HETEROFUNCTIONAL COMPOUNDS. Hydroxy acids. Oxo acids.

Some types of combining functional groups in heterofunctional compounds

Heterofunctional classes	Functional groups		Representatives	
			formula	trivial name
Amino alcohols	NH_2	OH	$H_2NCH_2CH_2OH$	Colamine
Hydroxy carbonyl compounds	OH	$\rangle C{=}O$	$HOCH_2CH(OH)CH{=}O$	Glyceraldehyde
Hydroxy carboxylic acids	OH	COOH	$HOCH_2COOH$	Glycolic acid
Amino acids	NH_2	COOH	H_2NCH_2COOH	Glycine
Oxo acids	$=O$	COOH	$CH_3C(=O)COOH$	Pyruvic acid

Hydroxyl, amino, oxo, and carboxyl groups are encountered most widely in heterofunctional compounds. A ***combination of different functional groups*** results in the formation of mixed classes of organic compounds, some of them are given in Table (other combinations are possible, of course).

Biological role:

- Heterofunctional compounds are widespread in the nature. They are in fruits and vegetable leafs. Also they are formed in body.
- So, the lactic acid is product of transformation glucose (glycolysis) in human body.
- A malic and citric acid formed in a cycle of tricarboxylic acids, which is also known as citric acid cycle or Krebs' cycle.
- Hydroxoacids such as: pyruvic acid, acetoacetic acid, oxaloacetic acid, -ketoglutaric acid are important in metabolism of carbohydrates

Hydroxy acids

- **Hydroxy acids** are organic compounds that contain a hydroxyl group and a carboxylic group

- Hydroxy acids are the derivatives of carboxyl acids that contain –OH group (1 or more).

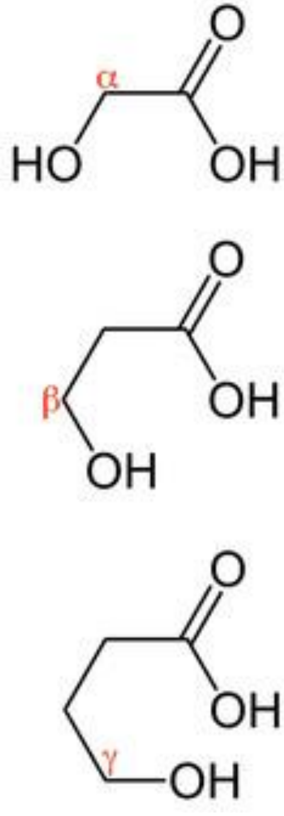
Methanoic acid 2-Methylpropanoic acid 3-Hydroxybutanoic acid

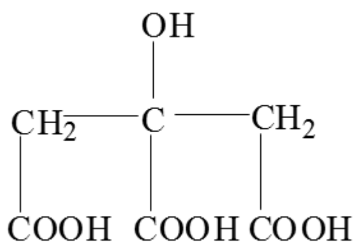
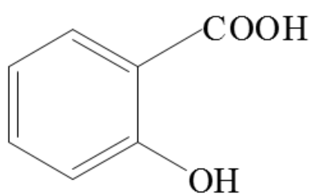
Classification of **Hydroxyacids**

<table>
<tr><th>Sign of classification</th><th colspan="2">Class name</th></tr>
<tr><td>the structure of the carbon radical</td><td>aliphatic</td><td>Aromatic</td></tr>
<tr><td rowspan="4">atomicity (quantity of –OH group) and basicity (quantity of –COOH group)</td><td>monobasic
diatomic</td><td rowspan="2">monobasic
diatomic</td></tr>
<tr><td>dibasic
triatomic</td></tr>
<tr><td>dibasic
tetratomic</td><td rowspan="2">monobasic
tetratomic</td></tr>
<tr><td>tribasic
tetratomic</td></tr>
<tr><td rowspan="3">Position of -OH and -COOH groups</td><td>α-Hydroxyacids</td><td rowspan="3"></td></tr>
<tr><td>β-Hydroxyacids</td></tr>
<tr><td>γ-Hydroxyacids</td></tr>
</table>

Alpha Hydroxy Acids(AHAs)

- occur naturally in fruit, milk, and sugarcane
- are used in skin care products



Formula	Name
$HO-CH_2-COOH$	**Glycolic acid**
$CH_3-CH(OH)-COOH$	**Lactic acid**
$HOOC-CHOH-CH_2-COOH$	**Malic acid**
$HOOC-CH(OH)-CH(OH)-COOH$	**Tartaric acid**
	**Citric acid**
	**Salicylic acid**

Physical and chemical properties of hydroxy carboxylic acid

- For physical properties of hydroxy carboxylic acids are colorless liquids or crystalline substance, soluble in water.
- Chemical properties: in the molecule of hydroxy acids ether –OH group or carboxyl group can react.

Chemical properties of Hydroxy acids (properties of COOH group)

For this we use the general formula **R-COOH**

1) Salt formation

$$2R-COOH+2Na \rightarrow 2R-COONa+H_2\uparrow$$

$$R-COOH+NaOH \rightarrow R-COONa+H_2O$$

$$2R-COOH+Na_2CO_3 \rightarrow 2R-COONa+H_2O+CO_2\uparrow$$

$$R-COOH+NH_3 \rightarrow R-COONH_4$$

2) **Amides formation:**

$$R-COOH+NH_3 \xrightarrow{t^0} R-CONH_2+H_2O$$

3) **Esterification:**

$$R_1-COOH+R_2-OH \rightarrow R_2-O-CO-R_1+H_2O$$

4) **Alcohol formation by decarboxylation:**

$$CH_3-\underset{\displaystyle OH}{\underset{|}{C}}H-COOH \xrightarrow{t^0} CH_3-CH_2-OH+CO_2$$

Loss of CO_2 from a molecule is called decarboxylation.

