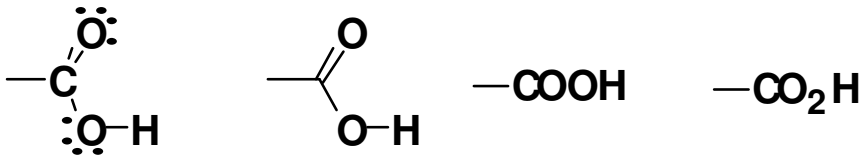
Carboxylic Acids

Chapter 17

Structure

- The functional group of a carboxylic acid is a carboxyl group

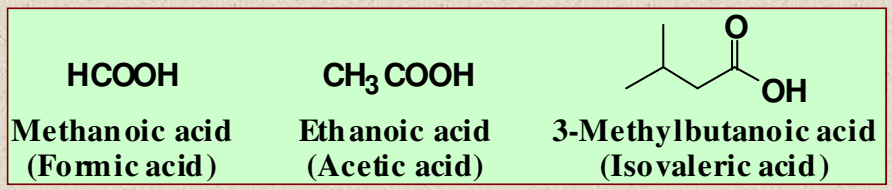


Alternative representations for a carboxyl group

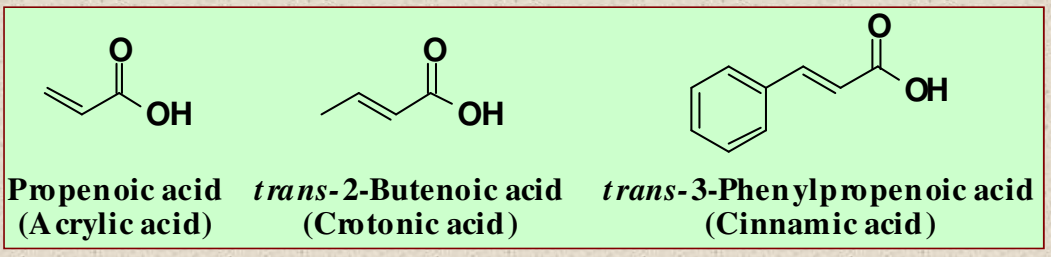
  - the general formula for an aliphatic carboxylic acid is RCOOH; that for an aromatic carboxylic acid is ArCOOH

Nomenclature

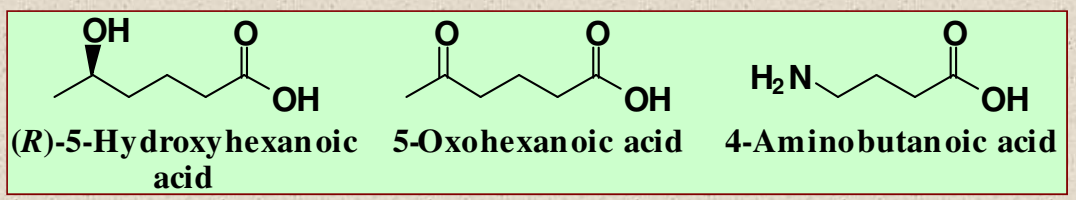
- IUPAC names: drop the -e from the parent alkane and add the suffix -oic acid

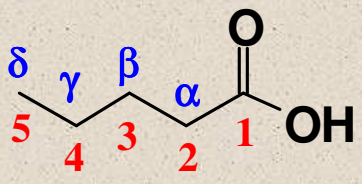


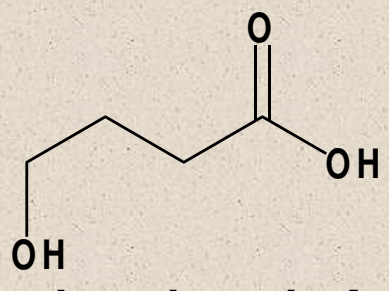
  - if the compound contains a carbon-carbon double bond, change the infix -an- to -en-



