

Polymerisation AS

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Read first: [An introduction to AS Level organic chemistry](#), [Hydrocarbons](#)

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What you need to know

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

1. **Describe addition polymerisation**, using poly(ethene), poly(propene) and poly(chloroethene), PVC, as the examples: many small alkene molecules (monomers) join through their C=C bonds into one long chain (the polymer), with nothing else made.
2. **Deduce the repeat unit** of the addition polymer that a given monomer makes, and draw it (or a section of the chain).
3. **Identify the monomer or monomers** that were used to make a given section of an addition polymer.
4. **Recognise why poly(alkene)s are hard to dispose of**: they are not biodegradable, and burning them can give harmful products.

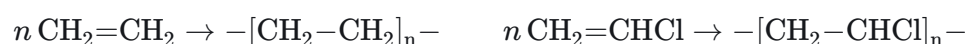
Condensation polymers (polyesters and polyamides), predicting the type of polymerisation and polymers that break down in light are A Level. At AS every polymer you meet is an addition polymer made from a monomer with a C=C bond.

Understand it

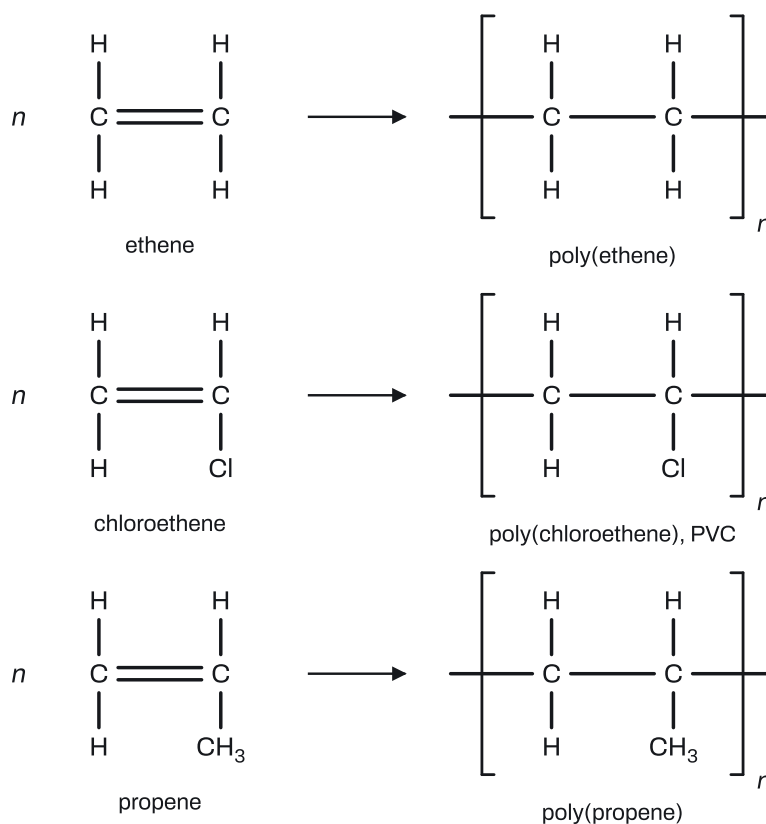
Monomers, polymers and repeat units

A **monomer** is a small molecule that can join to many copies of itself. A **polymer** is the very long molecule made when thousands of monomers join. The **repeat unit** is the smallest part of the chain that, repeated over and over, gives the whole polymer.

In **addition polymerisation** the monomer is an alkene (or another molecule with a C=C bond). The π bond of each C=C breaks, and the two carbons use those electrons to form new σ bonds to the neighbouring monomers on each side. Every atom of every monomer ends up in the polymer, so the polymer is the **only product**. That is why it is called *addition*.



The n is a large number (thousands). Poly(ethene) is used for bags and bottles; PVC, poly(chloroethene), for pipes, window frames and cable insulation.



