

CHEM 245

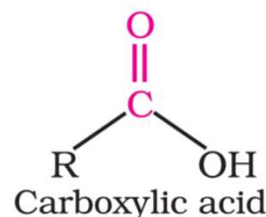
Organic Chemistry II

PRE-REQUISITES COURSE; CHEM 244
CREDIT HOURS; 2 (2+0)

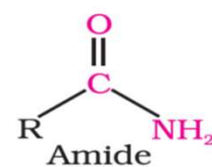
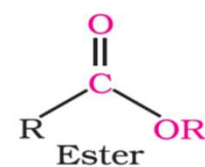
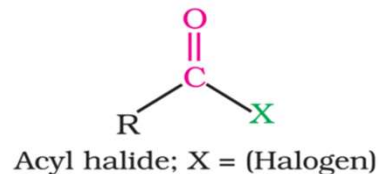
Carboxylic Acid and Derivatives

Carboxylic Acids

- Carbon compounds containing a *carboxyl functional group*, -COOH are called *carboxylic acids*.
- The carboxyl group, *consists of a carbonyl group attached to a hydroxyl group*, hence its name carboxyl.



- Depending on the group, alkyl or aryl, attached to carboxylic carbon, carboxylic acids may be
 - Aliphatic (R-COOH) or
 - Aromatic (Ar-COOH).
- *Fatty acids*, some higher members of aliphatic carboxylic acids ($\text{C}_{12} - \text{C}_{18}$), occur in natural fats as esters of glycerol.
- Carboxylic acids serve as *starting material* for several other important organic compounds such as *anhydrides*, *esters*, *acid chlorides*, *amides*, etc.



Nomenclature of Carboxylic Acids

A) Common Names

- The **common names** of carboxylic acids all end in *-ic acid*.
- These names usually come from some Latin or Greek word that indicates the original source of the acid.
- **Common name**, substituents are located with Greek letters, *beginning with the α -carbon atom*.

Carbon atoms	Formula	Source	Common name	IUPAC name
1	HCOOH	ants (Latin, <i>formica</i>)	formic acid	methanoic acid
2	CH ₃ COOH	vinegar (Latin, <i>acetum</i>)	acetic acid	ethanoic acid
3	CH ₃ CH ₂ COOH	milk (Greek, <i>protos pion</i> , first fat)	propionic acid	propanoic acid
4	CH ₃ (CH ₂) ₂ COOH	butter (Latin, <i>butyrum</i>)	butyric acid	butanoic acid
5	CH ₃ (CH ₂) ₃ COOH	valerian root (Latin, <i>valere</i> , to be strong)	valeric acid	pentanoic acid
6	CH ₃ (CH ₂) ₄ COOH	goats (Latin, <i>caper</i>)	caproic acid	hexanoic acid
7	CH ₃ (CH ₂) ₅ COOH	vine blossom (Greek, <i>oenanthe</i>)	enanthic acid	heptanoic acid
8	CH ₃ (CH ₂) ₆ COOH	goats (Latin, <i>caper</i>)	caprylic acid	octanoic acid
9	CH ₃ (CH ₂) ₇ COOH	pelargonium (an herb with stork-shaped seed capsules; Greek, <i>pelargos</i> , stork)	pelargonic acid	nonanoic acid
10	CH ₃ (CH ₂) ₈ COOH	goats (Latin, <i>caper</i>)	capric acid	decanoic acid

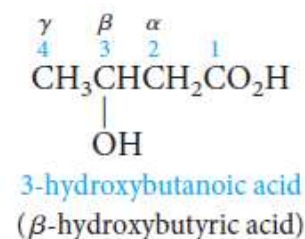
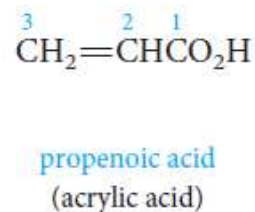
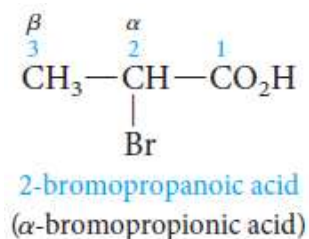
Nomenclature of Carboxylic Acids

B) IUPAC System

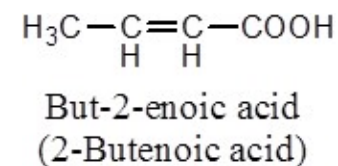
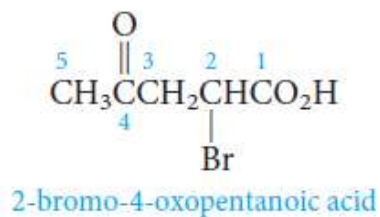
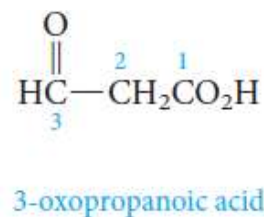
- We replace the final **e** in the name of the corresponding alkane with the suffix **-oic** and add the word **acid**.

Alkane-e** + **oic acid** = **Alkanoic acid****

- **IUPAC system**, the chain is numbered beginning with the carboxyl carbon atom, and substituents are located in the usual way.



- **The carboxyl group has priority over alcohol, aldehyde, or ketone** functionality in naming.
- The prefix **oxo-** is used to locate the carbonyl group of the aldehyde or ketone.



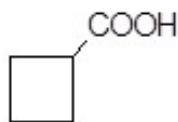
Nomenclature of Carboxylic Acids

Cycloalkane carboxylic acid

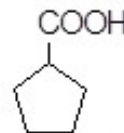
- When the carboxyl group is attached to a ring, the ending -carboxylic acid is added to the name of the parent cycloalkane. (i.e. **Cycloalkanecarboxylic acid**)



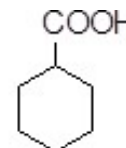
Cyclopropanecarboxylic acid



Cyclobutanecarboxylic acid



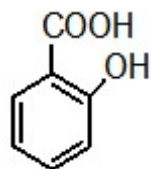
Cyclopentanecarboxylic acid



Cyclohexanecarboxylic acid

Aromatic Acids

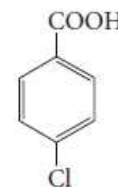
- Aromatic acids** are named by attaching the suffix *-oic acid* or *-ic acid* to an appropriate prefix derived from the aromatic hydrocarbon.



Common name: **Salicylic acid**
IUPAC name : 2-Hydroxybenzenecarboxylic acid



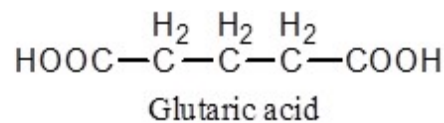
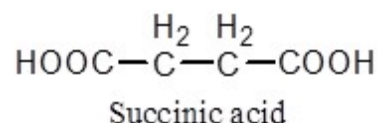
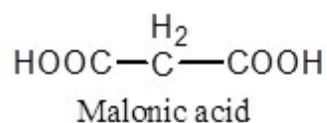
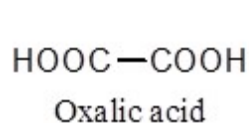
benzoic acid
(benzenecarboxylic acid)



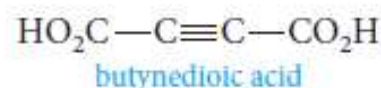
p-chlorobenzoic acid
(4-chlorobenzenecarboxylic acid)

Nomenclature of Carboxylic Acids

- **Dicarboxylic acids** (*acids that contain two carboxyl groups*) are known almost exclusively by their common names.

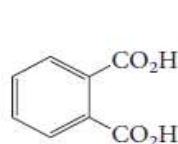


- **Aliphatic dicarboxylic acids** are given the suffix *-dioic acid* in the IUPAC system.



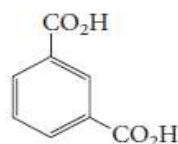
- The three **benzenedicarboxylic acids** are generally known by their common names.