- The carboxyl group takes precedence over most other functional groups



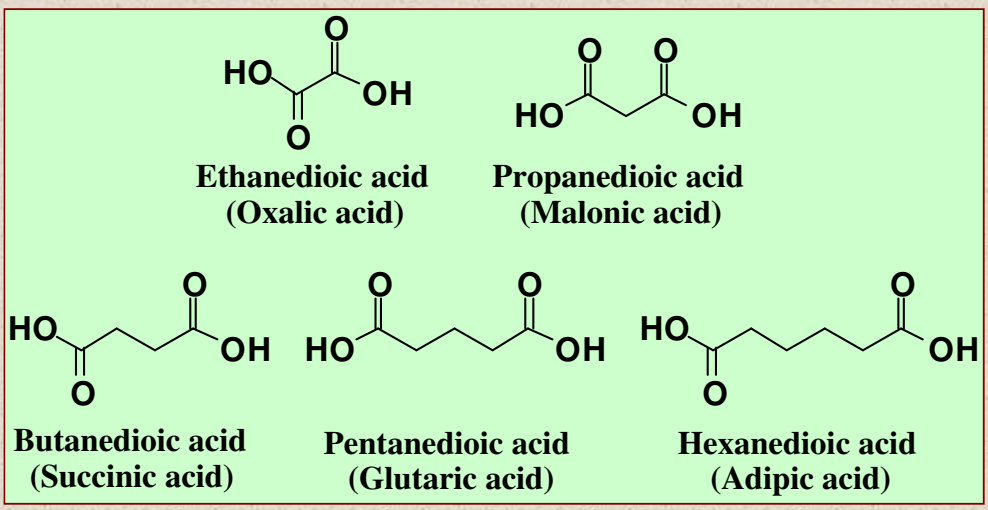




γ-hydroxybutyric Acid
GHB

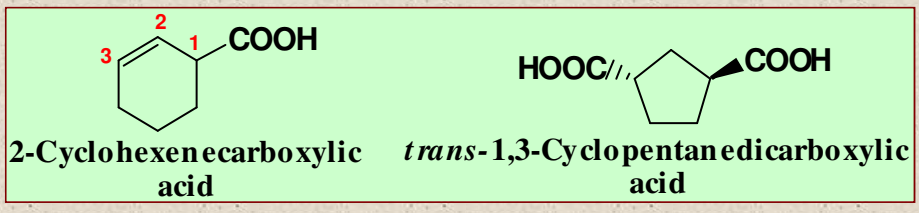
Nomenclature

– **dicarboxylic acids:** add the suffix -dioic acid to the name of the parent alkane containing both carboxyl groups



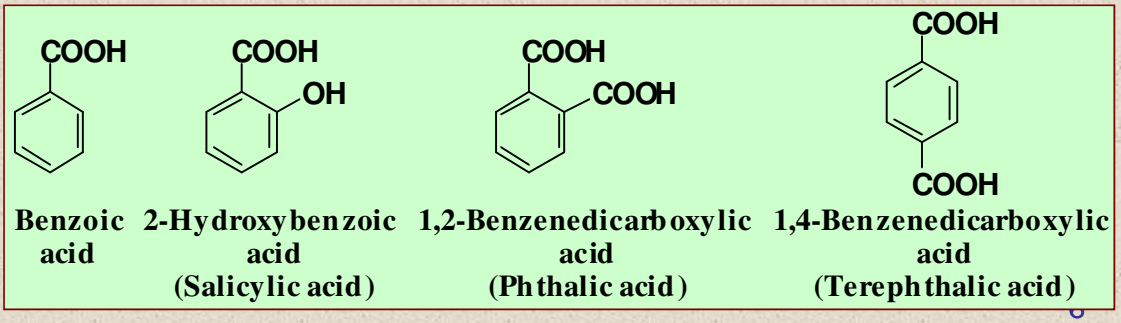
Nomenclature

– if the carboxyl group is bonded to a ring, name the ring compound and add the suffix -carboxylic acid



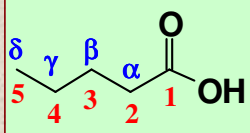
– **benzoic acid** is the simplest aromatic carboxylic acid

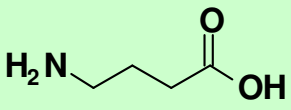
– use numbers to show the location of substituents



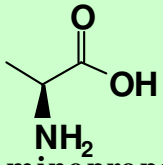
Nomenclature

– when **common names** are used, the letters α, β, γ, δ, etc. are often used to locate substituents





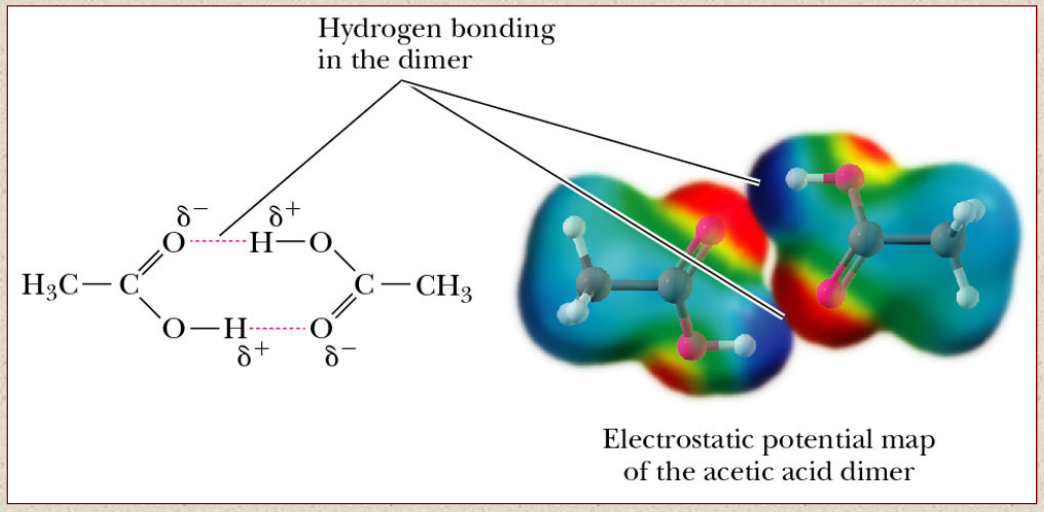
4-Aminobutanoic acid
(γ-Aminobutyric acid, GABA)



