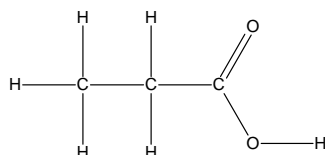


3.9 Carboxylic Acids and Derivatives

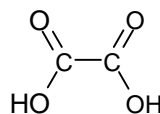
Naming Carboxylic acids

These have the ending **-oic acid** but no number is necessary for the acid group as it must always be at the end of the chain. The numbering always starts from the carboxylic acid end



Propanoic acid

If there are carboxylic acid groups on both ends of the chain then it is called a -dioic acid

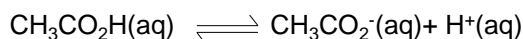


Ethanedioic acid

Note the **e** in this name

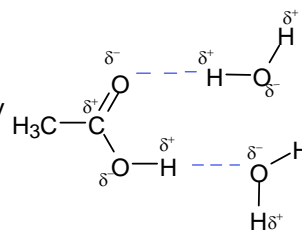
Acidity

The carboxylic acids are only weak acids in water and only slightly dissociate, but they are strong enough to displace carbon dioxide from carbonates.



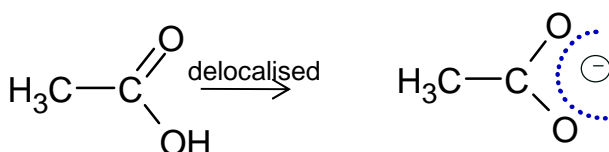
Solubility in Water

The smaller carboxylic (up to C4) acids dissolve in water in all proportions but after this the solubility rapidly reduces. They dissolve because they can hydrogen bond to the water molecules.



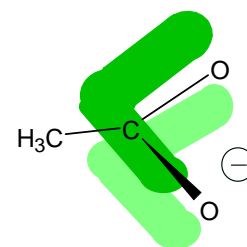
Delocalisation

The carboxylic acid salts are stabilised by delocalisation, which makes the dissociation more likely.

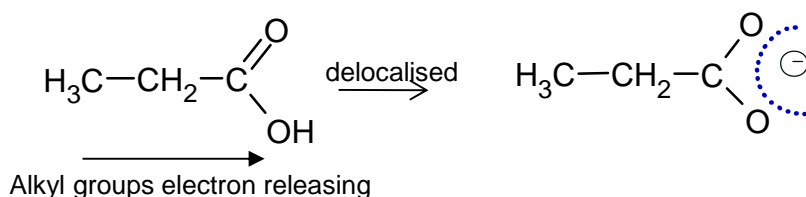


The delocalised ion has equal C-O bond lengths. If delocalisation did not occur, the C=O bond would be shorter than the C-O bond.

The pi charge cloud has delocalised and spread out. The delocalisation makes the ion more stable and therefore more likely to form.



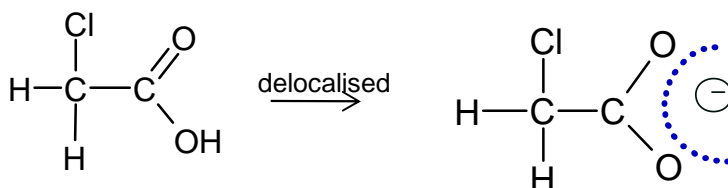
Strength of carboxylic acids



Alkyl groups electron releasing

Increasing chain length pushes electron density on to the COO^- ion, making it more negative and less stable. This makes the acid less strong.

Propanoic acid less acidic than ethanoic acid



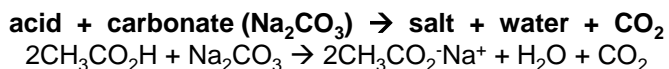
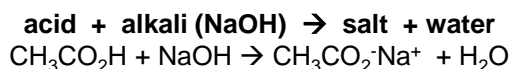
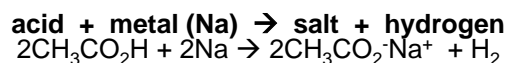
Chlorine electron withdrawing

Electronegative chlorine atoms withdraw electron density from the COO^- ion, making it less negative and more stable. This makes the acid more strong.

chloroethanoic acid more acidic than ethanoic acid

Salt formation reactions of carboxylic acids

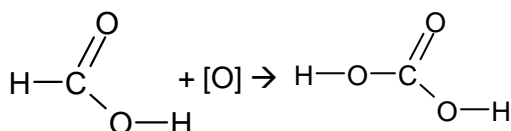
Carboxylic acids can form salts with metals, alkalis and carbonates.