Common name:
IUPAC name:



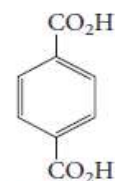
phthalic acid

Benzene-1,2-
dicarboxylic
acid



isophthalic acid

Benzene-1,3-
dicarboxylic
acid

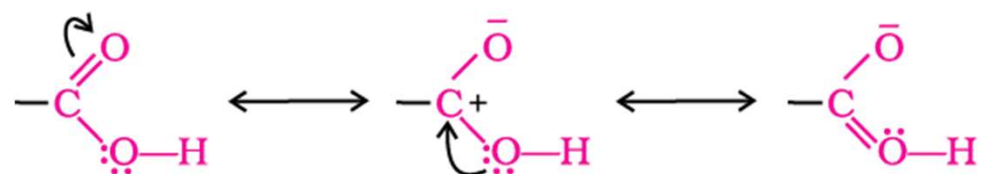


terephthalic acid

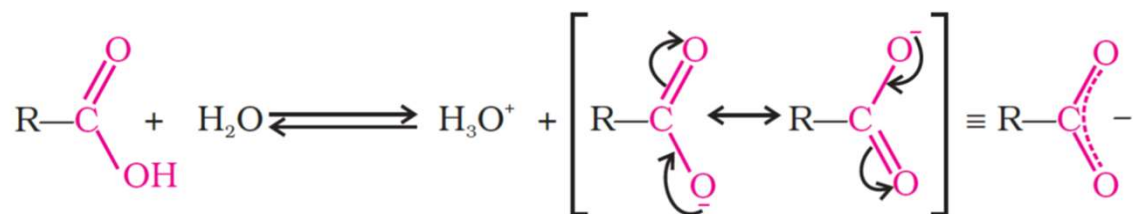
Benzene-1,4-
dicarboxylic
acid

Structure of Carboxyl Group

- In carboxylic acids, the bonds to the carboxyl carbon lie in one plane and are separated by about 120° .
- The carboxylic carbon is less electrophilic than carbonyl carbon because of the possible resonance structure.



- Carboxylic acids dissociate in water to give resonance stabilized carboxylate anions and hydronium ion.



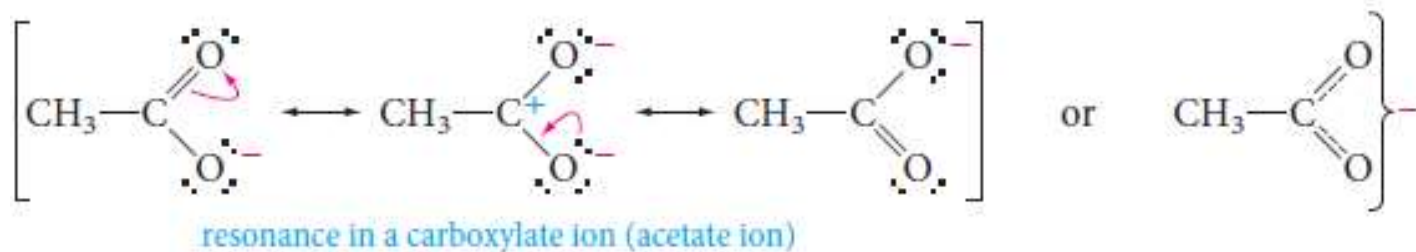
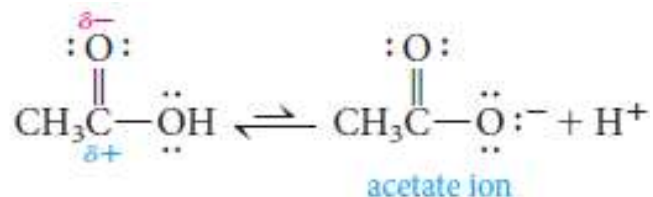
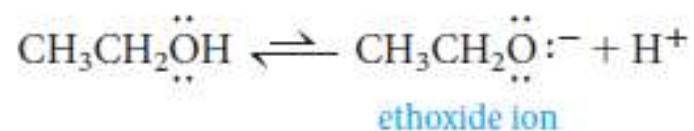
Acidity

Acid Strength and Structure

Acid Strength and Structure

Why carboxylic acids are more acidic than alcohols?

- In **ethoxide ion**, the negative charge is localized on a single oxygen atom.
- In **acetate ion**, on the other hand, the negative charge can be delocalized through **resonance**.

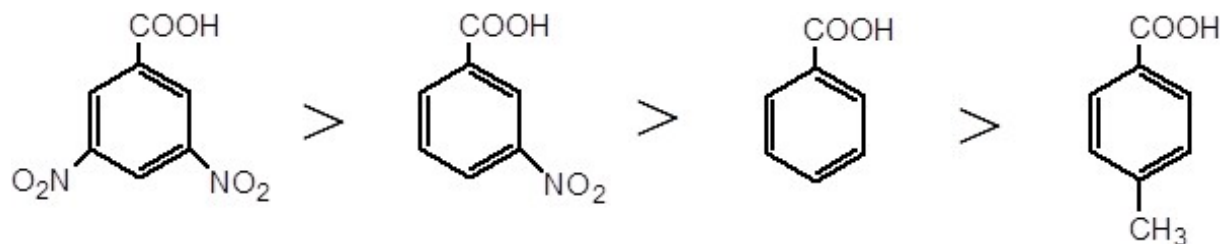


Acid Strength and Structure

Effect of Structure on Acidity; the Inductive Effect

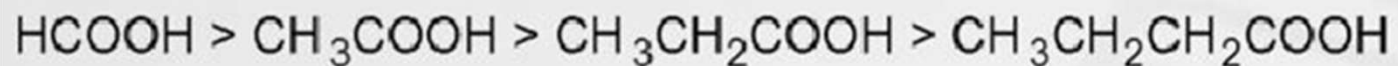
- Acidities can vary depending on what other groups are attached to the molecule.
- Recall that *electron-withdrawing groups (-I) enhance acidity*, and *electron-releasing groups (+I) reduce acidity*.

This effect relays charge through bonds, by displacing bonding electrons toward electronegative atoms, or away from electropositive atoms.



- **Formic acid is a substantially stronger acid than acetic acid.**

This suggests that the methyl group is more electron-releasing (hence anion-destabilizing and acidity-reducing) than hydrogen.

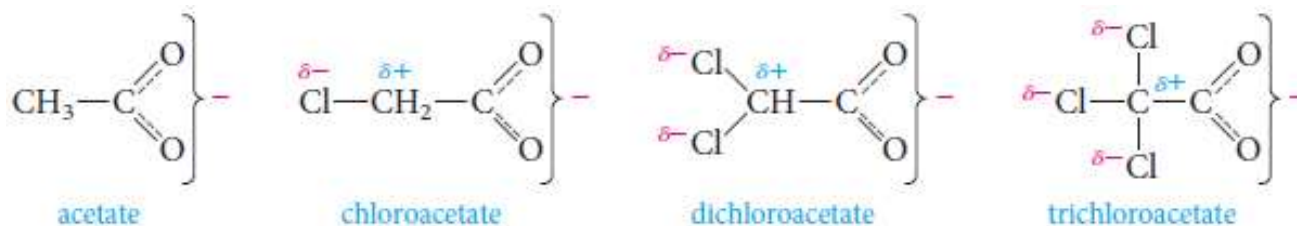
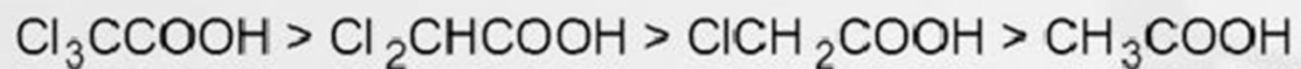


Acid Strength and Structure

Effect of Structure on Acidity; the Inductive Effect

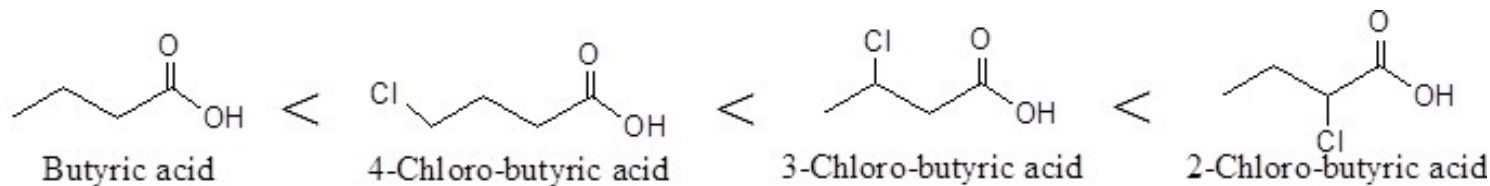
- **Example:** acetic acid with those of mono-, di-, and trichloroacetic acids.