(*S*)-2-Aminopropanoic acid
[(*S*)-α-Aminopropionic acid; L-alanine]

Physical Properties

- In the liquid and solid states, carboxylic acids are associated by hydrogen bonding into dimeric structures



Electrostatic potential map
of the acetic acid dimer

Physical Properties

- Carboxylic acids have significantly **higher boiling points** than other types of organic compounds of comparable molecular weight
  - they are polar compounds and form very strong intermolecular hydrogen bonds

Physical Properties

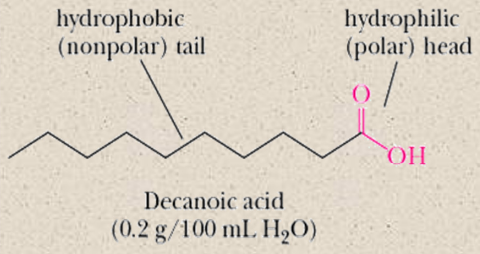
- Carboxylic acids **are more soluble in water than alcohols**, ethers, aldehydes, and ketones of comparable molecular weight
  - they form hydrogen bonds with water molecules through their C=O and OH groups

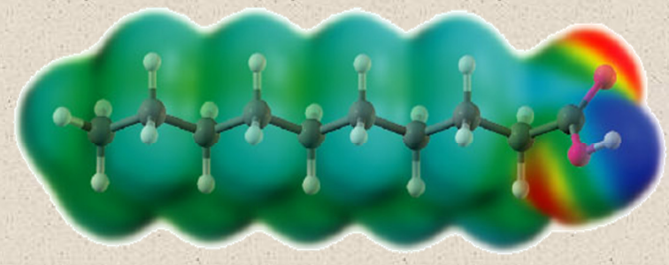
Physical Properties

Structure	Name	Molecular Weight (g/mol)	Boiling Point (°C)	Solubility (g/100 g H_2O)
CH_3COOH	Acetic acid	60.1	118	Infinite
$CH_3CH_2CH_2OH$	1-Propanol	60.1	97	Infinite
CH_3CH_2CHO	Propanal	58.1	48	16
$CH_3(CH_2)_2COOH$	Butanoic acid	88.1	163	Infinite
$CH_3(CH_2)_3CH_2OH$	1-Pentanol	88.1	137	2.3
$CH_3(CH_2)_3CHO$	Pentanal	86.1	103	Slight
$CH_3(CH_2)_4COOH$	Hexanoic acid	116.2	205	1.0
$CH_3(CH_2)_5CH_2OH$	1-Heptanol	116.2	176	0.2
$CH_3(CH_2)_5CHO$	Heptanal	114.1	153	0.1

Physical Properties

– water solubility decreases as the relative size of the hydrophobic portion of the molecule increases

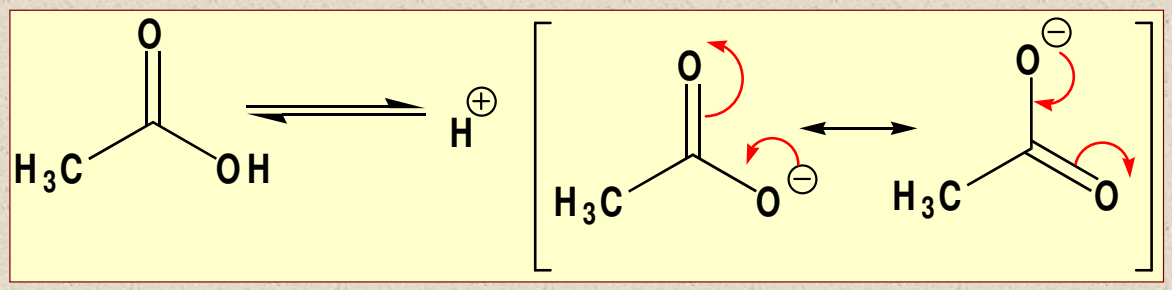




Electrostatic potential map

Acidity

- Carboxylic acids are **weak acids**
  - values of pK_a for most aliphatic and aromatic carboxylic acids fall within the range 4 to 5
- The greater acidity of carboxylic acids relative to alcohols (both compounds that contain an OH group) is due to resonance stabilization of the carboxylate anion:



