

Cambridge AS & A Level · Chemistry 9701 · Notes

Polymerisation A2

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Read first: [Polymerisation](#), [Carboxylic acids and derivatives](#)

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What you need to know

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

1. **Describe how polyesters form**, both from a diol with a dicarboxylic acid or a dioyl chloride, and from a single hydroxycarboxylic acid (a molecule with an OH group at one end and a COOH group at the other).
2. **Describe how polyamides form**: from a diamine with a dicarboxylic acid or a dioyl chloride, from a single aminocarboxylic acid, and from amino acids joining into a polypeptide.
3. **Draw the repeat unit**. You are shown the starting molecule, or two starting molecules, and you draw the small piece that repeats along the chain, with the new ester or amide link shown bond by bond.
4. **Work backwards to the starting molecules**. You are shown a stretch of chain and you say which molecule or molecules were joined to make it.
5. **Tell the two kinds of polymerisation apart from the starting molecules**: does the chain grow through a C=C (addition), or by two groups reacting and losing a small molecule (condensation)?
6. **Tell the two kinds apart from a stretch of chain**: is the backbone only carbon, or does it contain O or N atoms from ester or amide links?
7. **Know why plastic bags and bottles last so long**: poly(ethene), poly(propene) and the other poly(alkenes) hardly react with anything, so bacteria, water and weather barely break them down.
8. **Know that sunlight can break some polymers into pieces**.
9. **Know why polyesters and polyamides do break down**: their links can be split by water with an acid or an alkali, which turns the chain back into small molecules.

Addition polymerisation itself (repeat units from alkenes, monomers from poly(alkene) sections, disposal) is AS: see the AS Polymerisation note. Here it only comes back when you have to tell the two types apart.

Understand it

Condensation polymerisation

In **addition** polymerisation, alkene molecules join through their C=C bonds and nothing else is made. In **condensation** polymerisation, two functional groups react together, the monomers join, and each new link also gives out a **small molecule**: water, or hydrogen chloride when an acyl chloride is used.

It is the same chemistry as making one ester or one amide:



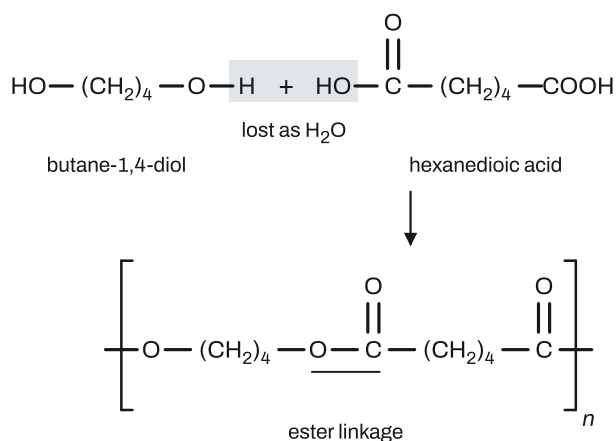
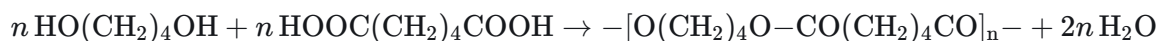
To make a **chain** instead of one small molecule, every monomer needs **two** reacting groups, one at each end. After one end has reacted, the other end is still free to react with the next monomer, and so on thousands of times. A molecule with only one reacting group, such as ethanoic acid, stops the chain: once its COOH has reacted there is nothing left to join on to.

There are two ways to put the two groups in place:

- **Two different monomers**, each with two identical groups: a diol ($\text{HO}-\dots-\text{OH}$) with a dicarboxylic acid ($\text{HOOC}-\dots-\text{COOH}$), for example. They must alternate along the chain, because an OH can only react with a COOH, never with another OH.
- **One monomer with two different groups**, such as a hydroxycarboxylic acid ($\text{HO}-\dots-\text{COOH}$). The OH of one molecule reacts with the COOH of the next.

Polyesters

Diol with a dicarboxylic acid. Heating butane-1,4-diol with hexanedioic acid (with an acid catalyst) joins them through **ester linkages**, $-\text{CO}-\text{O}-$. At every link the acid loses OH and the alcohol loses H, and together they leave as water:



The **repeat unit** holds one residue of each monomer: the diol minus its two H atoms from OH, the acid minus its two OH groups. It has one continuation bond at each end, one from an O and one from a C=O carbon.