Comparison of acid strengths of acetic Acid and chlorinated acetic acids



The more chlorines, the greater the effect and the greater the strength of the acid.

- **Comparison of acid strengths** of butyric acid and the monochlorinated acids.



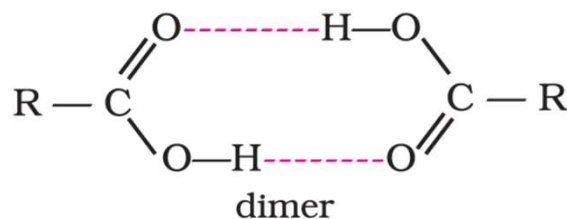
Physical Properties of Carboxylic Acids

○ Physical State

- Aliphatic carboxylic acids up to nine carbon atoms are colorless liquids at room temperature with unpleasant odors.
- The higher acids are wax like solids and are practically odorless due to their low volatility.

○ Boiling Points

- Carboxylic acids are **higher boiling liquids than aldehydes, ketones and even alcohols** of comparable molecular masses. This is due to more extensive association of carboxylic acid molecules through **intermolecular hydrogen bonding**.
- The hydrogen bonds are not broken completely even in the vapor phase.
- In fact, most **carboxylic acids exist as dimer** in the vapor phase or in the aprotic solvents.

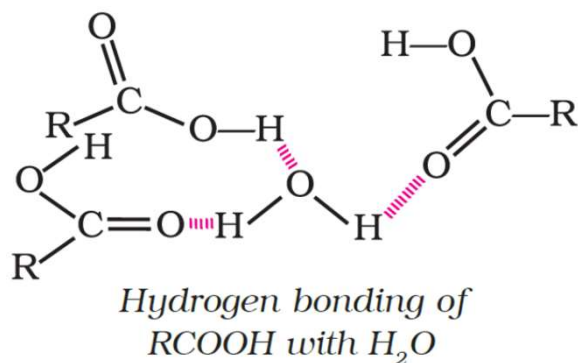


*In vapour state or in
aprotic solvent*

Physical Properties of Carboxylic Acids

○ Solubility in Water

- Simple *aliphatic carboxylic acids having up to four carbon atoms are miscible in water* due to the *formation of hydrogen bonds with water*.
- The solubility decreases with increasing number of carbon atoms.
- *Higher carboxylic acids* are practically *insoluble in water* due to the *increased hydrophobic interaction of hydrocarbon part*.
- *Benzoic acid*, the simplest aromatic carboxylic acid is nearly *insoluble in cold water*.
- Carboxylic acids are also soluble in less polar organic solvents like benzene, ether, alcohol, chloroform, etc.

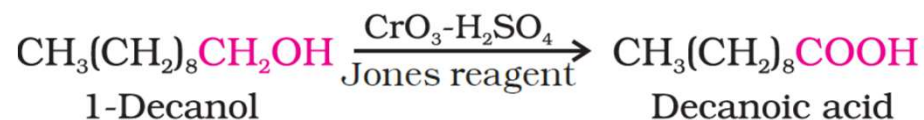
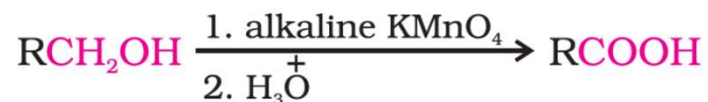


Structure	Name	Mol. Wt.	b.p. °C	Solubility in H_2O at 25°C
HCOOH CH ₃ CH ₂ OH	Formic acid Ethyl alcohol	46 46	100 78	Very soluble Very soluble
CH ₃ COOH CH ₃ CH ₂ CH ₂ OH	Acetic acid <i>n</i> -Propyl alcohol	60 60	118 97	Very soluble Very soluble
CH ₃ (CH ₂) ₃ COOH CH ₃ (CH ₂) ₄ CH ₂ OH	Valeric acid <i>n</i> -Hexyl alcohol	102 102	187 156	4.0 g/100 g H ₂ O 0.6 g/100 g H ₂ O
Ph-COOH Ph-CH ₂ CH ₂ OH	Benzoic acid 3-Phenylethanol	122 122	250 250	Insoluble Insoluble

Preparation of Carboxylic Acids

1. From Primary Alcohols and Aldehydes

- **Primary alcohols** are readily oxidized to carboxylic acids with common oxidizing agents such as potassium permanganate (KMnO_4) in neutral, acidic or alkaline media or by potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) and chromium trioxide (CrO_3) in acidic media (Jones reagent).



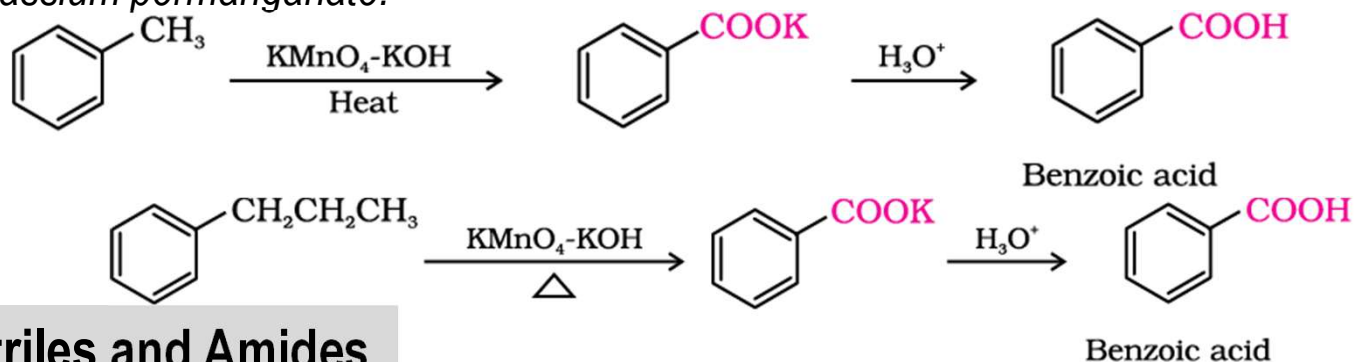
- Carboxylic acids are also prepared **from aldehydes** by the use of mild oxidizing agents



Preparation of Carboxylic Acids

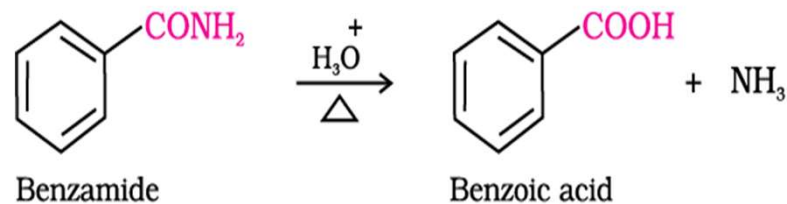
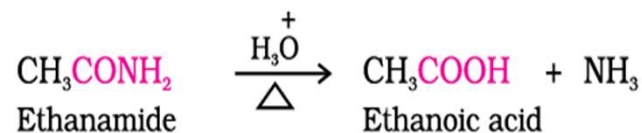
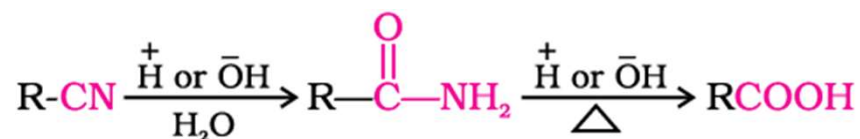
2. From Alkylbenzenes

- Aromatic carboxylic acids** can be prepared by vigorous oxidation of alkyl benzenes with chromic acid or acidic or alkaline potassium permanganate.