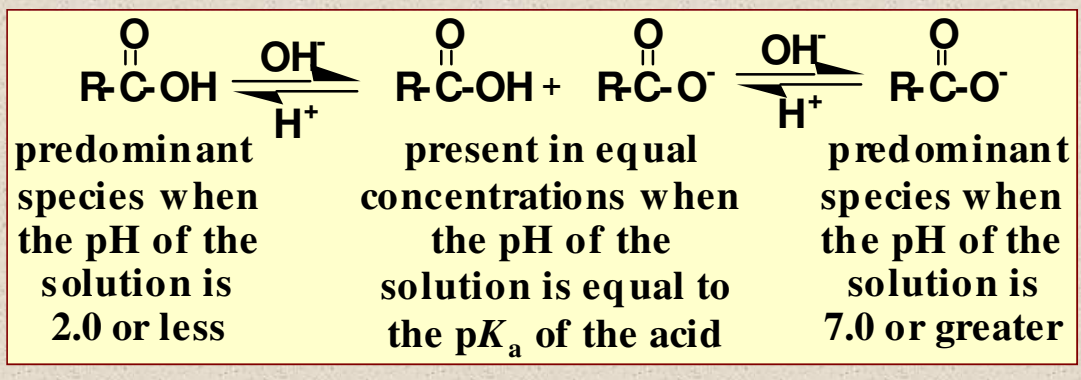
Acidity

- electron-withdrawing substituents near the carboxyl group increase acidity through their inductive effect

Formula:	CH_3COOH	$ClCH_2COOH$	$Cl_2CHCOOH$	Cl_3CCOOH
Name:	Acetic acid	Chloroacetic acid	Dichloroacetic acid	Trichloroacetic acid
pK_a:	4.76	2.86	1.48	0.70

Increasing acid strength

– the form of a carboxylic acid present in aqueous solution depends on the pH of the solution



$$pH = pK_a + \log_{10} \frac{[A^-]}{[HA]}$$

For organic acids in equilibrium:

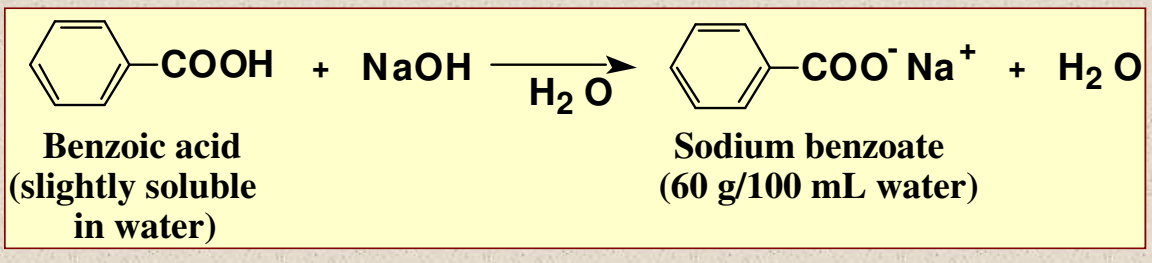
$$HA \rightleftharpoons H^+ + A^-$$

Henderson-Hasselbalch equation:

$$pH = pK_a + \log_{10} \frac{[A^-]}{[HA]}$$

Reaction with Bases

Carboxylic acids, whether soluble or insoluble in water, react with NaOH, KOH, and other strong bases to give water-soluble salts



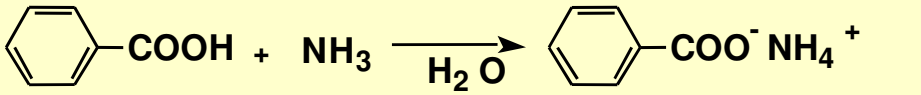
Benzoic acid (slightly soluble in water)

Sodium benzoate (60 g/100 mL water)

Acid + Base → Salt + water

Reaction with Bases

- They also form water-soluble salts with ammonia and amines

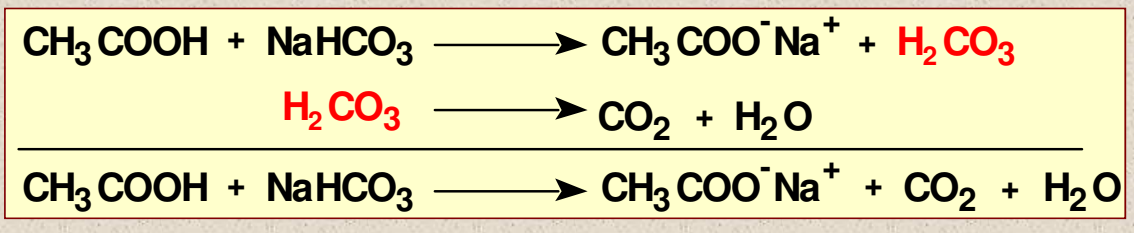


Benzoic acid (slightly soluble in water)