Drawing a repeat unit from a monomer

Look only at the **two carbons of the C=C**. They become the two carbons of the chain in the repeat unit. Everything attached to them keeps its place and **hangs off the chain as a side group**:

1. Draw the two C=C carbons in a row, joined by a **single** bond.
2. Put each carbon's other two groups above and below it, exactly as in the monomer.
3. Add a **continuation bond** (a bond sticking out) on each end, and brackets with n if asked.

So propene, $\text{CH}_2=\text{CH}-\text{CH}_3$, gives $-\text{CH}_2-\text{CH}(\text{CH}_3)-$. The CH_3 is **not** part of the chain: the chain is always made only of the carbons that were in C=C bonds. A monomer with a bigger side part, such as but-3-en-2-one, $\text{CH}_2=\text{CH}-\text{CO}-\text{CH}_3$, is no different: the whole COCH_3 group hangs off the second carbon, $-\text{CH}_2-\text{CH}(\text{COCH}_3)-$.

A **section** of polymer showing two or three repeat units is just the repeat unit drawn two or three times in a row, head to tail:

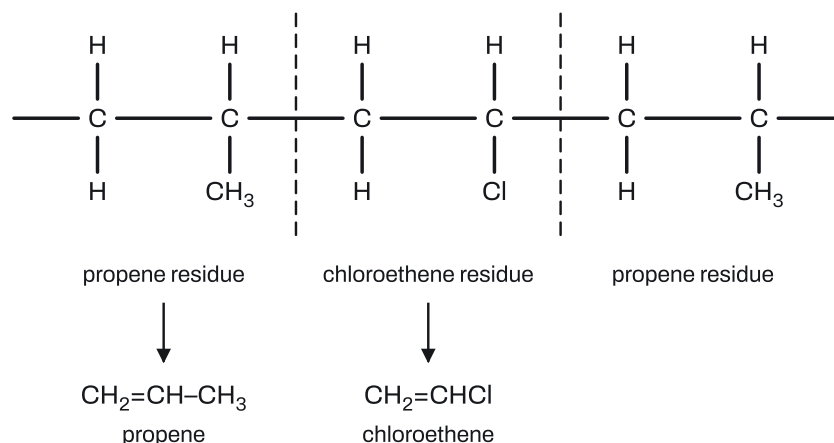


Finding the monomer from a section

Work backwards. In an addition polymer the chain carbons always come in **pairs**, one pair per monomer, so:

1. Find the **main chain** (the longest line of carbons that runs through the whole section, with continuation bonds at the ends). Side groups are not part of it.

2. **Cut the chain into pairs of carbons**, starting at one end.
3. For each pair, put back the C=C between the two carbons and keep all their side groups. That is the monomer.



If every pair is the same, there is **one** monomer. If the pairs differ, the polymer is made from **two** different monomers (a copolymer), and a section usually shows each monomer at least once. A repeat unit with **four** chain carbons, such as $-\text{CH}_2-\text{CHF}-\text{CH}_2-\text{CH}(\text{CH}_3)-$, must come from **two** monomers (here fluoroethene and propene), because one alkene only puts two carbons into the chain.

To **name** a monomer, name the alkene in the usual way. A pair $-\text{CH}(\text{CH}_2\text{CH}_3)-\text{CH}(\text{CH}_2\text{CH}_3)-$ becomes $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{CH}_3$, hex-3-ene; a pair $-\text{CH}_2-\text{C}(\text{CH}_3)(\text{CH}_2\text{CH}_3)-$ becomes $\text{CH}_2=\text{C}(\text{CH}_3)\text{CH}_2\text{CH}_3$, 2-methylbut-1-ene. Skeletal formulas of polymers are the hardest to read: draw the pair out in full first.

What changes in the bonds

When one monomer joins the chain:

- one **π bond breaks** (the C=C becomes C–C);
- **σ bonds form** between neighbouring monomers, so every chain carbon ends up with four σ bonds;
- the two carbons change from **sp^2** (trigonal planar, 120°) to **sp^3** (tetrahedral, 109.5°).

