Cambridge IGCSE · Chemistry 0620 · Notes

Polymers

Read online at **pastopic.com/cambridge/chemistry-0620/notes/polymers**

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Read first: **Alkenes**, **Alcohols and carboxylic acids**

What you need to know

By the end of this topic you should be able to:

1. **Define a polymer**: a large molecule built up from many smaller molecules called **monomers**.
2. **Describe how poly(ethene) is made** from ethene monomers, as an example of **addition polymerisation**.
3. **State that plastics are made from polymers.**
4. **Describe how the properties of plastics affect their disposal**: they are unreactive and do not break down.
5. **Describe the environmental problems plastics cause**: disposal in **landfill sites**, **build-up in oceans**, and **toxic gases when they are burned**.
6. **Extended only: identify the repeat unit and the linkages** in addition polymers and in condensation polymers.
7. **Extended only: deduce the structure or repeat unit of an addition polymer from its alkene**, and the alkene from the polymer.
8. **Extended only: deduce the structure or repeat unit of a condensation polymer from its monomers**, and the monomers from the polymer, for **polyamides** (from a dicarboxylic acid and a diamine) and **polyesters** (from a dicarboxylic acid and a diol).
9. **Extended only: describe the differences between addition and condensation polymerisation.**
10. **Extended only: describe and draw the structures of nylon** (a polyamide) and **PET** (a polyester). You don't need PET's full name.
11. **Extended only: state that PET can be turned back into its monomers and polymerised again.**
12. **Extended only: describe proteins as natural polyamides** made from **amino acid** monomers, and draw the general structure of an amino acid.
13. **Extended only: describe and draw the structure of a protein.**

The C=C of alkenes and their other reactions are in the Alkenes note; making a single ester from an acid and an alcohol is in the Alcohols and carboxylic acids note. This note recaps only the parts polymers need.

Understand it

Monomers and polymers

A **polymer** is a very large molecule (a long chain) made by joining together **many** small molecules, the **monomers**. The reaction that joins them is **polymerisation**. Small monomers go in; one large polymer molecule comes out. **Plastics** are made from polymers.

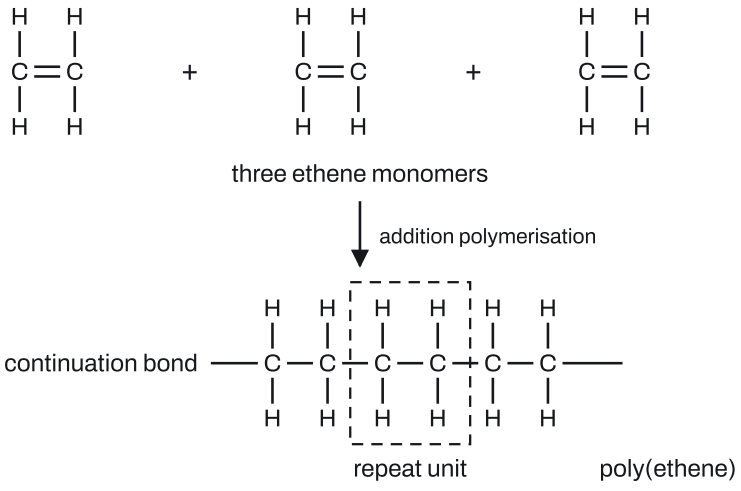
There are two ways of joining monomers:

	Addition polymerisation	**Condensation polymerisation**
Monomers	alkenes: each has a **C=C**	each has **two functional groups** (–COOH, –OH, –NH_2), one at each end (amino acids: both on one carbon)
Products	the polymer **only**	the polymer **and** a small molecule, **water**
Linkage between units	C–C single bonds	**ester** –COO– or **amide** –CONH–
Examples	poly(ethene), poly(propene)	nylon, PET, proteins

Addition polymerisation: poly(ethene)

Ethene, $\mathrm{CH_2{=}CH_2}$, is the monomer. When ethene molecules polymerise, one of the two bonds of each C=C opens and each carbon forms a new single bond to the next molecule. Thousands of molecules join into one long chain, and nothing else is made. Because the chain has only single C–C bonds, poly(ethene) is **saturated**: it does not decolourise aqueous bromine.

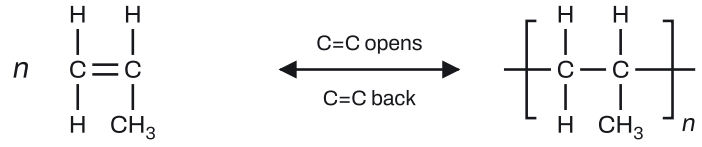
$$n\,\mathrm{CH_2{=}CH_2} \rightarrow -[\mathrm{CH_2{-}CH_2}]_n-$$



- The **repeat unit** is the smallest part of the chain that repeats. For an addition polymer it has the same atoms as one monomer, with the C=C now a C–C.
- The lines at the ends of a section are **continuation bonds**: they show that the chain carries on. Never put an H on the end of them.
- n is a large number (thousands). Different chains in a sample have different lengths, so a polymer has **no fixed molecular formula**; its empirical formula is the same as its monomer's (poly(ethene) is $\mathrm{CH_2}$, like ethene).
- The name is "poly" + the monomer's name in brackets: **poly(ethene)**, never poly(ethane). Ethane has no C=C and cannot polymerise.

