قسم الكيمياء
محاضرات المرحلة الثانية

مادة الكيمياء العضوية

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Chemistry Department

Lectures in organic chemistry

Second class

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Phenols

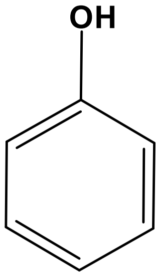
Phenols are compounds that have a hydroxyl group bond directly benzene or benzenoid ring. The parent compound of this group , C_6H_5OH,called simply phenol , is an **important industrial chemical and pharmaceutical chemistry.**

Phenols are compounds of the general formula Ar-OH ,when Ar=phenyl ,substituted phenyl. Phenols differ alcohols in having the hydroxyl group attached directly to an aromatic ring(phenyl or substituted phenyl).but the hydroxyl group in alcohol compounds are attached directly to an aliphatic group

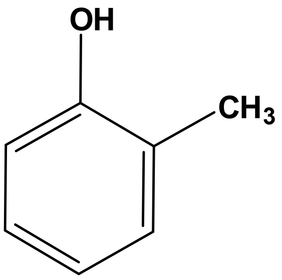
Nomenclature

An old name for benzene was phene , and its hydroxyl derivative came to be called phenol ,the systematic name for phenol is benzenol =(C_6H_5OH).this, like many other entrenched common names , is an acceptable IUPAC name.

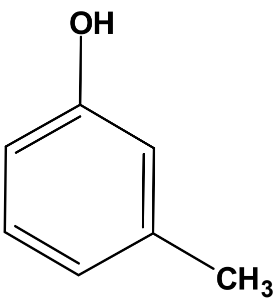
(**International Union of Pure and Applied Chemistry**). Likewise ,o-,m- ,and p-cresol are acceptable names for the various ring-substituted hydroxyl derivatives of toluene **.** more highly substituted compounds are named as derivatives of phenols . numbering of the ring begins at the hydroxyl- substituted carbon and proceeds in the direction that gives the lower number to the next substituted carbon. Substituent are cited in alphabetical order.



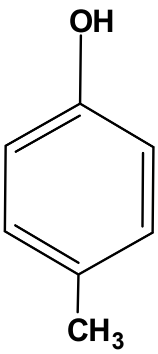
phenol



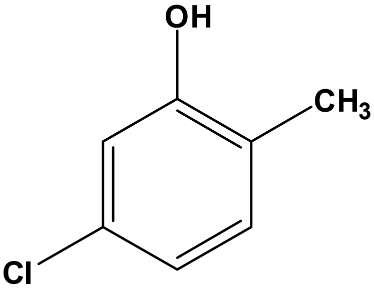
***o*-cresol**



***m*-cresol**

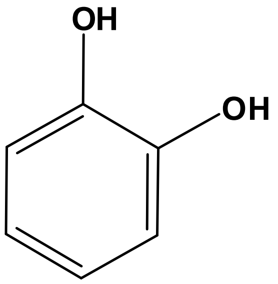


***p*-cresol**

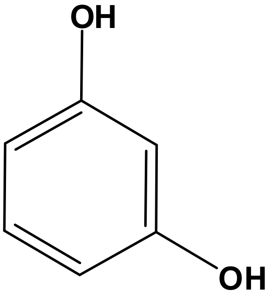


5-chloro-2-methylphenol

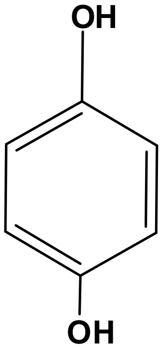
the three dihydroxy derivatives of benzene may be named as 1,2- , 1,3 and 1,4-benzenediol ,respectively ,but each is more known by the common name .



pyrocatechol
1,2-benzenediol



resorcinol
1,3-benzenediol



hydroquinone
1,4-benzenediol

Problem

Write structural formulas for each of the following compounds :

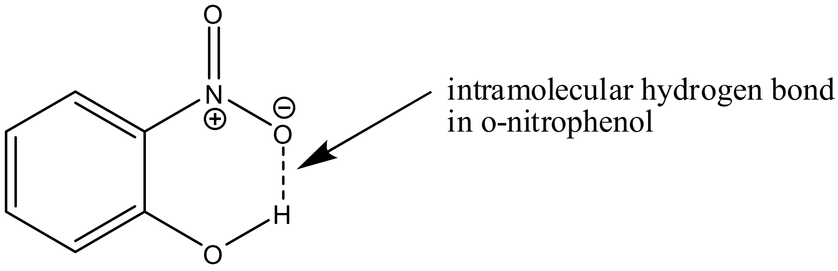
(a) Pyrogallol
(b) O-benzylphenol
(c) 3-nitro-1-naphthol
(d) 4-chlororesorcinol

(e) salicylic acid (f) 1-naphthol

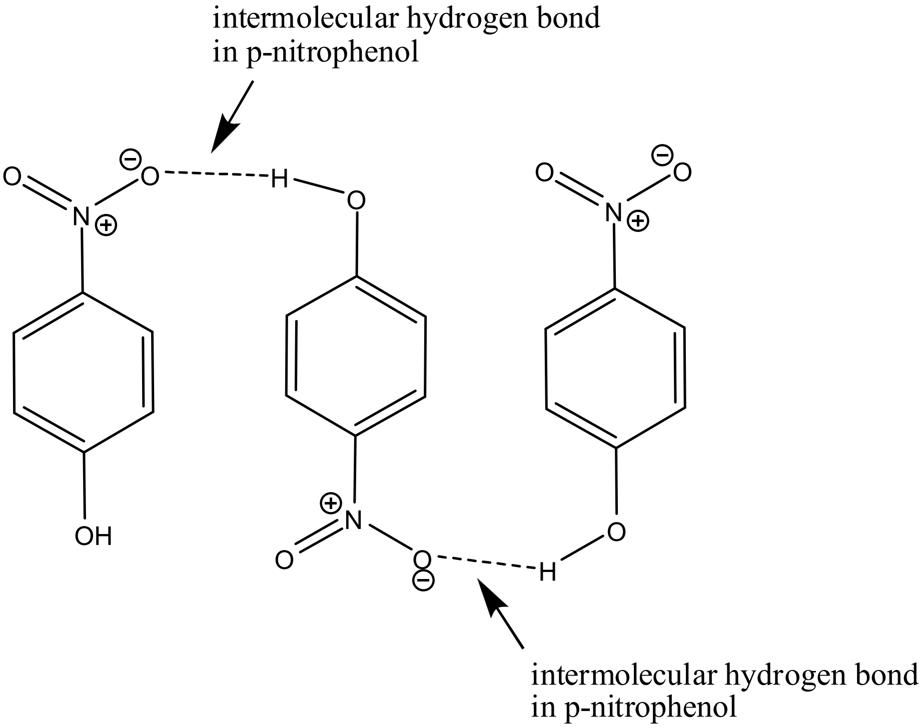
(g) B-naphthol (h) p-hydroxy benzoicacid

Physical properties of phenols

The physical properties of phenols are strongly influenced by the hydroxyl group. The simplest phenols are liquids or low- melting points solids, because of hydrogen bonding ,they have quite high boiling points. Some ortho-substituted phenols ,such as o-nitrophenol, have significantly lower boiling points than those of the meta and para isomers.this is because the intramolecular hydrogen bond that forms between the hydroxyl group and nitro group.



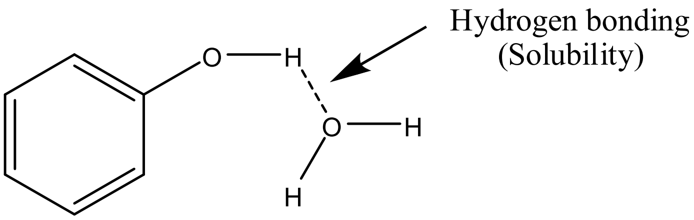
intramolecular hydrogen bond
in o-nitrophenol



intermolecular hydrogen bond
in p-nitrophenol

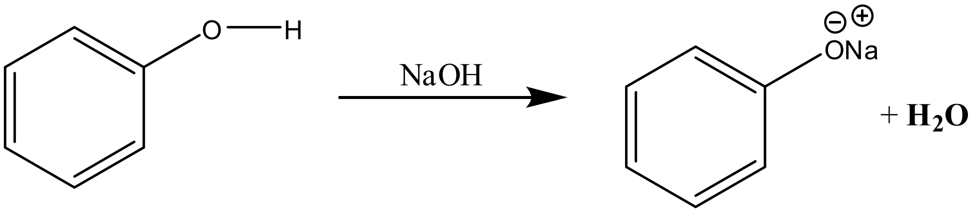
intermolecular hydrogen bond
in p-nitrophenol

Phenols are soluble in water because of hydrogen bonding between hydroxyl group in phenols and water.

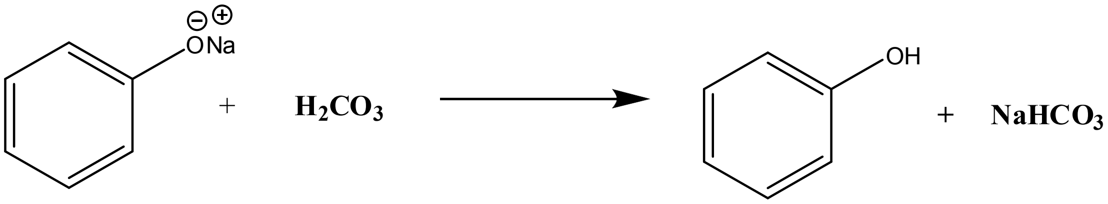


Acidity of phenols

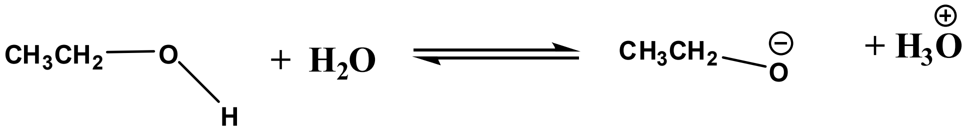
The most characteristic property of phenols is their acidity. Phenols are more acidic than alcohols but less acidic than carboxylic acids. Phenols are converted into their salts by aqueous hydroxide.

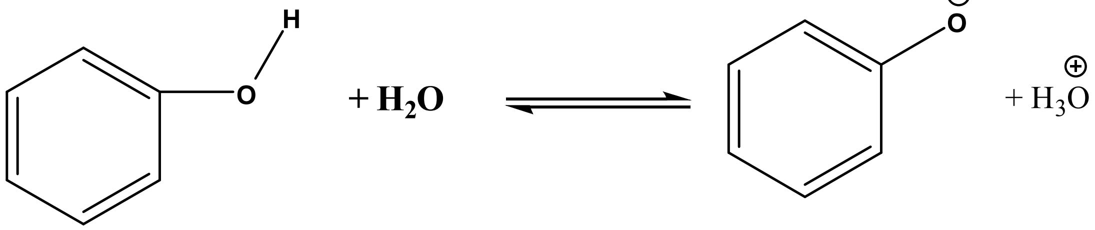


Most phenols are weaker than carbonic acid see below:

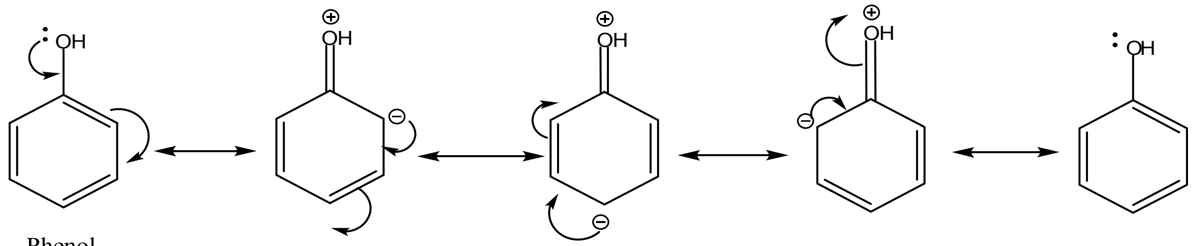


Now to help us understand why phenols are more acidic than alcohols ,let's compare the ionization equilibria for phenol and ethanol. In particular, consider the differences in charge delocalization in ethoxide ion and in phenoxide ion. The negative charge in ethoxide ion is localized on oxygen and is stabilized only by salvation forces. But the negative charge in phenoxide ion is stabilized both by salvation and by electron delocalization into the ring.

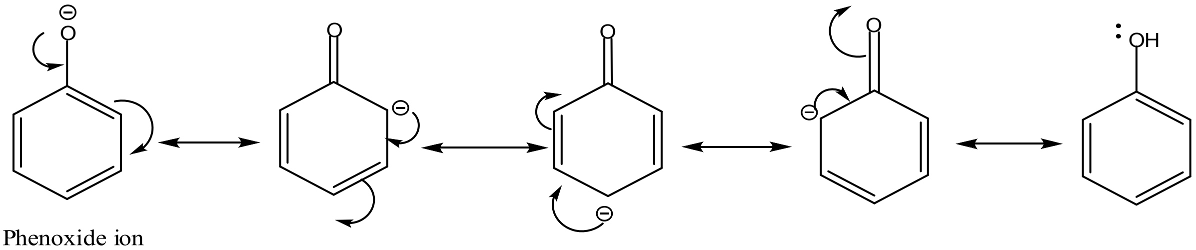




Resonance of phenols



Phenol A B C



Phenoxide ion E F G

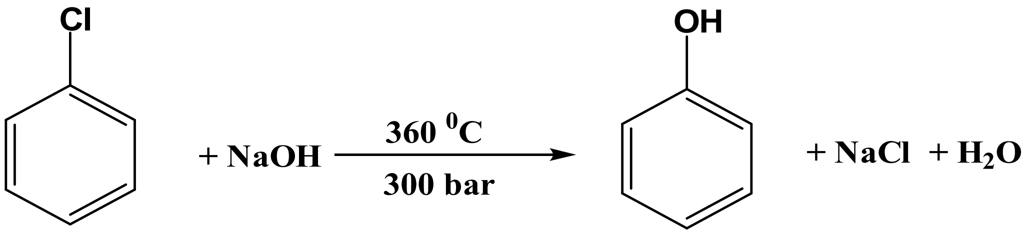
Structures A,B,C for phenol carry both positive and negative charges ; structures E,F,G for phenoxide ions carry only negative charges, the structure of phenol should contain more energy and hence the less stable than the structure of phenoxide ion. We have already encountered the effect of separation of charges on stability , the net effect of resonance is there for to stabilize the phenoxide ion to greater extent than the phenol.

Preparation of phenols

Industrial source :

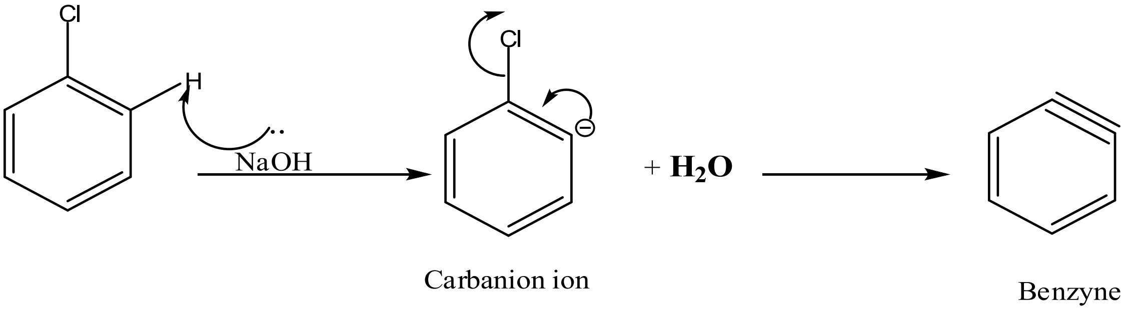
1-Dow process:

This process was referred to the preparation of phenol from chlorobenzene . chlorobenzene is treated with dilute sodium hydroxide at 350 °C and 300 bar to convert it to phenol.

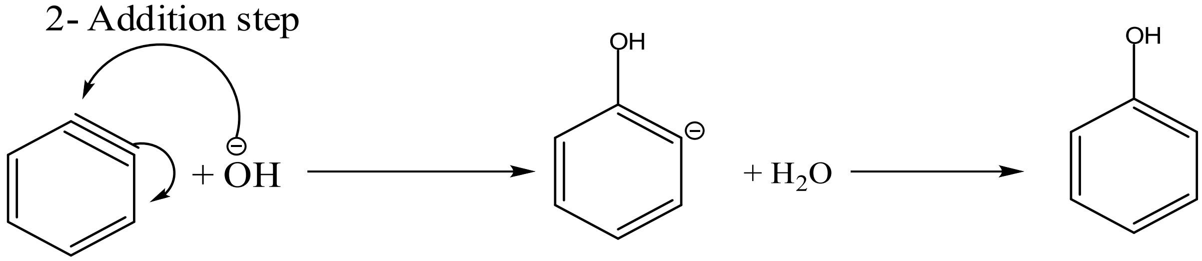


Mechanism:

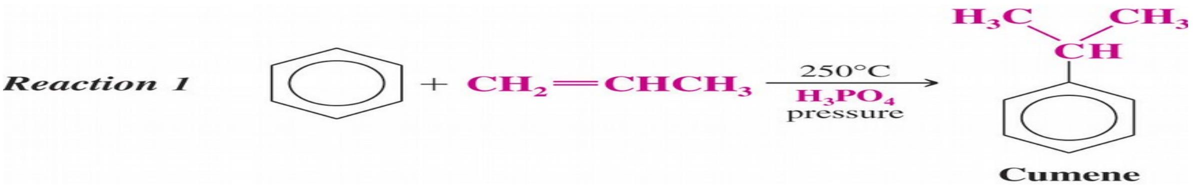
1- Elimination step

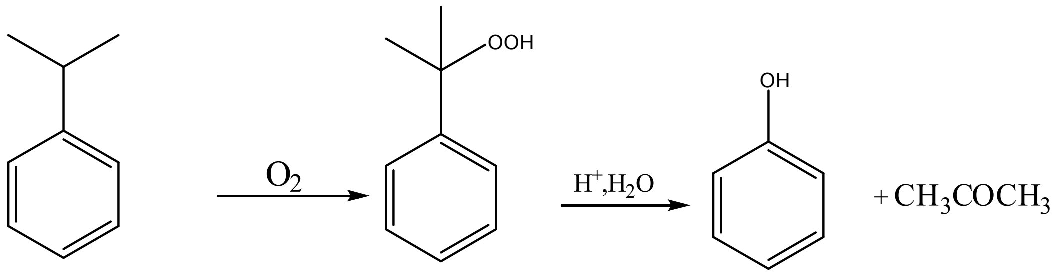


2- Addition step



2- Nearly all phenol is made today ,however ,by a newer process that starts with cumene,isopropylbenzene. Cumene is converted by air oxidation into cumene hydroperoxide , which is converted by aqueous acid into phenol and acetone.

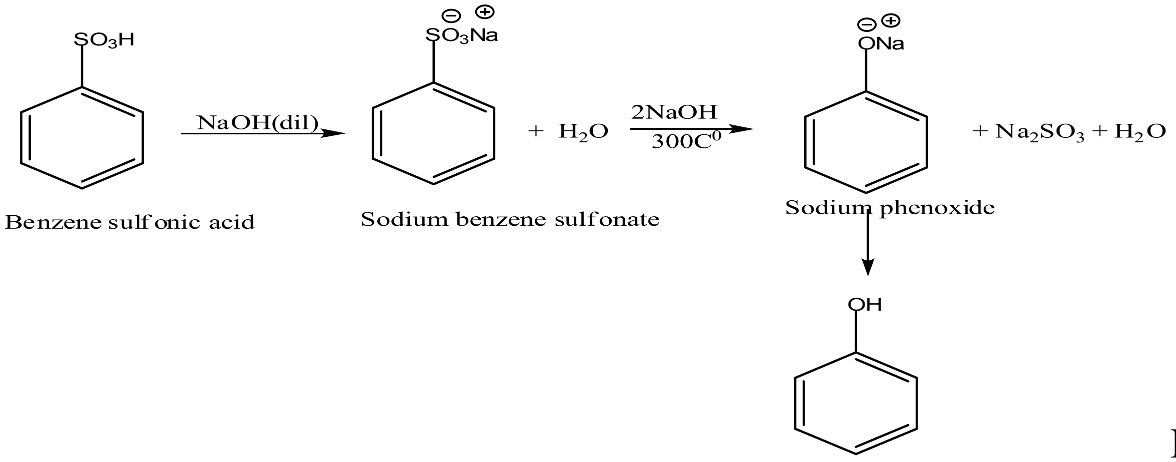




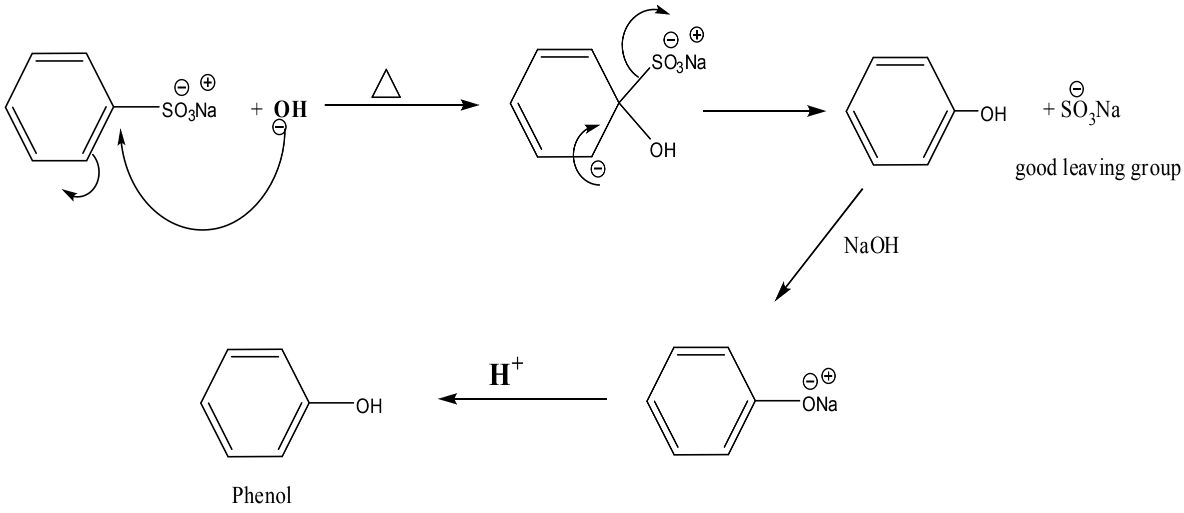
In the laboratory

1- Alkali fusion of sulfonates :

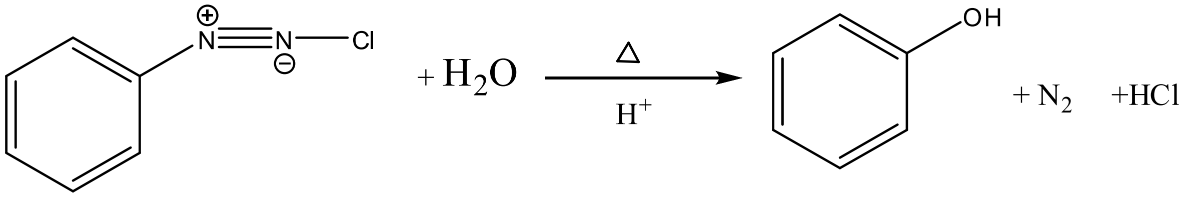
One of the synthetic processes used is the fusion of sodium benzene sulfonate with alkali medium.



Mechanism



2- Hydrolysis of diazonium salt

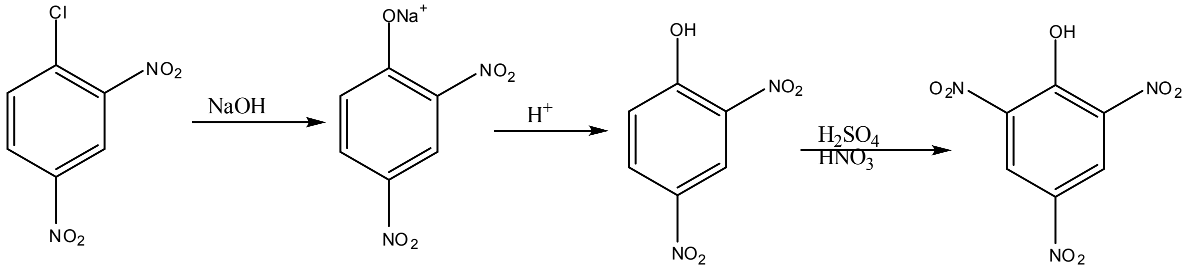


Phenol

B

enzenediazonium salt

- The hydrolysis of aryl halides containing strongly electron with drawing groups ortho and para to the halogen ; 2,4-di nitro phenol are produced in this way on a large scale:

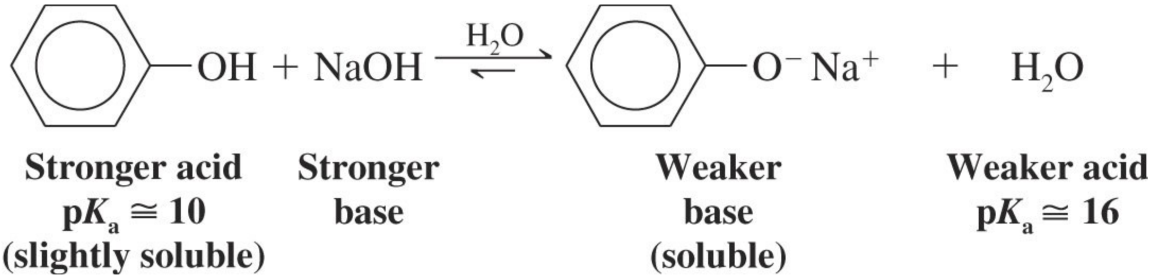


Picric acid

Reactions of phenols:

1- Reaction of phenols as acid

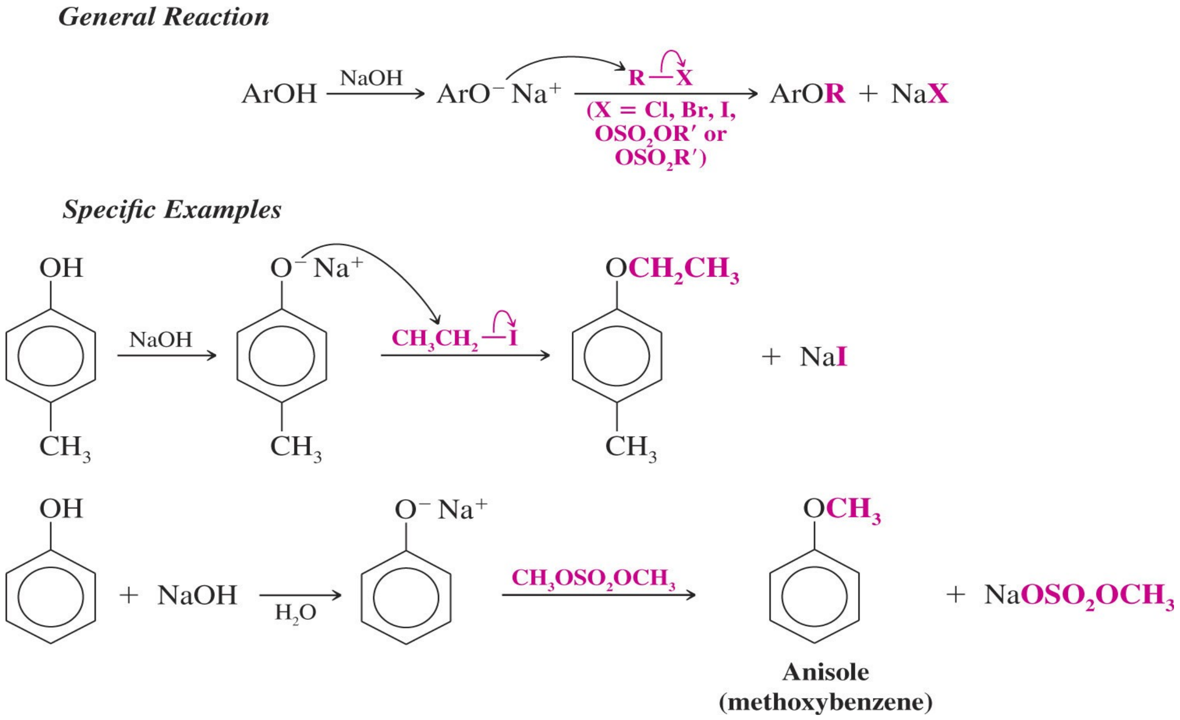
-Separating Phenols from Alcohols and Carboxylic Acids. Phenols are soluble in aqueous sodium hydroxide because of their relatively high acidity - most alcohols are not.



