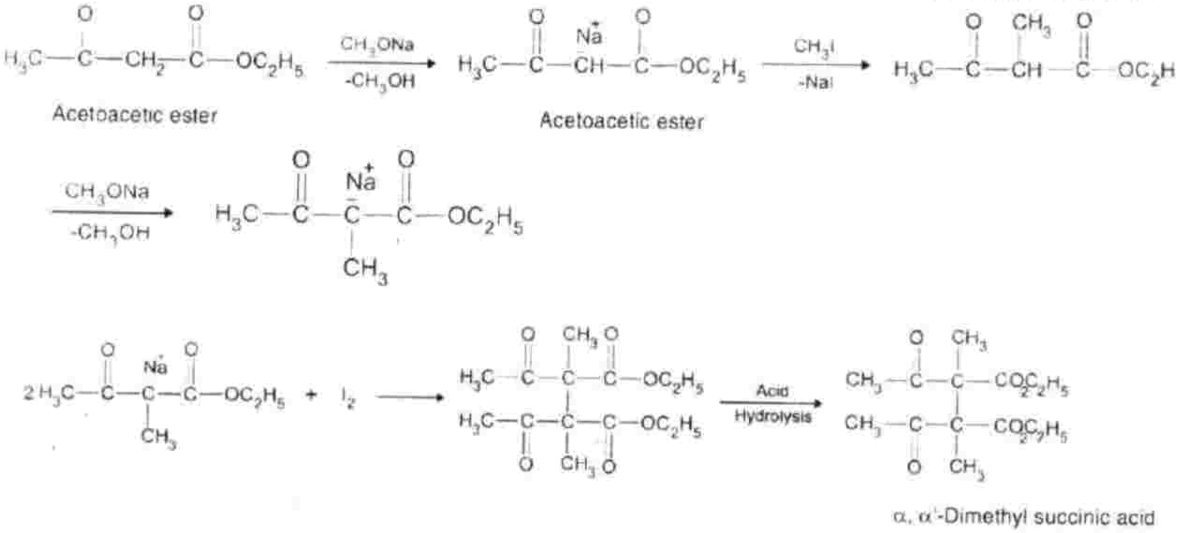


Since acetic acid is water soluble and the substituted acetic acid probably will not be, the two are easily separated. Otherwise they would be separated by fractional distillation.

(3) ***Synthesis of dibasic acids.*** When sodio-derivative of acetoacetic ester is condensed with a chlorofatty acid ester and the product is subjected to acid hydrolysis, a dibasic acid is obtained.

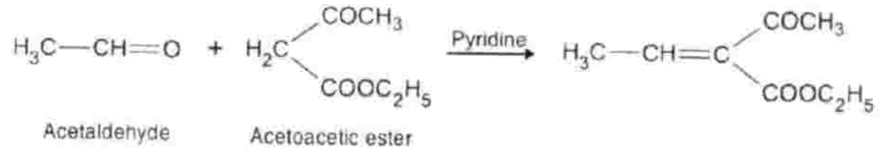


Dialkylsuccinic acid can be prepared from acetoacetic ester in a similar manner.



α, α'-Dimethyl succinic acid

(4) ***Synthesis of α,β-unsaturated acids.*** Acetoacetic ester undergoes the **Knoevenagel reaction** due to the presence of an active methylene group. It condenses with aldehydes or ketones in the presence of a base and the products on acid hydrolysis yield α,β-unsaturated acids.

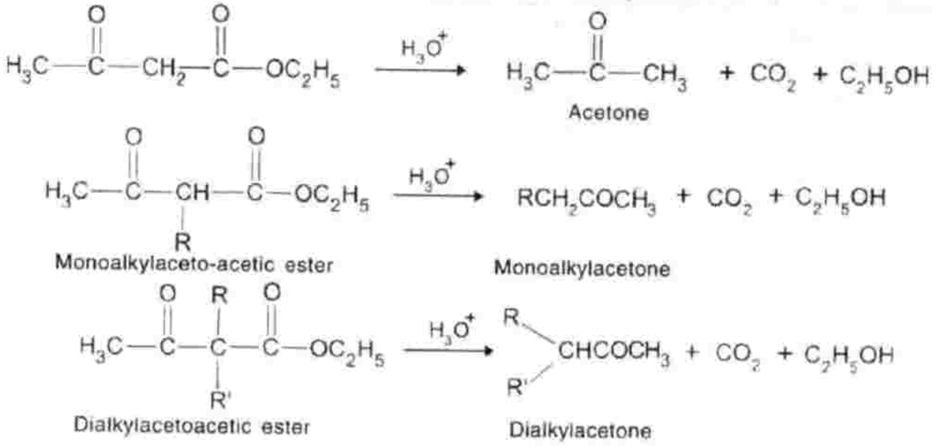


$$\xrightarrow[H^+]{H_2O} H_3C-CH=CHCOOH + CH_3COOH + C_2H_5OH$$

Crotonic acid

The mechanism of this reaction involves the formation of a carbanion.

(5) ***Synthesis of ketones.*** When acetoacetic ester or its alkyl derivatives are *heated with dilute acid or alkali* (ketonic hydrolysis) ketones are obtained.

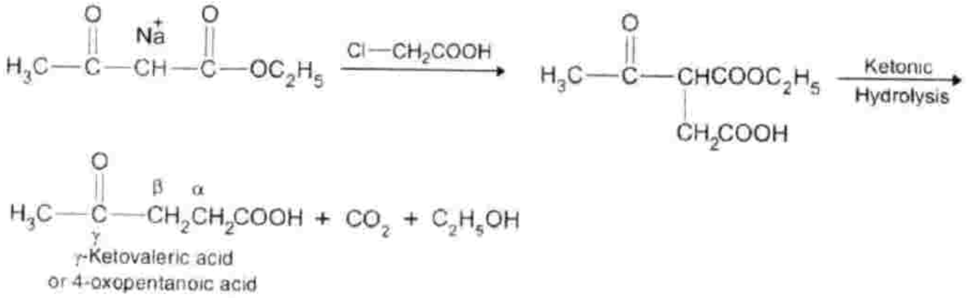


$$H_3C-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5 \xrightarrow{H_3O^+} \underset{\text{Acetone}}{H_3C-\overset{O}{\overset{\|}{C}}-CH_3} + CO_2 + C_2H_5OH$$

$$\underset{\text{Monoalkylaceto-acetic ester}}{H_3C-\overset{O}{\overset{\|}{C}}-\underset{R}{\underset{|}{CH}}-\overset{O}{\overset{\|}{C}}-OC_2H_5} \xrightarrow{H_3O^+} \underset{\text{Monoalkylacetone}}{RCH_2COCH_3} + CO_2 + C_2H_5OH$$

$$\underset{\text{Dialkylacetoacetic ester}}{H_3C-\overset{O}{\overset{\|}{C}}-\overset{R}{\overset{|}{\underset{R'}{\underset{|}{C}}}}-\overset{O}{\overset{\|}{C}}-OC_2H_5} \xrightarrow{H_3O^+} \underset{\text{Dialkylacetone}}{\begin{matrix}R\\R'\end{matrix}\!\!>CHCOCH_3} + CO_2 + C_2H_5OH$$

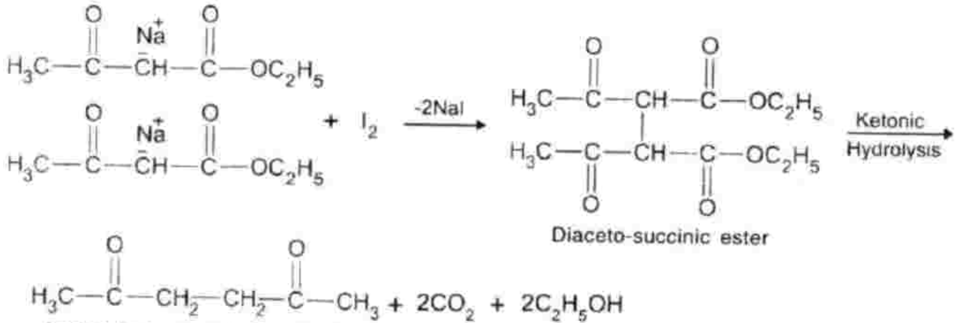
(6) ***Synthesis of γ-ketonic acids.*** When sodio-derivative of acetoacetic ester is treated with α-chloro fatty acids and the product is subjected to *ketonic hydrolysis*, we get γ-ketonic acids.



$$H_3C-\overset{O}{\overset{\|}{C}}-\overset{\overset{+}{Na}}{CH}-\overset{O}{\overset{\|}{C}}-OC_2H_5 \xrightarrow{Cl-CH_2COOH} H_3C-\overset{O}{\overset{\|}{C}}-\underset{CH_2COOH}{\underset{|}{CHCOOC_2H_5}} \xrightarrow[\text{Hydrolysis}]{\text{Ketonic}}$$

$$\underset{\substack{\gamma\text{-Ketovaleric acid}\\ \text{or 4-oxopentanoic acid}}}{H_3C-\underset{\gamma}{\overset{O}{\overset{\|}{C}}}-\overset{\beta}{C}H_2\overset{\alpha}{C}H_2COOH} + CO_2 + C_2H_5OH$$

(7) ***Synthesis of diacetosuccinic ester and acetonylacetone.*** Two molecules of sodioacetoacetic ester condense when treated with iodine and diacetosuccinic ester is produced. The product on ketone hydrolysis gives acetonylacetone.



Diaceto-succinic ester

Acetonylactone or 2, 5-pentadione

(8) ***Synthesis of hydrocarbons.*** On electrolytic reduction, acetoacetic ester and its alkyl derivatives give rise to hydrocarbons.

$$CH_3COCH_2COOC_2H_5 \longrightarrow CH_3CH_2CH_2CH_3$$

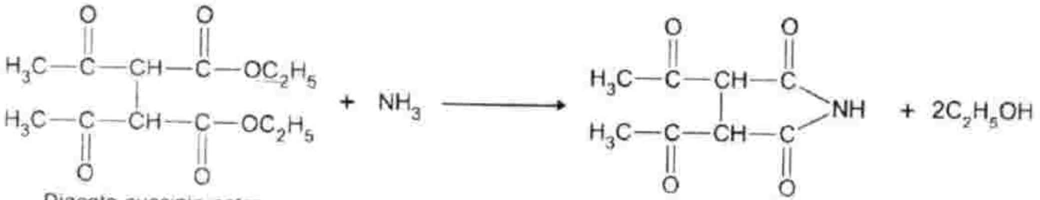
Acetoacetic ester → *n*-Butane

$$CH_3COCHRCOOC_2H_5 \longrightarrow CH_3CH_2CHRCH_3$$

Alkylacetoacetic ester → 2-Alkylbutane

(9) ***Synthesis of heterocyclic compounds.*** Acetoacetic ester condenses with various reagents to form different types of cyclic compounds. The following may be given as typical examples:

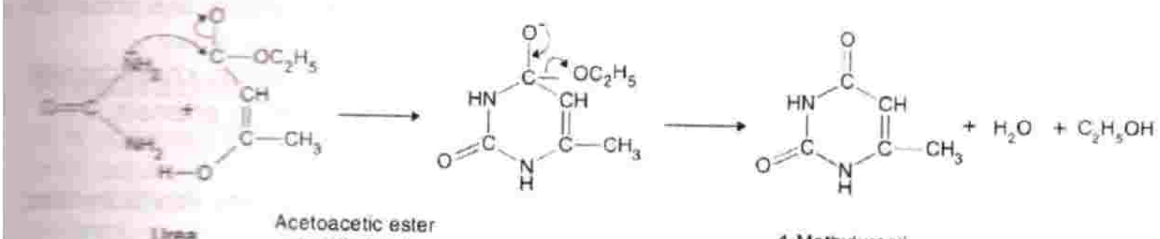
(*i*) Diacetosuccinic ester obtained in (7) above by condensing two molecules of sodio-acetoacetic ester in the presence of iodine, when treated with ammonia gives pyrrole derivative.



Diaceto-succinic ester

Pyrrole derivative

(*ii*) **With urea** it gives the ring compounds, 4-methyl-uracil from which uric acid may be synthesised.

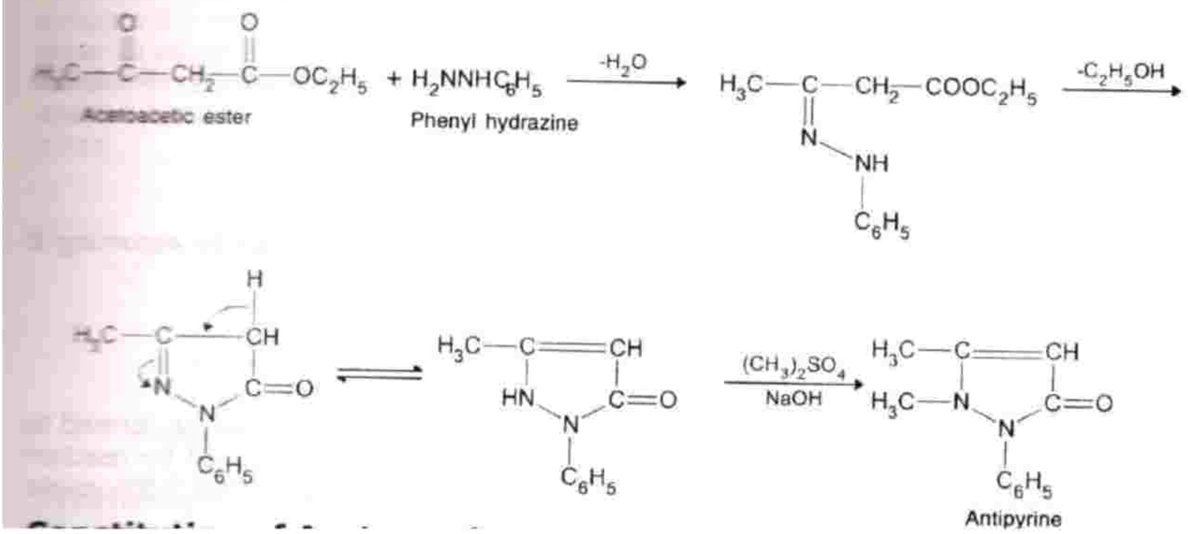


Urea

Acetoacetic ester (enolic form)

4-Methyluracil

([illegible]) *Synthesis of antipyrine*



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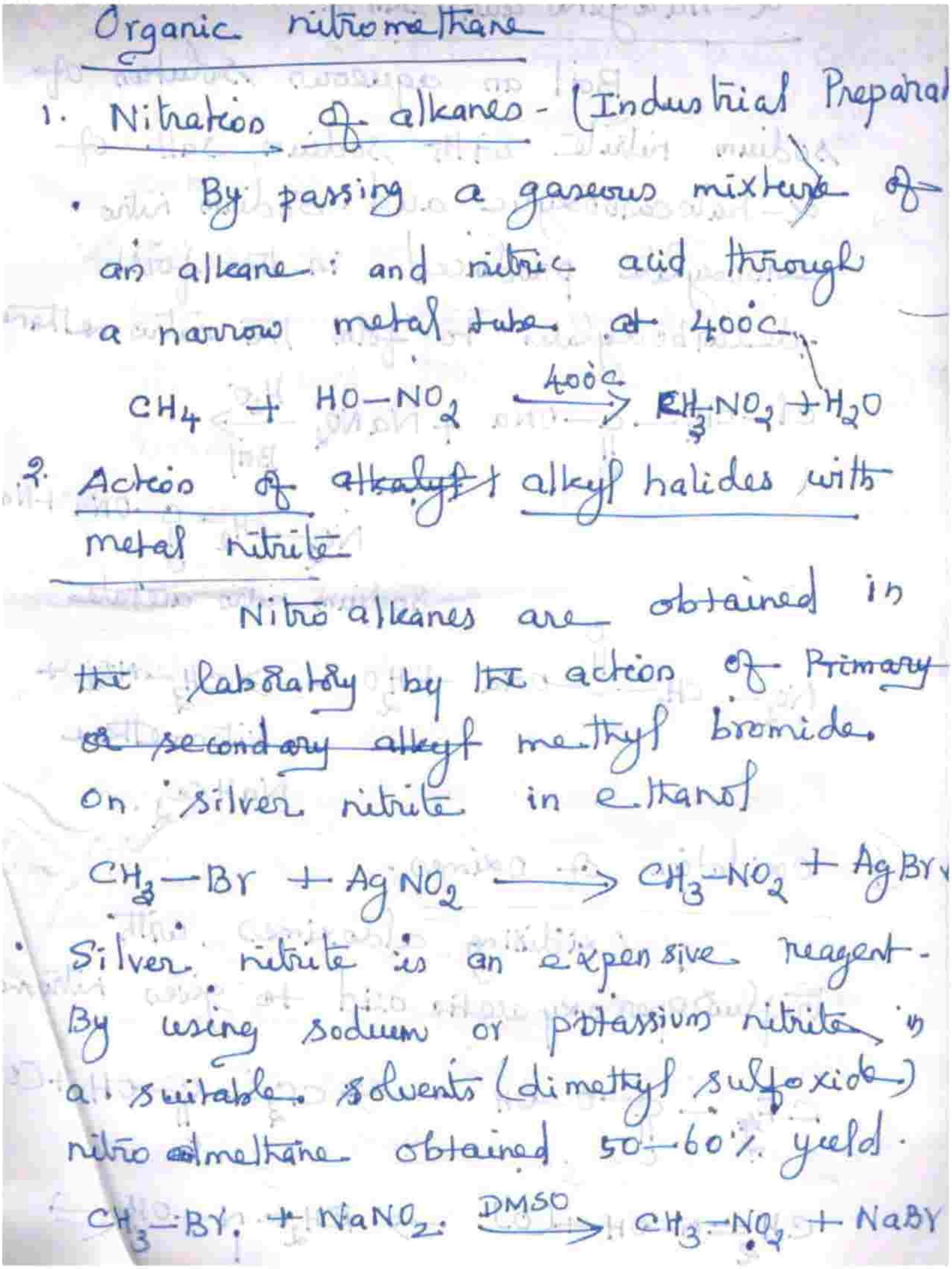


Organic nitromethane

1. Nitration of alkanes - (Industrial Prepara

- By passing a gaseous mixture of an alkane and nitric acid through a narrow metal tube at 400c.

$$CH_4 + HO-NO_2 \xrightarrow{400c} CH_3NO_2 + H_2O$$

2. Action of ~~alkalyl~~ / alkyl halides with metal nitrite

Nitro alkanes are obtained in the laboratory by the action of ~~Primary or secondary alkyl~~ methyl bromide on silver nitrite in ethanol

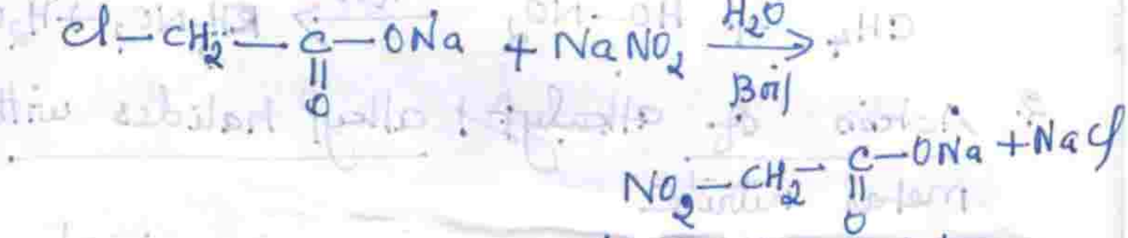
$$CH_3-Br + AgNO_2 \longrightarrow CH_3-NO_2 + AgBr$$

- Silver nitrite is an expensive reagent. By using sodium or potassium nitrite in a suitable solvents (dimethyl sulfoxide) nitro ~~al~~methane obtained 50-60% yield.

$$CH_3-Br + NaNO_2 \xrightarrow{DMSO} CH_3-NO_2 + NaBr$$

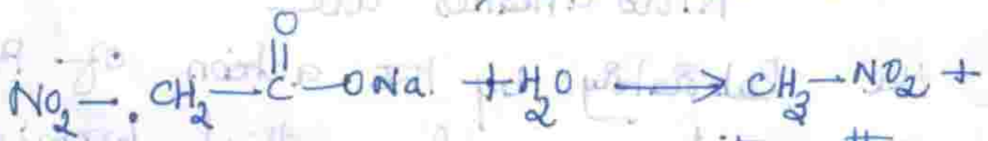
③ Action of sodium nitrite with α-halogeno acid salts.

Boil an aqueous solution of sodium nitrite with sodium salt of α-halocarboxylic acid. Sodium nitro carboxylate produced ~~in the first~~ decarboxylates to form the nitromethane



$$Cl-CH_2-\underset{\underset{O}{\|}}{C}-ONa + NaNO_2 \xrightarrow[Boil]{H_2O} NO_2-CH_2-\underset{\underset{O}{\|}}{C}-ONa + NaCl$$

Sodium nitro acetate



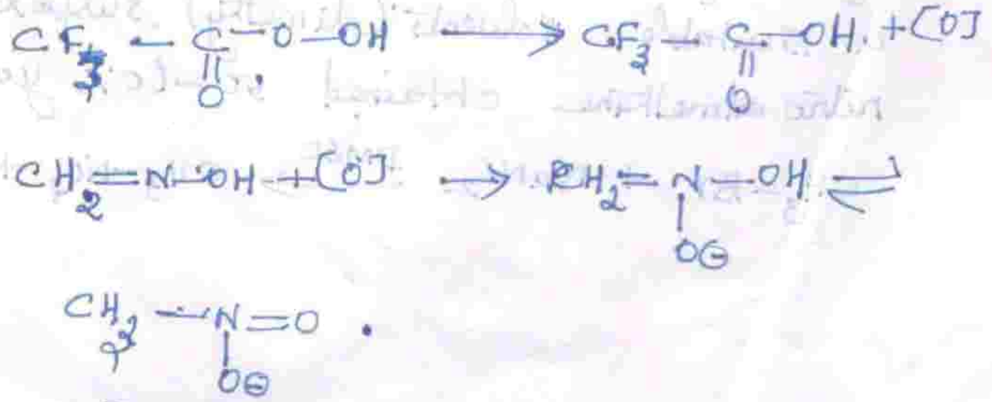
$$NO_2-CH_2-\overset{\overset{O}{\|}}{C}-ONa + H_2O \longrightarrow CH_3-NO_2 +$$

Nitromethane

$NaHCO_3$.

④ Oxidation of oximes.

Oxidising aldoximes with trifluroperoxy acetic acid to gives nitromethane



$$CF_3-\underset{\underset{O}{\|}}{C}-O-OH \longrightarrow CF_3-\underset{\underset{O}{\|}}{C}-OH + [O]$$

$$CH_2=N-OH + [O] \longrightarrow RH_2=\underset{\underset{O^{\ominus}}{|}}{N}-OH \rightleftharpoons$$

$$CH_3-\underset{\underset{O^{\ominus}}{|}}{N}=O .$$

nitro methane

Properties

②

① The lower nitro alkanes are colourle pleasant smelling liquids at ordinary temperature.

② It is about 10% soluble in water but higher alkanes are insoluble. This shows that there is no hydroge bonds.

③ They have abnormally high boiling points

Chemical Properties

(1) Action of Heat

It is decomposed on moderate heating beyond 300°C. ~~A~~

(2) Formation of Salt

The α-hydrogen of nitromethane is acidic in nature. It dissolves in NaOH or KOH solution form salts.

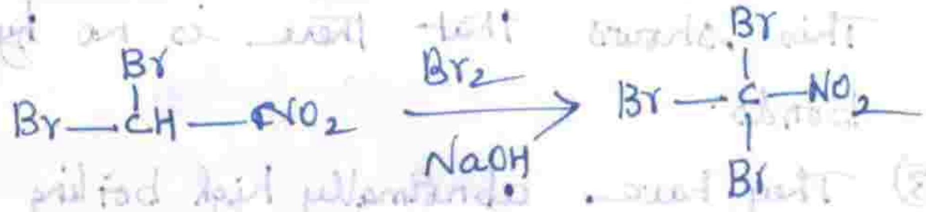
$$CH_3-NO_2 \xrightarrow{NaOH} \overset{-}{C}H_2\overset{+}{Na}-NO_2 + H_2O$$

Sodium salt.

③ Halogenation

When treated with halogen in alkaline solution are halogenated. The α- hydrogens are replaced by the halogen.

$$CH_3-NO_2 \xrightarrow[NaOH]{Br_2} Br-CH_2-NO_2 \xrightarrow[NaOH]{Br_2}$$



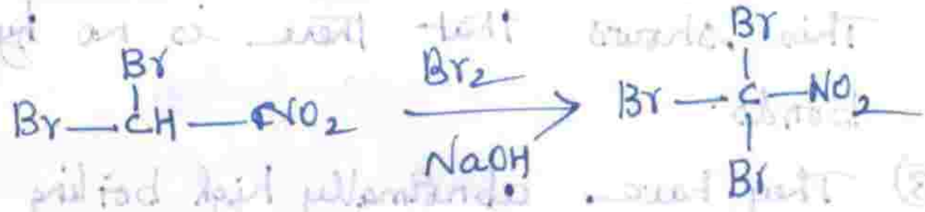
$$Br-\overset{Br}{\overset{|}{C}}H-NO_2 \xrightarrow[NaOH]{Br_2} Br-\underset{Br}{\underset{|}{\overset{Br}{\overset{|}{C}}}}-NO_2$$

All the three hydrogen atoms are replace by halogen to form trichloro nitro methane.

③ Halogenation

When treated with halogen in alkaline solution are halogenated. The α-hydrogens are replaced by the halogen.

$$CH_3-NO_2 \xrightarrow[NaOH]{Br_2} Br-CH_2-NO_2 \xrightarrow[NaOH]{Br_2}$$

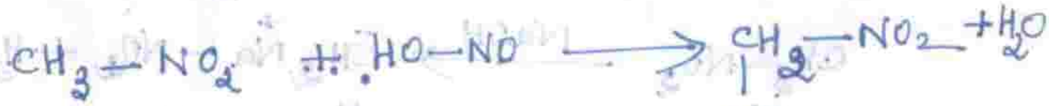


$$Br-\overset{Br}{\overset{|}{C}}H-NO_2 \xrightarrow[NaOH]{Br_2} Br-\underset{Br}{\overset{Br}{C}}-NO_2$$

All the three hydrogen atoms are replace by halogen to form trichloro nitro methane.

④ Reaction with nitrous acid

Nitromethane gives a blue nitrosonitro alkane when treated with nitrous acid. The reactive hydrogen atom on α-carbon to NO group are involved in the reaction.



$$CH_3-NO_2 + HO-NO \longrightarrow \underset{NO}{\underset{|}{CH_2}}-NO_2 + H_2O$$

Nitrosonitro alkane.