Chemical properties of Hydroxyacids (properties of OH group)

For this we use the general formula **R-OH**

1) **Alcoholate formation:**

$$2R-OH+2Na \xrightarrow{t^0} 2R-ONa+H_2\uparrow$$

2) **Acetylation:**

$$R_1-OH+R_2-COCl \rightarrow R_1-O-CO-R_2+HCl$$

3) replacement of the alcohol group with a halogen atom:

$$R - OH + HCl \rightarrow R - Cl + H_2O$$

4) Oxidation (Oxidation is carried out in living systems (*in vivo)* under the control of a dehydrogenase coenzyme such as nicotinamide adenine dinucleotide (*NAD*; *NADH.H*$^+$)).

$$R-CHOH-COOH \xrightarrow{[NAD]} R-CO-COOH$$

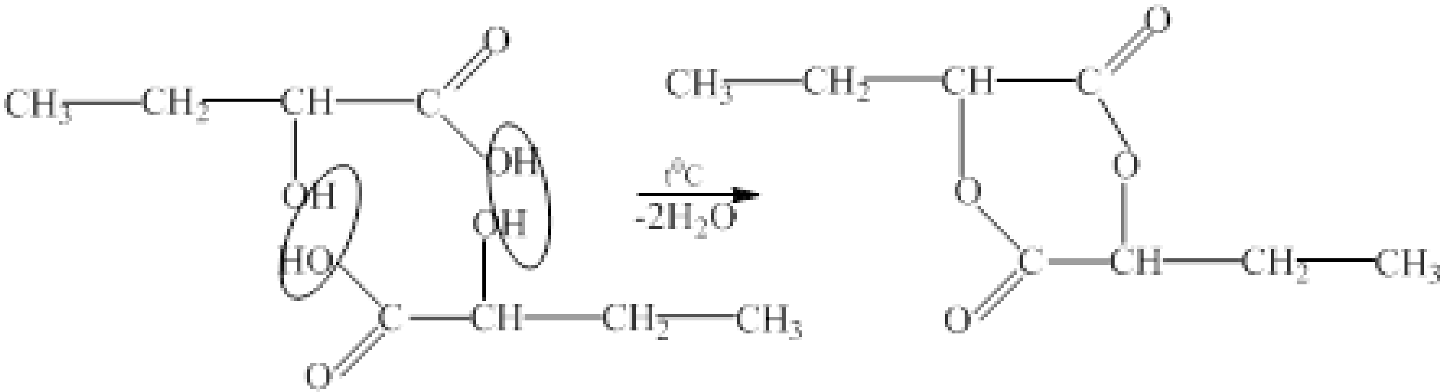
Chemical properties of aliphatic hydroxy acids

(on an example of glycolic acid)

CH_2OH-COOH	**reaction of –COOH group**
	1 *neutralization* $+ NaOH \xrightarrow[-H_2O]{} CH_2OH - COONa + H_2O$ sodium glycollate
	2 $+ Na_2CO_3 \xrightarrow[-H_2O,\ -CO_2\uparrow]{} CH_2OH - COONa$ sodium glycollate
	3 *esterification* $+ CH_3 - OH \xrightarrow{H^+} CH_2OH - CO\text{-}O\text{-}CH_3 + H_2O$
	4 *amide formation* $+ NH_3 \xrightarrow{t^o} CH_2OH - CONH_2 + H_2O$
	5 *oxidation* $\xrightarrow{[O]} HOC - COOH \xrightarrow{[O]} HOOC - COOH$ $- H_2O$ glyoxalic acid oxalic acid
	reaction of -OH
	1 *acetilation* $+ H_3C - COCl \xrightarrow[-HCl]{} CH_3 - CO - O - CH_2 - COOH$
	2 $+ HBr \xrightarrow[-H_2O]{} CH_2Br - COOH$

Specific properties

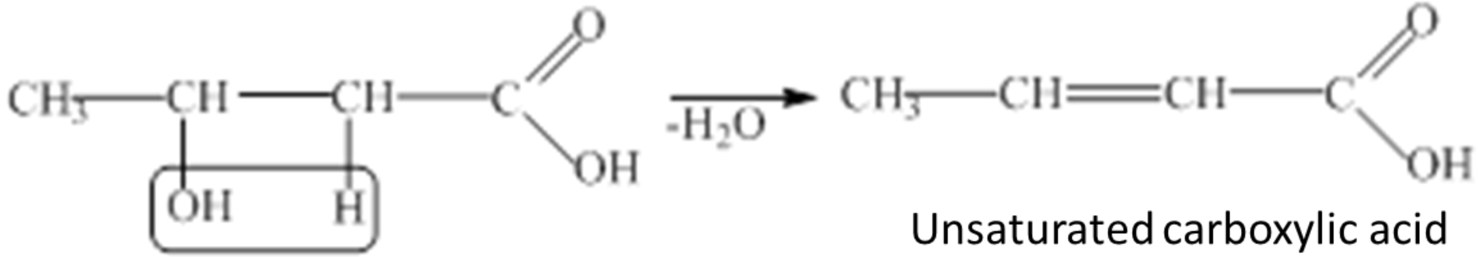
Intermolecular dehydration (for α-Hydroxy acids)