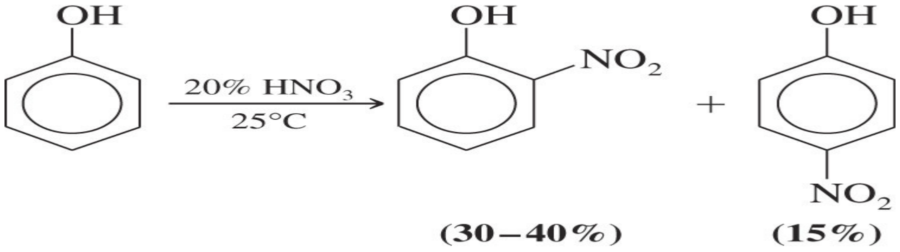
$$CH_3(CH_2)_4CH_2OH + NaOH \underset{H_2O}{\rightleftharpoons} CH_3(CH_2)_4CH_2O^- Na^+ + H_2O$$

Weaker acid **pK_a ≅ 18** **(very slightly soluble)**	**Weaker base**	**Stronger base**	**Stronger acid** **pK_a ≅ 16**

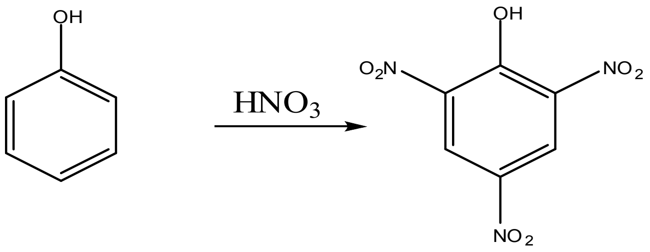
2 -Phenols in the Williamson Ether Synthesis. Phenoxides (phenol anions) react with primary alkyl halides to form ethers by an SN2 mechanism.



2- Nitration of phenols

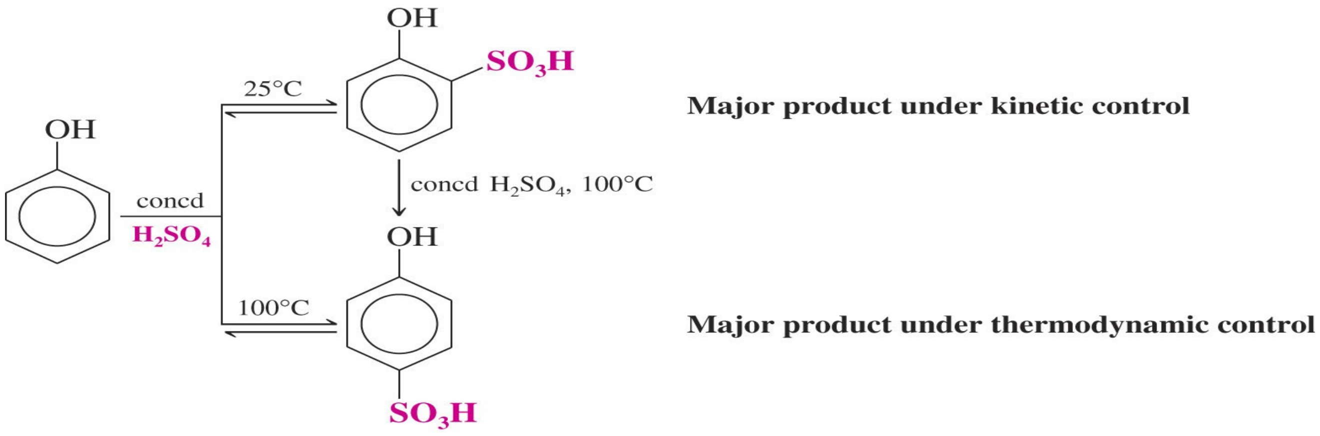


Synthesis of picric acid:-



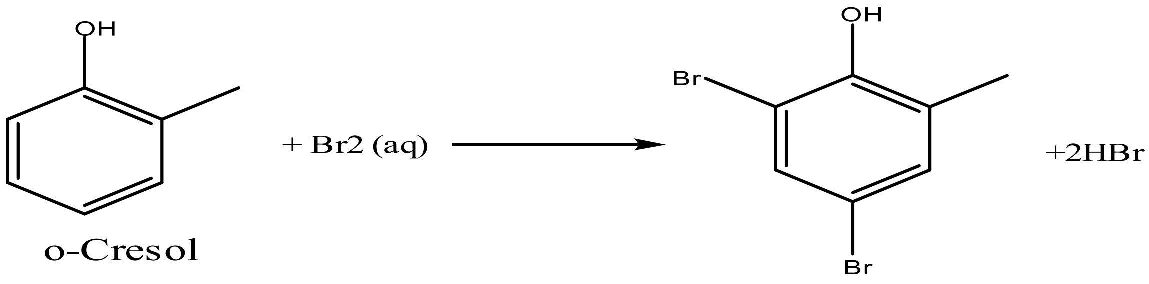
Sulfonation

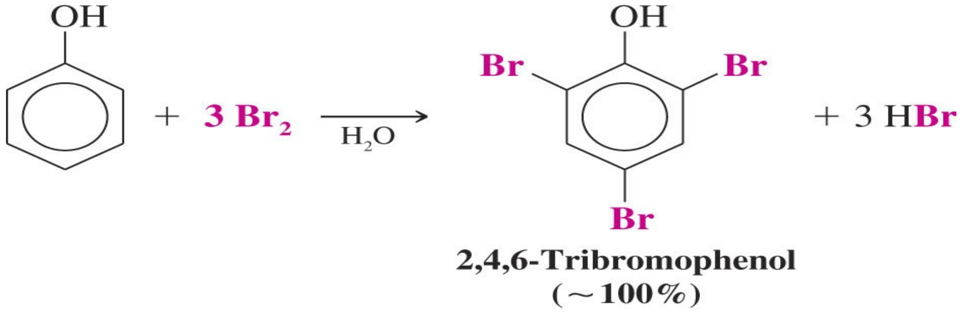
- Sulfonation gives mainly the ortho (kinetic) product at low temperature and the para (thermodynamic) product at high temperature.(ortho or para phenol sulfonic acid).



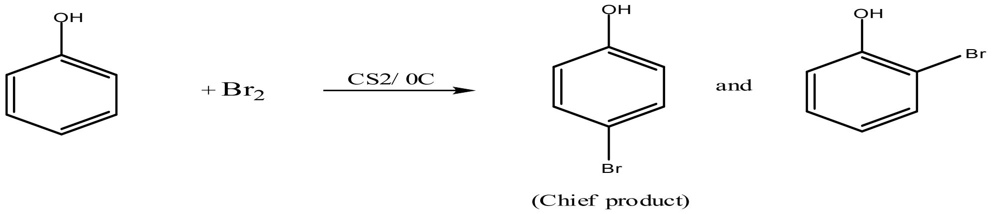
- Haloganation

  Treatment of phenol with aqueous solution of bromine results in replacement of every hydrogen (ortho or para)to the –OH group ; and may even cause displacement of certain other groups.

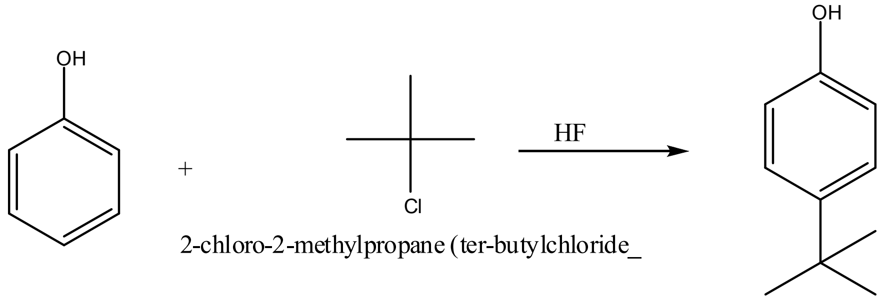




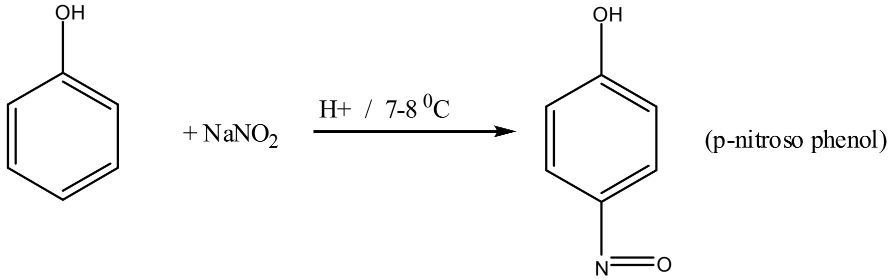
If halogenation is carried out in a solvent of low polarity such as chloroform, CCL_4, CS_2 reaction can be limited to mono halogenations.



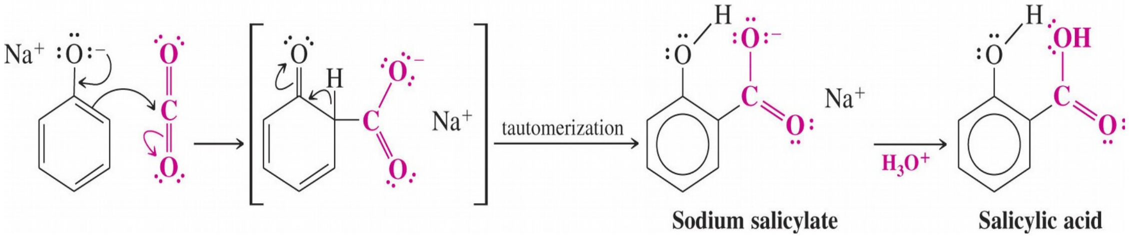
- Friedl – crafts alkylation:

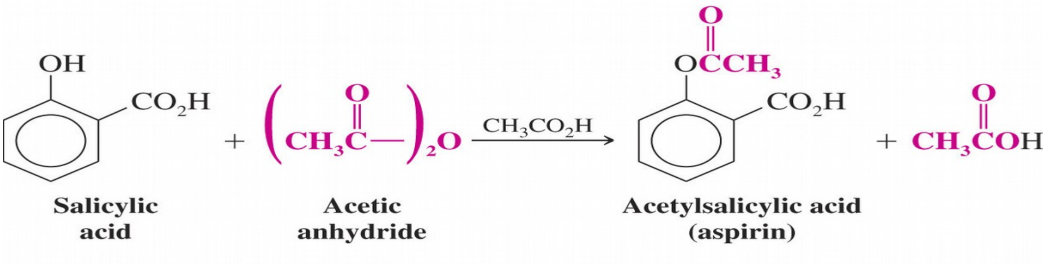


-Nitrosation:-



- Kolbe reaction
- Carbon dioxide is the electrophile for an electrophilic aromatic
- substitution with phenoxide anion
- – The phenoxide anion reacts as an enolate
- – The initial keto intermediate undergoes tautomerization to the phenol
- – Kolbe reaction of sodium phenoxide results in salicyclic acid, a
- synthetic precursor to acetylsalicylic acid (aspirin).

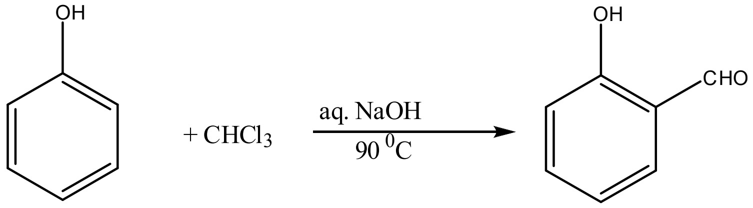




Rimer-tiemann reaction

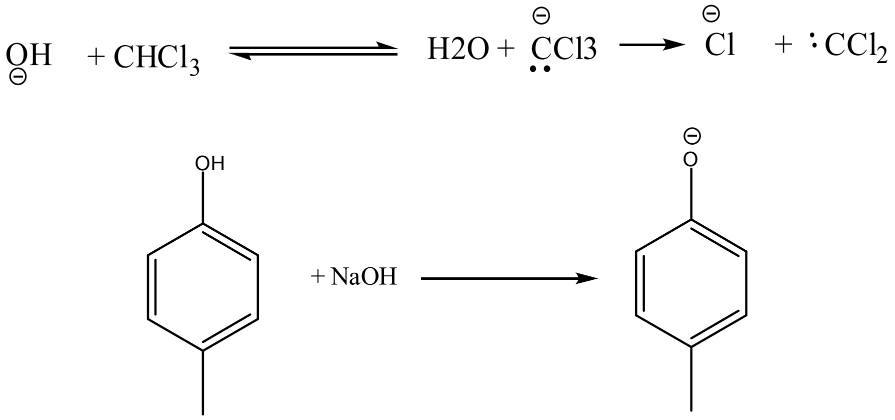
Treatement of a phenol with chloroform and aqueous hydroxide introduces an aldehyde group- CHO ,into the aromatic ,generally (ortho) to the –OH .

This reaction is known as the rimer tiemann reaction .

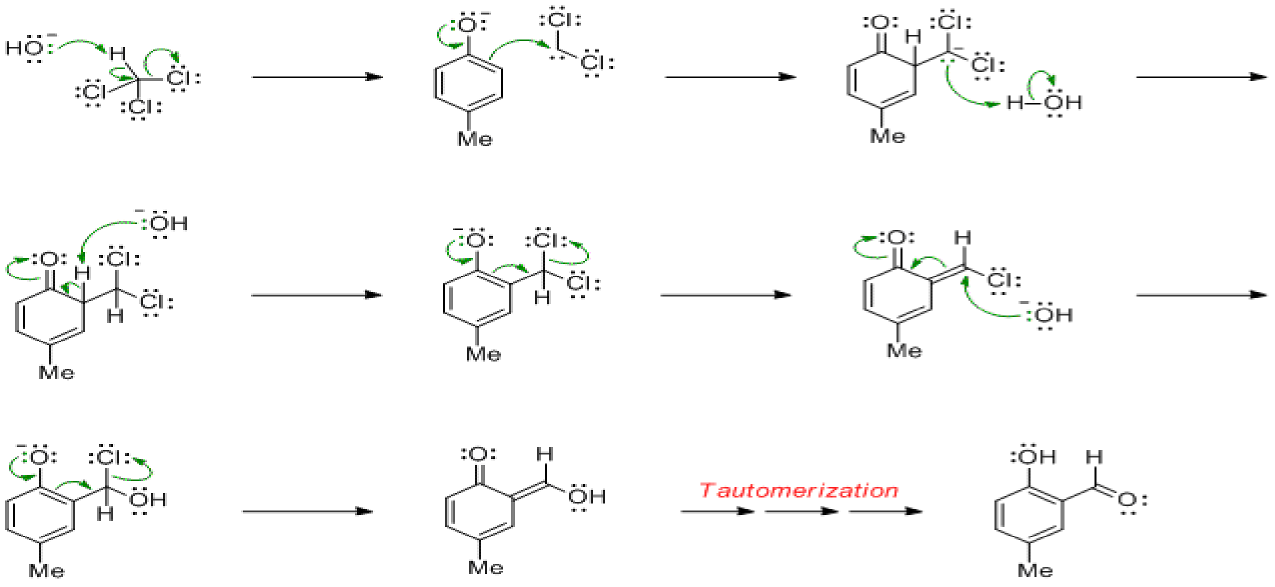


Salicyldehyde

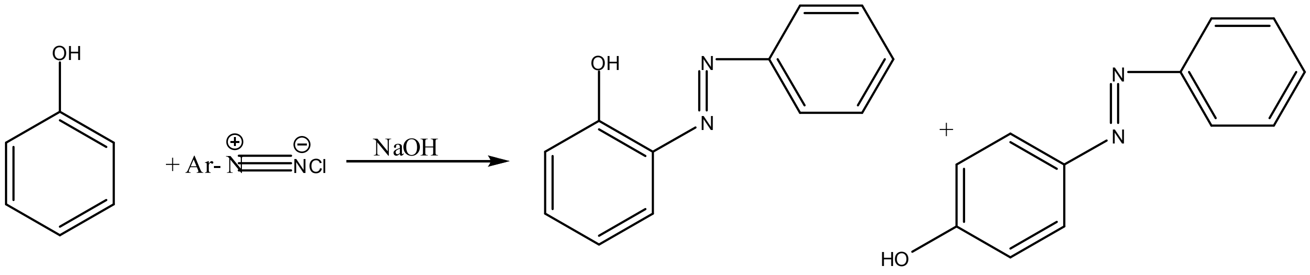
Mechanism:



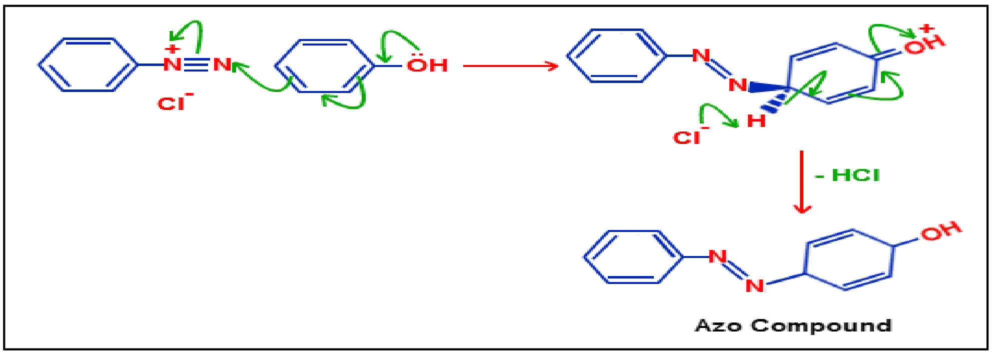
$$\overset{\ominus}{OH} + CHCl_3 \rightleftharpoons H2O + \overset{\ominus}{\underset{\bullet\bullet}{C}}Cl3 \longrightarrow \overset{\ominus}{Cl} + :CCl_2$$



Azo compound formation

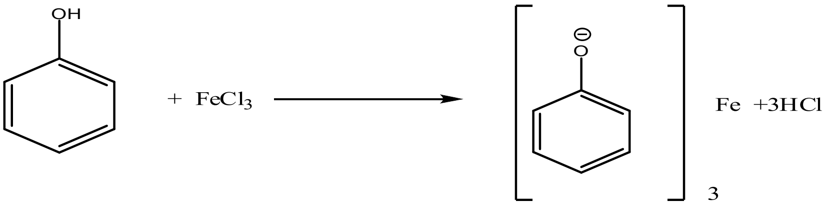


2-(phenyldiazenyl)phenol



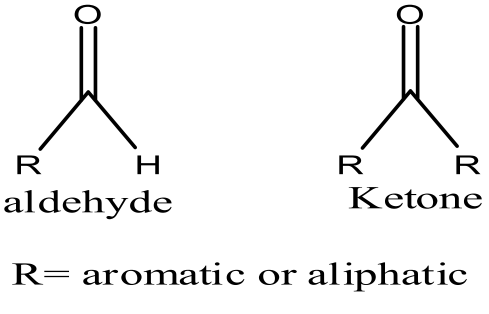
Identified of phenol

Many but not all phenols form colored complexes (ranging from green through blue and violet to red)with ferric chloride.



Aldehydes and ketones

All aldehydes have a carbonyl group , bonded on one side to a carbon and on the other side to a hydrogen. In ketones , the carbonyl group is situated between two carbon atoms.



Both aldehydes and ketones contain the carbonyl group, C O, and are often referred to collectively as carbonyl compounds. However, there is a hydrogen atom attached to the carbonyl group of aldehydes, and there are two organic groups attached to the carbonyl group of ketones. This difference in structure affects their properties in two ways: (a) aldehydes are quite easily oxidized, whereas ketones are oxidized only with difficulty; (b|) aldehydes are usually more reactive than ketones toward nucleophilic addition, the characteristic reaction to carbonyl compounds.

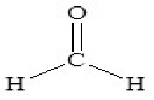
Nomenclature

The common names of aldehydes are derived from the names of the corresponding carboxylic acids by replacing -ic add by -aldehyde.

The IUPAC names of aldehydes follow the usual pattern. The longest chain carrying the CHO group is considered the parent structure and is named by replacing the -e of the corresponding alkane by -al. The position of a substituent is indicated by a number, the carbonyl carbon always being considered as C-l. Here, as with the carboxylic acids, we notice that C-2 of the IUPAC name corresponds to alpha of the common name.

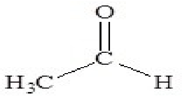
Summary of Aldehyde Nomenclature rules:

1. Aldehydes take their name from their parent alkane chains. The ***-e*** is removed from the end and is replaced with ***-al***.
2. The aldehyde funtional group is given the #1 numbering location and this number is not included in the name.
3. For the common name of aldehydes start with the common parent chain name and add the suffix ***-aldehyde***. Substituent positions are shown with Greek letters.
4. When the -CHO functional group is attached to a ring the suffix ***-carbaldehyde***is added, and the carbon attached to that group is C1.



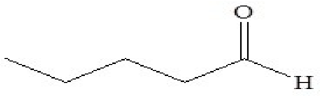
Methanal

(Formaldehyde)



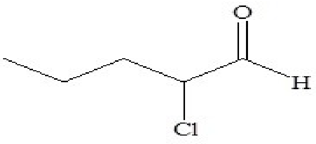
Ethanal

(Acetaldehyde)



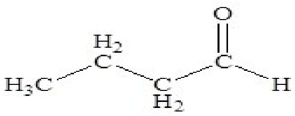
Pentanal

(Valeraldehyde)



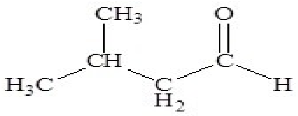
2-Chloropentanal

(a-Chlorovaleraldehyde)



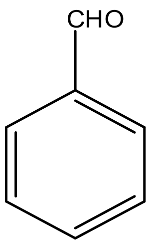
Butanal

(Butyraldehyde)

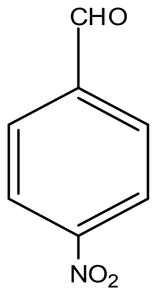


3-Methylbutanal

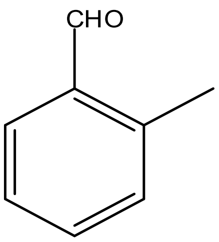
(isovaleraldehyde)



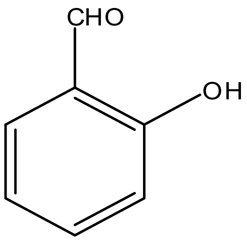
benzaldehyde



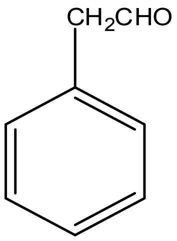
4-nitrobenzaldehyde



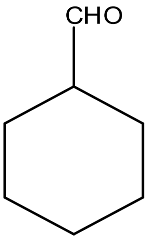
2-methylbenzaldehyde
(o-tolualdehyde)



2-hydroxybenzaldehyde
(salicyldehyde)



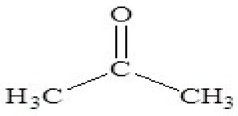
phenylacetaldehyde
(phenylethanal)



cyclohexanecarbaldehyde

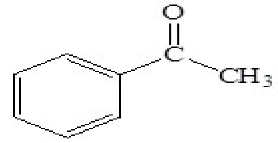
The simplest aliphatic ketone has the common name of acetone. For most other aliphatic ketones we name the two groups that are attached to carbonyl carbon, and follow these names by the word ketone. A ketone in which the carbonyl group is attached to a benzene ring is named as a -phenone, as illustrated below.