⑤ Reduction

Nitromethane is reduced to aminomethane with hydrogen on Raney Nickel and with LiAlH4

$$CH_3-NO_2 + 3H_2 \xrightarrow{Ni} CH_3-NH_2 + 2H_2O$$

$$CH_3-NO_2 \xrightarrow{LiAlH_4} CH_3-NH_2$$

⑥ Hydrolysis

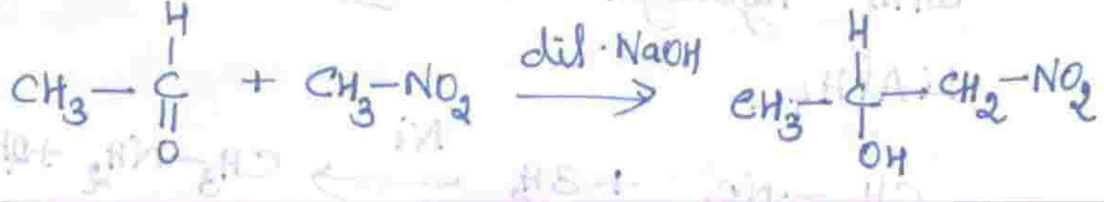
Nitroalkane on boiling with conc. HCl or H_2SO_4 are hydrolysed to form a carboxylic acid and hydroxylamine.

$$CH_3-NO_2 + H_2O \xrightarrow{H^+} H-COOH + NH_2-OH$$

This reaction proceeds by oxidation of CH_3 group and reduction of NO_2 group accompanied by C–N bond cleavage. It is used for the commercial production of hydroxylamine.

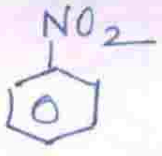
⑦ condensation with aldehyde and ketones.

Nitromethane react with aldehyde in presence of dilute alkali. This reaction yield nitroalcohol is quite similar to Aldol condensation.



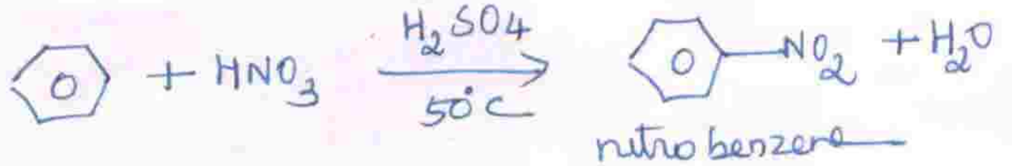
$$CH_3-\underset{\underset{O}{\|}}{\overset{\overset{H}{|}}{C}} + CH_3-NO_2 \xrightarrow{dil \cdot NaOH} CH_3-\underset{\underset{OH}{|}}{\overset{\overset{H}{|}}{C}}-CH_2-NO_2$$

Nitrobenzene



Preparation

Both Laboratory as well as industry, nitrobenzene is prepared by heating benzene with a mixture of conc. HNO_3 and conc. H_2SO_4 at 50°C



nitro benzene

Benzene

The resulting nitrobenzene is separated and washed with sodium carbonate solution to remove acid and purified by distillation using an air condenser.

Properties

It is a pale yellow liquid,

It has bitter almonds;

It is insoluble in water but soluble in organic solvent

It is steam volatile and highly toxic.

chemical properties

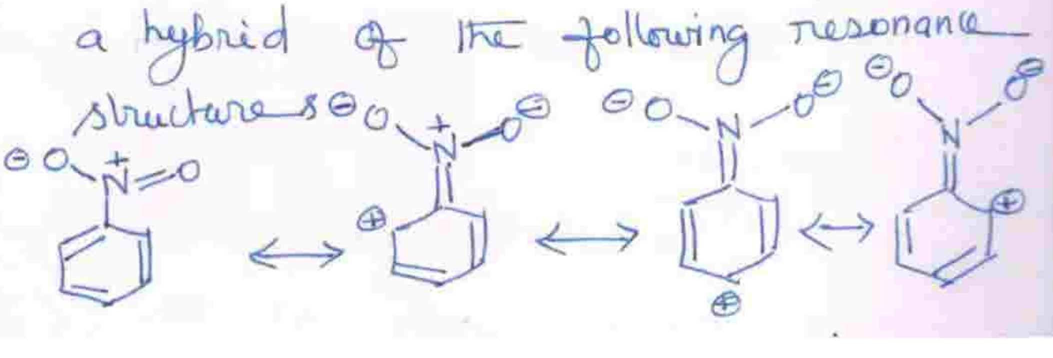
The chemical properties of nitro benzene are those of nitro group and phenyl group.

(I) Reactions of benzene ring

(a) Electrophilic substitution reaction.

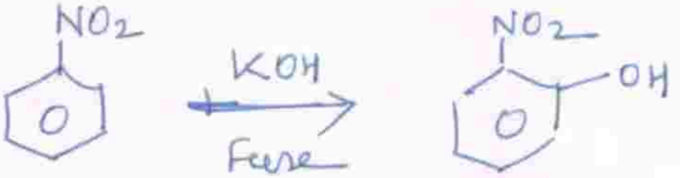
The nitro group $(-NO_2)$ acts as a meta director and deactivating when it is present on a benzene ring undergoing electrophilic substitution.

Nitrobenzene can be represented as a hybrid of the following resonance structures



The ortho and para positon in the resonance structures carry a positive charge. So ~~the~~ an electrophile cannot attack these position. It will attack

When heated with KOH nitrobenzene gives o-nitrophenol by attack of -OH group on ring.

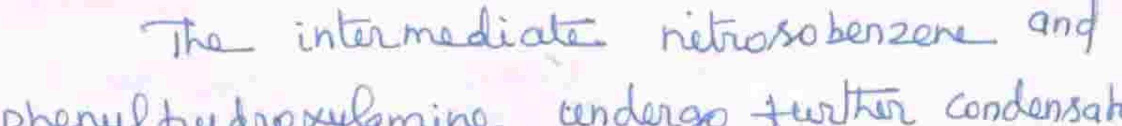


o-nitrophenol.

Reactions of the nitro group.

Reduction of nitro group.

Aromatic nitro compounds gives a variety of products depending on the reagent and condition used.

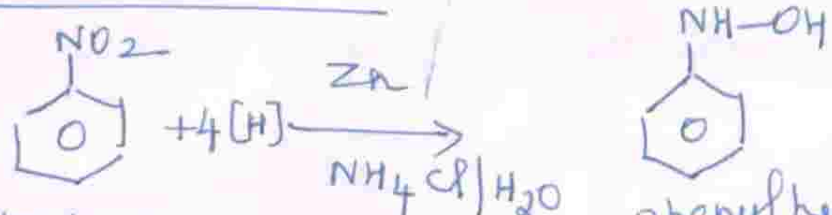


nitrobenzene Nitrosobenzene phenyl hydroxylamine Aniline

The intermediate nitrosobenzene and phenylhydroxylamine undergo further condensation reaction to form bimolecular reduction products

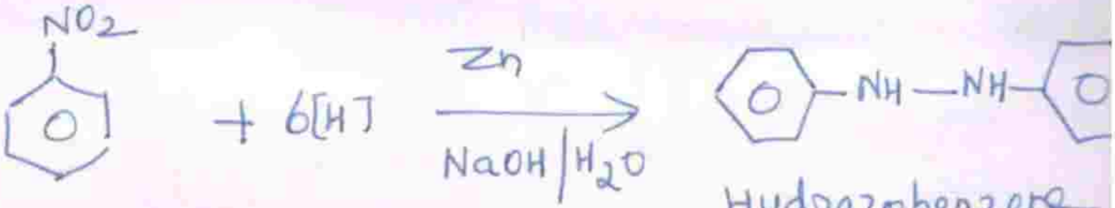
· catalytic hydrogenation (H_2 in presence Ni or Pt)

Neutral medium



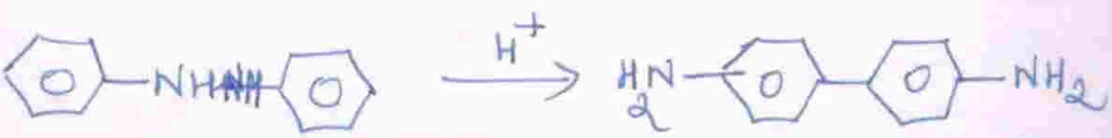
nitrobenzene phenylhydroxylamine

Alkaline medium



Hydrazobenzene

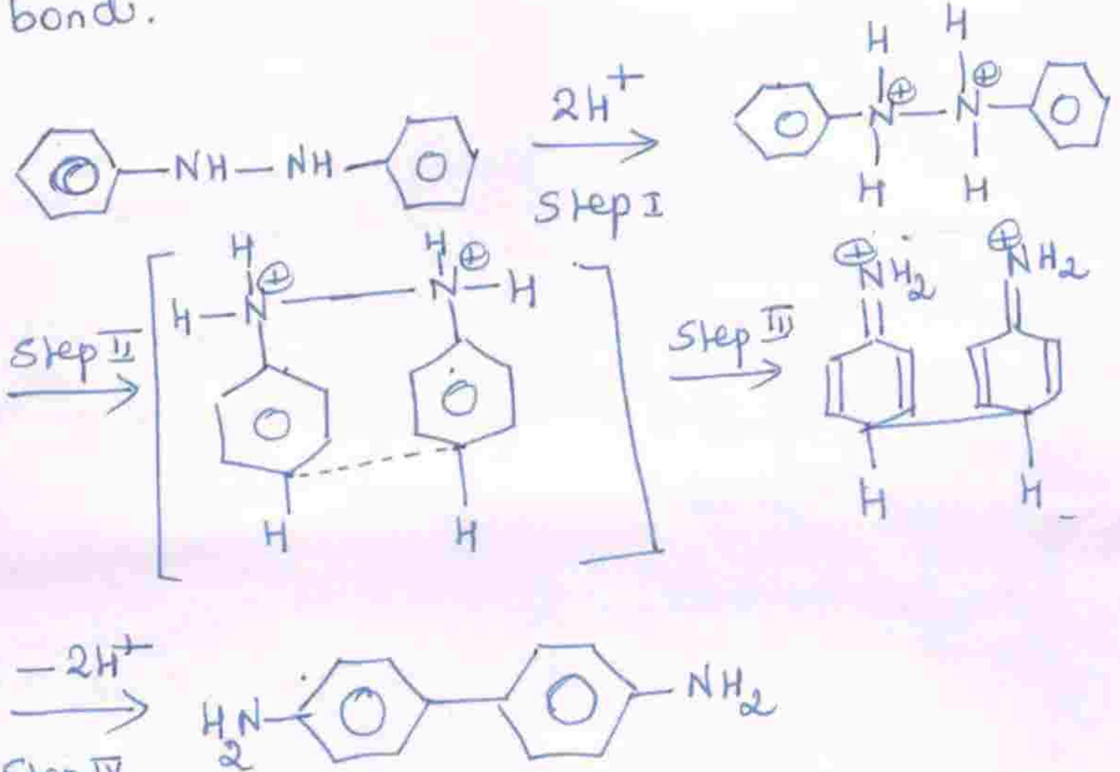
When treated with conc. HCl, hydrazoben undergoes rearrangements to give benzidin Acid catalysed rearrangements are called Benzidine rearrangements.



Hydrazobenzene Benzidine.

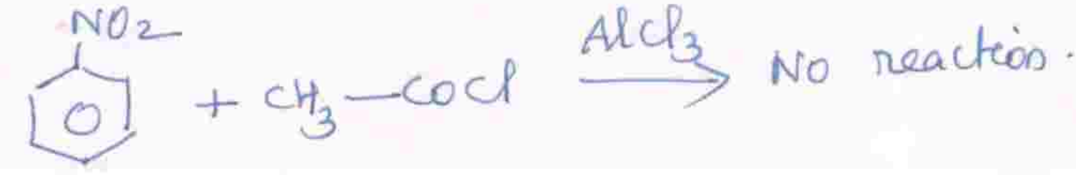
Mechanism

It involves the formation of a bond between the para position of the two rings and ~~cleag~~ cleavage of the nitrogen-nitrogen bond.



Benzedine

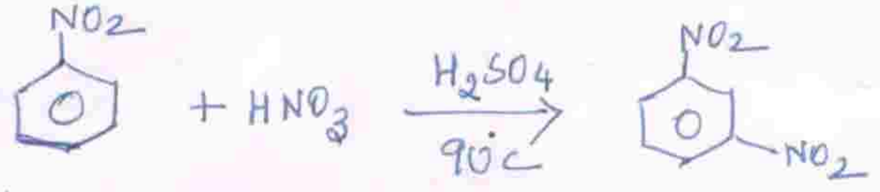
In Nitrobenzene $-NO_2$ group is a deactivati group. As a result, it does not undergo Friedal – crafts reactions.



m-dinitrobenzene.

Preparation

It is prepared by vigorous nitration of nitrobenzene with a mixture of conc. HNO_3 and conc. H_2SO_4.



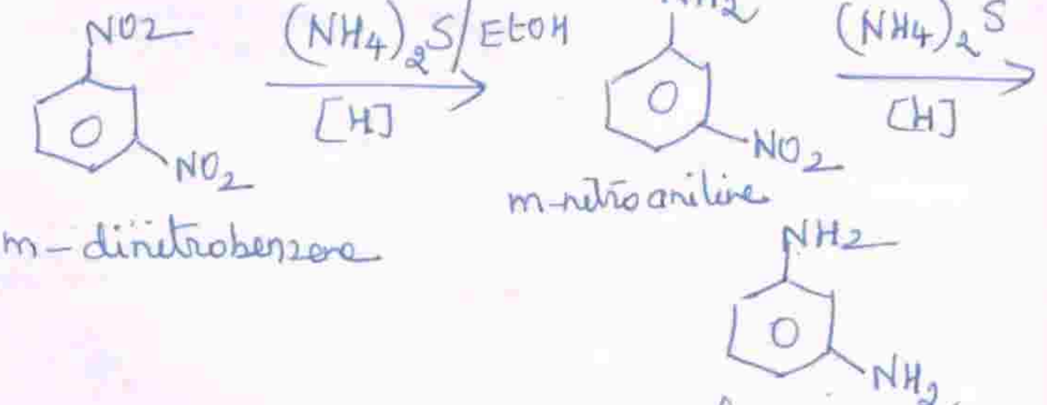
nitrobenzene

m-dinitrobenzene.

7% of o-isomer is removed during crystallization.

Properties

When reduced with ethanolic ammonium sulphide, first converted to m-nitro anilene and then to m-phenylenediamine.

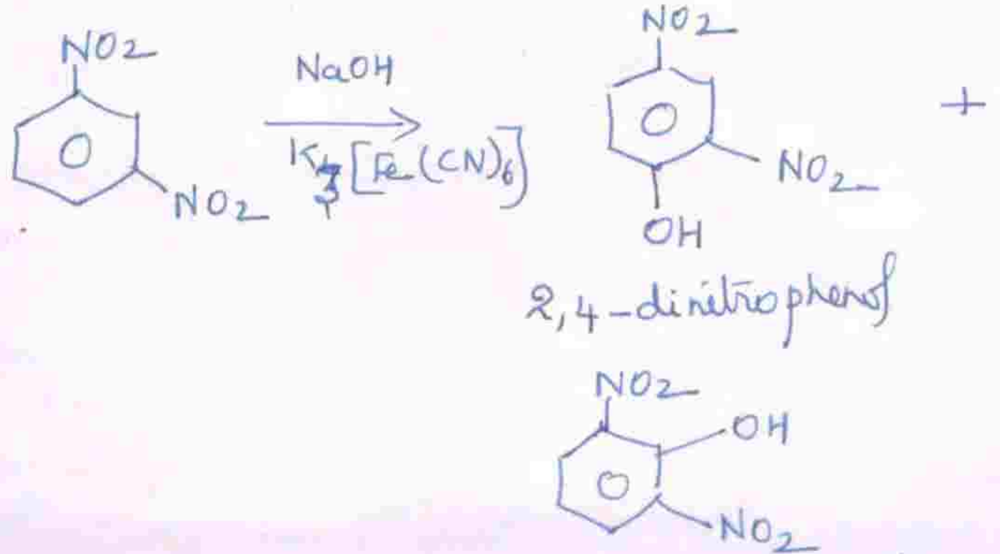


m-dinitrobenzene

m-nitroaniline

m-phenylene diamine

It undergoes nucleophilic substitution with NaOH and potassium ferricyanide to give 2,4-dinitrophenol mainly and 2,6-dinitrophenol small amount.



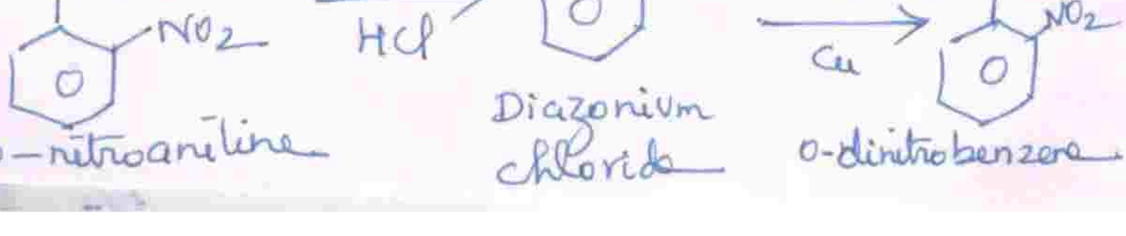
2,4-dinitrophenol

2,6-dinitrophenol.

o-Dinitrobenzene

Preparation

It is prepared from o-nitroaniline by replacing the $-NH_2$ group by $-NO_2$ by diazotization and ~~tredone~~ treatment with sodium nitrite ~~+~~ in the presence of Copper powder.

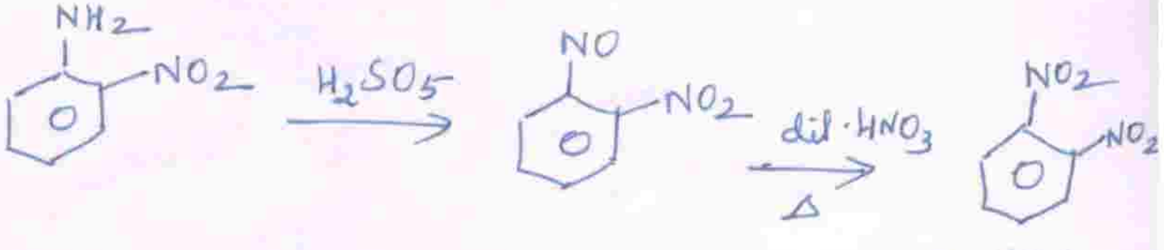


o-nitroaniline

Diazonium chloride

o-dinitrobenzene.

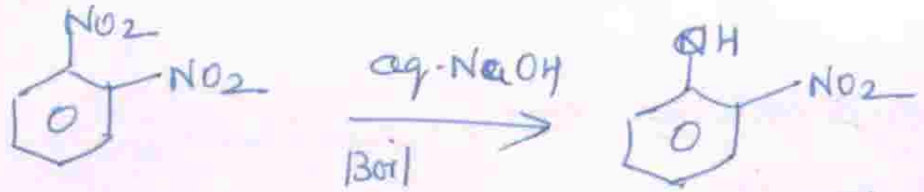
It is prepared by oxidation of o-nitroaniline with Caro's acid (H_2SO_5) and then oxidize the mono nitroso derivativ with ~~hot~~ hot dilute nitric acid.



o-dinitrobenzen

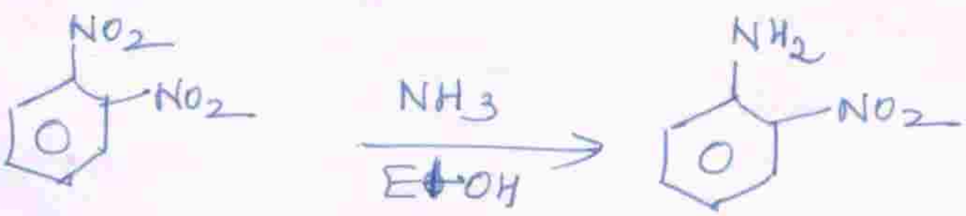
Properties

It is boiled with aqueous NaOH $-NO_2$ group is replaced by $-OH$.



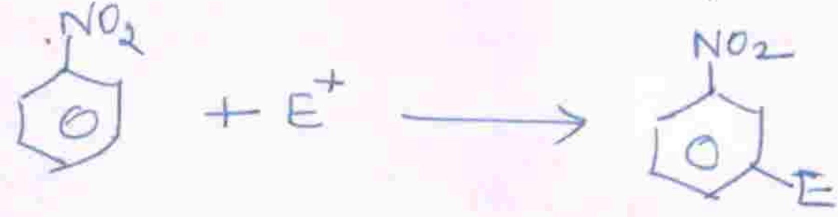
o-nitrophenol.

It is treated with ethanolic ammonia to give o-nitroaniline.



o-nitroanilene.

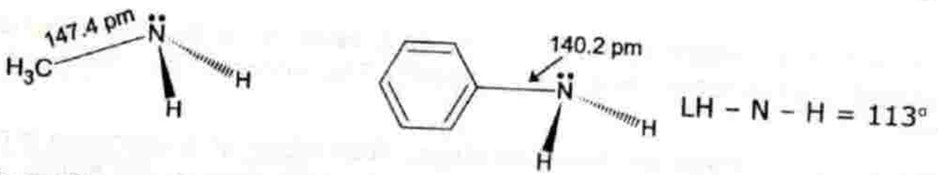
the meta position which are releatively electron rich. Thus nitro group direct all electrophiles to the meta position.



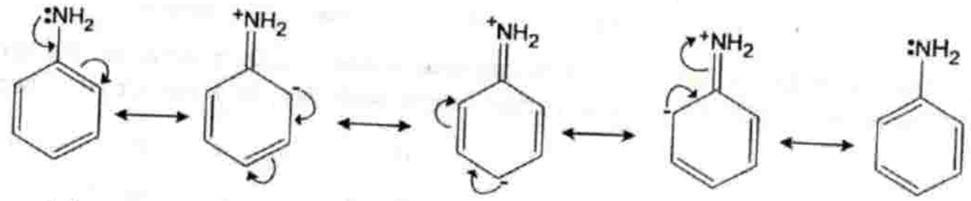
The $-NO_2$ group is deactivating. The nitrobenzene undergoes electrophilic substitution more slowly than benzene. The $-NO_2$ group withdraws electrons from the ring by resonance. It decreases electron density of the ring and makes it less attractive to an incoming electrophile. Thus the electrophilic substitution is slow. and requires vigorous reagent and conditions.

The $-NO_2$ group is deactivating and meta director.

AMINES



The carbon-nitrogen bond in aniline (140.2 pm) is, however, shorter than that in methylamine (147.4 pm). This is explained by (*i*) sp^2–hybridisation of carbon and (*ii*) involvement of nitrogen lone pair in conjugation with the π–electrons of the ring. The C–N bond in aniline involves sp^2–orbital of carbon which gives a shorter bond than the sp^3–orbital of carbon in methylamine. Moreover, in aniline the lone pair of electrons are delocalised into the aromatic ring as can be seen from the following resonance forms of aniline.

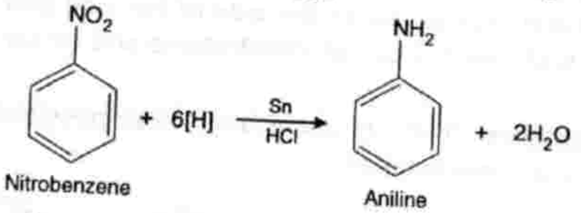


Such a delocalisation of lone pair of electrons of nitrogen gives a partial double bond character to C–N bond, strengthen it and shortens it. As a result, the electron density on nitrogen decreases and thus aryl amines are less basic than alkyl amines. Another consequence of this delocalisation is the increase in electron density in the ring and thus aniline exhibits a high reactivity in electrophilic substitution reactions.

General Methods of Preparation of Primary Amino Compounds

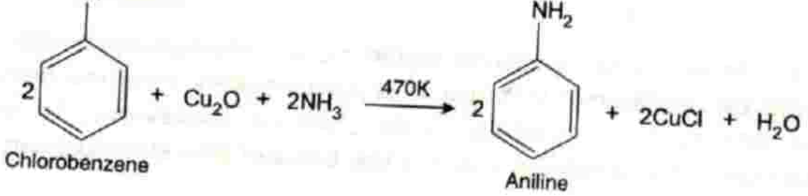
(1) ***By reduction of Nitro–compounds.*** Various reducing agents which may be used to reduce nitro compounds to amines are tin, iron or zinc with hydrochloric acid.

$$ArNO_2 + 6[H] \xrightarrow[+\ acid]{Metal} ArNH_2 + 2H_2O$$



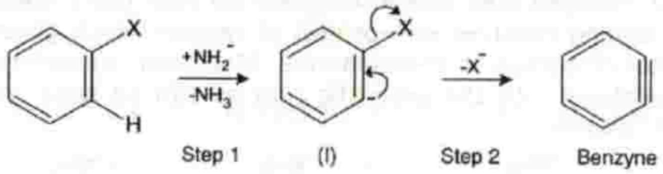
(2) ***Ammonolysis of halogen–compounds*** with liquid ammonia under pressure and high temperature in the presence of a catalyst (Cu_2O).

For Example,

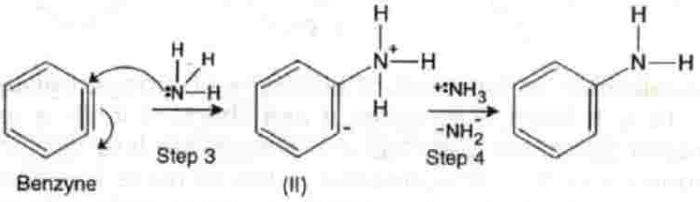


This is not as simple a displacement as it appears to be. The reaction involves two stages : *elimination* and then *addition*. The intermediate molecule is termed *benzyne*.

(*i*) Elimination stage involves two steps: abstraction of a hydrogen atom (step 1) by the amide ion to form NH_3 and carbanion I which then losses halide ion (step 2) to form benzyne.



(*ii*) The addition of NH_2^- also involves two steps : attachment of the amide ion (step 3) to form carbanion II, which then reacts with NH_3 to abstract H^+ (step 4).



The addition of a nucleophile may involve a single step in some cases. If this is so, the transition state is probably the one in which the attachment of nitrogen has proceeded to a greater extent than attachment of hydrogen and it has, therefore, considerable carbanion character.

In benzyne, an additional weak bond is formed between two carbon atoms by sideway overlap of sp^2 hybrid orbitals (Fig. 7.1). The new bond orbital lies on the side of the ring and has little interaction with the π–electron cloud above and below the ring.