lactide

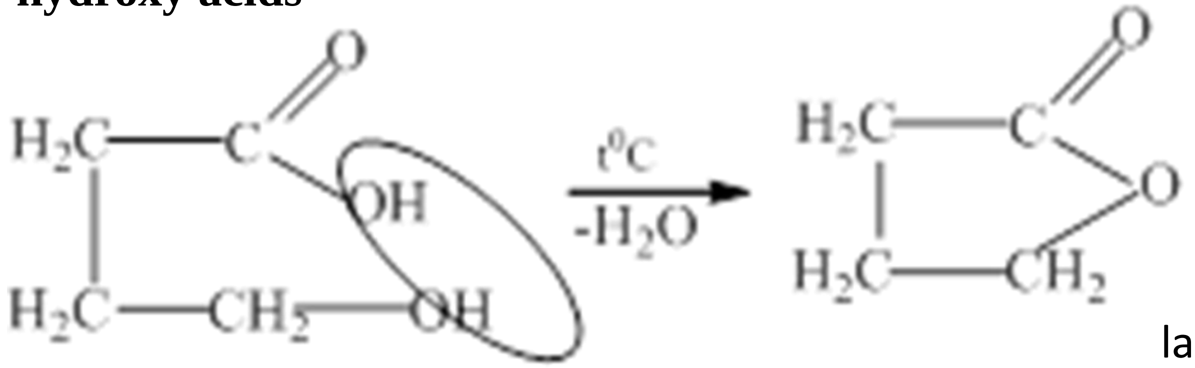
Intramolecular dehydration

β-Hydroxy acids



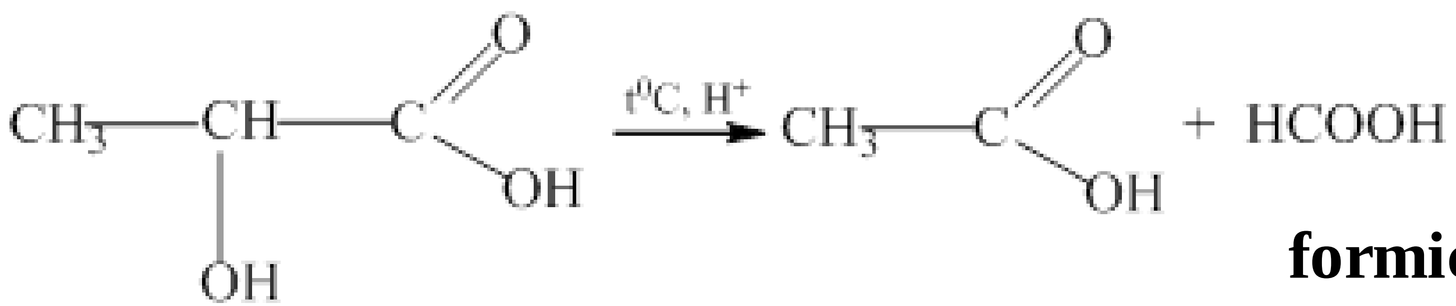
Unsaturated carboxylic acid

γ-hydroxy acids



lactone

The ratio of α-hydroxy acids to heating in the presence of mineral acids (one of the reaction products is always formic acid)

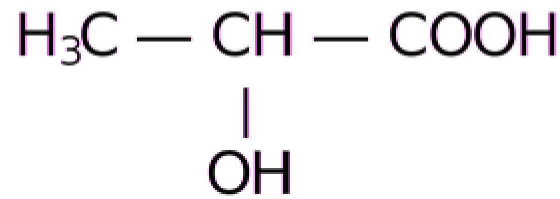


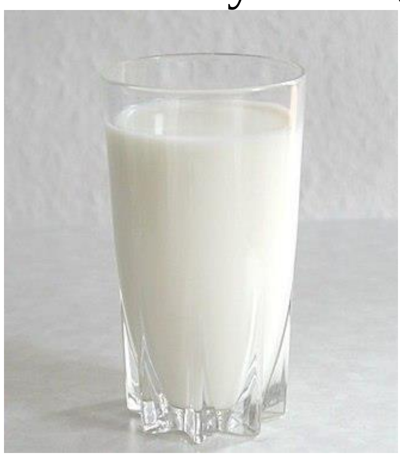
formic acid

lactic acid

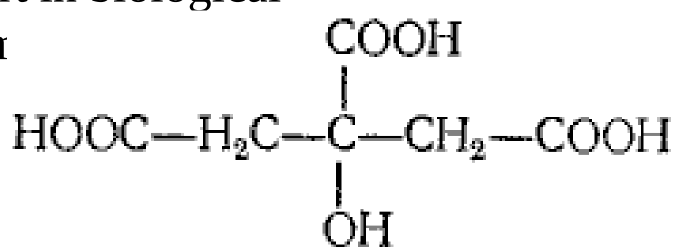
Representatives of hydroxy acids:

Lactic acid. lactic acid is a trivial name because at first it was extracted from milk. It is present in yogurt, sour milk and other milk products. It can form in muscles during hard and prolonged work. Salts of milk acid are used in medicine. Lactic acid is produced industrially by bacterial fermentation of carbohydrates (sugar, starch) or by chemical synthesis from acetaldehyde



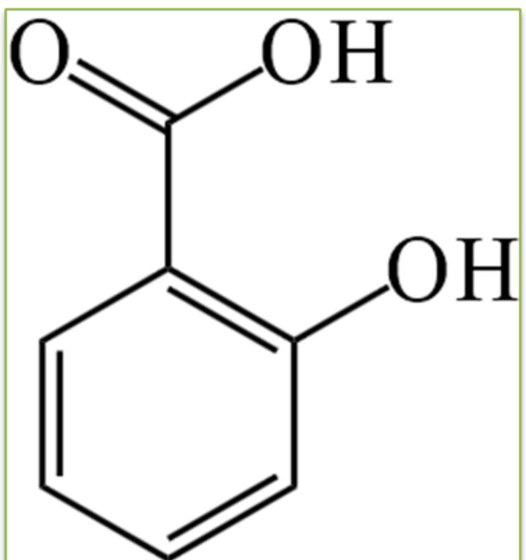


Citric acid . It is present in orange, lemon and other citric fruits. It takes part in biological processes in human organism



Aromatic hydroxy acids

Or phenolacids are the derivatives of aromatic carboxyl acids that contain –OH group (1 or more).