Extended only: any alkene gives an addition polymer

Only the two carbons of the C=C go into the main chain. Everything else on them (H atoms, $\mathrm{CH_3}$, $\mathrm{C_2H_5}$, Cl, even a –COOH group) becomes a **side group** hanging off the chain, unchanged.



monomer: propene repeat unit of poly(propene)

So the recipe for a repeat unit is: **draw the two C=C carbons joined by a single bond, keep every group on them in place, and add a continuation bond on each side.** A section of three repeat units is a chain of **six** carbons with the side groups on every other carbon. Brackets and n are optional.

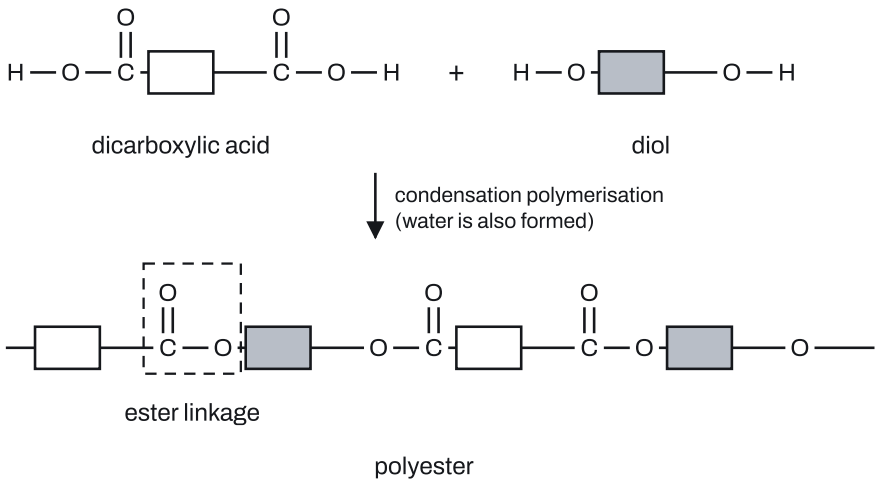
Going backwards (polymer → monomer): pick any two neighbouring carbons of the main chain that make one repeat unit, remove the continuation bonds, and put a **double bond** between them. The number of monomers used to make a section = main-chain carbons ÷ 2.

Extended only: condensation polymerisation

Here each monomer has a reactive group **at each end**. When a –COOH group meets an –OH or $\mathrm{–NH_2}$ group on another monomer, they join and a **water** molecule is lost (the OH from the acid and an H from the other group). Because every monomer has two groups, joining can carry on at both ends, building a chain. **One water molecule is made for every linkage formed.**

The syllabus draws the carbon chain of each monomer as a **box**, so that only the functional groups need to be shown.

Polyesters are made from a **dicarboxylic acid** (HOOC–□–COOH) and a **diol** (HO–■–OH). The linkage is the **ester linkage**, –C(=O)–O–, the same one as in a simple ester made from an acid and an alcohol.



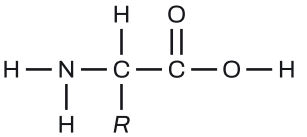
PET is a polyester: –CO–□–CO–O–■–O–, repeated. Its repeat unit contains **one** acid block and **one** diol block: –CO–□–CO–O–■–O–. PET can be broken down back into its monomers, which can then be polymerised again to make new PET; this is one way it is recycled. (Older papers call a similar polyester **Terylene**.)

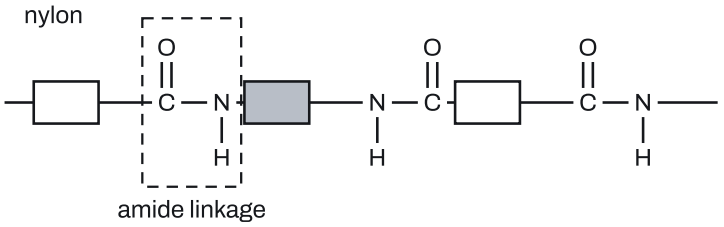
Polyamides are made from a **dicarboxylic acid** (HOOC–□–COOH) and a **diamine** (H_2N–■–NH_2). The linkage is the **amide linkage**, –C(=O)–N(H)–. **Nylon** is a synthetic polyamide: –CO–□–CO–NH–■–NH–, repeated.