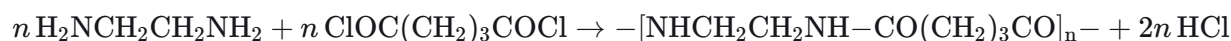
Diol with a dioyl chloride. A dioyl chloride, $\text{ClOC}-\dots-\text{COCl}$, gives exactly the same polymer, but each link gives out **HCl** instead of water. Acyl chlorides are far more reactive than carboxylic acids, so this works at room temperature, fast, with no catalyst.

One hydroxycarboxylic acid. A molecule such as 4-hydroxybutanoic acid, $\text{HO}(\text{CH}_2)_3\text{COOH}$, polymerises on its own: the OH of each molecule reacts with the COOH of the next. The repeat unit is one residue, $-\text{O}(\text{CH}_2)_3\text{CO}-$. Poly(lactic acid), made from 2-hydroxypropanoic acid (lactic acid), is a polyester of this kind

that is used because it biodegrades.

Polyamides

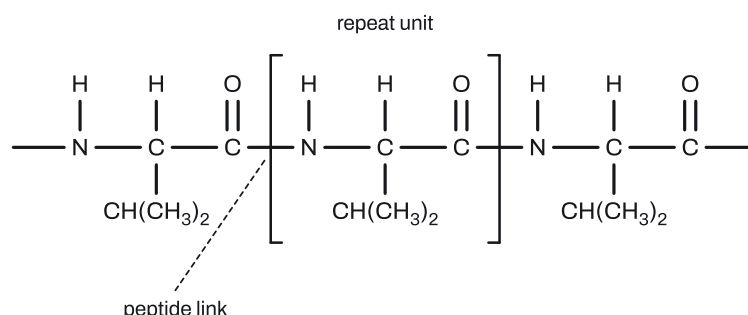
Diamine with a dicarboxylic acid or diacyl chloride. An amine group reacts with a COOH (on heating, losing water) or, much more easily, with a COCl (losing HCl) to form an **amide linkage**, $-\text{CO}-\text{NH}-$. Ethane-1,2-diamine with pentanedioyl chloride gives:



Nylons are polyamides of this type.

One aminocarboxylic acid. A molecule with NH_2 at one end and COOH at the other, such as 3-aminopropanoic acid, $\text{H}_2\text{N}(\text{CH}_2)_2\text{COOH}$, polymerises on its own to $-\text{NH}(\text{CH}_2)_2\text{CO}-$.

Amino acids. The 2-amino acids, $\text{H}_2\text{NCH}(\text{R})\text{COOH}$, are aminocarboxylic acids too. The NH_2 of one reacts with the COOH of the next, and the amide link is called a **peptide link**. A long chain is a **polypeptide** (proteins are polypeptides). The chain runs $-\text{NH}-\text{CH}(\text{R})-\text{CO}-\text{NH}-\text{CH}(\text{R})-\text{CO}-$, with each R group (the side chain) hanging off, **unchanged**. Different amino acids can join in any order, so a polypeptide can contain many different R groups.



If the side chain has its own reactive group, the chain is still built from the NH_2 and COOH on the **same carbon** (the α carbon). The extra group, such as the second NH_2 in lysine or the OH in a hydroxy side chain, stays in the side chain unless the question says otherwise. An amide group in a side chain ($-\text{CONH}_2$) never forms the chain: it is not an amine.

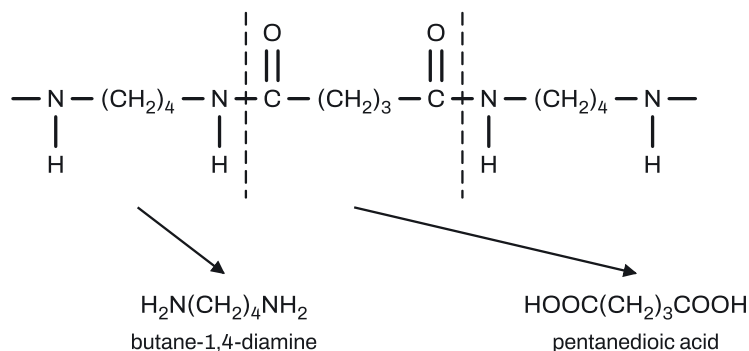
Drawing a repeat unit

1. **Find the reacting groups** in each monomer: OH or NH_2 on one side, COOH or COCl on the other.
2. **Remove what leaves:** an H from each OH or NH_2 that reacts, and the OH (or Cl) from each COOH (or COCl).
3. **Join the pieces** through the new ester or amide linkage, drawn **displayed**: the C=O shown as a double bond to O, and the C–O or C–N bond shown, with the H on N.
4. **Add one continuation bond at each end.** From two monomers the repeat unit contains one residue of each; from one monomer it contains one residue.