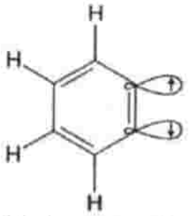
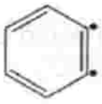


Fig. 7.1. Benzyne molecule

Structure of Benzyne. It is still uncertain. Three possible structures of benzyne are given below:

I
Benzyne

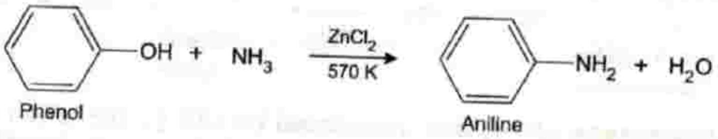


II
Diradical

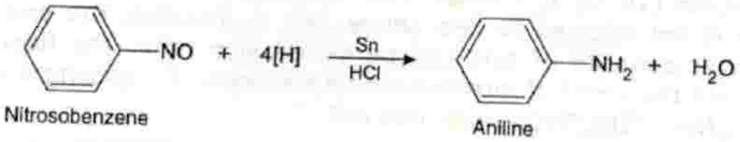
III
Dipolar ion

If structure I is accepted, benzyne would be a distorted acetylene and should therefore, would be unstable. Structure II is also unlikely because benzyne shown has little resemblance to a diradical in its chemical behaviour. In structure III benzyne is represented as a dipolar ion. On the basis of this structure we can explain the attack by nucleophiles like NH_2^-. Because of this uncertainty of structure, some people prefer to name it as *1, 2-dehydrobenzene*(which is a non committal name for benzyne) which implies the presence of a triple bond.

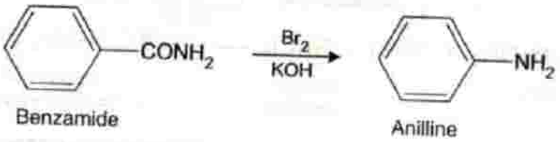
(3) ***Ammonolysis of phenols*** with ammonia in the presence of $ZnCl_2$ at 570 K.



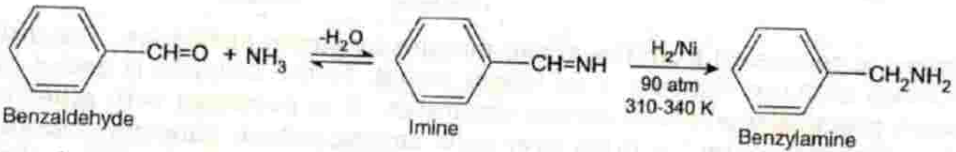
(4) ***By reduction of nitroso compounds*** with tin and hydrochloric acid.



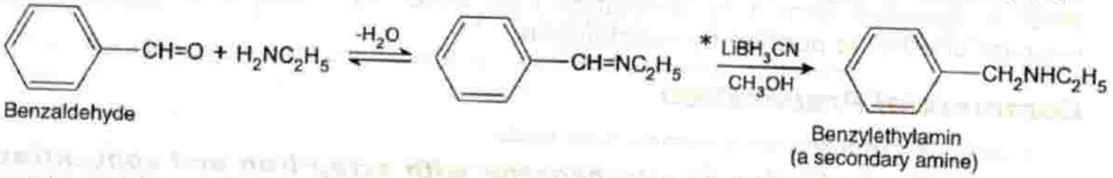
(5) ***Hofmann's hypobromite method.*** By the action of bromine and alkali on amides.



(6) ***Through reductive amination of aldehydes and ketones.*** Aldehydes and ketones can be converted into primary amines by their catalytic or chemical reduction in the presence of ammonia. The process is termed *reductive amination* which proceeds with the formation of an imine as an intermediate product.



Secondary amines are obtained on using a primary amine in place of ammonia.□



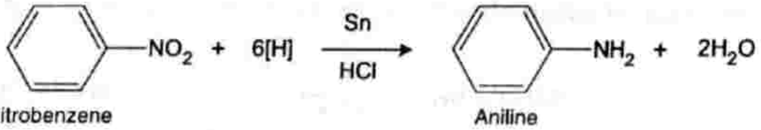
Aniline (Benzenamine), $C_6H_5NH_2$

Aniline was first prepared by Unverdorben (1826) who obtained it by distilling indigo and named it as aniline (after the Portuguese word *anil* meant for *indigo*).

□* A reducing agent similar to $LiBH_4$. It reduces iminium group more rapidly than it reduces the carbonyl group.

Preparation : (a) Laboratory Method

In the laboratory, aniline is prepared by the reduction of nitrobenzene with tin and hydrochloric acid.



Expt. Nitrobenzene (20 g) and granulated tin (40 g) are taken in a round-bottom flask fitted with a reflux condenser. To this is added conc. hydrochloric acid (100 ml) in small amounts (10 ml at a time). The flask is shaken after each addition and the temperature is not allowed to rise above 360 K. Towards the end, the reaction is slow and larger quantity of acid can be added at a time. The flask is heated on a water bath until the smell of nitrobenzene disappears. On cooling a solid mass of the formula $(C_6H_5NH_2.HCl)_2.SnCl_4$ separates out.

$$\underset{\text{Nitrobenzene}}{C_6H_5NO_2} \xrightarrow[6[H]]{Sn/HCl} \underset{\text{Aniline}}{C_6H_5NH_2}$$

$$\underset{\text{Aniline}}{2C_6H_5NH_2} + 5HCl + \underset{\substack{\text{Stannic}\\ \text{chloride}}}{SnCl_4} \longrightarrow \underset{\substack{\text{Double salt}\\ (\textit{A solid mass})}}{(C_6H_5NH_2.HCl)_2SnCl_4}$$

The solid mass is treated with a concentrated caustic soda solution until the solution is clear and alkaline. Aniline is liberated and floats as a dark brown oil.

$$\underset{\text{Solid mass}}{(C_6H_5NH_2.HCl)_2.SnCl_4} + 8NaOH \longrightarrow \underset{\substack{\text{Aniline}\\ (\textit{Oily layer})}}{2C_6H_5NH_2} + \underset{\substack{\text{Sodium stannate}\\ (\textit{Soluble})}}{Na_2SnO_3} + 6NaCl + 5H_2O$$

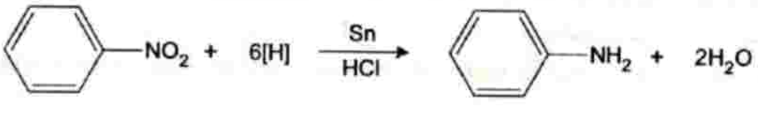
Aniline is recovered from the above mixture by steam distillation. The distillation is continued until the distillate is no longer turbid. To the distillate is added common salt when practically whole of aniline separates. It is extracted with ether in small lots. The ethereal extract is dried over solid caustic potash (calcium chloride is not used as a drying agent because it forms an addition compound with aniline) and ether is removed from it by distillation over water bath. Aniline so obtained after removal of ether is purified by redistillation.

Commercial Preparation

Aniline is prepared on a commercial scale:

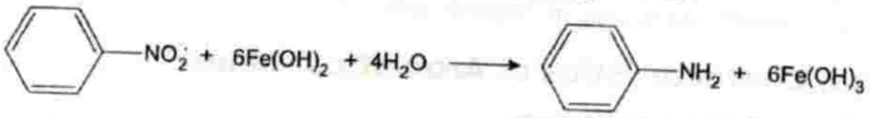
(*i*) ***By the reduction of nitrobenzene with scrap iron and concentrated hydrochloric acid.***

$$Fe + 2HCl \longrightarrow FeCl_2 + 2[H]$$



Here not only costly tin is replaced by cheaper iron but also there is a saving of hydrochloric acid as a portion of the acid gets regenerated by hydrolysis of ferrous chloride.

$$FeCl_2 + 2H_2O \longrightarrow Fe(OH)_2 + 2HCl$$



Thus only 1/40th of the theoretical amount of hydrochloric acid is actually used.

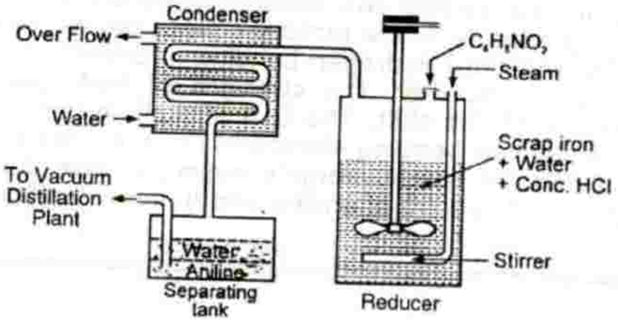


Fig. 7.2. Manufacture of aniline

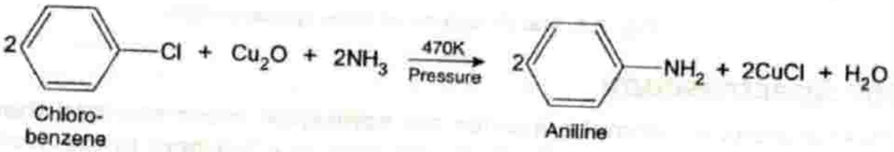
Process. Concentrated hydrochloric acid, water and scrap iron are placed in the reducing pan (*Reducer*—Fig. 7.2). Steam is blown into the reducer and nitrobenzene run in a fine stream, the contents are kept in agitation by a stirrer fitted in the reducing pan. No further heating is necessary as the heat of reaction is enough to complete the reduction.

At the end, milk of lime is added to neutralise the acid and to decompose aniline hydrochloride ($C_6H_6\ NH_2.HCl$) formed and aniline set free is separated by distillation in steam. The distillate is collected wherein crude aniline forms the lower layer. Crude aniline is taken to a vacuum distillation plant and distilled under reduced pressure when pure aniline distils over.

(*ii*) ***By the catalytic reduction of nitrobenzene.*** Aniline may also be manufactured by catalytic reduction of nitrobenzene using nickel as a catalyst.

(*iii*) ***By the action of ammonia on chlorobenzene.*** Chlorobenzene reacts with excess of aqueous ammonia when treated at 470 K under pressure in the presence of cuprous oxide.

The later decomposes the ammonium chloride formed in the reaction and thus renders the reaction irreversible.



Physical Properties

When freshly prepared, aniline is a colourless oily liquid (b.p. 457 K) with an unpleasant odour and it is poisonous in nature. Being sensitive to oxidation, its colour rapidly changes to dark brown when exposed to air. It is practically insoluble in water but readily dissolves in organic solvents.

Chemical Properties

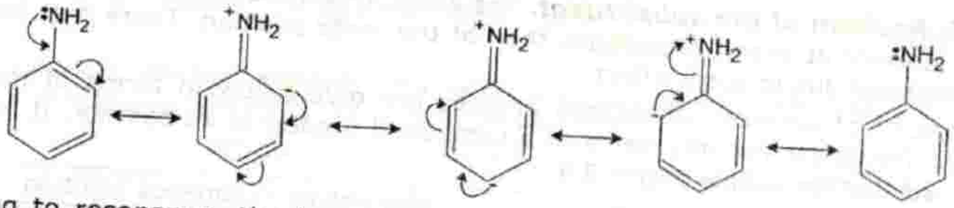
Aniline, $C_6H_5NH_2$ is made up of (*i*) an amino-group attached to the benzene nucleus carbon, and (*ii*) the benzene nucleus. Its reactions are therefore the reactions of these two groups:

(a) Reactions of the Amino-Group

(1) *Basic Nature*

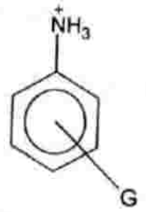
Aniline is weakly basic and gives salts with acids, *e.g.*, aniline hydrochloride, $C_6H_5NH_2.HCl$, with hydrochloric acid, aniline sulphate $(C_6H_5NH_2)_2.H_2SO_4$ with sulphuric acid and double salts $C_6H_5NH_2.HCl\ PtCl_4$, with platinic chloride, $(PtCl_4)$.

Aniline is a weaker base than primary amines due to resonance which is not possible in aliphatic amines.



Owing to resonance, the lone pair of electrons on the nitrogen atom is less available for coordinating with a proton. In addition to this, the small positive charge on the nitrogen atom tends to repel the proton.

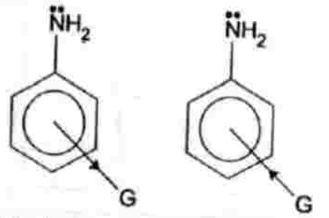
Aniline may accept a proton to give a small concentration of the cation (anilinium ion) which does not show resonance.



Since there are more resonating structures possible for aniline than for the anilinium ion, the former will be stabilized with respect to the latter.

Effect of Ring Substitution on Basicity. The effect of ring substituent, G on basicity depends on the following factors:

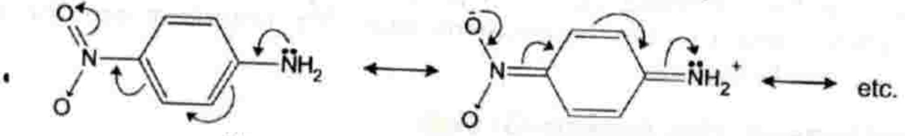
(*i*) ***Nature of G whether it is electron-attracting or electron-releasing.*** An electron-releasing group reduces the resonance of NH_2 group with the ring and, therefore, increases the basicity. Similarly an electron-withdrawing group (—I effect) tends to draw the electron pair of the $\ddot{N}$ atom of NH_2 group into the ring and consequently decreases the basicity.



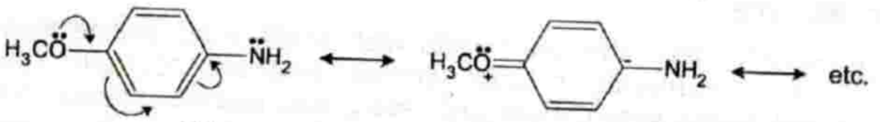
G is electron withdrawing- decreases the basicity

G is electron releasing increases the basicity

(*ii*) ***Ability of G to enter into resonance with the amino-group.*** Groups like nitro group which have a strong—R effect decrease the basicity and others like methoxy group having a strong +R effect increase the basicity.



Nitro group decreases the basicity due to – R effect



Methoxy group increase the basicity due to + R effect

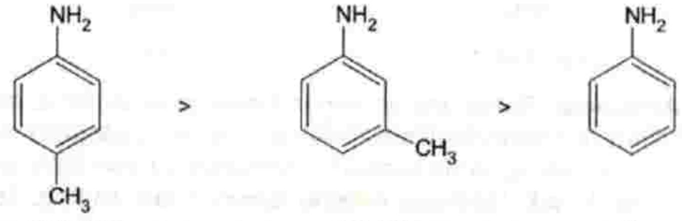
(*iii*) ***Position of the substituent.*** The electron-withdrawing or electron-releasing effect is more at *o*-and *p*-positions than at the *meta* position. There may be added complications due to steric effect.

Basicity of various substituted anilines are give below in terms of their *pKb* values. The lower the *pKb* value of a compound greater is its basicity. It has been observed that for aniline *pKb* = 9.4

Substituent G in $G{-}C_6H_4{-}NH_2$	*pKb values in aqueous solution*		
	ortho–	*meta–*	*para–*
H	9.4	9.4	9.4
CH_3	9.5	9.3	8.7
CH_3O	9.4	9.8	8.7
Cl	11.3	10.4	10.2
$COCH_3$	11.6	10.4	11.3
CN	13.1	11.2	12.3
NO_2	14.3	11.5	13.0

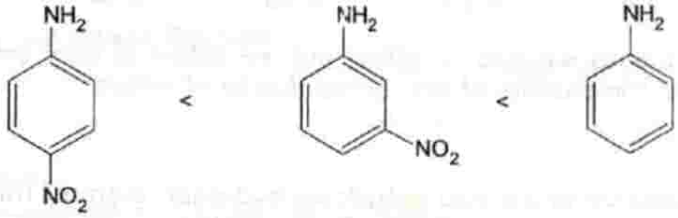
Effect of various substituents on the basicity of aniline as seen from the *p*K*b* values given in the above table can be explained as follows:

(*i*) **CH_3**. It has a +I effect and, therefore, increase the basicity from *PKb* = 9.4 to 9.3 (for *m*–) 8.7 (for *p*–). The effect is more when CH_3 is in *p*-position than in *m*-position as explained earlier.



p-Toluidine *m*-Toluidine aniline

(*ii*) **NO_2**. It exerts —*R* as well as –I effects and, therefore, decreases the basicity as seen from an increase in *p*K*b* values. The effect in *o*– and *p*–position is much more than in the *m*–position. This is because from *m*– position it cannot exert —R effect. Decrease in basicity is only due to –I effect.



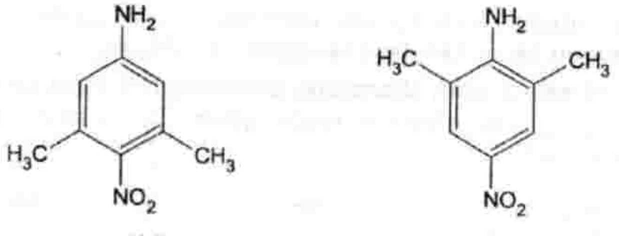
p-Nitroaniline *m*-Nitroaniline aniline

(*iii*) **Methoxy and Amino Groups.** The *p*–OMe group has a +R effect and the basicity is increased due to its presence. In the *m*–position it exerts only an inductive effect and this decreases the basicity. Effect of amino group can be explained similarly.

(*iv*) All groups, whether **electron releasing** or **electron withdrawing,** decrease the basic strength when present in the ortho position.

This is known as the **ortho effect** and is probably due to a combination of steric and electronic factors.

It is evident from the above discussion that when the substituent group can enter into resonance with rest of the molecule, it exerts a marked effect on its basicity. For resonance to be operative, the resonating structures must be planar or nearly planar. If the planarity is partially reduced or completely prevented due to some steric factor, the resonance is diminished or completely prevented. This is called *steric inhibition of resonance*. For example, 3,5–dimethyl–4–nitroaniline is a stronger base than 2,5–dimethyl–4–nitroaniline on account of steric inhibition. In the first case, the nitro group cannot enter into resonance with the amino-group and is not able to reduce the basicity appreciably. In the second case, it can enter into resonance and, therefore, reduces the basicity appreciably.



*p*K*b* ~ 11.5 ~ 13

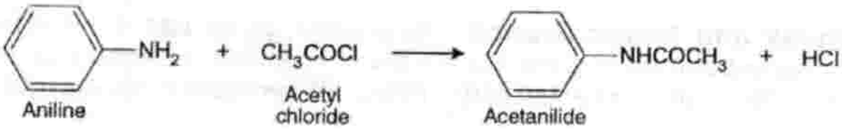
N–Alkylated Anilines. *These are stronger bases than aniline, and N–ethylaniline* is a stronger base than *N*–methylaniline. This cannot be explained on the basis of + I effect of alkyl groups resulting in increased resonance of the lone pair with the ring, since that would make *N*–alkylanilines weaker bases than aniline. It is considered to be due to the steric effect, which inhibits resonance of the lone pair on nitrogen and makes it more available for protonation. Ethyl group being bigger than methyl, it has a greater steric effect. Consequently *N*–ethylaniline is a stronger base than *N*–methylaniline. pKb values of some of these are given below for reference purposes.

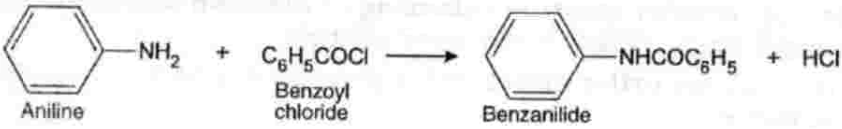
Base	$PhNH_2$	PhNHMe	PhNHEt	$PhNMe_2$	$PhNEt_2$
pKb	9.4	9.15	8.89	8.94	7.44

Halogens exert both +R and –I effect but +R effect is very small. Presence of halogens decreases the basicity of NH_3 group due to –I effect.

(2) *Acylation*

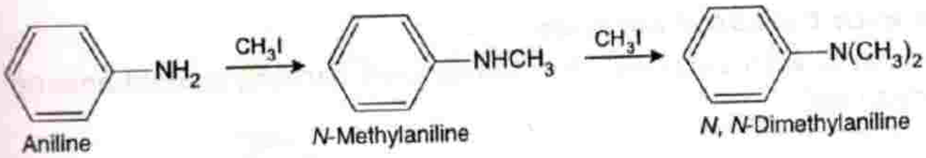
With an acid chloride or an acid anhydride hydrogen atom of the amino-group is replaced by acyl group to give an anilide; for example,





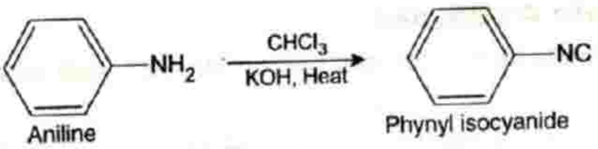
(3) *Alkylation*

When treated with alkyl halides, the hydrogen atoms of the amino-group are replaced by alkyl groups to give mixed, secondary and tertiary amino-compounds.



Carbylamine Reaction

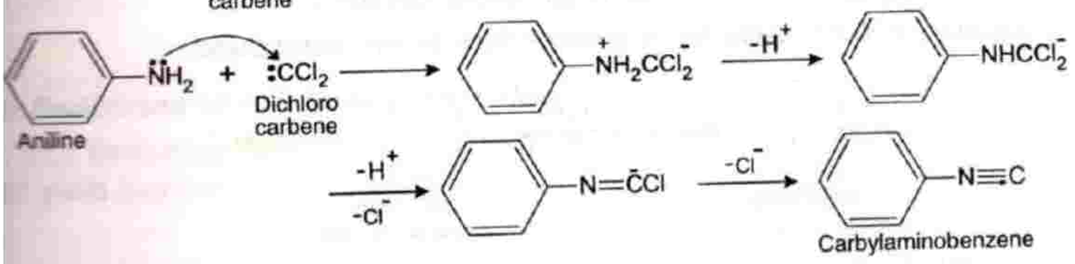
n heating aniline with chloroform and alcoholic potash, an obnoxious smell of ylamine (an isocyanide) is noticed.



he mechanism proposed for the reaction is as follows.

$$CHCl_3 + \bar{O}H \rightleftharpoons :\bar{C}Cl_3 + H_2O$$

$$:\bar{C}Cl_3 \longrightarrow \underset{\text{Dichloro carbene}}{:CCl_2} + Cl^-$$



Action with Grignard Reagent

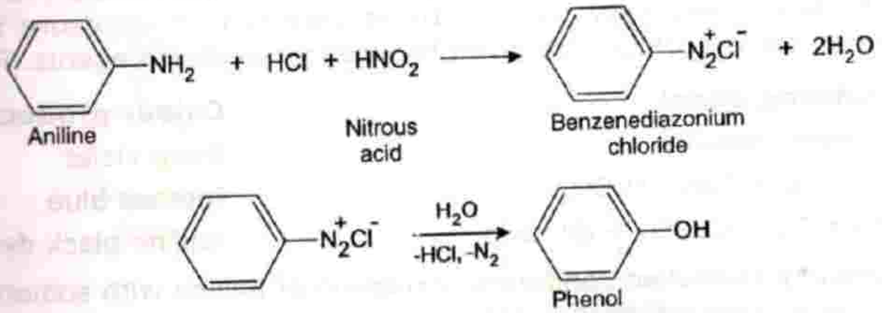
Aniline reacts with Grignard reagent to form hydrocarbons.

$$RMgBr + C_6H_5NH_2 \longrightarrow RH + C_6H_5NHMgBr$$

Diazotisation

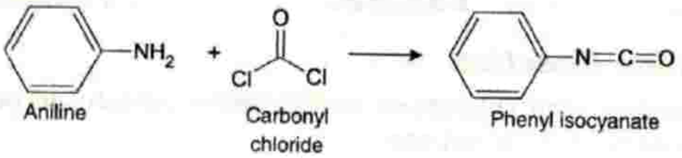
When an ice-cold solution of aniline in hydrochloric acid is treated with an ice-cold tion of sodium nitrite, it gives benzenediazonium chloride, which decomposes on rming to give phenol.

$$NaNO_2 + HCl \longrightarrow HNO_2 + NaCl$$



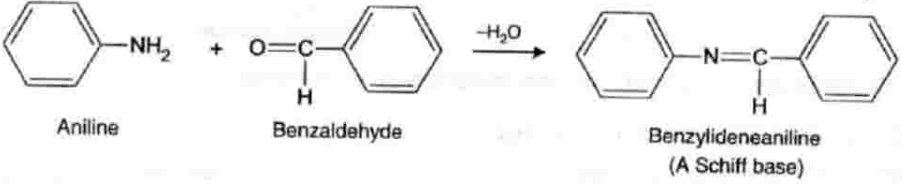
(7) *Action with Carbonyl Chloride*

Aniline reacts with carbonyl chloride to give carbonylaminobenzene (also called phenyl isocyanate).



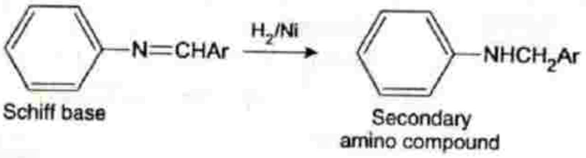
(8) *Condensation with Aldehydes*

Aniline gives condensation products (*Schiff bases*) with aromatic aldehydes.



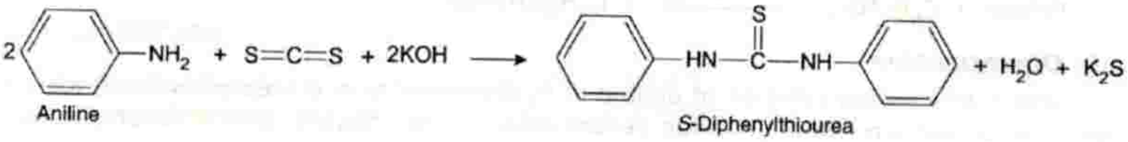
The Schiff bases on hydrolysis easily give free amine. Their formation offers an easy method of protecting an amino-group before nitration.

On reduction, a Schiff base gives a secondary amino-compound.



(9) ***Action with Carbon Disulphide***

On heating with an alcoholic solution of carbon disulphide and solid KOH, it gives phenylthiourea or thiocarbanilide (used in vulcanisation of rubber).