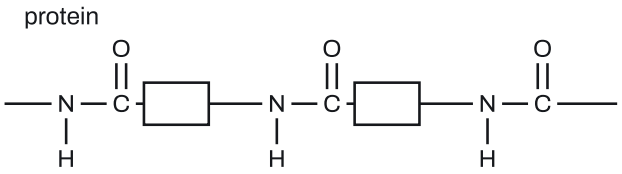
Extended only: proteins are natural polyamides

Amino acids have an **amine group, –NH_2**, and a **carboxylic acid group, –COOH**, on the **same carbon atom**, which also carries an H atom and a **side-chain R**. Different amino acids have different R groups: R = H in the simplest one, R = CH_3 in the one with three carbon atoms (2-aminopropanoic acid).

Amino acids join by condensation polymerisation: the –COOH of one reacts with the –NH_2 of the next, making an amide linkage and a water molecule. The polymer is a **protein**. A protein is a **natural polyamide**; nylon is a **synthetic** one with the same linkage.







Telling nylon from a protein on paper:

- **Nylon:** two kinds of block. One block has C=O at **both** ends, the next has N–H at **both** ends, so the amide linkages point alternately one way and the other.
- **Protein:** every unit is –NH–□–CO– (from one amino acid), so every amide linkage points the **same** way along the chain.

Plastics and the environment

Plastics are useful because they are **unreactive**: they don't react with water, air (oxygen), acids or alkalis. The same property causes the disposal problems.

- **Landfill:** most plastics are **non-biodegradable**. They don't rot or decompose, so they take up landfill space for a very long time.
- **Oceans:** plastic waste doesn't dissolve or break down in water; many plastics are also less dense than water and float and spread. It **builds up in the oceans**, where animals swallow it or get trapped in it.
- **Burning:** burning plastics releases **toxic gases** (and acidic gases from some plastics, such as those containing chlorine), which pollute the air.

This is why plastics should be reduced, reused and recycled.

Key facts and formulas

Nothing here is given in the exam (the paper gives only the Periodic Table), so everything below is to learn.

Formula	Status
Polymer: a large molecule built up from many small molecules (monomers)	Learn it
$n\,\mathrm{CH_2{=}CH_2} \rightarrow -[\mathrm{CH_2{-}CH_2}]_n-$ (addition polymerisation; only product)	Learn it
Extended: addition polymer repeat unit = the two C=C carbons joined by a single bond, same side groups, continuation bonds	Learn it
Extended: monomers in a section of an addition polymer = main-chain carbons ÷ 2	Learn it
Extended: polyester: dicarboxylic acid + diol; ester linkage –COO–	Learn it
Extended: polyamide: dicarboxylic acid + diamine (or amino acids); amide linkage –CONH–	Learn it
Extended: condensation: one water molecule per linkage formed	Learn it
Extended: amino acid $\mathrm{H_2N{-}CH(R){-}COOH}$; $M_\mathrm{r} = 74 + M_\mathrm{r}(\mathrm{R})$	Learn it
Plastic problems: landfill (non-biodegradable), oceans (accumulate, harm animals), burning (toxic gases)	Learn it

How to do it

In the questions we have tagged for this topic (116 questions, 2021–2025, on all four papers), the types came up this often. 40 of the 116 questions mix types, so the counts add up to more than 116.

Question type	Questions
State the type of polymerisation or the other product	33
Identify the linkage or kind of polymer from a structure	24
Name or classify polymers	20
Define polymer, monomer and polymerisation	20
Deduce the monomers of a condensation polymer	16
Poly(ethene) and ethene: names and structures	15
Draw or choose an addition polymer from its alkene	14
Environmental problems of plastics	14
Deduce the monomer of an addition polymer	8

Question type	Questions
Proteins and amino acids	8
Draw a condensation polymer from its monomers	7

1. State the type of polymerisation or the other product (33 questions)

1. **Look at the monomer.** An alkene (a C=C) → **addition**. Two functional groups on each monomer (–COOH with –OH or $–NH_2$), or amino acids → **condensation**.
2. **Look at the product.** Polyester, polyamide, nylon, PET or protein → **condensation**. Poly(ethene), poly(propene) or any poly(alkene) → **addition**.
3. **The other product of condensation is water.** Addition makes no other product.

Variations you will meet:

- **Core: circle the word** (addition, from a list with substitution, oxidation, neutralisation): addition for poly(ethene).
- **"How many molecules of water form when this section is made?"** Count every linkage drawn (each C=O next to an O or an N), including those at the ends of the section next to a continuation bond: one water each. For example, –CO–O–□–O–CO–□–CO–O– has 3 ester linkages, so 3 water molecules.
- **Multiple choice with a table of "type" and "other product":** nylon → condensation, water; poly(ethene) → addition, none.
- **Multiple-choice statements.** True: water forms when a protein is made from amino acids; a polymer can be made from one type of monomer or from two different types. False: "monomers are always joined by addition"; "water is always produced"; "addition polymers only contain C and H" (side groups can hold Cl or O); "addition polymers have C=C in the main chain".
- **"Which homologous series forms addition polymers?"** Alkenes.