The effervescence caused by production of CO_2 with carboxylic acids with solid Na_2CO_3 or aqueous NaHCO_3 can be used as a functional group test for carboxylic acids

Oxidation of methanoic acid

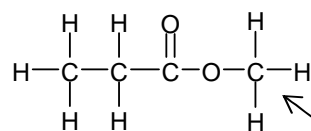
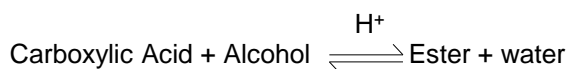
Carboxylic acids cannot be oxidised by using oxidising agents but methanoic acid is an exception as its structure has effectively an aldehyde group



It forms carbonic acid (H_2CO_3) which can decompose to give CO_2

Esterification

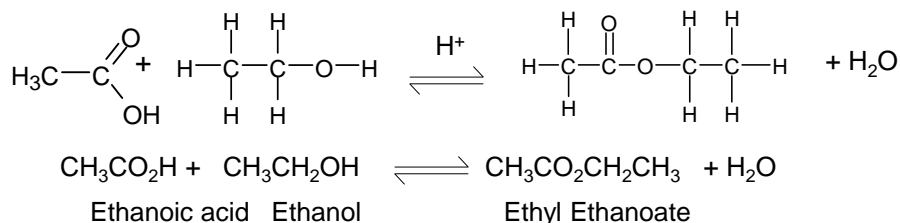
Carboxylic acids react with alcohols, in the presence of a strong acid catalyst, to form esters and water.



Esters have two parts to their names, eg **methyl** propanoate.

The bit ending in **-anoate** comes from the carboxylic acid and includes the C in the $\text{C}=\text{O}$ bond.

The bit ending in **-yl** comes from the alcohol that has formed it and is next to the single bonded oxygen.



The reaction is reversible. The reaction is quite slow and needs heating under reflux, (often for several hours or days). Low yields (50% ish) are achieved. An acid catalyst (H_2SO_4) is needed.

Uses of Esters

Esters are sweet smelling compounds that can be used in **perfumes** and **flavourings**.

Esters can be used as **solvents** for polar organic substances

Ethyl ethanoate is used as a solvent in glues and printing inks

Esters can be used as **plasticisers** for polymers

Esters can have pleasant smells

For use in perfumes they need to be non toxic, soluble in solvent such as ethanol, volatile (turns into gas easily), and not react with water.

Although polar, they do not form hydrogen bonds (reason: there is no hydrogen bonded to a highly electronegative atom) thus, they have much lower b.p. than the hydrogen-bonded carboxylic acids they came from. They are also almost insoluble in water

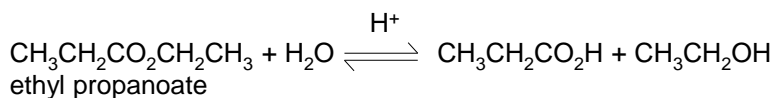
Often pure polymers have limited flexibility because the polymer chains cannot move over each other. Incorporating some plasticiser into the polymer allows the chains to move more easily and the polymer can become more flexible.

Hydrolysis of esters

Esters can be hydrolysed and split up by either heating with acid or with sodium hydroxide.

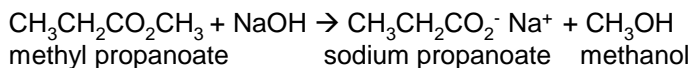
i) with acid
reagents: dilute acid (HCl)
conditions: heat under reflux

This reaction is the reverse reaction of ester formation. When an ester is hydrolysed a carboxylic acid and an alcohol are formed.