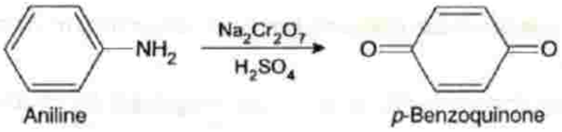


(10) ***Oxidation***

The high electron density on the ring in the aniline molecule makes oxidation (*electron removal*) very easy. Thus it turns dark red on exposure to air due to oxidation. More intense colours are given by stronger oxidising agents. For example,

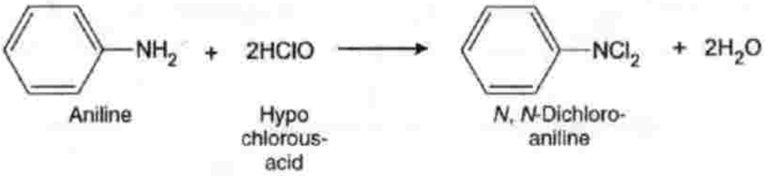
Oxidising agent	**Colour produced**
Bleaching powder	Deep violet
$Na_2Cr_2O_7$ + Conc. H_2SO_4	Intense blue
$Na_2Cr_2O_7$ + $CuSO_4$ + dil. acid.	Aniline black dye

Under carefully controlled conditions, oxidation of aniline with sodium dichromate and sulphuric acid gives *p*–benzoquinone.

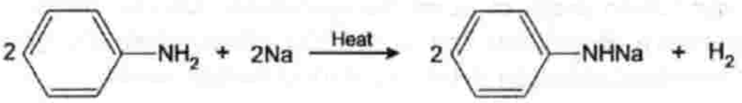


(11) ***Action with Hypohalous Acids or Alkali Metals***

Hydrogen atoms of the amino-group are replaced by halogen atoms when aniline is treated with hypohalous acids, *e.g.*, with hypochlorous acid, HClO, aniline forms *N, N*–dichloroaniline.

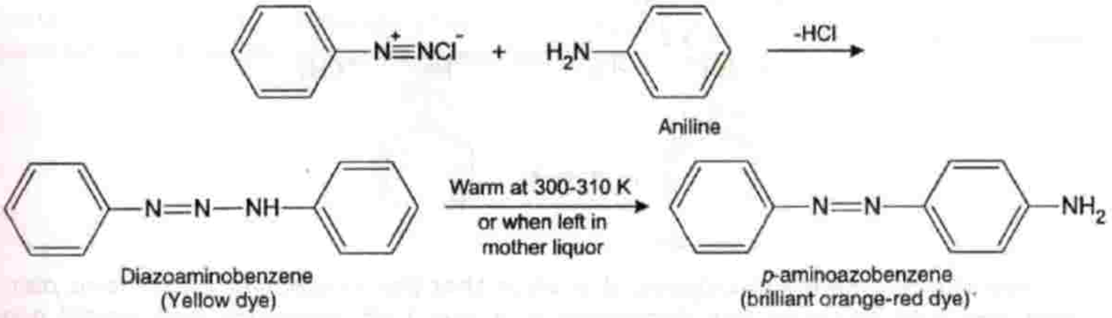


When heated with sodium or potassium, the metal dissolves in aniline with the evolution of hydrogen.

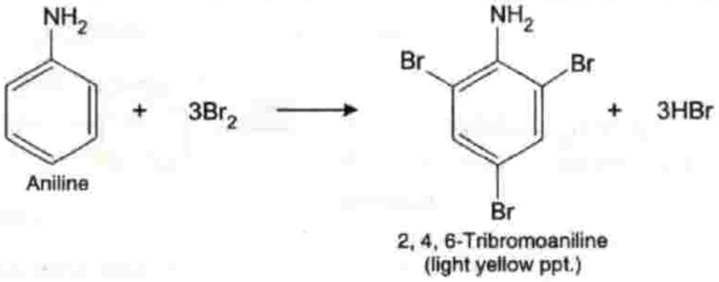


(*b*) ***Reactions of the Benzene Nucleus***

(1) ***Coupling Reaction.*** Aniline gives a coupling reaction with diazonium salts and yield azo-dyes.

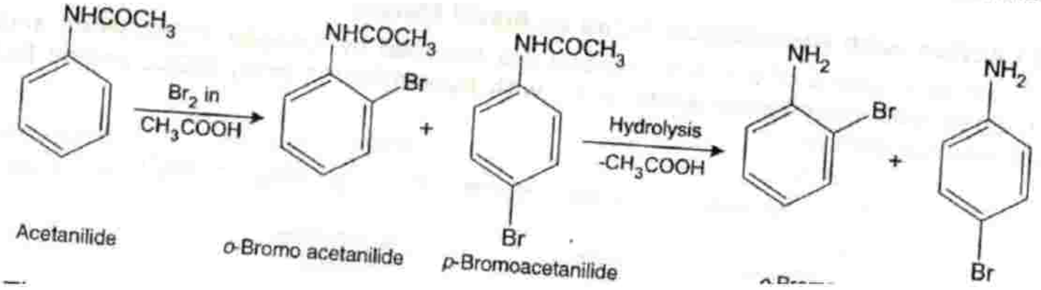


(2) ***Halogenation.*** Presence of amino-group in the benzene nucleus facilitates halogenation. A symmetrical trisubstitution product is obtained on chlorination or bromination.



In chlorination, a water-free solvent such as chloroform should be used otherwise oxidation takes place.

Monochloro or monobromoaniline may be prepared by chlorination or bromination of acetanilide.



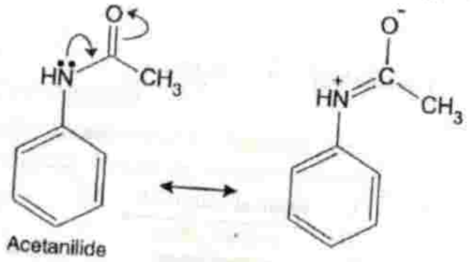
o-Bromo aniline

p-Bromo aniline

These on hydrolysis give the corresponding bromoanilines.

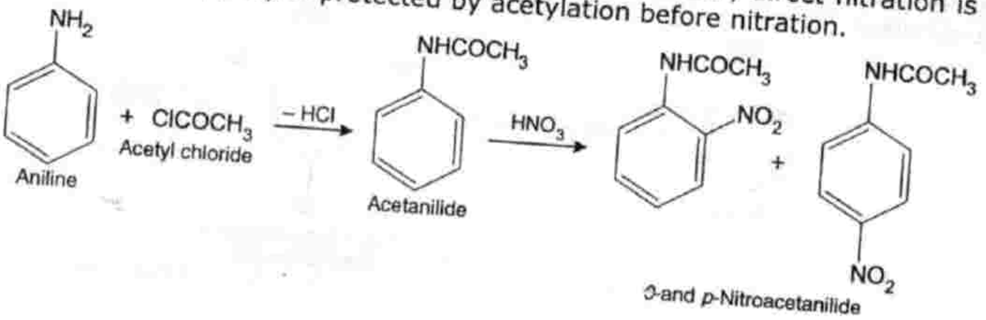
It should be noted that $-\ddot{N}H_2$ group in aniline is strongly activating so aniline gives a trisubstitution product upon halogenation. On the other hand in acetanilide (the aryl derivative of aniline) the activating effect of amino group is reduced and thus it gives monosubstitution products during halogenation.

Deactivating effect of the acetyl group in acetanilide. It is considered to be due to the fact that the lone pair of the: NH_2 group enters into resonance with the carbonyl group and as a result its resonance with the ring decreases considerably.

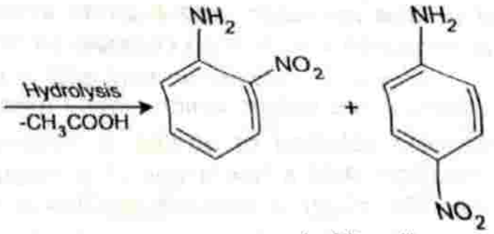


From the resonance structures, it is clear that *the availability of the lone pair for resonance with benzene ring decreases as a result of resonance with acetyl group. This explains the deactivating effect of the acetyl group in acetanilide.*

(3) ***Nitration.*** Aniline being very susceptible to oxidation, direct nitration is not observed. The amino-group is protected by acetylation before nitration.



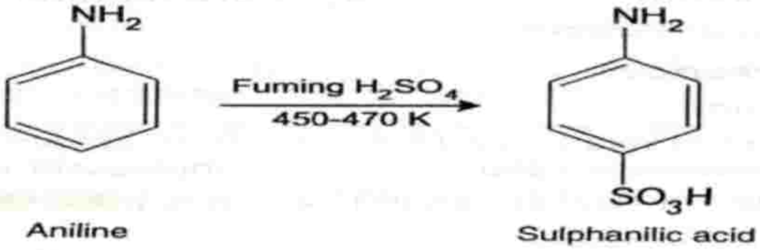
o-and p-Nitroacetanilide



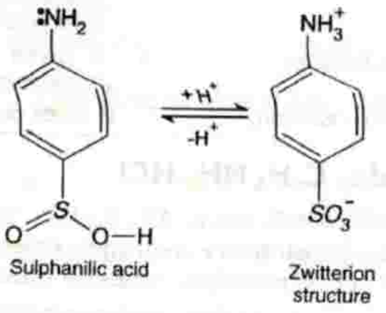
o-and p-Nitroaniline

The p–nitroaniline far exceeds the ortho-derivative in yield.

(4) ***Sulphonation.*** Aniline on heating with fuming sulphuric acid to 450–470 K, gives *p*–aminobenzenesulphonic acid (*sulphanilic acid*). Why? This is because sulphonation is known to be reversible and the *p*–isomer is known to be the most stable isomer.



Sulphanilic acid contains both acidic (SO_3H) and basic (NH_2) groups. These groups interact to form an internal salt called **Zwitterion.** *Thus sulphanilic acid exists mainly as its zwitterion structure* in which a proton from sulphonic acid is taken up by the amino group as shown below.



Comparison of Aniline with Ethylamine

(a) Points of Similarity:

(*i*) Basic nature (*ii*) Alkylation (*iii*) Acylation
(*iv*) Action of Sodium (*v*) Carbylamine reaction
(*vi*) With Grignard reagent.

(b) Points of Difference:

Ethylamine	*Aniline*
1. It is a colourless inflammable liquid (b.p. 292 K) with fishy ammoniacal odour.	1. It is colourless liquid (b.p. 457 K) with unpleasant odour.
2. It is highly soluble in water giving alkaline solutions.	2. It is practically insoluble in water.
3. With nitrous acid, it gives ethyl alcohol and nitrogen.	3. It gives diazonium salt in cold and phenol on heating.
4. It is not easily oxidised.	4. It is very susceptible to oxidation.
5. No substitution takes place in the ethyl group.	5. Substitution in the benzene nucleus proceeds readily. It can be nitrated, sulphonated and halogenated.
6. It does not react with aldehydes.	6. It gives a Schiff's base with aromatic aldehydes.
7. It does not give a coupling reaction.	7. It gives positive coupling reactions.

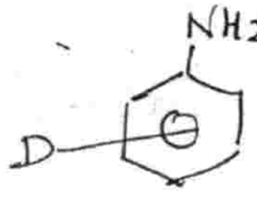
Relative basic character of Aromatic amine (Aniline) with aliphatic amine

① Aryl amine (aniline) is less basic than alkyl amine.

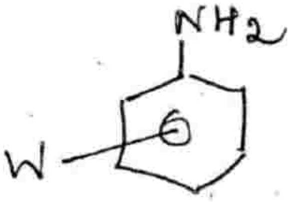
② The lone pair of electron on nitrogen in ethylamine is localised on N-atom but in arylamine (aniline) electron is delocalised on the benzene ring. This decreases electron density on nitrogen and makes aniline is less basic. pKa value support this reasoning.

③ Substituted aniline is more or less basic than aniline, it depends on the nature of substituent.

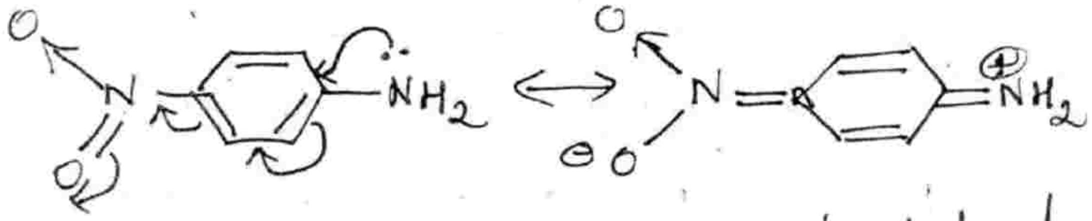
ⓐ Electron donating substituent increases electron density to the benzene ring and it makes more basic than aniline



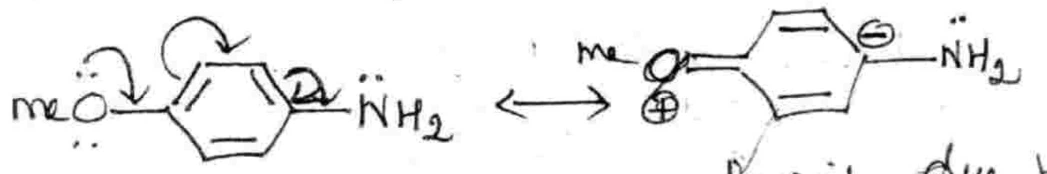
(b) Electron withdrawing group decreases electron density from benzene and it makes less basic than aniline



(c) The ability of donation and withdrawing of electrons enter into resonance with $-NH_2$ group. $-NO_2$ group has strong $-R$ effect and it decreases basicity and other $-O-me$ group has a strong $+R$ effect and it increases basicity



$-NO_2$ group decreases basicity due to $-R$ effect.



$-OCH_3$ group increases Basicity due to $+R$ effect.

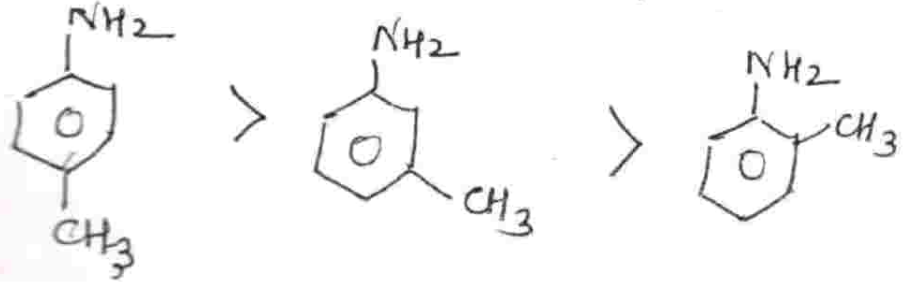
④ Position of the substituent

The electron withdrawing or electron releasing effect is more at o & p than m due to ~~seb~~ steric effects

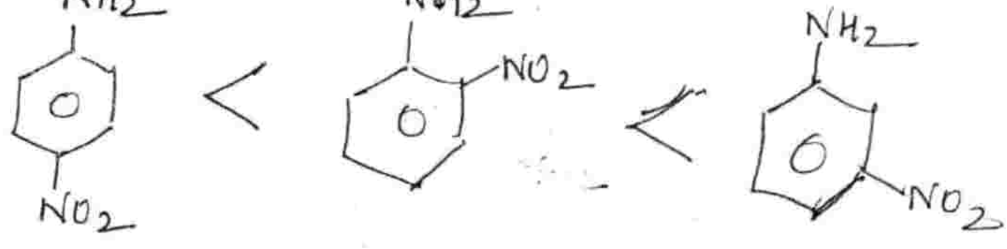
	pKb value Basicity		
Substituent	o	m	p.
H	9.4	9.4	9.4
CH_3	9.5	9.3	8.7
OCH_3	9.4	9.8	8.7
Cl	11.3	10.4	10.2
$COCH_3$	11.6	10.4	11.3
CN	13.1	11.2	12.3
NO_2	14.3	11.5	13.0

Lower the pK_b value greater the basicity.

⑤ In CH_3 +I effect increases the basicity 9.4 to 9.3 at meta and 8.7 at para.
This effect ~~of~~ CH_3 is more at para than meta.



⑤ In $-NO_2$ group $-R$ effect as well as $-I$ effect deactivate the benzene and decreases basicity. o & p this effect is more than m-position. In m-position it not excert $-R$ effect and the decrease of basicity is due $-I$ effect.

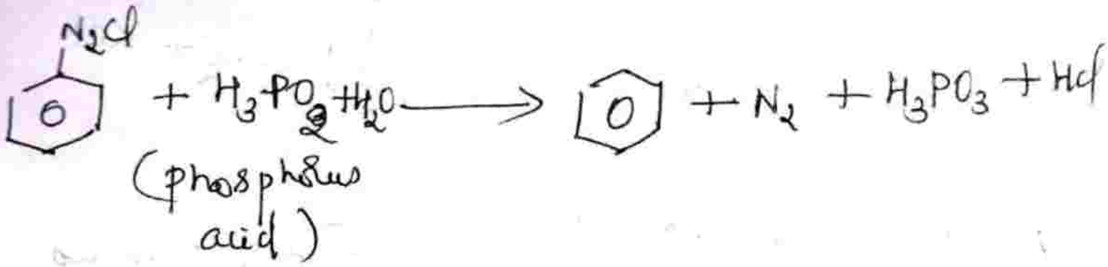


⑥ In $-OCH_3$ p- has a $+R$ effect and basicity ∴ decreases and in m-position it excerts only $+I$ effect and decoreases basicity.

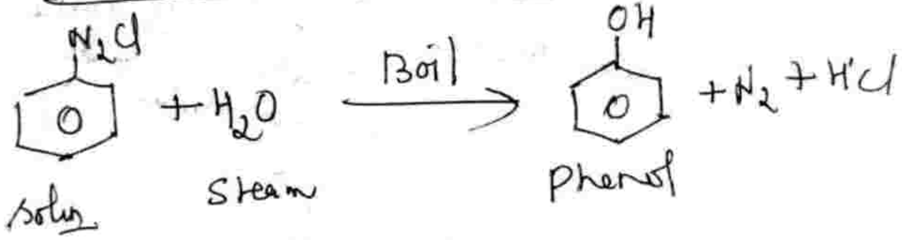
All groups (ie) electron withdrawi. and electron releasing group decreases basicity at ortho position due to combination of steric and electromeric effect.

Synthetic Applications of Benzene diazonium salt.

① [H] in Arenes [— N_2X by H]

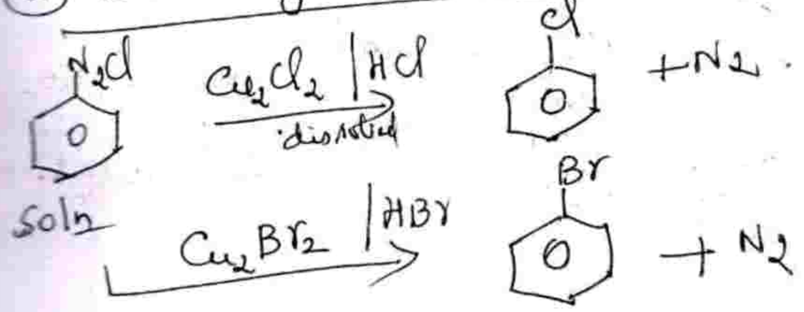


② — N_2Cl by — OH

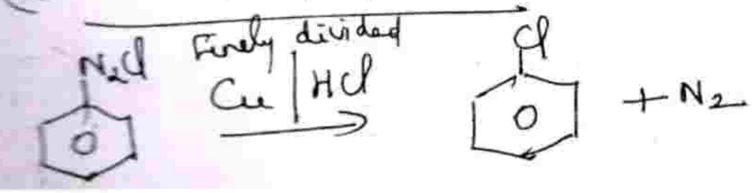


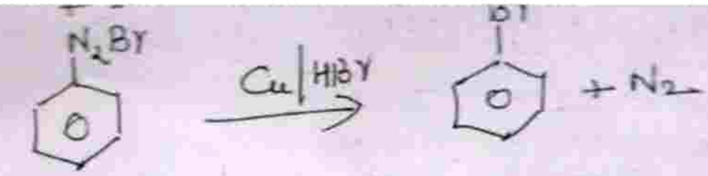
③ By halogen

ⓐ Sandmeyer Reaction.

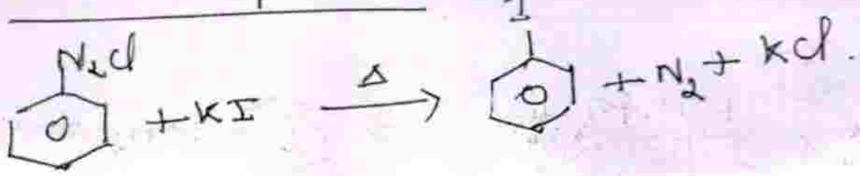


(b) Gattermann Reaction

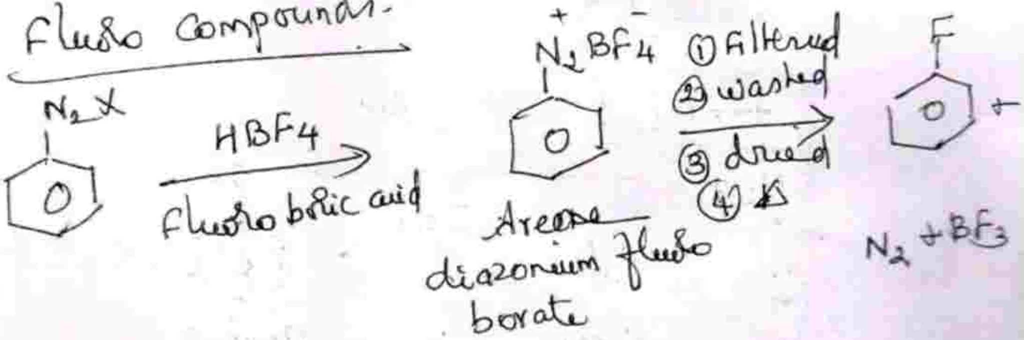




Iodo compounds

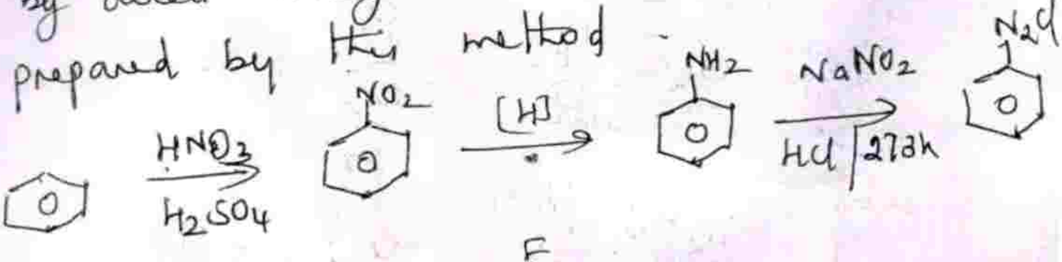


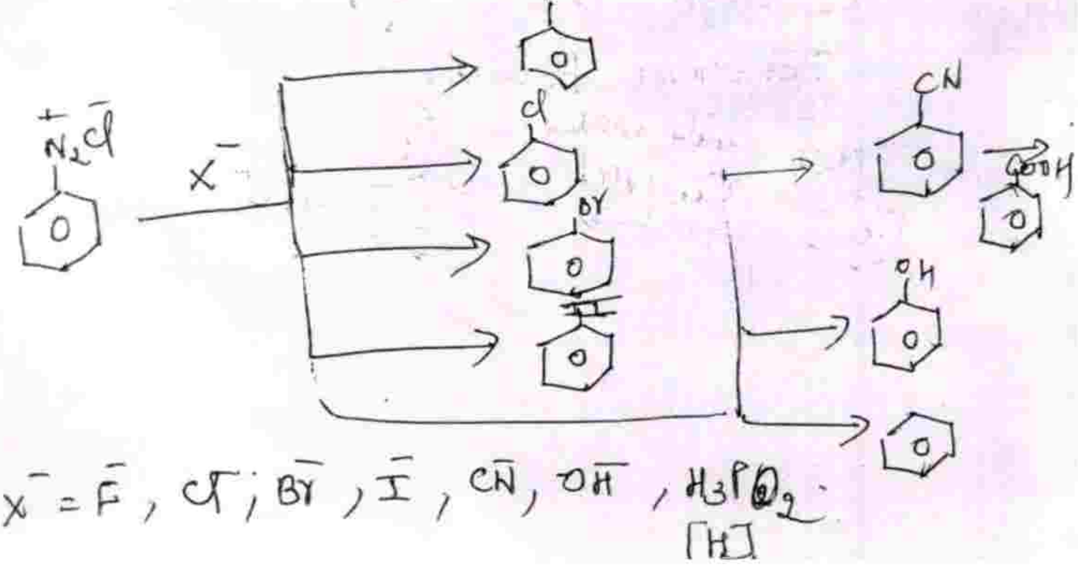
(d) Fluoro compounds.



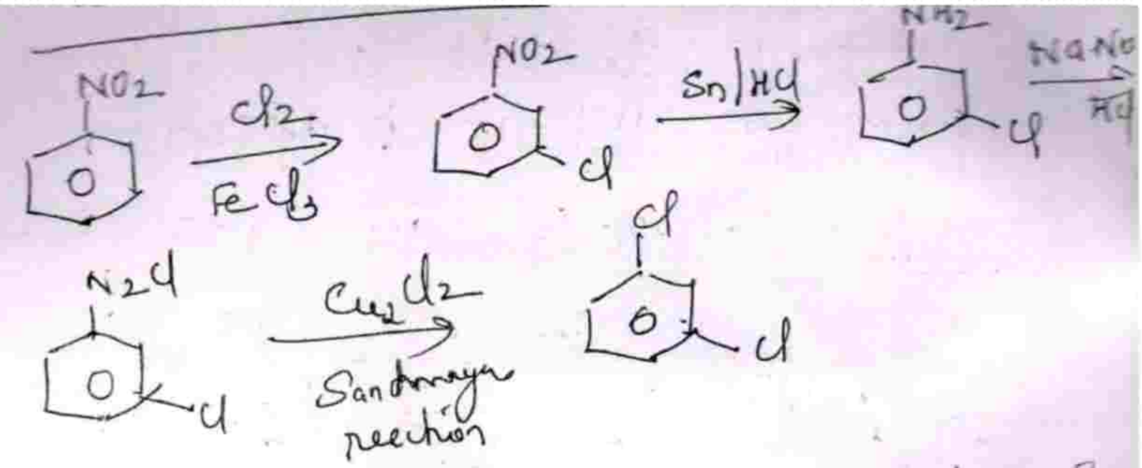
Synthesis of Aryl halides.

Aryl fluoride & iodide can not be prepared by direct halogenation. That compounds are prepared by this method.