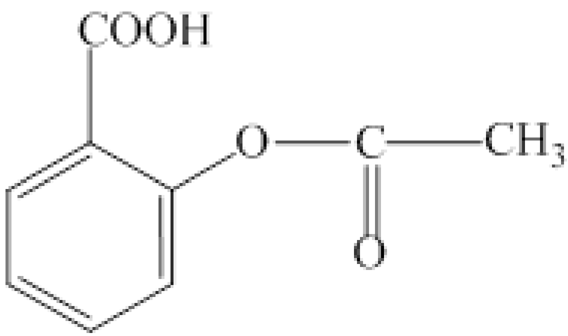


salicylic acid

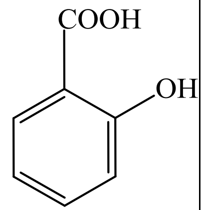
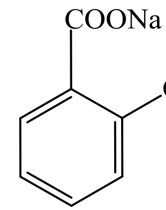
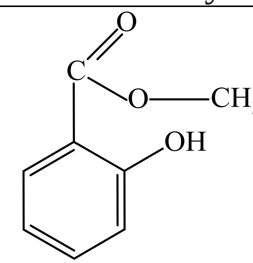
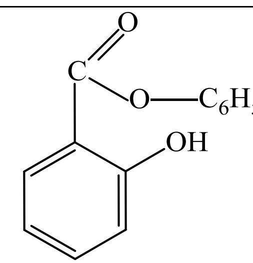
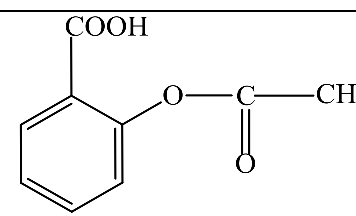
o-hydroxybenzoic acid

Occurs in natural products, usually in the form of methyl salicylate. Is used in medicine, in analytical chemistry and food industry .

Chemical properties of phenol acids:

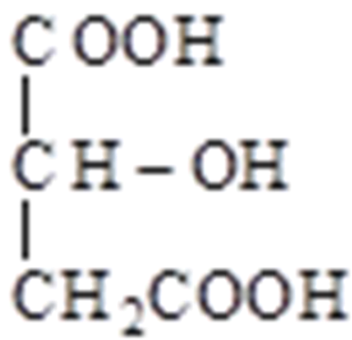


Aspirin, also known as *acetylsalicylic* acid (ASA), is a medication used to treat pain, fever, or inflammation

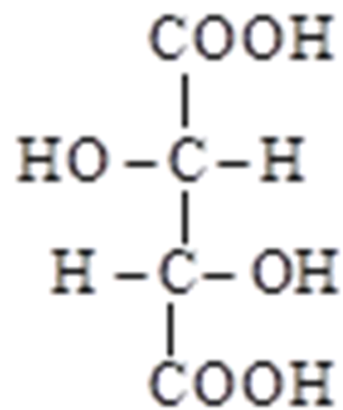
	$\xrightarrow[-CO_2\uparrow, H_2O]{Na_2CO_3}$	 sodium salicylate
	$\xrightarrow[-H_2O]{CH_3OH; H^+}$	
	$\xrightarrow[-H_2O]{C_6H_5OH; H^+}$	 phenyl salicylate
	$\xrightarrow[-CH_3COOH]{(CH_3-CO)_2O}$	 acetylsalicylic acid (aspirin)

Poly heterofunctional compounds are the compounds that contain more than two different functional groups.

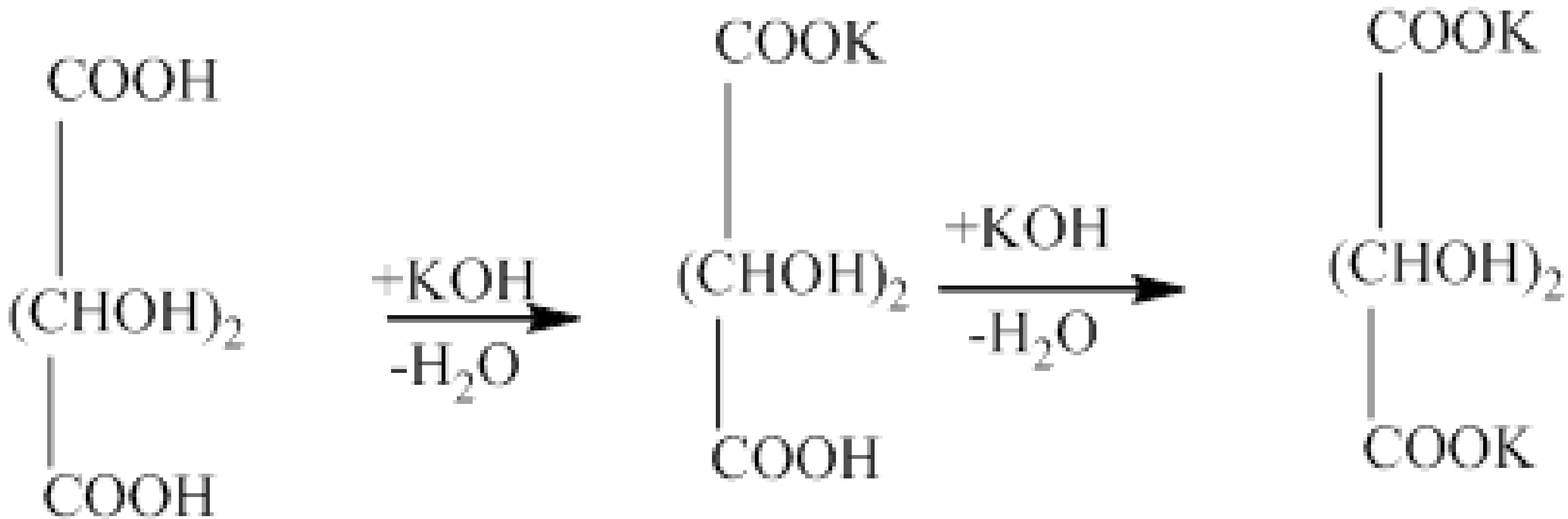
- **The malic acid** is a dicarboxylic acid that is made by all living organisms, contributes to the sour taste of fruits, and is used as a food additive. The malic acid was first isolated from apples. The name "malic" derives from Latin, with "malus" meaning "apple",



