

Organic chemistry

IGCSE Chemistry 0620 · Topic 11 revision notes

Everything from the 10 lessons of this topic on a few pages: the key idea of each lesson, the diagram to remember, the points to learn and the traps examiners set. Read it, cover it, test yourself.

1. Formulae, functional groups and homologous series

2. Naming organic compounds

3. Fuels and fractional distillation

4. Alkanes

5. Alkenes

6. Cracking

7. Alcohols

8. Carboxylic acids and esters

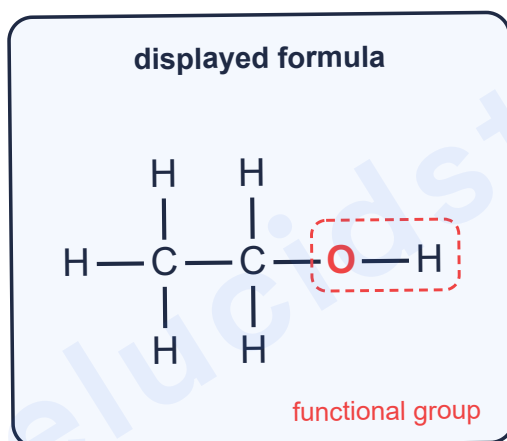
9. Addition polymers

10. Condensation polymers and proteins

1 Formulae, functional groups and homologous series

Syllabus 11.1

A **molecular formula** gives the number and type of each atom (C_2H_6O); a **structural formula** shows how the atoms are arranged without drawing bonds (CH_3CH_2OH); a **displayed formula** shows every atom and every bond. A **functional group** is the atom or group of atoms that decides the chemical properties of a compound: $C=C$ in alkenes, $-OH$ in alcohols, $-COOH$ in carboxylic acids. A **homologous series** is a family of compounds with the **same general formula** and **same functional group**, so they have **similar chemical properties** and a **trend in physical properties**; neighbouring members differ by CH_2 . A **saturated** compound has only $C-C$ single bonds; an **unsaturated** compound contains at least one $C=C$ double (or $C\equiv C$ triple) bond.



molecular

C_2H_6O (atoms of each kind)

structural

CH_3CH_2OH (no bonds drawn)

general (alcohols)

$C_nH_{2n+1}OH$

functional group

$-OH$ (hydroxyl)

ethanol four ways; only the displayed one shows every bond

Fig. 1: ethanol as molecular, structural, displayed and general formulae

Four formulae, three groups.

- ✓ **Molecular** C_2H_6O , **structural** CH_3CH_2OH , **displayed** every bond.
- ✓ **Functional groups:** $C=C$ alkene, $-OH$ alcohol, $-COOH$ carboxylic acid.
- ✓ **Homologous series:** same general formula and functional group, similar chemistry, trend in physical properties.
- ✓ **Saturated** = $C-C$ single bonds only; **unsaturated** = contains $C=C$.

Watch out!

A homologous series has **similar chemical** properties but a **trend in physical** properties: do not swap the two words. "Saturated" means only single carbon-carbon bonds, not "contains as much hydrogen as possible dissolved in it". And the $-OH$ in an alcohol is a covalently bonded group, not a hydroxide ion: alcohols are not alkalis.

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2 Naming organic compounds

Syllabus 11.2

The **stem** counts the carbon atoms in the chain: **meth-** 1, **eth-** 2, **prop-** 3, **but-** 4. The **ending** names the homologous series: **-ane** for alkanes, **-ene** for alkenes, **-ol** for alcohols and **-oic acid** for carboxylic acids. A number shows where the functional group sits when it could be in more than one place, as in propan-1-ol or but-2-ene. **(Extended)** An **ester** is named alcohol part first (ending -yl) then acid part (ending -oate); ethanol + ethanoic acid gives **ethyl ethanoate**. **(Extended)** **Structural isomers** have the **same molecular formula but different structural formulae**, such as butane and methylpropane (both C_4H_{10}).

stem: carbon atoms

1 C	meth-
2 C	eth-
3 C	prop-
4 C	but-

ending: homologous series

-ane	alkanes, C-C only
-ene	alkenes, C=C
-ol	alcohols, -OH
-oic acid	carboxylic acids, -COOH
-yl -oate	esters, -COO-

prop + **ene** = propene, $CH_3CH=CH_2$

but + **anoic acid** = butanoic acid, $CH_3CH_2CH_2COOH$

Fig. 1: the stem counts carbons, the ending names the homologous series

Stem, number, ending.