So the polymer is **saturated**. It has no C=C, and this explains its properties:

- **It is unreactive.** An electrophile such as Br_2 is attracted to the high electron density of a π bond. Propene has one, so it decolourises bromine water; poly(propene) has only strong, non-polar C–C and C–H σ bonds, like an alkane, so it does not react.
- **The infrared absorption of C=C ($1500\text{--}1680\text{ cm}^{-1}$) disappears** when a monomer turns into its polymer. Other groups, such as an ester's C=O, stay.
- **The empirical formula does not change.** The polymer is n copies of the monomer's atoms: poly(propene), $(\text{C}_3\text{H}_6)_n$, has the same empirical formula as propene, CH_2 . Likewise the M_r of a chain is $n \times M_r(\text{monomer})$.

Chiral carbons in a polymer. Stereoisomers have the same structural formula but a different arrangement of their atoms in space. A chain carbon that carries **one H and one other side group** is bonded to four different groups: the H, the side group and the two chain pieces on either side (which differ in length). So it is chiral, and the polymer shows **optical isomerism**. In poly(but-1-ene), $-\text{CH}_2-\text{CH}(\text{CH}_2\text{CH}_3)-$, every $\text{CH}(\text{CH}_2\text{CH}_3)$ carbon is chiral. A chain carbon with **two identical** side groups is not: in poly(1,1-dichloroethene), $-\text{CH}_2-\text{CCl}_2-$, no carbon is chiral.

Disposal of poly(alkene)s

The same unreactivity that makes poly(alkene)s useful makes them a problem when thrown away:

- **Non-biodegradable.** Bacteria and fungi cannot break down the long saturated C–C chains, so items last for hundreds of years in landfill and in the sea.
- **Harmful combustion products.** Burning gives carbon dioxide (a greenhouse gas) and, with too little oxygen, **carbon monoxide** (toxic). PVC also gives **hydrogen chloride**, a toxic, **acidic** gas:



A polymer with only C and H (poly(ethene), poly(propene)) cannot give HCl; one with Cl in it can.

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, O 16.0, N 14.0, F 19.0, Cl 35.5	Given
Infrared: C=C 1500–1680 cm^{-1}	Given
$n \text{ CH}_2=\text{CH}_2 \rightarrow -[\text{CH}_2-\text{CH}_2]_n-$, poly(ethene)	Learn it
$n \text{ CH}_2=\text{CHCl} \rightarrow -[\text{CH}_2-\text{CHCl}]_n-$, poly(chloroethene), PVC	Learn it
$n \text{ CH}_2=\text{CHCH}_3 \rightarrow -[\text{CH}_2-\text{CH}(\text{CH}_3)]_n-$, poly(propene)	Learn it
Repeat unit: the two C=C carbons joined by a single bond, side groups unchanged, continuation bond at each end	Learn it
Monomer from a section: cut the chain into pairs of carbons and put back each C=C	Learn it
Polymerisation: π bond broken, σ bonds formed, C changes from sp^2 to sp^3 ; polymer is saturated	Learn it

Formula or fact	Status
Polymer and monomer have the same empirical formula; $M_r(\text{chain}) = n \times M_r(\text{monomer})$	Learn it
Disposal problems: non-biodegradable; burning gives CO (toxic) and, from PVC, HCl (toxic, acidic)	Learn it

How to do it

We have tagged 39 questions on this topic from 2021–2025 (34 different, since some papers share questions). 9 of them mix more than one type, so the counts add up to more than 39.

Question type	Questions
Identify the monomer from a polymer section	19
Draw the repeat unit from a monomer	17
Disposal of poly(alkene)s	6
Bonds and properties of addition polymers	5
The M_r of a polymer chain	1

1. Identify the monomer from a polymer section (19 questions)

- Draw the section out in full** if it is given as a skeletal or condensed formula, with every chain carbon and its two side groups.
- Mark the main chain** and cut it into **pairs of carbons**.
- Rebuild each monomer**: a C=C between the pair, side groups unchanged. Make sure no side group has been moved into the chain.
- Name it**: find the longest chain that contains the C=C, number it so the C=C gets the lowest number, then add the side groups.

