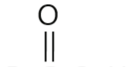
24. CARBOXYLIC ACID AND DERIVATIVES

1. INTRODUCTION

Compounds containing the carboxyl group are distinctly acidic and are called carboxylic acids.

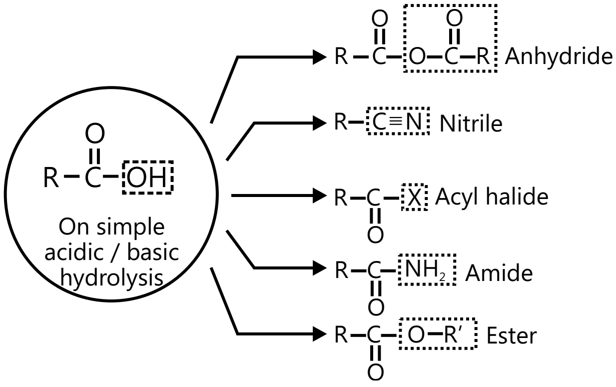


$R-\overset{\overset{O}{\|}}{C}-O-H$

Carboxylic Acid

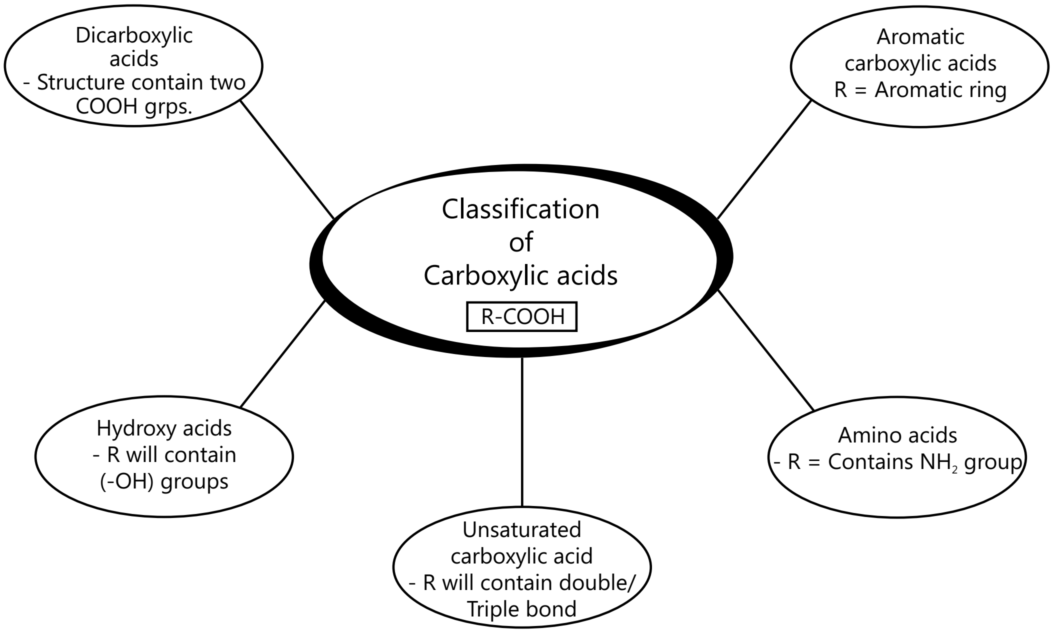
They have general formula $C_nH_{2n}O_2$

Carboxylic acid derivatives are compounds with functional groups that can be converted to carboxylic acids by a simple acidic or basic hydrolysis.



Flowchart 24.1: Derivatives of carboxylic acid

2. CLASSIFICATION OF CARBOXYLIC ACIDS



Flowchart 24.2: Classification of carboxylic acid

3. NOMENCLATURE OF CARBOXYLIC ACIDS

The IUPAC system of nomenclature assigns a characteristic suffix to these classes. The ending "e" is removed from the name of the parent chain and is replaced –"oic" acid.

Name → Alkan$\boxed{\text{e}}$ → Alkan$\boxed{\text{oic acid}}$

→ Given the # 1 location

Position in numbering.

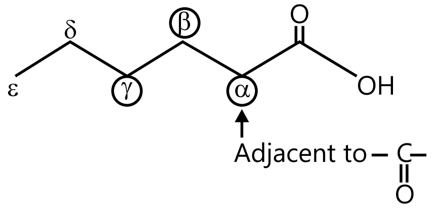
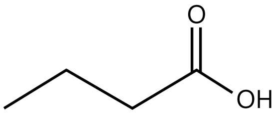


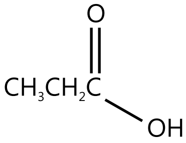
Table 24.1: IUPAC name of simple carboxylic acid

Formula	Common Name	Source	IUPAC Name	Melting Point	Boiling Point
HCOOH	Formic acid	Ants (L. Formica)	Methanoic acid	8.4 °C	101 °C
CH_3COOH	Acetic acid	Vinegar (L. Acetum)	Ethanoic acid	16.6 °C	118 °C
CH_3CH_2COOH	Propionic acid	Milk (Gk. Protus prion)	Propanoic acid	-20.8 °C	141 °C
$CH_3(CH_2)_2COOH$	Butyric acid	Butter (L. Butyrum)	Butanoic acid	-5.5 °C	164 °C
$CH_3(CH_2)_3COOH$	Valeric acid	Valerian root	Pentanoic acid	-34.5 °C	186 °C
$CH_3(CH_2)_4COOH$	Caproic acid	Goats (L. Caper)	Hexanoic acid	-4.0 °C	205 °C
$CH_3(CH_2)_5COOH$	Enanthic acid	Vines (Gk. Oenanthe)	Heptanoic acid	-7.5 °C	223 °C
$CH_3(CH_2)_6COOH$	Caprylic acid	Goats (L. Caper)	Octanoic acid	16.3 °C	239 °C
$CH_3(CH_2)_7COOH$	Pelargonic acid	Pelargonium (an herb)	Nonanoic acid	12.0 °C	253 °C
$CH_3(CH_2)_8COOH$	Capric acid	Goats (L. Caper)	Decanoic acid	31.0 °C	219 °C

Example:

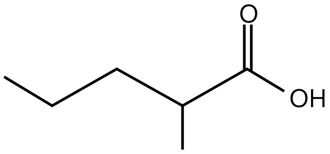


Butanoic acid
(Butyric Acid)

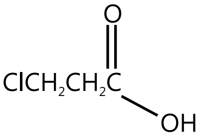


$CH_3CH_2C(=O)OH$

Propanoic acid
(Propionic Acid)



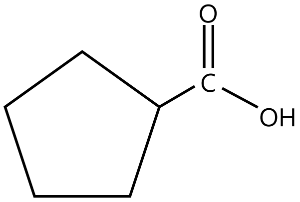
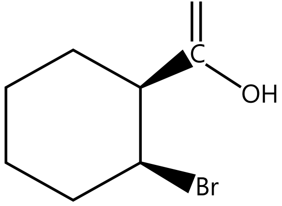
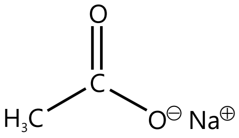
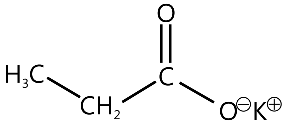
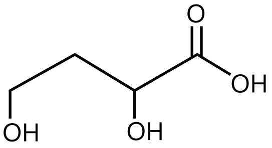
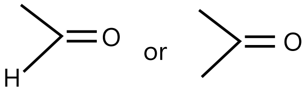
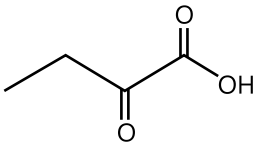
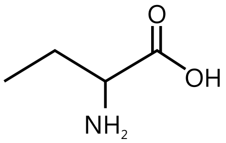
2-Methylpentanoic acid
(β-Methylvaleric acid)

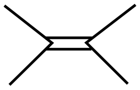
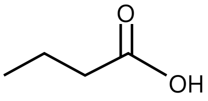
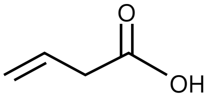
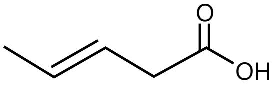
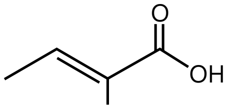
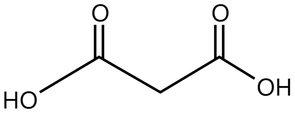


$ClCH_2CH_2C(=O)OH$

3-Chloropropanoic acid
(γ-Chloropropionic acid)

Table 24.2: IUPAC naming of substituted carboxylic acid

(1) Naming carboxyl groups attached to a ring	- Carboxyl group added to a ring. - Suffix " carboxylic acid" added to name of the cyclic compound	Example  Cyclopentanecarboxylic acid  Cis-2-Bromocyclohexanecarboxylic acid
(2) Naming carboxylates	- Carboxyl group attached to a cation Sodium ↓ Cation Acetate ↓ "-ic acid" replaced by "-ate"	 Sodium ethanoate (Sodium Acetate)  Potassium Propanoate (Potassium propionate)
(3) Naming the acids containing other functional groups (-COOH = highest priority)	i) Hydroxyl substituent –OH 'ℓ' from hydroxyl is removed	 2, 4- Dihydroxybutanoic acid
	ii) Aldehyde / ketone substituent  Aldehyde / Ketone	Name as " OXO-"  2- Oxobutanoic acid
	iii) Amino substituent – NH_2	 2-Aminobutanoic acid

	iv) Alkene substituent  cis/trans or E/Z nomenclature for the alkene needs to be included if necessary.	 Butanoic acid  3-Butenoic acid Position  Trans-3-pentenoic acid  (E) -2-Methyl-2-butenoic acid
(4) Di-carboxylic acids	- Carboxyl groups occupy the ends of the chain	 Propanedioic acid

4.PHYSICAL PROPERTIES OF ACIDS AND ACID DERIVATIVES

(a) Physical appearance and odour

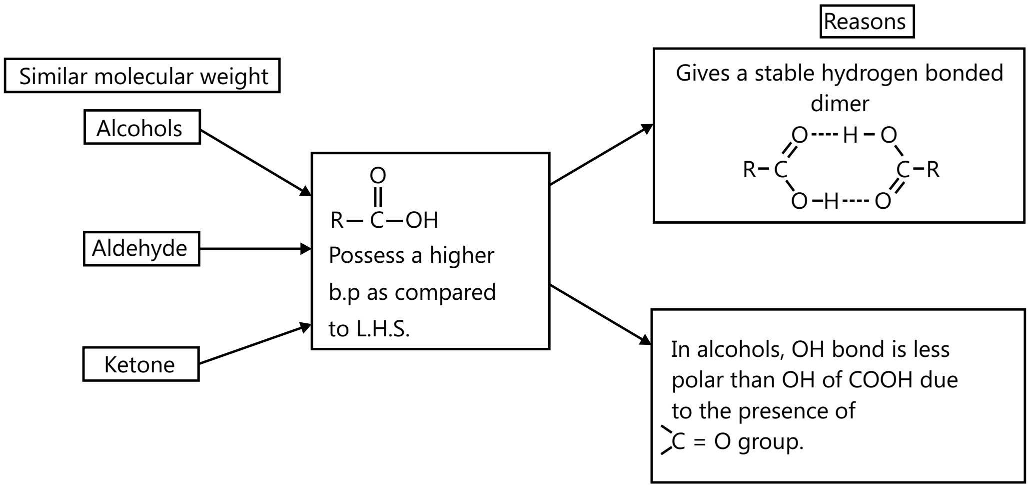
$C_1 – C_3$ = Liquid = Colourless & pungent smelling

$C_4 – C_6$ = Liquid (oily) = Colourless & unpleasant smell

$C > C_7$ = waxy solids= Colourless

(b) Boiling oints: Refer the following Flow-chart for a better understanding.

(L.H.S.=Left Hand Side)



Possess a higher b.p as compared to L.H.S.

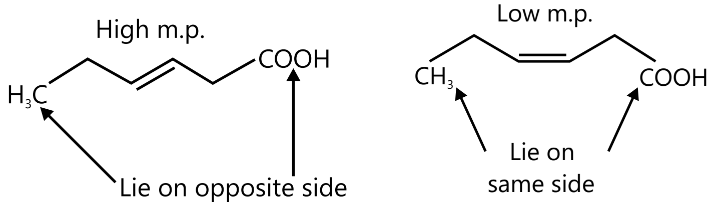
Gives a stable hydrogen bonded dimer

In alcohols, OH bond is less polar than OH of COOH due to the presence of >C = O group.

Flowchart 24.3: Comparison of B.p of carboxylic acid with other carbonyl compound

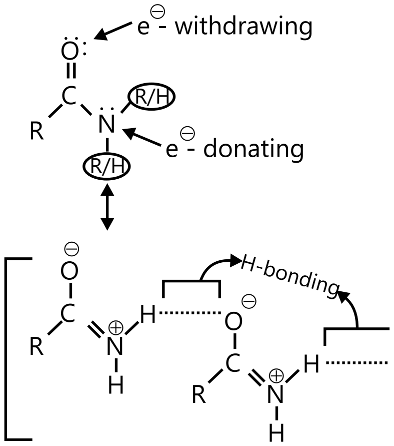
(c) Melting Points:

(i) Carboxylic acid with more than 8 carbon atom and a double bond have low melting point due to the inability to form a stable lattice.