- ✓ **Stems:** meth 1, eth 2, prop 3, but 4 (count the -COOH carbon too).
- ✓ **Endings:** -ane, -ene, -ol, -oic acid.
- ✓ **Extended:** esters are alcohol-yl acid-oate; ethyl ethanoate.
- ✓ **Extended:** isomers = same molecular formula, different structural formula.

Watch out!

A chain drawn with a bend is **the same molecule**, not an isomer: follow the bonds, not the shape on the page. Name the longest unbroken carbon chain, so a "bent butane" is still butane. In esters the **alcohol gives the first word** (ethyl) and the **acid gives the second** (ethanoate), the reverse of the order in the word equation.

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3 Fuels and fractional distillation

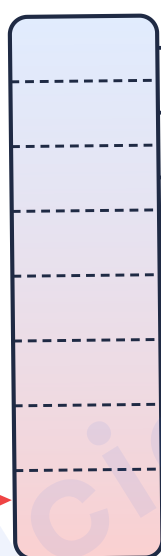
Syllabus 11.3

The **fossil fuels** are **coal**, **natural gas** and **petroleum** (crude oil). The main constituent of natural gas is **methane**, CH_4 . Petroleum is a **mixture of hydrocarbons** (compounds of hydrogen and carbon only) that is separated by **fractional distillation**: the oil is vaporised, the vapour rises up a column that is hot at the bottom and cooler at the top, and each **fraction** condenses at the level where the temperature falls below its boiling point. Going **down** the column the molecules have **longer chains**, **higher boiling points**, **lower volatility** and **higher viscosity**.

cool, top
25 °C

hot, bottom
350 °C

heated
crude oil



refinery gas: heating and cooking

gasoline / petrol: fuel for cars

naphtha: chemical feedstock

kerosene / paraffin: jet fuel

diesel / gas oil: diesel engines

fuel oil: ships, home heating

lubricating oil: lubricants, waxes

bitumen: surfacing roads

lower down the column: longer chains, higher boiling points,
more viscous and less volatile fractions

Fig. 1: the fractionating column, its fractions and their uses

Gas at the top, bitumen at the base.

- ✓ **Fossil fuels:** coal, natural gas (mainly methane), petroleum.
- ✓ **Order:** refinery gas, gasoline, naphtha, kerosene, diesel, fuel oil, lubricating oil, bitumen.
- ✓ **Down the column:** longer chains, higher b.p., less volatile, more viscous.
- ✓ **Separation:** by boiling point; a physical process, no bonds broken.

Watch out!

Fractional distillation is a **physical** separation: no bonds inside molecules are broken, so it is not cracking. Do not say the fractions are separated by **melting** point or by density; they condense at different **temperatures** because they have different **boiling points**. A volatile fraction evaporates easily, so **high volatility** goes with a **low boiling point**.

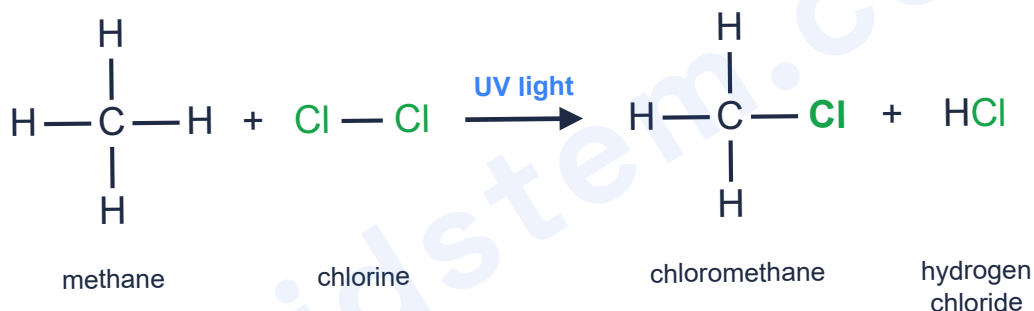
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4 Alkanes

Syllabus 11.4

Alkanes are **saturated hydrocarbons** with the general formula C_nH_{2n+2} ; every bond is a single covalent bond. They are **generally unreactive**, except for **combustion** and **substitution by chlorine**. In **complete combustion** an alkane burns in plenty of oxygen to give **carbon dioxide and water**, releasing a lot of energy, which is why alkanes are used as fuels. In **substitution** a hydrogen atom is replaced by a chlorine atom: $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$. **(Extended)** This is a **photochemical reaction**: **ultraviolet light** provides the activation energy.

substitution: one H atom is replaced by a Cl atom



saturated alkanes react by substitution, not addition



Fig. 1: methane and chlorine in ultraviolet light give chloromethane and hydrogen chloride

Two reactions only.