This reaction is reversible and does not give a good yield of the products.

ii) with sodium hydroxide
reagents: dilute sodium hydroxide
conditions: heat under reflux



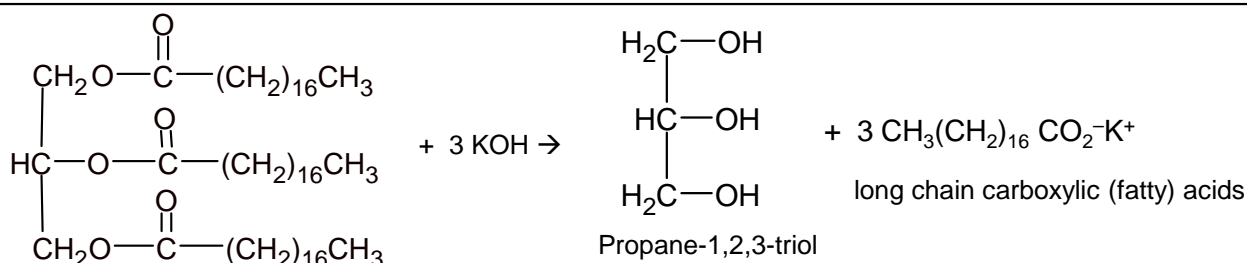
This reaction goes to completion.

The carboxylic acid salt product is the anion of the carboxylic acid. The anion is resistant to attack by weak nucleophiles such as alcohols, so the reaction is not reversible.

Fats and soaps

Fats and oils are ESTERS of glycerol and long chain carboxylic acids (fatty acids)

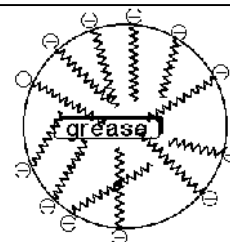
Vegetable oils and animal fats can be hydrolysed to give soap, glycerol and long chain carboxylic (fatty) acids



Glycerol forms hydrogen bonds very easily and is readily soluble in water. It is used in cosmetics, food and in glues.

Soap

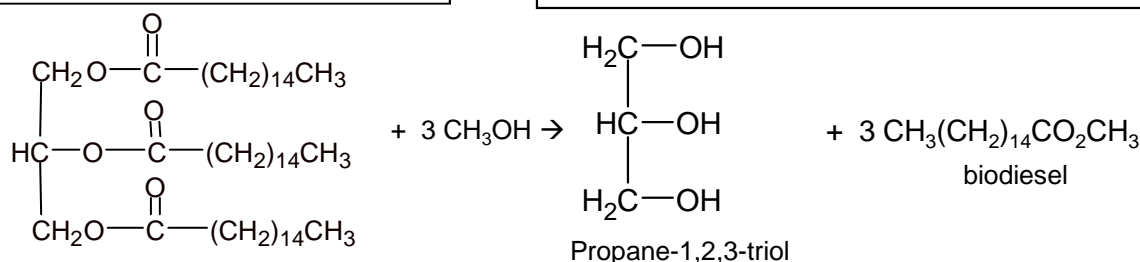
Long chain carboxylic (fatty) acids, produced by the hydrolysis of fats, act as soaps. The polar CO_2^- end is hydrophilic and mixes with water. The long non-polar hydrocarbon chain is hydrophobic and mixes with grease. So this allows the grease and water to mix and be washed away.



Biodiesel

Biodiesel is a mixture of methyl esters of long chain carboxylic acids

Vegetable oils can be converted into biodiesel by reaction with methanol in the presence of a (strong alkali) catalyst



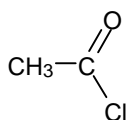
It can be argued that the biodiesel produced from this method is classed as carbon-neutral as any carbon dioxide given off when the biofuel is burnt would have been extracted from the air by photosynthesis when the plant grew.

This does not take into account any energy needed to irrigate plants, extract the oil, heat the reaction with methanol mixture or process the fuel. If the energy for this process comes from fossil fuels then the biofuel produced is not carbon neutral.

