Condensation polymerisation

4.7.3.2 · Organic chemistry · revision notes

How monomers with two functional groups join to form condensation polymers, losing a small molecule such as water each time, with polyesters as the main example. Higher tier only, and GCSE Chemistry only. Expect monomers drawn as blocks, with questions asking you to complete the equation, identify the molecule lost or compare condensation with addition polymerisation.

Key facts

- Condensation polymerisation: monomers with two functional groups; a small molecule (usually water) lost at each link
- Diol + dicarboxylic acid → polyester + water
- n HO–□–OH + n HOOC–□–COOH → –(O–□–O–CO–□–CO)$_n$– + 2n H_2O
- Addition: C=C monomers, one product. Condensation: two functional groups, two products
- Diol: two –OH groups. Dicarboxylic acid: two –COOH groups
- Ester link: –COO–
- Water forms from the OH of –COOH and the H of –OH

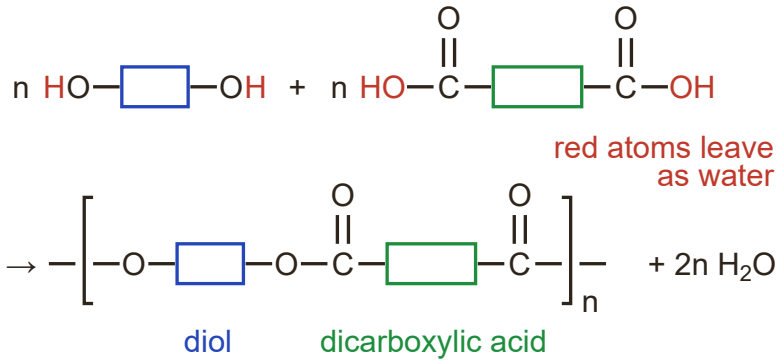
Notes

What condensation polymerisation is

- In **condensation polymerisation**, each monomer has **two functional groups**.
- When the functional groups react, the monomers join together and a **small molecule** is usually lost each time, such as **water**. Reactions like this are called condensation reactions.
- Water is the usual small molecule. If a monomer has –COCl groups instead of –COOH groups, hydrogen chloride, HCl, is lost instead.
- So there are two products: the polymer and the small molecule. The repeating unit has fewer atoms than the monomers put together.

Polyesters

- The simplest condensation polymers are made from **two different monomers**, each with two of the **same** functional group.
- A **diol** has two –OH groups, e.g. ethanediol, $HO–CH_2–CH_2–OH$.
- A **dicarboxylic acid** has two –COOH groups, e.g. hexanedioic acid, $HOOC–(CH_2)_4–COOH$.
- Each –COOH reacts with an –OH to form an **ester link**, –COO–, and a molecule of water. The OH comes from the –COOH and the H comes from the –OH. The polymer is a **polyester**.
- With blocks standing for the carbon chains:
  n HO–□–OH + n HOOC–□–COOH → $–(O–□–O–CO–□–CO)_n–$ + 2n H_2O
  where each CO in the repeating unit is a C=O group.



Each –OH (red, from the acid) and H (red, from the diol) leave as water. The ester links are –O–CO–.

- Each repeating unit contains two ester links, so 2n molecules of water are made.

Addition and condensation compared

- Monomers: addition needs a C=C; condensation needs two functional groups on each monomer.
- Types of monomer: addition usually uses one; condensation often uses two different monomers.
- Products: addition gives only the polymer; condensation gives the polymer and a small molecule such as water.
- Repeating unit: in addition polymers it has the same atoms as the monomer; in condensation polymers it has fewer atoms than the monomers.

How to answer each type of question

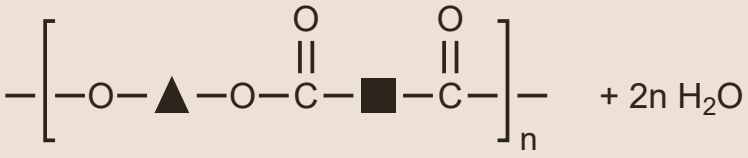
Complete a condensation polymerisation equation

2 to 3 marks | Grade 7

1. Take an H off each –OH and an OH off each –COOH.
2. Join the blocks with ester links: –O– from the diol next to C=O from the acid.
3. Put the repeating unit in brackets with n, with a bond sticking out at each end.
4. For n of each monomer, write 2n H_2O.