Count atoms at the end: the repeat unit has the atoms of the monomers minus the small molecules lost (two per repeat unit from two monomers, one from a single monomer).

Finding the monomers from a section

Work backwards: hydrolyse the section on paper.



1. **Find every linkage** in the chain: ---CO---O--- (ester) or ---CO---NH--- (amide).
2. **Cut the bond between the C=O carbon and the O or N.**
3. **Add OH to each C=O** (giving COOH; COCl is also accepted) and **H to each O or N** (giving OH or NH_2).
4. **Compare the pieces.** Two different kinds, one with two COOH groups and one with two OH or NH_2 groups, means two monomers. One kind, with a COOH at one end and an OH or NH_2 at the other, means one monomer.

A linkage you haven't met, such as the anhydride link ---CO---O---CO--- , is cut the same way the question says it forms.

Addition or condensation?

From the monomer:

- A C=C , and no pair of groups that can condense: **addition**. The chain grows through the C=C and nothing is lost.
- Two groups that react together (OH or NH_2 with COOH or COCl), either in one monomer or one on each of two monomers: **condensation**.
- A monomer with a C=C **and** two condensing groups can do either, depending on the conditions; the two polymers look quite different.

From a section of polymer:

- A main chain of **carbon atoms only**, with every functional group hanging off it: **addition**.
- **O or N atoms in the main chain**, inside ester or amide linkages: **condensation**.

A group such as CONH_2 or COOCH_3 in a monomer with a C=C does not make it a condensation monomer: an amide or ester group has no partner to react with. Propenamide, $\text{CH}_2=\text{CHCONH}_2$, forms the addition polymer $\text{---[CH}_2\text{---CH(CONH}_2\text{)]}_n\text{---}$.

Degradable polymers

Poly(alkenes) are inert. Their chains contain only C–C and C–H bonds, which are strong and almost non-polar. There is no polar group for water, acids, alkalis or the enzymes of microorganisms to attack, so they **cannot be hydrolysed** and biodegrade extremely slowly.

Some polymers are broken down by light. A polymer can be made so that it contains groups that absorb ultraviolet light, C=O groups for example. The absorbed energy breaks bonds in the chain, which falls apart into smaller pieces. These are called **photodegradable** polymers. They only break down in sunlight, not when buried.

Polyesters and polyamides can be hydrolysed. Their ester and amide links are polar, with a $\delta+$ carbon that water (slowly), H^+ or OH^- can attack, just like simple esters and amides. Hydrolysis breaks the chain back into its monomers, so these polymers are **biodegradable**. What you get depends on the conditions:

Link	Heated with dilute acid, H^+ (aq)	Heated with dilute alkali, OH^- (aq)
Ester, $-CO-O-$	carboxylic acid $-COOH$ + alcohol $HO-$	carboxylate ion $-COO^-$ + alcohol $HO-$
Amide, $-CO-NH-$	carboxylic acid $-COOH$ + ammonium ion $-NH_3^+$	carboxylate ion $-COO^-$ + amine $-NH_2$

In acid the amine end is protonated; in alkali the acid end loses its proton.

Key facts and formulas

"Given" means it is in the 9701 Data Booklet (or printed in the question). "Learn it" means you must remember it.