(ii) Structures with even number of C atoms have a higher melting point as compared to structures having odd number of C-atoms.

(iii) The high M.Pof primary and secondary amides is due to the strong hydrogen bonding and the presence of electron-withdrawing and electron-donating group.



(d) Solubility:

(i) Lower carboxylic acid $\left(C_1 - C_2\right)$ are - miscible with water acids

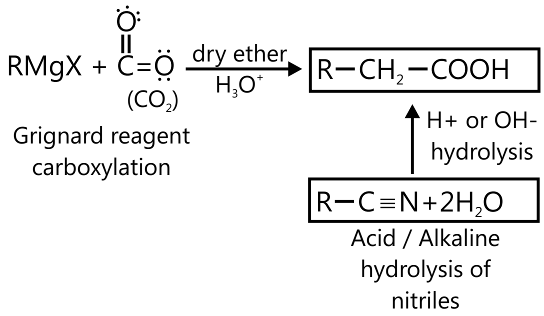
(ii) Instead of dimerization, they form H-bonds with water.

(iii) As the length of chain increases, the solubility decreases.

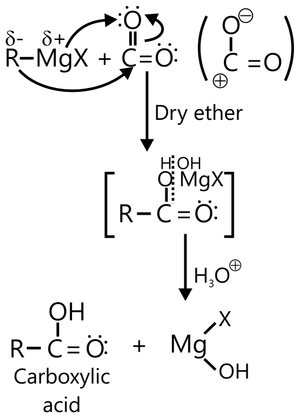
(iv) The derivatives like acid chlorides and anhydrides react with solvents like H_2O & alcohol.

5. METHODS OF PREPARATION OF CARBOXYLIC ACIDS

General reaction of preparation of carboxylic acid

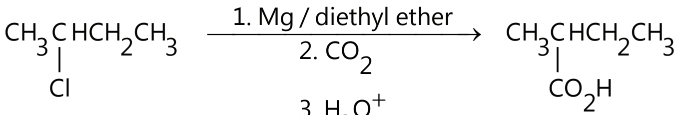


(a) Synthesis of carboxylic acids by the carboxylation of Grignard reagents



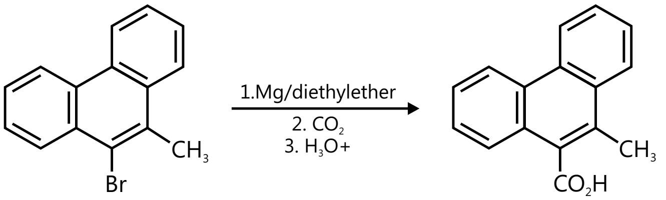
-RMgX acts as a nucleophile

Example:

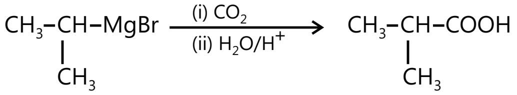


$$CH_3\underset{\underset{Cl}{|}}{C}HCH_2CH_3 \xrightarrow[\substack{2.\ CO_2\\3.\ H_3O^+}]{1.\ Mg\ /\ diethyl\ ether} CH_3\underset{\underset{CO_2H}{|}}{C}HCH_2CH_3$$

2-Chlorobutane 2-Methylbutanoic acid (78 - 88%)



9-Bromo-10-methylphenanthrene 10-Methylphenanthrene-8-carboxylic acid

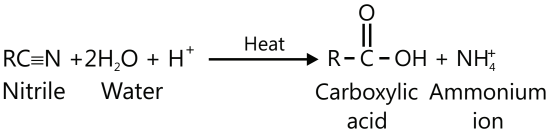


$$CH_3-\underset{\underset{CH_3}{|}}{CH}-MgBr \xrightarrow[(ii)\ H_2O/H^+]{(i)\ CO_2} CH_3-\underset{\underset{CH_3}{|}}{CH}-COOH$$

Isobutyric acid (2-methyl propanoic acid)

(b) Synthesis of Carboxylic acids by the hydrolysis of nitriles Mechanism:

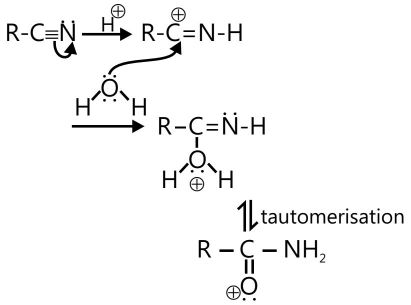
Hydrolysis of cyanides (Acid catalysed):



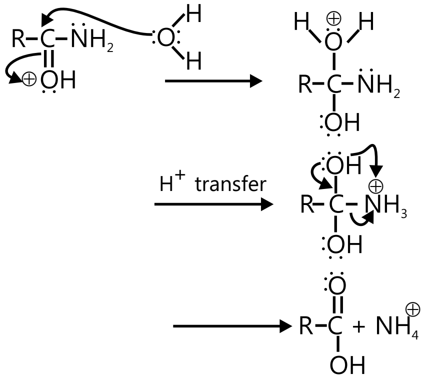
$$RC{\equiv}N + 2H_2O + H^+ \xrightarrow{Heat} R-\overset{\overset{O}{\|}}{C}-OH + NH_4^+$$

Mechanism:

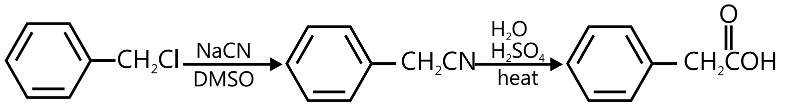
(a) Formation of Amide



(b) Formation of Acid



Example:



Benzyl chloride Benzyl cyanide (92%) Phenylacetic acid (77%)

MASTERJEE CONCEPTS

- Alkyl cyanides needed for the purpose can easily be prepared from the corresponding alkyl halides with alcoholic KCN or NaCN.

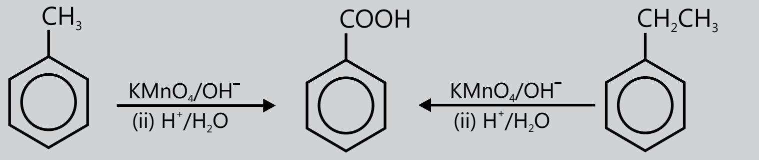
  $R - Cl + KCN \rightarrow R - C \equiv N + KCl$

- This reaction is used to ascend the series having one carbon atom more than the corresponding alkyl halides which are prepared from alcohol on treating with phosphorus halide.

  $ROH + PX_5 \rightarrow R - X + POX_3 + HX$

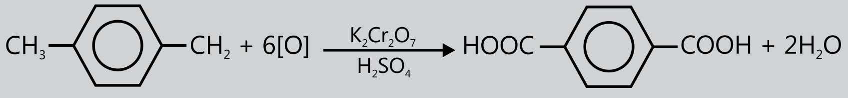
- This hydrolysis of alkyl cyanide provides a useful method to get carboxylic acid having one carbon atom more than the original alkyl halide and alcohols.

By Oxidation of alkyl benzenes – aromatic acids are produced.



Toluene Benzoic acid Ethylbenzene

E.g



p-Xylene Terephthalic acid

Vaibhav Krishnan (JEE 2009, AIR 22)

6. CHEMICAL REACTIONS

6.1. Acidic Strength

Acidity of carboxylic acids :

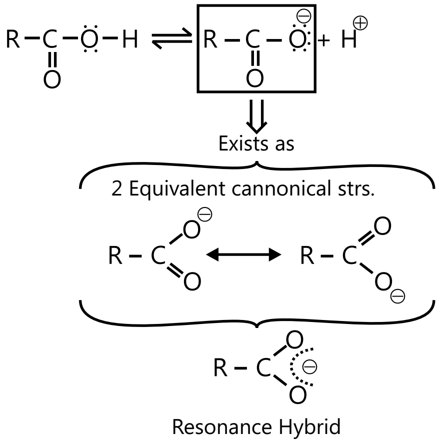
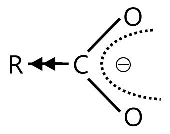
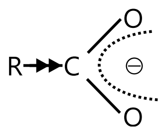
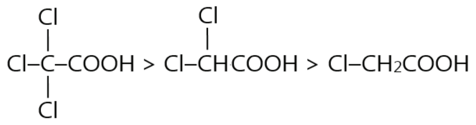
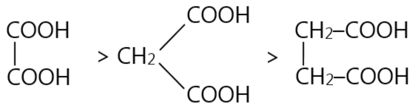


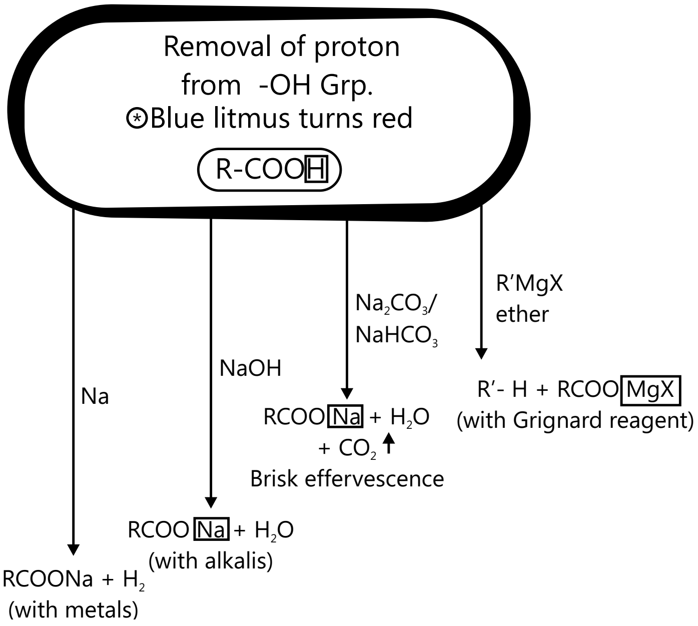
Table 24.3: Comparative acidity of Carboxylic acid with electron withdrawing group vs Carboxylic acid with electron donating group

R= Electron withdrawing Group	**R= Electron Donating Group**
⇒ Shows -I effect ⇒ Stabilises anion & increases acidic nature ⇒ Example 	⇒ Shows +I effect ⇒ Destabilizes anion & decrease acidic nature ⇒ Example 
∴ $\text{F–CH}_2\text{COOH} > \text{Cl – CH}_2\text{COOH} > \text{Br–CH}_2\text{COOH}$ OR ← Increasing acid strength ——  $\text{Cl}-\overset{\text{Cl}}{\underset{\text{Cl}}{\text{C}}}-\text{COOH} > \text{Cl}-\overset{\text{Cl}}{\text{CH}}\text{COOH} > \text{Cl}-\text{CH}_2\text{COOH}$	$\text{HCOOH} > \text{CH}_3\text{COOH} > \text{CH}_3\text{–CH}_2\text{–COOH}$  $\begin{matrix}\text{COOH}\\ \vert\\ \text{COOH}\end{matrix} > \text{CH}_2\begin{matrix}\text{COOH}\\ \text{COOH}\end{matrix} > \begin{matrix}\text{CH}_2\text{–COOH}\\ \vert\\ \text{CH}_2\text{–COOH}\end{matrix}$ $\boxed{\therefore \text{RCOOH} > \text{HOH} > \text{ROH} > \text{HC}\equiv\text{CH} > \text{NH}_3 > \text{RH}}$

Tips and Tricks

Acidity of acids is compared by comparing stability of conjugate base

6.2 Reactions Involving Removal of Proton From–OH Group



Flowchart 24.4: n Reaction involving displacement of H from -OH group.

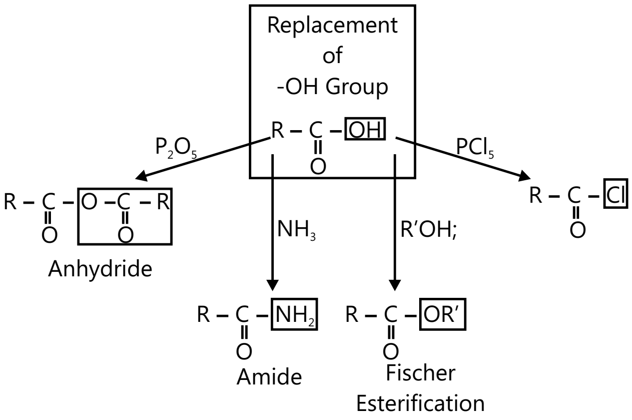
Important Point:

A stronger acid displaces a weaker acid from the salt of the weaker acid.