Example. A polyester is made from the monomers HO–▲–OH and HOOC–■–COOH.
Complete the equation.
n HO–▲–OH + n HOOC–■–COOH → _____ + _____ H_2O

Model answer.



–(O–▲–O–CO–■–CO)$_n$–, with each CO drawn as C=O (1)

Brackets with n and a bond at each end (1)

2n H_2O (1)

Explain why a reaction is condensation polymerisation

2 to 3 marks | Grade 7

1. Say that each monomer has two functional groups.
2. Say that the groups react, joining the monomers into a long chain.
3. Say that a small molecule (water) is lost each time two monomers join.

Example. Propanediol, HO–CH_2–CH_2–CH_2–OH, and hexanedioic acid react to form a polyester.
Explain why this reaction is described as condensation polymerisation.

Model answer. Each monomer has two functional groups: two –OH groups or two –COOH groups (1). The –OH and –COOH groups react, joining the monomers into a long chain (1). A small molecule, water, is lost each time two monomers join (1).

Compare addition and condensation polymerisation

4 to 6 marks | Grade 8

1. Compare the monomers: a C=C, or two functional groups each.
2. Compare how many types of monomer are used: usually one, or often two.
3. Compare the products: polymer only, or polymer and water.
4. Compare the repeating unit: same atoms as the monomer, or fewer atoms than the monomers.

Example. Compare the formation of poly(ethene) with the formation of a polyester from ethanediol and hexanedioic acid. (4 marks)

Model answer. Poly(ethene) is made from one monomer (ethene), but the polyester is made from two different monomers (1). Ethene has a C=C double bond, whereas each polyester monomer has two functional groups (–OH or –COOH) (1). Poly(ethene) is the only product, but water is also made when the polyester forms (1). The repeating unit of poly(ethene) has the same atoms as ethene, but the polyester's repeating unit has fewer atoms than the two monomers together, because water is lost (1).

Calculate the relative formula mass of a repeating unit

2 marks | Grade 8

1. Add the relative formula masses of one of each monomer.
2. Subtract 18 for each water molecule lost per repeating unit (two for a polyester).

Example. Ethanediol (M_r = 62) and hexanedioic acid (M_r = 146) form a polyester. Two molecules of water (M_r = 18) are lost for each repeating unit.
Calculate the relative formula mass of the repeating unit.

Model answer.

62 + 146 − (2 × 18) (1)
= 172 (1)

Don’t lose marks

- Forgetting the water in the equation, or writing n H_2O instead of 2n H_2O for a polyester.
- Leaving whole –OH or –COOH groups inside the repeating unit. Only the ester links remain.
- Saying condensation monomers need a C=C double bond. They need two functional groups.
- Losing oxygen atoms: the repeating unit keeps the –O– from each end of the diol and the C=O from each end of the acid.
- Saying the repeating unit of a condensation polymer has the same atoms as the monomers.

More tips

Memory tricks

- Condensation means water comes out, like condensation forming on a cold window.
- Two ends, two groups: a monomer needs a functional group at each end to keep the chain growing.
- Polyester water count: one water per ester link, so 2n H_2O for n of each monomer.
- Addition makes 1 product; condensation makes 2.

Exam technique

- When monomers are drawn as blocks, only show what happens at the functional groups; the blocks stay the same.
- In compare questions, write matched pairs of points using 'whereas' or 'but'.
- If asked to identify the ester link, point to the –COO– group: a C=O next to an O in the chain.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 6 — **Identify the small molecule lost**
Usually water, H_2O, formed each time two monomers join.

Grade 6 — **Name the functional groups in polyester monomers**
A diol has two –OH groups; a dicarboxylic acid has two –COOH groups.

Grade 7 — **Explain what condensation polymerisation is**
Monomers with two functional groups join together, and a small molecule is lost at each link.

Grade 7 — **Complete a polyester equation using block diagrams**
Remove H from each –OH and OH from each –COOH, join the blocks with ester links, and add 2n H_2O.

Grade 8 — **Compare addition and condensation polymerisation**
Compare the monomers, the number of products and how the repeating unit relates to the monomers.

Grade 8 — **Calculate the Mr of a repeating unit**
Add the M_r values of the monomers and subtract 18 for each water molecule lost.

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