It also does not take into account the effect on land available for food production.

Carboxylic acid derivatives: Acyl Chlorides and Acid Anhydrides

Acyl Chlorides

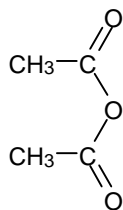


Acyl chlorides are much more reactive than carboxylic acids

ethanoyl chloride

The Cl and $-\text{OCOCH}_3$ groups are classed as good leaving groups (to do with less effective delocalisation.) This makes acyl chlorides and acid anhydrides much more reactive than carboxylic acids and esters

Acid Anhydrides



ethanoic anhydride.

Acid anhydrides have a similar reactivity to acyl chlorides and therefore bring about the same changes in functional groups.

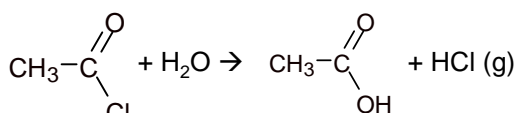
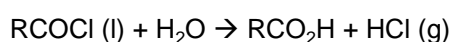
The main difference is the by-products. Acyl chlorides mostly give off HCl. Acid anhydrides give off RCOOH

Reaction with water

Change in functional group: **acyl chloride** → **carboxylic acid**

Reagent: **water**

Conditions: **room temp.**

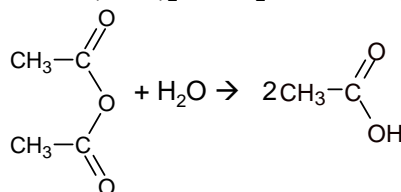
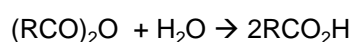


Observation: Steamy white fumes of HCl are given off

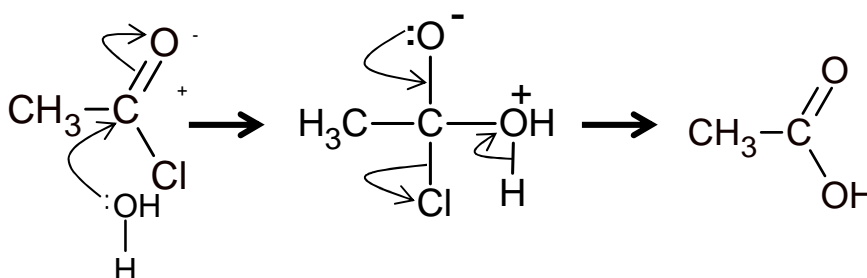
Change in functional group: **acid anhydride** → **carboxylic acid**

Reagent: **water**

Conditions: **room temp.**



Nucleophilic Addition Elimination Mechanism

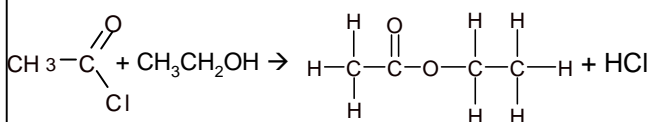
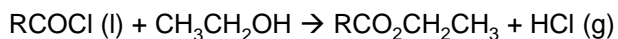


Reaction with alcohol

Change in functional group: **acyl chloride** → **ester**

Reagent: **alcohol**

Conditions: **room temp.**

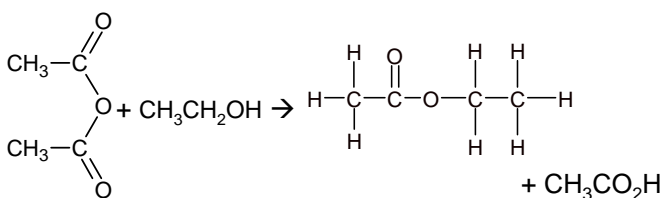
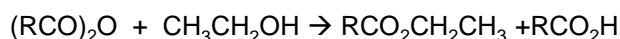