- **Tartaric acid** is a white, crystalline organic acid that occurs naturally in many fruits, most notably in grapes, but also in bananas, tamarinds, and citrus. Its salt, potassium bitartrate, commonly known as cream of tartar, develops naturally in the process of winemaking.



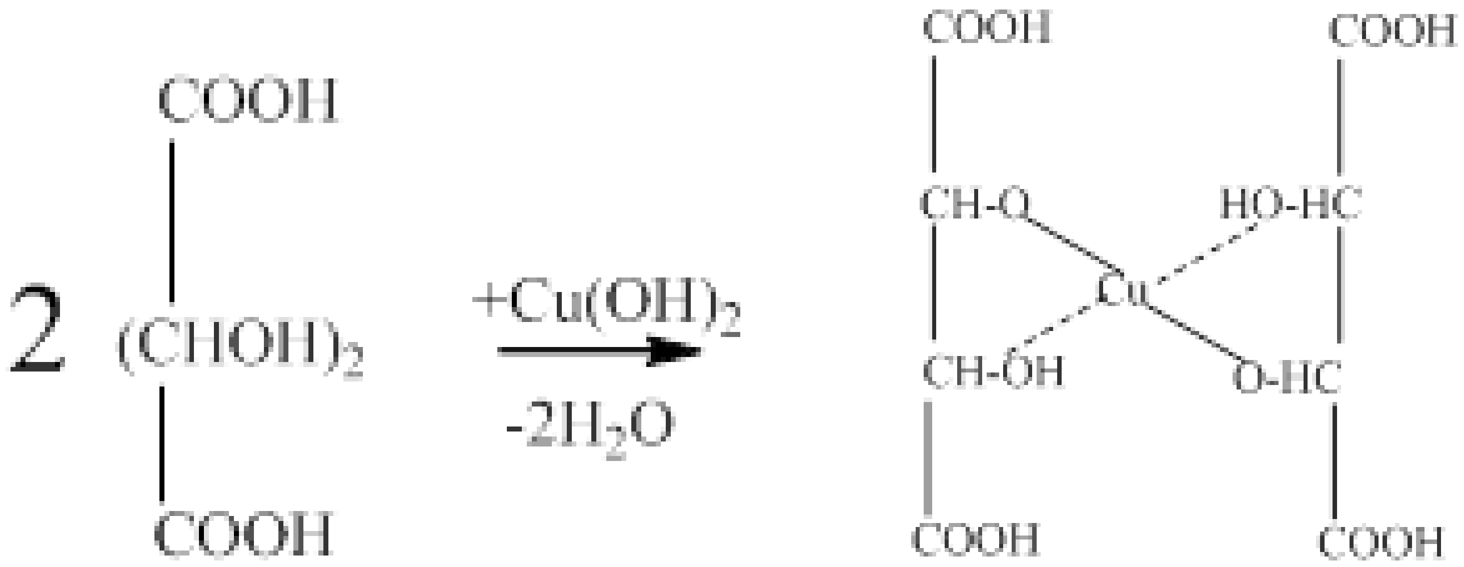
Tartaric acid as polybasic acid



Potassium hydrogen tartrate (tartar)

Potassium bitartrate in an empty white wine bottle

Tartaric acid as a polyatomic alcohol



Copper (II) tartrate (dark blue compound)

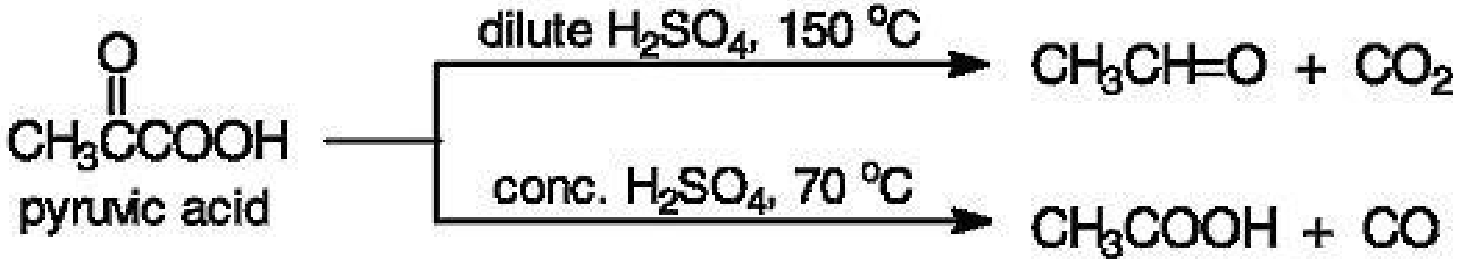
Oxoacids

Oxo acids include aldehydo- and ketono acids. These compounds include in the structure the carboxyl group, aldehyde functional group or ketone functional group.