According to the IUPAC system, the longest chain carrying the carbonyl group is considered the parent structure, and is named by replacing the -e of the corresponding alkane with -one. The positions of various groups are indicated by numbers, the carbonyl carbon being given the lowest possible number.



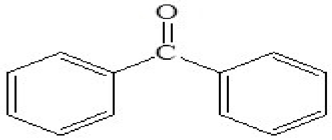
Propanone

(Acetone)



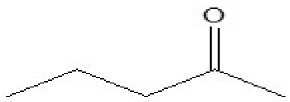
Acetophenone

(Methyl phenyl ketone)



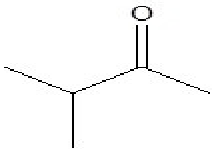
Benzophenone

(Diphenyl ketone)



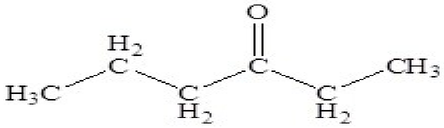
2-Pentanone

(Methyl propyl ketone)



3-Methyl-2-butanone

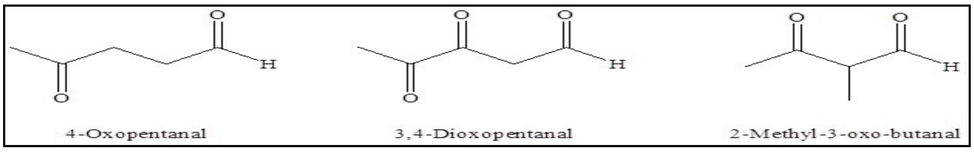
(Methyl isopropyl ketone)



3-Hexanone

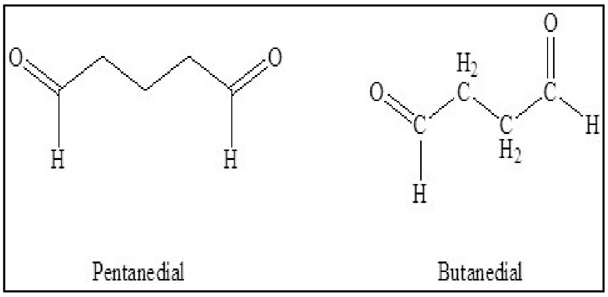
(Ethyl propy ketone)

Naming Aldehydes and Ketones in the Same Molecule

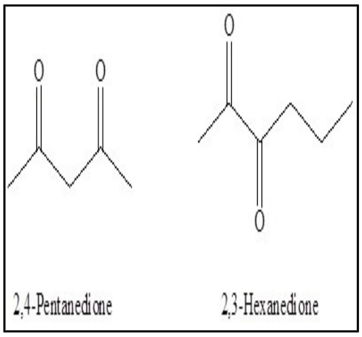


4-Oxopentanal 3,4-Dioxopentanal 2-Methyl-3-oxo-butanal

Naming Dialdehydes and Diketones



Pentanedial Butanedial



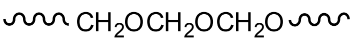
2,4-Pentanedione 2,3-Hexanedione

Physical properties

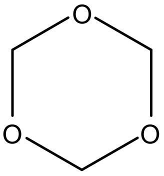
The polar carbonyl group makes aldehydes and ketones polar compounds, and hence they have higher Boiling points has non polar compounds or comparable molecular weight .aldehydes and ketones have lower boiling points than comparable alcohols or carboxylic acids; for example:-
example, compare -**butyraldehyde** (b.p, 76) and **methyl ethyl** ketone (b.p. 80)
n-pentane (b.p. 36) and **ethyl ether** (b.p. 35) on the one hand, and with
n-butyl alcohol (b.p. 118) and **propionic acid** (b.p. 141) on the other.

The lower aldehydes and ketones are appreciably soluble in water, presumably because of hydrogen bonding between solute and solvent molecules; borderline solubility is reached at abolil live taibum. Aldehydes and ketones are soluble in the usual organic solvents.

Formaldehyde is a gas (b.p. 21), and is handled either as an aqueous solution (Formalin), or as one of its solid polymers: paraformaldehyde $(CH_2O)n$, or trioxane $(CH2O)_3$. When dry formaldehyde is desired as for Example, for reaction with a Griniard reagent, it is obtained by heating paraformaldehyde or trioxane.

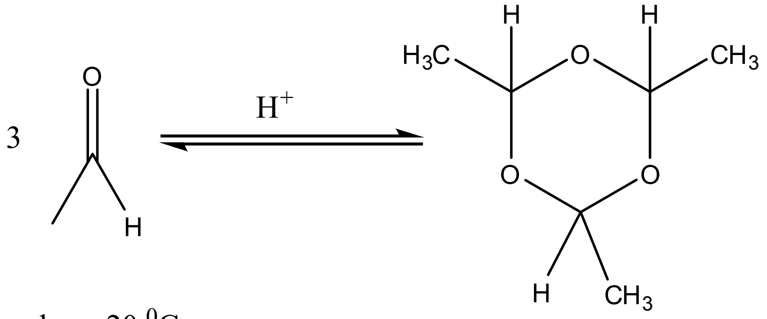


paraformaldehyde



trioxane

Acetaldehyde (b.p. 20) is often generated from its higher-boiling trimer by heating the trimer with acid:



b.p= 20 ^0C

b.p= 125 ^0C

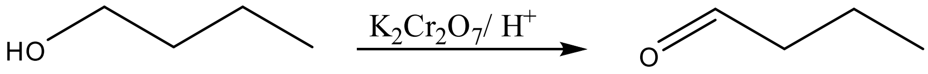
Preparation of aldehydes

A few of the many laboratory methods of preparing aldehydes and ketones are outlined below; most of these are already familiar to us. Some of the methods involve oxidation or reduction in which an alcohol, hydrocarbon, or acid chloride is converted into an aldehyde or ketone of the same carbon number. Other methods involve the formation of new carbon-carbon bonds, and yield aldehydes or ketones of higher carbon number than the starting materials.

1- Oxidation of primary alcohols

$$RCH_2OH \xrightarrow{K_2Cr_2O_7/\ H^+} R\text{-}CHO$$

example



n-butyl alcohol

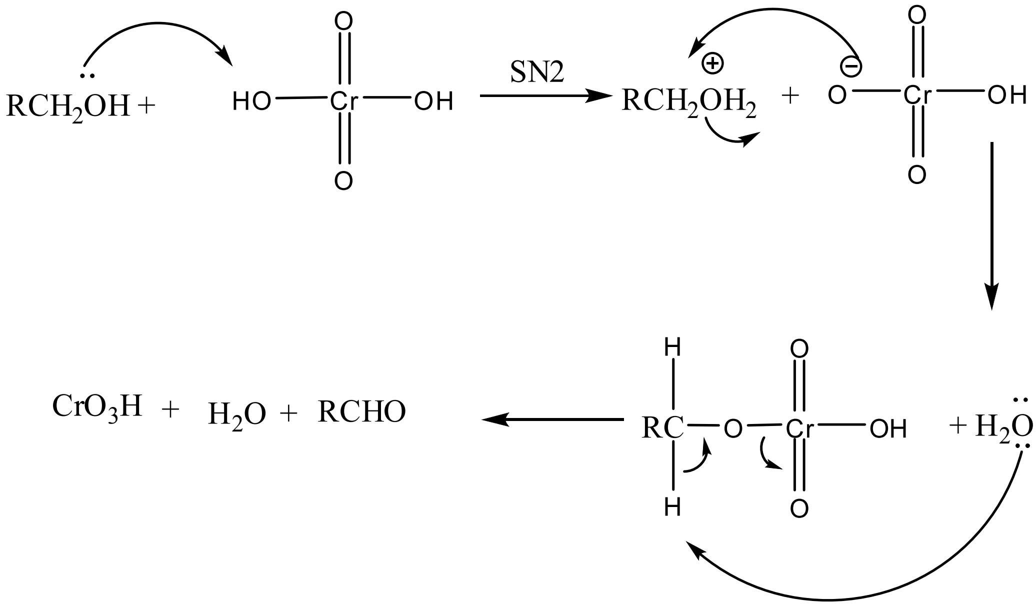
butanal

Mechanism

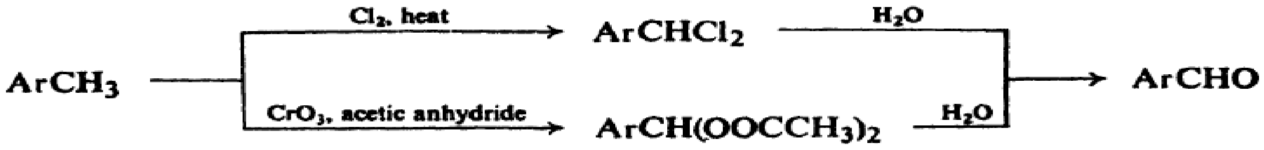
$$K_2Cr_2O_7 + H_2SO_4 \longrightarrow H_2Cr_2O_7 + K_2SO_4$$

$$H_2Cr_2O_7 + H_2O \longrightarrow 2H_2CrO_4$$

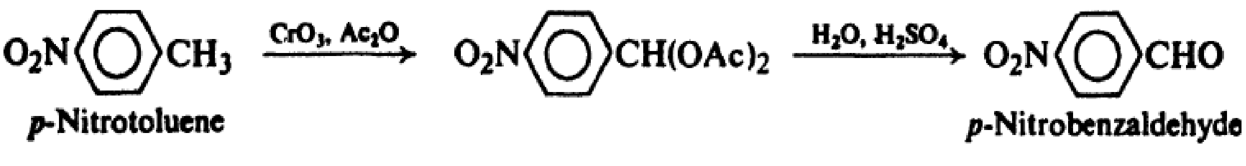
chromic acid
(more oxidized than $K_2Cr_2O_7$)



Oxidation of toluene



Examples:



3- Reduction of acid chlorides

$$RCOCl \text{ or } ArCOCl \xrightarrow{LiAlH(Bu\text{-}t)_3} RCHO \text{ or } ArCHO$$

Acid chloride **Aldehyde**

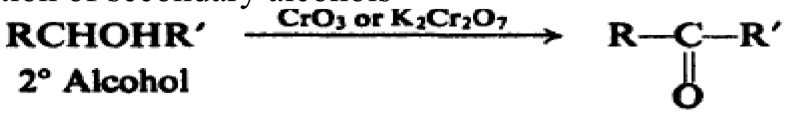
Examples:

***p*-Nitrobenzoyl chloride** ***p*-Nitrobenzaldehyde**

- Rimer Tiemann reaction (see chapter 1 for phenol)

<u>Preparation of ketones</u>

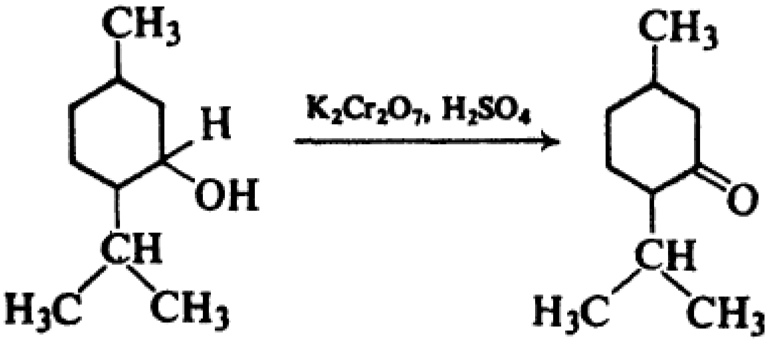
1- Oxidation of secondary alcohols



$$RCHOHR' \xrightarrow{CrO_3 \text{ or } K_2Cr_2O_7} R{-}\overset{O}{\overset{\|}{C}}{-}R'$$

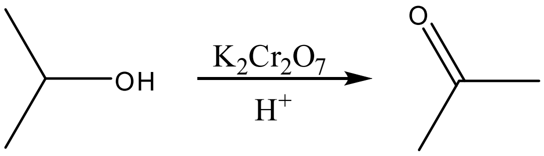
2° Alcohol **Ketone**

Example



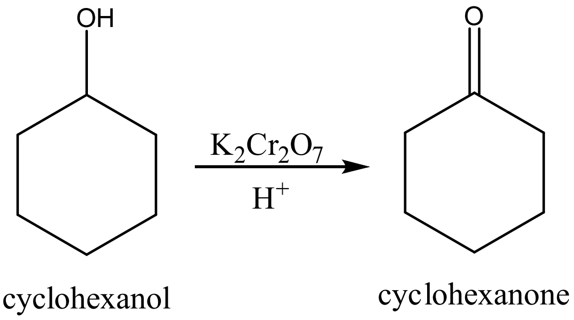
(−)-Menthol **(−)-Menthone**

Give the name of the menthol?

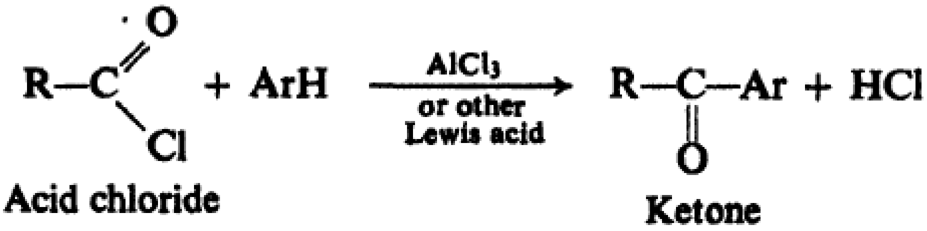


isopropylalcohol acetone

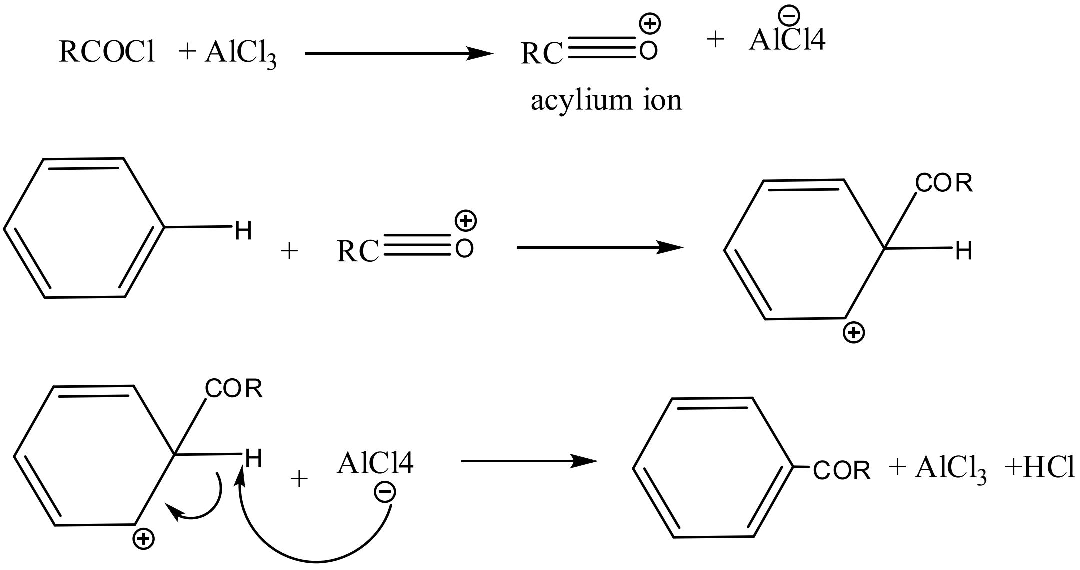
Give the mechanism of the title reaction?

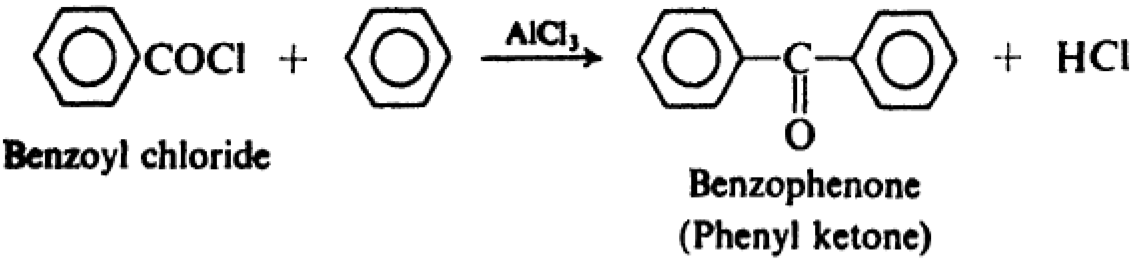


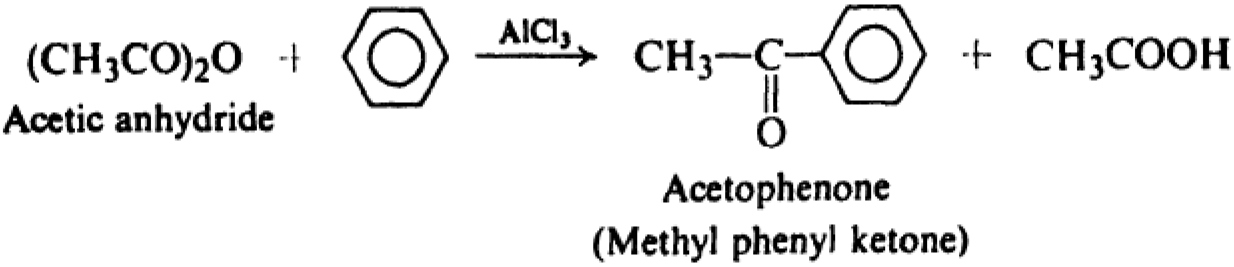
2- Friedel- crafts acylation



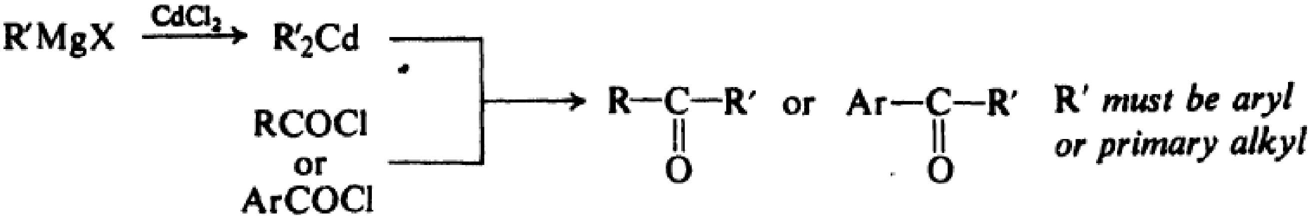
Mechanism



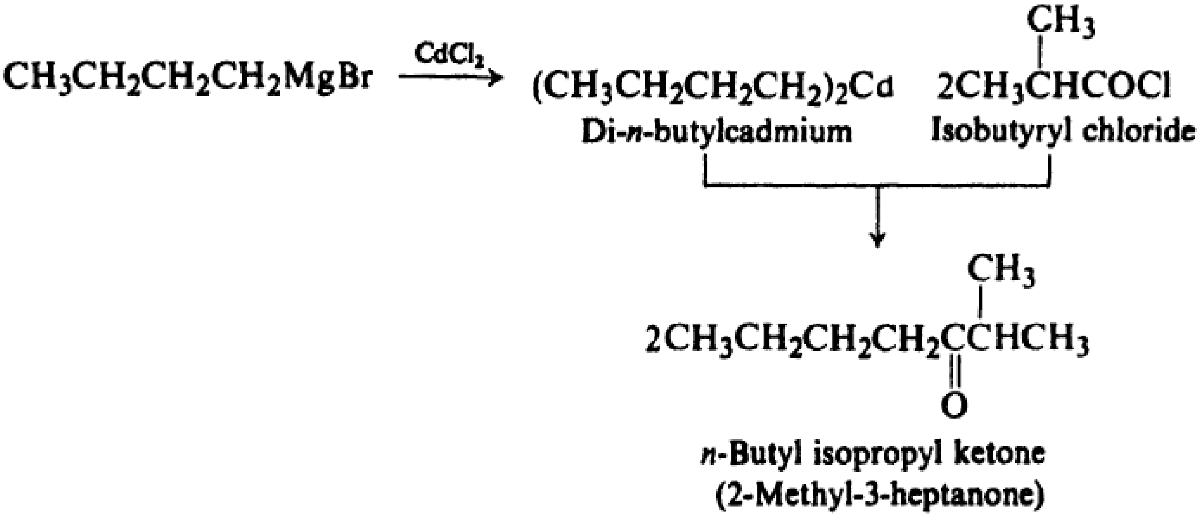




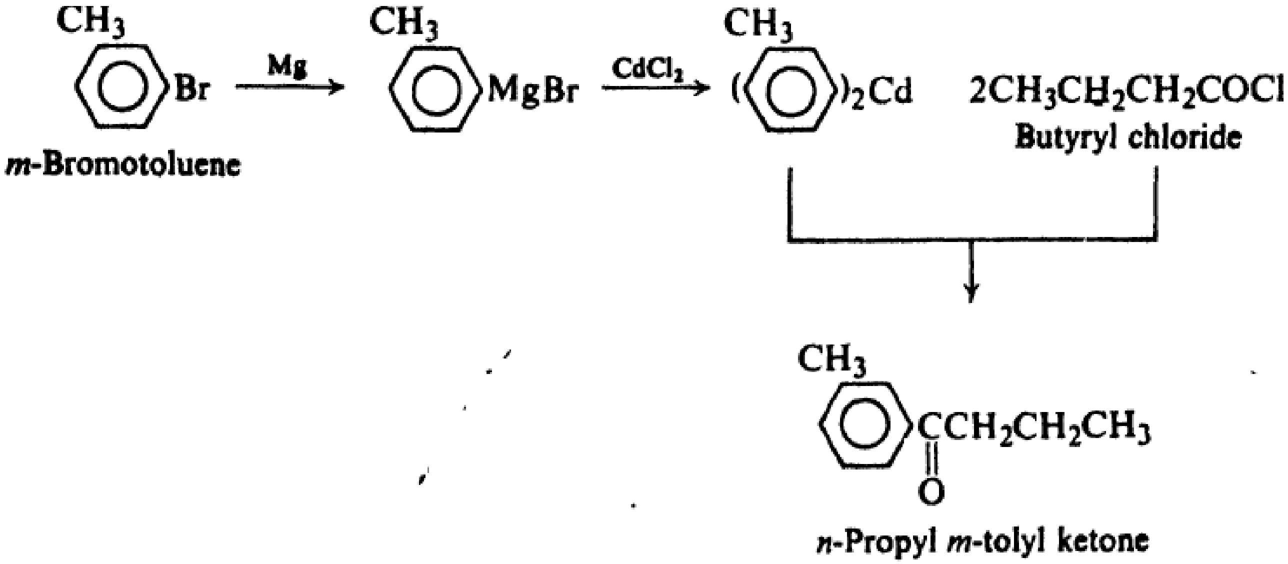
3- **Reaction of acid chlorides with organocadmium compounds.**



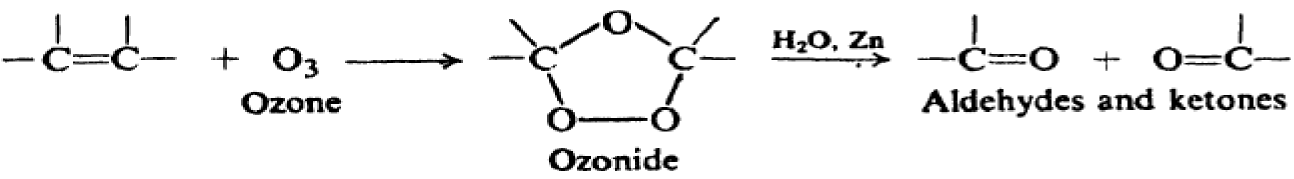
Examples:



Example

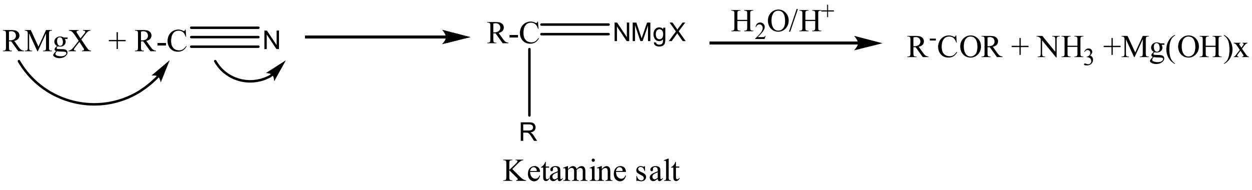


4- Oxidation of alkene by ozone



2-methyl-2-pentene + O_3 ⟶ ? (ozonide) ⟶ ? + ?