Formula or fact	Status
Relative atomic masses: C 12.0, H 1.0, N 14.0, O 16.0, Cl 35.5	Given
Ester linkage $-CO-O-$: diol + dicarboxylic acid (loses H_2O) or dioyl chloride (loses HCl); or one hydroxycarboxylic acid	Learn it
Amide linkage $-CO-NH-$: diamine + dicarboxylic acid (loses H_2O) or dioyl chloride (loses HCl); or one aminocarboxylic acid; peptide link between amino acids	Learn it
Condensation monomers need two reacting groups each; a molecule with one group ends the chain	Learn it
Repeat unit from two monomers = one residue of each; from one monomer = one residue; continuation bond at each end	Learn it
Monomers from a section: cut $C(=O)-O$ or $C(=O)-N$, add OH to the C=O and H to the O or N	Learn it
C=C only $\rightarrow$ addition; two condensing groups $\rightarrow$ condensation; O or N in the main chain $\rightarrow$ condensation	Learn it

Formula or fact	Status
Poly(alkenes): inert, non-polar C–C and C–H bonds, cannot be hydrolysed, so they persist	Learn it
Photodegradable polymers: groups such as C=O absorb UV light and the chain breaks	Learn it
Polyesters and polyamides: hydrolysed by acid or alkali, so biodegradable	Learn it
Repeat-unit formula = monomers' formulae – small molecules lost; chain $M_r \approx n \times M_r(\text{repeat unit})$	Learn it

How to do it

We have tagged 24 questions on this topic from 2021–2025 (18 different, since some papers share questions), all on Paper 4. 12 of them mix more than one type, so the counts add up to more than 24.

Question type	Questions
Draw the repeat unit of a condensation polymer from two monomers	12
Explain or predict biodegradability	9
Draw a chain from a single monomer and label the repeat unit	7
State the type of polymerisation and the linkage	6
Identify the monomers from a section of polymer	4
Draw the repeat unit of an addition polymer from a functionalised alkene	3
Deduce small products of a diacid or dioyl chloride with a diol	3

1. Draw the repeat unit of a condensation polymer from two monomers (12 questions)

- Decide the linkage:** OH + COOH or COCl gives an ester; NH_2 + COOH or COCl gives an amide.
- Write the diol or diamine residue:** the monomer without one H on each OH or NH_2 , so $-\text{O}- \dots -\text{O}-$ or $-\text{NH}- \dots -\text{NH}-$.
- Write the acid residue:** without the OH (or Cl) of each end, so $-\text{CO}- \dots -\text{CO}-$.
- Join them once** and draw the new linkage **fully displayed**: C double-bonded to O, and the single bond to the O or to the N (with its H).
- Put one continuation bond on each end** and stop. Check every carbon has four bonds and every hydrogen is there.

Variations you will meet:

- Short or unusual acids.** Ethanedioic acid, $\text{HOOC}-\text{COOH}$, gives a residue $-\text{CO}-\text{CO}-$ with the two C=O carbons bonded directly. Propanedioic acid gives $-\text{CO}-\text{CH}_2-\text{CO}-$.

- **A benzene ring in a monomer** (benzene-1,4-dicarboxylic acid, benzene-1,4-diamine): the ring stays whole, and the links are on the ring carbons that carried the groups.
- **A C=C in a monomer** (an unsaturated dicarboxylic acid): condensation does not touch it, so the C=C stays in the repeat unit.
- **The monomer comes from an earlier step**, such as a diol made from an alkene with cold dilute acidified KMnO_4 , or a diol chloride made from the acid with SOCl_2 . Work out the monomer first, then join.
- **Two amino acids** (or an amino acid with another aminocarboxylic acid): each residue is $-\text{NH}-\dots-\text{CO}-$; join one of each through a peptide link.
- **"Draw two repeat units"**: the pattern twice, with three linkages inside and a continuation bond on each end.

2. Explain or predict biodegradability (9 questions)

1. **Poly(alkenes) biodegrade slowly** because they are chemically inert: the C–C and C–H bonds are non-polar, so they cannot be hydrolysed.
2. **Polyesters and polyamides biodegrade** because their ester or amide links **can be hydrolysed** (by acids, alkalis or enzymes), breaking the chain into small molecules.

Variations you will meet:

- **"Explain why condensation polymers biodegrade more readily than addition polymers"**: condensation polymers can be hydrolysed; addition polymers cannot. One clear sentence using the word *hydrolysed* is what is rewarded.
- **"Predict whether this polymer is biodegradable"**: look for ester or amide links in the chain. Yes, with the reason "it can be hydrolysed".
- **"Suggest how it can be degraded"**: hydrolysis, by heating with dilute acid or dilute alkali. This works for any linkage made by condensation, including an unfamiliar one such as an anhydride.
- **"An advantage of a polyamide over poly(propene) for packaging"**: it is biodegradable.
- **Light**: a polymer designed with C=O groups in it can break down in sunlight (photodegradable).