Ammonium benzoate (20 g/100 mL water)

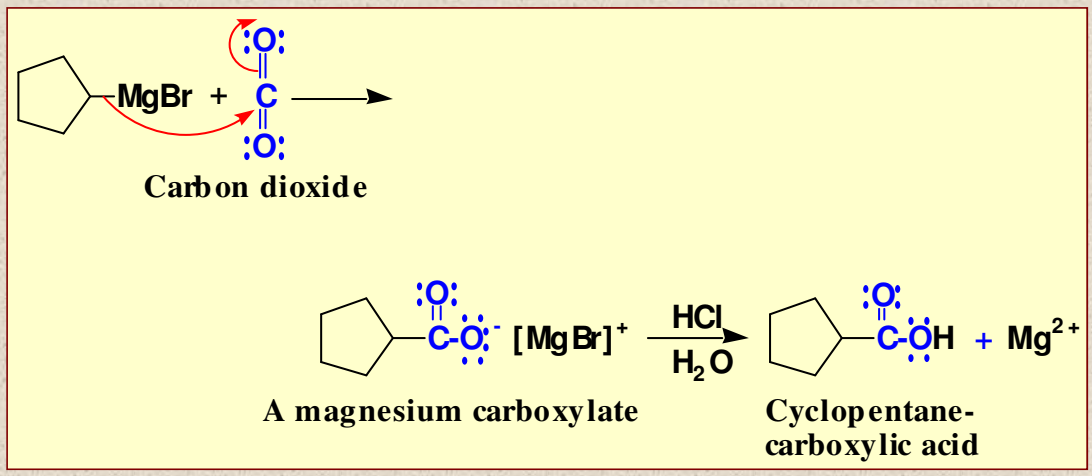
Reaction with Bases

- Carboxylic acids react with sodium bicarbonate and sodium carbonate to form water-soluble salts and carbonic acid
  - carbonic acid, in turn, breaks down to carbon dioxide and water



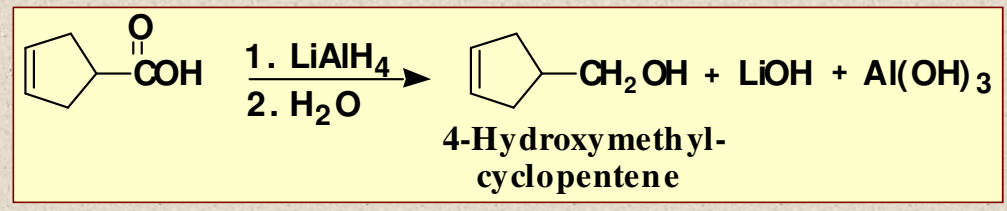
Preparation

- Carbonation of Grignard reagents
  - treatment of a Grignard reagent with carbon dioxide followed by acidification gives a carboxylic acid



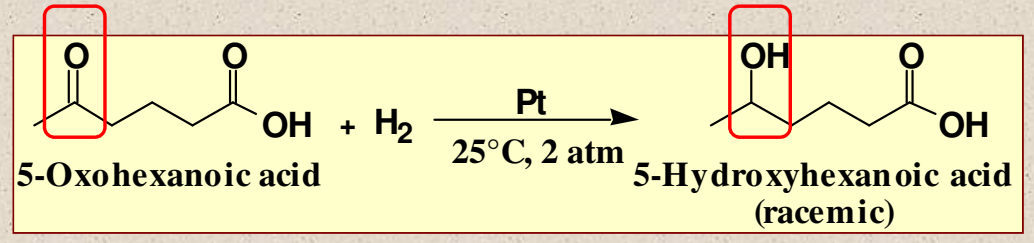
Reduction

- The carboxyl group is very resistant to reduction
  - it is not affected by catalytic hydrogenation under conditions that easily reduce aldehydes and ketones to alcohols, and reduce alkenes and alkynes to alkanes; it is not reduced by $NaBH_4$
- **Lithium aluminum hydride reduces a carboxyl group to a 1° alcohol**
  - reduction is carried out in diethyl ether, THF, or other nonreactive, aprotic solvent