Variations you will meet:

- Two monomers (a copolymer)**. Different pairs give different monomers. For $-\text{CH}(\text{CH}_3)-\text{CH}_2-\text{CH}_2-\text{CH}(\text{CH}_2\text{CH}_3)-$ the pairs are $\text{CH}(\text{CH}_3)-\text{CH}_2$ (propene) and $\text{CH}_2-\text{CH}(\text{CH}_2\text{CH}_3)$ (but-1-ene). A pair can face either way: $\text{CH}(\text{CH}_3)-\text{CH}_2$ is still propene.
- Choose from names**. Check each option by drawing its repeat unit and comparing, rather than guessing from the formula. $-\text{CH}(\text{CH}_2\text{CH}_3)-\text{CH}(\text{CH}_2\text{CH}_3)-$ comes from hex-3-ene, not hex-1-ene (which gives $-\text{CH}_2-\text{CH}(\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3)-$).
- A described polymer**, such as "every chain carbon carries one H and one Cl": both C=C carbons have one H and one Cl, so the monomer is $\text{CHCl}=\text{CHCl}$, 1,2-dichloroethene.
- Statements about a repeat unit**. Count the chain carbons: 2 means one monomer, 4 means two (unless a C=C is left in the chain, below). Check whether it contains Cl (HCl on burning).

- **A C=C still in the chain.** A section such as $-\text{CH}_2-\text{C}(\text{CH}_3)=\text{CH}-\text{CH}_2-$ repeated comes from a monomer with **two** C=C bonds, 2-methylbuta-1,3-diene, $\text{CH}_2=\text{C}(\text{CH}_3)-\text{CH}=\text{CH}_2$: both old double bonds open and a new one forms in the middle, so each monomer puts **four** carbons into the chain. The question will give you enough to spot this.
- **Draw the monomer** as a displayed or structural formula with its C=C clear; don't add continuation bonds or extra CH_3 groups at the ends.

2. Draw the repeat unit from a monomer (17 questions)

1. **Find the C=C** in the monomer (it may come from an earlier part, such as the alkene made by elimination or dehydration).
2. **Draw those two carbons** joined by a single bond, each with its two other groups above and below.
3. **Add a continuation bond at each end**, through brackets if you use them. Draw **one** repeat unit unless the question asks for a section of two or more.
4. **Check the atoms**: the repeat unit has exactly the monomer's formula, and only two chain carbons.

Variations you will meet:

- **A monomer with a functional group**, such as a ketone, a halogenoalkane or an ester: the group is untouched and hangs off the chain. 3-chloropropene, $\text{CH}_2=\text{CHCH}_2\text{Cl}$, gives $-\text{CH}_2-\text{CH}(\text{CH}_2\text{Cl})-$, with the CH_2Cl as a side group.
- **Internal alkenes**, such as hept-3-ene, $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{CH}_2\text{CH}_3$: the chain carbons are C3 and C4, so the repeat unit is $-\text{CH}(\text{CH}_2\text{CH}_3)-\text{CH}(\text{CH}_2\text{CH}_2\text{CH}_3)-$. Putting the end groups into the chain is the classic mistake.
- **"Identify the type of polymerisation"** or "the type of polymer": addition. Don't name the polymer instead.
- **A ring alkene** such as cyclopentene: the two C=C carbons join the chain, and the rest of the ring stays attached to both of them, so the chain carries a ring on every pair.
- **Choose the right section** from four drawings: for a monomer $\text{CH}_2=\text{CHX}$ the X groups must be on **every other** chain carbon, one per two carbons, never two on one carbon or on neighbouring carbons.
- **"Draw a section showing two repeat units"**: four chain carbons, the side groups on alternate carbons for a monomer like propene.