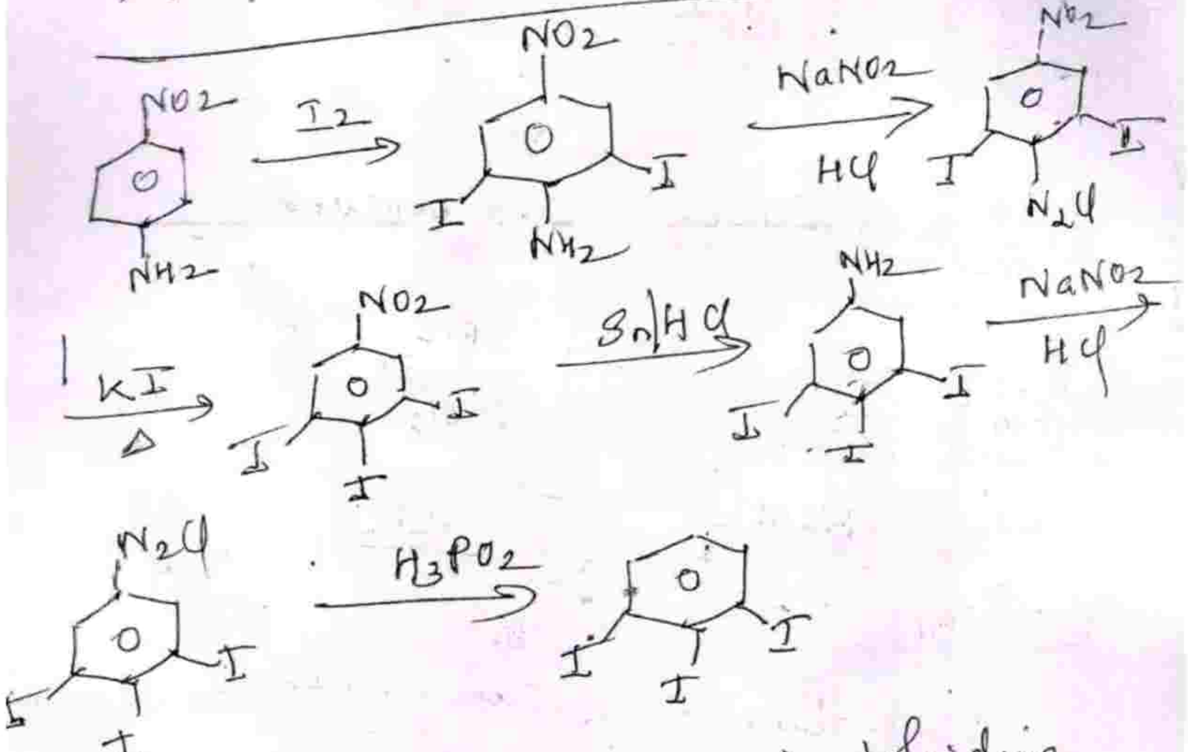




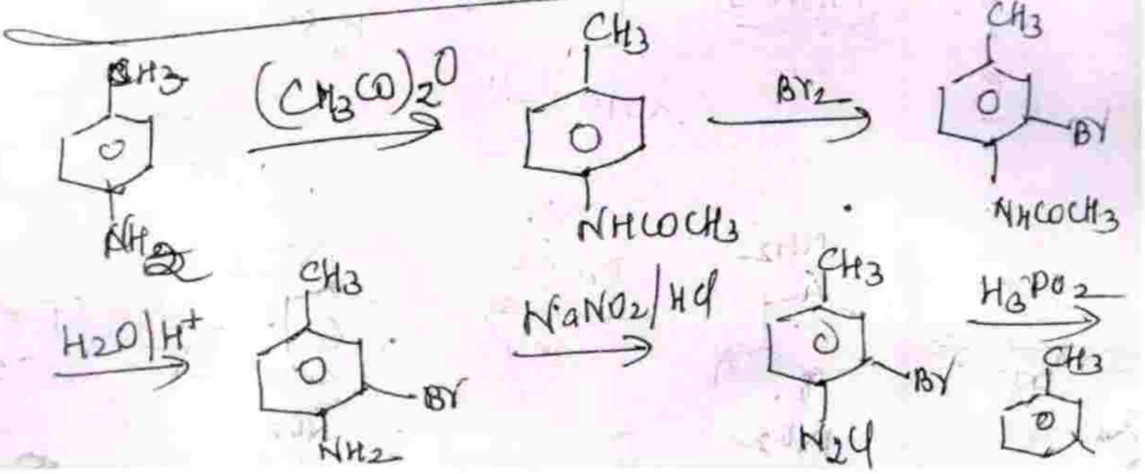
$X^- = F^-, Cl^-, Br^-, I^-, CN^-, OH^-, H_3PO_2$ [H]



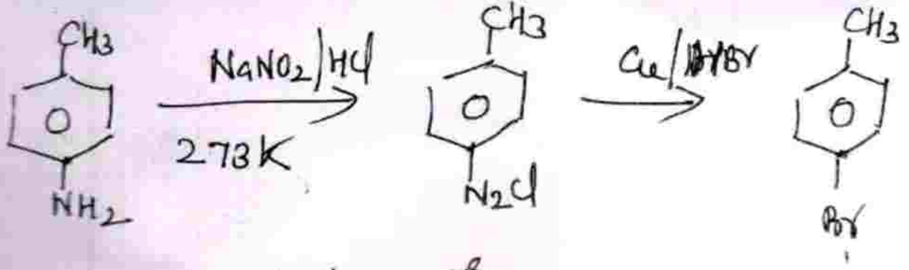
1, 2, 3 — Tri iodo benzene from p-nitro aniline



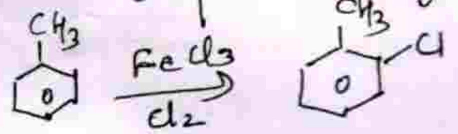
m-bromotoluene from p-toluidine



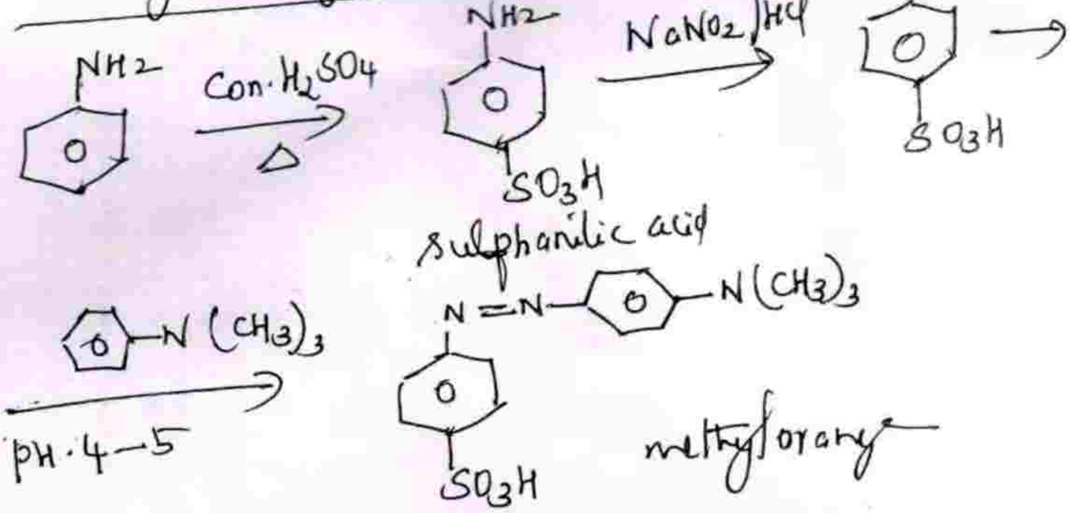
p- bromotoluene from p-toluidine



o-product major



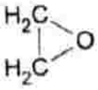
methyl orange from aniline

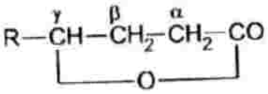


HETEROCYCLIC COMPOUNDS

Introduction

Heterocyclic compounds are cyclic compounds in which the ring includes on more polyvalent atoms such as oxygen, nitrogen and sulphur in addition to ca atoms. (Greek. *Hetero* = other, different). Some of the heterocyclic rings are re opened and do not possess aromatic properties, *e.g.*, ethylene oxide, γ-an lactones etc. These are generally not considered as heterocyclic compounds.


Ehtylene oxide


γ-Lactone

Heterocyclic compounds with a heteroatom in a five or six membered rin considerably stable. A wide range of such compounds are present in plants animals and have in fact played a crucial role in the origin of life on the eart plants and animals, they participate in important physiological functions su photosynthesis (chlorophyll), oxygen transport (haemoglobin), energy tra (Adenosine Tri Phosphate, ATP), oxidation and reductions (NAD & NA metabolism, muscle movement, protein synthesis, cell division, and nerve transmission. They are associated with important biomolecules such as nucleic proteins, carbohydrates, vitamins, haemoglobin anthocyanins and alkaloids. these compounds are essential for life and its various activity.

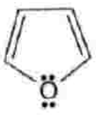
Classification

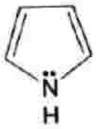
Heterocyclic compounds containing a five or six membered ring and possess aromatic properties are classified into following categories :

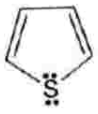
I. Five membered heterocyclic compounds

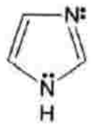
These are considered to be derived from benzene by replacement of one (–CH=CH–) group by a heteroatom such as oxygen, nitrogen or sulphur. The further classified into the following two types :

(*a*) **Compounds having one heteroatom** : Some common heter compounds of this type are furan, pyrrole and thiophene.

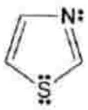

Furan

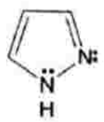

Pyrrole

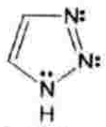

Thiophene


Imidazole


Oxazole


Thiazole


Pyrazole

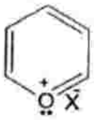

1, 2, 3-Triazole

II. Six membered heterocyclic compounds

These are considered to be derived from benzene by replacement of one of its CH– group by a heteroatom such as nitrogen, oxygen or sulphur. These are further classified into two types :

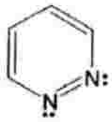
(*a*) **Compounds having one heteroatom :** Some common heterocyclic compounds of this type are pyridine, pyrylium salt and thiopyrylium salt.

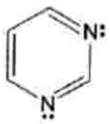

Pyridine

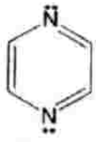

Pyrylium salt


Thiopyrylium salt

(*b*) **Compounds having more than one heteroatom**

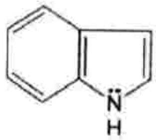

Pyridazine

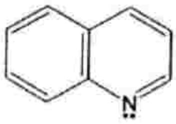

Pyrimidine

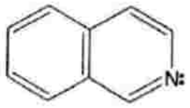

Pyrazine

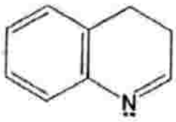
III. Condensed heterocyclic compounds

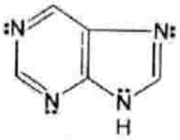
These compounds have a heterocyclic ring system (five membered or six membered) fused with a benzene ring or other heterocyclic ring system.


Indole


Quinoline


Isoquinoline

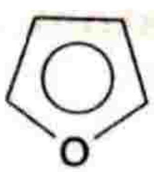

Quiniline


Purine

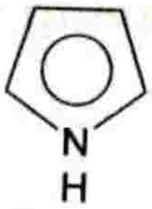
In this chapter, we shall be discussing five membered heterocyclic compounds containing one heteroatom and an important six membered heterocyclic compound, pyridine.

Five membered heterocyclic compounds

Furan, thiophene and pyrrole are the common five membered heterocyclic compounds. Each of these behaves as a resonance hybrid of different structures. For convenience their hybrid structures are represented as given below :

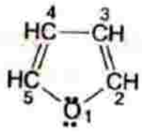

Furan

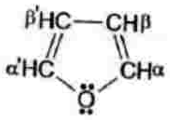

Thiophene


Pyrrole

Furan, Oxacyclopenta-2, 4-diene (furfuran)

Furan derives its name from furfur (Latin=bran) because its aldehyde furfural is prepared by distilling bran with hydrochloric acid. It contains one oxygen atom in its ring. The positions of side-chains or substituents are indicated by Greek letters or numbers, number 1 being given to the hetero atom.



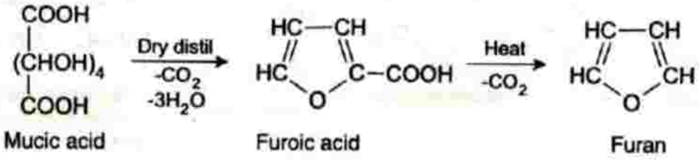


Thus there are two mono-substituted derivatives of furan, *viz.*, 2 or α, and 3 or β. Similarly there are four disubstitution products, *viz.*, 2:3 (α:β), 2:4 (α:β′), 2:5 (α:α′) and 3:4 (β:β′).

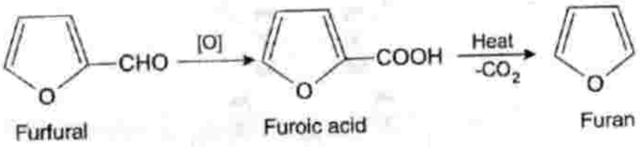
Preparation

(*i*) Furan is obtained by distillation of pine wood,

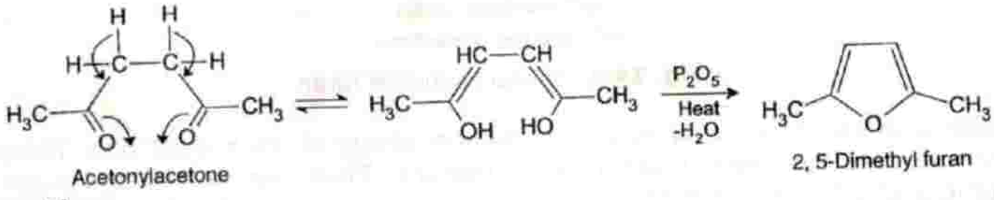
(*ii*) Dry distillation of mucic acid gives furoic acid which when heated at its b.p. yields furan.



(*iii*) Furfural on oxidation gives furoic acid which on heating decarboxylates to give furan.



(*iv*) **The Paul-Knorr synthesis.** 1,4-Dicarbonyl compound such as acetonylacetone on heating with phosphorous pentoxide (P_2O_5) undergoes dehydration to form 2, 5-dimethylfuran. The synthesis is called Paal-Knorr synthesis.



Properties

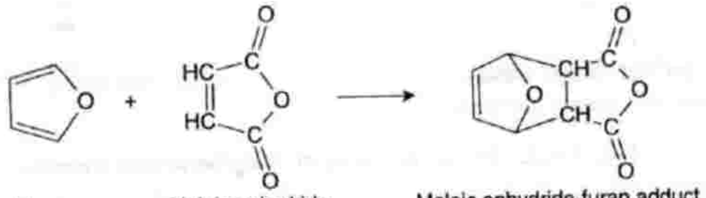
Physical Properties

It is a colourless liquid (b.p. 305 K), which is insoluble in water but soluble in alcohol and ether. It turns a pine splint moistened with hydrochloric acid, green in colour (Test).

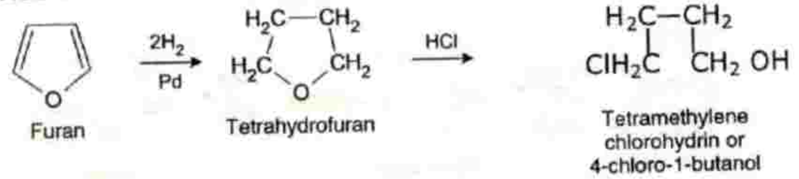
Chemical Properties

Chemically furan resembles benzene but tends to break open readily at the oxygen linkages. Some important reactions of furan are :

(1) **Diels-Alder Reaction.** Furan is less aromatic than thiophene and pyrrole and is the only one of these which undergoes Diels-Alder reaction.

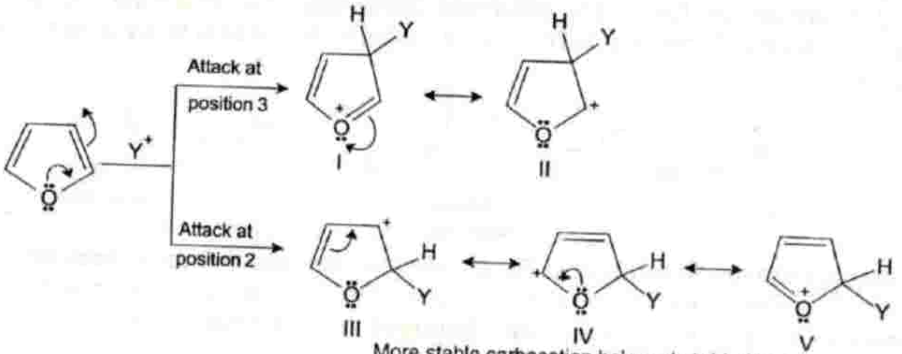


(2) **Reduction.** On catalytic reduction using Raney nickel or Pd-C/H_2 catalyst, it forms tetrahydrofuran (THF—*an inert solvent*) which breaks open on treatment with hydrogen chloride to form tetramethylene chlorohydrin.



(3) **Electrophilic Substitution Reactions.** As stated earlier furan is a resonance hybrid having a larger electron density at position 2 (or 5) than at position 3 (or 4). During electrophilic substitution, the electrophile is expected to attack at position 2 (or 5) this being a centre of higher electron density. In practice, 2-substitution is actually favoured.

Alternatively the rate controlling step in the electrophilic aromatic substitution is the attachment of electrophilic reagent to the aromatic ring in such a way so as to yield the most stable carbocation. Let us apply this very approach to account for the reactions of furan.



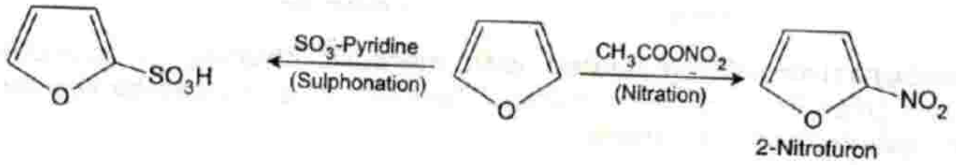
More stable carbocation being a hybrid of larger number of resonating structures resulting in greater spreading of charge.

Attack at position 3 gives a carbocation which is the resonance hybrid of two structures I and II. Attack at position 2 yields a resonance hybrid of three structures III, IV and V. The extra stabilization conferred on the later hybrid by larger number of resonating structures resulting in greater spreading of charge makes this carbocation more stable.

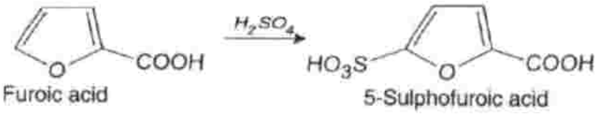
Hence 2-substitution will be favoured for electrophilic substitution, since it results in the formation of a more stable carbocation.

Furan ring is more reactive than benzene. This is because of the donation of the oxygen lone-pair as a result of which furan ring becomes activated. Thus, furan undergoes substitution reactions more readily than does benzene. Substituents enter 2-or 5-position. If both these positions are occupied, the substituent enters the 3-position.

(*i*) **Nitration and Sulphonation.** Furan is very readily attacked by concentrated acids and probably the reaction involves the formation of an oxonium salt (positive charge on oxygen). Attempts at direct nitration (with acid mixture) and sulphonation results in the formation of resinified products. However, 2-nitrofuran is obtained by nitrating it with acetyl nitrate. 2-Sulphonic acid may be prepared by treating furan with pyridine-sulphur trioxide.

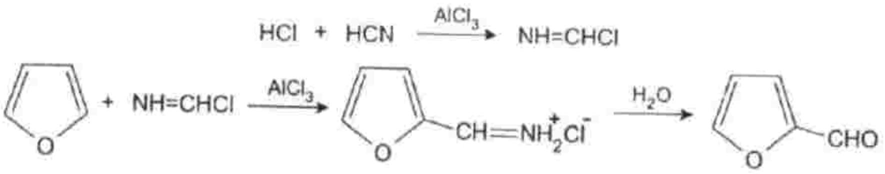


Sulphonation can, however, be carried out directly if a group with –I effec present in the ring, *e.g.*, *furoic acid can be directly sulphonated to yield sulphofuroic acid.*

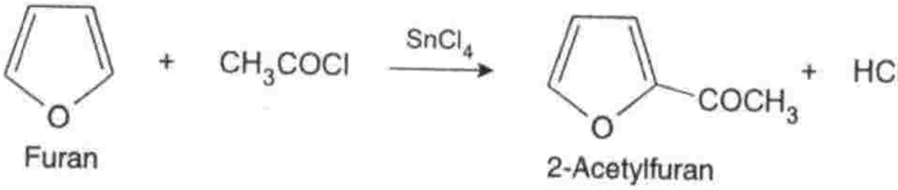


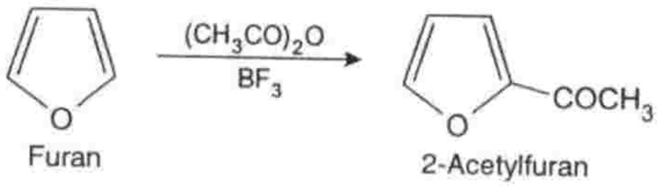
(*ii*) **Halogenation.** Furan readily reacts with halogens but polymerisation *caused by the halogen acid liberated during the reaction. Because of this difficulty halogen derivatives of furan are obtained indirectly. For example, furoic acid on bromination gives 5-bromo-furoic acid which on decarboxylation yields 2-bromofuran.*

(*iii*) **Gattermann Reaction.** Furan undergoes Gattermann reaction to yield furfural when treated with a mixture of hydrogen cyanide and hydrogen chloride in the presence of aluminium chloride, followed by decomposition of the complex produced with water.

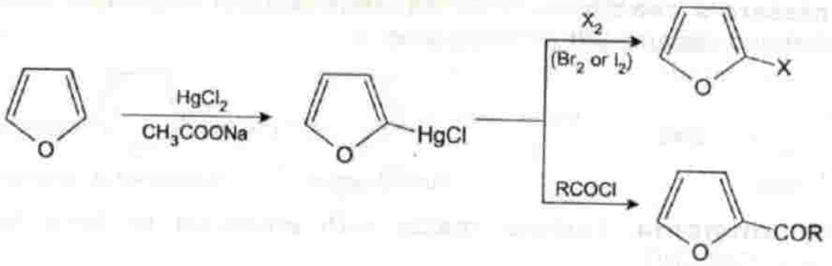


(*iv*) **Friedel-Crafts Reaction.** Since aluminium chloride attacks the furan ring, a weaker Lewis acid like stannic chloride is used in its place to carry out Friedel-Crafts reactions. Alkylation reactions with furan result in polymerisation and are, therefore, not possible. Friedel-Crafts acylation can, however, be brought about with acid chlorides or anhydrides using stannic chloride as a catalyst. Boron trifluoride in ether has proved to be a better catalyst in acylation with anhydrides.

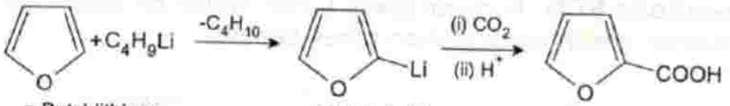




(*v*) **Mercuration.** When heated with mercuric chloride in aqueous sodium acetate, furan gives 2-chloromercurifuran. The mercuri-group can be readily replaced by bromine, iodine or an acyl group.

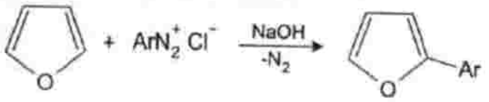


(*vi*) **Reaction with *n*-butyl-lithium.** Furan when treated with *n*-butyl-lithium gives 2-lithiated furan which gives the usual reactions of organo-lithium compounds, *e.g.*, with carbon dioxide it gives furoic acid.



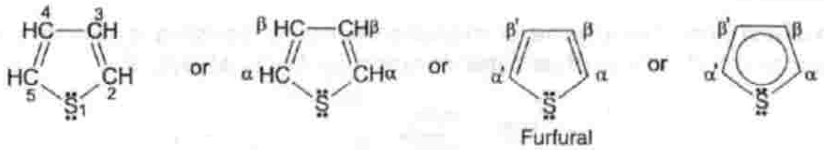
n-Butyl-lithium   2-Lithiated furan   Furoic acid

(*vii*) **Gomberg Reaction.** Furan on treatment with diazonium salts in alkaline solution gives arylfurans (Gomberg reaction):

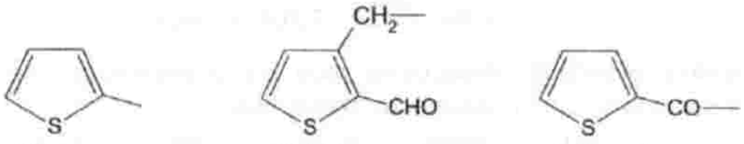


Thiophene, Thiacyclopenta-2, 4-diene, C_4H_4S

Thiophene contains one sulphur atom in its ring. The positions of side-chains or substituents in thiophene are indicated by Greek letters or numbers as given below:

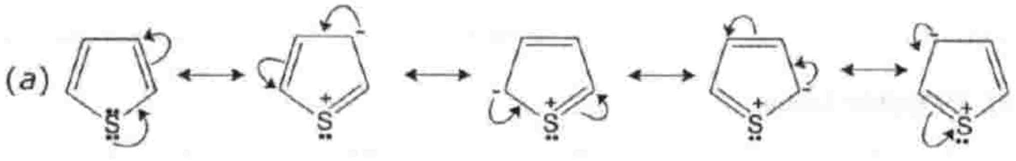


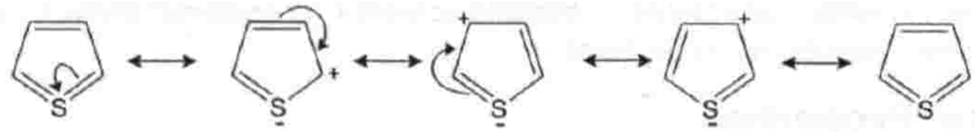
There is a close similarity between thiophene and benzene. For example, thiophene like benzene, can be easily sulphonated, nitrated and chlorinated. This close similarity between the two has resulted in a similar nomenclature, *e.g.*,



2-thienyl (*cf.* phenyl)   3-thienyl (*cf.* benzyl)   2-thienoyl (*cf.* benzoyl)

Thiophene as a resonance hybrid. Thiophene behaves as a resonance hybrid and its resonance energy is 117-130 kJ mol⁻¹. Like oxygen atom in furan, sulphur atom in thiophene contributes two electrons to form a $(4n + 2)$ π-electron molecule. In comparison to oxygen and nitrogen atoms, sulphur is less electronegative and it can also use 3*d*-orbitals. On account of these facts more canonical forms are possible for thiophene than for furan or pyrrole. In the canonical forms of thiophene given below, in group (*a*) structures, the sulphur atom uses *p*-orbitals whereas in group (*b*) structures, it makes use of its *d*-orbitals also.



