Cambridge IGCSE · Chemistry 0620 · Notes

Alkenes

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

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Read first: **Organic formulae, functional groups and naming**, **Fuels and alkanes**

What you need to know

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

1. **State that alkenes contain a carbon–carbon double bond**, C=C, a double covalent bond, and that alkenes are **unsaturated hydrocarbons**.
2. **Describe how alkenes and hydrogen are made by cracking** larger alkane molecules, using a **high temperature** and a **catalyst**.
3. **Give the reasons for cracking** larger alkanes.
4. **Describe the aqueous bromine test** that tells a saturated hydrocarbon from an unsaturated one.
5. **Extended only: state that in an addition reaction only one product is formed.**
6. **Extended only: describe the addition reactions of alkenes** with bromine (or aqueous bromine), with hydrogen using a nickel catalyst, and with steam using an acid catalyst, and draw the structural or displayed formulae of the products.

Questions on alkenes also ask for things from nearby syllabus sections, so they are here too: the general formula $\mathrm{C}_n\mathrm{H}_{2n}$, drawing ethene, and (Extended) naming but-1-ene and but-2-ene (11.1–11.2); the temperature and pressure for adding steam to ethene (11.6); that alkenes are the monomers for addition polymers (11.8); burning alkenes; and (Extended) bond-energy sums for addition reactions. The Fuels and alkanes note covers petroleum and fractional distillation; everything a cracking question on alkenes needs is here below.

Understand it

What an alkene is

An **alkene** is a hydrocarbon (a compound of carbon and hydrogen only) whose molecules contain one **C=C double bond**: two carbon atoms joined by two shared pairs of electrons. The C=C is the **functional group** of the alkenes. Every other bond in the molecule is single.

Alkenes form a **homologous series**: the same functional group, the same general formula, each member differing from the next by a $-\mathrm{CH_2}-$ unit, a trend in physical properties and similar chemical properties. Their names end in **-ene**.

Name	Molecular formula	Structural formula	M_r
ethene	$\mathrm{C_2H_4}$	$\mathrm{CH_2{=}CH_2}$	28
propene	$\mathrm{C_3H_6}$	$\mathrm{CH_2{=}CHCH_3}$	42
but-1-ene	$\mathrm{C_4H_8}$	$\mathrm{CH_2{=}CHCH_2CH_3}$	56
but-2-ene	$\mathrm{C_4H_8}$	$\mathrm{CH_3CH{=}CHCH_3}$	56

- **General formula:** $\mathrm{C}_n\mathrm{H}_{2n}$: twice as many hydrogen atoms as carbon atoms. An alkene with 6 carbon atoms is $\mathrm{C_6H_{12}}$. An alkane with the same number of carbons has two more hydrogens ($\mathrm{C}_n\mathrm{H}_{2n+2}$), which is why ethene has fewer H atoms than ethane.
- M_r**:** $12n + 2n = 14n$, so each member is 14 more than the one before (the extra $\mathrm{CH_2}$), and $M_\mathrm{r} \div 14$ gives the number of carbon atoms.
- **Empirical formula:** every alkene is $\mathrm{CH_2}$, because $\mathrm{C}_n\mathrm{H}_{2n}$ divides by n.
- **Drawing ethene** (Core): two C atoms joined by a double bond, two H atoms on each carbon, so each carbon has four bonds. It is drawn in the addition-reactions diagram below.
- **Extended only:** from four carbons the double bond can be in different places, so the name gives its position: **but-1-ene** has the C=C starting at carbon 1, **but-2-ene** at carbon 2. They are **structural isomers**: the same molecular formula, $\mathrm{C_4H_8}$, but different structural formulae. A branched isomer, **methylpropene** $\mathrm{CH_2{=}C(CH_3)CH_3}$, is a third $\mathrm{C_4H_8}$ alkene. "Butene" on its own is not accepted when a question asks you to name one of them.
- **Trend:** as the chain gets longer, the boiling point increases: ethene, propene and the butenes are gases at room temperature, and from about five carbon atoms alkenes are liquids. A missing value in a table lies **between** its neighbours.