3. From Nitriles and Amides

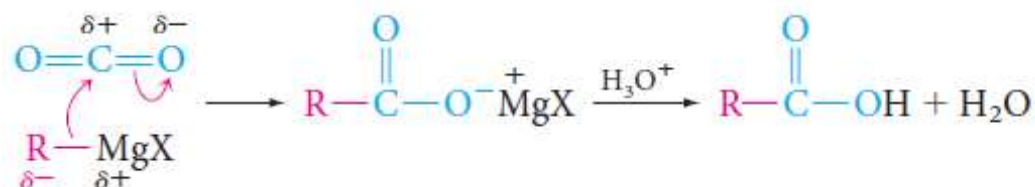
- Nitriles are hydrolyzed to amides** and then to acids in the presence of H^+ or HO^- as catalyst.



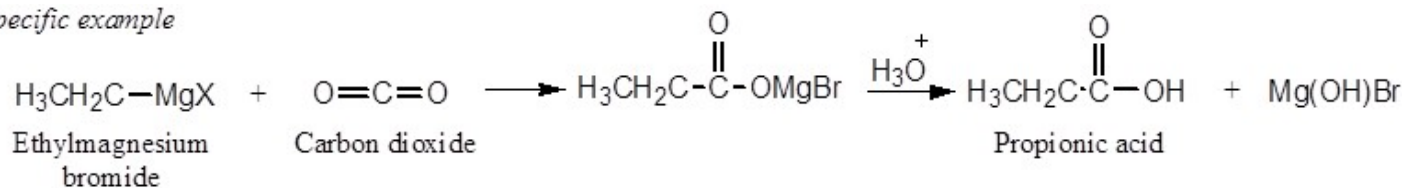
Preparation of Carboxylic Acids

4. From Grignard Reagents

Grignard reagents react with carbon dioxide (dry ice) to form salts of carboxylic acids which in turn give corresponding carboxylic acids after acidification with mineral acid.



Specific example

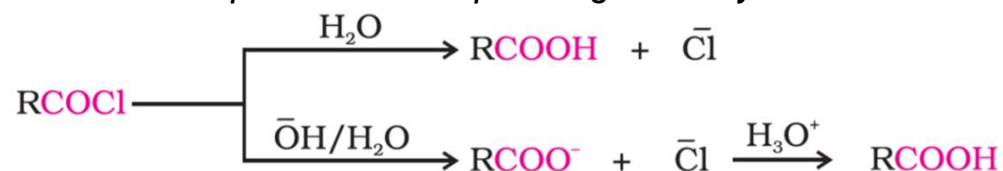


Note: the Grignard reagents and nitriles can be prepared from alkyl halides.

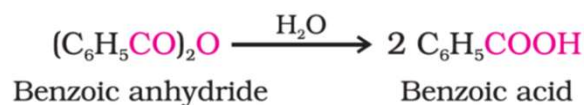
Preparation of Carboxylic Acids

5. From Acyl Halides, Anhydrides and Esters

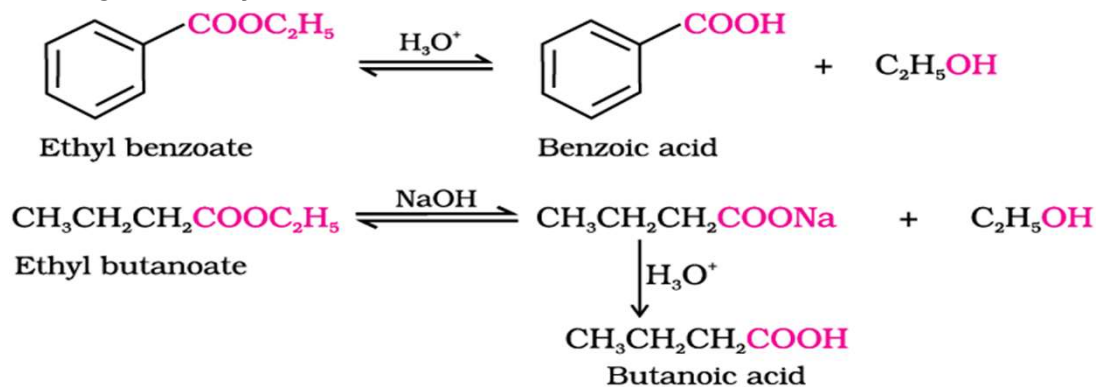
- **Acid chlorides** when hydrolyzed with water give carboxylic acids or more readily hydrolyzed with aqueous base to give carboxylate ions which on acidification provide corresponding carboxylic acids.



- **Anhydrides** on the other hand are hydrolyzed to corresponding acid(s) with water.



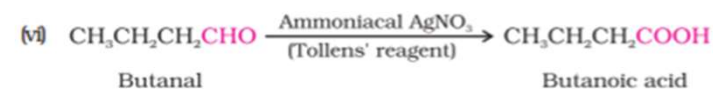
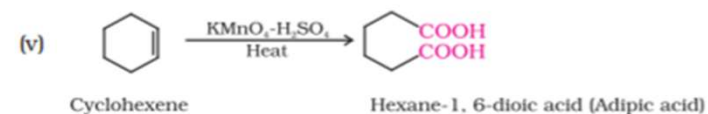
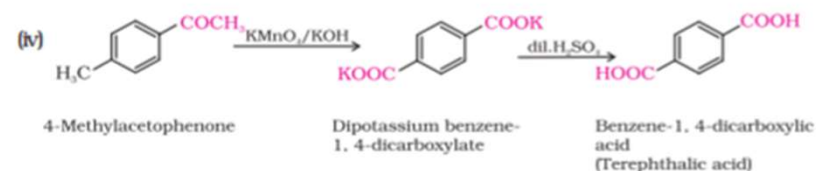
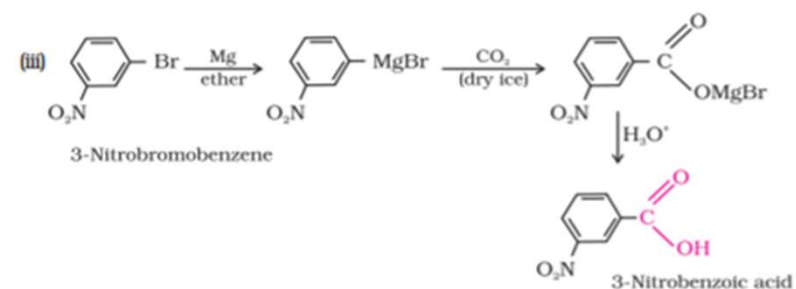
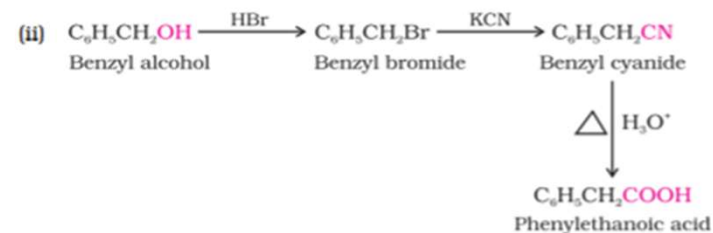
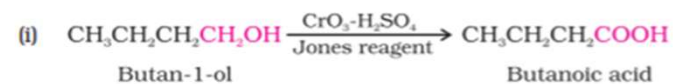
- **Acidic hydrolysis of esters** gives directly carboxylic acids while basic hydrolysis gives carboxylates, which on acidification give corresponding carboxylic acids.