- ✓ **Alkanes:** C_nH_{2n+2} , saturated, generally unreactive.
- ✓ **Complete combustion:** $CO_2 + H_2O$; balance C, H, then O.
- ✓ **Substitution:** Cl_2 in UV light; $CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$.
- ✓ **Extended:** photochemical, UV light supplies the activation energy.

Watch out!

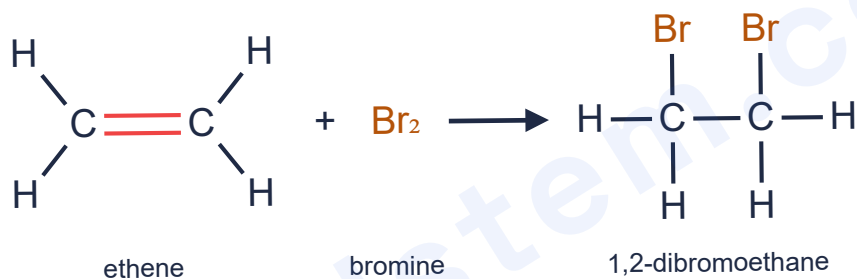
Substitution makes **two** products: do not forget the **HCl**. Alkanes do **not** undergo addition, because they have no $C=C$ bond to open. The condition is ultraviolet light, not heat with a catalyst, and the chlorine replaces a **hydrogen**, never a carbon.

5 Alkenes

Syllabus 11.5

Alkenes are **unsaturated hydrocarbons** with the general formula C_nH_{2n} and a **C=C double bond** as the functional group. To tell an alkene from an alkane, shake it with **aqueous bromine**: an alkene turns it from **orange to colourless**, an alkane leaves it orange. **(Extended)** Alkenes undergo **addition reactions**, in which the double bond opens and two atoms or groups add on, giving a **single product**: with **bromine** (ethene $\rightarrow$ 1,2-dibromoethane), with **hydrogen** using a **nickel catalyst** (ethene $\rightarrow$ ethane), and with **steam** using an **acid catalyst** (ethene $\rightarrow$ ethanol).

addition: the C=C opens and both atoms add on



 aqueous bromine (orange) $\rightarrow$  colourless (alkene)

with an alkane the bromine water stays orange

Fig. 1: bromine adds across the C=C bond of ethene, which decolourises bromine water

Test, then add.

- ✓ **Alkenes:** C_nH_{2n} , unsaturated, $C=C$.
- ✓ **Test:** aqueous bromine, orange to colourless.
- ✓ **Extended, hydrogen:** nickel catalyst, gives an alkane.
- ✓ **Extended, steam:** H_3PO_4 catalyst, 300 °C, 6000 kPa, gives an alcohol.

Watch out!

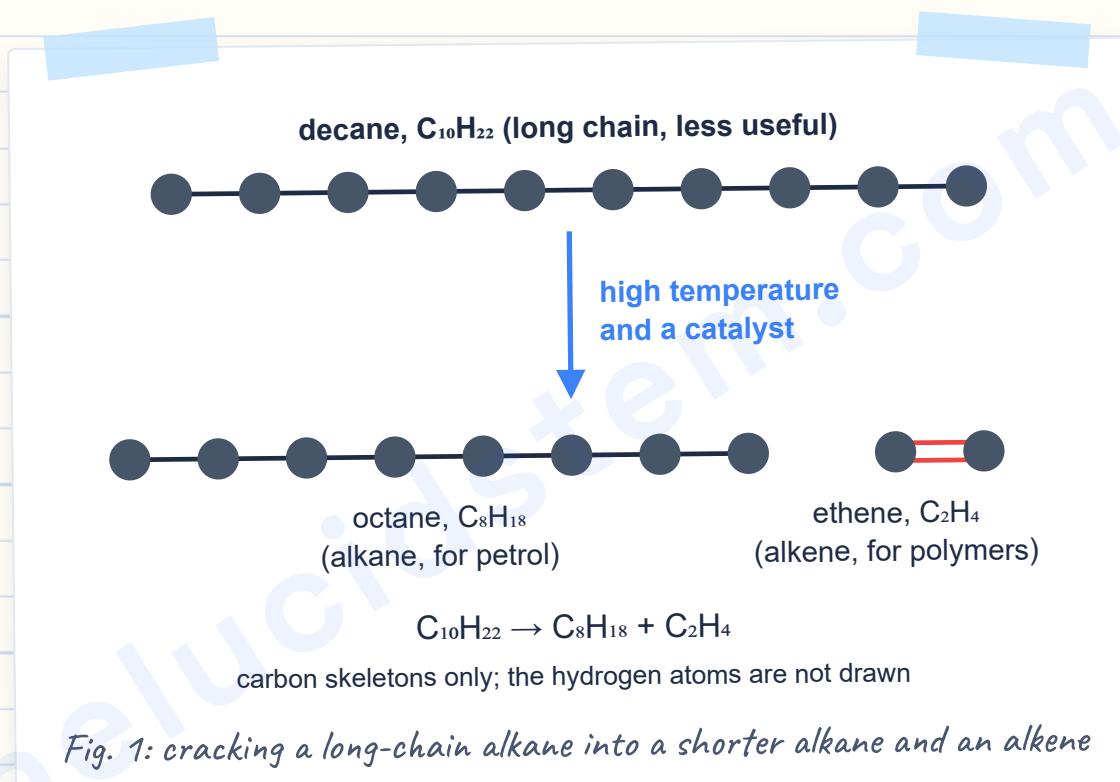
An addition reaction gives **one product only**; there is no HBr or H_2O left over, unlike substitution. Learn the catalysts as pairs: **hydrogen with nickel, steam with an acid (phosphoric acid)**. And the bromine test result is **orange to colourless**, never "clear": clear means transparent, and orange bromine water is already clear.