3. Draw a chain from a single monomer and label the repeat unit (7 questions)

1. **Find the two groups that form the chain**: OH and COOH (polyester) or, for an amino acid, the NH_2 and COOH on the α carbon (polyamide).
2. **Write one residue**: $-\text{O}-\dots-\text{CO}-$ or $-\text{NH}-\text{CH}(\text{R})-\text{CO}-$, side groups unchanged.
3. **Repeat it** the number of times asked (two or three residues), head to tail, with every linkage displayed.
4. **Add a continuation bond at each end** and **mark one repeat unit** with brackets or a circle around exactly one residue.

Variations you will meet:

- **A side chain with its own group** (CONH_2 , OH, an extra NH_2): leave it unchanged in the side chain. Building the chain through it is the classic error.
- **A monomer that can make two condensation polymers** (for example one with OH, NH_2 and COOH): read which one is asked for. A polypeptide uses $\text{NH}_2 + \text{COOH}$; a polyester uses OH + COOH.

- **"Draw a dipeptide"** is not a polymer: it ends in $\text{H}_2\text{N}-$ and $-\text{COOH}$, with no continuation bonds, and it is not a ring.
- **Methyl groups** may often be written as CH_3 , but the question may ask for all other bonds displayed: do exactly what it says.

4. State the type of polymerisation and the linkage (6 questions)

1. **Monomer with a $\text{C}=\text{C}$ and nothing to condense with:** addition.
2. **Monomers with two condensing groups:** condensation, and name the linkage (ester or amide; peptide for amino acids).
3. **A section:** carbon-only main chain means addition; ester or amide links in the chain mean condensation.

Variations you will meet:

- **A table of monomers** to classify: check each one separately. A $\text{C}=\text{C}$ monomer with a COOH or ester side group, such as $\text{CH}_2=\text{CHCOOCH}_3$, is still addition when it is the only monomer.
- **Type of reaction vs type of polymerisation.** Forming one ester from a diacid and a diol is *esterification* (a condensation, an addition–elimination); forming the polymer is *condensation polymerisation*.
- **"Type of polymerisation"** means addition or condensation. Don't give the polymer's name.

5. Identify the monomers from a section of polymer (4 questions)

1. **Find the repeat unit:** the smallest piece that repeats.
2. **Addition section** (carbon-only chain): cut the chain into pairs of carbons and put back the $\text{C}=\text{C}$.
3. **Condensation section:** cut each $\text{C}(=\text{O})-\text{O}$ or $\text{C}(=\text{O})-\text{N}$ bond, add OH to each $\text{C}=\text{O}$ and H to each O or N .
4. **Draw each monomer in full**, with no continuation bonds.

Variations you will meet:

- **One or two monomers?** If every residue is the same and has different ends (NH_2 and COOH , or OH and COOH), there is one monomer.
- **Acid or acyl chloride:** either form is accepted for the acid monomer.
- **An unfamiliar linkage given with its reaction**, such as an acyl chloride with a sodium carboxylate giving an anhydride link: cut the link and give the two partners that the given reaction needs (here a dioyl chloride and a disodium dicarboxylate).

6. Draw the repeat unit of an addition polymer from a functionalised alkene (3 questions)

1. **Take the two $\text{C}=\text{C}$ carbons** as the chain, joined by a single bond.
2. **Hang every other group off them unchanged**, even COOH or NH_2 groups.
3. **One continuation bond on each end.**

Such a question is usually set next to the condensation polymer of the same monomer, to test the difference: the addition repeat unit has a carbon-only chain with the functional groups as side groups, and the condensation repeat unit has the functional groups joined into the chain, while the C=C survives.

7. Deduce small products of a diacid or dioyl chloride with a diol (3 questions)

A diol and a diacid (or dioyl chloride) do not only make long chains. Short products form too, and questions give you their molecular formulae.

1. **Write what each possible product is:** one of each joined once (free OH and COOH or COCl ends); two of one and one of the other (both ends the same); or one of each joined **at both ends**, forming a **ring**.
2. **Work out each formula:** add the monomers' formulae and take away one H_2O (or HCl) per link.
3. **Match the formula** given, and use the clues: "does not react with sodium" means no OH or COOH is left, which points to the ring.