Questions

Write chemical reactions to affect the following transformations:

- (i) Butan-1-ol to butanoic acid
- (ii) Benzyl alcohol to phenylethanoic acid
- (iii) 3-Nitrobromobenzene to 3-nitrobenzoic acid
- (iv) 4-Methylacetophenone to benzene-1,4-dicarboxylic acid
- (v) Cyclohexene to hexane-1,6-dioic acid
- (vi) Butanal to butanoic acid.



Questions

Show how each of the following compounds can be converted to benzoic acid.

(i) Ethylbenzene (ii) Acetophenone

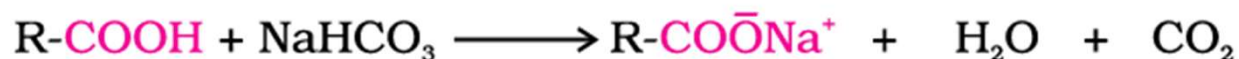
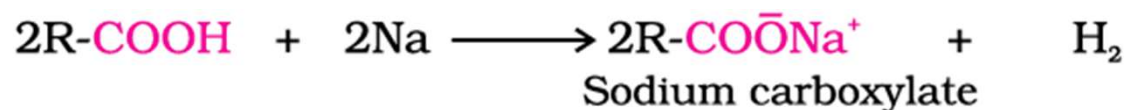
(iii) Bromobenzene (iv) Phenylethene (Styrene)

Chemical Reactions of Carboxylic Acids

Reactions Involving Cleavage of O–H Bond

(i) Acidity: Reactions with Metals and Alkalies

- The carboxylic acids *like alcohols* evolve hydrogen with *electropositive metals* and form salts with *alkalies similar to phenols*.



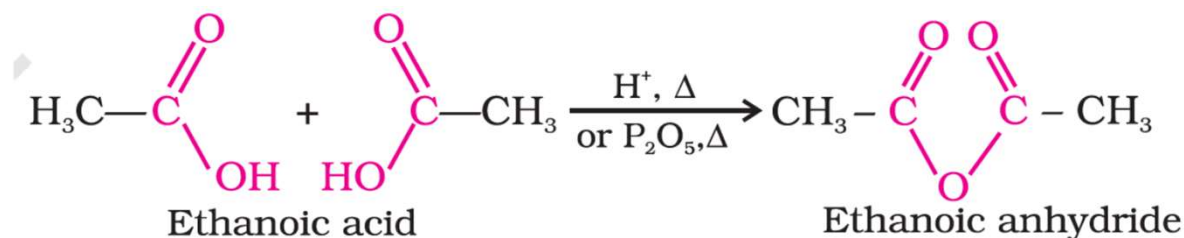
- However, *unlike phenols* they react with *weaker bases* such as carbonates and hydrogencarbonates to evolve carbon dioxide (detection of the presence of carboxyl group in an organic compound).

Chemical Reactions of Carboxylic Acids

Reactions Involving Cleavage of C–OH Bond

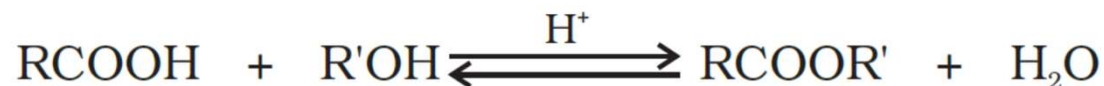
1. Formation of Anhydride

Carboxylic acids on heating with mineral acids such as H_2SO_4 or with P_2O_5 give corresponding **anhydride**.



2. Esterification

Carboxylic acids are **esterified with alcohols or phenols** in the presence of a mineral acid such as concentrated H_2SO_4 or HCl gas as a catalyst.

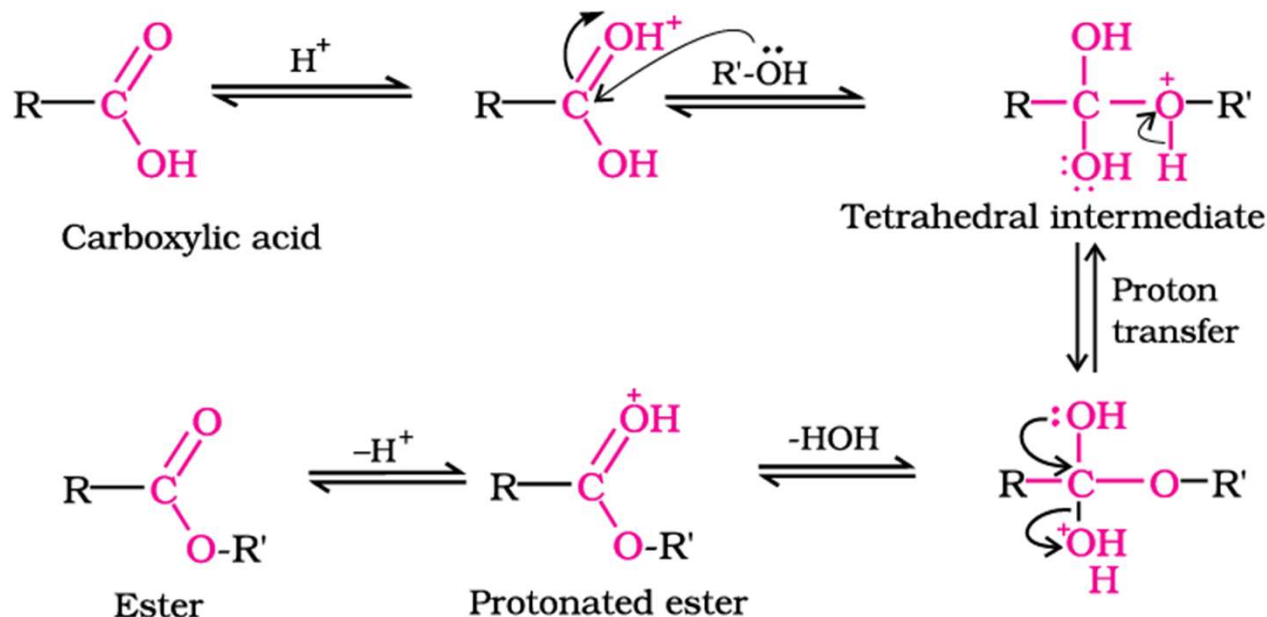


Chemical Reactions of Carboxylic Acids

Reactions Involving Cleavage of C–OH Bond

Mechanism of Esterification of Carboxylic Acids: Nucleophilic Acyl Substitution

- **Protonation** of the carbonyl oxygen activates the carbonyl group towards nucleophilic addition of the alcohol.
- **Proton transfer in the tetrahedral intermediate** converts the hydroxyl group into $-^+OH_2$ group, which, being a better leaving group, is eliminated as neutral water molecule.
- The protonated ester so formed finally **loses a proton to give the ester**.

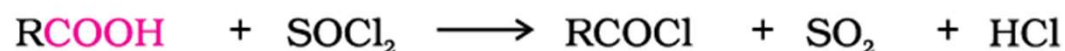
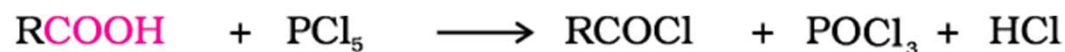


Chemical Reactions of Carboxylic Acids

Reactions Involving Cleavage of C–OH Bond

3. Reactions with PCl_5 , PCl_3 and SOCl_2

The hydroxyl group of carboxylic acids, behaves like that of alcohols and is easily replaced by chlorine atom on treating with PCl_5 , PCl_3 or SOCl_2 .



4. Reaction with Ammonia

Carboxylic acids react with ammonia to give ammonium salt which on further heating at high temperature give amides.

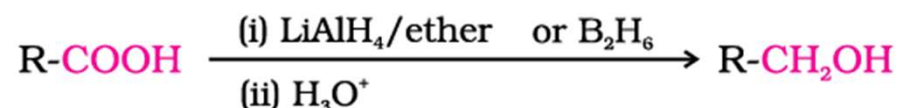


Chemical Reactions of Carboxylic Acids

Reactions Involving –COOH Group

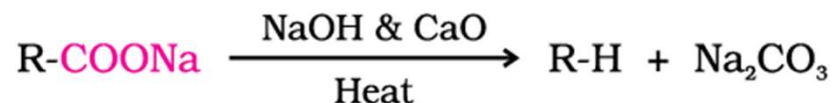
1. Reduction

Carboxylic acids are **reduced to primary alcohols** by lithium aluminum hydride or better with diborane.