3. Disposal of poly(alkene)s (6 questions)

1. **Non-biodegradable**: they are not broken down by microorganisms (because they are saturated and unreactive), so they persist in landfill.
2. **Burning gives harmful products**: carbon monoxide (toxic) and carbon dioxide (greenhouse gas); a chlorine-containing polymer such as PVC also gives **HCl**, which is toxic and **acidic**.

Variations you will meet:

- **"State two difficulties"**: one of each, non-biodegradable **and** harmful combustion products.

- **A given gas's effect:** CO is toxic because it binds to haemoglobin; CO₂ adds to the greenhouse effect; HCl is toxic and forms acid rain. Don't give "acid rain" or "ozone depletion" for CO.
- **Which polymers give HCl?** Only those containing chlorine; HCl dissolves in water to give an acidic solution.

4. Bonds and properties of addition polymers (5 questions)

1. **Bonds:** each monomer's π bond breaks and new σ bonds join the monomers; the C=C carbons change from sp^2 to sp^3 .
2. **Saturation:** the polymer has no C=C, so it does not decolourise bromine water and does not react with electrophiles.
3. **Infrared:** the monomer has a C=C absorption at $1500\text{--}1680\text{ cm}^{-1}$ and the polymer does not.
4. **Empirical formula:** the same for polymer and monomer.

Variations you will meet:

- **"Which molecules can undergo addition polymerisation?"** Any with a C=C. Find **at least one** structure with a C=C that fits the formula: C₃H₅Br can be CH₂=CHCH₂Br, so yes; C₂H₆O (ethanol or methoxymethane) has no isomer with a C=C, so no.
- **Explaining why a monomer reacts with electrophiles but its polymer does not:** the monomer's π bond is a region of high electron density that attracts electrophiles; the polymer has none.
- **Counting σ and π bonds** in a monomer: every single bond is one σ ; a double bond is one σ and one π . But-3-en-2-one, CH₂=CHCOCH₃, has 10 σ and 2 π bonds.

5. The M_r of a polymer chain (1 question)

1. **Number of repeat units** = $M_r(\text{chain}) \div M_r(\text{monomer})$, or $M_r(\text{monomer}) = M_r(\text{chain}) \div n$.
2. From $M_r(\text{monomer})$, find the molecular formula (for a hydrocarbon, C_nH_{2n} with $14n = M_r$).
3. Use any other clue (such as chiral centres) to choose between isomers: a chain carbon with one H and one side group is chiral; one with two identical side groups is not.

For example, a chain of 2500 units with $M_r = 140\,000$ has $M_r(\text{monomer}) = 140\,000 \div 2500 = 56$, so C₄H₈. If the chain has chiral centres, the monomer is but-1-ene or but-2-ene, not methylpropene.

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

PVC is made from chloroethene, $\text{CH}_2=\text{CHCl}$.

(a) Name the type of polymerisation and write an equation for the formation of PVC. **[2]**

(b) Write a balanced equation for the complete combustion of chloroethene units, $\text{C}_2\text{H}_3\text{Cl}$, when PVC is burned. **[1]**

(c) One molecule of PVC has $M_r = 93\,750$. Calculate the number of monomer units in it. **[2]**

(d) State two difficulties in disposing of PVC. **[2]**

(a) Addition polymerisation. **B1**

$n \text{CH}_2=\text{CHCl} \rightarrow -[\text{CH}_2-\text{CHCl}]_n-$ **B1**, with the continuation bonds on the repeat unit.

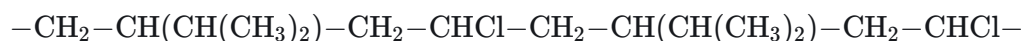
(b) $2\text{C}_2\text{H}_3\text{Cl} + 5\text{O}_2 \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O} + 2\text{HCl}$ **B1**

(c) $M_r(\text{C}_2\text{H}_3\text{Cl}) = 2(12.0) + 3(1.0) + 35.5 = 62.5$ **M1**; $93\,750 \div 62.5 = 1500$ monomer units. **A1**

(d) It is non-biodegradable, so it persists in landfill. **B1** Burning it gives toxic, acidic hydrogen chloride (and toxic CO). **B1**

Example 2

A section of an addition polymer is shown.