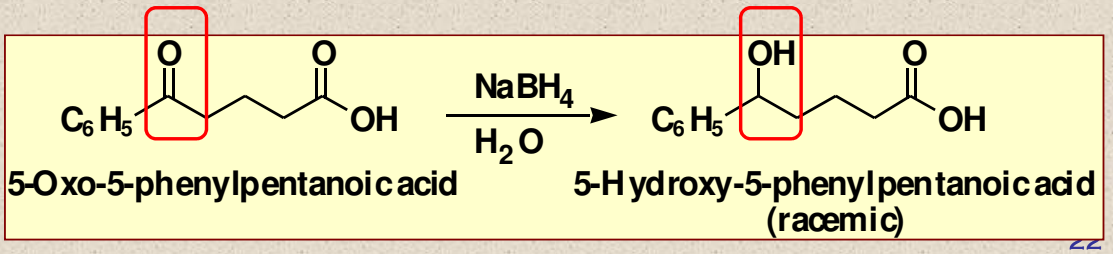


Selective Reduction

- carboxyl groups are not affected by catalytic reduction under conditions that reduce aldehydes and ketones

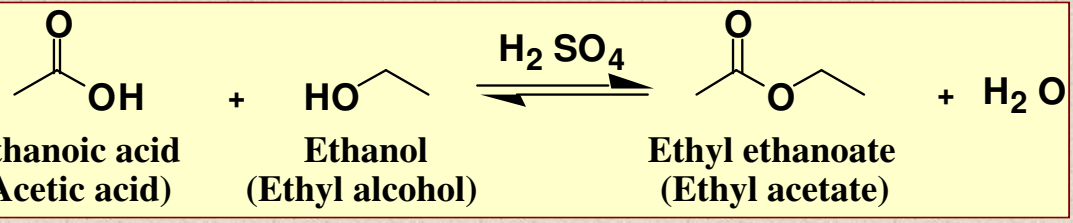


- nor are carboxyl groups reduced by $NaBH_4$

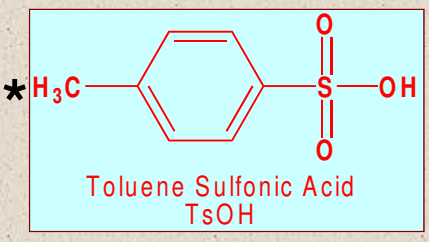


Fischer Esterification

- Esters can be prepared by treating a carboxylic acid with an alcohol in the presence of an acid catalyst, commonly H_2SO_4, $ArSO_3H$*, or gaseous HCl



Ethanoic acid (Acetic acid) + **Ethanol (Ethyl alcohol)** ⇌ **Ethyl ethanoate (Ethyl acetate)** + H_2O



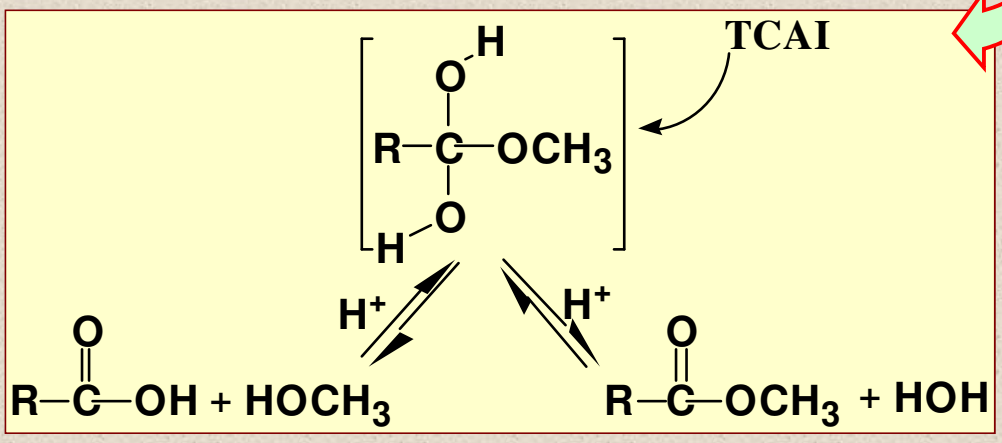
Fischer Esterification

Fischer esterification is an **equilibrium reaction:**

- by careful control of experimental conditions, it is possible to prepare esters in high yield
- if the alcohol is inexpensive relative to the carboxylic acid, it can be used in excess to drive the equilibrium to the right
- alternatively, water can be removed by azeotropic distillation and a Dean-Stark trap

Fischer Esterification

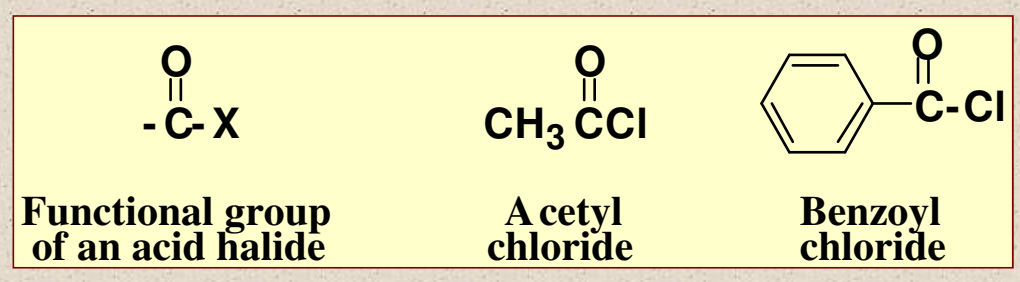
a key intermediate in Fischer esterification is the **tetrahedral carbonyl addition intermediate** formed by addition of ROH to the C=O group