2. Decarboxylation

Carboxylic acids **lose carbon dioxide to form hydrocarbons** when their sodium salts are heated with sodalime (NaOH and CaO in the ratio of 3 : 1).

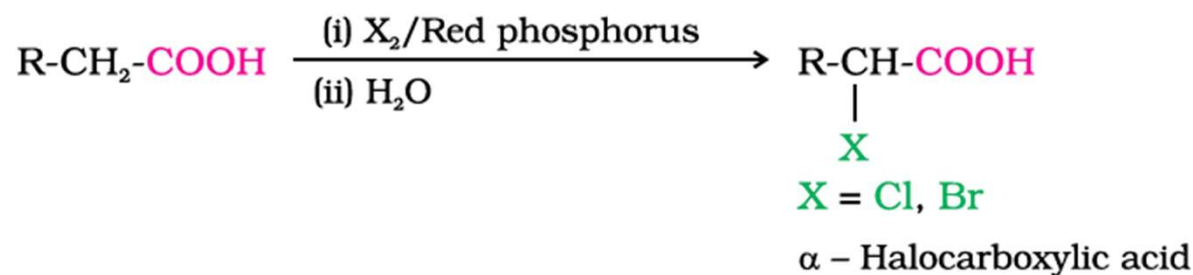


Chemical Reactions of Carboxylic Acids

Substitution Reactions in the Hydrocarbon Part

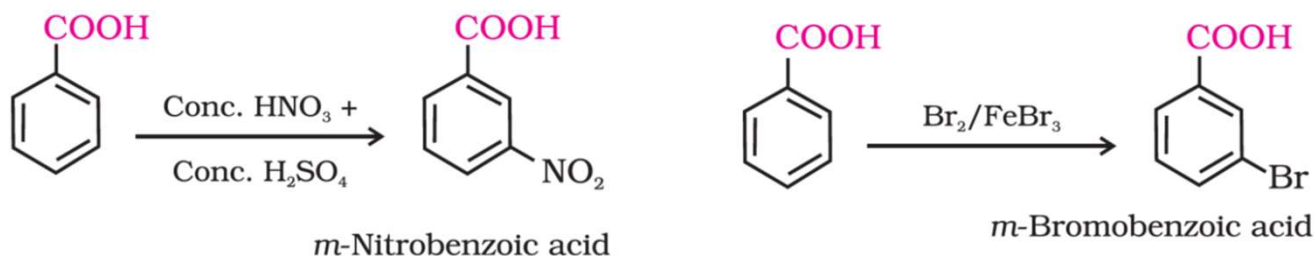
1. Halogenation (Hell-Volhard-Zelinsky reaction)

Carboxylic acids having an α -hydrogen are halogenated at the α -position on treatment with chlorine or bromine in the presence of small amount of red phosphorus to give *α -halocarboxylic acids*.

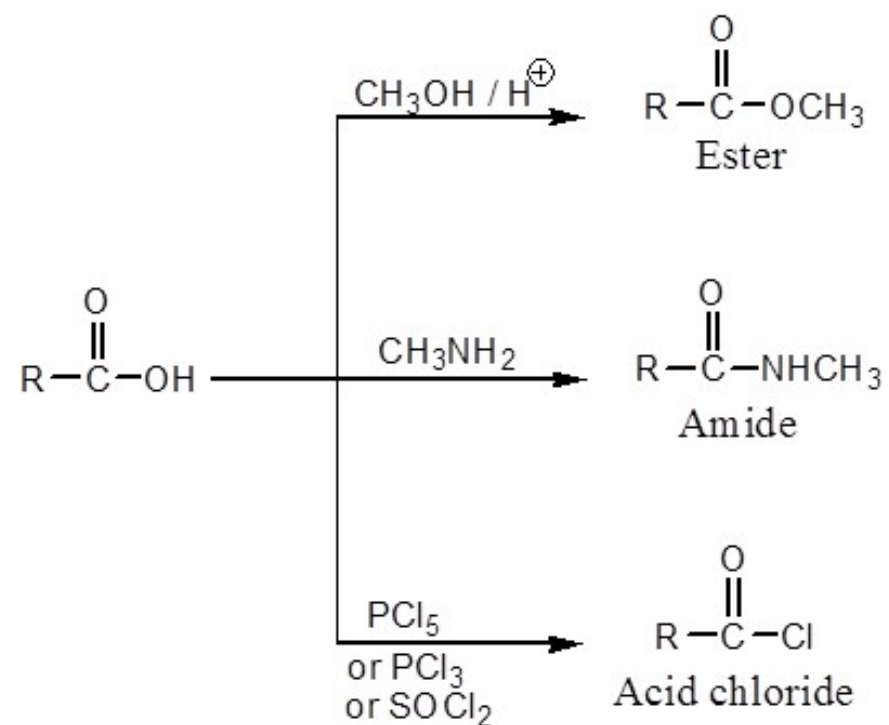
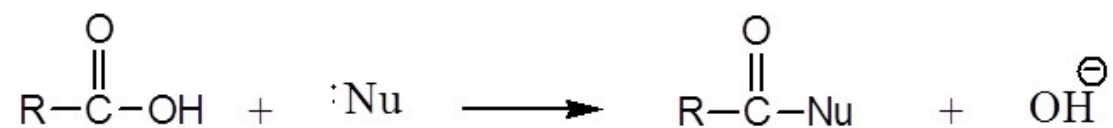


2. Ring Substitution

Aromatic carboxylic acids undergo *electrophilic substitution reactions* in which the carboxyl group acts as a deactivating and meta-directing group.

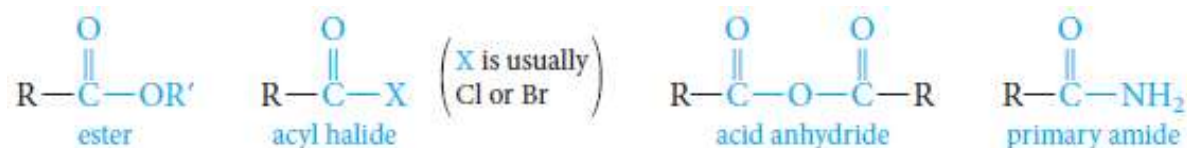


Carboxylic Acid Derivatives



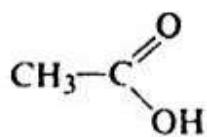
Carboxylic Acid Derivatives

- Carboxylic acid derivatives are compounds in which the hydroxyl part of the carboxyl group is replaced by various other groups.

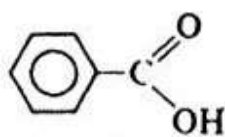


- All acid derivatives can be hydrolyzed to the corresponding carboxylic acid.