2. Identify the linkage or kind of polymer from a structure (24 questions)

Extended only.

1. **Find the linkages** between the blocks. C=O next to O → **ester** (polyester). C=O next to N–H → **amide** (polyamide).
2. **Name the kind**: polyester or polyamide, both **condensation** polymers.
3. **Tell nylon from a protein**: two kinds of block with linkages alternating in direction → nylon; one repeating –NH–□–CO– unit, all linkages the same way → protein.

Variations you will meet:

- **"Circle one amide (or ester) linkage":** ring the C=O carbon with its O, and the N–H (or the –O–) next to it. Not a whole block.

- **"Circle one repeat unit" of PET or nylon:** it must hold one of **each** block and both linkages' atoms once: from a point on one block to the same point on the next identical block. Starting at one end of the drawn section is easiest.
- **Count linkages in a mixed chain:** go along and label each C=O: with N next to it, amide; with O next to it, ester.
- **Pick the structure of nylon, PET or a protein** from four: reject any with C=C, O–O, N–N or N–O links, or with an ester where an amide should be.
- **Two sections side by side** (for example nylon and a protein): same **amide** linkage, **different** monomers (diacid + diamine versus amino acids).
- **Fill the gaps**: "a polyamide formed by condensation polymerisation" (or polyester, condensation).

3. Name or classify polymers (20 questions)

Learn these facts; they come as single words or as multiple-choice statements.

Polymer	Kind	Natural or synthetic	Linkage
poly(ethene), poly(propene)	addition	synthetic	none (C–C chain)
nylon	polyamide, condensation	synthetic	amide –CONH–
PET (Terylene)	polyester, condensation	synthetic	ester –COO–
proteins	natural polyamide, condensation	natural	amide –CONH–

- **"Name a polyester"**: PET. **"Name a synthetic polyamide"**: nylon. **"Name a natural polymer"**: protein. **"Which polymers have the same linkage?"**: proteins and polyamides (nylon).
- **"Name the type of condensation polymer"** wants the **kind**, polyester or polyamide, not an example.
- **PET** can be converted back into monomers and re-polymerised. It is not an addition polymer, not a polyamide, and not made from amino acids.
- **Nylon contains nitrogen**, so burning it does not give only $\mathrm{CO_2}$ and $\mathrm{H_2O}$. A diol is a PET monomer but not a nylon monomer.
- **Sort by "synthetic"**: nylon and PET; not proteins. A substance "made by combining many small molecules" is a polymer; the largest molecules in petroleum and the alkenes from cracking are not.
- Older papers (before 2023) also asked for uses (nylon and Terylene for clothing and ropes) and named carbohydrates as natural polymers; these are not in the current syllabus.

4. Define polymer, monomer and polymerisation (20 questions)

1. **Polymer**: a **large molecule** (a long-chain molecule) **built up from many small molecules (monomers)**. Two ideas, a mark each.
2. **Monomer**: one of the small molecules that join to make a polymer. "Complete the sentence … many smaller molecules called ___": **monomers**.
3. **Polymerisation**: the process that joins monomers into a polymer (the answer to "name the process used to make large molecules from monomers").

Variations you will meet:

- **Sizes**: monomers are **small**, polymers are **large**; small monomers join to form a large polymer (never the reverse).
- **Table of terms** for "many $\mathrm{CH_2{=}CH_2} \rightarrow$ one molecule X only": the reaction is **addition**, $\mathrm{CH_2{=}CH_2}$ is the **monomer**, X is the **polymer**. Not substitution, and not cracking (cracking breaks big molecules; polymerisation joins small ones).
- **"Which term describes the small unit used to make this molecule?"**: monomer.
- **Trap**: "the polymer of ethene is poly(ethane)" is false.

5. Deduce the monomers of a condensation polymer (16 questions)

Extended only.

1. **Find each linkage** and **break it**: split the C–O bond of an ester (or the C–N bond of an amide).
2. **Add back the water**: put –OH on the C=O side (making –COOH) and –H on the O or N side (making –OH or $–NH_2$).
3. **Write each different block once, with a group at each end.** Polyester → HOOC–□–COOH and HO–■–OH. Polyamide → HOOC–□–COOH and H_2N–■–NH_2.
4. **Show every atom and bond in the functional groups** if asked (C=O as a double line, O–H, N–H twice), with each group joined to the block through its C, O or N atom, never through H.