(*b*) 

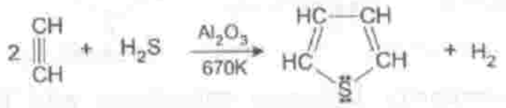
Preparation

(*i*) **From Coal-tar.** Benzene obtained from coal-tar contains thiophene. It is difficult to separate them by fractional distilltion as their boiling points are very close to each other.

The mixture is shaken with cold concentrated sulphuric acid when thiophene gives thiophenesulphonic acid which is dissolved out in water. Thiophenesulphonic acid is treated with superheated steam to recover thiophene.

A better method of separation of thiophene from benzene is by refluxing their mixture with aqueous mercuric acetate when thiophene is mercurated while benzene remains unaffected. Mercurated derivative is distilled with hydrochloric acid to recover thiophene.

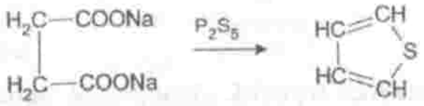
(*ii*) **Manufacture.** Thiophene is manufactured by passing a mixture of acetylene and hydrogen sulphide through a tube containing Al_2O_3 at 670 K.



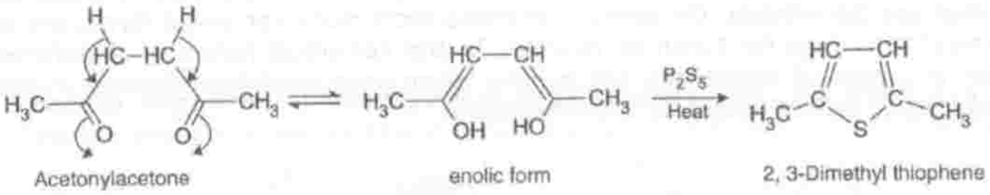
It is also manufactured by a reaction between *n*-butane and sulphur in vaour phase.

$$C_4H_{10} + 4S \xrightarrow{920K} C_4H_4S + 3H_2S$$

(*iii*) **Laboratory Method.** Thiophene may be prepared in the laboratory by heating sodium succinate with phosphorus trisulphide.



(*iv*) **The Paal-Knorr synthesis.** This involves heating of an enolizable 1, 4-diketone (*e.g.*, acetonyl acetone) in the presence of phosphorus penta sulphide.



Physical Properties

Thiophene is a colourless liquid (b.p. 357 K) with a smell like that of benzene. It is insoluble in water but soluble in organic solvents. It does not show basic properties and is stable towards aqueous acids.

Chemical Properties

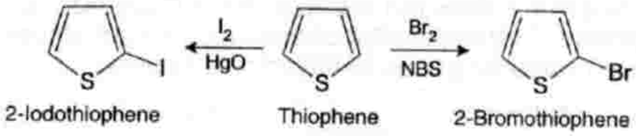
Chemically thiophene closely resembles benzene. When compared with furan and pyrrole, it is comparatively more stable. Its important reactions are :

(1) **Substitution reactions.** Like furan, thiophene undergoes electrophilic substitution. On the basis of charge distribution and stabilities of the carbocations, the electrophilic substitution would be expected to take place at position 2 (or 5). This is what actually happens in practice.

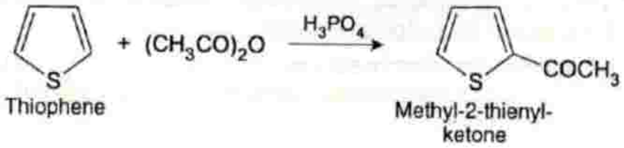
(*i*) **Nitration and sulphonation.** Nitration of thiophene with fuming nitric acid in acetic anhydride gives 2-nitrothiophene and sulphonation with cold concentatred sulphuric acid gives thiophene-2-sulphonic acid.

(*ii*) **Halogenation.** Chlorination results in the formation of both substitution and addition products. However, at 240 K, 2-chloro and 2, 5-dichloro thiophenes are the main products.

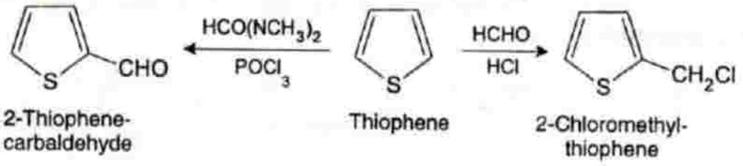
On bromination with N-bromosuccinimide (NBS) it gives 2-bromothiophene while 2-iodothiophene is obtained with iodine in the presence of yellow mercuric oxide.



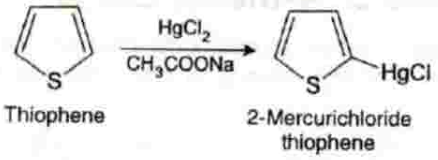
(*iii*) **Friedel-Crafts reaction.** Like benzene, thiophene gives Friedel-Crafts reaction in the presence of stannic chloride. For example it is readily acylated in 2-position when treated with acid chloride in the presence of $SnCl_4$ or better with acid anhydride in the presence of phosphoric acid to yield methyl 2-thienyl ketone.



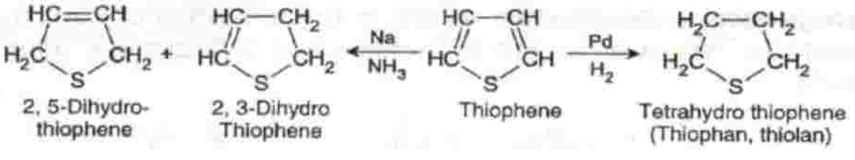
(*iv*) **Chloromethylation and Formylation.** Thiophene may be chloromethylated (with HCHO + HCl) and formylated (with dimethyl formamide and $POCl_3$) in 2-position.



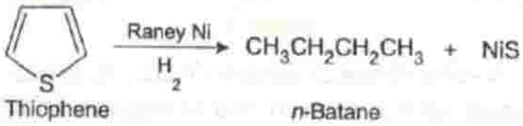
(*v*) **Mercuration.** On mercuration with mercuric chloride in the presence of sodium acetate (small amount), it gives 2-mercurichloride thiophene as the main product.



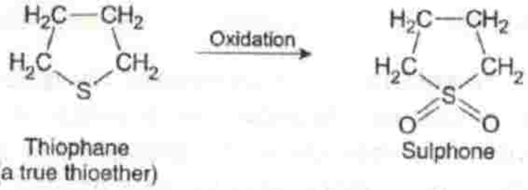
(2) **Reduction.** Catalytic hydrogenation of thiophene using large amount of the catalyst gives tetrahydrothiophene (thiophan). On reduction with sodium in liquid ammonia it gives 2, 3-, and 2, 5-dihydrothiophene.



Catalytic reduction of thiophene with Raney nickel as catalyst gives *n*-butane a the main product, *i.e.*, it results in the removal of sulphur.

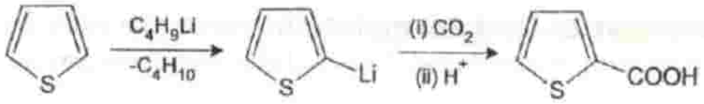


(3) **Oxidation.** Thiophene does not behave like a thioether, It cannot be oxidise to sulphoxide or sulphone. Tetrahydrothiophene (also called thiophane) on the othe hand behaves like true thioether and is oxidised to sulphone.

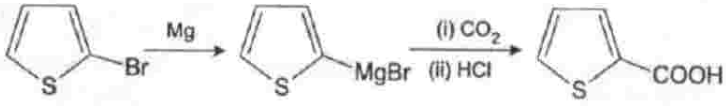


Oxidation with hydrogen peroxide, however, results in the opening of thiophen ring with oxidation of sulphur to sulphuric acid.

(4) **Formation of Lithium derivative.** Thiophene on treatment with *n*-buty lithium in ether, gives 2-lithiothiophene which is very useful in the synthesis various 2-substituted thiophenes.



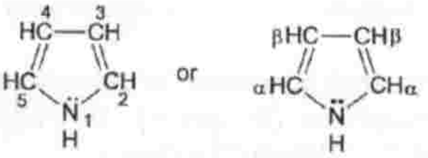
Various derivatives of thiophene may be obtained from the monobromo derivatives. For example,



(5) **Indophenin reaction.** On treatment with isatin and sulphuric acid thiophene gives a blue colour (Test).

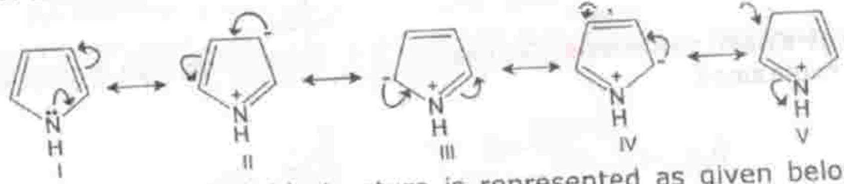
Pyrrole, Azacyclopenta-2, 4-diene, C_4H_5N

Pyrrole is an important heterocyclic compound having a five-member rin containing a nitrogen atom. Various atoms of the ring are numbered as follows :



It occurs in coal-tar and bone oil.

Pyrrole as a resonance hybrid. Pyrrole behaves as a resonance hybrid of the following five resonating structures (I or V) but the main contributing structures are I, III and IV. Its resonace energy is 87.8-130 kJ mol^{-1}.



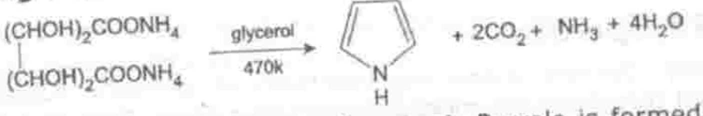
For convenience the hybrid structure is represented as given below which is hybrid of structures I to V.

Preparation

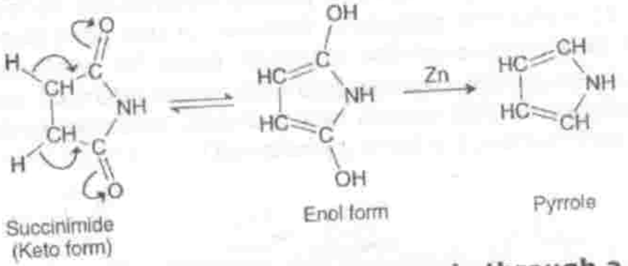
(*i*) **Isolation from bone oil.** Bone oil is first washed with dilute alkali to remove acidic substance and then with acid to remove strongly basic substances (pyridine bases). It is then fractionated when pyrrole distils over in the fraction boiling between 370 and 420K. This is fused with potassium hydroxide. Solid potassiopyrrole is formed which on steam-distillation yields pure pyrrole.

$$\underset{\text{Potassio-pyrrole}}{C_4H_4NK} + H_2O \xrightarrow[\text{distillation}]{\text{Steam}} \underset{\text{Pyrrole}}{C_4H_4NH} + KOH$$

(*ii*) **By distilling a mixture of ammonium mucate and glycerol at 470 K.**



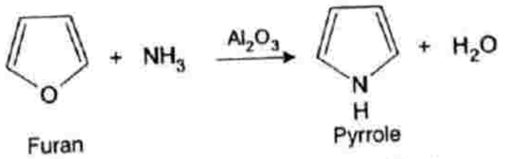
(*iii*) **By distilling succinimide with zinc dust.** Pyrrole is formed on distilling succinimide with zinc dust.



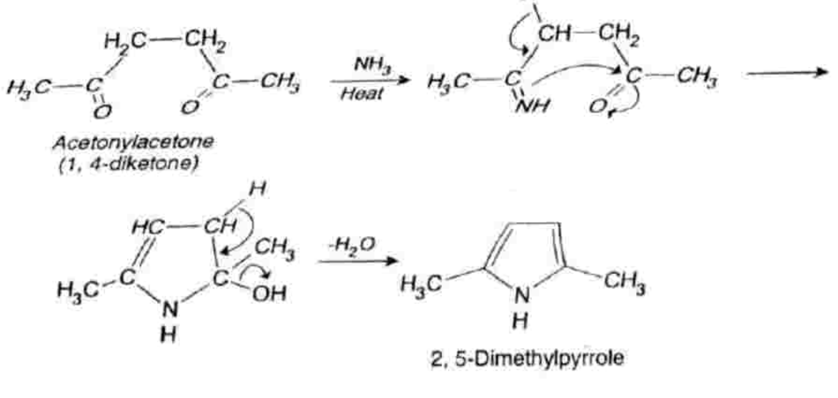
(*iv*) **By passing acetylene mixed with ammonia through a red-hot tube.**

$$2C_2H_2 + NH_3 \rightarrow C_4H_5N + H_2$$

(*v*) **Manufacture.** Pyrrole can be manufactured by passing a mixture of furan, ammonia and steam over heated alumina (catalyst).



(*vi*) **Paal-Knorr synthesis.** On heating a 1, 4-diketone with ammonia, *derivative is obtained.*



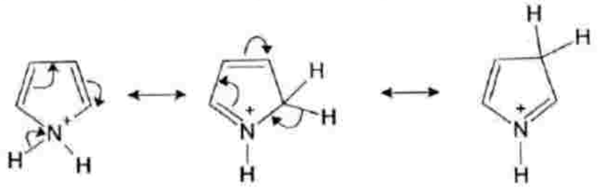
Physical Properties

It is a colourless liquid (b.p. 404 K) sparingly soluble in water but readily soluble in alcohol and ether. It rapidly darkens on exposure to air and finally forms a resinous mass. A pine splint moistened with hydrochloric acid turns red by pyrrole vapours. Pyrrole derives its name from this characteristic reaction (Green : *Pyrros* = fiery red; Latin : *Oleum* = oil)

Chemical Properties

Chemically, pyrrole shows the reactions of aromatic compounds. It is less aromatic than thiophene but more aromatic than furan. Some important reactions of pyrrole are :

(1) **Basic nature.** Nitrogen atom in pyrrole contributes its lone pair of electrons to form a $(4n + 2)$ π-electron molecule. Because of this contribution, the availability of the lone pair of electrons of the nitrogen atom for protonation is very much decreased. As a result of this, *pyrrole is a very weak base* (*cf.* aniline). However, in acid solution, protonation also occurs at the 2-and 3-positions, and in concentrated solution, pyrrole polymerises (to form pyrrole-red).

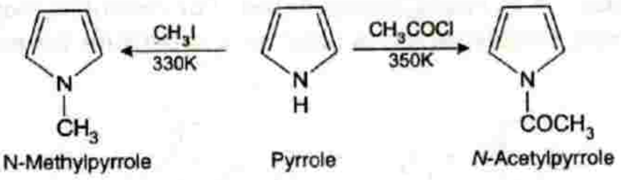


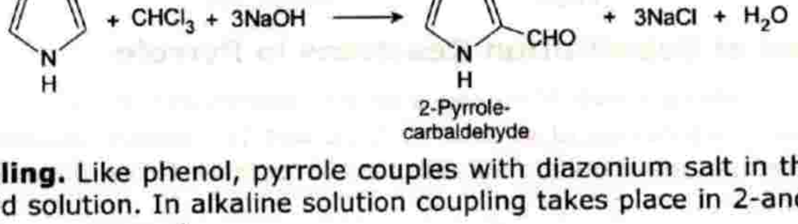
(2) **Replacement of imino-hydrogen.** The imino-hydrogen of pyrrole is replaced by sodium, potassium, alkyl or acyl radicals. For example, on heating it with solid caustic potash potassiopyrrole is formed.

$$C_4H_4NH + KOH \rightarrow C_4H_4N{-}K^+ + H_2O$$

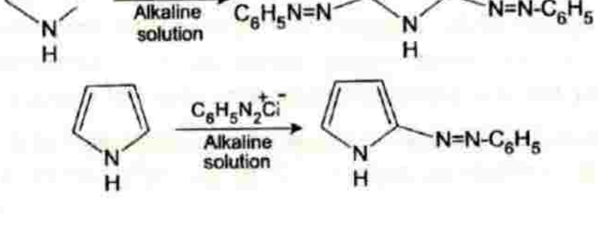
This reaction shows that *pyrrole is a weak acid*.

It reacts with acetyl chloride at about 350 K to give *N*-acetyl pyrrole. With methyl iodide at 330 K it forms *N*-methylpyrrole.



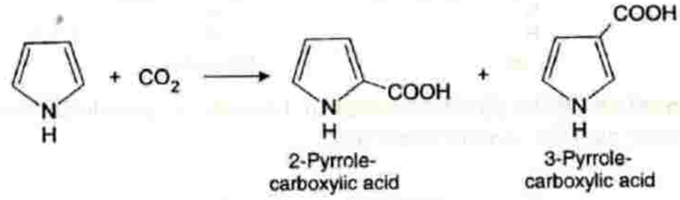


(*ii*) **Coupling.** Like phenol, pyrrole couples with diazonium salt in the 2-position in weakly acid solution. In alkaline solution coupling takes place in 2-and 5-positions to give a bisazo-compound.

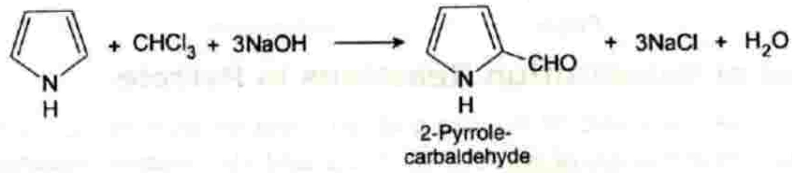


These reactions when carried out at higher temperatures (420-490 K) give the 2- or 3-substituted products in place of the *N*-substituted compound. This is probable due to the rearrangement of the *N*-substituted compound formed in the first instance.

(3) **Resemblance with Phenols.** (*i*) *Kolbe's-Schmidt reaction* Potassiopyrrole reacts with carbon dioxide to form 2-and 3-pyrrolecarboxylic acid (*cf.* Kolbe-Schmidt reaction).



Pyrrole reacts with chloroform in the presence of a base to yield pyrrole carbaldehyde (*cf.* Reimer-Tiemann reaction).



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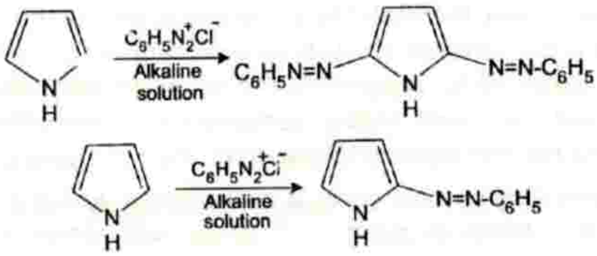
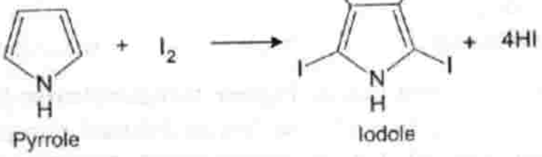


Coupling takes place in the 3-position if both 2-and 5-positions are not free.

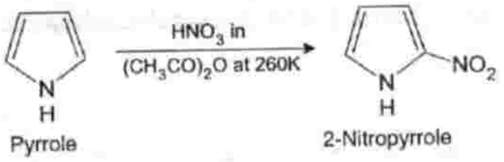
(4) **Electrophilic substitution reactions.** Pyrrole undergoes the usual electrophilic substitution reactions of aromatic compounds to give mainly 2 (or 5) substituted products.

Some important electrophilic substitution reactions of pyrrole are given below:

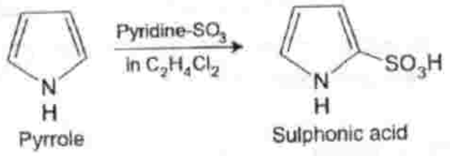
(*i*) **Halogenation.** It is easily halogenated. For example, with iodine solution it gives tetraiodo-pyrrole (iodole)which is used as a substitute for iodoform.



(*ii*) **Nitration.** With nitric acid in acetic anhydride at 260 K, pyrrole gives 2-nitropyrrole.



(*iii*) **Sulphonation.** With pyridine-sulphur trioxide in ethylene chloride, pyrrole is sulphonated to give pyrrole 2-sulphonic acid.

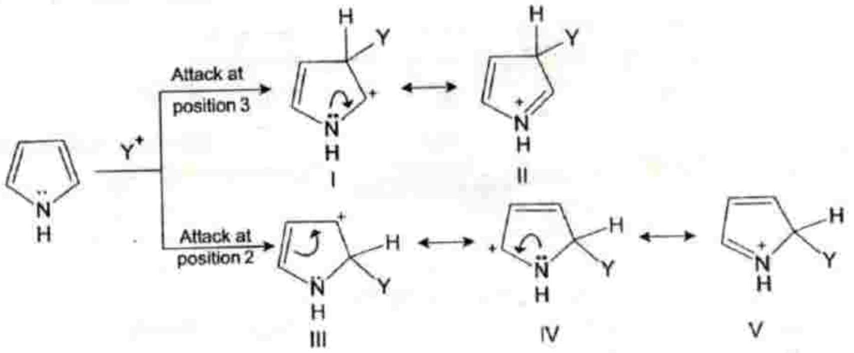


Orientation of Substitution Reactions in Pyrrole

Pyrrole is a resonace hybrid having a larger electron density at 2 and 5 positions due to greater contribution of structures I, III and IV towards resonance hybrid (p. 3.387). Therefore, electrophilic substitution in pyrrole takes place preferably at position 2 (or 5).

Alternatively, the preffered position for electrophilic attack in pyrrole can be determined by considering the stability of carbocations in the rate determining step. We know that the rate controlling step in electrophilic substitution reaction is the attachment of the electrophilic reagent to the aromatic ring which takes place in such a way so as to yield the most stable carbocation intermediate. Let us study this approach to account for the electrophilic substitution of pyrrole.

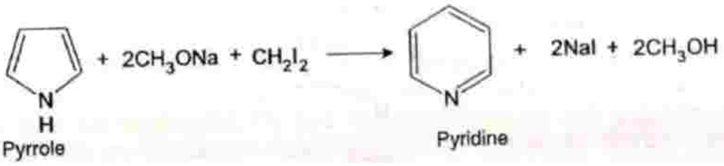
Attack at position 3 of pyrrole gives a carbocation which is a resonance hybrid of structures I and II. Attack at position 2 of pyrrole yields a resonance hybrid of structures III, IV and V. The extra stabilisation conferred on the latter hybrid by one additional structure V makes the carbocation more stable.



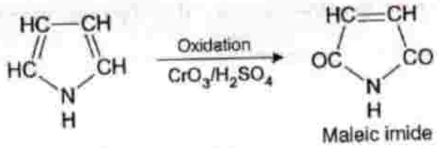
Hence electrophilic attack is favoured at position 2. Compared to benzene, pyrrole is more reactive towards electrophilic subsitution reactions. This is due to ability of nitrogen to share its electron pair with pyrrole ring which makes the ring more activated towards electrophilic attack.

Orientation of substitution in furan and thiophene as well as their high reactivity can be accounted for in a similar way.

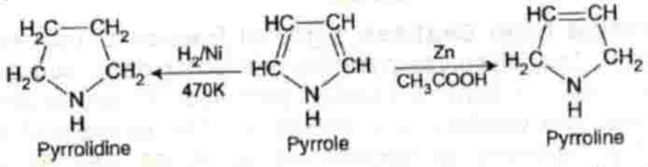
(5) **Ring expansion.** When treated with sodium methoxide and methylene iodide, pyrrole gives pyridine (a six-membered ring compound).



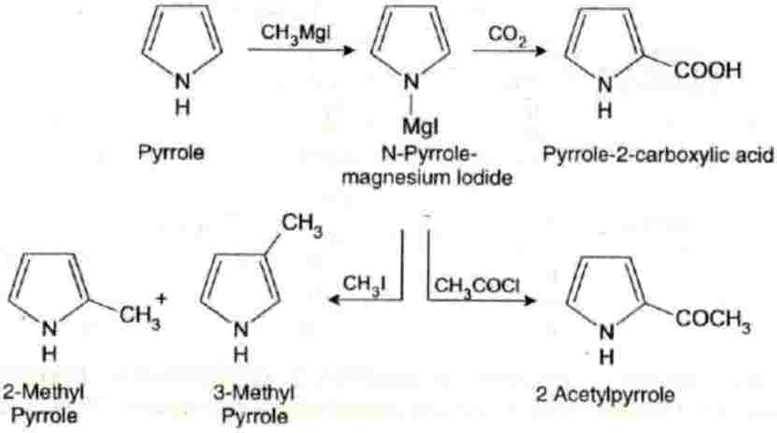
(6) **Oxidation.** When oxidised with chromium trioxide in sulphuric acid pyrrole gives maleic imide.



(7) **Reduction.** Pyrrole on reduction with zinc and acetic acid gvies pyrroline (2, 5-dihydropyrrole). With H_2 in presence of nickel at 470 K (catalytic reduction) pyrrole gives pyrrolidine (tetrahydropyrrole).

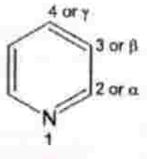


(8) **Reaction with Grignard reagent.** When pyrrole is treated with methylmagnesium iodide, *N*-pyrroylmagnesium iodide is formed. This behaves as if the magnesium were combined at the 2-position also because it yields 2-substituted pyrroles from this reaction as well.



Pyridine, Azabenzene, C_5H_5N

Pyridine is an important heterocyclic compound containing a six-member ring. It may be regarded as benzene in which one =CH— group has been replaced by =N—. Different positions in pyridine are indicated by numbers or Greek letters, *e.g.*,



Pyridine

Pyridine is a resonance hybrid of two Kekule structures and charged structures given on to be inserted. For convenience, its hybrid strucrture is represented as given below:

Pyridine occurs in the light oil fraction of coal-tar and in bone oil. It is a decompsoiton product of several alkaloids.

Isolation of Pyridine from Coal-tar. Light oil fraction of coal-tar is treated with dilute sulphuric acid. This dissolves pyridine and other basic substances which form soluble sulphates. The acid layer is treated with sodium hydroxide when the bases are liberated. These are purified by rectification. The mixture of pyridine bases so obtained is used industrially in denaturing spirit, as well as a solvent in the purification of crude anthracene. Pyridine can be separated from this mixture of pyridine bases by repeated fractional distillation.

Properties

Physical Properties

Pyridine is a colourless refractive liquid (b.p. 398 K) which has an unpleasant odour. It is miscible with water in all proportions and is hygroscopic. It is a good solvent for most organic compound and dissolves many inorganic salts.