5- Griniard reagent addition to cyanide compounds:



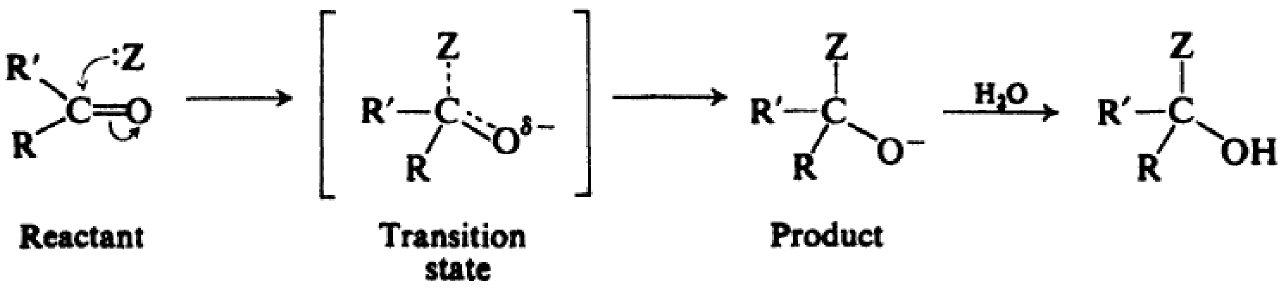
$$RMgX + R\text{-}C{\equiv}N \longrightarrow \underset{R}{R\text{-}C}{=}NMgX \xrightarrow{H_2O/H^+} R^{-}COR + NH_3 + Mg(OH)x$$

Ketamine salt

Reactions. Nucleophilic addition

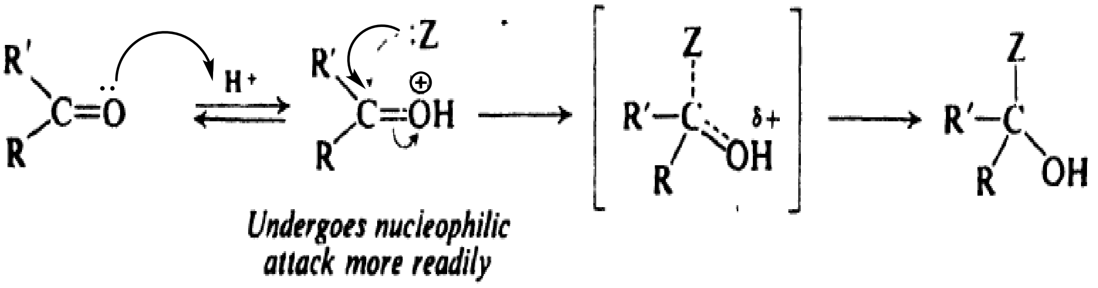
The typical reaction of aldehyde and ketones is nucleophilic addition:-

1- Without catalyst



Acid-catalyzed nucleophilic addition

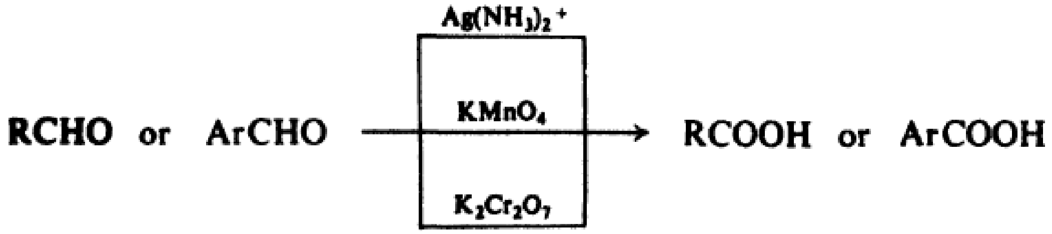
If acid is present, hydrogen ion becomes attached to carbonyl oxygen.



REACTIONS OF ALDEHYDES AND KETONES

1. Oxidation. Discussed in Sec. 19.9.

(a) Aldehydes



$$\text{RCHO or ArCHO} \xrightarrow[\boxed{\begin{array}{c}KMnO_4\\ K_2Cr_2O_7\end{array}}]{Ag(NH_3)_2^+} \text{RCOOH or ArCOOH}$$

Used chiefly for detection of aldehydes

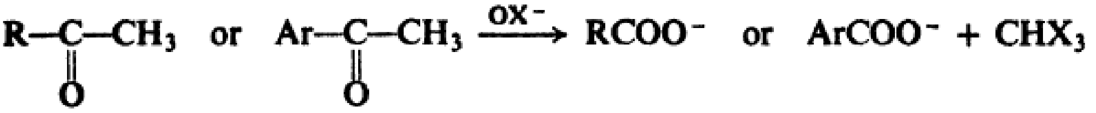
Examples:

$$CH_3CHO + 2Ag(NH_3)_2^+ + 3OH^- \longrightarrow \underset{\text{Silver mirror}}{2Ag} + CH_3COO^- + 4NH_3 + 2H_2O$$

Colorless solution (for $2Ag(NH_3)_2^+$)

Tollens' test

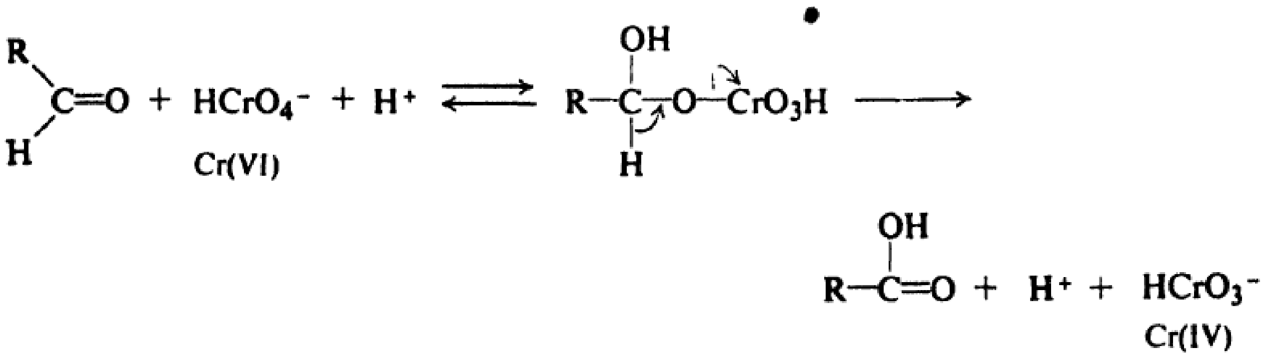
(b) Methyl ketones



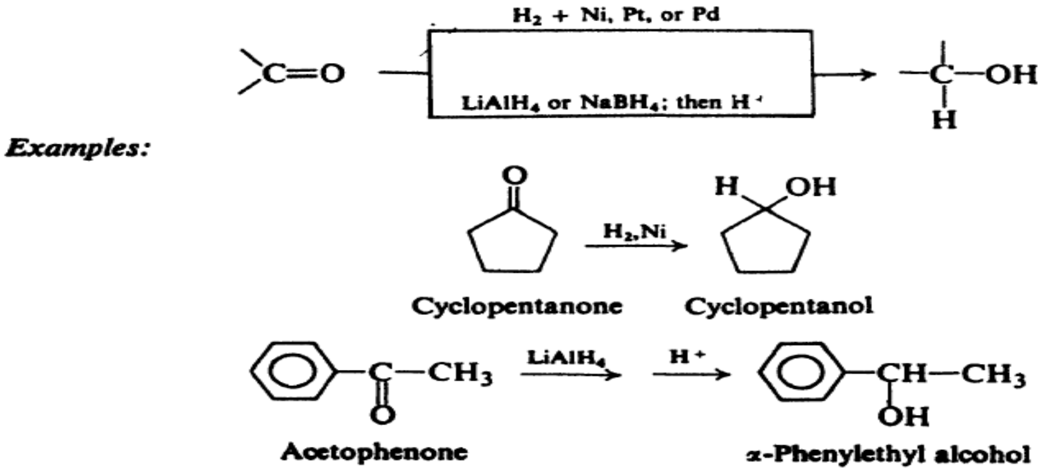
$$R\underset{\underset{O}{\|}}{C}CH_3 \text{ or } Ar\underset{\underset{O}{\|}}{C}CH_3 \xrightarrow{OX^-} RCOO^- \text{ or } ArCOO^- + CHX_3$$

Haloform reaction

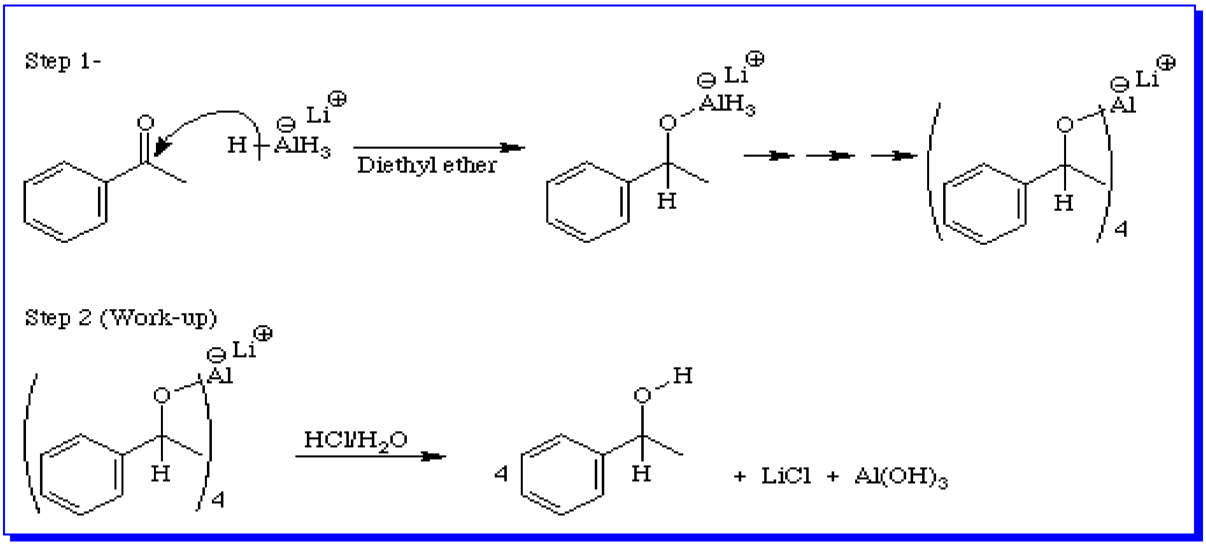
Mechanism of reaction between aldehyde and potassium dichromate



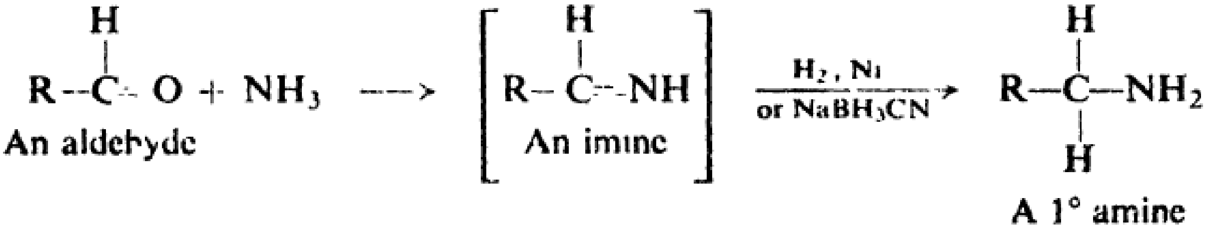
2-reduction to alcohol

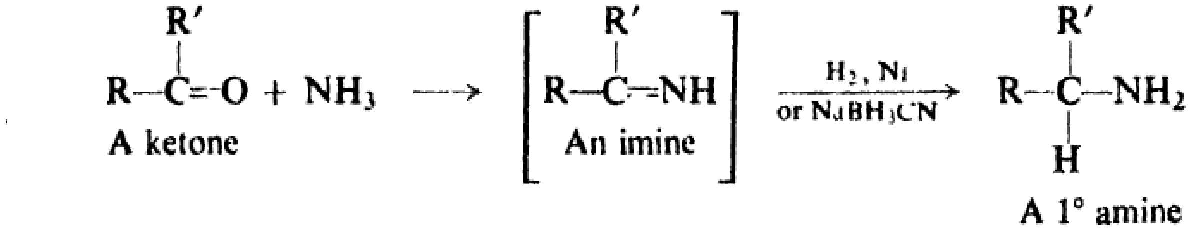


Mechanism of the reduction of acetophenone

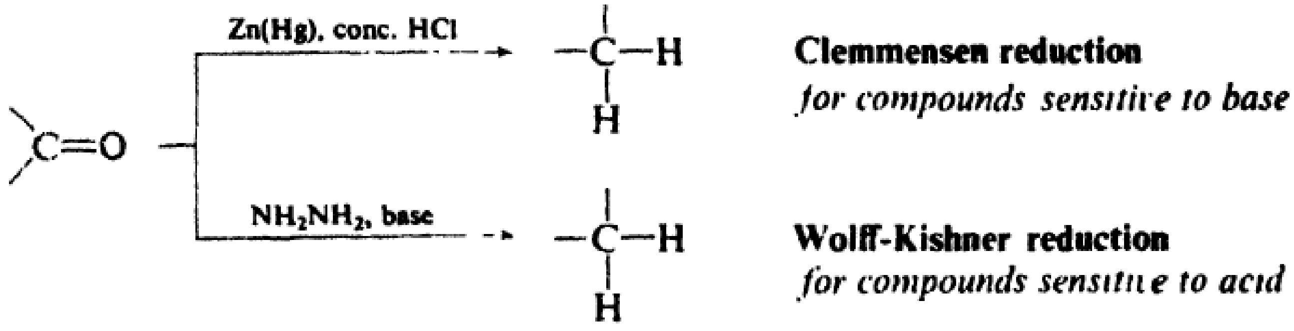


3-reduction amination

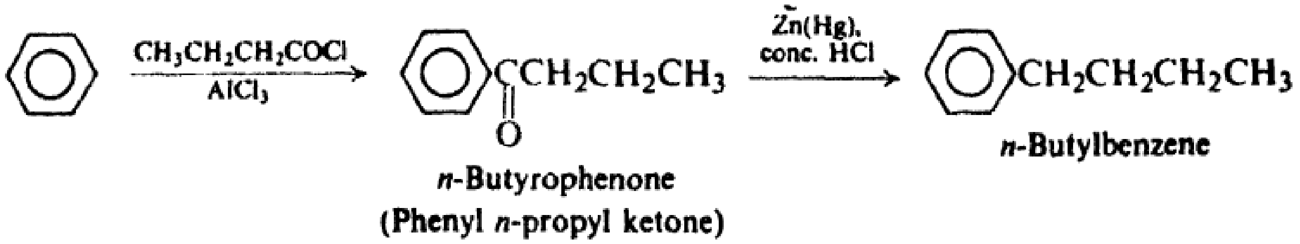


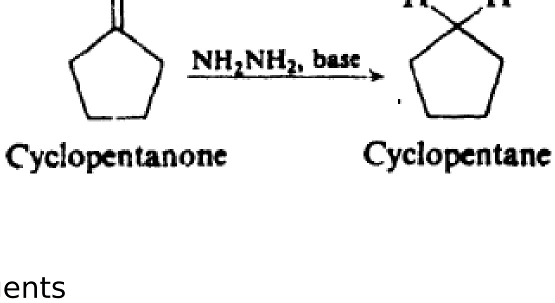


4- reduction to hydrocarbons

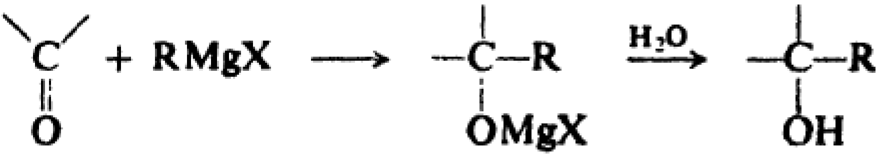


Examples:





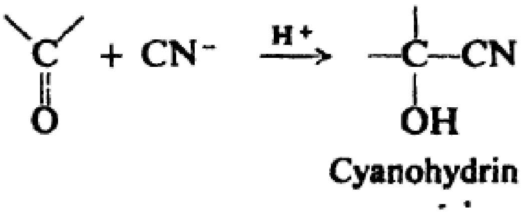
5-addition of griniard reagents



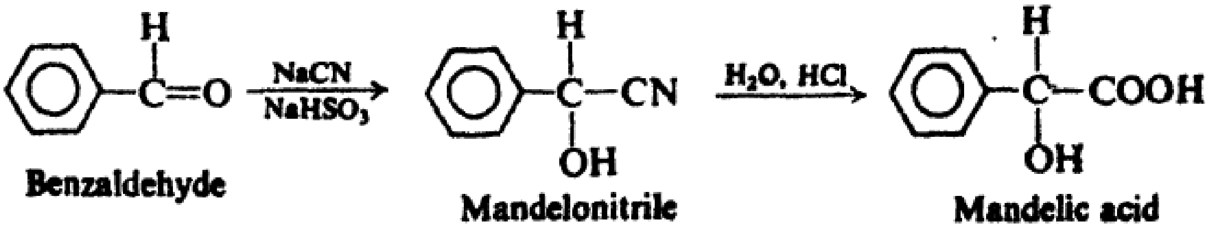
Give the mechanism of the title reaction

6-addition of cyanide to formation of cyanohydrins

$$HCN + \overset{\ominus}{OH} \longrightarrow \overset{\ominus}{CN} + H_2O$$

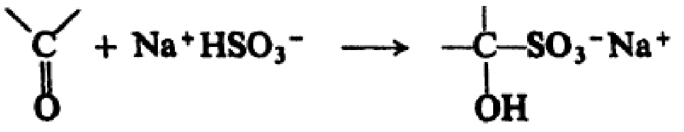


Examples:



Give the mechanism

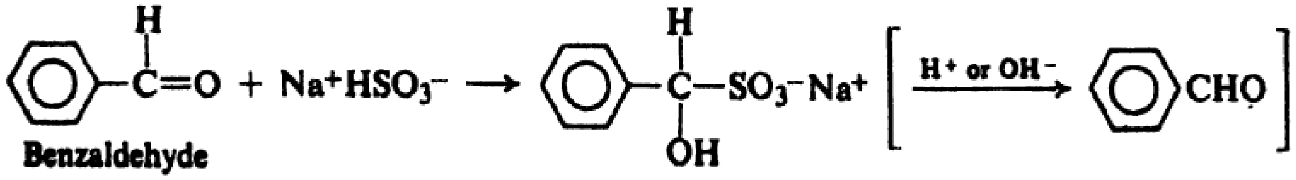
7-addition of bisulfate



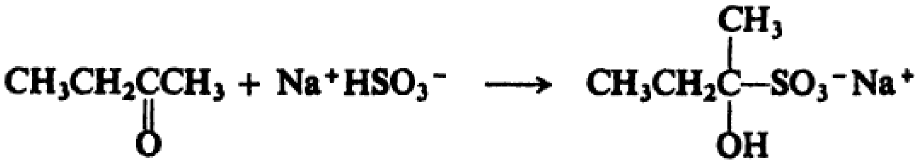
Bisulfite addition product

Used in purification
Not for hindered ketones

Examples:



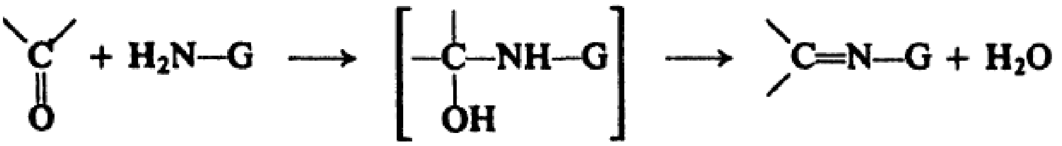
Benzaldehyde



$$CH_3CH_2\underset{\overset{\|}{O}}{C}CH_3 + Na^+HSO_3^- \longrightarrow CH_3CH_2\underset{OH}{\overset{CH_3}{C}}{-}SO_3^-Na^+$$

Methyl ethyl ketone
2-Butanone

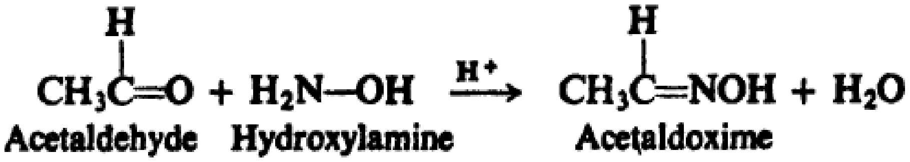
8-addition of derivatives of ammonia



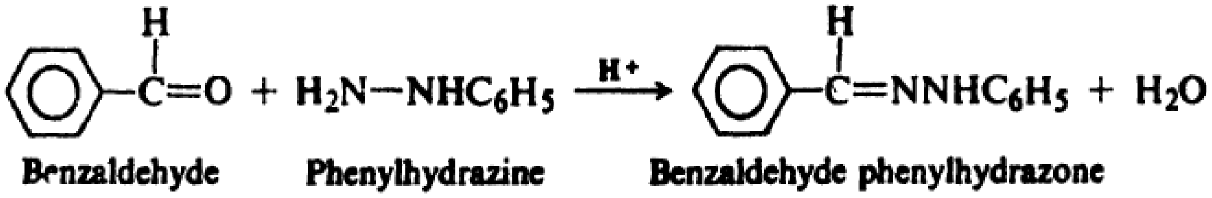
Used for identification

H_2N--G		Product	
$H_2N{-}OH$	Hydroxylamine	$>C{=}NOH$	Oxime
$H_2N{-}NH_2$	Hydrazine	$>C{=}NNH_2$	Hydrazone
$H_2N{-}NHC_6H_5$	Phenylhydrazine	$>C{=}NNHC_6H_5$	Phenylhydrazone
$H_2N{-}NHCONH_2$	Semicarbazide	$>C{=}NNHCONH_2$	Semicarbazone

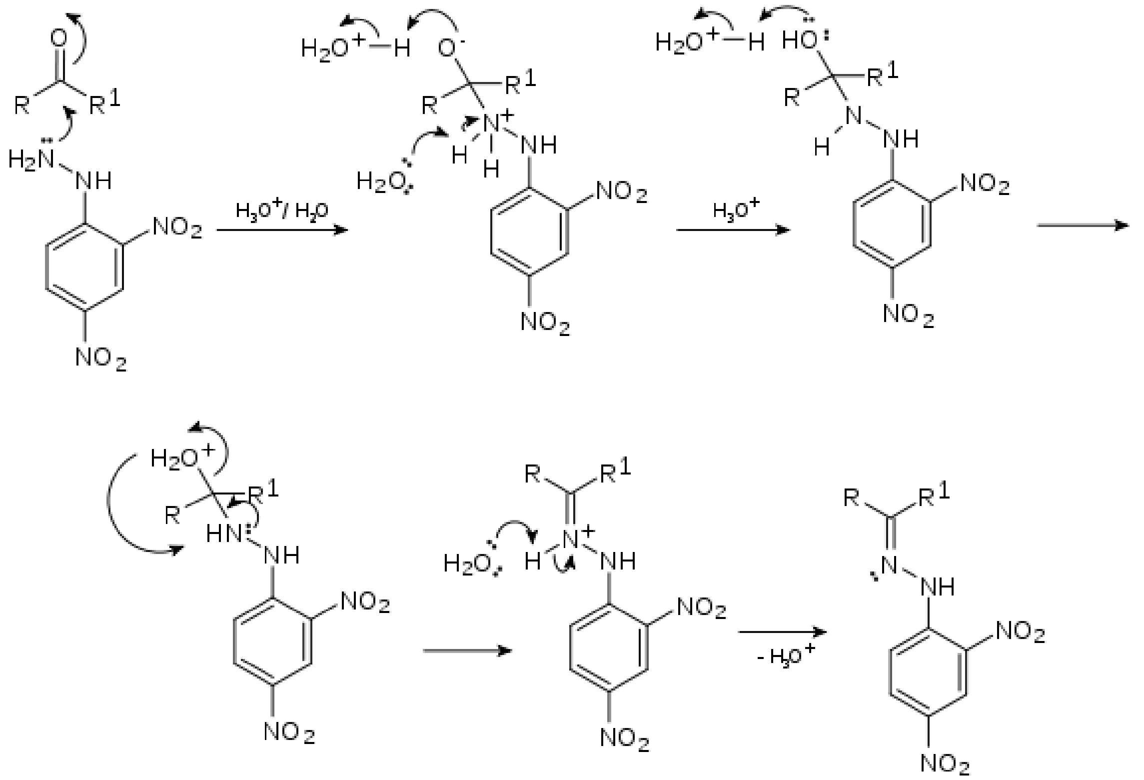
Examples:



$$CH_3\overset{H}{C}{=}O + H_2N{-}OH \xrightarrow{H^+} CH_3\overset{H}{C}{=}NOH + H_2O$$

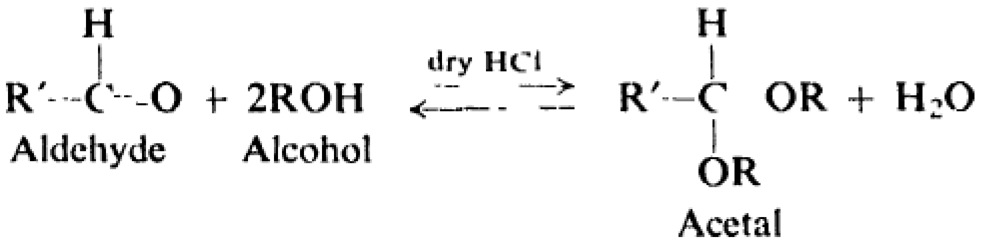


Mechanism

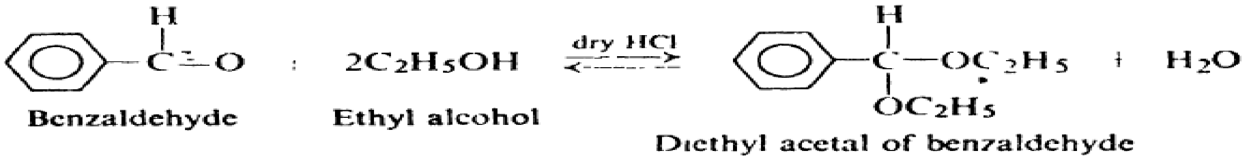


Certain compounds related to ammonia add to the carbonyl group to form derivatives that are important chiefly for the characterization and identification of aldehydes and ketones the product contain a carbon – nitrogen double bond resulting from elimination of a molecule of water from the initial addition products.

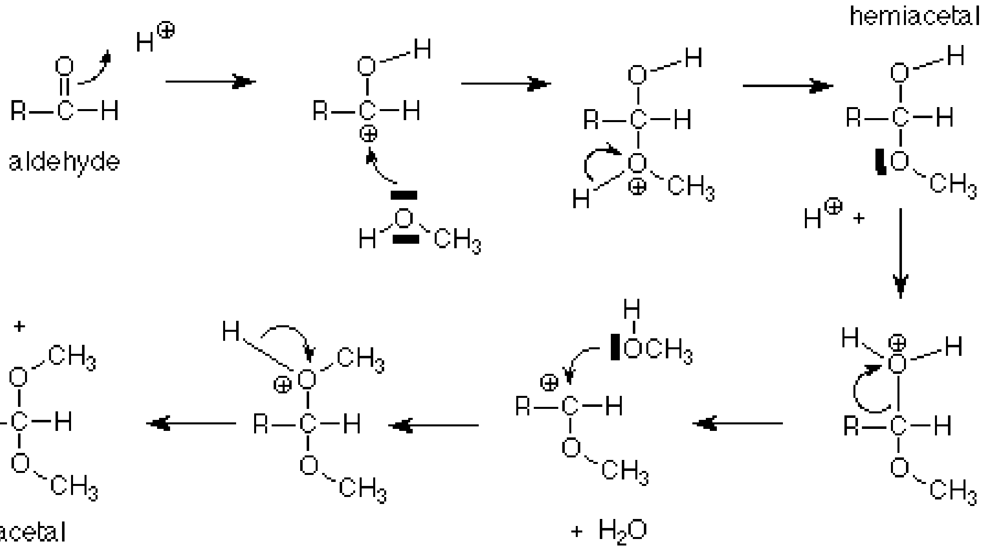
9-addition of alcohols to formation acetal and ketal



Example



Mechanism



Cannizaro reaction

The *Cannizaro* reaction represents the disproportionation of an aldehyde into a carboxylic acid and an alcohol. Alternatively, the reaction can be classified as a redox reaction because one molecule of aldehyde oxidizes another to the acid and is itself reduced to the primary alcohol. More useful is the crossed-*Cannizaro* reaction in which formaldehyde is reacted with another aldehyde. The formaldehyde reduces the aldehyde to alcohol and is itself oxidized to formic acid.