Variations you will meet:

- **Monomers have no continuation bonds.** They are separate, complete molecules.
- **Put the right groups on the right block**: the block between two C=O groups becomes the acid; the block between two O (or two N) atoms becomes the diol (or diamine).
- **Chains written without boxes**, such as –CO–CH_2CH_2–CO–O–$CH_2CH_2CH_2$–O–: the same method gives HOOC–CH_2CH_2–COOH and HO–$CH_2CH_2CH_2$–OH.
- **"Name the two types of monomer" or "homologous series"**: dicarboxylic acids and diols (carboxylic acids and alcohols); for a synthetic polyamide, carboxylic acid and amine groups. The –OH group is the **alcohol** group.
- **"Which functional groups form an amide linkage?"**: $–NH_2$ and –COOH.
- **Which molecules could make a polymer with a dicarboxylic acid?** Any with **two** groups that react with –COOH (–OH or $–NH_2$), one at each end: a diol, a diamine, or one with –OH at one end and $–NH_2$ at the other. A molecule with only one such group can't carry the chain on.
- **All the linkages point the same way and there is only one kind of block**: the polymer comes from **one** monomer with a different group at each end, such as HO–□–COOH (a polyester) or H_2N–□–COOH (a polyamide).

6. Poly(ethene) and ethene: names and structures (15 questions)

Mostly Core.

1. **Name the polymer from ethene**: **poly(ethene)**.
2. **The monomer**: **ethene**, C_2H_4. Draw it with a C=C (two lines) and two H on each carbon.
3. **The polymerisation**: **addition**.

Variations you will meet:

- **Choose the monomer** from a list of formulae: C_2H_4 (not C_2H_6).
- **Choose the poly(ethene) structure**: a chain of single C–C bonds, two H on every carbon, continuation bonds at both ends, and no H on the end of the chain.
- **Statements**: true: poly(ethene) is made by an addition reaction; ethene is a monomer; poly(ethene) does not easily decompose. False: the monomer is ethane; poly(ethene) is a monomer; poly(ethene) decolourises aqueous bromine (it is saturated).
- **Complete the sentences** "When ethene polymerises it produces ___; the type of reaction is ___": poly(ethene); addition.

7. Draw or choose an addition polymer from its alkene (14 questions)

Extended only.

1. **Redraw the alkene with the C=C horizontal** and every other group above or below its two carbons.
2. **Change the C=C to a C–C single bond.**
3. **Keep all the groups** on those two carbons exactly where they were.
4. **Add a continuation bond** on the left of the first carbon and the right of the second. Brackets and n are allowed but not needed.
5. For "**three repeat units**", draw a six-carbon chain and repeat the pattern three times.

Variations you will meet:

- **Side groups**: propene gives CH_3 on every other carbon; but-1-ene gives C_2H_5; but-2-ene gives a CH_3 on **both** chain carbons; an alkene carrying –COOH keeps the –COOH as a side group (only the C=C reacts). Draw the side group's bonds too (all the C–H bonds in CH_3) if the question says "all the atoms and all the bonds".
- **Choose the repeat unit** from four: the right one has exactly two chain carbons, single bond, the monomer's groups, and continuation bonds. Reject a chain that includes the side group's carbon (a three-carbon chain for propene) or still has a C=C.
- **Suggest the name**: poly(monomer): poly(propene), poly(but-2-ene), poly(chloroethene).
- **Choose the equation** for making the polymer: n monomers on the left, the bracketed repeat unit with n on the right.

8. Environmental problems of plastics (14 questions)

Core.

1. **Give the problem and its cause**, one mark each point:

- they are **non-biodegradable** (don't decompose), so they **fill landfill sites**;
- they **accumulate in oceans** (and rivers), harming animals that swallow them or get trapped;
- **burning** them makes **toxic gases**.

2. Be specific: "pollution" or "bad for the environment" alone earns nothing.

Variations you will meet:

- **Why are plastics hard to remove from the environment?** They **don't react with water** and **resist oxidation** (they are unreactive). Being a poor conductor or having a low density is not the reason.
- **Why do poly(ethene) bags build up in oceans?** Poly(ethene) **does not decompose in water**. It being saturated, or made from hydrocarbons, is true but not the reason.
- **Why recycle?** All three problems (landfill, oceans, toxic gases) are reasons.
- **Distractors to reject**: plastics quickly decompose in landfill; they burn to non-toxic products; they dissolve in the sea; plastic waste is made of small molecules.

9. Deduce the monomer of an addition polymer (8 questions)

Extended only.

1. **Take two neighbouring carbons** of the main chain that make one repeat unit, with their side groups.
2. **Remove the continuation bonds and make the C–C a C=C.**
3. **Draw it with all atoms and bonds** (each carbon has four bonds) and **name it**: $\mathrm{CH_3}$ on every other carbon → propene; $\mathrm{C_2H_5}$ on every other carbon → but-1-ene; $\mathrm{CH_3}$ on every chain carbon → but-2-ene.

Variations you will meet:

- **Number of monomer units** in the section shown: main-chain carbons ÷ 2.
- **Why can't you write the polymer's molecular formula?** The chains have no fixed length (n varies).
- **Empirical formula of the polymer**: the same as the monomer's (any polymer of an alkene $\mathrm{C_nH_{2n}}$ is $\mathrm{CH_2}$).
- **"Identify the functional group in alkenes that reacts when they polymerise"**: the C=C.
- **Two different side groups** (for example Cl and $\mathrm{CH_3}$) on alternate carbons: the chain could come from one monomer carrying both groups, or from two different monomers; check each pair of neighbouring chain carbons.
- **Don't** draw continuation bonds on the monomer (that gives carbons with five bonds).