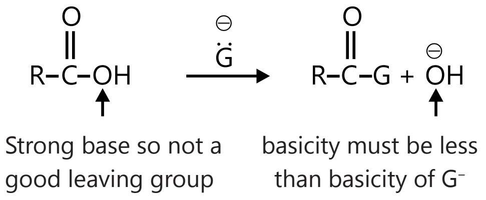
Example: $CH_3COOH\ (\text{Strongeracid}) + CH_3ONa \rightarrow CH_3COONa + CH_3 - OH$

Example: CH_3COOH (Stronger acid) + $NaHCO_3 \rightarrow CH_3COONa + H_2CO_3$ (Weaker acid) $\rightarrow H_2O + CO_2\uparrow$ (lab. test of carboxylic acid)

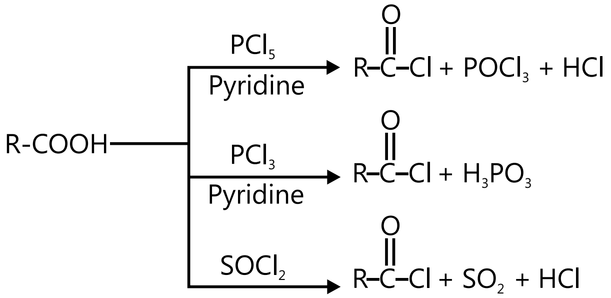
6.3 Reactions Involving Replacement of –OH Group



Flowchart 24.5: Reaction Involving removal of OH group.



(a) Formation of acid chlorides

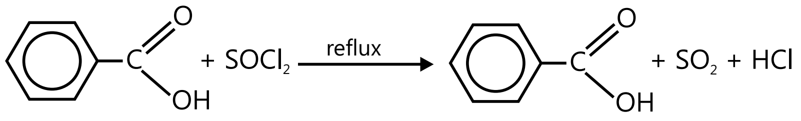


$$R-COOH \xrightarrow[\text{Pyridine}]{PCl_5} R-\overset{\overset{O}{\|}}{C}-Cl + POCl_3 + HCl$$

$$R-COOH \xrightarrow[\text{Pyridine}]{PCl_3} R-\overset{\overset{O}{\|}}{C}-Cl + H_3PO_3$$

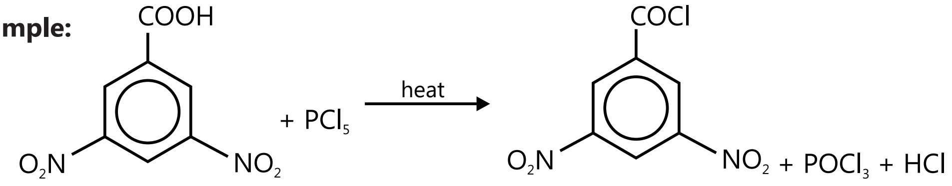
$$R-COOH \xrightarrow{SOCl_2} R-\overset{\overset{O}{\|}}{C}-Cl + SO_2 + HCl$$

Example:



Benzoic acid Benzoyl chloride

Example:

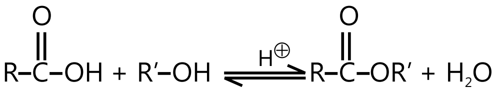


3, 5-Dinitrobenzoic acid

3, 5-Dinitrobenzoyl chloride

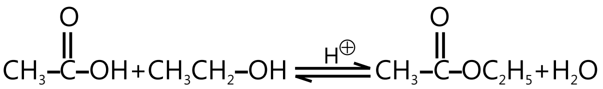
(b) Fisher Esterification: Carboxylic acid react with alcohol to form esters through a condensation reaction known as esterification.

General Reaction:

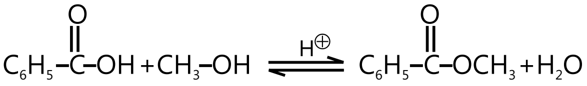


$$R-\overset{\overset{O}{\|}}{C}-OH + R'-OH \overset{H^{\oplus}}{\rightleftharpoons} R-\overset{\overset{O}{\|}}{C}-OR' + H_2O$$

Specific Examples:



$$CH_3-\overset{\overset{O}{\|}}{C}-OH + CH_3CH_2-OH \overset{H^{\oplus}}{\rightleftharpoons} CH_3-\overset{\overset{O}{\|}}{C}-OC_2H_5 + H_2O$$



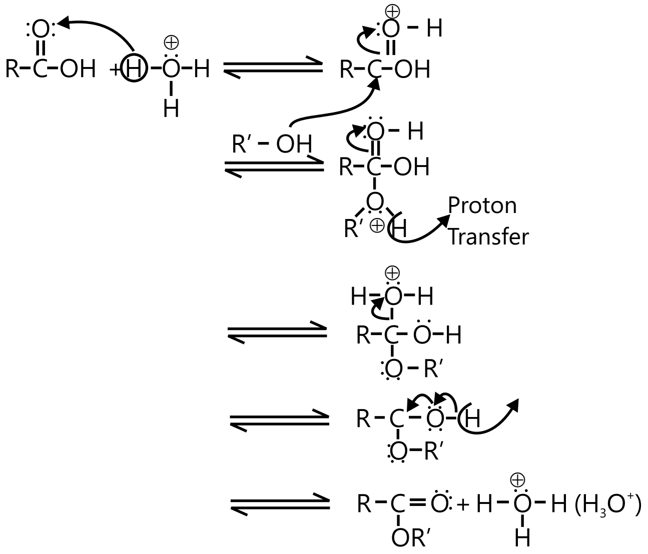
$$C_6H_5-\overset{\overset{O}{\|}}{C}-OH + CH_3-OH \overset{H^{\oplus}}{\rightleftharpoons} C_6H_5-\overset{\overset{O}{\|}}{C}-OCH_3 + H_2O$$

Mechanism : (Acid catalysed esterification)

(i) A reactive electrophile is generated by addition of a proton or a Lewis acid.

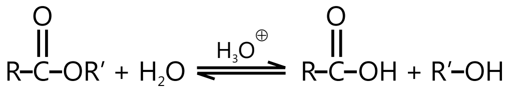
(ii) A tetrahedral intermediate containing two equivalent hydroxyl groups is obtained by the nucleophilic attack of the alcohol .

(iii) Elimination of these hydroxyl groups after a proton shift (tautomerism) occurs leading to the formation of water and the ester.



The forward reactions give acid catalysed esterification of an acid while the reverse account for the acid catalysed hydrolysis of an ester

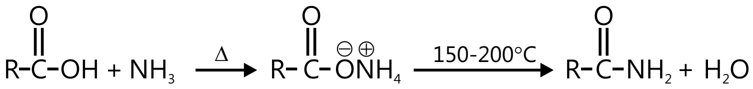
Acid catalysed ester hydrolysis.



$$R-\overset{O}{\overset{\|}{C}}-OR' + H_2O \xrightleftharpoons{H_3O^{\oplus}} R-\overset{O}{\overset{\|}{C}}-OH + R'-OH$$

For esterification of an acid we can use an excess of the alcohol and removal of water to prevent the reverse reaction, Hydrolysis of an ester uses a large excess of water and refluxing the ester with dilute aqueous HCl or dilute aqueous H_2SO_4 occurs.

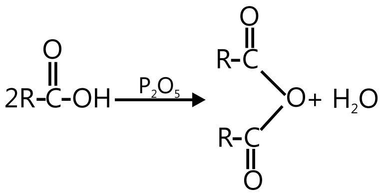
(c) Formation of amides:



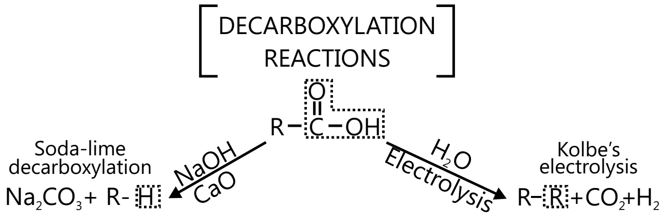
$$R-\overset{O}{\overset{\|}{C}}-OH + NH_3 \xrightarrow{\Delta} R-\overset{O}{\overset{\|}{C}}-\overset{\ominus}{O}\overset{\oplus}{N}H_4 \xrightarrow{150\text{-}200°C} R-\overset{O}{\overset{\|}{C}}-NH_2 + H_2O$$

In fact, amides cannot be prepared from carboxylic acids and amines unless the ammonium salt is heated strongly to dehydrate it. This is not usually a good method of preparing amides.

(d) Formation of acid anhydride:

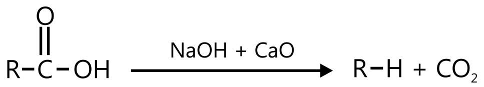


6.4 Decarboxylation Reactions



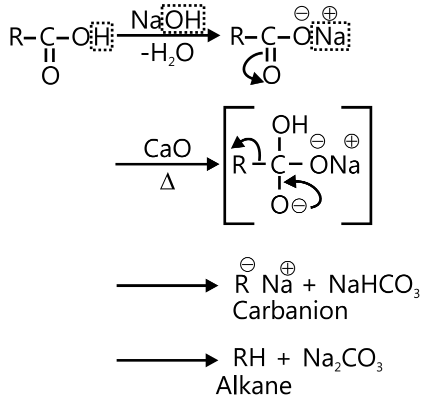
(a) Soda-lime decarboxylation:

General reaction:



$$R-\overset{O}{\overset{\|}{C}}-OH \xrightarrow{NaOH + CaO} R-H + CO_2$$

Mechanism

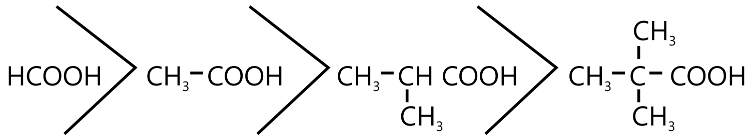


$$R-\underset{\underset{O}{\|}}{C}-OH \xrightarrow[-H_2O]{NaOH} R-\underset{\underset{O}{\|}}{C}-\overset{\ominus}{O}\overset{\oplus}{Na} \xrightarrow[\Delta]{CaO} \left[R-\overset{OH}{\underset{O^{\ominus}}{\overset{|}{\underset{|}{C}}}}-\overset{\ominus}{O}\overset{\oplus}{Na}\right] \longrightarrow \overset{\ominus}{R}\,\overset{\oplus}{Na} + NaHCO_3 \longrightarrow RH + Na_2CO_3$$

(i) The stability of carbanion intermediate decides the rate of reaction .

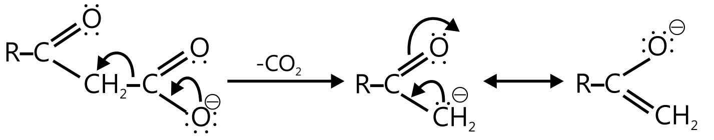
(ii) Rate of decarboxylation increases with the presence of electron withdrawing group at R-COOH.

Example:



$$HCOOH > CH_3-COOH > CH_3-\underset{\underset{CH_3}{|}}{CH}\,COOH > CH_3-\overset{CH_3}{\overset{|}{\underset{\underset{CH_3}{|}}{C}}}-COOH$$

(iii) Presence of some functional groups on aliphatic acids enable the decarboxylation.

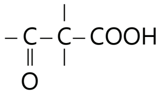
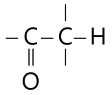
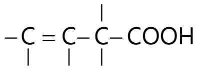
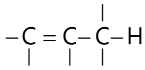


Resonance
stabilized anion

Aliphatic acids that do undergo successful decarboxylation have certain functional groups or double or triple bonds in the α or β positions.