Chemical Properties

Pyridine is basic in nature and resembles benzene in many of its properties. It is, however, less reactive and is only very slowly attacked by boiling nitric acid or chromic acid. Important reactions of pyridine are given below :

(1) **Basic nature.** It is a strong tertiary base which gives salts with inorganic acids and forms quaternary salts when heated with alkyl halides. These reactions involve nitrogen directly and are due to its unshared pair of electrons.

$$\underset{\substack{\text{Pyridine methiodide}\\ \text{or N-Methylpyri-}\\ \text{dinium iodide}}}{C_5H_5\overset{+}{N}.CH_3\}I^-} \xleftarrow[\text{Heat}]{CH_3I} \underset{\text{Pyridine}}{C_5H_5N} \xrightarrow{HCl} \underset{\substack{\text{Pyridine hydro-}\\ \text{chloride or}\\ \text{pyridinium chloride}}}{C_5H_5NH\}Cl}$$

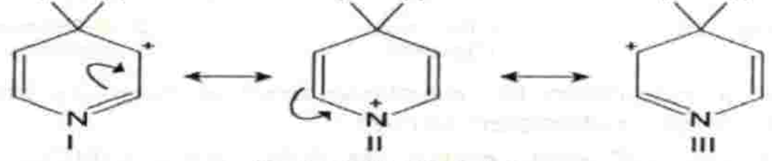
The quaternary salt on heating to 570 K forms 2- and 1-methyl pyridines. On treatment with moist silver oxide it gives *N*-alkyl-pyridinium hydroxide, a strong base.

$$\underset{\substack{N\text{-Methylpyridinium}\\ \text{iodide}}}{C_5H_5\overset{+}{N}.CH_3\}I^-} \longrightarrow \underset{\substack{N\text{-Methylpyri-}\\ \text{dinium hydroxide}\\ (\textit{a strong base})}}{C_5H_5\overset{+}{N}.CH_3\}OH^-}$$

Pyridine is a stronger base than pyrrole because its lone pair of electrons is not involved in the aromatic sextet. It is, however, a weaker base than aliphatic tertiary amines. This can be explained by the hybridisation of the orbitals having the lone pair of electrons. In pyridine, lone pair of electrons is in sp^2 hybrid orbital where it is held more tightly by the nucleus while in case of aliphatic tertiary amines lone pair is in a sp^3-hybrid orbital.

(2) **Electrophilic substitution in pyridine.** It gives electrophilic substitution reactions and resembles a highly deactivated benzene derivative such as nitrobenzene. It undergoes nitration, sulphonation and halogenation only under very vigorous conditions and does not undergo Friedel-Crafts reaction at all. Substitution occurs chiefly at 3- (or β-) position.

Let us try to account for the reactivity and orientation in pyridine on the basis of stability of the intermediate carbocation (σ-complex). Attack of an electrophile y^+ at the 4-position yields a carbocation which is a resonance hybrid of structures I, II and III.

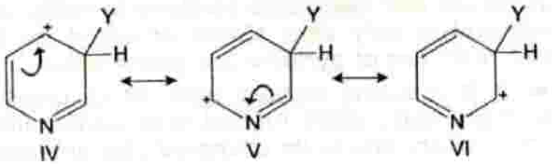


Espectally unstable
nitrogen has sextet only

(Attack at the 2-position resembles attack at the 4-position just as the ortho attack resembles the para attack in benzene ring.)

Out of the above structures, II is especially unstable since in it the electronegative nitrogen has only a sextet of electrons. As a result, attack at the 4-position (or 2-position) is especially slow.

Similarly electrophilic attack at 3-position of pyridine yields a carbocation which is a resoance hybrid of stable structures IV, V and VI.



Thus we find that an attack at 3-position yields a carbocation which is resonance hybrid of three stable structures. On the other hand attack at 2 or 4-position yields a carbocation which is a resonance hybrid of only two stable structures. Due to this, electrophilic substitution in pyridine occurs predominantly in position 3.

Some important electrophilic substitution reactions of pyridine are :

(1) **Halogenation.** Pyridine undergoes halogenation but less readily than in benzene.

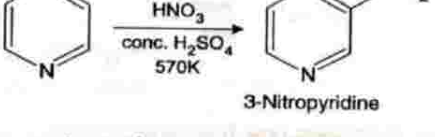
(*i*) At ordinary temperatures addition occurs to form dihalides, *e.g.*, $C_5H_5\overset{+}{N}Br\}Br^-$, 1-bromopyridinium bromide.

(*ii*) At 570 K in the presence of a catalyst (pumice or charcoal), it forms a mixture of 3-bromopyridine and 3, 5-dibromopyridine (or corresponding chloro-derivatives).

(*iii*) At 770 K in the presence of a catalyst, it gives 2-bromo and 2, 6-dibromo-derivatives.

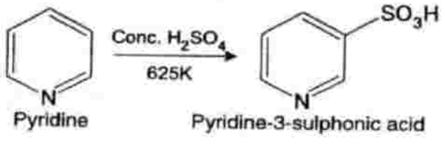
Halogen atom in 2-or 4-position is reactive and is readily replaced by —OH, —CN, —NH_2, *etc.*, (*cf. o*-and *p*-chloronitrobenzene).

(2) **Nitration.** On heating with conc. H_2SO_4 and HNO_3 at 570 K, it gives 3-nitropyridine.

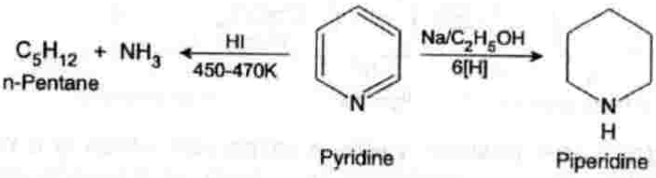


Pyridine reacts with concentrated nitric acid readily only when an —OH or —NH_2 group is present in the ring.

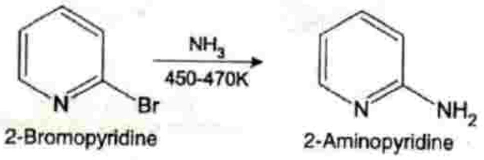
(3) **Sulphonation.** Sulphonation of pyridine is difficult. On heating with concentrated sulphuric acid at 625 K for some hours, it gives pyridine-3-sulphonic acid.

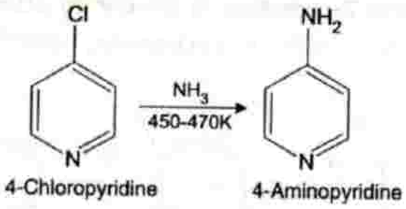


(4) **Reduction.** Pyridine on reduction with sodium and ethanol gives piperidine. Electrolytic reduction or catalytic reduction using nickel also gives piperidine. However on heating with hydriodic acid at 570 K, the reduction is accompanied by ring fission to form *n*-Pentane and ammonia.

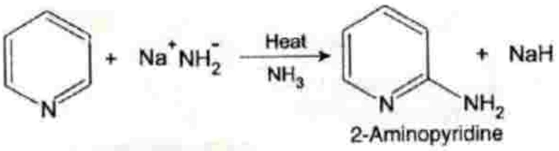


(5) **Nucleophilic substitution in pyridine.** Pyridine resembles benzene derivatives containing strongly eletron-withdrawing groups. Therefore in pyridine, nucleophilic substitution takes place readily, particularly at the 2- and 4-positions. For example, a halogen atom at the 2- and 4-positions is readily replaced by OH, CN, NH_2 *etc.*

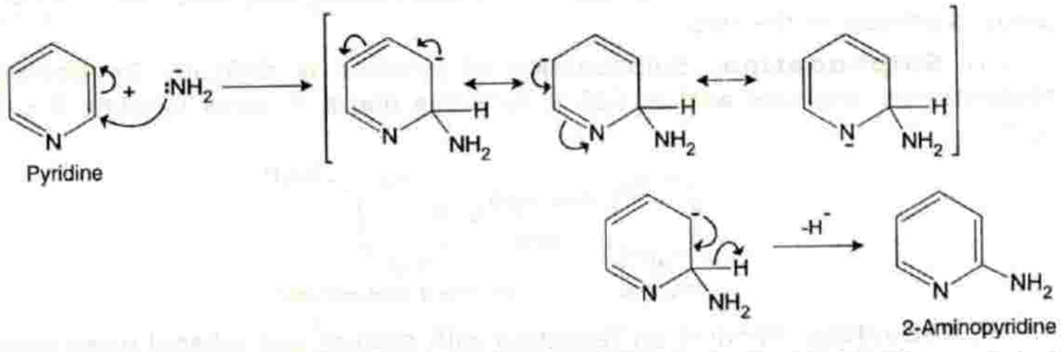




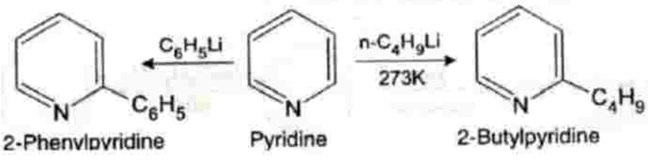
An important example of nucleophilic substitution in pyridine is its amination by sodamide **(Chichibabin reaction)**



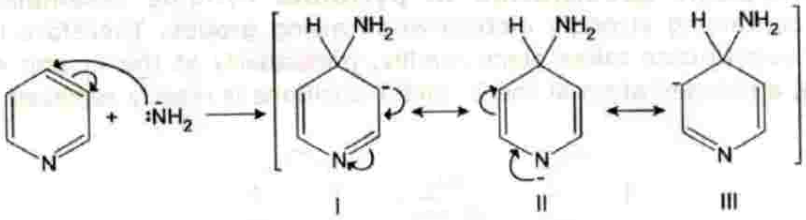
The reaction mechanism involves the following steps



Similarly, with *n*-butyl lithium and phenyl lithium at 383 K, pyridine forms 2-butyl pyridine and 2-phenyl pyridine respectively.



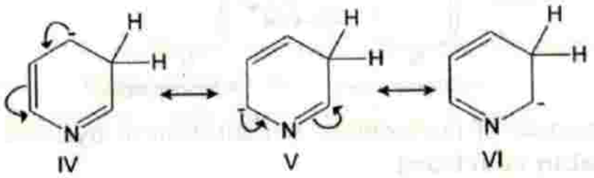
Nucleophilic attack at 4-position yields a carbanion which is a resonace hybrid of structure I, II and III.



(Especially stable)
negative charge on nitrogen

(Nucleophilic attack at the 2- position is similar to attack at 4-position.)

Attack at the 3-position yields a carbanion, which is a resonace hybrid of structures IV, V and VI.



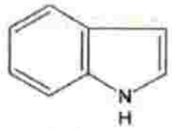
Thus substitution at 2- or 4-position is favoured since it results in the formation of a stable carbanion.

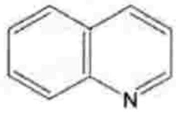
All these structures are more stable as compared to the corresponding benzene derivatives on account of the electron-withdrawing nature of the nitrogen atom. Structure II is especially stable since the negative charge is located on the electronegative nitrogen atom which can accommodate it the best. Stability of these structures accounts for rapider nucleophilic substitution in pyridine than in benzene. Since structure II is expecially stable, it is reasonable to predict that nucleophilic substitution would occur more rapidly at the 2- and 4- positions than at the 3-position.

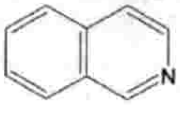
Thus we find that it is electron-withdrawing nature of nitrogen that makes pyridine less reactive towards electrophilic substitution and highly reactive towards nucleophilic substitution.

CONDENSED RING SYSTEMS

The heterocyclic compounds described in the last chapter were monocyclic compounds because each of them contained only one heterocyclic ring. There are many other important heterocyclic compounds in which a benzene ring is condensed with a five or a six membered heterocyclic ring, *e.g.*, indole, quinoline and isoquinoline.

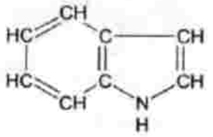

Indole

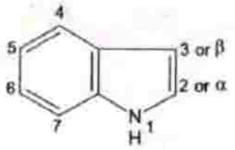

Quinoline

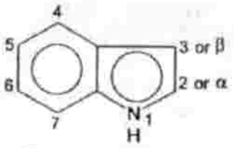

Isoquinoline

INDOLE, 1H-1-AZAINDENE, BENZOPYRROLE, C_8H_7N

The molecule of indole is made up of a benzene ring fused with a pyrrole ring. To name its derivatives various atoms of indole are numbered as follows:







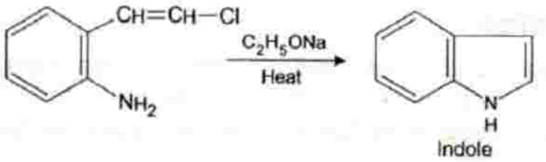
Resonance hybrid structure

Indole occurs in coal-tar, jasmine flowers and orange blossoms. It is the parent substance of natural indigo.

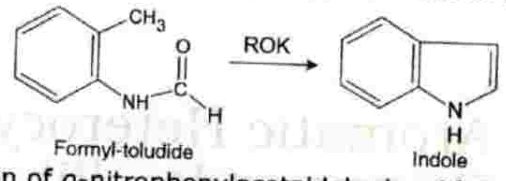
Synthesis

Indole may by synthesised:

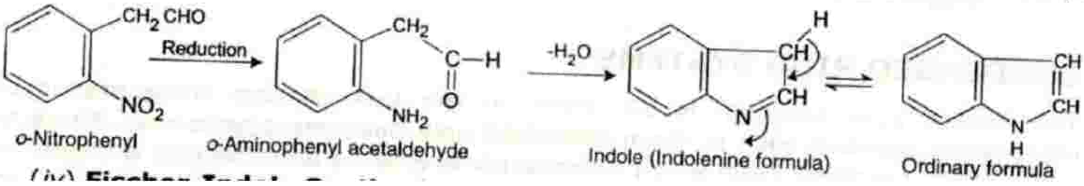
(*i*) By heating *o*-amino-ω-chlorostyrene with sodium ethoxide.



(*ii*) By heating formyl-*o*-toluidide with potassium alkoxide **(Madelung synthesis).**

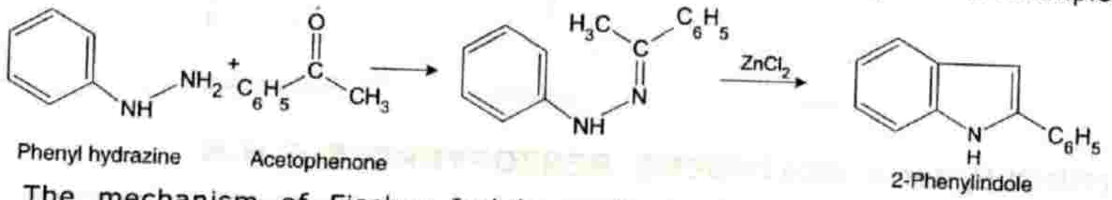


(*iii*) By the reduction of *o*-nitrophenylacetaldehyde with iron powder and sodium bisulphite solution. The amino compound produced changes to indole spontaneously.

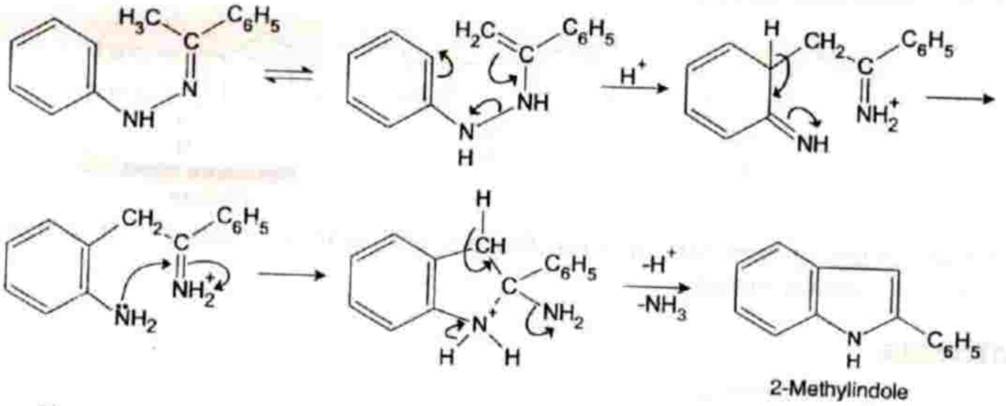


(IV) Fischer-Indole Synthesis

This involves cyclization of a phenyl hydrazone of an aldehyde or a ketone in the presence of sulphuric acid or anhydrous $ZnCl_2$ or other acidic catalysts. For example,



The mechanism of Fischer Indole synthesis involves an acid catalyzed rearrangement as given below :



Properties of Indole

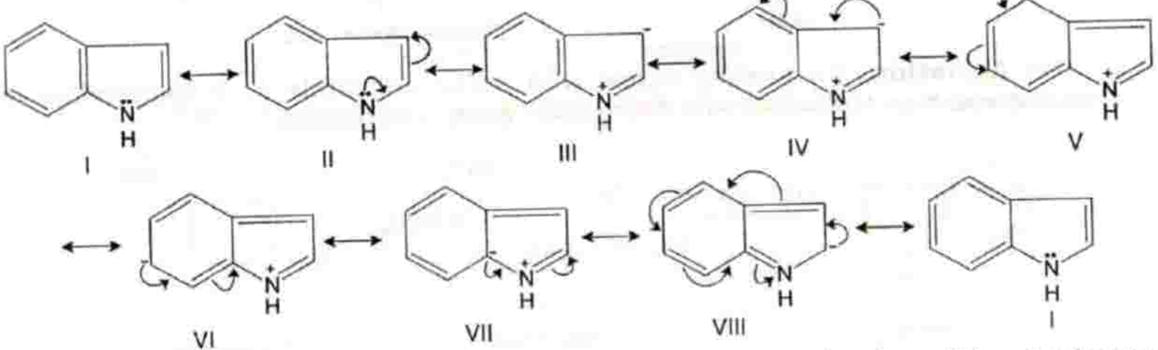
Physical Properties

Indole is a crystalline solid (m.p. 325 K) which gives plate-like crystals. Impure indole has a strong unpleasant faecal odour while pure indole in dilute solutions has a pleasant smell and is used in perfumery for preparing jasmine and orange blossom blends.

Chemical Properties

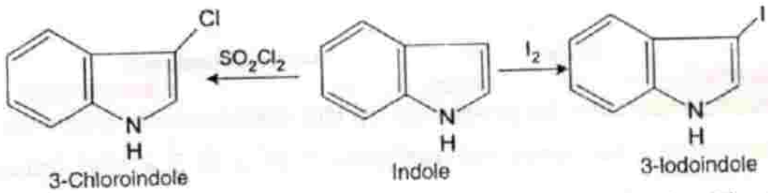
Chemically indole resembles pyrrole in many of its properties. It is oxidised by ozone to indigotin. Indole solution imparts a cherry-red colour to pine shavings moistened with alcohol and hydrochloric acid.

(1) ***Electrophilic Substitution Reactions.*** Indole is considered to be a resonance hybrid of the following five canonical structures

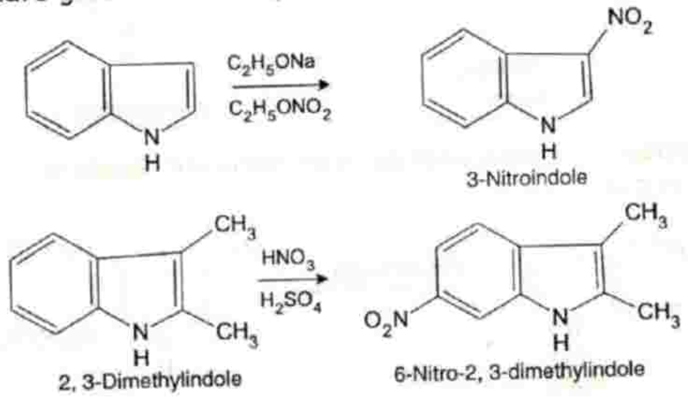


Out of these, the fully conjugated structure I is most stable. Two of the structures III and IV carry a negative charge at position 3. Therefore, electrophilic substitution in indole normally occurs in the 3-position. However, if this position is blocked, substitution takes place in 2-position and if both 2-and 3-positions are occupied substitution occurs in the benzene ring at 6-position. For example,

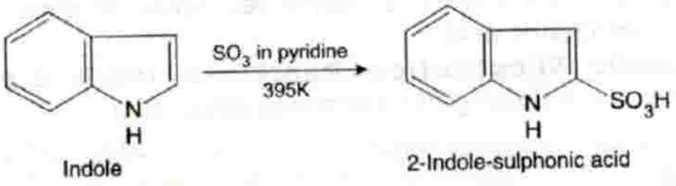
(*i*) *Halogenation*. It is brominated or iodinated in 3-position. With SO_2Cl_2 it gives 3-chloroindole.



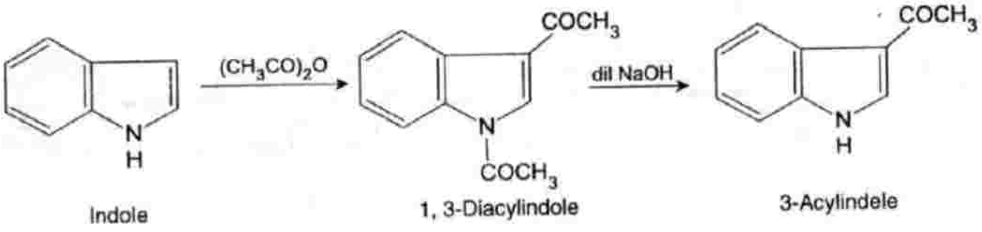
(*ii*) *Nitration.* On treating indole with sodium ethoxide mixed with ethyl nitrate, 3-nitroindole is obtained. On the other hand, nitration of 2,3-dimethylindole with nitrating acid mixture gives the corresponding 6-nitro derivative.



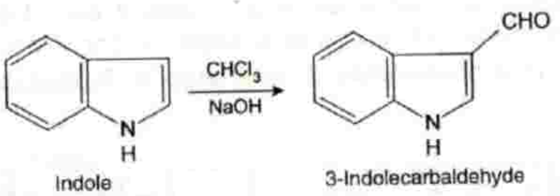
(*iii*) *Sulphonation.* On treating indole with SO_3 in pyridine at about 390 K, 2-indole sulphonic acid is produced. It is rather an unusual case of orientation.



(*iv*) **Acylation.** On heating indole with acetic anhydride 1, 3-diacylindole is obtained which on hydrolysis with dilute alkali gives 3-acylindole.

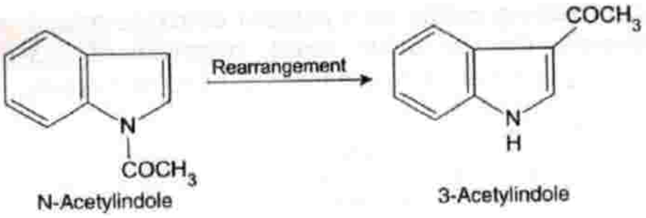


(2) **Reimer-Tiemann reaction.** With chloroform and sodium hydroxide, indole gives Indole-3-aldehyde.

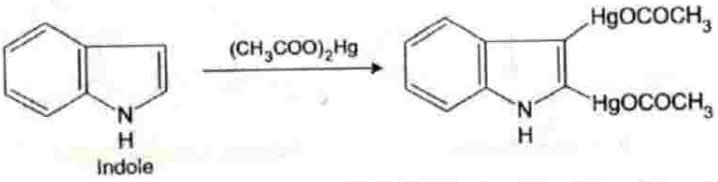


This compound may also be prepared by the Gattermann aldehyde synthesis.

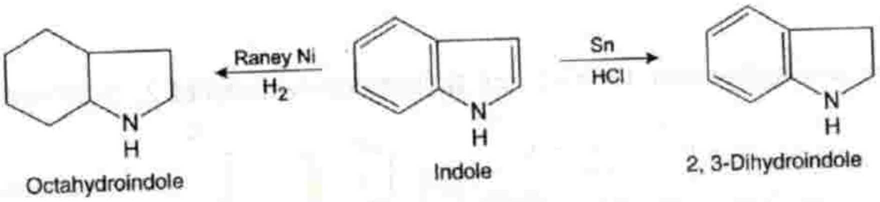
(3) *N*-Acetylindole undergoes rearrangement to give 3-acetyl-indole.



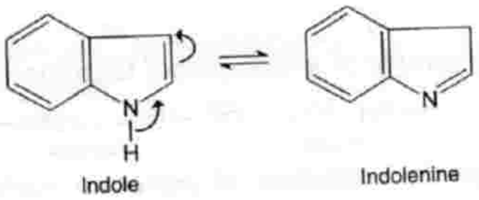
(4) **Mercuration.** On mercuration with mercuric acetate, indole gives 2,3-di acetoxymercuri-indole.



(7) **Reduction.** Indole on electrolytic reduction gives 2, 3-dihydroindole (indoline). Reduction with metal and acid (*Sn* + HCl or zinc dust + H_3PO_4) gives the same product. Catalytic reductions with Raney nickel gives octahydroindole.

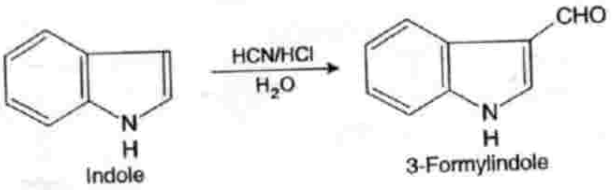


Indole behaves as a tautomer of *Indolenine*.



Indolenine itself has never been isolated but its derivatives are known.

(8) **Gettermann reaction.** Indole reacts with HCN and HCl to form 3-formyl-indole.



Dyes and Pigments

Dyes:-

* Dyes are coloured Organic Compounds that are used to impart color to Various substrate, including Paper, leather, Fur, hair, drugs, cosmestics, Waxes, greases, Plastics and textile Materials.

* A dye is a colored compound, normally used in solution, which is capable of being fixed to a fabric.

* The dye has a colour due to the Presence of chromophore and its fixed Property to the acid or basic groups such as OH, SO_3H, NH_2, NR_2, etc..

* The polar auxochrome makes the dye water-soluble and binds the dye to the Fabric by interaction with the oppositely charged groups of fabric structure.

Synthetic dyes:-

Almost all the colors that y see today are synthetic dyes.

* Synthetic dyes are used everywhere in everything from clothes to paper, from Food to wood. This is because they are cheaper to Produce, brighter, more color-fast and easy to apply to fabric.

E.g., Acid dyes, Azo dyes, Basic dyes, Mordant dyes, etc.,

Natural Dyes:-

* Natural dyes are dyes or colorants derived from Plants, invertebrates or Minerals.