10. Proteins and amino acids (8 questions)

Extended only.

1. **Natural polyamides** are called **proteins**; their monomers are **amino acids**; they form by **condensation** polymerisation.

2. **Draw an amino acid**: H–N–H (the –NH_2, both N–H bonds shown) on one carbon, which also has an H and R; on the same carbon, a –COOH drawn as C=O and C–O–H. Mark schemes give a mark for each fully displayed group.
3. **A given amino acid**: put its R on that central carbon. The amino acid with **three** carbon atoms has R = $\mathrm{CH_3}$: $\mathrm{H_2N–CH(CH_3)–COOH}$.

Variations you will meet:

- **Find R from M_r**: everything except R adds up to $14 + 2 + 12 + 1 + 12 + 32 + 1 = 74$, so $M_\mathrm{r}(\mathrm{R}) = M_\mathrm{r} - 74$. Then find the $\mathrm{C}_n\mathrm{H}_{2n+1}$ group with that mass ($\mathrm{CH_3} = 15$, $\mathrm{C_2H_5} = 29$, $\mathrm{C_3H_7} = 43$, $\mathrm{C_4H_9} = 57$).
- **Show the working**: write the subtraction, then R.
- Older papers (before 2023) also asked how proteins are broken back down to amino acids (**hydrolysis**, using **acids** or **enzymes**) and how the amino acids are then separated and identified (**chromatography**, a **locating agent**, R_f values). These are not in the current syllabus for this topic.

11. Draw a condensation polymer from its monomers (7 questions)

Extended only.

1. **Line up the blocks alternately**: acid, diol (or diamine), acid, diol ... For amino acids, one block after another.
2. **Join each pair** with a fully displayed linkage: ester –C(=O)–O– or amide –C(=O)–N(H)–. The C=O always stays on the block that came from the –COOH.
3. **Orientation**: for a polyester or nylon, the acid block has C=O at **both** ends and the diol block has O at both ends (diamine block: N–H at both ends). For a protein, every linkage points the same way: –NH–□–CO–NH–□–CO–.
4. **Ends**: finish with **continuation bonds**, not –OH, –H or –COOH end groups.
5. **Count**: two molecules of each monomer make three links between blocks; "two repeat units" of PET means acid, diol, acid, diol. To count water molecules for a section, count every linkage drawn, including any at the ends: one water each.

Variation: multiple choice: pick the repeat unit from two given monomers: it has one of each block, joined by the right linkage, with continuation bonds, and no –OH or –H left on the linkage.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

Poly(ethene) is used to make plastic crates for carrying fruit.

(a) State what is meant by the term polymer. **[2]**

(b) Draw the displayed formula of the monomer used to make poly(ethene). **[1]**

(c) Name the type of polymerisation that forms poly(ethene). **[1]**

(d) Poly(ethene) does not react with water or with oxygen in the air. Explain why this causes a problem when old crates are thrown away. **[1]**

(e) Describe two other environmental problems caused by the disposal of plastics. **[2]**

(a) A large molecule **B1**, built up from many small molecules called monomers **B1**.

(b) Ethene: two C atoms joined by a double bond (two lines), with two H atoms on each carbon. **B1**

(c) Addition. **B1** ("Additional" is not accepted.)

(d) It is non-biodegradable: it doesn't decompose, so it stays in landfill sites for a very long time. **B1**

(e) Any two: it builds up in the oceans, harming animals **B1**; burning it releases toxic gases **B1**.

Example 2 (Extended)

Tetrafluoroethene, $\mathrm{CF_2{=}CF_2}$, forms an addition polymer used to coat frying pans.

(a) Draw one repeat unit of this polymer. Show all of the atoms and all of the bonds. **[2]**

(b) Suggest the name of the polymer. **[1]**

A section of a different addition polymer, Q, is shown.

$$\mathrm{-CH_2-C(CH_3)_2-CH_2-C(CH_3)_2-CH_2-C(CH_3)_2-CH_2-C(CH_3)_2-}$$

(c) State the number of monomer molecules needed to make this section. **[1]**

(d) Draw the displayed formula of the monomer of Q. **[2]**

(e) Deduce the empirical formula of Q. **[1]**

(f) Suggest why Q is not given a molecular formula. **[1]**

(a) Two carbon atoms joined by a **single** bond, each with two F atoms (one above, one below), and a continuation bond on each side: $-\mathrm{CF_2}-\mathrm{CF_2}-$. **M1** for two C joined by a single bond with continuation bonds; **A1** for four F atoms, correctly placed.