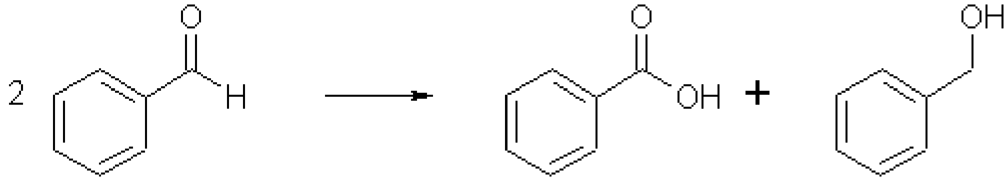


Fig.1

Disproportionation of benzaldehyde

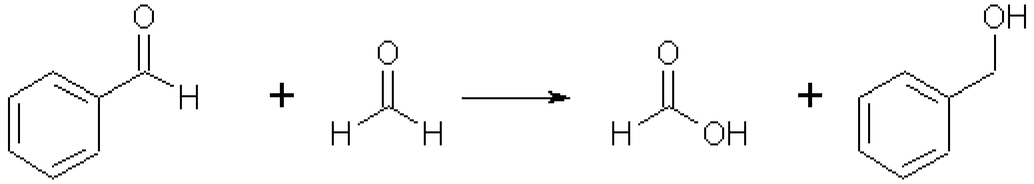
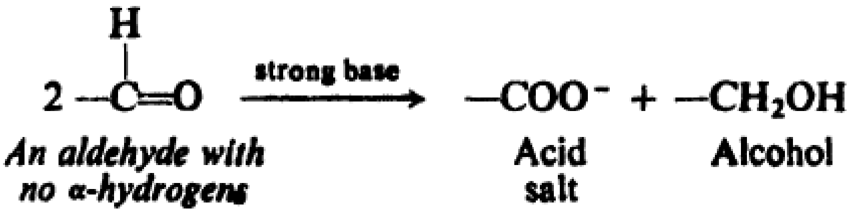


Fig.2

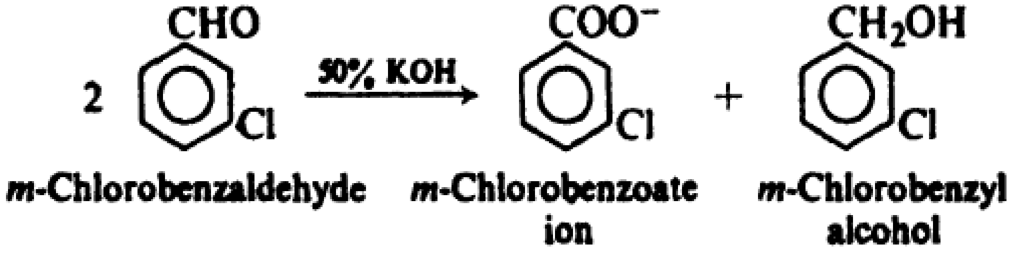


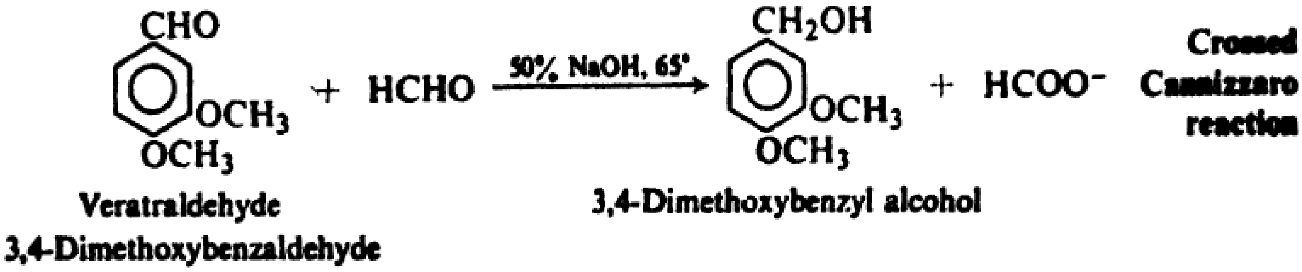
$$2\,-\overset{H}{\underset{|}{C}}{=}O \xrightarrow{\text{strong base}} -COO^- + -CH_2OH$$

Examples:

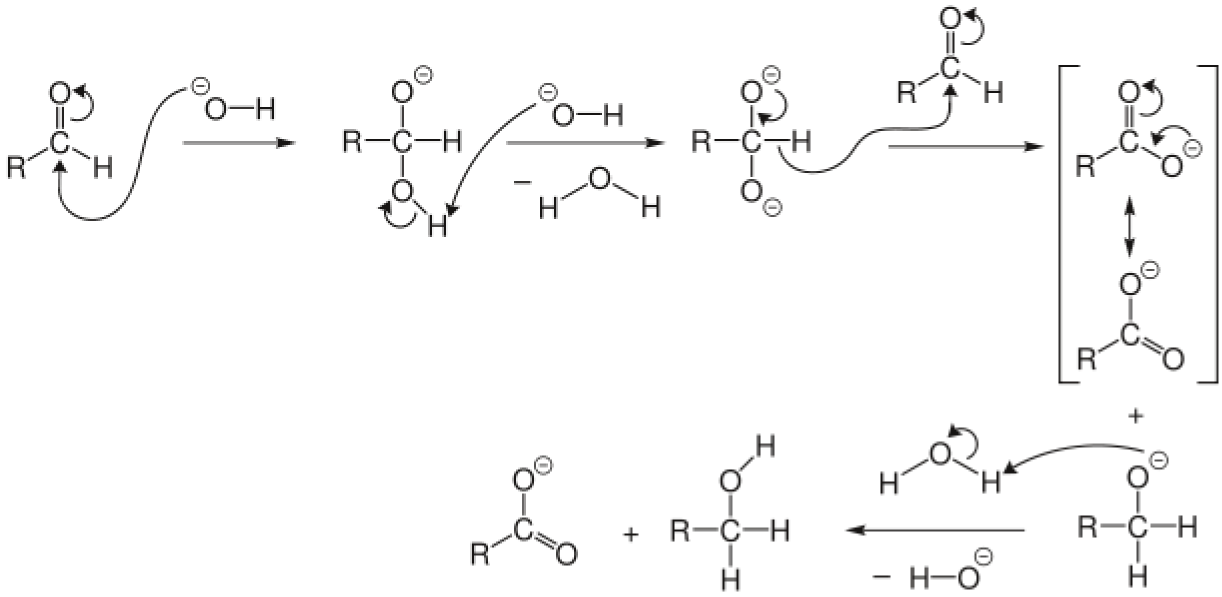
$$2\,HCHO \xrightarrow{\text{50\% NaOH, room temperature}} HCOO^- + CH_3OH$$

Formaldehyde — Formate ion — Methanol

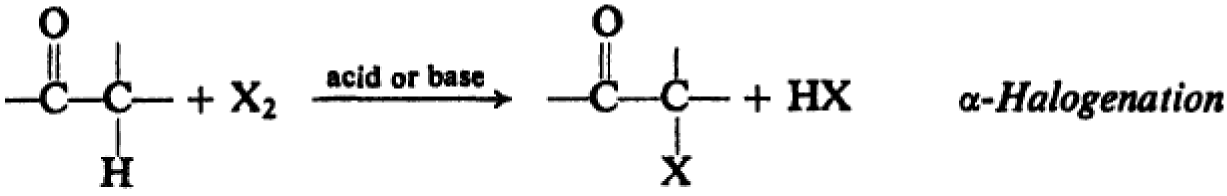




Mechanism



10-halogenation of ketones



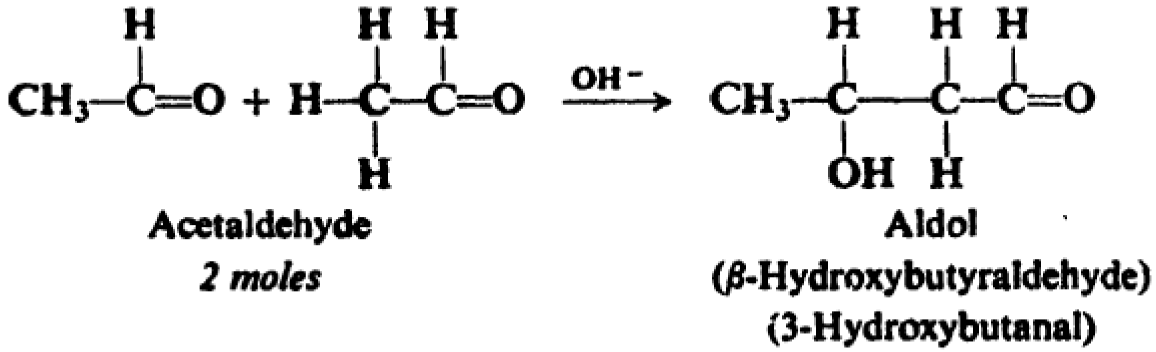
$X_2 = Cl_2, Br_2, I_2$

11- addition of carbanions:-

a- Aldol condensation

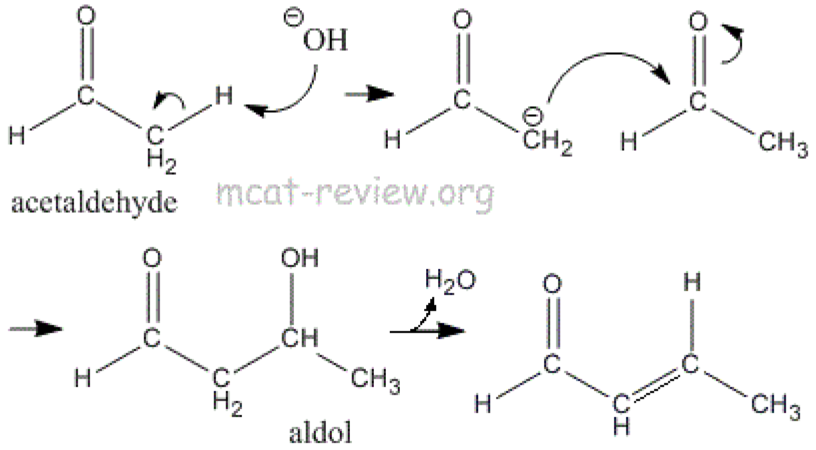
Under the influence of dilute base or dilute acid, two molecules of an aldehyde or a ketone may combine to form a β-hydroxyaldehyde or β-hydroxyketone. This reaction is called the aldol condensation:-

Note :-In this reaction aldehyde or ketone should be contains α-H atom.



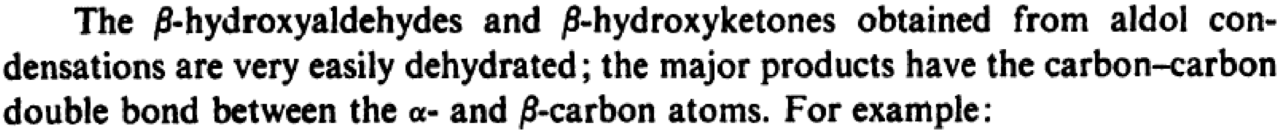
$$CH_3-CHO + H-CH_2-CHO \xrightarrow{OH^-} CH_3-CH(OH)-CH_2-CHO$$

Mechanism

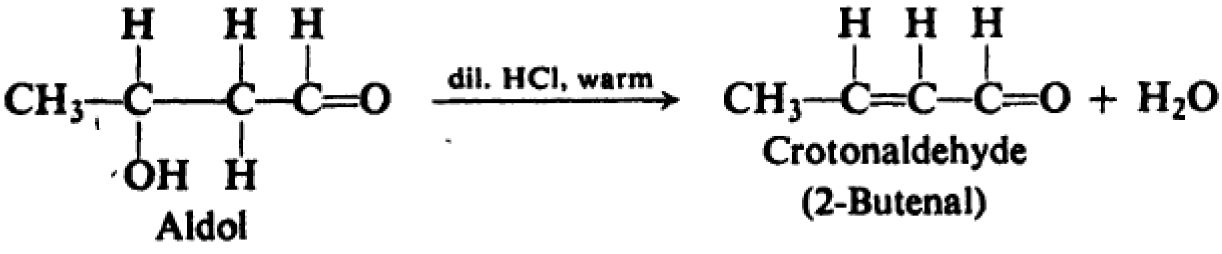


-give the mechanism reaction of 2 moles of acetone in alkaline medium?

12-dehydration of aldol products



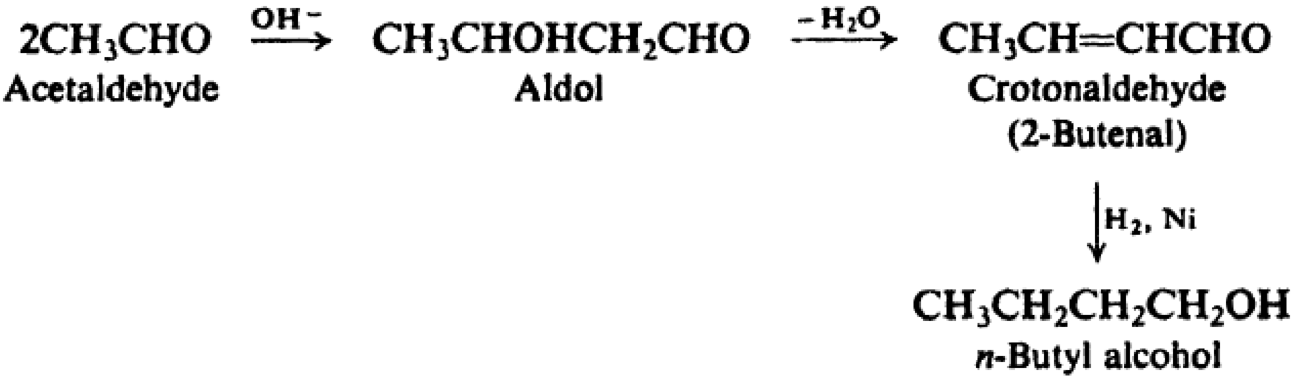
The β-hydroxyaldehydes and β-hydroxyketones obtained from aldol condensations are very easily dehydrated; the major products have the carbon–carbon double bond between the α- and β-carbon atoms. For example:



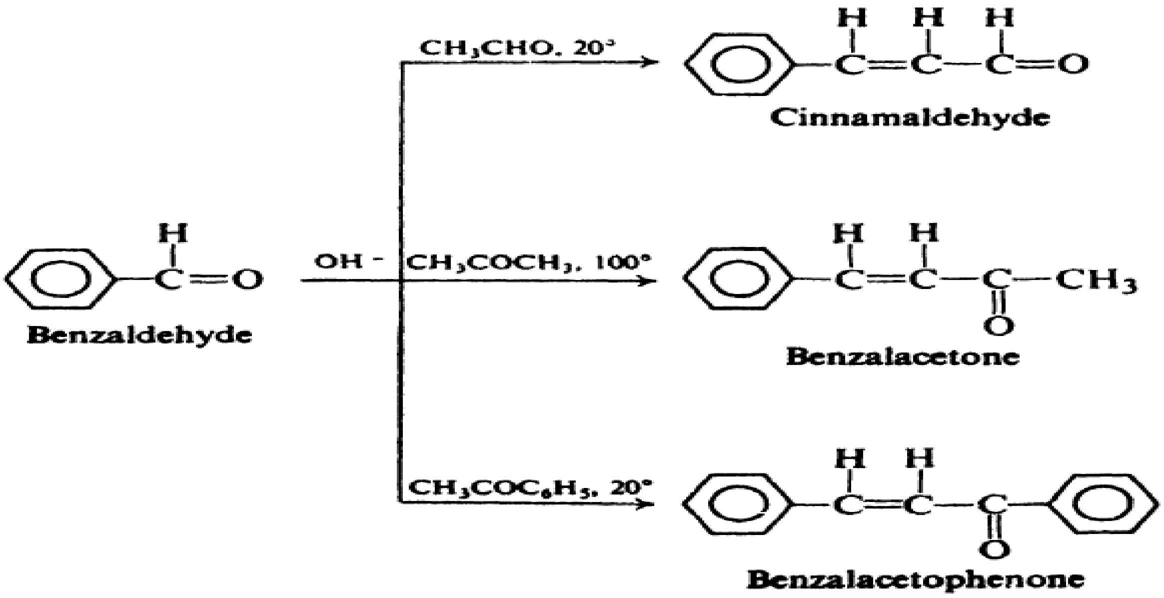
$$CH_3-CH(OH)-CH_2-CHO \xrightarrow{\text{dil. HCl, warm}} CH_3-CH=CH-CHO + H_2O$$

Write the mechanism of dehydration from aldol compound?

Q/ prepare the n-butyl alcohol from acetaldehyde as starting material?

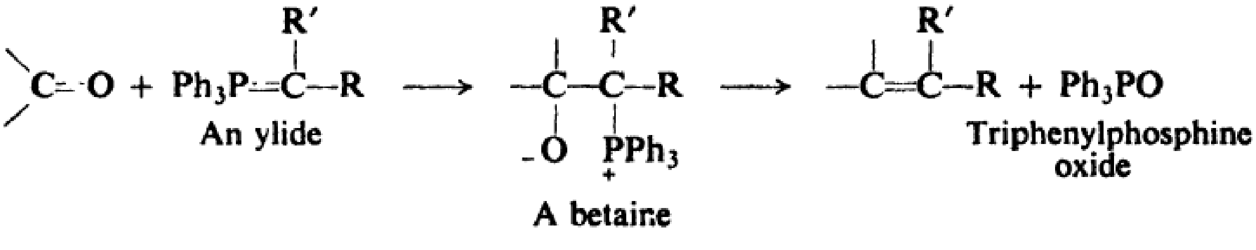


Examples

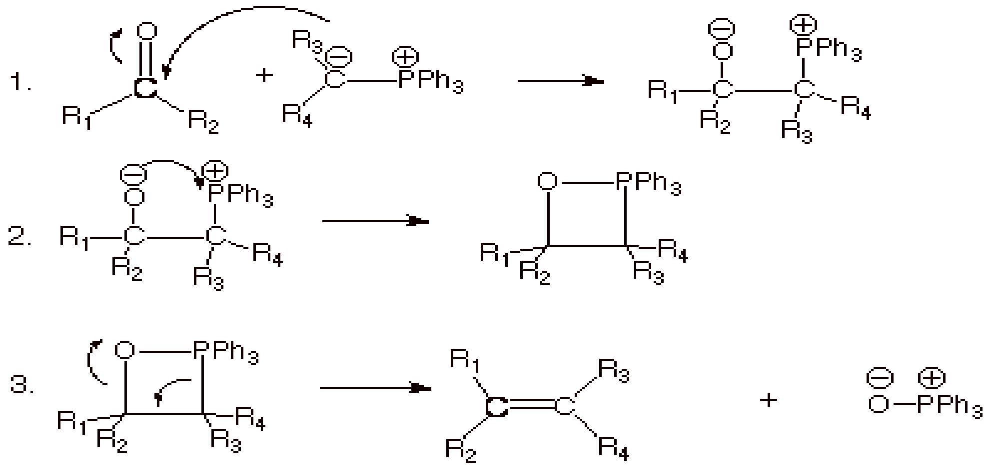


- Wittig reaction

  In 1954 george wittig reported a method of synthesizing alkenes from carbonyl compounds.

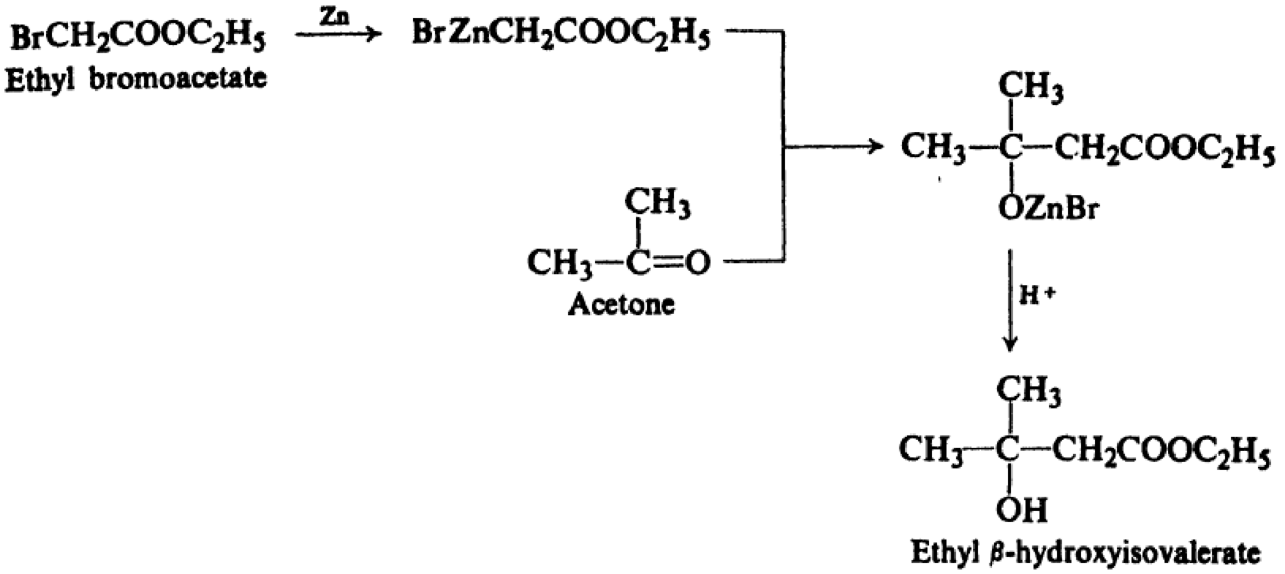


Mechanism

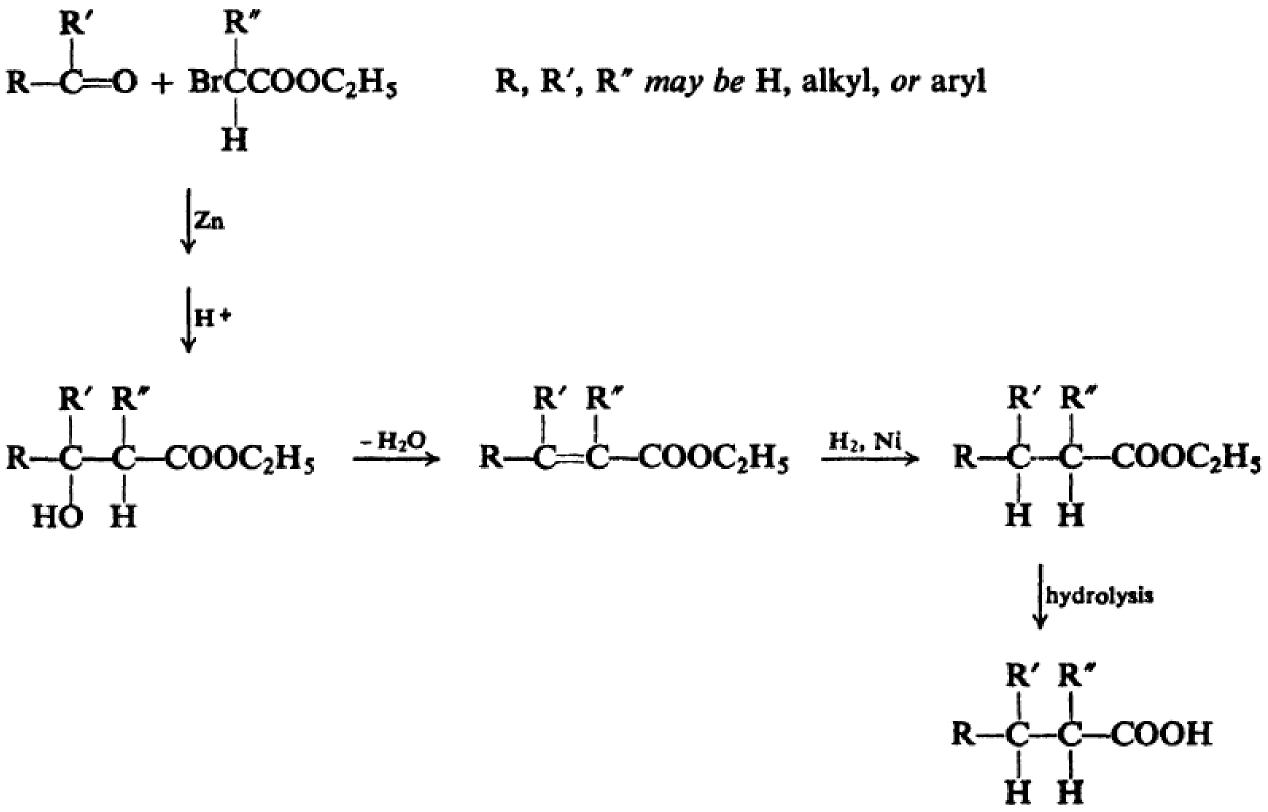


Reformatsky reaction. Preparation of β-hydroxy esters

If an α-bromo ester is treated with metallic zinc in the presence of an aldehyde or ketone, there is obtained a β-hydroxy ester. This reaction, known as the **reformatisky reaction.zinc is used in place** of magnesium simply because the organozinc compounds are less reactive than Grignard reagents; they do not react with the ester function but only with the aldehyde or ketone.