Test clues tell you which ends are left: sodium fizzes with any OH or COOH; sodium carbonate fizzes only with COOH. For example, butane-1,4-diol ($\text{C}_4\text{H}_{10}\text{O}_2$) with pentanedioic acid ($\text{C}_5\text{H}_8\text{O}_4$): one of each joined once gives $\text{C}_9\text{H}_{16}\text{O}_5$, which has an OH end and a COOH end, so it fizzes with both. Two diols on one acid give $\text{C}_{13}\text{H}_{24}\text{O}_6$, with an OH at each end: it fizzes with sodium but not with sodium carbonate.

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

Five compounds are available:

- **A** butane-1,4-diol, $\text{HO}(\text{CH}_2)_4\text{OH}$
- **B** butanedioic acid, $\text{HOOC}(\text{CH}_2)_2\text{COOH}$
- **C** butane-1,4-diamine, $\text{H}_2\text{N}(\text{CH}_2)_4\text{NH}_2$
- **D** ethanoic acid, CH_3COOH
- **E** 4-aminobenzoic acid, $\text{H}_2\text{NC}_6\text{H}_4\text{COOH}$

(a) Choose the two compounds that react together to make a polyester, and the two that make a polyamide. Name the small molecule lost in both. [2]

(b) One compound can form a polymer on its own. Draw a section of this polymer containing two monomer residues, and label one repeat unit. **[2]**

(c) A student mixes **A** with an excess of **D** and heats it with an acid catalyst. Explain why no polymer forms, and give the molecular formula of the organic product. **[2]**

(a) Polyester: **A** and **B** (OH groups with COOH groups). Polyamide: **B** and **C** (NH₂ groups with COOH groups). **B1** Water is lost in both. **B1**

(b) **E**: it has an NH₂ at one end and a COOH at the other. $\text{—NH—C}_6\text{H}_4\text{—CO—NH—C}_6\text{H}_4\text{—CO—}$, with each amide linkage displayed (C=O and N—H drawn), the C₆H₄ as a benzene ring bonded through its 1- and 4- carbons, and a continuation bond at each end. **B1** Brackets round exactly one $\text{—NH—C}_6\text{H}_4\text{—CO—}$. **B1**

(c) **D** has only one COOH group, so after it has reacted with an OH of **A** there is nothing left on it to join on to; each end of **A** reacts once and the chain stops. **B1** The product is the diester $\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OCOCH}_3$, C₈H₁₄O₄. **B1**

Example 2

A polyester is made by reacting propane-1,3-diol, HO(CH₂)₃OH, with hexanedioyl chloride, ClOC(CH₂)₄COCl, at room temperature.

(a) Draw the repeat unit of the polyester. Display the ester linkage. **[2]**

(b) Name the other product, and give one advantage of using hexanedioyl chloride rather than hexanedioic acid. **[2]**

(c) One chain of the polyester has $M_r = 37\,200$. Calculate the number of repeat units in it. Ignore the end groups. **[2]**

(d) Calculate the mass of the other product formed when 93.0 g of the polyester is made. **[2]**

(a) $\text{—O(CH}_2\text{)}_3\text{O—CO(CH}_2\text{)}_4\text{CO—}$: the linkage —C(=O)—O— drawn with the C=O as a double bond **M1**, one residue of each monomer and a continuation bond at each end **A1**.

(b) Hydrogen chloride, HCl. **B1** The acyl chloride is much more reactive, so the reaction is fast at room temperature with no catalyst (and does not stop at an equilibrium). **B1**

(c) The repeat unit is C₉H₁₄O₄ (the two monomers, C₃H₈O₂ and C₆H₈Cl₂O₂, minus 2 HCl). $M_r = 9(12.0) + 14(1.0) + 4(16.0) = 186.0$ **M1**; $37\,200 \div 186.0 = 200$ repeat units. **A1**

(d) $93.0 \div 186.0 = 0.500$ mol of repeat units. Each repeat unit forms 2 links, each giving one HCl, so 1.00 mol of HCl **M1**; $M_r(\text{HCl}) = 36.5$, so the mass is 36.5 g. **A1**

Example 3

A section of polymer **P** is shown.