Refer to mechanism worksheet

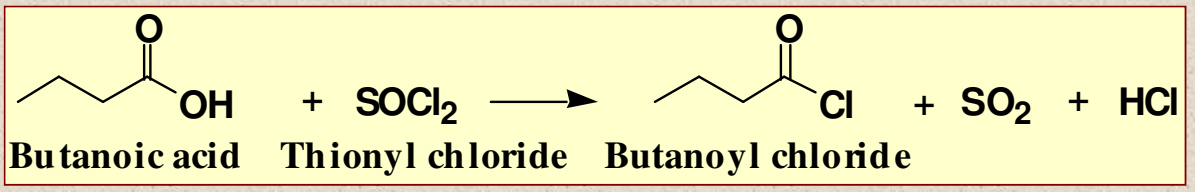
Acid Chlorides

- The functional group of an acid halide is a carbonyl group bonded to a halogen atom
  - among the acid halides, acid chlorides are by far the most common and the most widely used



Acid Chlorides

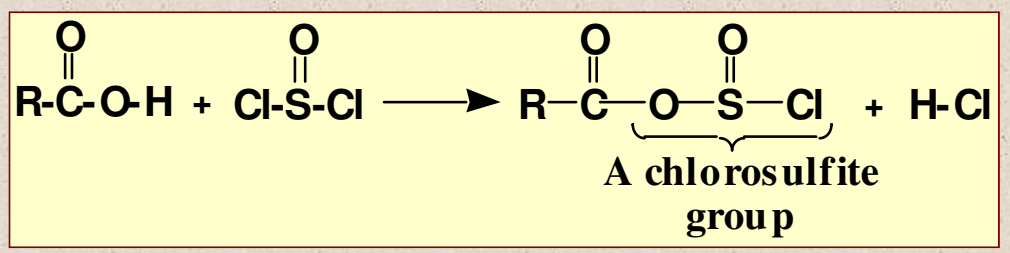
– acid chlorides are most often prepared by treating a carboxylic acid with **thionyl chloride**



Acid Chlorides

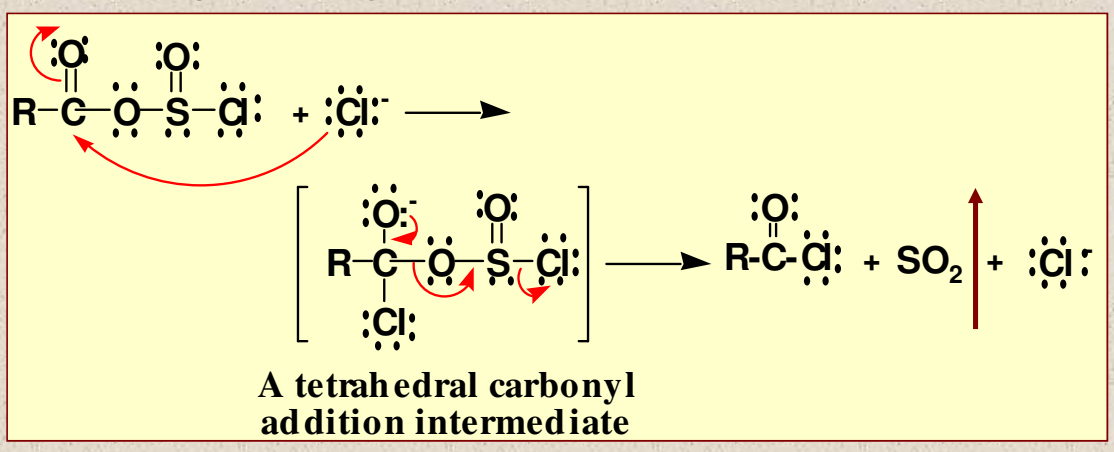
- The mechanism for this reaction is divided into two steps.