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6 Cracking

Syllabus 11.5

Cracking is the **thermal decomposition** of large alkane molecules into **smaller alkanes and alkenes**, and sometimes **hydrogen**. It needs a **high temperature** (about 500–600 °C) and a **catalyst** (such as silica or alumina, often in the form of zeolites). Cracking equations must balance: $C_{10}H_{22} \rightarrow C_8H_{18} + C_2H_4$. It is done because crude oil contains **more long-chain fractions than are needed** and **not enough short-chain fractions** such as petrol, and because the **alkenes** made are the starting materials for **polymers** and other chemicals such as ethanol.



Heat, catalyst, split.

- ✓ **Cracking:** thermal decomposition of large alkanes.
- ✓ **Conditions:** high temperature and a catalyst (silica or alumina).
- ✓ **Products:** smaller alkanes + alkenes (+ sometimes hydrogen).
- ✓ **Why:** match supply to demand; make alkenes for polymers.

Watch out!

Cracking is **thermal decomposition**, not combustion: no oxygen is involved and nothing burns. The products always include an alkene (unless the only other product is hydrogen), because there are not enough hydrogen atoms for every product to be saturated. Always check that both carbon and hydrogen balance.

7 Alcohols

Syllabus 11.6

Alcohols contain the **-OH** functional group; ethanol is C_2H_5OH . Ethanol is made by **fermentation**: aqueous glucose with **yeast** at **25–35 °C** in the **absence of oxygen**: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$. It is also made by the **catalytic addition of steam to ethene** at about 300 °C and 6000 kPa with an **acid catalyst** (phosphoric acid): $C_2H_4 + H_2O \rightarrow C_2H_5OH$. **Extended**: fermentation uses a **renewable** raw material and little energy but is slow and gives impure, dilute ethanol; hydration is fast, continuous and gives pure ethanol but uses **non-renewable** crude oil and much energy. Ethanol burns completely to carbon dioxide and water and is used as a **fuel** and a **solvent**.

fermentation



yeast, 25–35 °C
no oxygen (anaerobic)

batch process, slow
dilute, impure ethanol

renewable sugar (crops)

cheap equipment

hydration of ethene



steam, acid catalyst (H_3PO_4)
300 °C, 6000 kPa

continuous process, fast
pure ethanol

ethene from crude oil

(non-renewable)

two routes to ethanol, C_2H_5OH

uses: solvent and fuel

Fig. 1: making ethanol by fermentation and by the hydration of ethene

Two routes, one product.

- ✓ **Fermentation:** glucose, yeast, 25–35 °C, no oxygen; gives CO₂ too.
- ✓ **Hydration:** ethene + steam, 300 °C, 6000 kPa, acid catalyst.
- ✓ **Extended:** renewable but slow and impure vs fast and pure but non-renewable.
- ✓ **Combustion:** $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$.

Watch out!