- (a) Name the two different linkages in **P** and state the type of polymerisation. [2]
- (b) Draw the structures of the two monomers that could be used to make **P**. [2]
- (c) **P** is heated with dilute hydrochloric acid until it is fully hydrolysed. Give the structures of the two organic products. [2]
- (d) Give the structures of the two organic products when **P** is instead heated with an excess of NaOH(aq). [2]
- (e) Explain why **P** biodegrades more readily than poly(ethene). [1]
- (a) Amide ($-\text{CO}-\text{NH}-$) and ester ($-\text{CO}-\text{O}-$). **B1** Condensation polymerisation: there are N and O atoms in the main chain. **B1**
- (b) Cut every $\text{C}(=\text{O})-\text{N}$ and $\text{C}(=\text{O})-\text{O}$ bond, then add OH to each $\text{C}=\text{O}$ and H to each N and O. **M1** The pieces are 2-aminoethanol, $\text{H}_2\text{NCH}_2\text{CH}_2\text{OH}$, and pentanedioic acid, $\text{HOOC}(\text{CH}_2)_3\text{COOH}$ (or pentanedioyl chloride). **A1**
- (c) Pentanedioic acid, $\text{HOOC}(\text{CH}_2)_3\text{COOH}$ **B1**, and the protonated amine, $\text{HOCH}_2\text{CH}_2\text{NH}_3^+$ (as its chloride), because the acid protonates the NH_2 group. **B1**
- (d) The pentanedioate ion, $^-\text{OOC}(\text{CH}_2)_3\text{COO}^-$ (as the sodium salt) **B1**, and 2-aminoethanol, $\text{H}_2\text{NCH}_2\text{CH}_2\text{OH}$. **B1**
- (e) Its ester and amide linkages can be hydrolysed; poly(ethene) has only non-polar C–C and C–H bonds and cannot be. **B1**

Common mistakes

- **Drawing more than one repeat unit**, or a whole chain, when one repeat unit is asked for. Examiners see this almost every year. Draw exactly what is asked: one repeat unit, two, or a stated number of residues.
- **Leaving out hydrogen atoms** or putting in the wrong number, especially on N and on the CH_2 groups. Count bonds: four on every C, three on every N.
- **Missing the continuation bonds**, or drawing them from the wrong atoms. One at each end of the repeat unit, and only there.
- **An extra or missing oxygen** in a polyester. The ester linkage has one O between the $\text{C}=\text{O}$ carbon and the diol's carbon: $-\text{CO}-\text{O}-\text{CH}_2-$, not $-\text{CO}-\text{O}-\text{O}-$ or $-\text{CO}-\text{CH}_2-$.
- **Wrong peptide links**, such as $-\text{COO}-\text{NH}-$ or a carbon with only three bonds. The peptide link is $-\text{C}(=\text{O})-\text{NH}-$: the $\text{C}=\text{O}$ carbon is bonded directly to N.
- **Building the chain through a side-chain group**. Reports describe chains joined through the amide group of an amino acid's side chain instead of the $\alpha\text{-NH}_2$. Only the NH_2 and COOH on the α carbon form the chain; side chains stay as they are.
- **Continuation bonds on a dipeptide**, or drawing a ring. A dipeptide is a separate molecule with $\text{H}_2\text{N}-$ and $-\text{COOH}$ ends.
- **Naming the polymer when asked for the type**. "Type of polymerisation" is *addition* or *condensation*.

- **A vague reason for biodegradability.** "Polyesters are natural" or "addition polymers are strong" earns nothing: say the linkages **can be hydrolysed** (or the C–C bonds are non-polar and cannot be).

How to get the marks

- **"The new functional group formed should be displayed"**: draw the ester or amide link with every bond shown, C=O as a double bond and the C–O or C–N bond visible, with the H on N. The rest may be structural (CH₂, C₆H₄ as a ring) if every atom is clear.
- **Repeat unit marks** usually go one for the correct displayed linkage in the right place, and one for the rest of the unit correct with continuation bonds. So get the linkage right even if you are unsure of the rest.
- **"Draw a section... label the repeat unit"**: marks for the right number of residues, every linkage correct, side groups right, continuation bonds and the label round exactly one repeat unit. Often "any two of four points" for one mark and all four for full marks.
- **"Identify the monomers"**: full structures, no continuation bonds. The acid or the acyl chloride form both score.
- **"State the type of polymerisation"**: one word, and add the linkage if asked ("condensation; ester").
- **"Explain"** biodegradability: link structure to hydrolysis in one sentence, as in the common mistakes above.
- **"Suggest"** means an unfamiliar polymer or monomer: apply the same rules (cut the linkage, keep side groups) rather than recalling.
- **Error carried forward**: a monomer that is wrong in an earlier part but used correctly in the polymer can still earn the polymer mark, so always draw it.

