Alcohols and Carboxylic Acids

Matthew Williams • Chemistry • May 15, 2026

Alcohols and Carboxylic Acids

Alcohols and carboxylic acids each carry a specific functional group that controls their chemistry. Both series are water-soluble at shorter chain lengths, weakly acidic or reacting as acids, and connected to each other through oxidation — ethanol oxidises to ethanoic acid. Esters, formed from the reaction between these two families, are responsible for the fragrances of fruits, flowers, and many food flavourings.

Alcohols

The **alcohol** functional group is the hydroxyl group: **–OH**.

General formula: $\mathrm{C}n\mathrm{H}2n + 1\mathrm{OH}$

Name	Formula	Condensed formula
Methanol	CHO	CHOH
Ethanol	CHO	CHOH or CHCHOH
Propan-1-ol	CHO	CHCHCHOH
Propan-2-ol	CHO	CHCH(OH)CH

The hydroxyl group allows alcohols to form hydrogen bonds with water, making short-chain alcohols completely miscible with water. As chain length increases, the non-polar carbon chain dominates and solubility decreases.

Ethanol: Production

Fermentation

Ethanol is produced industrially (and in winemaking and rum manufacture) by the **fermentation** of sugars by yeast. Yeast contains enzymes that catalyse the anaerobic breakdown of glucose:

$$C_6H_{12}O_6 \xrightarrow{\text{yeast}} 2C_2H_5OH + 2CO_2$$

Conditions required:

- Yeast (enzyme catalyst)
- Warm temperature (about 25–35 °C) — too hot denatures the enzymes
- Absence of oxygen (anaerobic conditions)
- Slightly acidic pH

Carbon dioxide is produced as a by-product — the bubbling seen during fermentation is CO, escaping. The process stops when the alcohol concentration reaches about 15%, because yeast is inhibited by higher concentrations. Distillation is used to purify and concentrate the ethanol.

In the Caribbean, rum is produced from the fermentation of sugarcane molasses. Wine is produced from the fermentation of grape juice.

Industrial Hydration of Ethene

Ethanol is also produced on a large scale by the addition of steam to ethene at high temperature and pressure with a phosphoric acid catalyst:

$$C_2H_4 + H_2O \xrightarrow{H_3PO_4, 300^\circ C, \text{ high pressure}} C_2H_5OH$$

This method is faster and produces purer ethanol than fermentation, but requires ethene from petroleum and is therefore not renewable.

Reactions of Ethanol

Combustion

Ethanol burns completely in excess oxygen to produce carbon dioxide and water. The flame is blue:

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

Ethanol is used as a fuel (bioethanol) and as a fuel additive.

Reaction with Sodium

Ethanol reacts with sodium metal to produce hydrogen gas and sodium ethoxide:

$$2C_2H_5OH + 2Na \rightarrow 2C_2H_5ONa + H_2$$

The reaction is less vigorous than sodium with water, but the same hydrogen gas is produced. This demonstrates the weakly acidic nature of the –OH group.

Dehydration

When ethanol is heated with excess concentrated sulfuric acid at about 170 °C, water is eliminated and ethene is formed:

$$C_2H_5OH \xrightarrow{\text{conc. } H_2SO_4, 170^\circ C} C_2H_4 + H_2O$$

This is the reverse of hydration and shows that ethanol and ethene are interconvertible.

Oxidation

Ethanol is oxidised to ethanoic acid when treated with acidified potassium dichromate(VI) or potassium manganate(VII). In this oxidation, the orange dichromate turns green:

$$C_2H_5OH + [O] \rightarrow CH_3COOH + H_2O$$

This reaction is also what occurs naturally when wine is left open to air — bacteria oxidise the ethanol to ethanoic acid, producing vinegar.

Esterification

Ethanol reacts with carboxylic acids in the presence of a concentrated sulfuric acid catalyst (and heat) to form esters. This is covered in detail below.

Carboxylic Acids

The **carboxylic acid** functional group is: **–COOH** (the carboxyl group).

General formula: $CnH2n + 1COOH$

Name	Formula	Condensed formula
Methanoic acid	HCOOH	HCOOH
Ethanoic acid	CH,O,	CHƒCOOH
Propanoic acid	CƒHƒO,	CHƒCH,COOH

Carboxylic acids are **weak acids** — they ionise only partially in water:

$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$

Despite being weak acids, they display all the characteristic acid reactions:

Reaction	Equation	Products
With metals	2CHƒCOOH + Mg ’(CHƒCOO),Mg + H,	Salt + hydrogen
With metal oxides	2CHƒCOOH + CuO ’(CHƒCOO),Cu + H,O	Salt + water
With hydroxides	CHƒCOOH + NaOH ’CHƒCOONa + H,O	Salt + water
With carbonates	2CHƒCOOH + Na,COƒ 2CHƒCOONa + H,O + CO,	Salt + water + CO,
With alcohols	CHƒCOOH + C,H..H ÌCHƒCOOC,H.+.H,O	Ester + water

Esters and Esterification

An **ester** is the compound formed when a carboxylic acid reacts with an alcohol, with the elimination of water. The reaction is reversible and requires a concentrated sulfuric acid catalyst and heat:

$$\text{acid} + \text{alcohol} \rightleftharpoons \text{ester} + \text{water}$$

$$CH_3COOH + C_2H_5OH \underset{\text{conc. } H_2SO_4}{\overset{\Delta}{\rightleftharpoons}} CH_3COOC_2H_5 + H_2O$$

The product here is **ethyl ethanoate** (ethyl acetate). The ester is named from the alcohol first (ethyl, from ethanol) then the acid (ethanoate, from ethanoic acid).

Esters have characteristic **sweet, fruity smells** and are widely used as:

- perfumes and fragrances
- food flavourings (artificial fruit flavours)
- solvents (ethyl acetate in nail polish remover)

The functional group of an ester is –COO–, which links the two carbon chains.

Hydrolysis of Esters

Esterification is reversible — esters can be broken down back into the alcohol and acid by **hydrolysis** (reaction with water), catalysed by acid or alkali:

Acid hydrolysis:

$$CH_3COOC_2H_5 + H_2O \overset{\text{acid}}{\rightleftharpoons} CH_3COOH + C_2H_5OH$$

Saponification

Saponification is the alkaline hydrolysis of fats (which are esters of glycerol and long-chain carboxylic acids called fatty acids). When fats or oils are heated with sodium hydroxide solution, they break down to produce **soap** (sodium salt of the fatty acid) and **glycerol**:

$$\text{fat (triester)} + 3\text{NaOH} \rightarrow 3 \text{ soap molecules (sodium carboxylate)} + \text{glycerol}$$

This is the basis of traditional soap manufacture.

Soaps and Soapless Detergents

Both soaps and soapless detergents are cleaning agents with a similar molecular structure: a long non-polar hydrocarbon tail (attracted to grease) and a polar ionic head (attracted to water). This allows them to surround and emulsify grease particles.

Feature	Soap	Soapless detergent
Source	Made from natural fats/oils (saponification)	Synthesised from petroleum products
Behaviour in hard water	Forms scum (insoluble calcium/magnesium salts)	Does not form scum — effective in hard water
Behaviour in soft water	Effective	Effective
Biodegradability	Generally biodegradable	Some are not biodegradable; can cause foam in rivers
Environmental impact	Lower	Higher (persistent foam, aquatic toxicity)

📝 **Exam Tip**

The key distinction for exams: soaps are ineffective in hard water because Ca^{2+} and Mg^{2+} ions react with soap molecules to form an insoluble scum. Soapless detergents do not react with these ions, so they lather and clean effectively in hard water.