The Reformatsky reaction takes place only with esters containing bromine in the *alpha* position, and hence necessarily yields *beta*-hydroxy esters. By the proper **selection of ester and carbonyl compound.**



-Haloform reaction

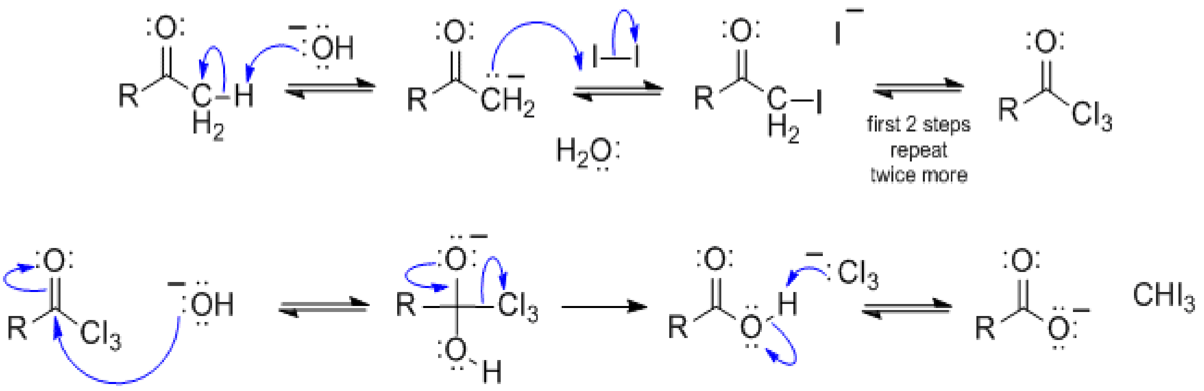
This reaction involves oxidation , halogenations,and cleavage

$$\begin{matrix} CH_3CHO \\ CH_3COCH_3 \end{matrix} + NaOH \xrightarrow{X_2} \begin{matrix} CHX_3 + HCOONa \\ CHX_3 + CH_3COONa \end{matrix}$$

$$NaOH + I_2 \longrightarrow NaOI$$

sodium hypoiodite

mechanism



Carboxylic acid

carboxylic acid, any of a class of organic compounds in which a carbon (C) atom is bonded to an oxygen (O) atom by a double bond and to a hydroxyl group (−OH) by a single bond. A fourth bond links the carbon atom to a hydrogen (H) atom. The carboxyl (COOH) group is so-named because of the *carb*onyl group (C=O) and hydr*oxyl* group.

Nomenclature

IUPAC

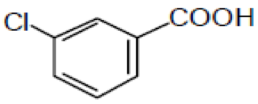
Alkanoic acid: cycloalkanecarboxylic acid

Take name of the alkane, drop the -e and add '–ic acid' or '-oic acid'. The acid functionality has the highest priority in organic nomenclature and always gets the lowest number

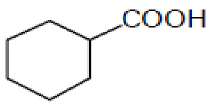
Common

There are some trivial names that must be memorized, e.g., Formic, Acetic, Propionic, Butyric, Acrylic, Crotonic, Cinnamic, etc., Acids.

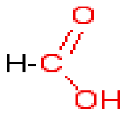
HCOOH	Methanoic Acid (Formic Acid)
CH_3COOH	Ethanoic Acid (Acetic Acid)
CH_3CH_2COOH	Propanoic Acid (Propionic Acid)
$CH_3CH_2CH_2COOH$	Butanoic Acid(Butyric Acid)



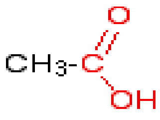
3-chlorobenzoic acid



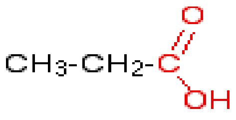
cyclohexanecarboxylic acid



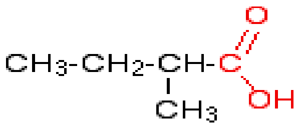
methanoic acid



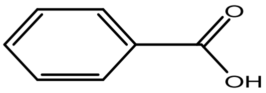
ethanoic acid

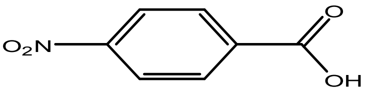


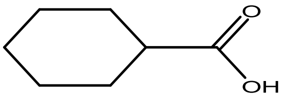
propanoic acid

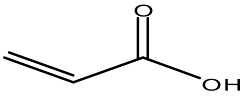


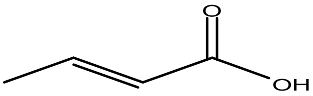
2-methylbutanoic acid

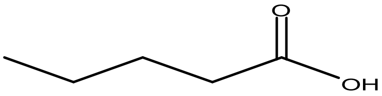

benzoic acid


4-nitrobenzoic acid or
p-nitrobenzoic acid


cyclohexanecarboxylic acid

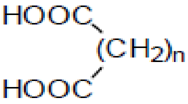

acrylic acid


2-butenoic acid


valeric acid

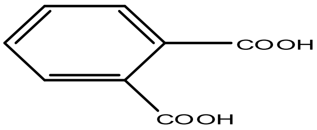
Dicarboxylic Acids:

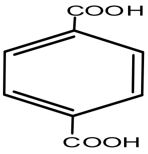
IUPAC: Alkanedioic acid; cycloalkane-1,n-dicarboxylic acid
Common: All the common dicarboxylic acids have trivial names that must be memorized. One can use the mnemonic: "Oh my such good apple pie sweet as sugar."

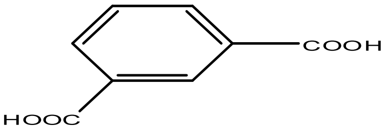


$$HOOC-(CH_2)_n-COOH$$

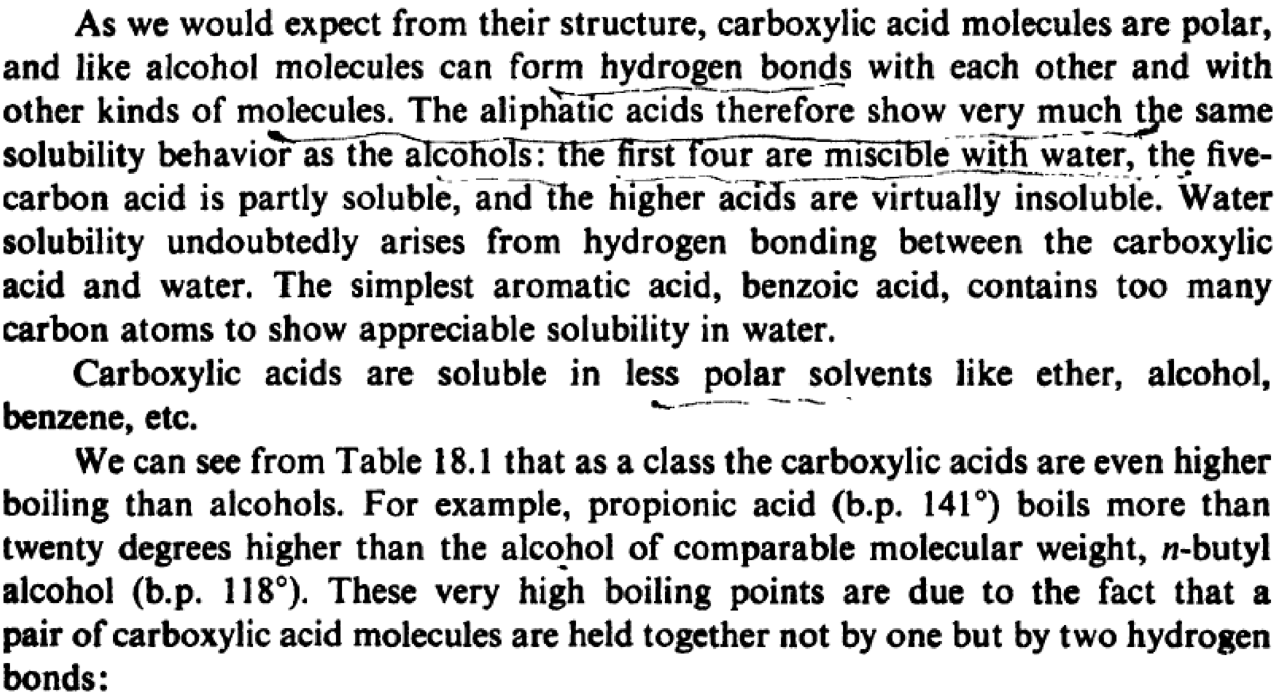
ethanedioic acid	n = 0	oxalic acid
propanedioic acid	n = 1	malonic acid
butanedioic acid	n = 2	succinic acid
pentanedioic acid	n = 3	glutaric acid
hexanedioic acid	n = 4	apidic acid
heptanedioic acid	n = 5	pimelic acid
octanedioic acid	n = 6	suberic acid
nonanedioic acid	n = 7	azelaic acid


phthalic acid


terephthalic acid


isophthalic acid

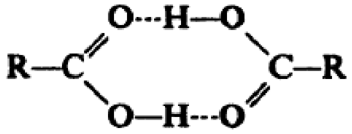
Physical properties



As we would expect from their structure, carboxylic acid molecules are polar, and like alcohol molecules can form hydrogen bonds with each other and with other kinds of molecules. The aliphatic acids therefore show very much the same solubility behavior as the alcohols: the first four are miscible with water, the five-carbon acid is partly soluble, and the higher acids are virtually insoluble. Water solubility undoubtedly arises from hydrogen bonding between the carboxylic acid and water. The simplest aromatic acid, benzoic acid, contains too many carbon atoms to show appreciable solubility in water.

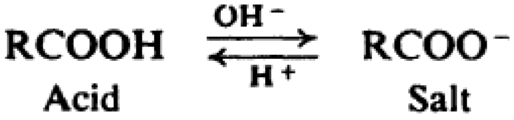
Carboxylic acids are soluble in less polar solvents like ether, alcohol, benzene, etc.

We can see from Table 18.1 that as a class the carboxylic acids are even higher boiling than alcohols. For example, propionic acid (b.p. 141°) boils more than twenty degrees higher than the alcohol of comparable molecular weight, *n*-butyl alcohol (b.p. 118°). These very high boiling points are due to the fact that a pair of carboxylic acid molecules are held together not by one but by two hydrogen bonds:



Salts of carboxylic acid

Although much weaker than the strong mineral acids (sulfuric, hydrochloric, nitric), the carboxylic acids are tremendously more acidic than the very weak organic acids (alcohols, acetylene) we have so far studied; they are much stronger acids than water.



$$\underset{\text{Acid}}{RCOOH} \underset{H^+}{\overset{OH^-}{\rightleftharpoons}} \underset{\text{Salt}}{RCOO^-}$$

$CH_3CH_2CO\overset{\ominus}{O}K$ potassium propionate

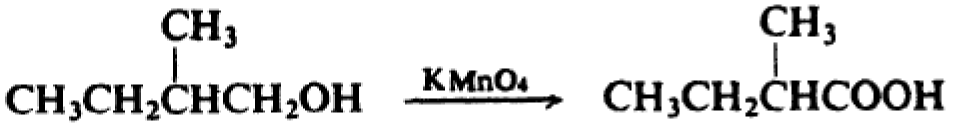
$CH_3CO\overset{\ominus\oplus}{OAl}$ aluminum(I) acetate aluminium ethanoate

Preparation of carboxylic acid

1- Oxidation of primary alcohol

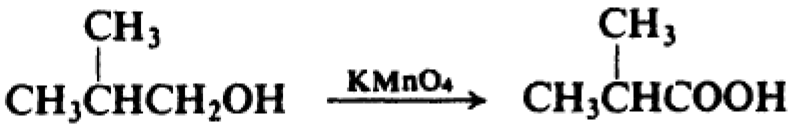
$$RCH_2OH \xrightarrow{KMnO_4} RCOOH$$

Examples



$$CH_3CH_2\overset{\overset{\displaystyle CH_3}{|}}{C}HCH_2OH \xrightarrow{KMnO_4} CH_3CH_2\overset{\overset{\displaystyle CH_3}{|}}{C}HCOOH$$

2-Methyl-1-butanol 2-Methylbutanoic acid



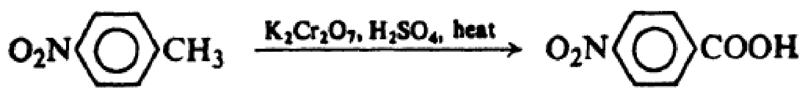
$$CH_3\overset{\overset{\displaystyle CH_3}{|}}{C}HCH_2OH \xrightarrow{KMnO_4} CH_3\overset{\overset{\displaystyle CH_3}{|}}{C}HCOOH$$

Isobutyl alcohol Isobutyric acid

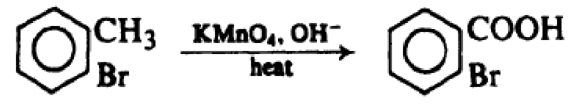
2- Oxidation of alkylbenzene

$$Ar{-}R \xrightarrow[K_2C_2O_7]{KMnO_4 \text{ or } K_2Cr_2O_7} Ar{-}COOH$$

Examples:



p-Nitrotoluene *p*-Nitrobenzoic acid

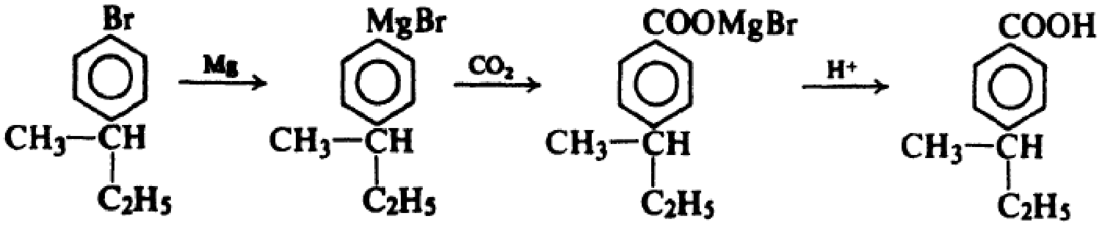


o-Bromotoluene *o*-Bromobenzoic acid

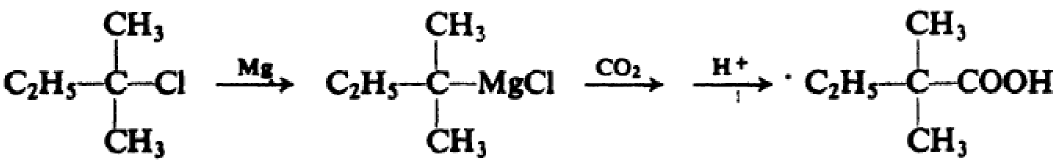
3- Carbonation of griniard reagents

$$\underset{(\text{or } ArX)}{RX} \xrightarrow{Mg} RMgX \xrightarrow{CO_2} RCOOMgX \xrightarrow{H^+} \underset{(\text{or } ArCOOH)}{RCOOH}$$

Examples:



p-Bromo-*sec*-butylbenzene *p*-*sec*-Butylbenzoic acid

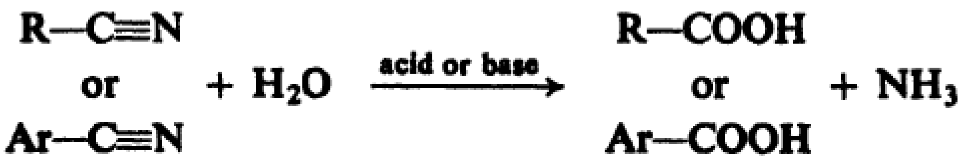


$$C_2H_5{-}\underset{\underset{\displaystyle CH_3}{|}}{\overset{\overset{\displaystyle CH_3}{|}}{C}}{-}Cl \xrightarrow{Mg} C_2H_5{-}\underset{\underset{\displaystyle CH_3}{|}}{\overset{\overset{\displaystyle CH_3}{|}}{C}}{-}MgCl \xrightarrow{CO_2} \xrightarrow{H^+} C_2H_5{-}\underset{\underset{\displaystyle CH_3}{|}}{\overset{\overset{\displaystyle CH_3}{|}}{C}}{-}COOH$$

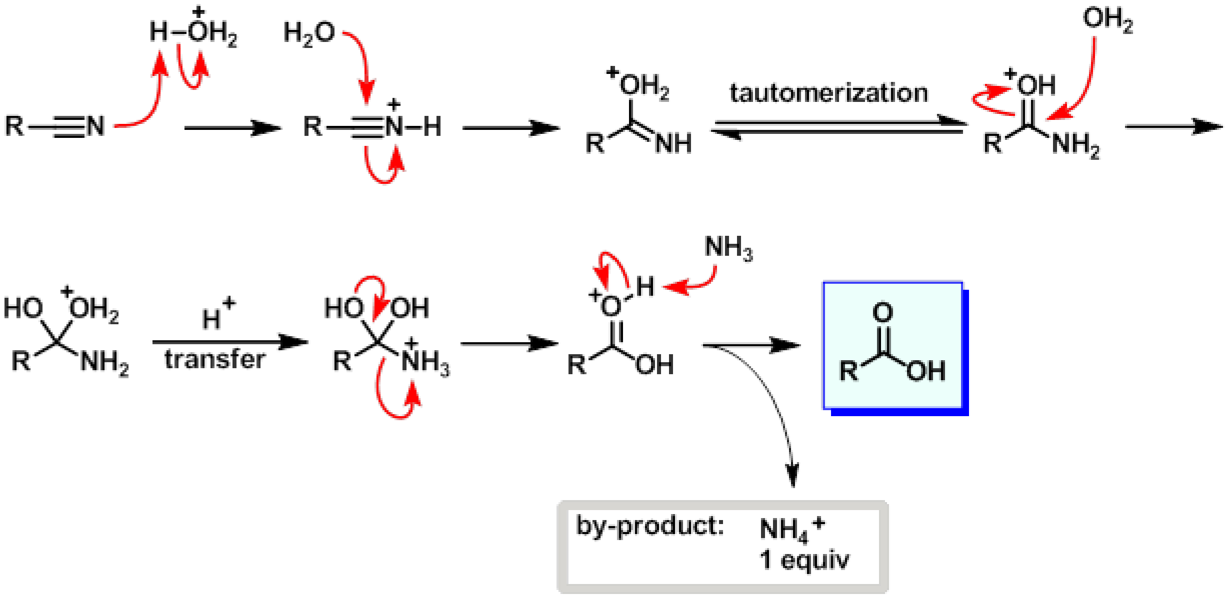
tert-Pentyl chloride

Ethyldimethylacetic acid
(2,2-Dimethylbutanoic acid)

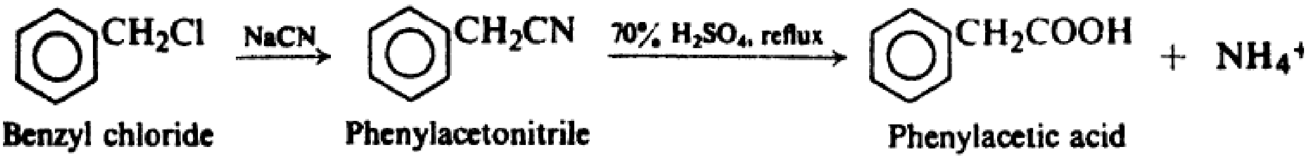
4- Hydrolysis of nitrilees

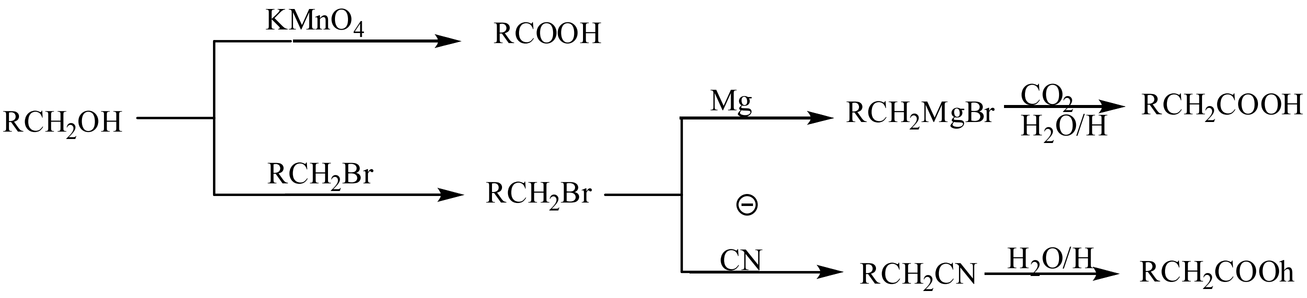


Mechanism



example





reactions of carboxylic acids

The characteristic chemical behavior of carboxylic acids is, of course, determined by their functional group, **carboxyl**, —COOH. This group is made up of a carbonyl group (C = O) and a hydroxyl group (—OH). As we shall see, it is the —OH that actually undergoes nearly every reaction—loss of H^+, or replacement by another group.

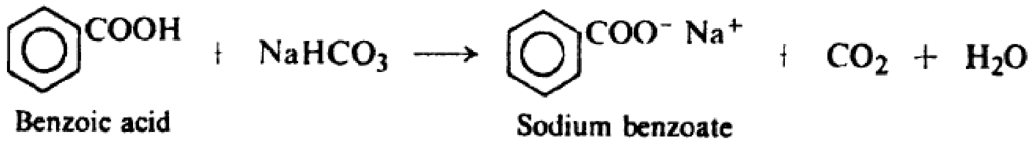
1- Acidity salt formation

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

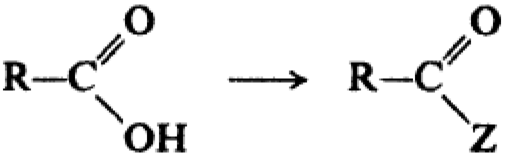
Examples:

$$\underset{\text{Acetic acid}}{2CH_3COOH} + Zn \longrightarrow \underset{\text{Zinc acetate}}{(CH_3COO^-)_2Zn^{++}} + H_2$$

$$\underset{\text{Lauric acid}}{CH_3(CH_2)_{10}COOH} + NaOH \longrightarrow \underset{\text{Sodium laurate}}{CH_3(CH_2)_{10}COO^-Na^+} + H_2O$$

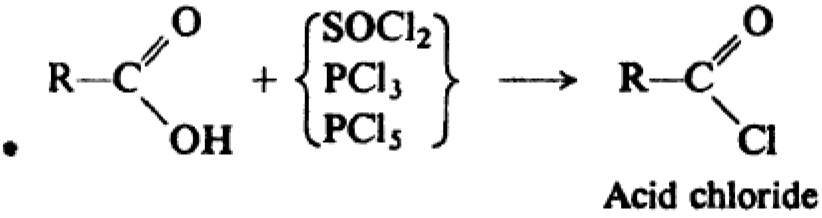


2- Conversion into functional derivatives

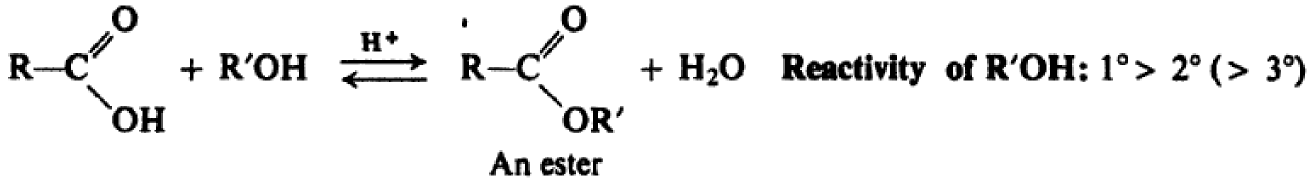


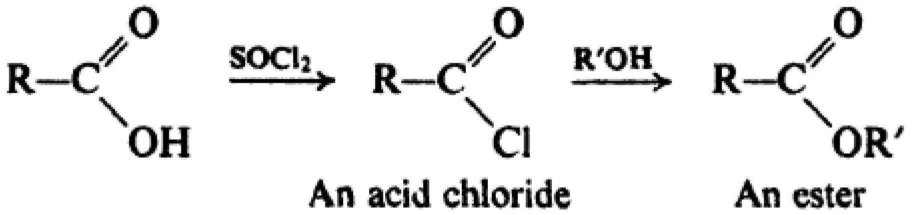
(Z = —Cl, —OR′, —NH$_2$)