* The Majority of Natural dyes are Vegetable dyes from Plant sources. E.g., Root, berries, bark, leaves and Wood.

* Other Organic Sources include fungi and lichens.

ere

Pigments:-

* Pigments are colour Particles that require a binding or dispersion agent to bind to the surface of the material to be coloured.

"Pigment is derived from word "Pigmentum" Means coloring Matter.

*Pigments are organic and inorganic Materials which are pratically insoluble in Medium in which they are incorporated.

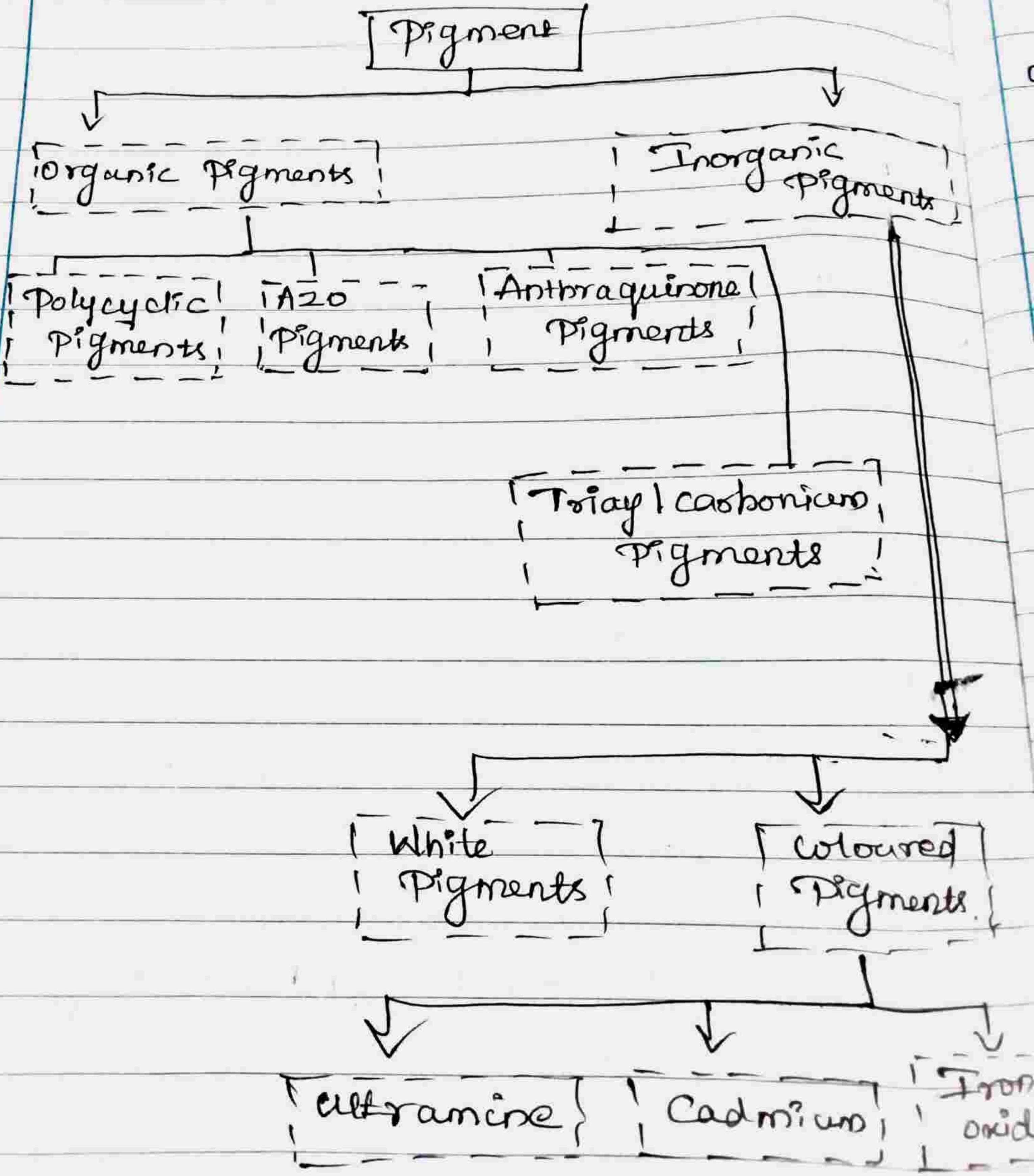
* Pigments are used almost 30,000 years ago.

* About 2000 BC natural other was burnt sometime in mixture with Manganese Ore to Produce red, violet and black pigments for pottery.

The first Synthetic Pigment was "Prussian blue" which was synthesized in 1704.

Application of pigments:- Pigments are used fo coloring of leather, buildings Materials, Paper, f Covering, ceramic glazes, Paint, ink, Plastic, Fabric, cosmestics food and other Materials.

Classification of pigments



Dye	Pigment
An intensely colored or fluorescent organic substance, which imparts color to a substrate by selective absorption of light.	The colored, black, white or fluorescent particulate organic or inorganic solids, usually are insoluble in, and essentially physically and chemically unaffected by the substrate in which they are incorporated.
* Very small	* Comparatively large
* Transparent	* opaque
* Soluble in water	* Not soluble in water and many solvents
* Organic	* Inorganic
* Present auxochrome groups	* No auxochromo groups Present
* Available in large number	Less available.
* Has a direct affinity to the material	* Has no direct affinity to the material.

Does not require binding agents	*Requires binding agents
*The structure of dyes, temporary alters during the application Process.	*The structure of Pigments does not alter during the application Process.
* Diffuses in the fabric	* Diffuses on the fabric
* Imports colors by the selective absorption	* Imparts colors by scattering of light or by selective absorption
* Costly	* cheap
* Low light-fastness	* High light-fastness
*The product resistance is lower	*The product resistance is higher
* Compatiable with burning	*Tends to clog the wick during burning
* Does not last long	* Lasts long
* Compatible with a wide range of materials	*Suitable materials for Pigments are limited.

Chromophores & Auxochromes

Chromophores:- The colour of organic compound due to the presence of certain multiple bonded groups are called chromophores.

Eg:- Nitro, azo, nitroso etc..

chroma = colour, phorein = to bear.

It is defined as isolated covalently bonded group that shows a characteristic absorption in the ultraviolet or the visible region. Some of the important chromophores are ethylenic, acetylenic, carbonyls, acids, esters, and nitrile group etc.. ($-CH_2-$, $-C \equiv C$, $-COOH-$, $-C \equiv N$ etc..)

Types of Chromophores:- (i) Independent chromophores:- If one chromophore is required to impart colour. Eg:- Azo group, $-N=N-$, Nitroso group, $-NO$.

(ii) Dependent chromophores:- If more than one chromophore is required to impart colour.

Eg:- Acetone having one ketone group is colorless whereas diacetyl having two ketone groups is yellow

* chromophore is which the group contains electrons and they undergo $n \rightarrow \pi^*$ transition. Such chromophores are ethylene's acetylene etc.

*. Chromophore which contains both π electrons and n (non-bonding) electrons. Such chromophores undergo two types of transition i.e., $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$.

Auxochromes:-

*. The functional group which non-bonding electrons that does not absorb radiation in near UV region but when attached to a chromophore alters the wavelength and intensity of absorption. eg:- OH, NH_2, Cl

* Substituents with unshared pair electrons like OH, SH, NH,... When attached to π chromophore they generally move the absorption max. to longer λ.

Two types:- 1. Basic (or) positive auxochromic group (NH_2, OH)

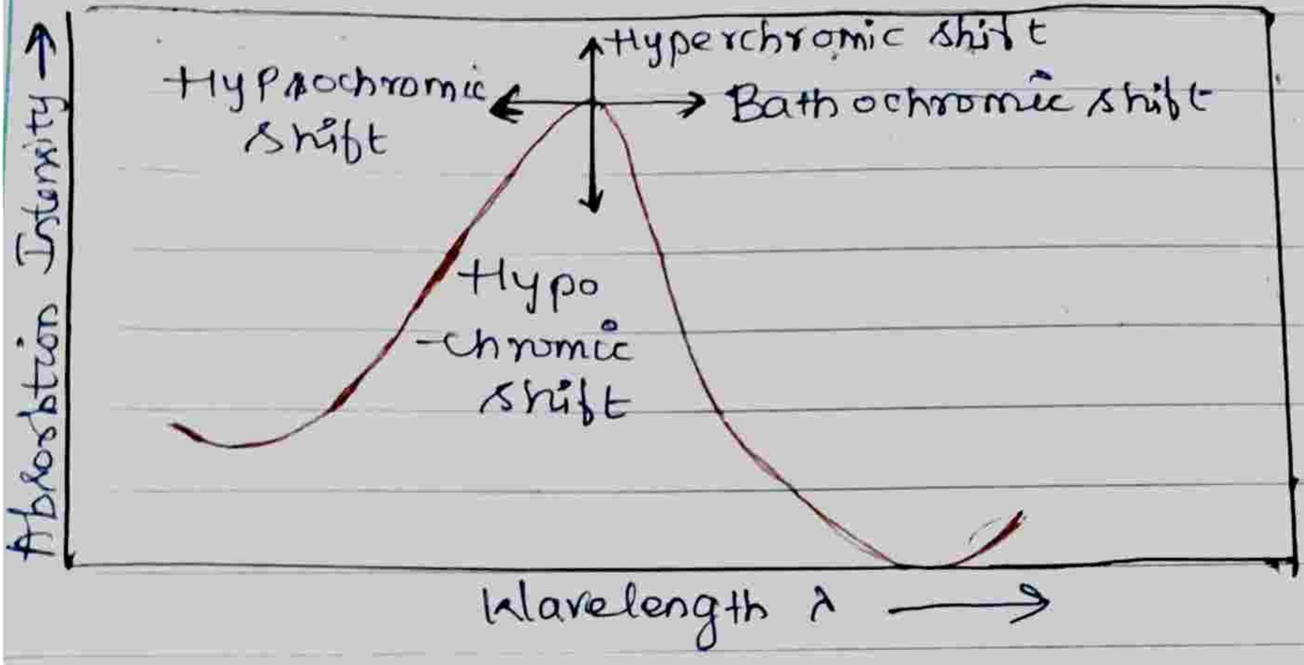
2. Acid (or) Negative auxochromic group (NO_2, CO).

Bathochromic shift:- Shift to longer λ, also called red shift.

Hypsochromic shift:- Shift to shorter λ, also called blue shift.

Hyperchromism:- Increase in ε of a bond

Hypochromism:- decrease in ε of a bond



other definition of Auxochrome:- An auxochrome is a functional group of atoms attached to the chromophore to absorb light, altering the wavelength or intensity of the absorption.

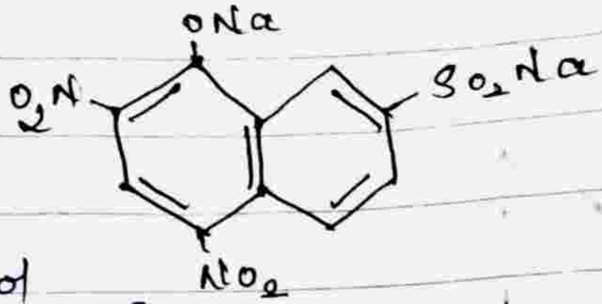
classification of dyes based on the chromophore:

* Dyes may be classified according to the type of chromophores present in their structures.

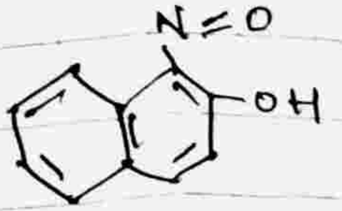
1. Nitro and Nitroso dyes
2. Azo dyes 3. Anthraquinone dyes
4. Indigo dyes.

Nitro and Nitroso dyes:- * These dyes contain nitro or nitroso groups as the chromophores and $-OH$ as auxochrome.

Ex:-



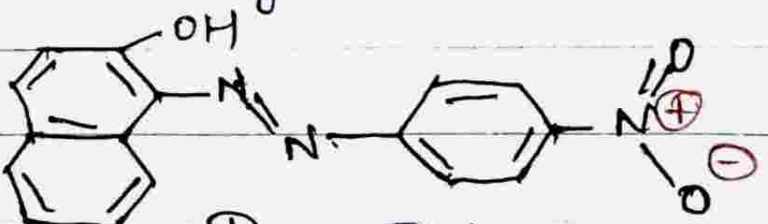
Naphthol yellow S.



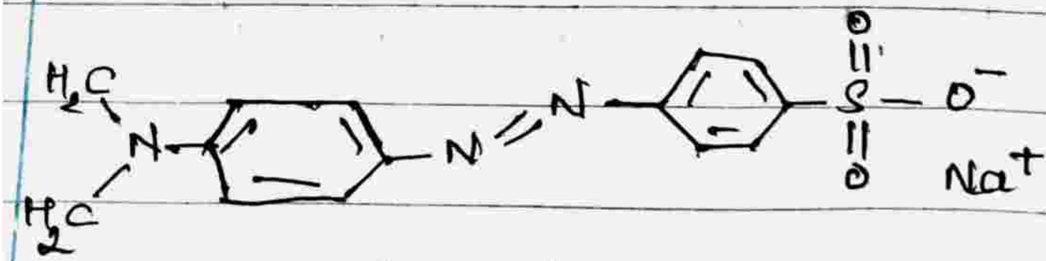
Mordant green 4.

Azo dyes:- Azo dyes is a large class of synthetic organic dyes that contain nitrogen as the group $-N=N-$ as primary chromophore their molecular structures.

These dyes are highly coloured and are prepared by diazotizing an aromatic and coupling with suitable aromatic compound.



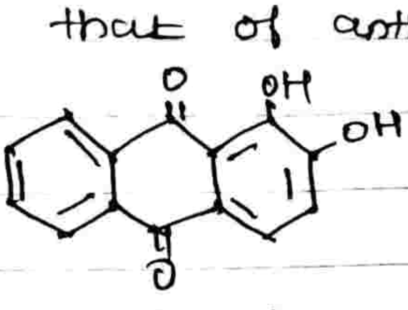
Para Red.



Methyl orange.

Azo dyes account for approximately 60-70% of all dyes used in food and textile manufacture.

Anthraquinone dyes:- Anthraquinone dye, any of a group of Organic dyes having molecular structure based upon that of anthraquinone.

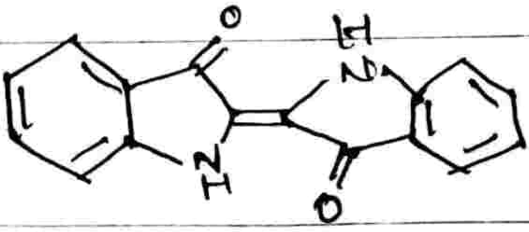


* Alizarin is the main ingredient for the Manufacture of the madder lake pigments known to Painter as Rose madder and Alizarin Crimson.

* Alizarin is also used commercially as a red textile dye.

Indigo dyes:- Indigo dye is an Organic Compound with a distinctive blue color Historically, indigo was a natural dye extracted from Plants. But today nearly all indigo dye is Produced synthetically.

It contains Carbonyl chromophore.



* The Primary use for indigo is as a dye for cotton yarn, which is mainly for the Production of denim cloth of blue Jeans.

* Small amounts are used for dyeing wool and silk.

Modern theory of colour and Consititution:-

Like the Physical and chemical Properties of organic compounds, there is a definite relationship between the color and constitution. E.g; Benzene is colorless, whereas its isomer, fulvene is colored. The following theories have been Proposed to explain the observed general relationships existing between color and consititutions. The two important theories, which explain plausibly the relation between color and constitution, require somewhat theoretical background about the effect of light on the molecule.

→ Valence bond theory
→ Molecular Orbital theory.

Valence bond theory:- The Various postulates of this theory as follows:

* chromophores are groups of atoms, the π- electrons of which may get transfered from ground state to excited State by the absorption of radiation, thus Producing the colour.

* Auxochromes are groups, Which tend to increase resonance by interacting the unshared pair of electrons on nitrogen

or oxygen atoms of the auxochromes with the π electrons of the aromatic ring. This increase in resonance increases the intensity of absorption of light and also shifts the absorption band to longer wavelength. Hence there occurs the depending of the color. from this it is evident that increase in resonance must deepen the color and actually it has been found to be so.

* The dipole moment changes as a result of oscillation of electron pairs. The following order has been observed for the case of excitation of different groups.

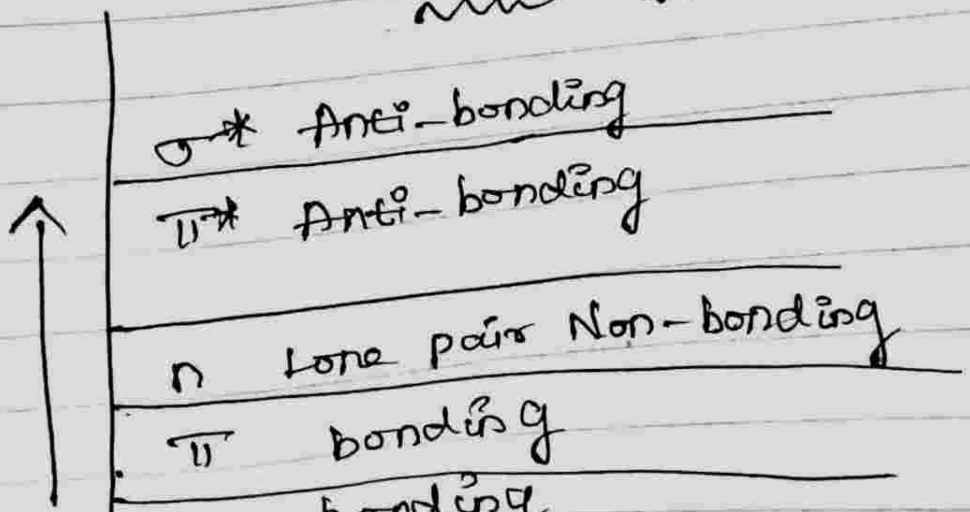
$$N=O > C=S > N=N > C=O > C=N > C=C$$

* Resonance theory explains the relation of the color and the symmetry of the molecule or dipole of the molecule because as the number of charged canonical structures increases, the color of the compound depens. The more the Possibility and longer the Path for a change to oscillate in a compound, the longer wavelength of light will be absorbed and therefore deeper would be the color of the compound

Molecular orbital theory:-

* According to this theory the excitation of a molecule means the transference of one electron from an orbital of lower energy to that of higher energy. These electrons may be σ, π, or n (non-bonding) electrons. The higher energy states are commonly known as anti-bonding orbitals. The anti-bonding associated with σ and π bonds are called σ* and π* orbitals respectively. However there are no anti-bonding orbitals associated with n (non-bonding) electrons because they do not form bonds. Chart of the simplest form, the essential types of energy are given is below.

Chart showing Molecular orbitals



Electron transitions

* The electronic transitions can occur by the absorption of ultraviolet and visible radiation. Although transitions are possible only the following types are allowed.

- $n \rightarrow \sigma^*$
- $n \rightarrow \pi^*$ and $\pi \rightarrow \pi^*$

* As $\sigma \rightarrow \sigma^*$ transitions takes place when a bonding σ-electron is excited to an antibonding σ-orbital. i.e, σ^*. This type of transition requires a very large amount of energy as σ-electrons are very tighty bond. Hence the compounds like saturated hydrocarbons which donot have any π or σ electrons may undergo only $\sigma \rightarrow \sigma^*$ transitions. However, these transitions donot take place by absorbing in the ordinary ultra-violet region.

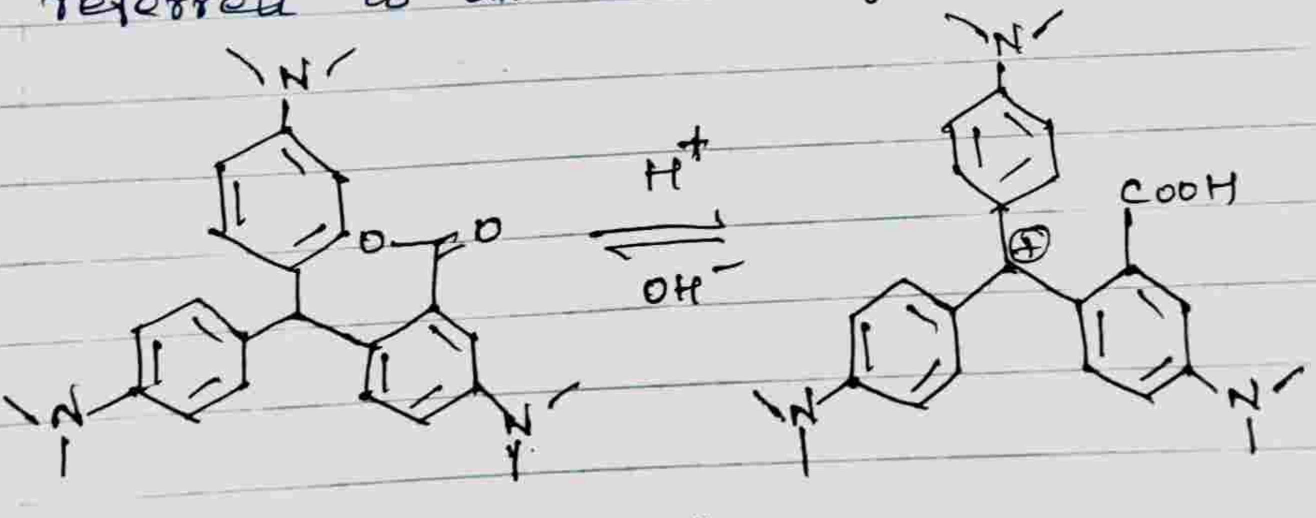
Eg; ethane absorbs at 135 mμ.

Leuco base and Mordants

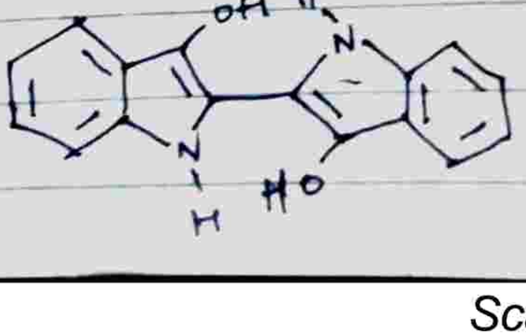
Definition:-

* A colorless or weakly colored amine that is formed by reduction of a dye (as a triphenylmethane dye) or its carbinol derivative and that on oxidation and treatment with acids usually gives back the dye.

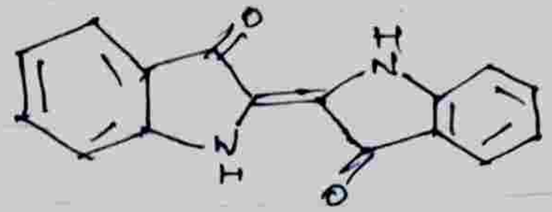
* A leuco dye (leukos ⇒ greek Means White) is a dye which can switch between two chemical forms; one which is colorless. Reversible transformations can be caused by heat, light or pH; resulting in examples of thermochromism, photochromism and halochromism respectively. Irreversible transformations typically involve reduction or oxidation. The colorless form is sometimes referred to as the "leuco form"



Examples:-



Indigo white
(leucoindigo)



Indigo

Mordant :-

* A Mordant or dye fixative is a substance used to set (ie.. bind) dyes on fabrics by forming a coordination complex with the dye, which then attaches to the fabric (or tissue). It may be used for dyeing fabrics or for intensifying stains in cell or tissue preparation. Although Mordants are still used, especially by small batch dyers, it has been largely displaced in industry by directs.

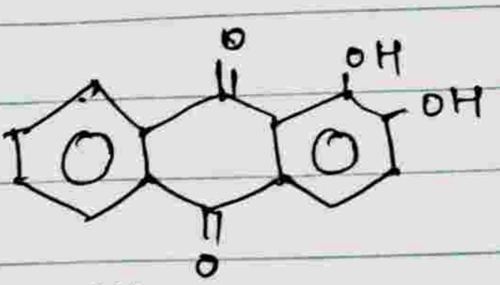
* The term mordant comes from the latin mordere "to bite". In the past, it was thought that a mordant helped the dye bite onto the fibre. so that it would hold fast during washing.

* A mordant is often a polyvalent Metal ion, often chromium (III). The resulting Coordination complex of dye and ion is colloidal and can be either acidic or alkaline.

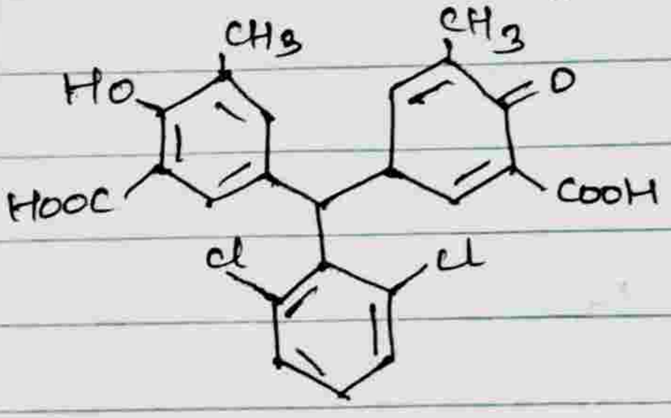
Common dye mordants:-

Mordants include tannic acid, alum, chrome alum, Sodium chloride, and certain salts of aluminium, chromium copper, iron, iodine, Potassium, sodium, tungsten and tin. $KAl(SO_4)_2 \cdot 12H_2O$.

Examples:-



Modant Red 11



Mordant Blue 1.

Color Index:-

* Each Dye gets identified by a unique five digit number, which is called CI or Colour Index number. A part from the number of each dye is given a Generic name or CI name, the name is based on the base action, dyes mode of behavior and the action. The CI name thus gives a specific way in which dyes can be identified.

Colour index numbers:-

Structure	Range	category
Nitroso	10000 - 10299	
Nitro	10300 - 10999	
Diazo	20000 - 39999	Azodyes
Natural dyes	75000 - 76999	
Inorganic Pigments	77000 - 77999	Inorganic pigments

Significance of dyes:-

Food dyes:- The Food dyes are classed as food additives, they are manufactured to a higher standard than some industrial dyes. Food dyes can be direct, mordant and vat dyes and their use is strictly controlled by legislation. Many are azo dyes, although anthraquinone and triphenyl-methane Compounds are used for colors such as green & blue. Some naturally occuring dyes are also used.

* Solvent dyes, for wood staining and producing Colored lacquers solvent inks, coloring oils, waxes

* Fluorescent brighteners, for textile fibres and paper.
* Leather dyes for leather.
* oxidation bases, for mainly and fur.