Saturated and unsaturated

- A **saturated** compound has only single carbon–carbon bonds (alkanes).
- An **unsaturated** compound has one or more carbon–carbon bonds that are not single: a **C=C double bond**. All alkenes are unsaturated hydrocarbons.

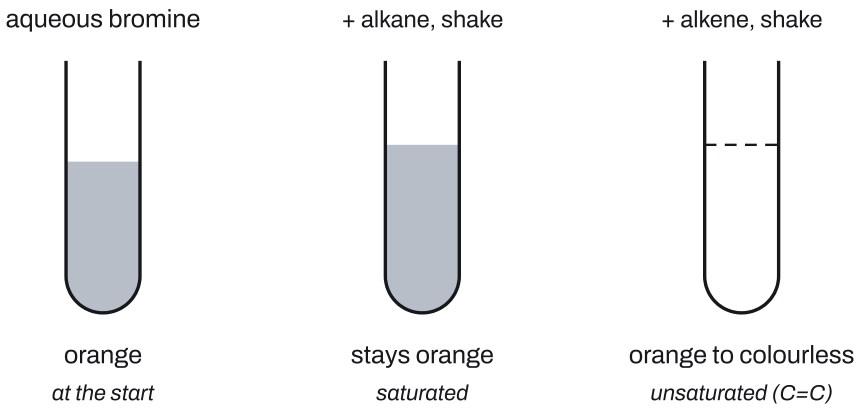
The C=C is what matters, not "a double bond" in general. A C=O double bond (in a carboxylic acid, for example) does **not** make a compound unsaturated. And there is never a double bond between carbon and hydrogen: hydrogen only ever forms one bond. An unsaturated molecule contains single bonds too (all its C–H bonds are single).

Any molecule with a C=C is unsaturated, even if it also has other groups. A molecule such as $\mathrm{CH_2{=}CHCH_2OH}$ is unsaturated (it has a C=C), but it is not a hydrocarbon (it has oxygen) and not an alkene.

Testing for unsaturation: aqueous bromine

Aqueous bromine (bromine water) is **orange**. Shake it with the compound:

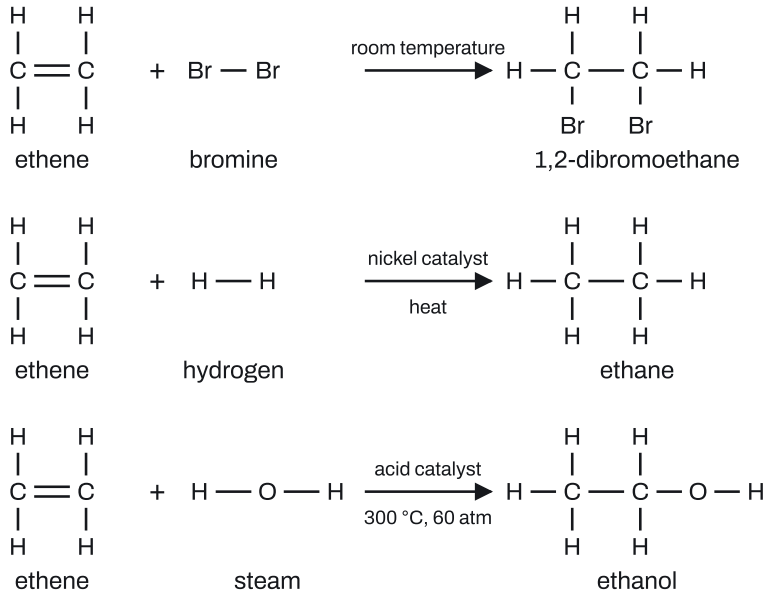
- **Unsaturated** (a C=C, e.g. any alkene): the bromine adds across the double bond and is used up, so the orange colour disappears. The solution turns from **orange to colourless**: the bromine is **decolourised**.
- **Saturated** (e.g. any alkane): no reaction at room temperature. The solution **stays orange**.



The colour change goes **from orange to colourless**, never the other way round. "Clear" is not the same as "colourless" (a clear solution can still be coloured), and nothing turns "red" in this test. Any compound with a C=C decolourises aqueous bromine, including acids and alcohols that contain a C=C.