(a) Conversion into acid chlorides. Discussed in Sec. 18.15

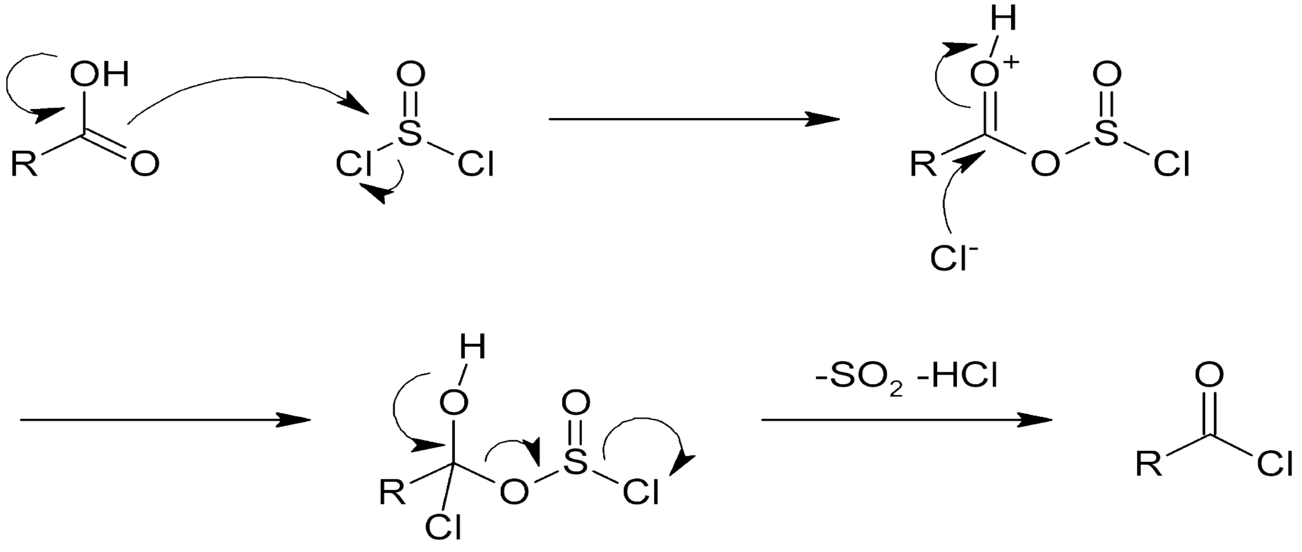


Conversion into esters

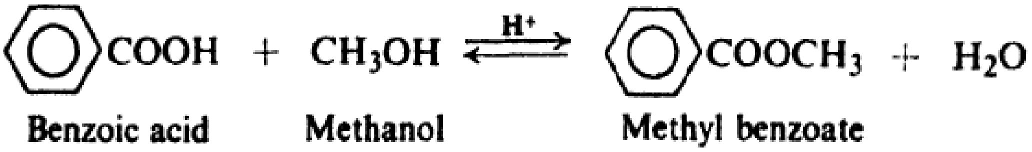


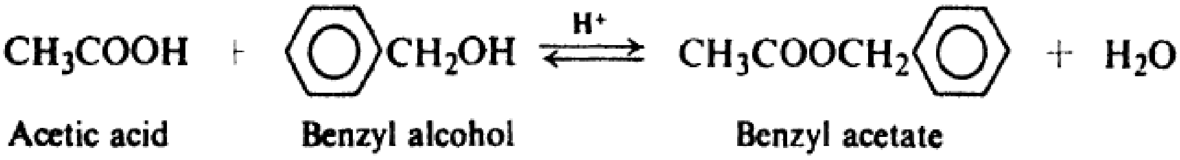


Mechanism (conversion into acid chloride)

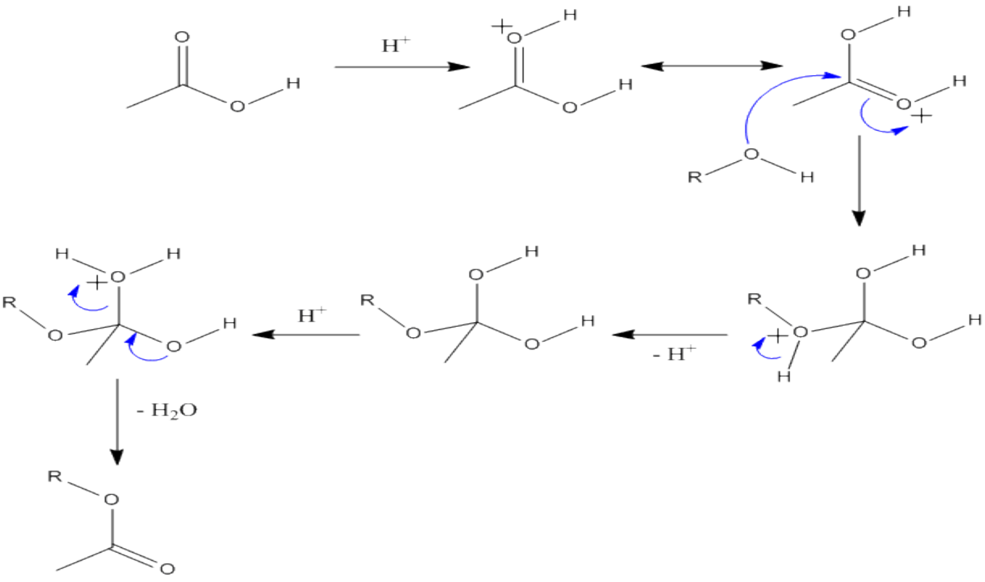


Examples:

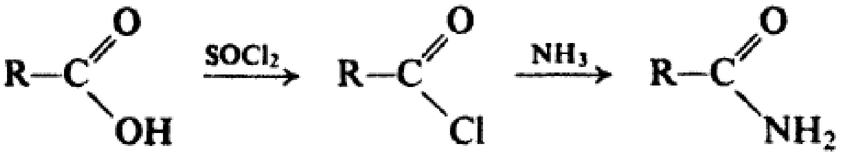




Mechanism



Conversion into amide



An acid chloride An amide

Example:

$$C_6H_5CH_2COOH \xrightarrow{SOCl_2} C_6H_5CH_2COCl \xrightarrow{NH_3} C_6H_5CH_2CONH_2$$

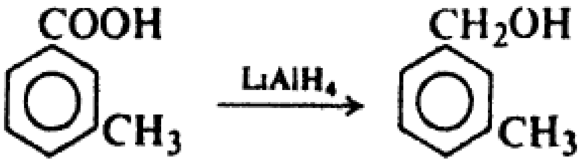
Phenylacetic acid Phenylacetyl chloride Phenylacetamide

Reduction of carboxylic acid

$$RCOOH \xrightarrow{LiAlH_4} RCH_2OH$$

1° alcohol

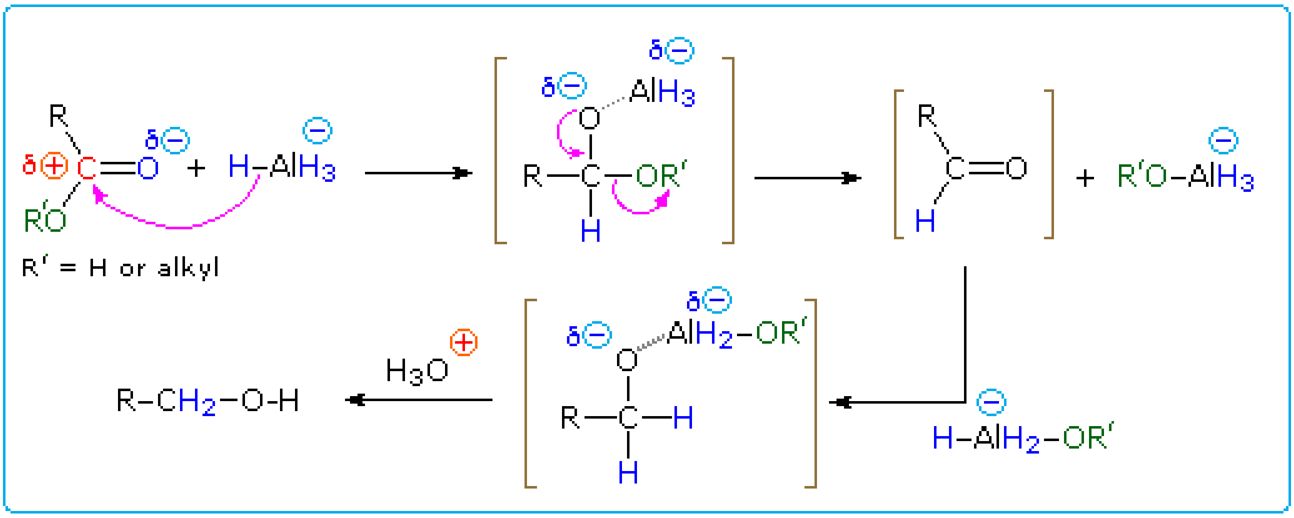
Example



m-Toluic acid *m*-Methylbenzyl alcohol

Mechanism

$LiAlH_4$ Reduction of a Carboxylic Ester or Acid



Substirurion in alkyl or aryl groups

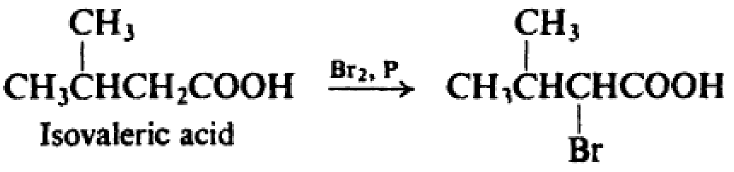
(a) Alpha-halogenation of aliphatic acids. Hell-Volhard-Zelinsky reaction.

$$RCH_2COOH + X_2 \xrightarrow{P} \underset{\displaystyle X}{\underset{|}{RCH}}COOH + HX \qquad X_2 = Cl_2, Br_2$$

An α-haloacid

Examples:

$$\underset{\text{Acetic acid}}{CH_3COOH} \xrightarrow{Cl_2,\,P} \underset{\text{Chloroacetic acid}}{ClCH_2COOH} \xrightarrow{Cl_2,\,P} \underset{\text{Dichloroacetic acid}}{Cl_2CHCOOH} \xrightarrow{Cl_2,\,P} \underset{\text{Trichloroacetic acid}}{Cl_3CCOOH}$$



$$CH_3\overset{\displaystyle CH_3}{\overset{|}{C}}HCH_2COOH \xrightarrow{Br_2,\,P} CH_3\overset{\displaystyle CH_3}{\overset{|}{C}}H\underset{\displaystyle Br}{\underset{|}{C}}HCOOH$$

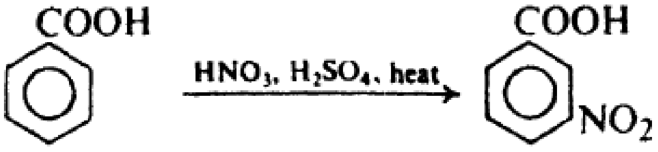
Isovaleric acid

α-Bromoisovaleric acid

Ring substitution in aromatic acids

—COOH: deactivates, and directs *meta* in electrophilic substitution.

Example:



Benzoic acid   *m*-Nitrobenzoic acid

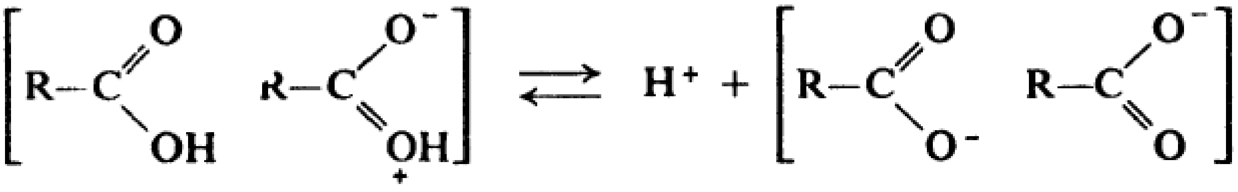
Acidity of carboxylic acid

Let us see how the acidity of carboxylic acids is related to structure. In doing this we shall assume that acidity is determined chiefly by the difference in stability between the acid and its anion.

First, and most important, there is the fact that carboxylic acids are acids at all. How can we account for the fact that the —OH of a carboxylic acid tends to release a hydrogen ion so much more readily than the —OH of, say, an alcohol? Let us examine the structures of the reactants and products in these two cases.

We see that the alcohol and alkoxide ion are each represented satisfactorily by a single structure. However, we can draw two reasonable structures (I and II) for the carboxylic acid and two reasonable structures (III and IV) for the carboxylate anion. Both acid and anion are resonance hybrids.

$$R{-}O{-}H \rightleftharpoons H^+ + R{-}O^-$$



I   II   III   IV

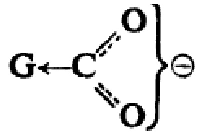
Non-equivalent:
resonance less important

Equivalent:
resonance more important

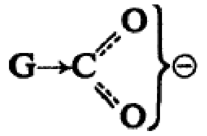
Effect of substituents on acidity

Electron withdrawing substituents

should disperse the negative charge, stabilize the anion, and thus increase acidity. Electron-releasing substituents should intensify the negative charge, destabilize the anion, and thus decrease acidity



G withdraws electrons: *stabilizes anion, strengthens acid*



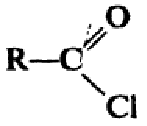
G releases electrons: *destabilizes anion, weakens acid*

$$Cl_3CCOOH > Cl_2CHCOOH > ClCH_2COOH$$

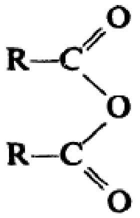
$$HCOOH > CH_3COOH > RCH_2COOH > R_2CHCOOH > R_3COOH$$

Functional derivatives of carboxylic acids

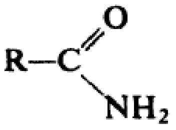
Closely related to the carboxylic acids and to each other are a number of chemical families known as **functional derivatives of carboxylic acids**: *acid chlorides, anhydrides, amides,* and *esters*. These derivatives are compounds in which the —OH of a carboxyl group has been replaced by —Cl, —OOCR, —NH_2, or —OR′.



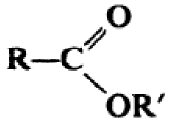
Acid chloride



Anhydride



Amide



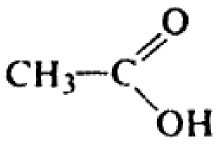
Ester

R *may be alkyl or aryl*

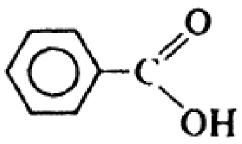
They all contain acyl group (RCO-)

Nomenclature

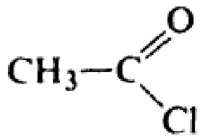
The names of acid derivatives are taken in simple ways from either the common name or the IUPAC name of the corresponding carboxylic acid. For example:



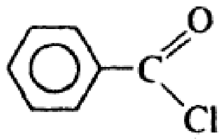
Acetic acid
Ethanoic acid



Benzoic acid

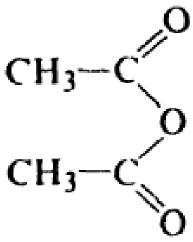


Acetyl chloride
Ethanoyl chloride

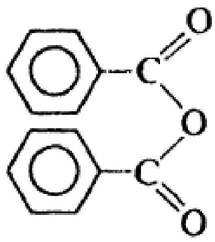


Benzoyl chloride

Change:
-ic acid to *-yl chloride*

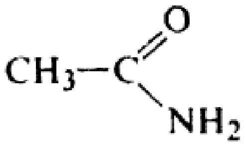


Acetic anhydride
Ethanoic anhydride

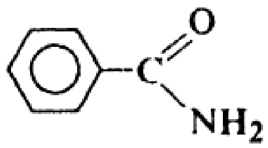


Benzoic anhydride

acid to *anhydride*

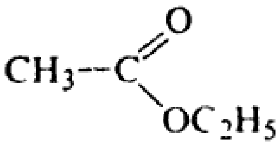


Acetamide
Ethanamide

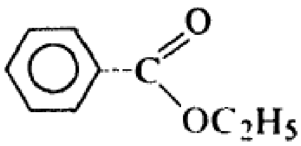


Benzamide

-ic acid of common name
(or *-oic acid* of IUPAC name)
to *-amide*



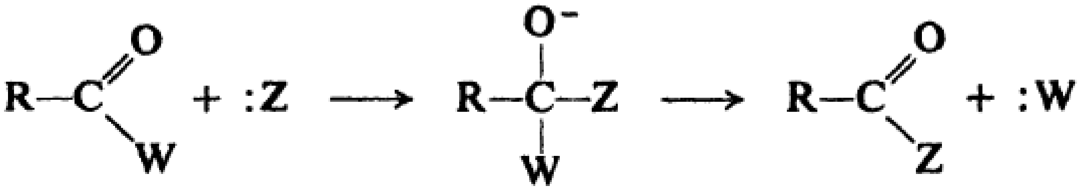
Ethyl acetate
Ethyl ethanoate



Ethyl benzoate

-ic acid to *-ate*,
preceded by name of
alcohol or phenol group

Acyl compounds—carboxylic acids and their derivatives—typically undergo **nucleophilic substitution** in which —OH, —Cl, —OOCR, —NH_2, or —OR′ is replaced by some other basic group(Z)

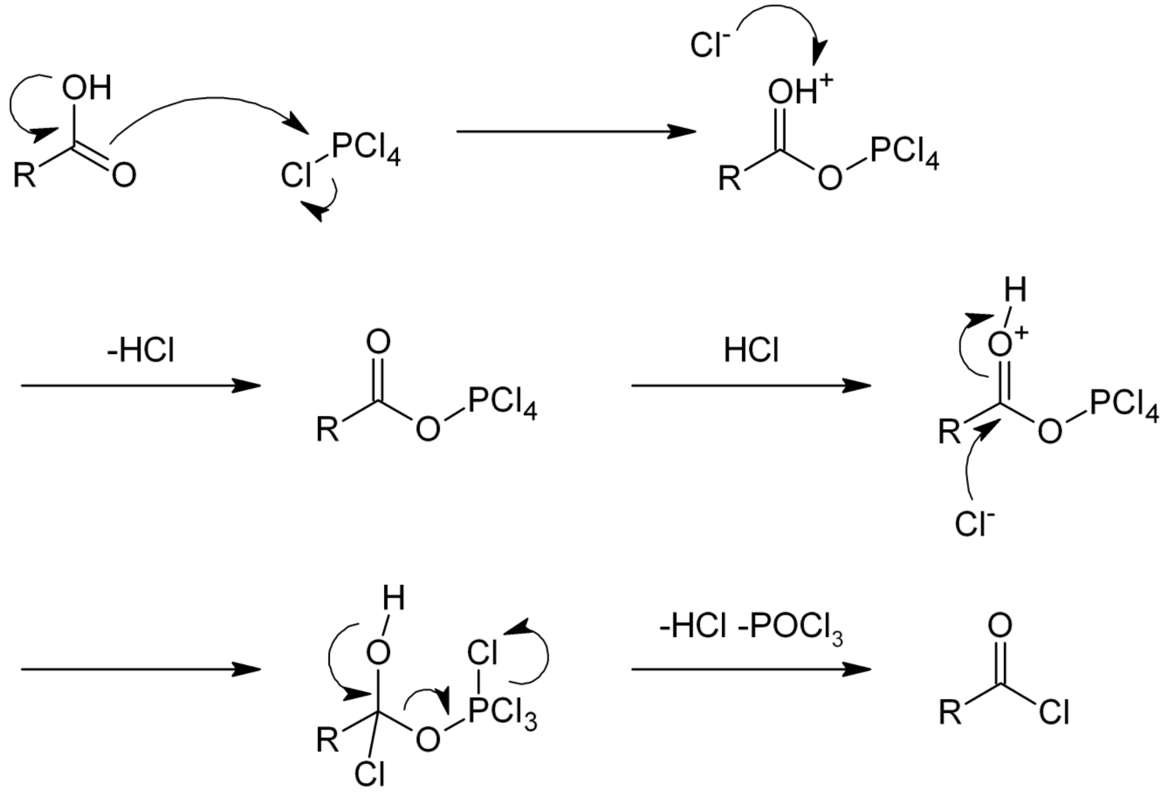


$—W = —OH, —Cl, —OOCR, —NH_2, —OR'$

ACID CHLORIDES

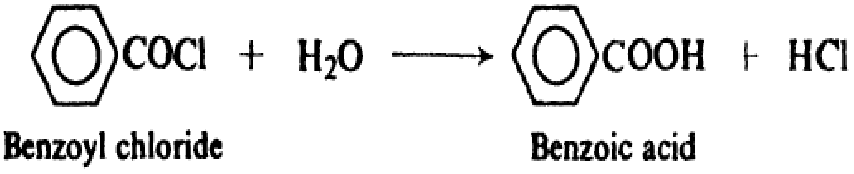
Acid chlorides are prepared from the corresponding acids by reaction with thionyl chloride ,PCl3,PCl5.

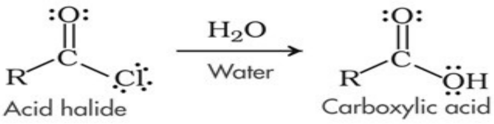
Mechanism with PCl5

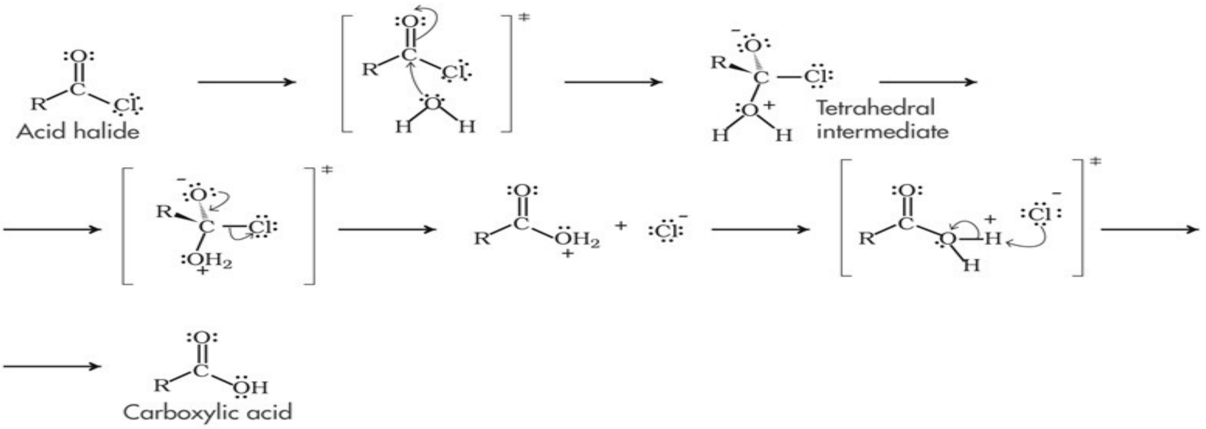


1- Conversion into acids
   Hydrolysis

Example:



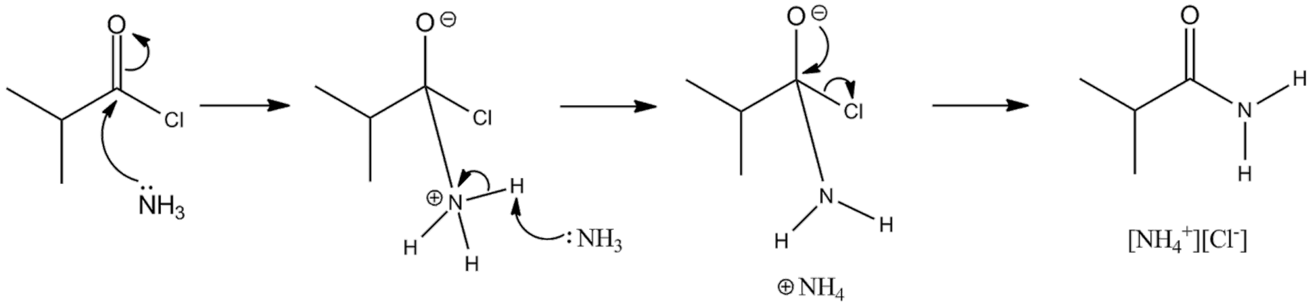




2- Conversion into amides

$$\mathrm{RCOCl} + 2\mathrm{NH_3} \longrightarrow \underset{\text{An amide}}{\mathrm{RCONH_2}} + \mathrm{NH_4Cl}$$

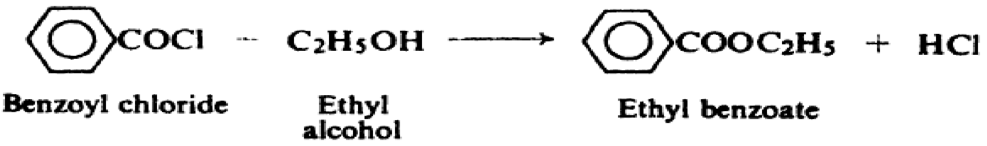
Mechanism

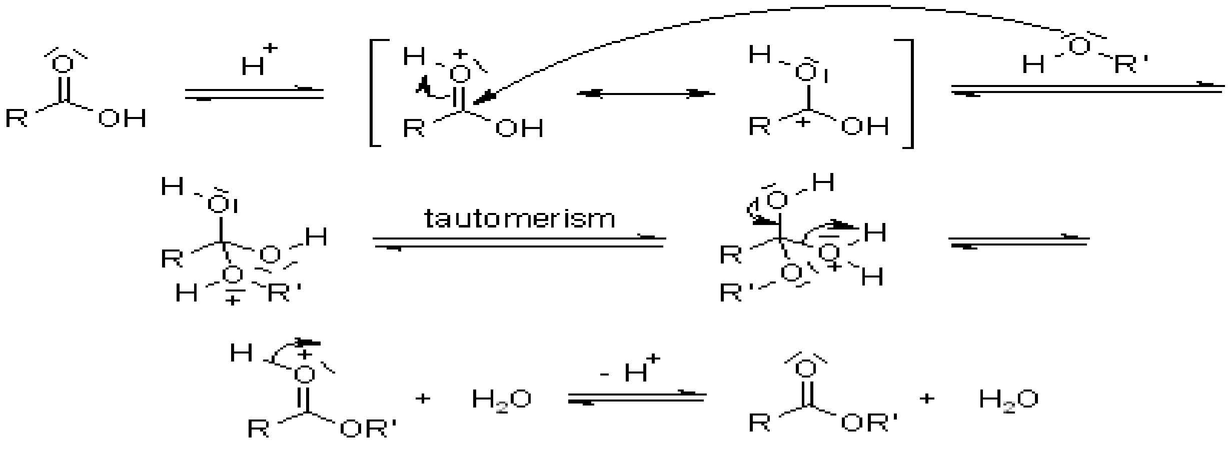


3- Conversion into esters

$$\mathrm{RCOCl} + \mathrm{R'OH} \longrightarrow \underset{\text{An ester}}{\mathrm{RCOOR'}} + \mathrm{HCl}$$

Example:



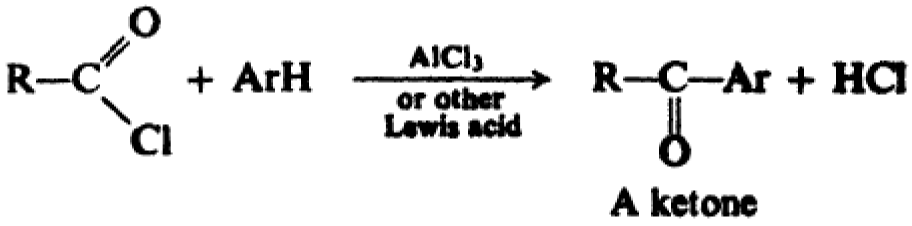


4. Formation of aldehydes by reduction.

$$RCOCl \text{ or } ArCOCl \xrightarrow{LiAlH(OBu\text{-}t)_3} RCHO \text{ or } ArCHO$$