(b) Poly(tetrafluoroethene). **B1**

(c) The main chain has 8 carbon atoms, so $8 \div 2 = 4$ monomer molecules. **B1**

(d) Take one $\mathrm{CH_2}$ and the $\mathrm{C(CH_3)_2}$ next to it and make the bond between them double: $\mathrm{CH_2{=}C(CH_3)_2}$. Drawn: a C=C; the left carbon has two H atoms; the right carbon has two $\mathrm{CH_3}$ groups, each drawn with three C–H bonds. **M1** for a C=C with each carbon having four bonds; **A1** for the whole structure.

(e) The monomer is $\mathrm{C_4H_8}$, which simplifies to $\mathrm{CH_2}$; the polymer has the same ratio. **B1**

(f) Its chains don't have a fixed length: n is different for different molecules. **B1**

Example 3 (Extended)

Pentanedioic acid, $\mathrm{HOOC{-}CH_2CH_2CH_2{-}COOH}$, reacts with ethane-1,2-diol, $\mathrm{HO{-}CH_2CH_2{-}OH}$, to form a polymer.

(a) Name the type of polymerisation and the other product formed. **[2]**

(b) Draw the part of the polymer formed from two molecules of each monomer. Show all of the atoms and all of the bonds in the linkages. **[3]**

(c) State the number of water molecules formed when the part of the polymer in (b) is made. **[1]**

(d) A section of a polyamide is shown. Draw the structures of its two monomers.

$$\mathrm{{-}NH{-}(CH_2)_4{-}NH{-}CO{-}(CH_2)_8{-}CO{-}NH{-}(CH_2)_4{-}NH{-}CO{-}(CH_2)_8{-}CO{-}}$$

[2]

(a) Condensation polymerisation **B1**; water **B1**.

(b) Join acid, diol, acid, diol with three ester linkages, each drawn with a C=O (two lines) and a single-bonded O:

$$\mathrm{{-}CO{-}CH_2CH_2CH_2{-}CO{-}O{-}CH_2CH_2{-}O{-}CO{-}CH_2CH_2CH_2{-}CO{-}O{-}CH_2CH_2{-}O{-}}$$

M1 one ester linkage fully displayed; **M1** all three linkages with the C=O on the acid block each time; **A1** continuation bonds at both ends and no –OH or –H left on the ends.

(c) Four molecules are joined by 3 linkages, so 3 water molecules. **B1**

(d) Break each amide linkage between C and N; add –OH to each C=O and –H to each N. **B1** $\mathrm{H_2N{-}(CH_2)_4{-}NH_2}$; **B1** $\mathrm{HOOC{-}(CH_2)_8{-}COOH}$. No continuation bonds on the monomers.

Example 4 (Extended)

(a) An amino acid has $M_\mathrm{r} = 117$. Its side-chain R contains carbon and hydrogen only. Deduce the formula of R. Show your working. (A_r: H = 1, C = 12, N = 14, O = 16) **[2]**

(b) Draw the displayed formula of the amino acid that has two carbon atoms. **[2]**

(c) Proteins and nylon both contain amide linkages. Describe one difference between the monomers used to make them. **[1]**

(d) Which statement about polymerisation is correct? **[1]**

- A Monomers used in condensation polymerisation contain a C=C bond.
- B Addition polymerisation forms water as well as the polymer.
- C Each monomer used to make a polyester has two functional groups.
- D The linkage in a polyester is –CONH–.

(a) Everything except R: $14 + 2 + 12 + 1 + 12 + 32 + 1 = 74$. **M1** $M_\mathrm{r}(\mathrm{R}) = 117 - 74 = 43$, which is $\mathrm{C_3H_7}$ ($3 \times 12 + 7 = 43$). **A1**

(b) R = H: $\mathrm{H_2N{-}CH_2{-}COOH}$. Drawn: N with two H atoms, joined to a C with two H atoms, joined to a C that has a double bond to O and a single bond to an O–H. **M1** for –NH_2 and –COOH fully displayed; **A1** for both on the same carbon, with every atom correct.

(c) A protein is made from amino acids, each having an –NH_2 **and** a –COOH group; nylon is made from two different monomers, a dicarboxylic acid and a diamine. **B1**

(d) A is wrong (that describes addition monomers); B is wrong (addition gives only the polymer); D is the amide linkage. Each polyester monomer has two –COOH or two –OH groups. **Answer C.**

Common mistakes

- **Vague definitions of a polymer.** "Lots of atoms joined", "polymers joining" or "a small macromolecule" earn nothing. Say "a large molecule built up from many small molecules (monomers)".
- **Writing "additional" polymerisation.** The word is **addition**; "additional" has been marked wrong.
- **Poly(ethane).** The polymer is poly(ethene), and its monomer is ethene, not ethane.
- **Keeping the C=C in the polymer.** An addition polymer's chain has only single C–C bonds. Examiners often see double bonds left in, or H atoms put on the ends of the chain.
- **Putting side-group carbons into the main chain.** For poly(propene), drawing a straight chain of nine carbons, or three separate three-carbon pieces, is wrong. The chain is made from the two C=C carbons only; $\mathrm{CH_3}$ hangs off every other carbon.