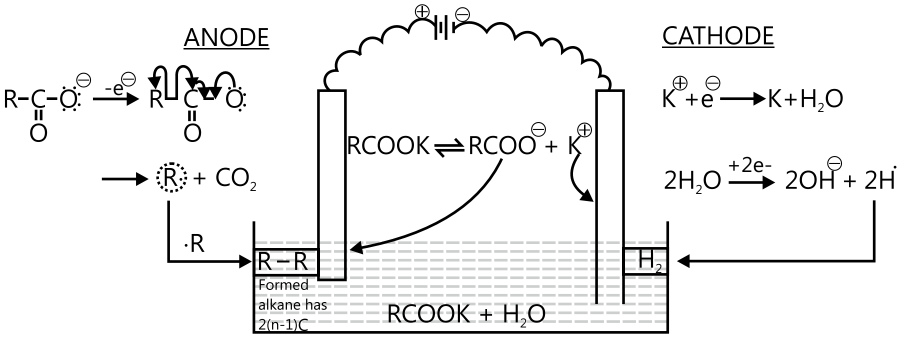
Table 24.4: Decarboxylation product of substituted carboxylic acid

		Acid type	**Decarboxylation product**
(1)	Malonic	$HOOC-\overset{|}{\underset{|}{C}}-COOH$	$HOOC-\overset{|}{\underset{|}{C}}-H$
(2)	α-Cyano	$NC-\overset{|}{\underset{|}{C}}-COOH$	$NC-\overset{|}{\underset{|}{C}}-H$
(3)	α-Nitro	$O_2N-\overset{|}{\underset{|}{C}}-COOH$	$O_2N-\overset{|}{\underset{|}{C}}-H$
(4)	α-Aryl	$Ar-\overset{|}{\underset{|}{C}}-COOH$	$Ar-\overset{|}{\underset{|}{C}}-H$

		Acid type	Decarboxylation product
(5)	β-Keto	 $-\underset{\underset{O}{\parallel}}{C}-\underset{\mid}{\overset{\mid}{C}}-COOH$	 $-\underset{\underset{O}{\parallel}}{C}-\underset{\mid}{\overset{\mid}{C}}-H$
(6)	α, α, α-Trihalo	$X_3C–COOH$	$X_3C–H$
(7)	β, γ-Unsaturated	 $-\underset{\mid}{C}=\underset{\mid}{C}-\underset{\mid}{\overset{\mid}{C}}-COOH$	 $-\underset{\mid}{C}=\underset{\mid}{C}-\underset{\mid}{\overset{\mid}{C}}-H$

(b) Kolbe's electrolysis

$$2RCOOK + 2HOH \xrightarrow{\text{Electrolysis}} R-R + 2CO_2 + H_2 + 2KOH$$



Example: $2CH_3-COOK + 2H_2O \xrightarrow{\text{Electrolysis}} CH_3CH_3 + 2CO_2 + H_2 + 2KOH$

6.5 HVZ Reaction (Halogenation of Aliphatic Acids and Substituted Acids)

Converts a carboxylic acid possessing an α-hydrogen to an α-halocarboxylic acid when treated with phosphorus and halogen. It is called as Hell-Volhard-Zelinsky reaction where regioselectivity allows alpha-halogenation only.

$$CH_3COOH \xrightarrow{Cl_2,P} ClCH_2COOH \xrightarrow{Cl_2,P} Cl_2CHCOOH \xrightarrow{Cl_2,P} Cl_3CCOOH$$

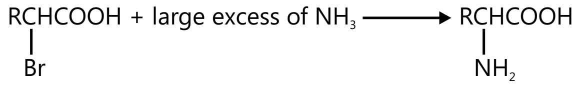
Mechanism

(a) Carbonyl oxygen reacts with phosphorus trihalide to form a P-O bond giving the release of a halide anion.

(b) Attack of halide forms an intermediate to release a rearranged acyl halide, an acid and a phosphine oxide.

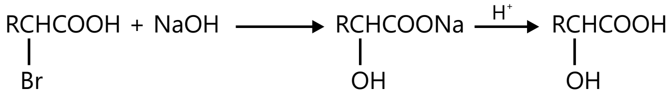
(c) Enol tautomer of acyl halide attacks the halogen molecule to form α-halo acyl halide.

(d) On hydrolysis, α-halocarboxylic acid is formed.



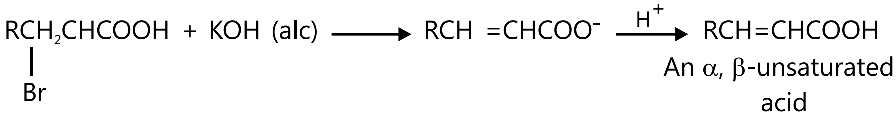
$$R\underset{\underset{Br}{\mid}}{C}HCOOH + \text{large excess of } NH_3 \longrightarrow R\underset{\underset{NH_2}{\mid}}{C}HCOOH$$

An α-halogenated acid An α-amino acid



$$R\underset{\underset{Br}{\mid}}{C}HCOOH + NaOH \longrightarrow R\underset{\underset{OH}{\mid}}{C}HCOONa \xrightarrow{H^+} R\underset{\underset{OH}{\mid}}{C}HCOOH$$

An α-hydroxy acid



$$RCH_2\underset{\underset{Br}{\mid}}{C}HCOOH + KOH\ (alc) \longrightarrow RCH=CHCOO^- \xrightarrow{H^+} RCH=CHCOOH$$

An α, β-unsaturated acid

7. CARBOXYLIC ACID DERIVATIVES

Functional derivatives of carboxylic acids

-Acid chlorides

-Anhydrides

-Amides

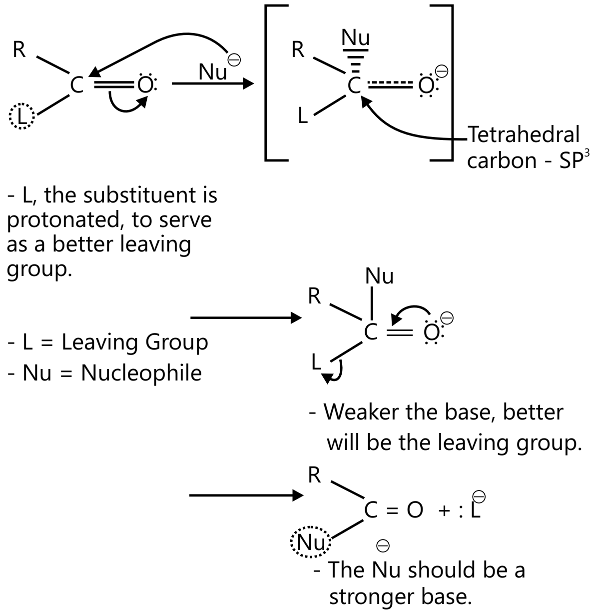
-Esters

The above are compounds in which the replacement of –OH of a carboxyl group is done by –Cl,–COOR , $-NH_2$,or –OR.

Characteristic reaction of acid derivatives (Nucleophilic acyl substitution):

Nucleophilic acyl substitution

-An addition - elimination mechanism



Tetrahedral carbon - SP^3

- L, the substituent is protonated, to serve as a better leaving group.

- L = Leaving Group
- Nu = Nucleophile

- Weaker the base, better will be the leaving group.

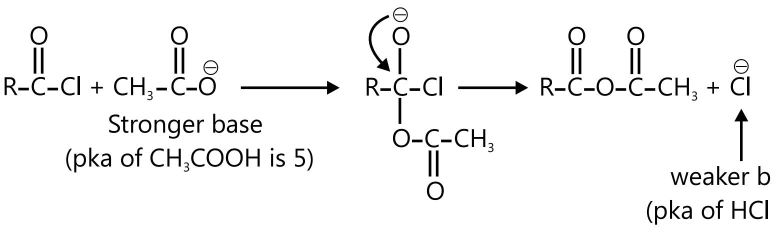
- The Nu should be a stronger base.

$$L = -X > -O-\overset{O}{\overset{\|}{C}}-R > -OR > -OH > -NH_2$$

[Order of Reactivity]

Examples:

(a)



$$R-\overset{O}{\overset{\|}{C}}-Cl + CH_3-\overset{O}{\overset{\|}{C}}-\overset{\ominus}{O} \longrightarrow R-\underset{O-\underset{\underset{O}{\|}}{C}-CH_3}{\overset{\overset{\ominus}{O}}{C}}-Cl \longrightarrow R-\overset{O}{\overset{\|}{C}}-O-\overset{O}{\overset{\|}{C}}-CH_3 + \overset{\ominus}{Cl}$$

Stronger base
(pka of CH_3COOH is 5)

weaker base
(pka of HCl = -7)

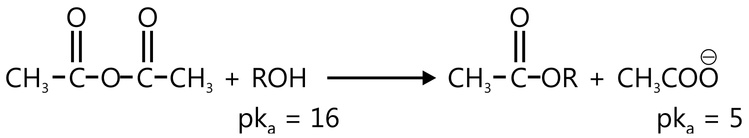
(b)

$$R-\overset{O}{\overset{\|}{C}}-OH + \overset{\ominus}{N}H_2 \qquad R-\overset{O}{\overset{\|}{C}}-NH_2 + \overset{\ominus}{O}H$$

Stonger base
(pka of NH_2 is 35)

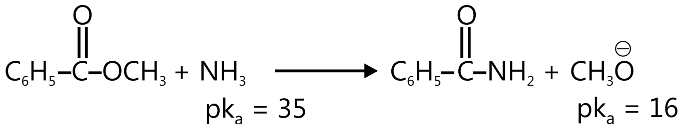
weaker base
(pka of HOH is 15)

(c)



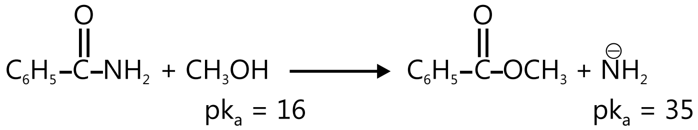
$$CH_3-\overset{O}{\overset{\|}{C}}-O-\overset{O}{\overset{\|}{C}}-CH_3 + \underset{pk_a\,=\,16}{ROH} \longrightarrow CH_3-\overset{O}{\overset{\|}{C}}-OR + \underset{pk_a\,=\,5}{CH_3CO\overset{\ominus}{O}}$$

(d)



$$C_6H_5-\overset{O}{\overset{\|}{C}}-OCH_3 + \underset{pk_a\,=\,35}{NH_3} \longrightarrow C_6H_5-\overset{O}{\overset{\|}{C}}-NH_2 + \underset{pk_a\,=\,16}{CH_3\overset{\ominus}{O}}$$

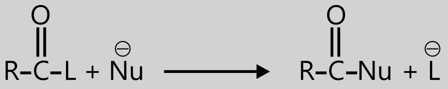
(e)



$$C_6H_5-\overset{O}{\overset{\|}{C}}-NH_2 + \underset{pk_a\,=\,16}{CH_3OH} \longrightarrow C_6H_5-\overset{O}{\overset{\|}{C}}-OCH_3 + \underset{pk_a\,=\,35}{\overset{\ominus}{N}H_2}$$

MASTERJEE CONCEPTS

Condition for nucleophilic substitution reaction:



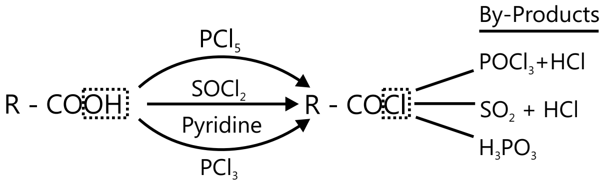
$$R-\overset{O}{\overset{\|}{C}}-L + \overset{\ominus}{Nu} \longrightarrow R-\overset{O}{\overset{\|}{C}}-Nu + \overset{\ominus}{L}$$

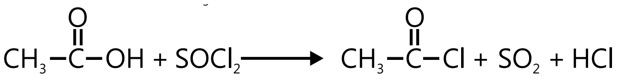
- L must be better leaving group than $Nu^{\ominus}$, i.e., basicity of Nu should be more than that of L.
- Must be a strong enough nucleophile to attack RCOL.
- Carbonyl carbon must be enough electrophilic to react with

Nikhil Khandelwal (JEE 2009, AIR 94)

7.1 Acid Halides

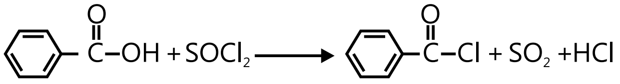
(a) Methods of preparation Acyl halides





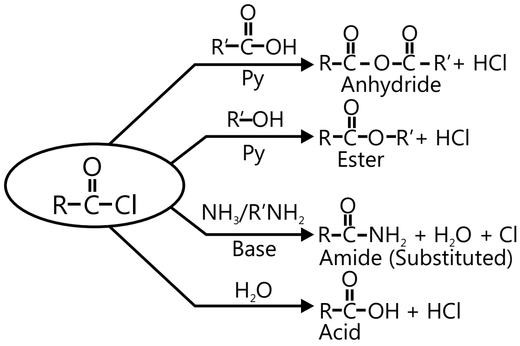
$$CH_3-\overset{O}{\overset{\|}{C}}-OH + SOCl_2 \longrightarrow CH_3-\overset{O}{\overset{\|}{C}}-Cl + SO_2 + HCl$$

E.g Ethanoic acid — Ethanoyl chloride



Benzoic acid — Benzoyl chloride

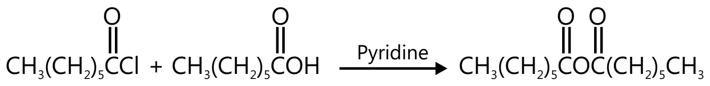
(b) Chemical Reactions



Flowchart 24.5: General reactions of Acid halides

(i) Reaction with carboxylic acids

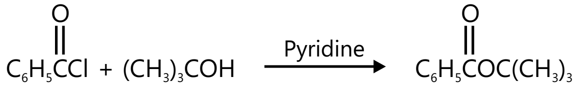
Carboxylic acids with acyl chlorides yield acid anhydrides with the help of a weak organic base, pyridine. Pyridine acts both as a catalyst and a base, which neutralizes the formed hydrogen chloride.



$$CH_3(CH_2)_5\overset{O}{\overset{\|}{C}}Cl + CH_3(CH_2)_5\overset{O}{\overset{\|}{C}}OH \xrightarrow{\text{Pyridine}} CH_3(CH_2)_5\overset{O}{\overset{\|}{C}}O\overset{O}{\overset{\|}{C}}(CH_2)_5CH_3$$

Heptanoyl chloride   Heptanoic acid   Heptanoic anhydride (78 - 83%)