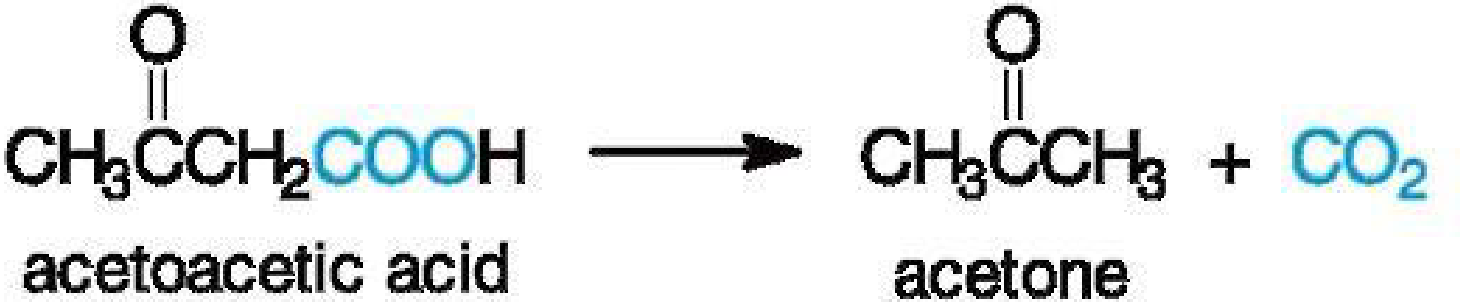
Formula	Name
$CH_3-\overset{O}{\overset{\Vert}{C}}-COOH$	**Pyruvic acid**
$CH_3-\overset{O}{\overset{\Vert}{C}}-CH_2-COOH$	**Acetoacetic acid**
$HOOC-\overset{O}{\overset{\Vert}{C}}-CH_2-COOH$	**Oxaloacetic acid**
$HOOC-\overset{O}{\overset{\Vert}{C}}-CH_2-CH_2-COOH$	α- ketoglutaric acid