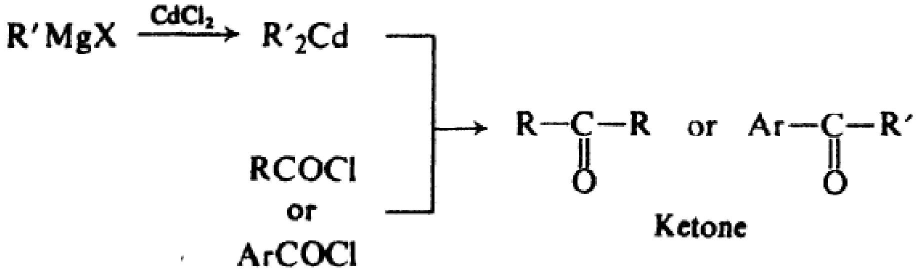
Aldehyde

5-formation of ketones, friedl-crafts acylation



Give the mechanism of the title reaction

6-formation of ketone with organocadmium compounds

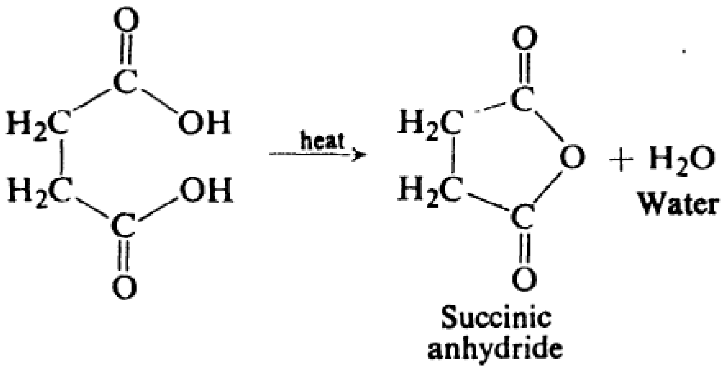


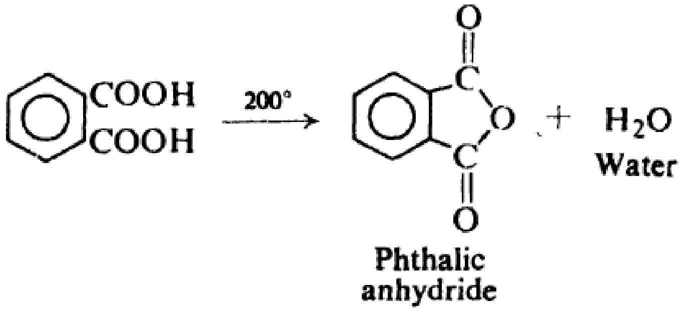
R′ must be aryl or primary alkyl

Preparation of acid anhydrides

$$CH_3COOH \xrightarrow[700^\circ]{AlPO_4} H_2O + CH_2{=}C{=}O \xrightarrow{CH_3COOH} (CH_3CO)_2O$$

Ketene Acetic anhydride





Reactions of acid anhydrides

conversion into acid and acid derivatives-1

$$(RCO)_2O + HZ \longrightarrow RCOZ + RCOOH$$

(a) Conversion into acids. Hydrolysis

Example:

$$\underset{\text{Acetic anhydride}}{(CH_3CO)_2O + H_2O} \longrightarrow \underset{\text{Acetic acid}}{2CH_3COOH}$$

(b) Conversion into amides. Ammonolysis

Examples:

$$\underset{\text{Acetic anhydride}}{(CH_3CO)_2O + 2NH_3} \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + \underset{\text{Ammonium acetate}}{CH_3COO^-NH_4^+}$$

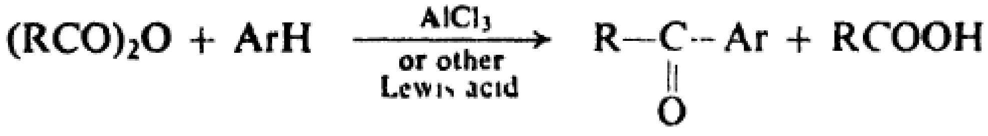
(c) Conversion into esters. Alcoholysis

Examples:

$$(CH_3CO)_2O + CH_3OH \longrightarrow CH_3COOCH_3 + CH_3COOH$$

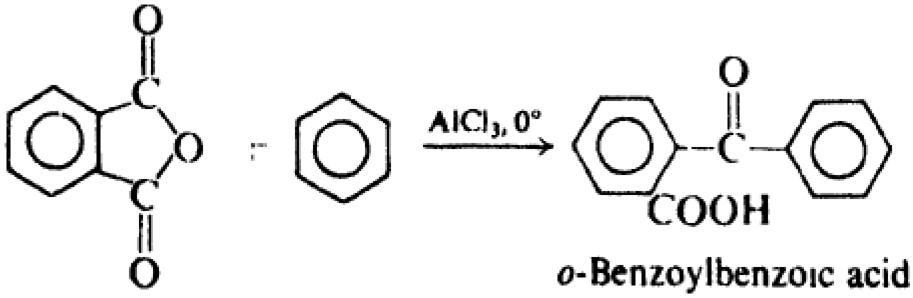
Acetic anhydride — Methyl acetate (An ester) — Acetic acid

Formation of ketones. Friedel-Crafts acylation.



$$(RCO)_2O + ArH \xrightarrow[\text{or other Lewis acid}]{AlCl_3} R-\underset{\underset{O}{\|}}{C}-Ar + RCOOH$$

A ketone



Phthalic anhydride

o-Benzoylbenzoic acid

Problem

give the structural formulas for compounds A through C

1- benzene + Phthalic anhydride $\xrightarrow{AlCl_3}$ A

2- A + $SOCl_2$ $\longrightarrow$ B

3- B + NH_3 $\longrightarrow$ C

Preparation of amides

In the laboratory amides are prepared by the reaction of ammonia with acid chlorides or, when available, acid anhydrides In industry they are often made by heating the ammonium salts of carboxylic acids.

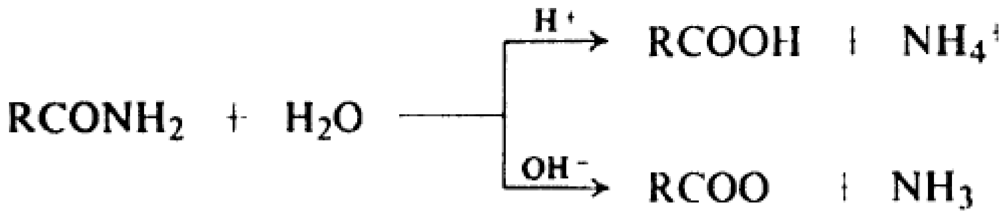
$$RCOCl + NH_3 \longrightarrow RCONH_2$$

$$(RCO)_2O + 2NH_3 \longrightarrow RCONH_2 + RCOOH$$

$$RCOOH + NH_3 \longrightarrow RCO\underset{\ominus}{O}\underset{\oplus}{N}H_3 \xrightarrow[\triangle]{} RCONH_2 + H_2O$$

Reactions of amides

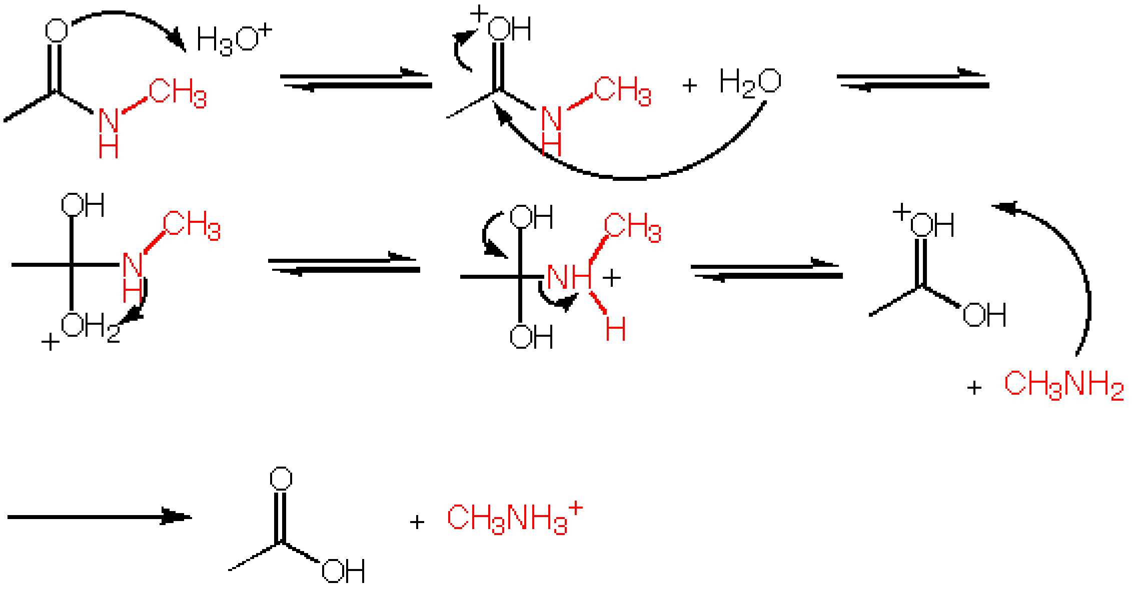
Hydrolysis of amides



$$RCONH_2 + H_2O \xrightarrow{H^+} RCOOH + NH_4^+$$

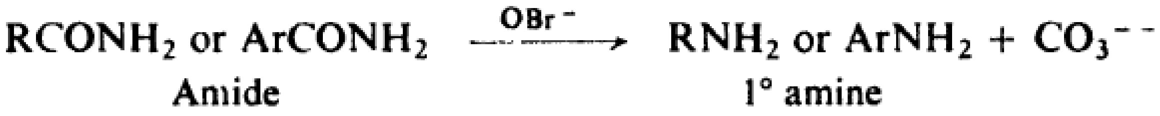
$$RCONH_2 + H_2O \xrightarrow{OH^-} RCOO + NH_3$$

Mechanism



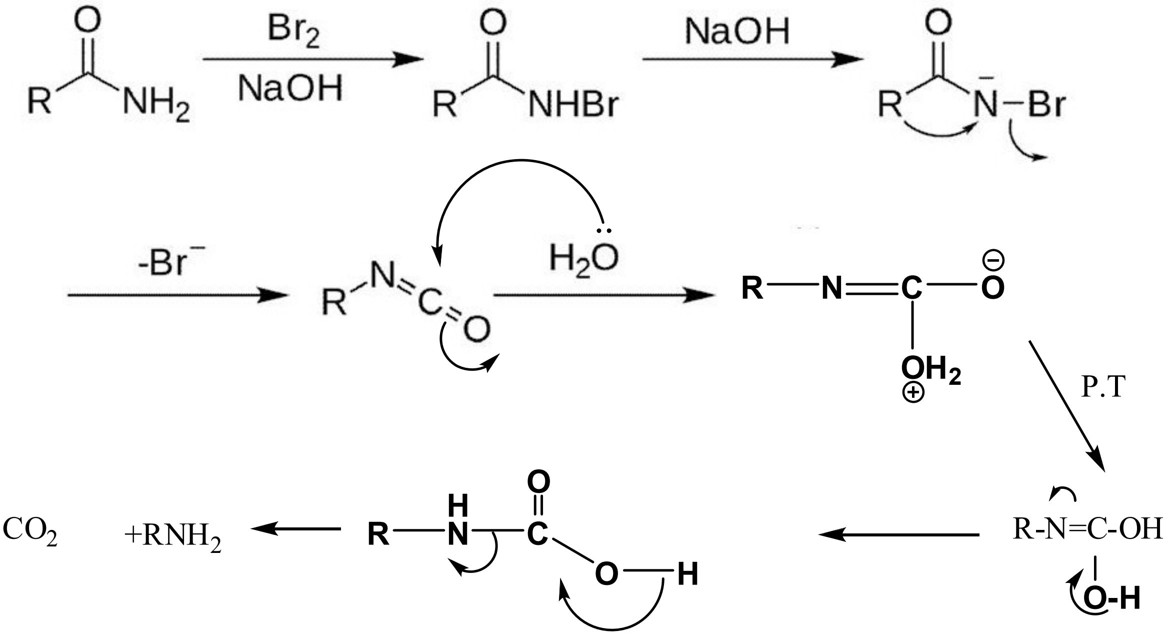
Give the mechanism in alkaline medium

Hofmann degradation of amides



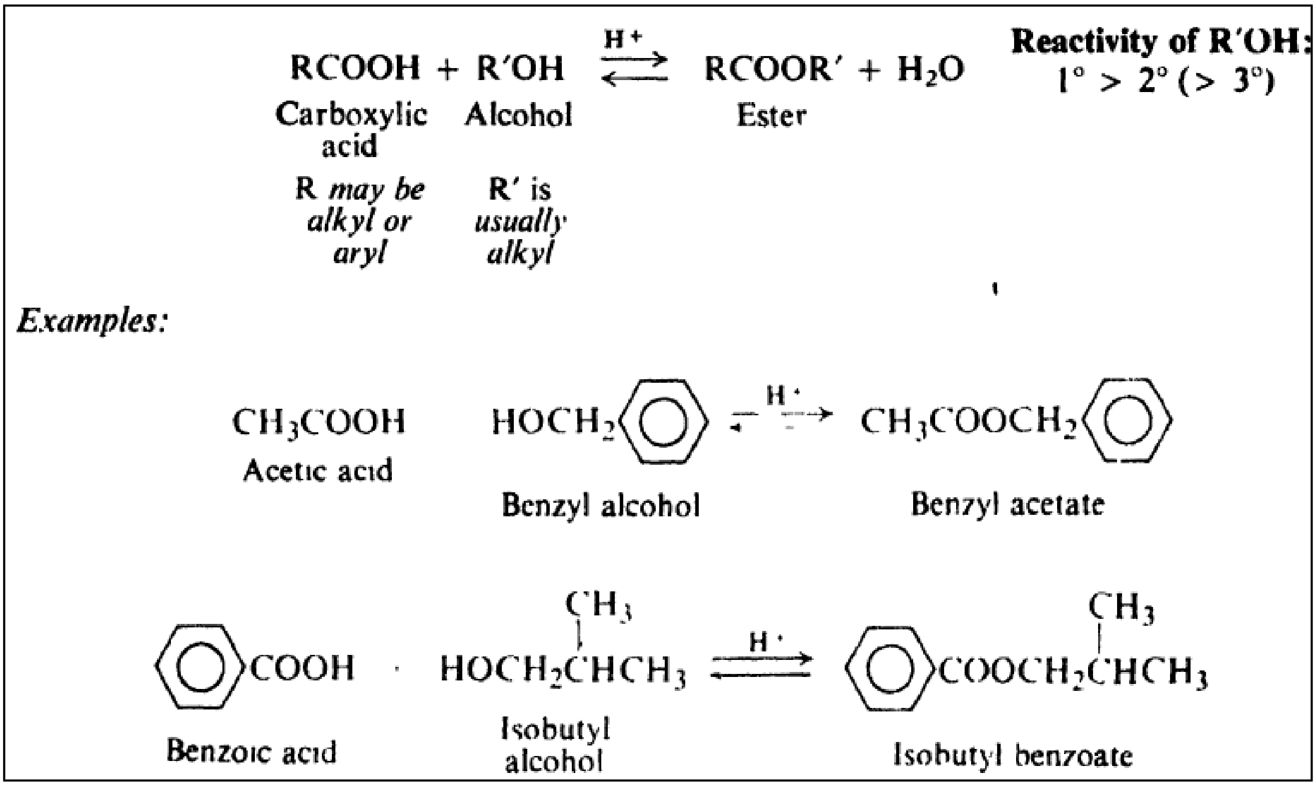
$$\underset{\text{Amide}}{RCONH_2 \text{ or } ArCONH_2} \xrightarrow{OBr^-} \underset{1° \text{ amine}}{RNH_2 \text{ or } ArNH_2} + CO_3^{--}$$

Mechanism

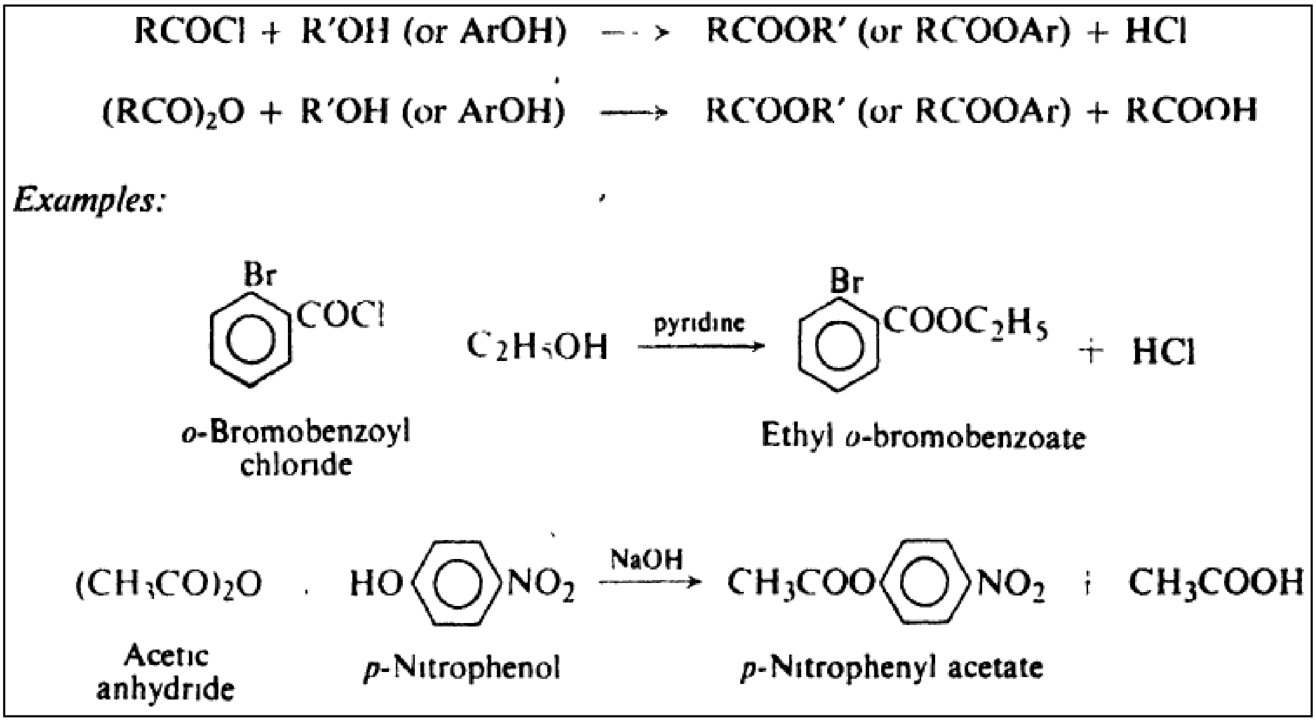


Preparation of esters

Esters are usually prepared by the reaction of alcohols or phenols with acids or acid derivatives.



From acid chlorides or anhydrides.



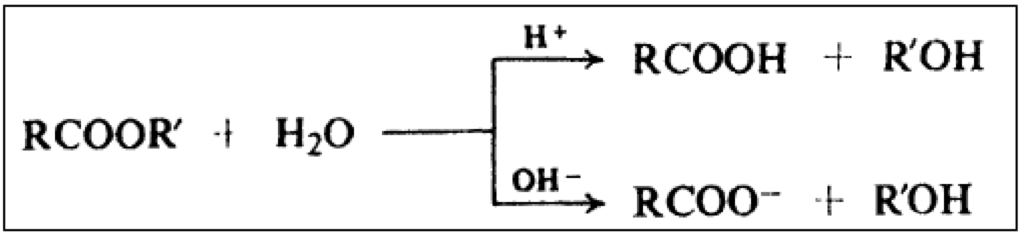
$$RCOCl + R'OH \text{ (or ArOH)} \longrightarrow RCOOR' \text{ (or RCOOAr)} + HCl$$

$$(RCO)_2O + R'OH \text{ (or ArOH)} \longrightarrow RCOOR' \text{ (or RCOOAr)} + RCOOH$$

Write these mechanism

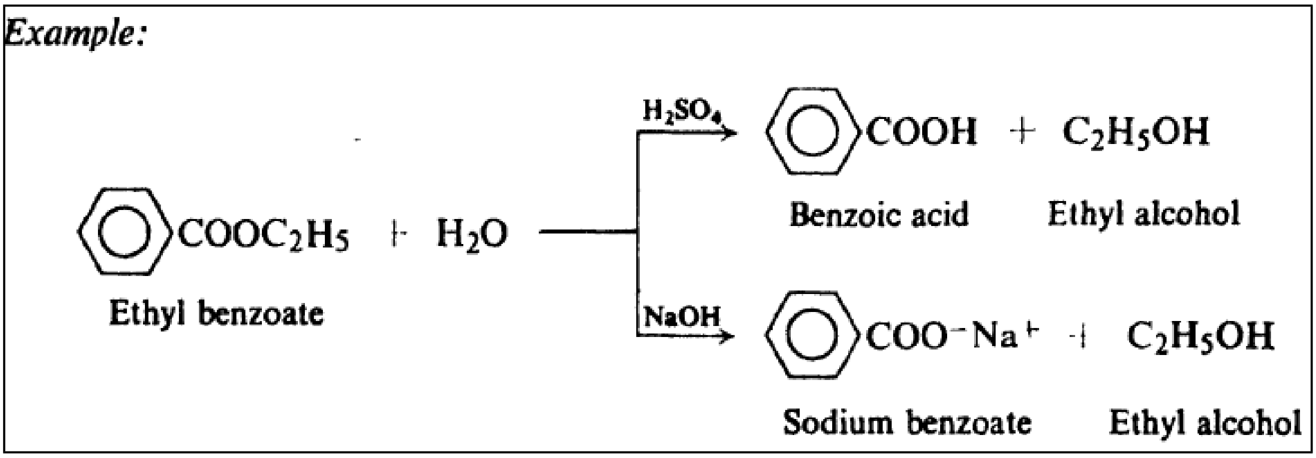
-reactions of esters

Conversion into acids and acid derivatives



$$RCOOR' + H_2O \xrightarrow{H^+} RCOOH + R'OH$$

$$RCOOR' + H_2O \xrightarrow{OH^-} RCOO^- + R'OH$$



Conversion into amides

$$RCOOR' + NH_3 \longrightarrow RCONH_2 + R'OH$$

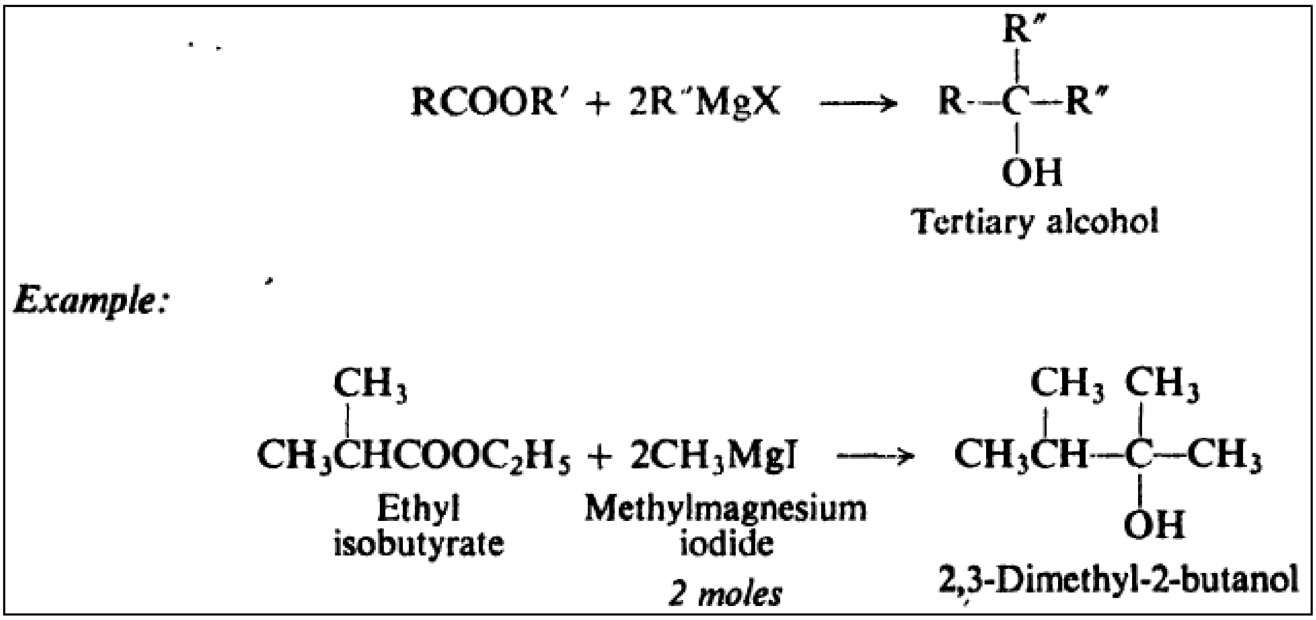
Example:

$$\underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + NH_3 \longrightarrow \underset{\text{Acetamide}}{CH_3CONH_2} + \underset{\text{Ethyl alcohol}}{C_2H_5OH}$$

Mechanism

Reaction with Grignard reagents.

mechanism



$$RCOOR' + 2R''MgX \longrightarrow \underset{\text{Tertiary alcohol}}{R-\overset{\overset{\displaystyle R''}{|}}{\underset{\underset{\displaystyle OH}{|}}{C}}-R''}$$

Example:

$$\underset{\substack{\text{Ethyl}\\\text{isobutyrate}}}{CH_3\overset{\overset{\displaystyle CH_3}{|}}{C}HCOOC_2H_5} + \underset{\substack{\text{Methylmagnesium}\\\text{iodide}\\\textit{2 moles}}}{2CH_3MgI} \longrightarrow \underset{\text{2,3-Dimethyl-2-butanol}}{CH_3\overset{\overset{\displaystyle CH_3}{|}}{C}H-\overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle OH}{|}}{C}}-CH_3}$$

mechanism

Addition of methyl magnesium bromide to ethyl benzoate to give 2-phenyl-2-propanol. (See *Notes*.)