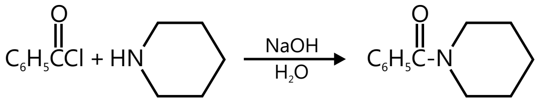
(ii) Reaction with alcohols



$$C_6H_5\overset{O}{\overset{\|}{C}}Cl + (CH_3)_3COH \xrightarrow{\text{Pyridine}} C_6H_5\overset{O}{\overset{\|}{C}}OC(CH_3)_3$$

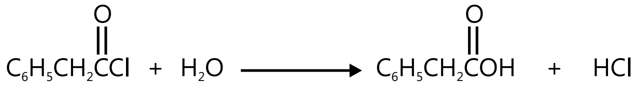
Benzoyl chloride   tert-Butyl alcohol   tert-Butyl benzoate (80%)

(iii) Reaction with ammonia and amines



Benzoyl chloride   Piperidine   N-Benzoylpiperidine (87-91%)

(iv) Hydrolysis

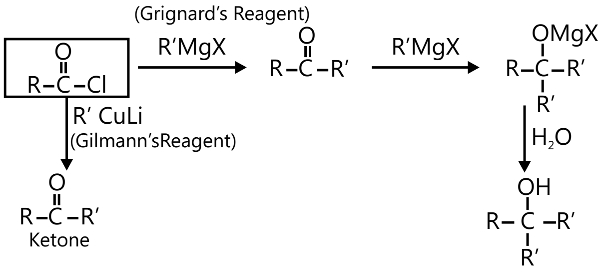


$$C_6H_5CH_2\overset{O}{\overset{\|}{C}}Cl + H_2O \longrightarrow C_6H_5CH_2\overset{O}{\overset{\|}{C}}OH + HCl$$

Phenylacetyl chloride   Water   Phenylacetic acid   Hydrogen chloride

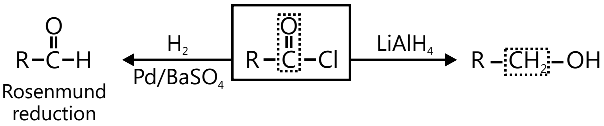
(v) Reaction of acid halide with organometallic

- With Grignard reagent
- Reaction with Gilmann reagent



(vi) Reduction of acid halides

- By $LiAlH_4$
- By $H_2/Pd/BaSO_4$ (Rosenmund reduction)

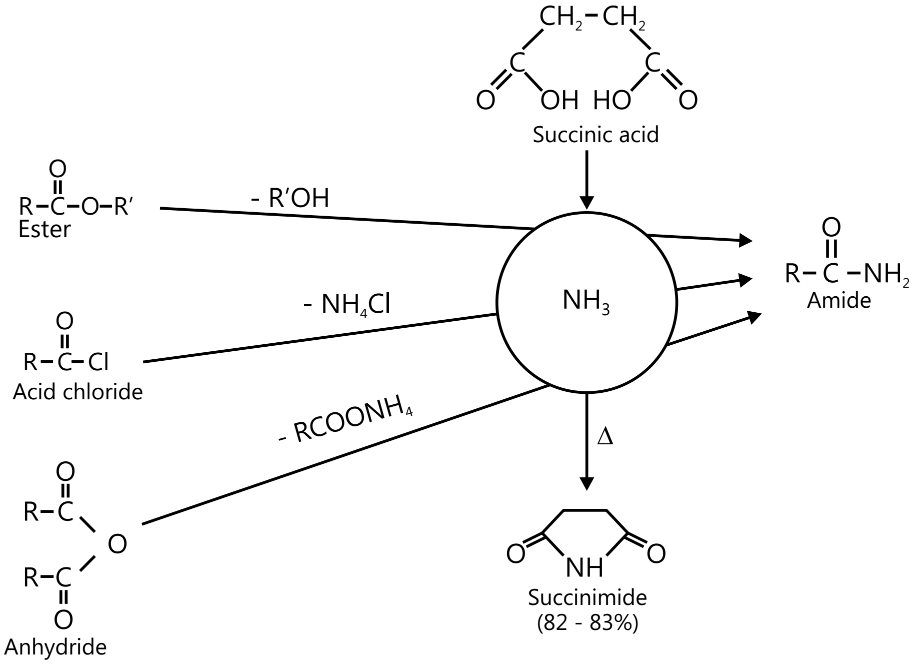


$$\underset{\text{Rosenmund reduction}}{R-\overset{O}{\overset{\|}{C}}-H} \xleftarrow[Pd/BaSO_4]{H_2} \boxed{R-\overset{O}{\overset{\|}{C}}-Cl} \xrightarrow{LiAlH_4} R-CH_2-OH$$

7.2 Acid Amides

Methods of preparation of acid amide

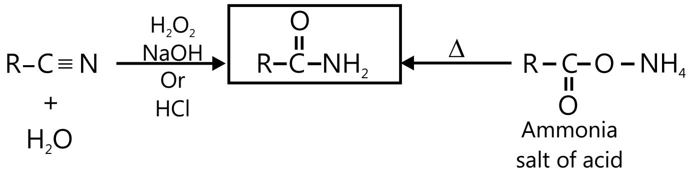
(a) With ammonia



Flowchart 24.6: Preparation of amides from acid derivative

(b) With (i) Cyanide (ii) Ammonia salt of acid

General reaction:



$$\begin{matrix} R-C\equiv N \\ + \\ H_2O \end{matrix} \xrightarrow[\text{Or HCl}]{H_2O_2,\ NaOH} \boxed{R-\overset{O}{\overset{\|}{C}}-NH_2} \xleftarrow{\Delta} \underset{\text{Ammonia salt of acid}}{R-\underset{O}{\underset{\|}{C}}-O-NH_4}$$

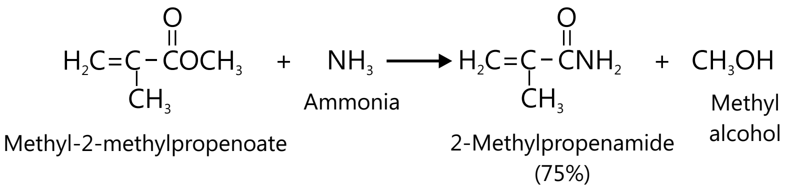
(i) From ammonia salts of carboxylic acid

$CH_3COONH_4 \xrightarrow{\Delta} CH_3CONH_2$

(ii) From cyanides

$CH_3C\equiv N + H_2O \xrightarrow{dil.H_2SO_4} CH_3-CONH_2$

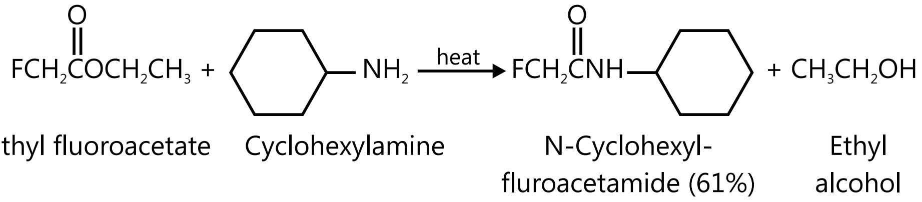
Example:



$$H_2C{=}\underset{CH_3}{\underset{|}{C}}{-}\overset{O}{\overset{||}{C}}OCH_3 + NH_3 \longrightarrow H_2C{=}\underset{CH_3}{\underset{|}{C}}{-}\overset{O}{\overset{||}{C}}NH_2 + CH_3OH$$

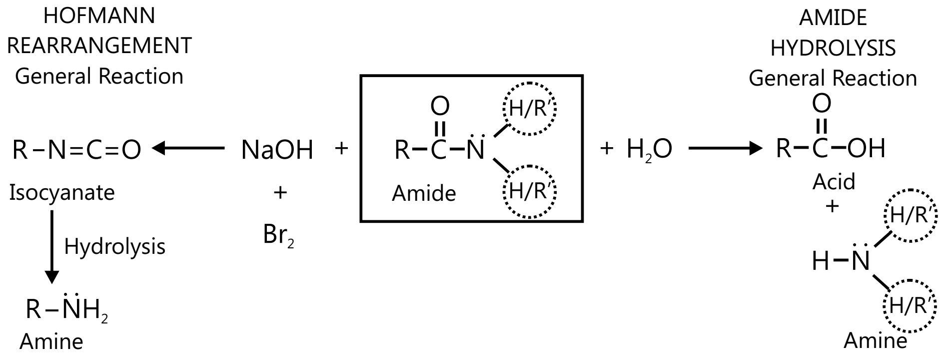
Amines, which are substituted derivatives of ammonia, react similarly

Example:



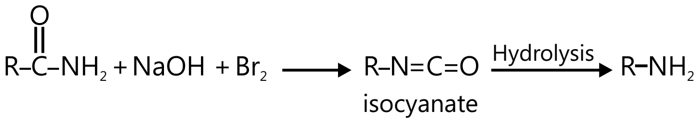
Important Chemical Reactions

General reaction:



(a) **Hoffmann rearrangement:** In the Hofmann rearrangement an unsubstituted amide is treated with sodium hydroxide and bromine to give a primary amine that has one carbon fewer than starting amide

General reaction:



$$R{-}\overset{O}{\overset{||}{C}}{-}NH_2 + NaOH + Br_2 \longrightarrow \underset{\text{isocyanate}}{R{-}N{=}C{=}O} \xrightarrow{\text{Hydrolysis}} R{-}NH_2$$

Mechanism:

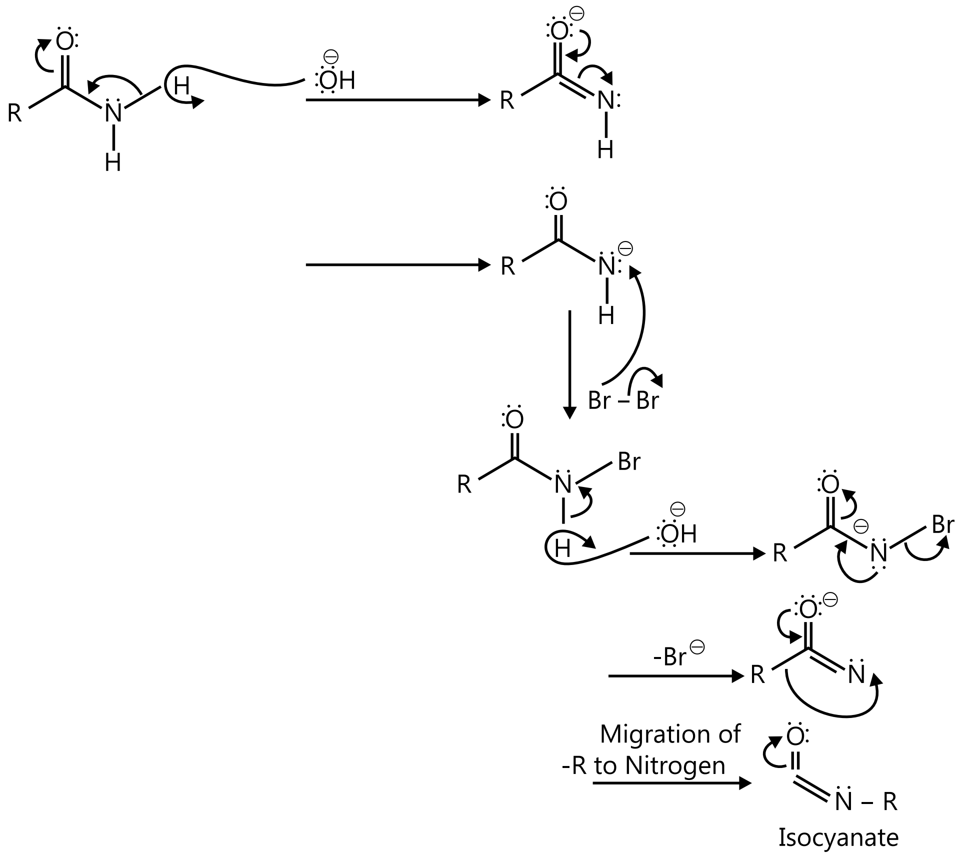
The mechanism is divided into 3 parts:-

(i) Formation of Isocyanate intermediate

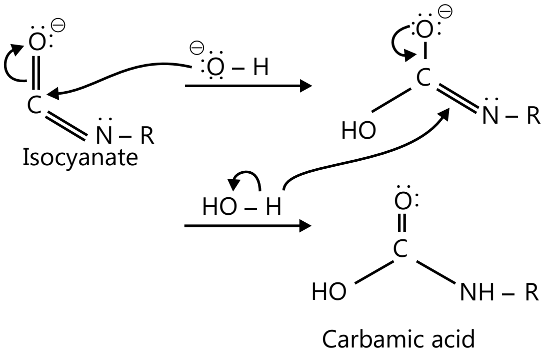
(ii) Formation of carbamic acid

(iii) Decarboxylation to give Amine

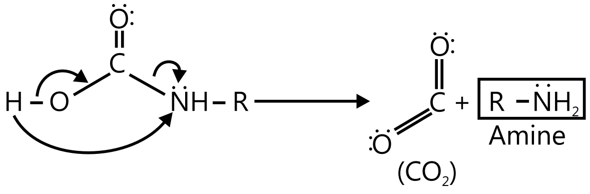
(i) Formation of Isocyanate intermediate