Addition reactions

Extended only: In an **addition reaction** two molecules join to make **only one product**. Alkenes react this way because one of the two bonds in the C=C breaks, and each of the two carbon atoms gains a new single bond to an incoming atom or group. The C=C becomes C–C, so the product is **saturated**.



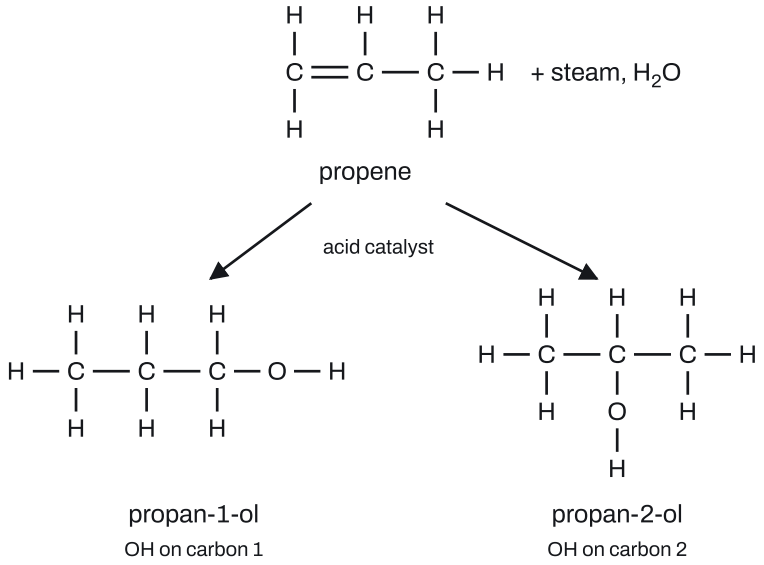
Reagent	Conditions	Product from ethene	General result
bromine, $\mathrm{Br_2}$ (or aqueous bromine)	room temperature, no catalyst	1,2-dibromoethane, $\mathrm{CH_2BrCH_2Br}$	one Br on each C=C carbon
hydrogen, $\mathrm{H_2}$	**nickel** catalyst, heated	ethane, $\mathrm{CH_3CH_3}$	the alkane with the same carbons
steam, $\mathrm{H_2O(g)}$	**acid** catalyst (phosphoric acid), $300\ ^\circ\mathrm{C}$, $60\ \mathrm{atm}$ $(6000\ \mathrm{kPa})$	ethanol, $\mathrm{CH_3CH_2OH}$	an alcohol: H on one C=C carbon, OH on the other

$$\mathrm{C_2H_4 + Br_2 \rightarrow C_2H_4Br_2} \qquad \mathrm{C_2H_4 + H_2 \rightarrow C_2H_6} \qquad \mathrm{C_2H_4 + H_2O \rightarrow C_2H_5OH}$$

The rule for any alkene: **the new atoms go on the two carbons of the C=C, one on each**; the rest of the molecule is unchanged. So the molecular formula of the product is simply the alkene plus the reagent: $\mathrm{C_4H_8 + Br_2 \rightarrow C_4H_8Br_2}$.

- **Bromine:** the two Br atoms go on neighbouring carbons (the old C=C carbons), never both on one carbon and never on the end of a chain the C=C wasn't on. Propene gives **1,2-dibromopropane**, $\mathrm{CH_2BrCHBrCH_3}$ (also written $\mathrm{CH_3CHBrCH_2Br}$); but-2-ene gives **2,3-dibromobutane**, $\mathrm{CH_3CHBrCHBrCH_3}$. The numbers in the name are the carbons carrying Br. Chlorine adds the same way: propene and chlorine give $\mathrm{CH_3CHClCH_2Cl}$.
- **Hydrogen:** the product is an alkane: propene gives propane, either butene gives butane. This is how unsaturated alkenes are turned into saturated alkanes.
- **Steam:** the product is an alcohol. For ethene, and for any alkene whose two C=C carbons look the same (but-2-ene), there is only one possible alcohol: but-2-ene gives only butan-2-ol.