(a) Identify and name the two monomers used to make it. **[2]**

(b) State the number of σ and π bonds in each monomer molecule. **[2]**

(c) Explain what happens to these bonds when the monomers form the polymer. **[2]**

(a) Cut the chain into pairs: $\text{CH}_2-\text{CH}(\text{CH}(\text{CH}_3)_2)$ and CH_2-CHCl . **M1** Put back the $\text{C}=\text{C}$: $\text{CH}_2=\text{CHCH}(\text{CH}_3)_2$, 3-methylbut-1-ene, and $\text{CH}_2=\text{CHCl}$, chloroethene. **A1**

(b) 3-methylbut-1-ene: 14 σ and 1 π . **B1** Chloroethene: 5 σ and 1 π . **B1**

(c) The π bond of each C=C breaks **M1** and the electrons form new C–C σ bonds to the neighbouring monomers, so the chain carbons change from sp^2 to sp^3 and the polymer is saturated. **A1**

Example 3

Compound **R**, C_5H_{10} , is a branched alkene. Its two C=C carbons carry three methyl groups and one hydrogen atom between them.

(a) Draw the repeat unit of the addition polymer of **R**. **[1]**

(b) Identify which chain carbons of this polymer are chiral, and explain why the others are not. **[2]**

(c) Describe how a sample of **R** and a sample of its polymer could be told apart with bromine water. **[2]**

(d) State how the infrared spectrum of the polymer differs from that of **R**. **[1]**

(a) **R** is 2-methylbut-2-ene, $(CH_3)_2C=CHCH_3$, so the repeat unit is $-C(CH_3)_2-CH(CH_3)-$ with a continuation bond at each end. **B1**

(b) Each $CH(CH_3)$ carbon is bonded to H, CH_3 and two different chain pieces, so it is chiral. **B1** Each $C(CH_3)_2$ carbon carries two identical CH_3 groups, so it is not. **B1**

(c) **R** decolourises bromine water (orange to colourless) **B1** because its C=C reacts by electrophilic addition; the saturated polymer leaves it orange. **B1**

(d) The absorption at $1500-1680\text{ cm}^{-1}$ (C=C) is present for **R** and absent for the polymer. **B1**

Example 4

Ethenyl ethanoate, $CH_2=CHOCOCH_3$, forms an addition polymer used in wood glue.

(a) Draw a section of the polymer showing two repeat units. **[2]**

(b) One chain of this polymer has $M_r = 43\,000$. Calculate the number of repeat units in the chain. **[2]**

(c) The monomer and the polymer both absorb at $1710-1750\text{ cm}^{-1}$ in the infrared. Suggest why. **[1]**

(d) State whether burning this polymer could give hydrogen chloride, and explain your answer. **[1]**

(a) $-CH_2-CH(OCOCH_3)-CH_2-CH(OCOCH_3)-$ **B1** (four chain carbons with an ester side group on alternate carbons), continuation bonds at both ends. **B1**

(b) $M_r(C_4H_6O_2) = 4(12.0) + 6(1.0) + 2(16.0) = 86.0$ **M1**; $43\,000 \div 86.0 = 500$ repeat units. **A1**

(c) Only the C=C takes part in polymerisation; the ester C=O is unchanged, so its absorption stays. **B1**

(d) It contains only C, H and O, so it cannot give HCl; burning gives CO_2 and water (and CO if oxygen is limited). **B1**