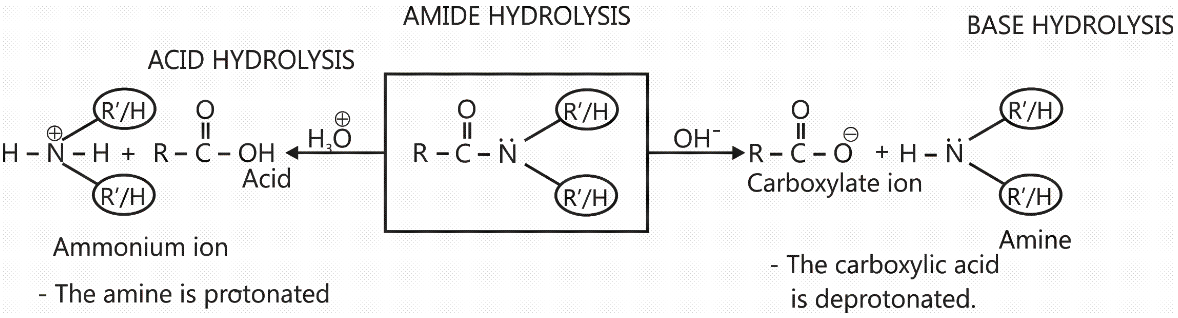
(ii) Formation of carbamic acid



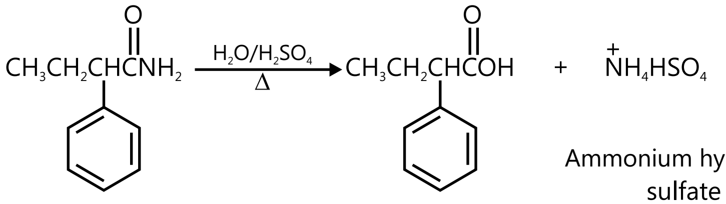
(iii) Decarboxylation to give Amine



(b) Hydrolysis of amides



Example:

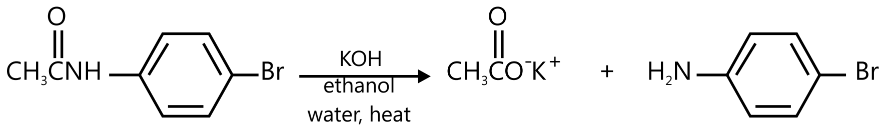


2-Phenylbutanamide

2-Phenylbutanoic acid (88-90%)

Ammonium hydrogen sulfate

Example:



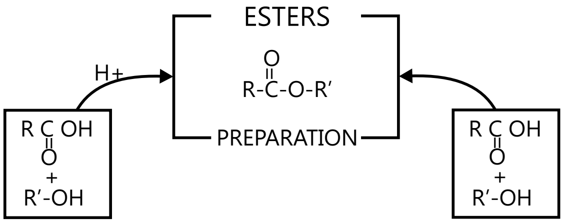
N-(4-Bromophenyl) acetamide (p-bromoacetanilide)

Potassium acetate

p-Bromoaniline (95%)

7.3 Esters

(a) Methods of Preparation



Examples:

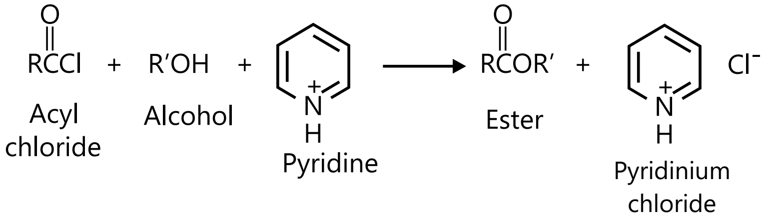
(i) $$\underset{\text{Acetic acid}}{CH_3COOH} + C_2H_5OH \xrightarrow{H^+} CH_3COOC_2H_5 + H_2O$$

$$C_6H_5COOH + CH_3OH \xrightarrow{H^+} C_6H_5COOCH_3 + H_2O$$

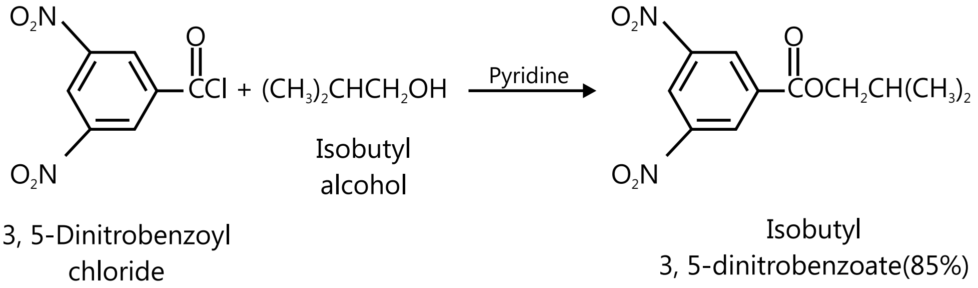
(ii) $$CH_3COCl + C_2H_5OH \xrightarrow{\text{Pyridine}} CH_3COOC_2H_5 + HCl$$

Alcohols react with acyl chlorides by nucleophilic acyl substitution to yield esters. These reactions are typically performed in the presence of a weak base such as pyridine.

Here conc. H_2SO_4 is used in the obove reactions which acts as a catalyst & a dehydeating agent.

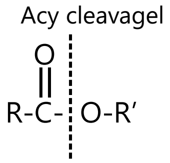


Example:



Example: $C_6H_5COCl + CH_3CH_2OH \xrightarrow{NaOH} C_6H_5COOCH_2CH_3 + HCl$

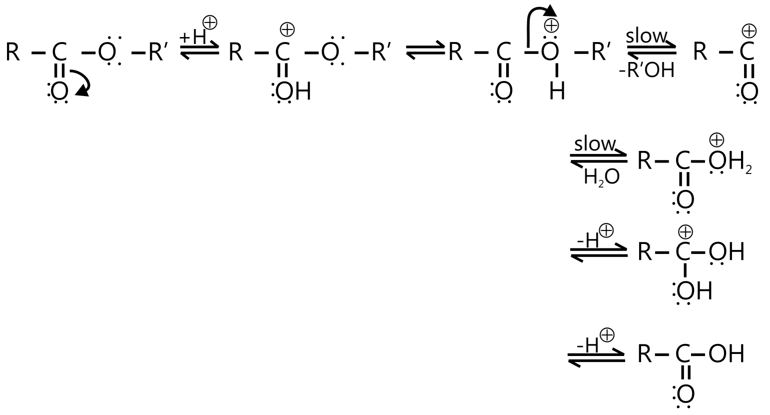
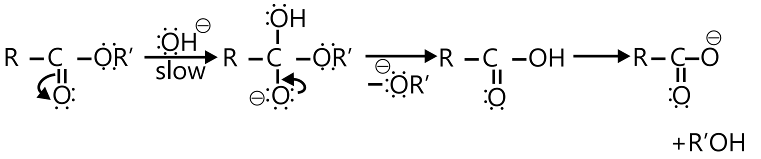
(b) Chemical Reactions: The acid and base catalysed ester hydrolysis involves the acyl cleavage of the ester group.



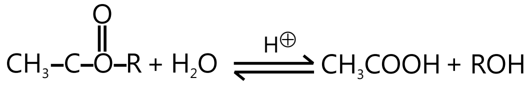
AAc$_2$ is Acid catalysed ester hydrolysis by acyl cleavage through bimolecular mechanism.

BAc$_2$ is Base catalysed ester hydrolysis by acyl cleavage through bimolecular mechanism.

Table 24.5: Mechanism of Acid catalysed and Base catalysed ester hydrolysis

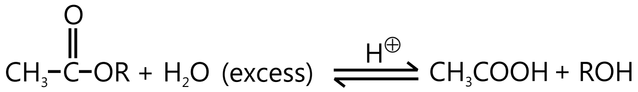
Acid Catalysis	Acyl Cleavage	AAc$_2$	
Base Catalysis	Acyl Cleavage	BAc$_2$	

(i) Acid catalysed hydrolysis of ester (AAc_2):



$$CH_3-\overset{\overset{O}{\|}}{C}-O-R + H_2O \underset{}{\overset{H^{\oplus}}{\rightleftharpoons}} CH_3COOH + ROH$$

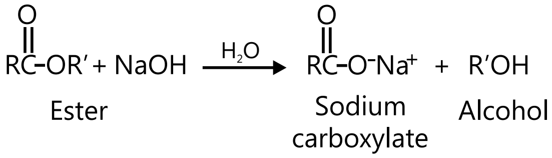
The yield of products would be raised by adding excess of water.



$$CH_3-\overset{\overset{O}{\|}}{C}-OR + H_2O \text{ (excess)} \overset{H^{\oplus}}{\rightleftharpoons} CH_3COOH + ROH$$

(ii) Base-Promoted Hydrolysis of Esters : Saponification (BAc_2):

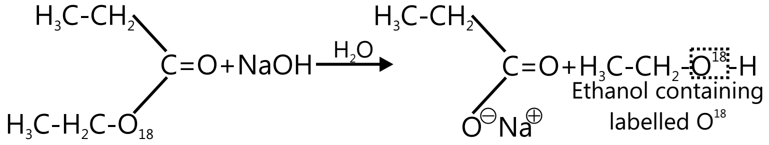
The base catalysed hydrolysis is also known as Saponification.



$$\underset{\text{Ester}}{R\overset{\overset{O}{\|}}{C}-OR'} + NaOH \xrightarrow{H_2O} \underset{\text{Sodium carboxylate}}{R\overset{\overset{O}{\|}}{C}-O^-Na^+} + \underset{\text{Alcohol}}{R'OH}$$

The unreactive negatively charged carboxylate ion does not undergo nucleophilic substitution. The irreversible nature of this reaction,i.e., the base-promoted hydrolysis of an ester is seen over here. The mechanism for this reaction also involves a nucleophilic addition-elimination at the acyl carbon.

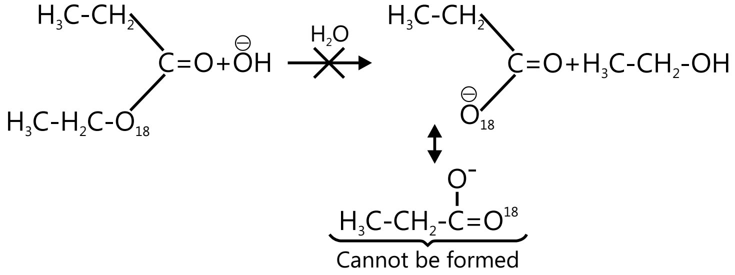
Mechanism:

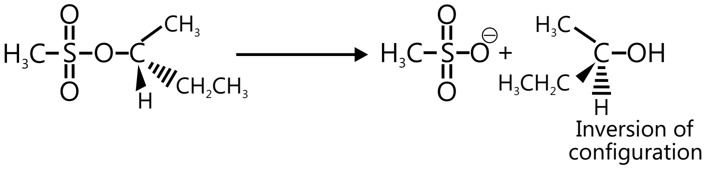


The mechanism is studied with the help of isotopically labelled esters. Ethyl propionate consisting of labelled ^{18}O in the ether-type oxygen of the ester undergoes hydrolysis with aqueous NaOH wherein the ^{18}O is observed to be contained in the produced ethanol only.

The result would have been different if it was an alkyl cleavage instead of the acyl one. But attack at the alkyl is not possible.

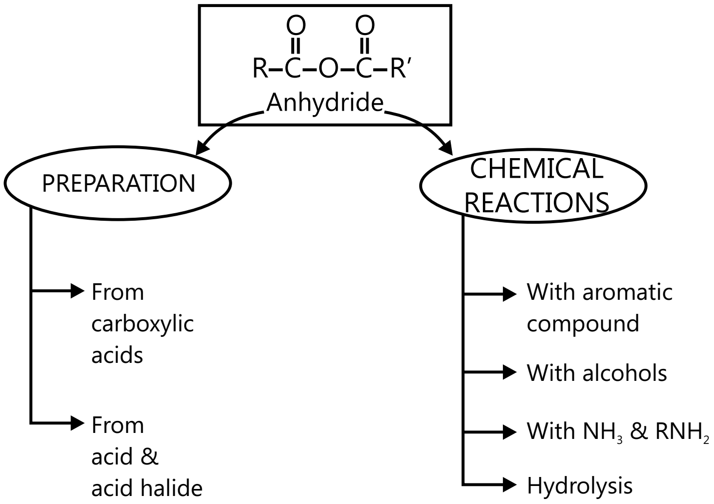
Such kind of attack of the nucleophile at the alkyl carbon occurs rarely in the case of carboxylic acid esters, but such attacks are preferred in case of esters of sulfonic acids (e.g. tosylates and mesylates)





Alkyl attack is seen in cases of alkyl sulfonates.