Chemical properties of Oxo acids

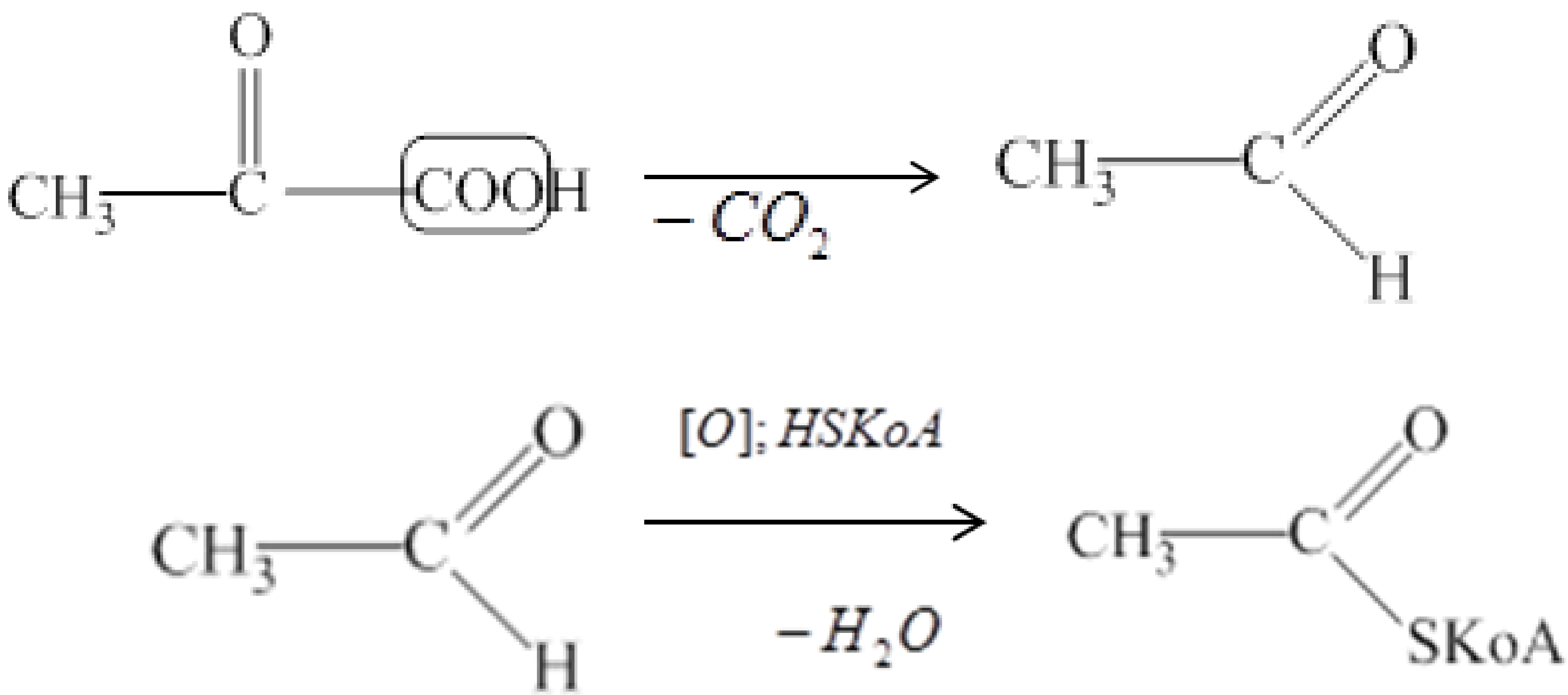
1.Decarboxylation of α-oxoacids



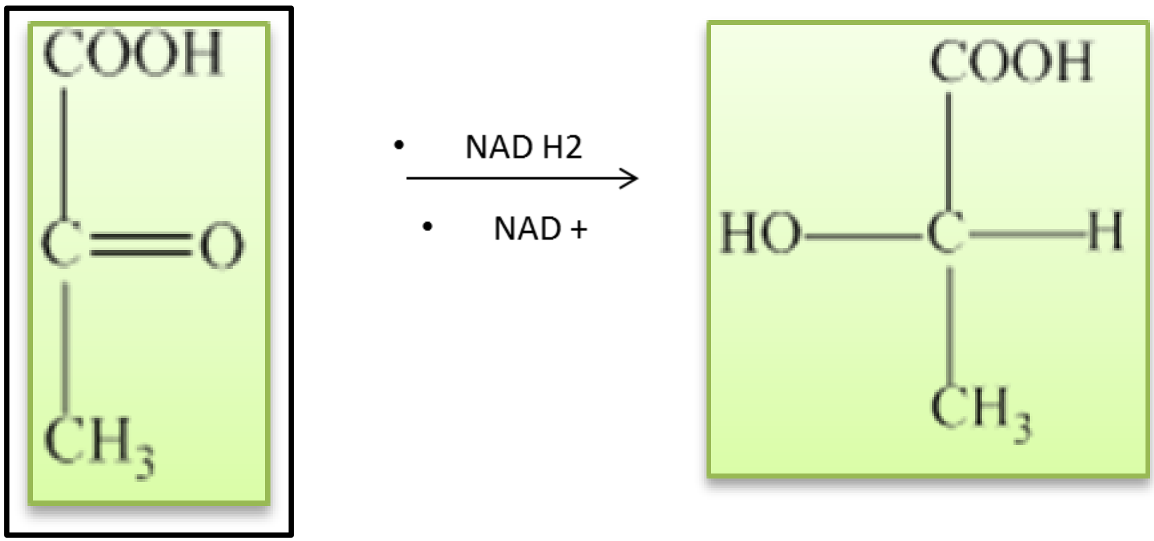
2.Decarboxylation of β-oxoacids



3) Decarboxylation (*in vivo*) in the presence of decarboxylase with higher oxidation and conversion to acetylcosim A

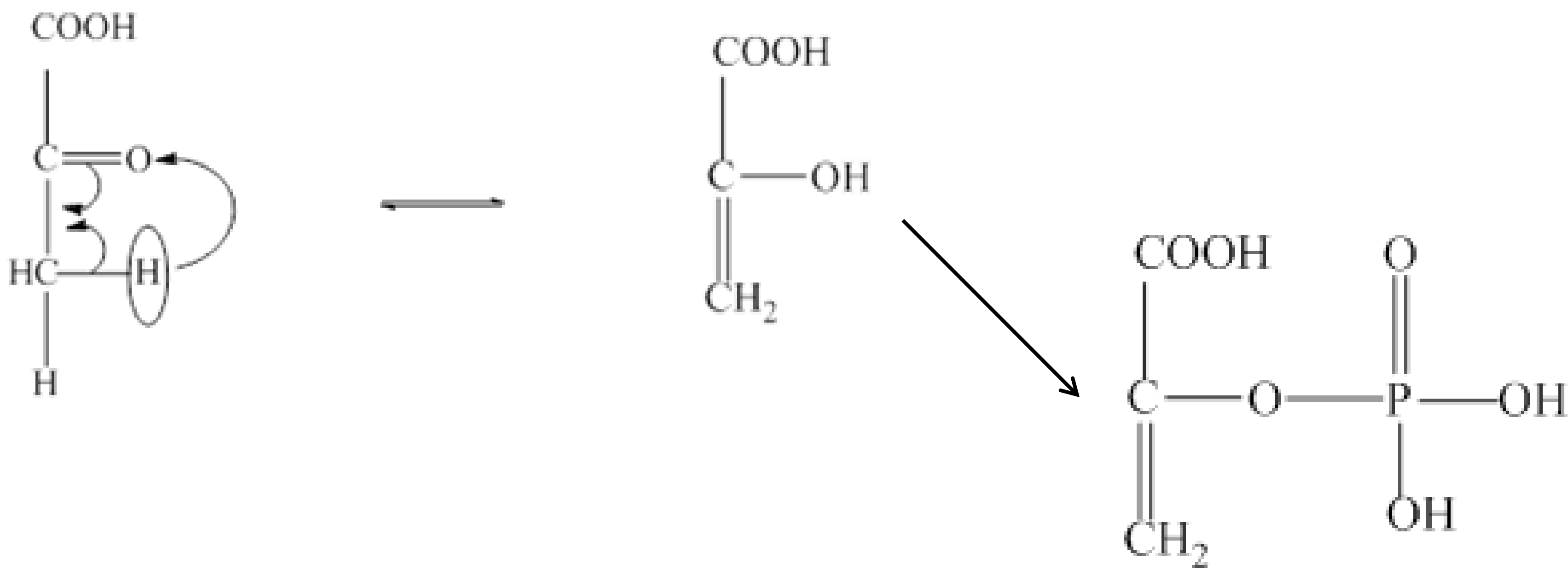


- 4) Reduction (in vivo)