Fermentation needs the **absence of oxygen**, but combustion of ethanol needs oxygen: do not mix them up. The fermentation temperature is **25–35 °C**, not a high temperature: heating kills (denatures the enzymes in) the yeast. In the hydration equation water is **steam**, and the catalyst is an **acid** (phosphoric acid), not yeast.

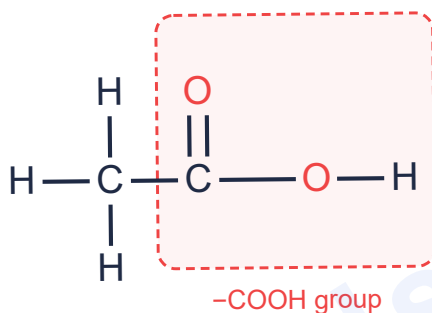
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8 Carboxylic acids and esters

Syllabus 11.7

Carboxylic acids contain the **-COOH** functional group; ethanoic acid is CH_3COOH . Ethanoic acid is a **weak acid**: it reacts with **metals** to give a salt and hydrogen, with **bases** to give a salt and water, and with **carbonates** to give a salt, water and carbon dioxide. Its salts are **ethanoates**. **Extended**: ethanoic acid is made by **oxidising ethanol**, either with **acidified aqueous potassium manganate(VII)** or by **bacterial oxidation** during vinegar production. A carboxylic acid reacts with an alcohol in the presence of an **acid catalyst** to form an **ester** and water; ethanoic acid + ethanol $\rightleftharpoons$ ethyl ethanoate + water.

ethanoic acid, CH_3COOH



a weak acid: partly ionises

metal $\rightarrow$ salt + hydrogen

base $\rightarrow$ salt + water

carbonate $\rightarrow$ salt + water
+ carbon dioxide

making an ester (Extended), acid catalyst

ethanoic acid + ethanol $\rightleftharpoons$ ethyl ethanoate + water



Fig. 1: ethanoic acid, its reactions as an acid, and the formation of an ester

Weak acid, oxidised alcohol, fruity ester.

- ✓ **Ethanoic acid:** weak acid; metal, base, carbonate give ethanoates.
- ✓ **Extended, oxidation:** acidified KMnO_4 (purple to colourless) or bacteria in air.
- ✓ **Extended, esterification:** acid + alcohol $\rightleftharpoons$ ester + water, conc. H_2SO_4 catalyst.
- ✓ **Naming:** alcohol part first (ethyl), acid part second (ethanoate).

Watch out!

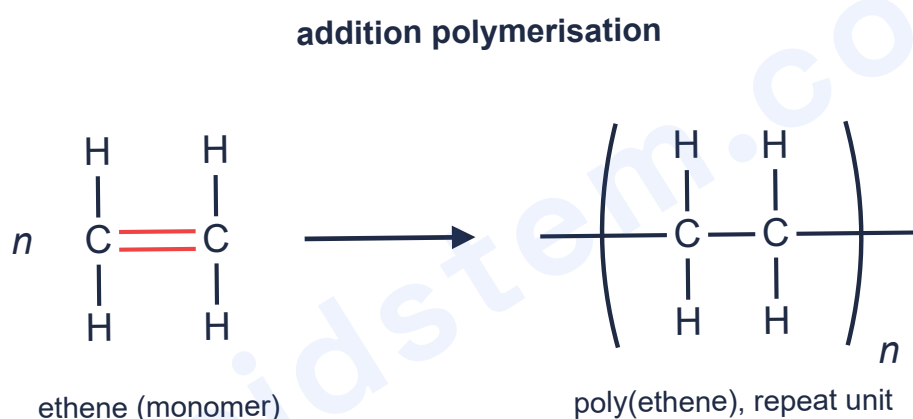
In an ester name the **alcohol** part comes **first** (ethyl, methyl) and the **acid** part second (ethanoate, propanoate), even though the formula $\text{CH}_3\text{COOC}_2\text{H}_5$ is written acid part first. Methanol + ethanoic acid gives **methyl ethanoate**, not ethyl methanoate. Ethanoic acid is weak because it is only partly **dissociated**, not because it is dilute: weak and dilute mean different things.

9 Addition polymers

Syllabus 11.8

Polymers are large molecules built up from many small molecules called **monomers**. Many **plastics** are polymers made from chemicals obtained from **crude oil**. In **addition polymerisation**, alkene monomers join when their **C=C double bonds** open; the polymer is the **only product**. Ethene forms **poly(ethene)**, whose **repeat unit** is $-\text{CH}_2-\text{CH}_2-$.