  Step 1: reaction with $SOCl_2$ transforms OH, a poor leaving group, into a chlorosulfite group, a good leaving group



Acid Chlorides

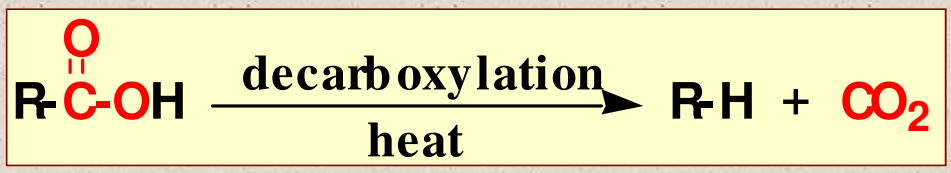
Step 2: attack of chloride ion gives a tetrahedral carbonyl addition intermediate, which collapses to give the acid chloride



Note: the reaction is irreversible

Decarboxylation

- Decarboxylation: loss of CO_2 from a carboxyl group
  - carboxylic acids, *if heated to a very high temperature*, undergo thermal decarboxylation

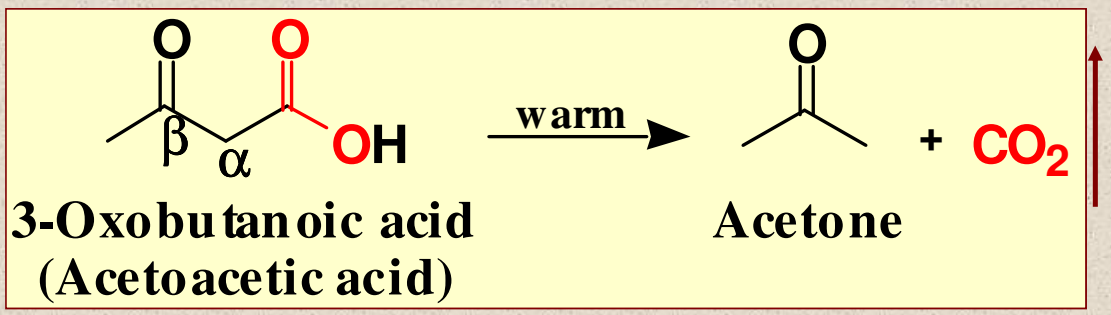


  - most carboxylic acids, however, are quite resistant to moderate heat and melt or even boil without decarboxylation

Decarboxylation

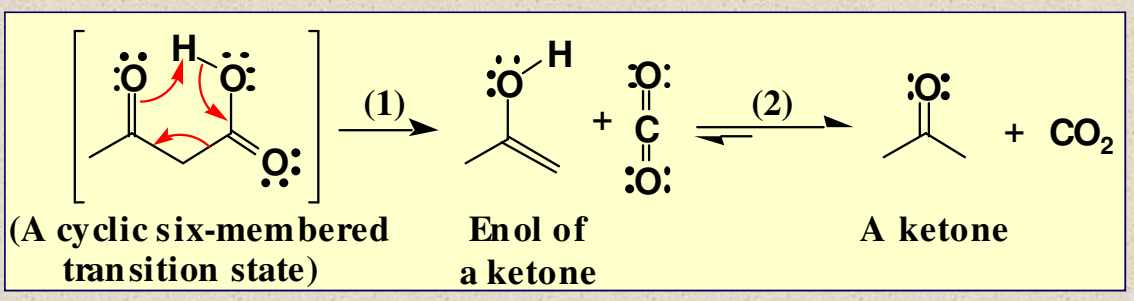
The most important exceptions are carboxylic acids that have a carbonyl group beta to the carboxyl group **i.e.- β keto-acids**

–this type of carboxylic acid undergoes decarboxylation on mild heating



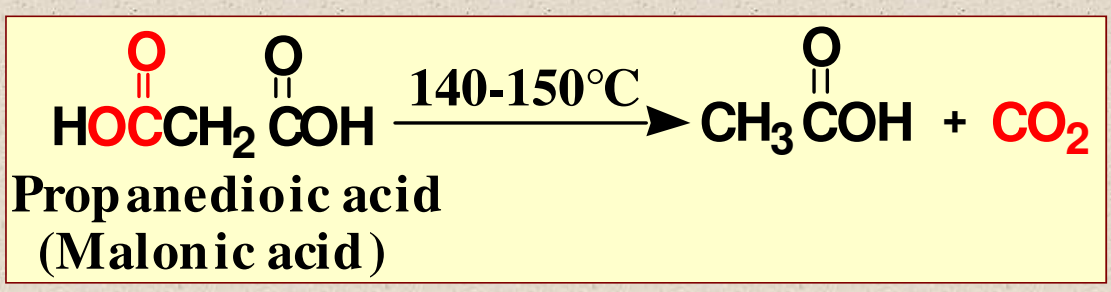
Decarboxylation

–thermal decarboxylation of a β-ketoacid involves rearrangement of six electrons in a cyclic six-membered transition state



Decarboxylation

- decarboxylation occurs if there is any carbonyl group beta to the carboxyl
- malonic acid and substituted malonic acids, for example, also undergo thermal decarboxylation



- thermal decarboxylation of malonic acids also involves rearrangement of six electrons in a cyclic six-membered transition state