- **Carbons with five bonds, or hydrogen with two.** Check every C has four bonds and every H one, especially where a continuation bond meets a side group, and when an –OH is joined to a block through its H.
- **Continuation bonds on monomers**, or no continuation bonds on the polymer. Monomers are separate molecules; a polymer section must carry on at both ends.
- **Linkages drawn the wrong way round.** In a polyester or nylon, each C=O belongs to the acid block. Look at which block had the –COOH before drawing.
- **Linkages not fully displayed.** When asked for all atoms and bonds in the linkage, draw C=O as two lines and show the O (or the N–H).
- **Giving an example instead of the kind.** "Name the type of condensation polymer" wants **polyester** (or polyamide), not PET, Terylene or nylon.
- **Mixing up nylon and proteins.** Both are polyamides; only proteins are natural, and only proteins come from amino acids. Nylon is not natural.
- **Environmental answers that are too vague.** "It pollutes" earns nothing; say landfill (non-biodegradable), oceans (harms animals) or toxic gases on burning.

How to get the marks

- **"State" and "Name"** want the exact word: addition, condensation, water, monomer, polymer, poly(ethene), polyester, polyamide, protein, amino acids, nylon, PET.
- **"Define" a polymer**: two ideas, two marks: **large molecule** and **built from many monomers**.
- **Drawing an addition polymer**: M1 for the two chain carbons joined by a single bond with continuation bonds; M2 for the side groups right. For "three repeat units", a six-carbon chain with side groups on alternate carbons earns a mark, the side groups another, and the whole structure with continuation bonds a third.
- **Drawing a condensation polymer**: one mark for a correct fully displayed linkage, one for every linkage the right way round, one for the whole section with continuation bonds and no leftover end groups.
- **Drawing monomers**: fully displayed functional groups (–COOH, –OH, $–NH_2$) on the correct blocks, no continuation bonds.
- **Drawing an amino acid**: $–NH_2$ fully displayed (a mark), –COOH fully displayed (a mark), both on the same carbon with H and R.
- **"Describe" environmental problems**: one specific problem per mark.
- **"Suggest"** means apply the pattern to something new: the name poly(but-2-ene), or why a polymer has no molecular formula (chains of different length).
- **Multiple choice**: label each structure (C=C? ester? amide? which blocks?) before looking at the options.

Quick check

1. Complete the sentence: polymers are large molecules built up from many smaller molecules called ___. Then name the process that joins them.

2. Give two properties of plastics that make them hard to dispose of, and one problem each causes.
3. (Extended) Pent-1-ene is $\mathrm{CH_2{=}CH{-}CH_2CH_2CH_3}$. Draw the part of its addition polymer that shows two repeat units, and suggest the polymer's name.
4. (Extended) A section of a polymer is –O–■–O–CO–□–CO–O–■–O–CO–□–CO–. Name the kind of polymer, state how many linkages the section contains and how many water molecules formed when it was made, and give the monomers.
5. (Extended) An amino acid has $M_\mathrm{r} = 131$, and R contains carbon and hydrogen only. Find R.

Answers

1. Monomers. The process is polymerisation.
2. They are unreactive / non-biodegradable, so they stay in landfill sites for a very long time; they don't break down in water, so they build up in the oceans and harm animals. (Burning them to get rid of them makes toxic gases.)
3. A four-carbon main chain joined by single bonds, with a continuation bond at each end; the first and third carbons have two H atoms each; the second and fourth have one H and a $\mathrm{CH_2CH_2CH_3}$ group: $\mathrm{–CH_2–CH(C_3H_7)–CH_2–CH(C_3H_7)–}$. The name is poly(pent-1-ene).
4. Each C=O is next to an O, so these are ester linkages: a polyester. Going along: ■–O–CO–□ (1), □–CO–O–■ (2), ■–O–CO–□ (3): 3 linkages, so 3 water molecules. Monomers: HO–■–OH (a diol) and HOOC–□–COOH (a dicarboxylic acid).
5. $M_\mathrm{r}(\mathrm{R}) = 131 - 74 = 57$, and $\mathrm{C_4H_9} = 4 \times 12 + 9 = 57$, so R is $\mathrm{C_4H_9}$.

Past questions to try

- **0620/41/O/N/24 Q6**: drawing an amino acid and a protein section from three amino acids.
- **0620/43/M/J/23 Q7**: the repeat unit of poly(but-2-ene) and the monomers of an unboxed polyester.
- **0620/42/M/J/22 Q6**: counting water molecules, monomers from a polyester, and a poly(alkene)'s monomer.
- **0620/22/O/N/24 Q36**: counting amide and ester linkages in one chain.