Extended: draw the polymer from a given alkene, and deduce the monomer from a section of polymer. Plastics are hard to dispose of; they are **non-biodegradable** and fill **landfill** sites, they **accumulate in oceans**, and **burning** them can release **toxic gases**. **Recycling** reduces these problems.



each C=C opens and the monomers join into one long chain
the polymer is the only product

Fig. 1: addition polymerisation of ethene and the repeat unit of poly(ethene)

C=C opens, chain grows.

- ✓ **Polymer:** large molecule made of many monomers.
- ✓ **Addition:** alkene C=C opens; polymer is the only product.
- ✓ **Extended, monomer:** two backbone carbons, put the C=C back.
- ✓ **Disposal:** landfill, oceans, toxic gases on burning; recycle.

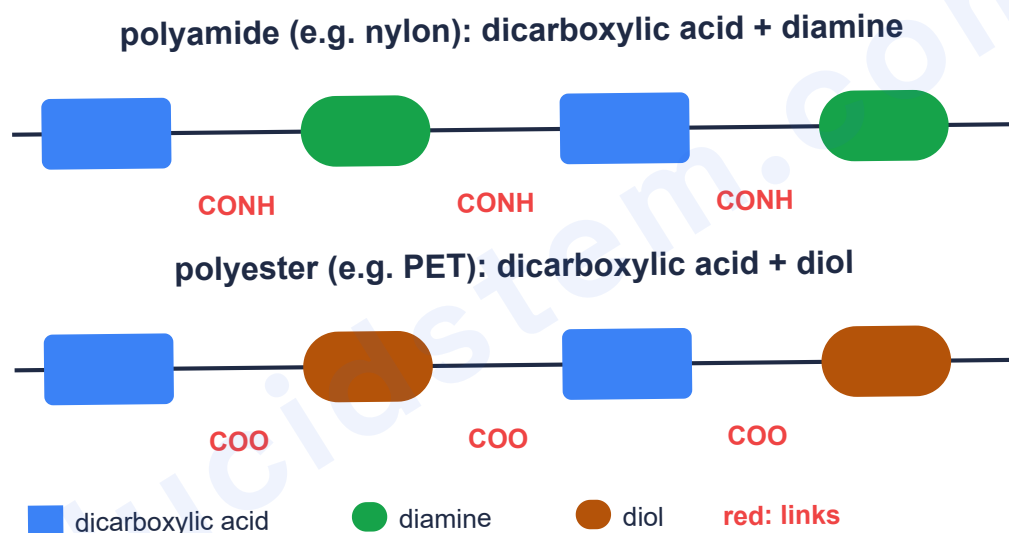
Watch out!

The repeat unit has **single** bonds only: the double bond belongs to the monomer, not the polymer. Do not include the side group in the backbone (poly(propene) has a **two-carbon** repeat unit with a CH₃ branch, not three carbons in a row). Plastics are made **from crude oil**, so they are not renewable; "non-biodegradable" means microorganisms cannot break them down.

10 Condensation polymers and proteins

Syllabus 11.8

Extended. In **condensation polymerisation** two different functional groups react to form a link and a **small molecule, usually water**, is released each time. **Nylon** is a **polyamide** made from a **dicarboxylic acid** and a **diamine**; the monomers join by **amide linkages**, $-\text{CONH}-$. **PET** is a **polyester** made from a **dicarboxylic acid** and a **diol**; the monomers join by **ester linkages**, $-\text{COO}-$. PET can be **converted back into its monomers and re-polymerised**, so it can be recycled. **Proteins** are natural **polyamides** made from **amino acids**, $\text{H}_2\text{N}-\text{CHR}-\text{COOH}$, joined by the same amide link; **hydrolysis** breaks them back into amino acids.



every link forms with the loss of a small molecule, water

Fig. 1: condensation polymerisation forming amide and ester linkages with loss of water

Two groups react, water leaves.

- ✓ **Nylon:** diacid + diamine, amide link -CONH- , polyamide.
- ✓ **PET:** diacid + diol, ester link -COO- , polyester; recyclable to monomers.
- ✓ **Condensation vs addition:** water released vs polymer only.
- ✓ **Proteins:** amino acids, amide links; hydrolysis gives amino acids back.

Watch out!

The amide link is -CO-NH- and the ester link is -CO-O- ; check whether the atom after the C=O is N or O. In a repeat unit, the water has already gone, so do not leave -OH or -H on the ends of the bracketed unit. Hydrolysis is the **reverse** of condensation: water is **used**, not released.

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