Observation: Steamy white fumes of HCl are given off

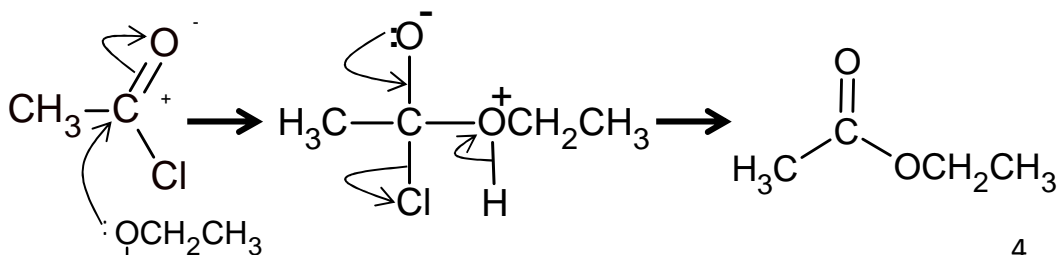
Change in functional group: **acid anhydride** → **ester**

Reagent: **alcohol**

Conditions: **room temp.**



This reaction for making esters is much better than using carboxylic acids as the reaction is much quicker and it is not a reversible reaction



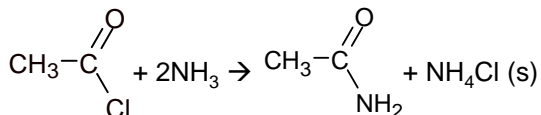
Nucleophilic Addition Elimination Mechanism

Reaction with ammonia

Change in functional group: **acyl chloride** → **primary amide**

Reagent: **ammonia**

Conditions: **room temp.**

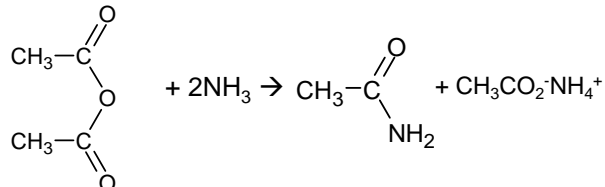


Observation: white smoke of NH_4Cl is given off

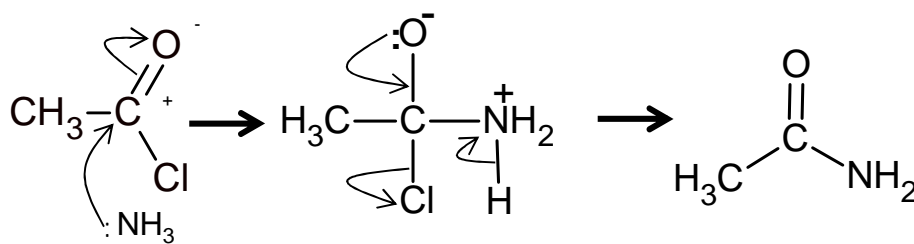
Change in functional group: **acid anhydride** → **primary amide**