Quick check

1. Say whether each can form a condensation polymer on its own, needs a second monomer, or forms no condensation polymer: (a) 3-hydroxypropanoic acid, HOCH₂CH₂COOH; (b) hexane-1,6-diol; (c) propan-1-ol; (d) 3-chloropropene, CH₂=CHCH₂Cl.
2. Identify the two monomers in this section, and name the linkage:
–NH–CH₂–CO–NH–CH(CH₂CH(CH₃)₂)–CO–NH–CH₂–CO–NH–CH(CH₂CH(CH₃)₂)–CO–
3. A polyester has the repeat unit –O–CH₂–C₆H₄–CH₂–O–CO–CH₂CH₂–CO– (a 1,4-substituted benzene ring). Give the products when it is heated with an excess of NaOH(aq).
4. (a) Explain why a poly(propene) bottle lasts for centuries in a landfill site. (b) A poly(alkene) film made with a few C=O groups in its chains breaks into small pieces after some weeks in sunlight. Suggest why.
5. A polyamide is made from pentane-1,5-diamine, H₂N(CH₂)₅NH₂, and hexanedioyl chloride, ClOC(CH₂)₄COCl. (a) Give the molecular formula and M_r of its repeat unit. (b) How many repeat units are in a chain of $M_r = 31\,800$? (c) Give the organic products when the polyamide is heated with an excess of dilute hydrochloric acid.

Answers

1. (a) On its own (polyester): it has OH and COOH. (b) Needs a second monomer with two COOH or COCl groups (polyester). (c) None: only one OH. (d) No condensation polymer: it has no pair of condensing groups; it forms an addition polymer through its C=C.
2. Cut each C(=O)–N bond and add OH and H: glycine, $\text{H}_2\text{NCH}_2\text{COOH}$, and leucine, $\text{H}_2\text{NCH}(\text{CH}_2\text{CH}(\text{CH}_3)_2)\text{COOH}$. The linkage is the peptide (amide) link, $-\text{CO}-\text{NH}-$.
3. Alkaline hydrolysis of the ester links gives the diol $\text{HOCH}_2\text{C}_6\text{H}_4\text{CH}_2\text{OH}$ ($\text{C}_8\text{H}_{10}\text{O}_2$) and the butanedioate ion, $^-\text{OOCCH}_2\text{CH}_2\text{COO}^-$ (as its sodium salt).
4. (a) Poly(propene) is chemically inert: its C–C and C–H bonds are non-polar, so water, acids, alkalis and microorganisms cannot hydrolyse it. (b) The C=O groups absorb ultraviolet light, and the energy breaks bonds in the chain, so it is photodegradable.
5. (a) $-\text{NH}(\text{CH}_2)_5\text{NH}-\text{CO}(\text{CH}_2)_4\text{CO}-$ is the monomers, $\text{C}_5\text{H}_{14}\text{N}_2$ and $\text{C}_6\text{H}_8\text{Cl}_2\text{O}_2$, minus 2 HCl: $\text{C}_{11}\text{H}_{20}\text{N}_2\text{O}_2$, $M_r = 11(12.0) + 20(1.0) + 2(14.0) + 2(16.0) = 212.0$. (b) $31\,800 \div 212.0 = 150$ repeat units. (c) Hexanedioic acid, $\text{HOOC}(\text{CH}_2)_4\text{COOH}$, and the diamine with both ends protonated, $^+\text{H}_3\text{N}(\text{CH}_2)_5\text{NH}_3^+$ (as its chloride).

Past questions to try

- **9701/42/O/N/23 Q8:** part (a), a chain of poly(lactic acid) with the repeat unit labelled, its type and whether it biodegrades.
- **9701/42/O/N/24 Q6:** part (d), a polyester from an aromatic dicarboxylic acid, the type and the linkage.
- **9701/42/M/J/22 Q8:** parts (c)–(e), monomers from a polyester section, a polypeptide from a monomer with three groups, and biodegradability.
- **9701/43/M/J/22 Q5:** part (e), the monomers of a polyanhydride from a given reaction, and how it degrades.