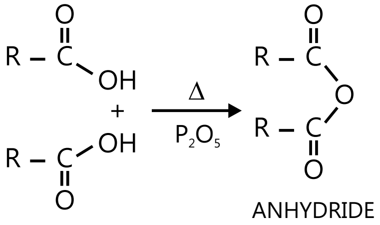
7.4 Acid anhydrides



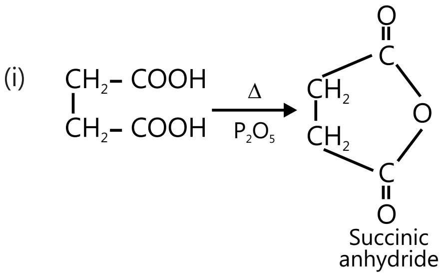
Flowchart 24.6: Preparation and reactions of anhydride

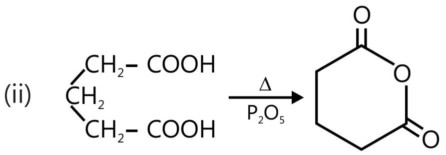
(a) Method of Preparation

(i) From carboxylic acids

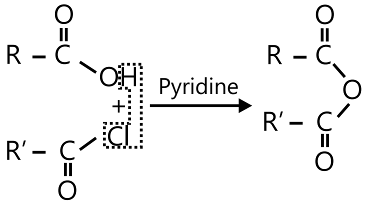


Example:

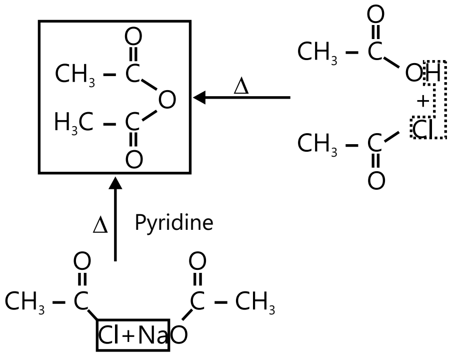




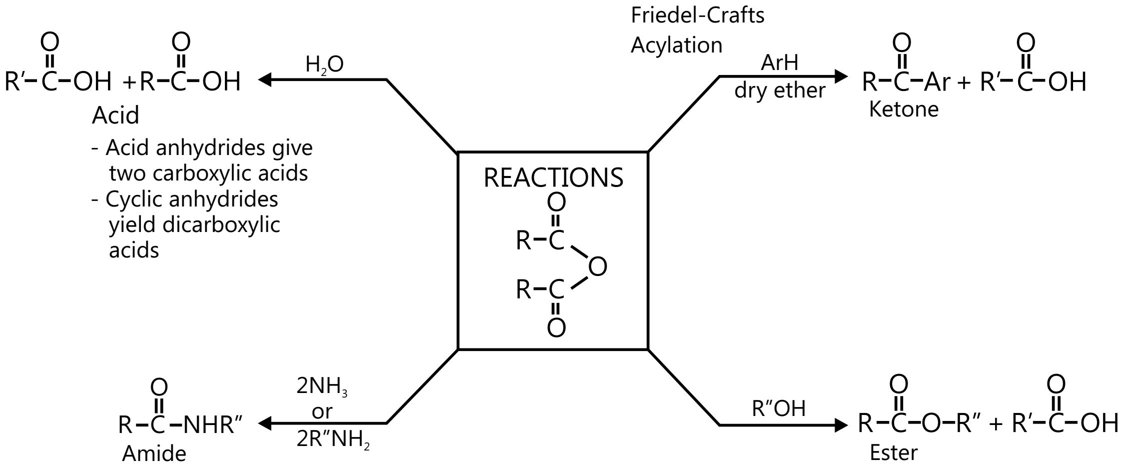
(ii) From acid and acid halide



Example:



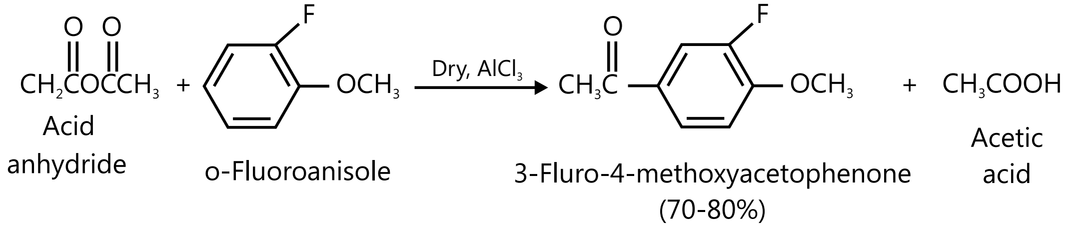
(b) Chemical Reaction



Flowchart 24.7: Important reaction of anhydride

(i) Reaction with aromatic compounds (Friedel-Crafts acylation)

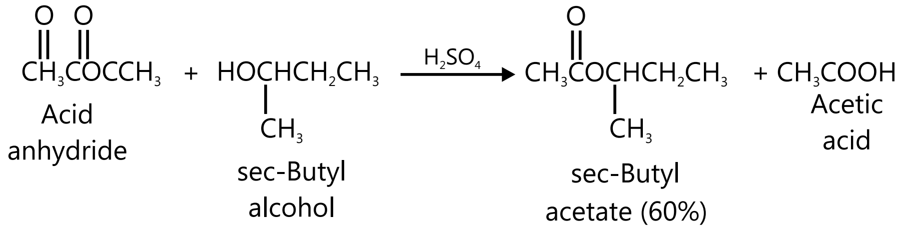
Example:



(ii) Reaction with alcohols: Esters are formed when acid anhydrides react with alcohols in presence of pyridine or a catalytic acid.

The below given example shows the incorporation of only one acyl group in the ester while the other forms an acetic acid molecule.

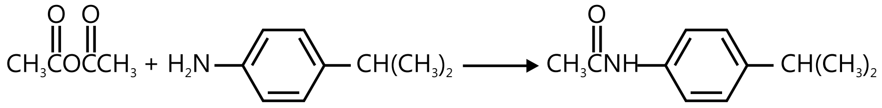
Example:



$$\underset{\text{Acid anhydride}}{CH_3\overset{O}{\overset{\|}{C}}O\overset{O}{\overset{\|}{C}}CH_3} + \underset{\text{sec-Butyl alcohol}}{HO\underset{CH_3}{\underset{|}{C}}HCH_2CH_3} \xrightarrow{H_2SO_4} \underset{\text{sec-Butyl acetate (60\%)}}{CH_3\overset{O}{\overset{\|}{C}}O\underset{CH_3}{\underset{|}{C}}HCH_2CH_3} + \underset{\text{Acetic acid}}{CH_3COOH}$$

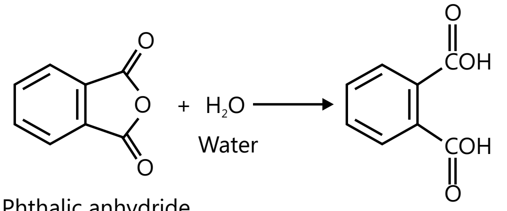
(iii) Reaction with ammonia and amines: Amides are formed when acid anhydride reacts with 2 molar equivalents of ammonia or amines.

The below given example shows the incorporation of only one acyl group into the amide and the other forms the amine salt of acetic acid.



Acetic anhydride | p-Isopropylaniline | p-Isopropylacetanilide (98%)

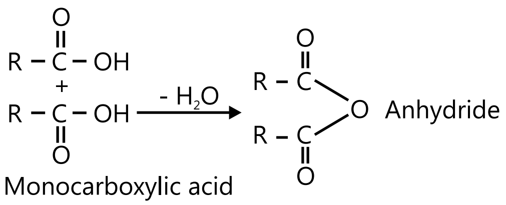
(iv) Hydrolysis: Carboxylic acids are formed when acid anhydrides react with water. Cyclic anhydrides hydrolyse to dicarboxylic acids.



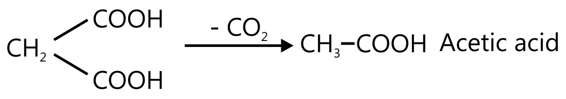
Phthalic anhydride

Phthalic acid

8. HEATING EFFECTS

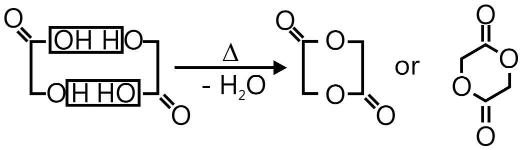
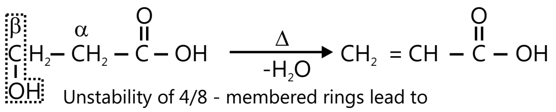
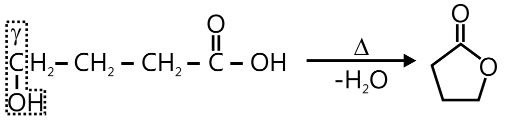


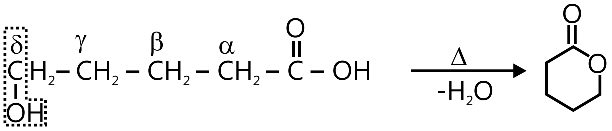
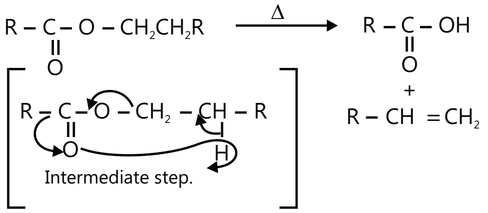
Monocarboxylic acid



Dicarboxylic acid

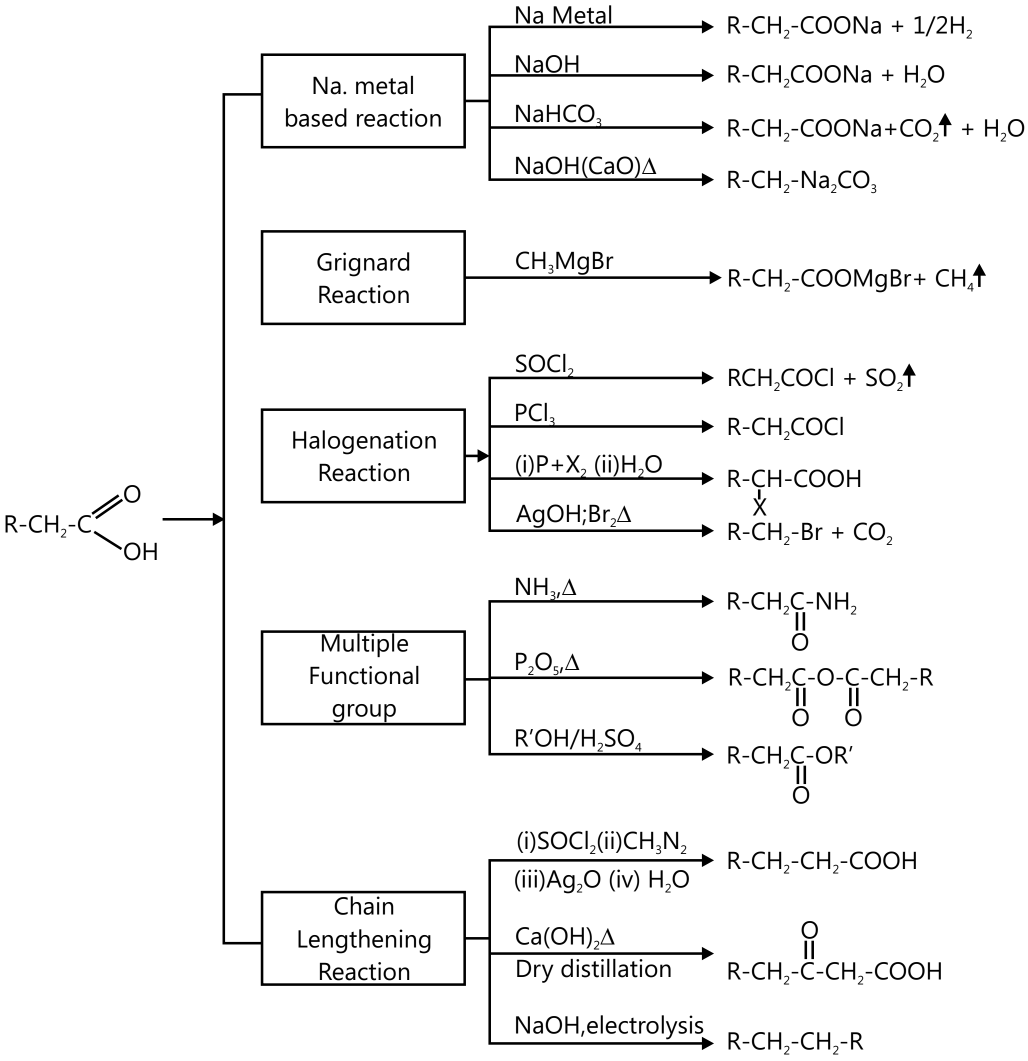
Table 24.8: Heating effects on hydroxy acids & ester