Reagent: **ammonia**

Conditions: **room temp.**



**Nucleophilic
Addition
Elimination
Mechanism**

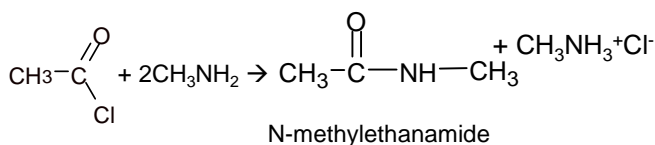


Reaction with primary amines

Change in functional group: **acyl chloride** → **secondary amide**

Reagent: **primary amine**

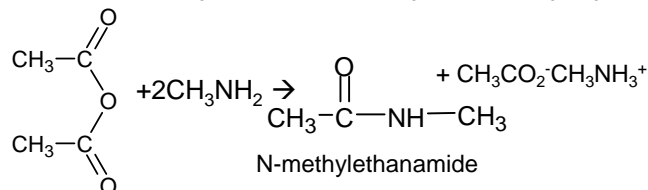
Conditions: **room temp.**



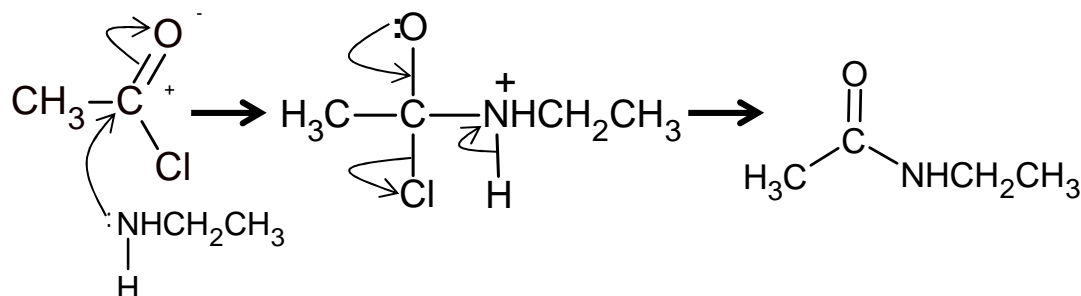
Change in functional group: **acid anhydride** → **secondary amide**

Reagent: **primary amine**

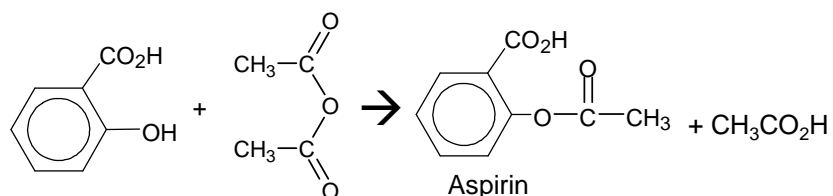
Conditions: **room temp.**



**Nucleophilic
Addition
Elimination
Mechanism**



Practical: Making Aspirin



Aspirin is made from 2-hydroxybenzoic acid which contains a phenol group. In the reaction the phenol group is turned into an ester by reacting it with the reactive ethanoic anhydride

Ethanoic anhydride is used instead of acid chlorides because it is cheaper, less corrosive, less vulnerable to hydrolysis, and less dangerous to use.

Purifying an organic solid: Recrystallisation

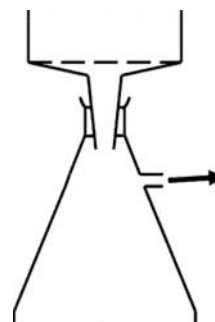
Used for purifying aspirin

Step	Reason
1. Dissolve the impure compound in a minimum volume of hot (near boiling) solvent .	An appropriate solvent is one which will dissolve both compound and impurities when hot and one in which the compound itself does not dissolve well when cold. The minimum volume is used to obtain saturated solution and to enable crystallisation on cooling
2. Hot filter solution through (fluted) filter paper quickly.	This step will remove any insoluble impurities and heat will prevent crystals reforming during filtration
3. Cool the filtered solution by inserting beaker in ice	Crystals will reform but soluble impurities will remain in solution form because they are present in small quantities so solution is not saturated. Ice will increase the yield of crystals
4. Suction filtrate with a Buchner flask to separate out crystals	The water pump connected to the Buchner flask reduces the pressure and speeds up the filtration.
5 Wash the crystals with distilled water	To remove soluble impurities
6. Dry the crystals between absorbent paper	

Loss of yield in this process

- Crystals lost when filtering or washing
- Some product stays in solution after recrystallisation
- other side reactions occurring

buchner flask



Measuring melting point

One way of testing for the degree of purity is to determine the melting "point", or melting range, of the sample.

If the sample is very pure then the melting point will be a sharp one, at the same value as quoted in data books.

If **impurities** are present (and this can include solvent from the recrystallisation process) the **melting point will be lowered** and the sample will **melt over a range** of several degrees Celsius

Melting point can be measured in an electronic melting point machine or by using a practical set up where the capillary tube is strapped to a thermometer immersed in some heating oil.

In both cases a small amount of the salt is put into a capillary tube. The tube is heated up and is **heated slowly near the melting point**

Comparing an experimentally determined melting point value with one quoted in a data source will verify the degree of purity.

Sometimes an error may occur if the temperature on the thermometer is not the same as the temperature in the actual sample tube.