Common mistakes

- **Putting side groups into the chain.** Reports see repeat units with four chain carbons for internal alkenes ($C=C$ not at the end of the chain), because the end groups were added to the backbone. Only the two $C=C$ carbons form the chain.
- **Leaving out the continuation bonds**, or drawing brackets with no bonds through them. A repeat unit must show a bond sticking out at each end.
- **Drawing more than one repeat unit** when one was asked for, or missing hydrogen atoms. Count: each chain carbon must have four bonds.
- **Keeping the $C=C$** in the repeat unit. The chain bond is single.
- **Adding atoms that aren't there**, such as an oxygen in the chain of a poly(alkene). The chain is only carbon.
- **Misreading skeletal formulas.** Reports say finding the monomer from a skeletal polymer is where most marks are lost, often by adding extra methyl groups at the ends of the monomer. Redraw the section with every carbon before cutting it into pairs.
- **Naming the polymer when asked for the type.** "Type of polymerisation" is **addition**, not "poly(propene)".
- **Wrong gases on burning.** CO is toxic, not a cause of acid rain or ozone depletion; HCl comes only from polymers that contain chlorine, and it is an acidic gas.

How to get the marks

- **"Draw the repeat unit":** two chain carbons, single bond, all side groups and hydrogens, a continuation bond at each end. Displayed or structural formulas both score if every atom is clear.
- **"Draw a section of the polymer showing two repeat units":** four chain carbons with continuation bonds, the pattern repeated head to tail.
- **"Draw the monomer":** a whole molecule with the $C=C$, no continuation bonds.
- **"Identify the type of polymerisation":** addition.
- **"State two difficulties with disposal":** non-biodegradable, and harmful (toxic) combustion products; for PVC name HCl .
- **"Explain"** about reactivity: link the π bond (high electron density) to electrophiles, and say the polymer has no π bond.
- **"Describe" or "define" stereoisomerism** and explain optical isomerism by a carbon with **four different groups**; a chain carbon with one H and one side group qualifies.
- **Calculations:** show M_r of the monomer with the Data Booklet values, then divide; give whole numbers of repeat units.
- **Multiple choice** on monomers: draw the repeat unit of each option and compare, pair by pair.

Quick check

1. Draw the repeat unit of the polymer made from pent-1-ene, and state whether the polymer contains chiral carbon atoms.
2. Name the monomer of the polymer with repeat unit $-\text{CF}_2-\text{CF}_2-$.
3. Identify the two monomers in this section:
 $-\text{CH}_2-\text{CH}(\text{CN})-\text{CH}_2-\text{CCl}_2-\text{CH}_2-\text{CH}(\text{CN})-\text{CH}_2-\text{CCl}_2-$.
4. A chain of poly(propene) has $M_r = 63\,000$. How many propene units does it contain?
5. Give two reasons why poly(ethene) is hard to dispose of, and one extra problem with burning PVC.

Answers

1. $-\text{CH}_2-\text{CH}(\text{CH}_2\text{CH}_2\text{CH}_3)-$ with a continuation bond at each end. Yes: each $\text{CH}(\text{C}_3\text{H}_7)$ carbon has four different groups (H, C_3H_7 and two different chain pieces), so it is chiral.
2. Tetrafluoroethene, $\text{CF}_2=\text{CF}_2$.
3. Pairs $\text{CH}_2-\text{CH}(\text{CN})$ and CH_2-CCl_2 : propenenitrile, $\text{CH}_2=\text{CHCN}$, and 1,1-dichloroethene, $\text{CH}_2=\text{CCl}_2$.
4. $M_r(\text{C}_3\text{H}_6) = 3(12.0) + 6(1.0) = 42.0$, so $63\,000 \div 42.0 = 1500$ units.
5. It is non-biodegradable, so it stays in landfill for a very long time; burning it gives CO (toxic) and CO_2 (greenhouse gas). PVC also gives HCl, a toxic, acidic gas.

Past questions to try

- [9701/22/M/J/22 Q4](#): part (c), the monomer from a skeletal polymer and a disposal problem.
- [9701/11/M/J/22 Q39](#): two monomers from a section, one of them a diene.
- [9701/22/F/M/23 Q4](#): part (a), the repeat unit of the polymer from an alkene made by elimination.
- [9701/22/F/M/22 Q4](#): part (b), the repeat unit of Perspex and its infrared spectrum.