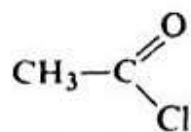
Acid derivative	H ₂ O (hydrolysis)
$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{Cl}$ acyl halide	$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{HCl}$
$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\overset{\text{O}}{\parallel}{\text{C}}-\text{R}$ acid anhydride	$2 \text{ R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH}$
$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{R}'$ ester	$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{R}'\text{OH}$
$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{NH}_2$ amide	$\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{NH}_3$
Main organic product	acid



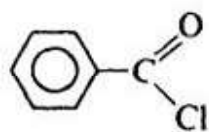
Acetic acid
Ethanoic acid



Benzoic acid



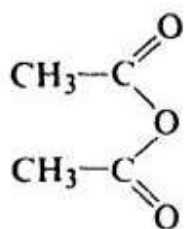
Acetyl chloride
Ethanoyl chloride



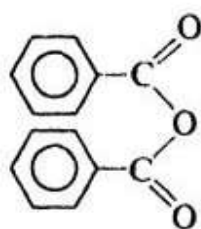
Benzoyl chloride

Change:

-ic acid to -yl chloride

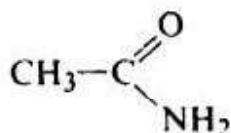


Acetic anhydride
Ethanoic anhydride

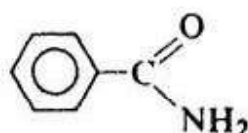


Benzoic anhydride

acid to anhydride

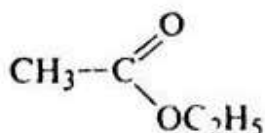


Acetamide
Ethanamide

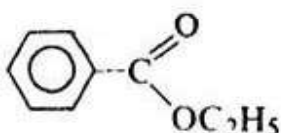


Benzamide

*-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*

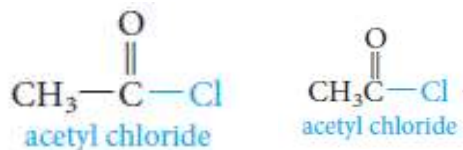
Carboxylic Acid Derivatives

Acid Chloride

- **Acyl chlorides** have the general formula RCOCl .
- **Acyl chlorides** are more common and less expensive than bromides or iodides.

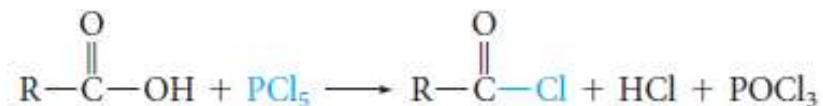
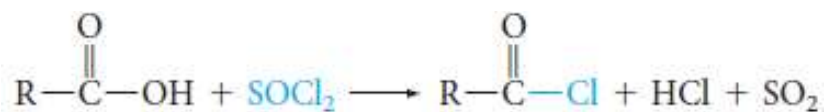
- **Nomenclature:**

Acyl chlorides, or acid chlorides, are named by replacing the -ic acid ending of the parent acid by -yl chloride.



- **Preparation:**

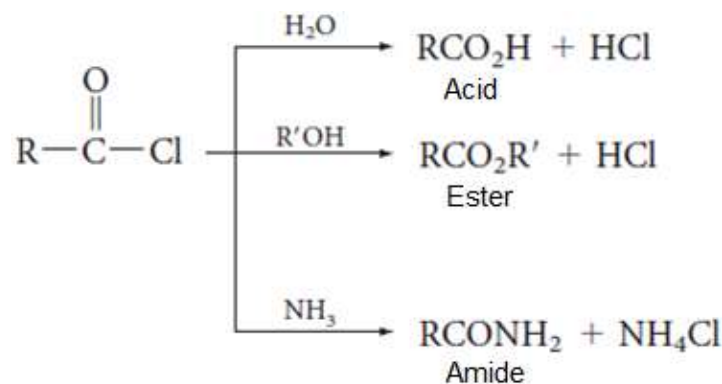
They can be prepared from acids by reaction with thionyl chloride or phosphorous pentachloride.



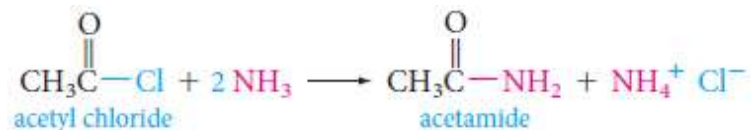
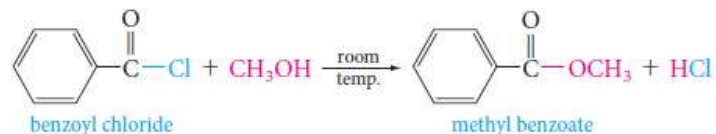
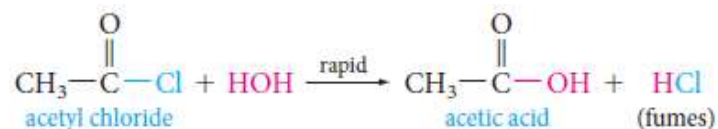
Carboxylic Acid Derivatives

Acid Chloride

- **Reactions:** They can react rapidly with most nucleophile.



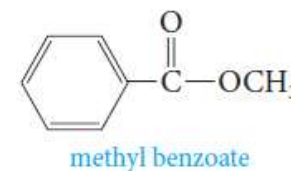
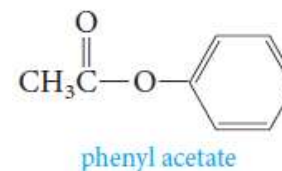
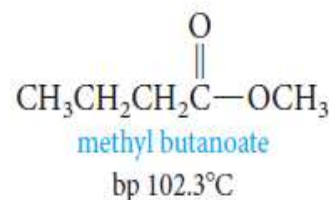
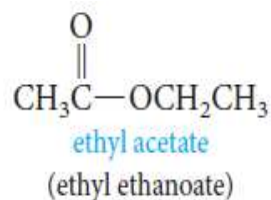
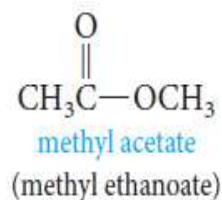
- **Examples:**



Carboxylic Acid Derivatives

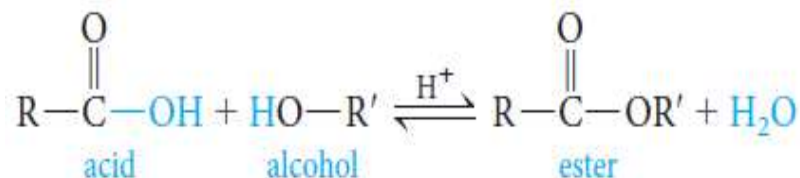
Esters

- **Esters** are derived from acids by replacing the -OH group by an -OR group and have the general formula $\text{R}'\text{COOR}$.
- **Nomenclature:**
 - They are named in a manner analogous to carboxylic acid salts.
 - The **R part of the -OR group is name first**, followed by the name of the acid, with the **-ic acid** ending changed to **-ate**.



Preparation:

When a carboxylic acid and an alcohol are heated in the presence of an acid catalyst (HCl or H_2SO_4), an equilibrium is established with the ester and water.

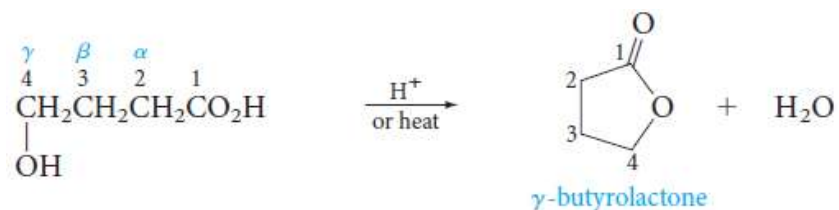


Carboxylic Acid Derivatives

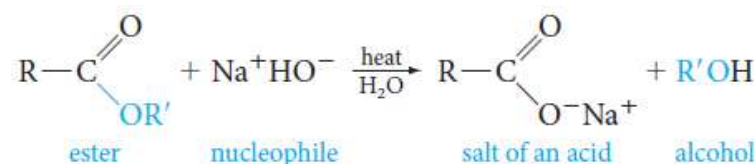
Esters

Reactions

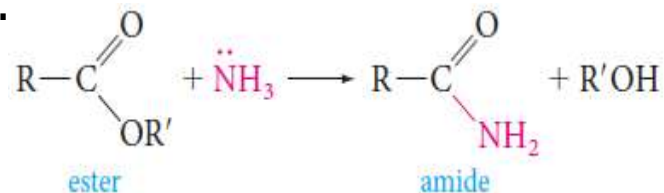
- **Cyclic esters (lactones)** can be prepared from hydroxy acids if these groups can come in contact through bending of the chain.



- **Saponification**; esters are commonly hydrolyzed with base.



- Ammonia converts esters to **amides**.