(1) α - Hydroxy acid	
(2) β - Hydroxy acid	 Unstability of 4/8 - membered rings lead to the formation of a,b - unsaturated acids
(3) γ - Hydroxy acid	

(4) δ - Hydroxy acid	
(5) Ester	

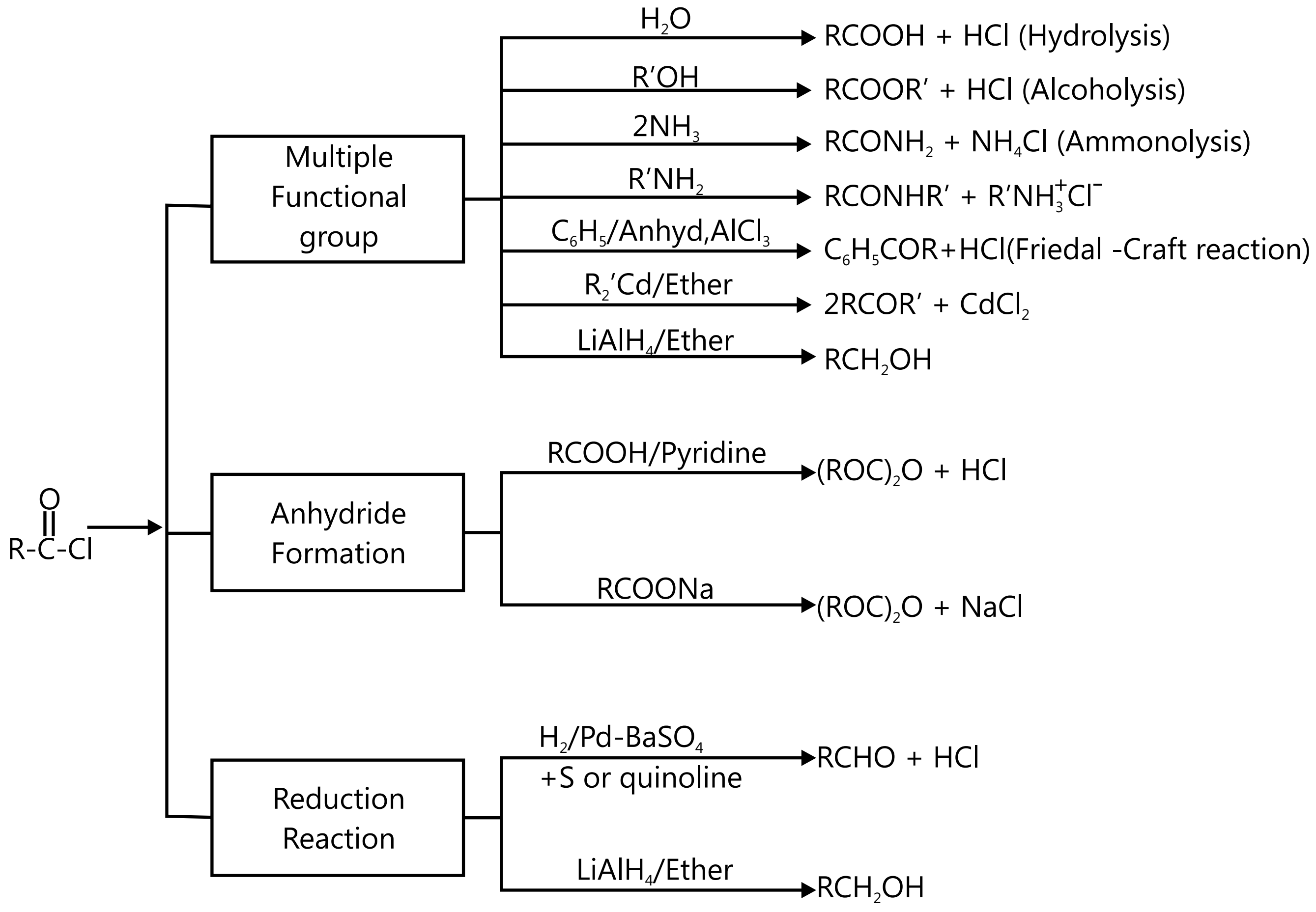
POINTS TO REMEMBER

(a) Summary of Reactions of Carboxylic Acids



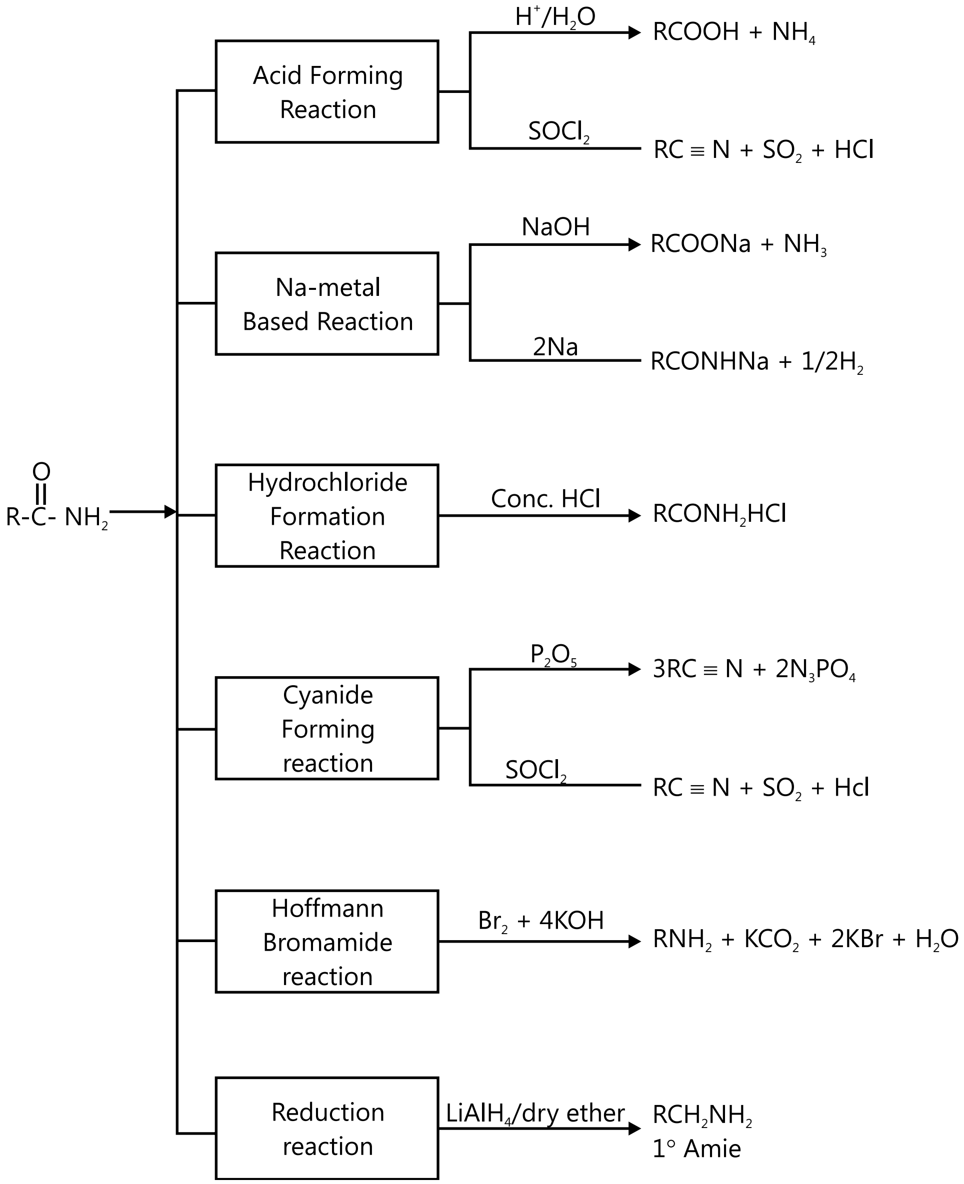
(b) Summary of Reactions of Acid Halides

Reaction of Acid Chloride

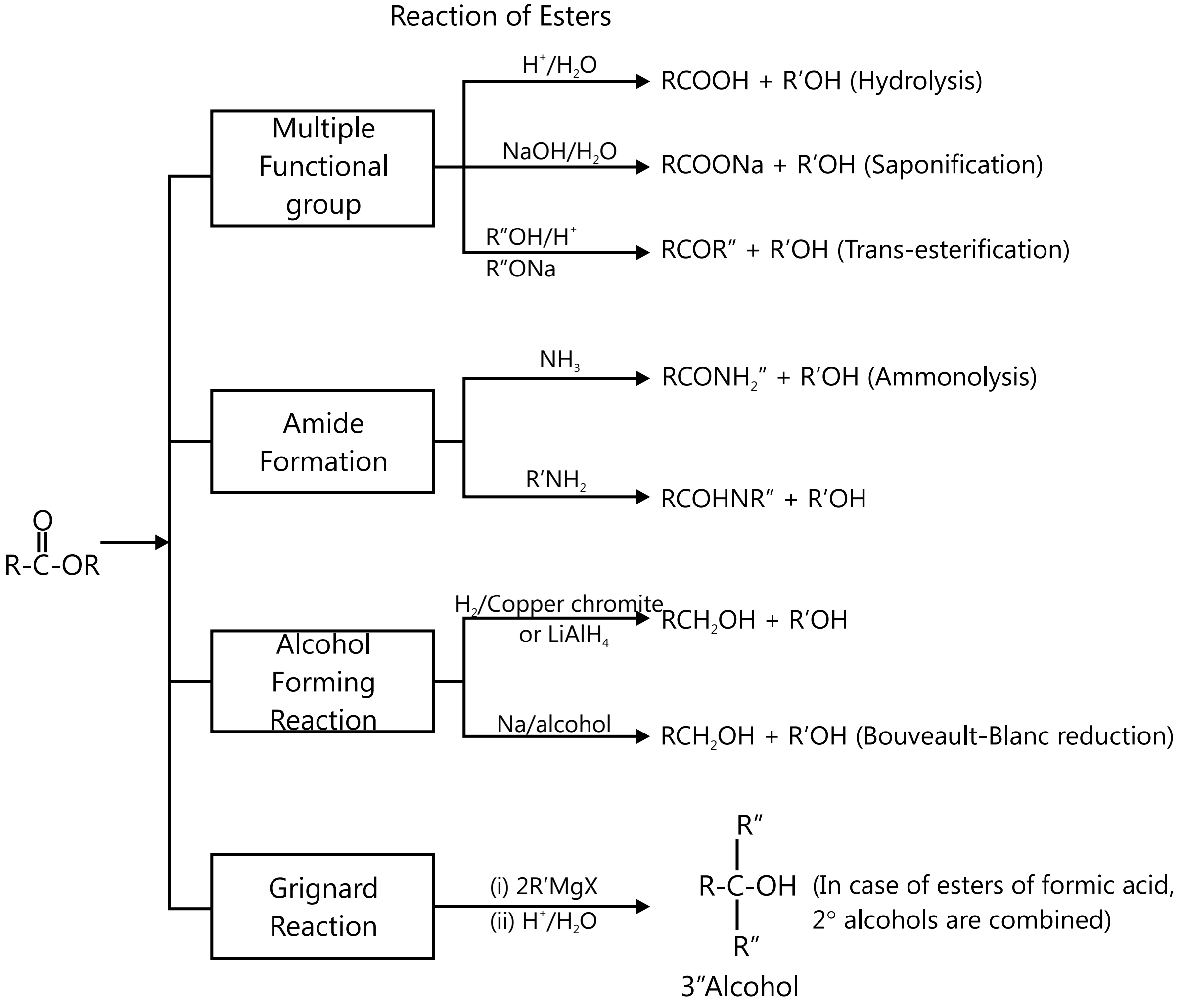


(c) Summary of Reactions of Amides

Reaction of amide



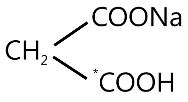
(d) Summary of Reactions of Esters


Reaction of Esters

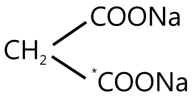
Solved Examples

JEE Main/Boards

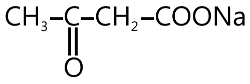
Example 1: Select the correct statement about the following compounds I, II, II.


$\mathrm{CH_2}\begin{array}{l}\diagup\,\mathrm{COONa}\\ \diagdown\,{}^{*}\mathrm{COOH}\end{array}$

(I)


$\mathrm{CH_2}\begin{array}{l}\diagup\,\mathrm{COONa}\\ \diagdown\,{}^{*}\mathrm{COONa}\end{array}$

(II)


$\mathrm{CH_3-\underset{\underset{O}{\|}}{C}-CH_2-COONa}$

(III)

(A) (I) decarboxylates faster than (II) on heating.

(B) Only $^*CO_2$ is eliminated on heating of compound(I).

(C) Compound (I) eliminates a mixture of CO_2 and $^*CO_2$ on heating.

(D) The rate of decarboxylation of (II) is faster than (III).

Sol 1: (A) Nature of functional group also has an influence on rate of decarboxylation. Presence of Electron Withdrawing Group-Increases its rate of decarboxylation.