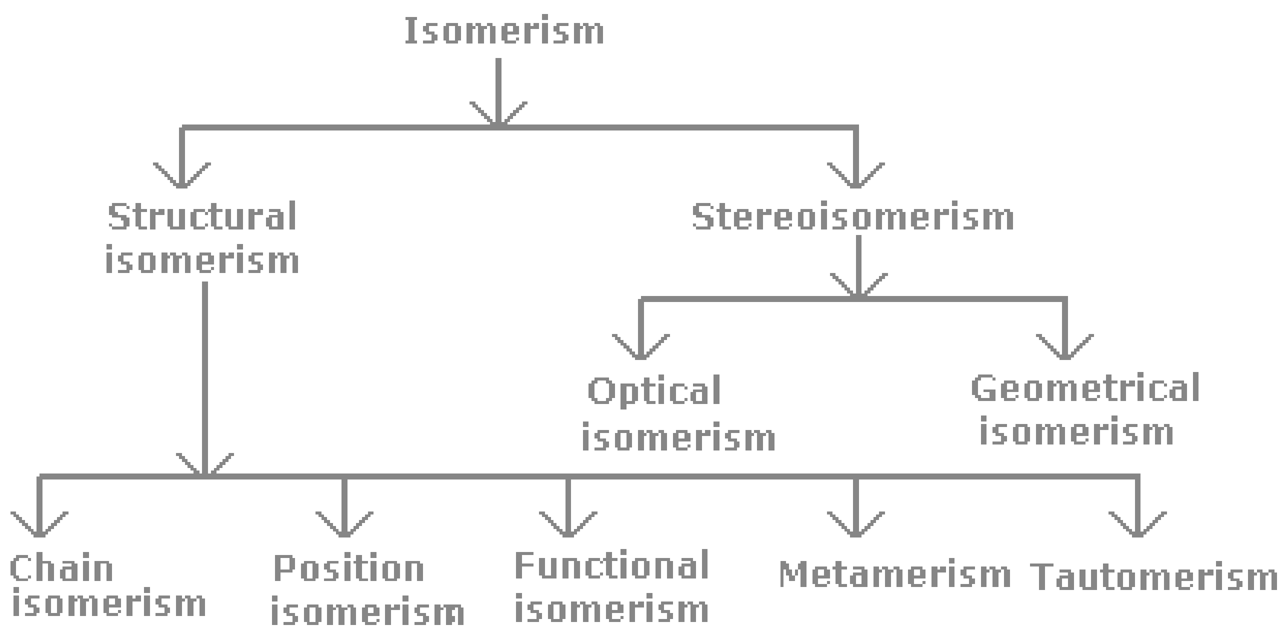
- Keto-enol tautomerism is characteristic of pyruvic acid. It has hydroxyl in the enol form, this allows it to react with acids to form esters

Keto-enol tautomerism



Isomerism

- Compounds which have same molecular formula but differ in modes of combination or arrangement of atoms within the molecule
- Isomers can have different physical or chemical properties.



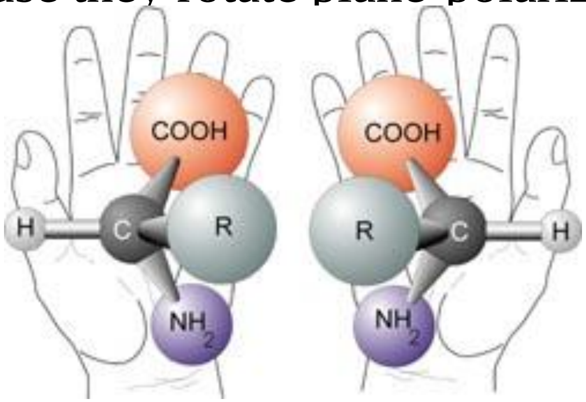
Stereoisomerism

- Stereoisomerism is a phenomenon in which compounds have the same molecular formula but differ in the relative positioning or orientation of atoms in space. The compounds which exhibit this type of isomerism are called as stereoisomers. These are further classified into:

- Geometrical isomerism
- Optical isomerism

Optical Isomerism

- Optical Isomerism occurs around a chiral center.
- If an atom is bonded to four different groups, its mirror image can not be rotated and superimposed onto the original molecule. Therefore, different molecules can be formed from the same atoms around a **chiral center.**
- **Enantiomers**, also known as **optical isomers**, are two stereoisomers that are related to each other by a reflection: they are mirror images of each other that are non-superimposable. Human hands are a macroscopic analog of this.
- The carbon in the figure to the right is an example of a chiral center. These isomers are called optical isomers because they rotate plane-polarized light in opposite directions.



Racemic Mixture

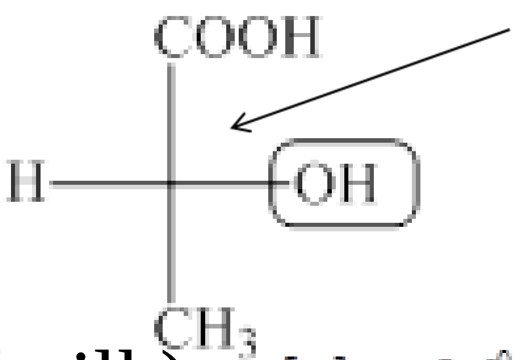
- **A racemic mixture** (containing equal amounts of both optical isomers) will not rotate plane polarized light since the optical effects of the two isomers cancel each other out.
- A racemic mixture is denoted by the prefix **(±)-** or **dl-** (for sugars the prefix **DL-** may be used), indicating an equal (1:1) mixture of dextro and levo isomers.
- Also the prefix ***rac-*** (or ***racem-***) or the symbols ***RS*** and ***SR*** (all in *italic* letters) are used.

Optical Activity

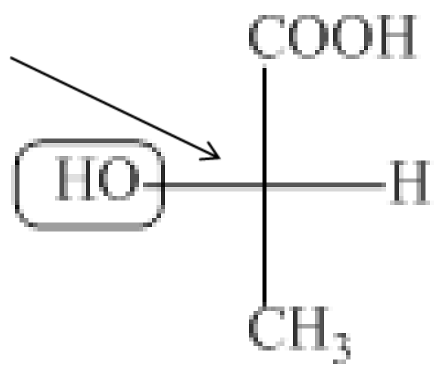
Observed rotation: the number of degrees, α, through which a compound rotates the plane of polarized light

- •Dextrotary (-): rotation of the plane of polarized light to the right
- •Levorotary (+): rotation of the plane of polarized light to the left

Chiral center



D (milk) $[\alpha] = -2{,}6^0$



L (meat) $[\alpha] = +2{,}6^0$