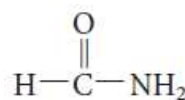
Carboxylic Acid Derivatives

Amides

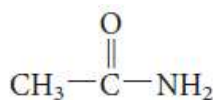
- **Amides** are the least reactive of the common carboxylic acid derivatives.
- Primary amides have general formula **RCONH₂**.

- **Nomenclature:**

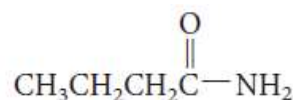
Amides are named by replacing the *-ic or -oic acid* ending of the acid name, either the common or the IUPAC name, with the *-amide* ending.



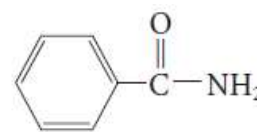
formamide
(methanamide)



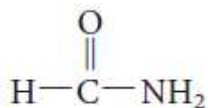
acetamide
(ethanamide)



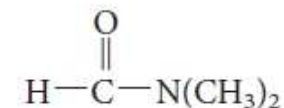
butanamide



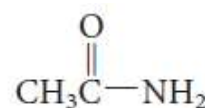
benzamide
(benzenecarboxamide)



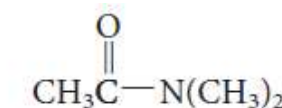
formamide



N,N-dimethylformamide



acetamide



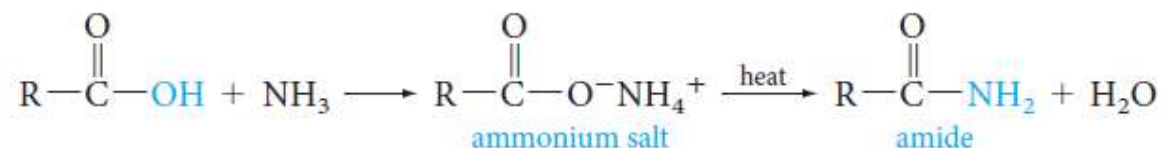
N,N-dimethylacetamide

Carboxylic Acid Derivatives

Amides

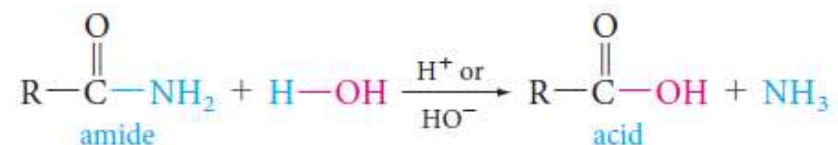
○ Preparation:

- They can be prepared by the reaction of ammonia with esters, with acyl halides, or with acid anhydrides.
- Amides can also prepared by heating the ammonium salts of acids.

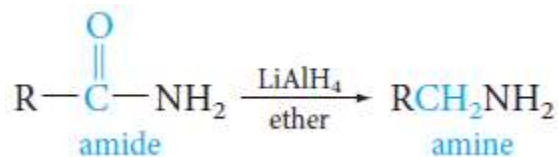


○ Reactions

- **Amides** react with nucleophiles and they can be hydrolyzed by water.



- **Amides** can be reduced by lithium aluminums hydride to give amines.



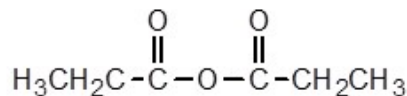
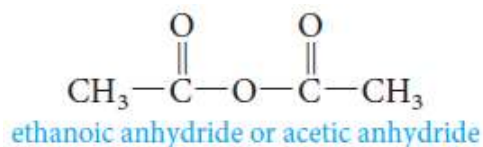
Carboxylic Acid Derivatives

Acid Anhydrides

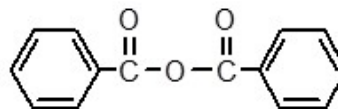
○ **Acid anhydrides** have general formula RCOOCOR .

○ **Nomenclature:**

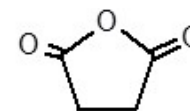
The name of an anhydrides is obtained by naming the acid from which is derived and replacing the word acid with anhydride.



IUPAC name: Propanoic anhydride
Common name: Propionic anhydride



Benzoic anhydride



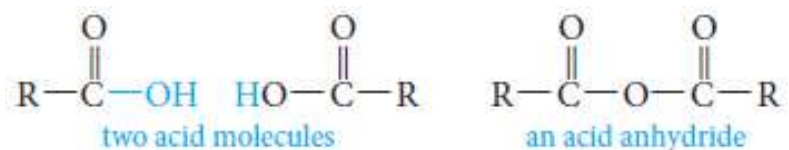
Succinic anhydride

Carboxylic Acid Derivatives

Acid Anhydrides

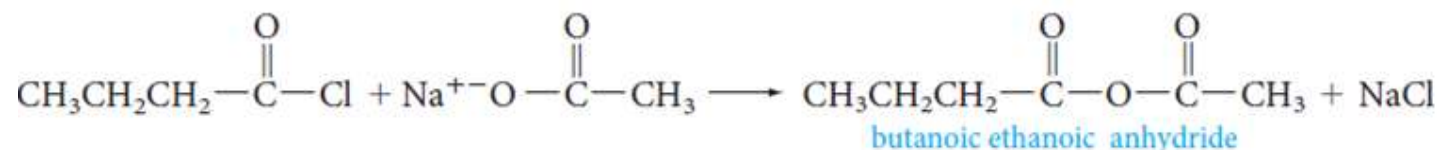
○ Preparation

- **Acid anhydrides** are derived from acids by removing water from two carboxyl groups and connecting the fragments.



- **Anhydrides** can also be prepared from acid chlorides and carboxylate salts.

*This method is used for preparing anhydrides derived from two different carboxylic acids (**mixed anhydrides**).*

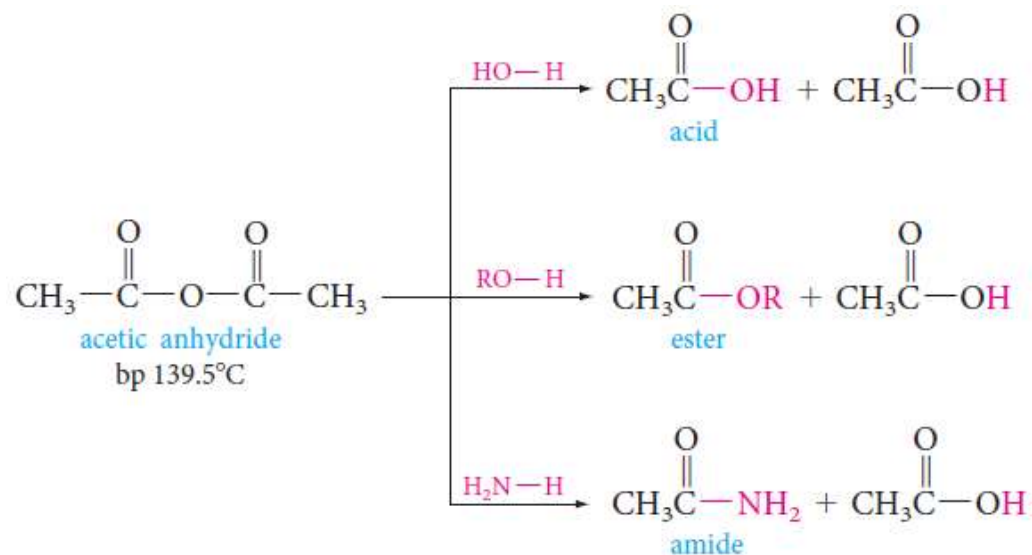


Carboxylic Acid Derivatives

Acid Anhydrides

○ Reactions

- **Anhydrides** undergo **nucleophilic acyl substitution reactions** (*They are more reactive than esters, but less reactive than acyl halides*).



Uses of Carboxylic Acids

- Hexane dioic acid is used in the manufacture of nylon-6, 6.
- Esters of benzoic acid are used in perfumery.
- Sodium benzoate is used as a food preservative.
- Higher fatty acids are used for the manufacture of soaps and detergents.