Extended only: when the two ends of the C=C are **different**, the OH can go on either carbon, so steam gives **two** alcohols (each reaction still has one product; different molecules react in the two ways). Propene gives propan-1-ol and propan-2-ol:



In the same way but-1-ene gives butan-1-ol and butan-2-ol. With bromine or hydrogen the two ends make no difference: one Br (or H) goes on each end anyway, so there is only one product.

Making alkenes: cracking

Alkenes are not found in petroleum in useful amounts. They are made by **cracking**: **breaking down long-chain (large) alkane molecules into shorter-chain molecules**, using a **high temperature** and a **catalyst**. Cracking is a **thermal decomposition** (a compound broken down by heat).

- **Feedstock:** large alkanes from the fractional distillation of **petroleum** (for example the kerosene or diesel oil fraction).
- **Products: shorter-chain alkanes**, **alkenes** and sometimes **hydrogen**. Only carbon and hydrogen go in, so only hydrocarbons and hydrogen come out: never water, carbon dioxide, alcohols or acids.
- **Why it is done:** fractional distillation gives more long-chain alkanes than are needed and not enough of the short ones. Cracking turns the surplus into products that are **in greater demand**: shorter alkanes for fuels such as petrol (gasoline), **alkenes to make polymers** (plastics) and other chemicals such as ethanol, and **hydrogen**.

Balancing a cracking equation. No atoms are gained or lost, so the carbon and hydrogen atoms must add up on each side:

$$\mathrm{C_{16}H_{34}} \rightarrow \mathrm{C_8H_{18}} + \mathrm{C_8H_{16}} \qquad \mathrm{C}: 16 = 8 + 8, \quad \mathrm{H}: 34 = 18 + 16$$

A useful check: the alkane that goes in fits $\mathrm{C}_n\mathrm{H}_{2n+2}$; each alkene out has exactly $2n$ hydrogens, and the "extra 2" can go to **only one** product molecule. So in a balanced cracking equation **exactly one** product molecule is an alkane or a hydrogen molecule, and all the others are alkenes. A split into two alkanes, or into two alkenes, can't balance.

Alkenes make polymers

Because of their C=C, alkene molecules (**monomers**) can join to one another in long chains: **addition polymerisation**. Ethene gives **poly(ethene)**, propene gives **poly(propene)** (not "poly(ethane)", and propene does not give poly(ethene)). The Polymers topic covers the details. For alkene questions, know that the polymer's chain has only **single** C–C bonds, so it is **saturated**: in a question that sorts compounds into alkanes and alkenes, the polymer goes with the alkanes.

Burning alkenes

Alkenes are fuels. With plenty of oxygen they burn completely to **carbon dioxide and water**:

$$\mathrm{C_5H_{10}}: \quad 2\mathrm{C_5H_{10}} + 15\mathrm{O_2} \rightarrow 10\mathrm{CO_2} + 10\mathrm{H_2O}$$

Balance C, then H, then O, and double everything if you need half an $\mathrm{O_2}$. With a **limited supply of oxygen** (incomplete combustion) they give **carbon monoxide** and/or **carbon** (soot), and water.

Bond energies of an addition reaction

Extended only: In an addition reaction, the bonds broken are the C=C and the bond in the reagent; the bonds made are a C–C and two new bonds to the carbons. All the other bonds (the C–H bonds) are there before and after, so they cancel: you can count them or leave them out, and ΔH comes out the same.

$$\Delta H = \text{energy to break bonds} - \text{energy released making bonds}$$

A negative answer means the reaction is exothermic. Worked example 3 shows the whole calculation.

Key facts and formulas

Nothing here is given in the exam (the paper gives only the Periodic Table, and bond energies are printed in the question when they are needed), so everything below is to learn.

Formula	Status
Alkenes: $\mathrm{C_nH_{2n}}$, so $M_\mathrm{r} = 14n$; empirical formula $\mathrm{CH_2}$	Learn it
Unsaturated: at least one C=C (a carbon–carbon bond that is not single); saturated: all C–C bonds single	Learn it
Test: aqueous bromine, orange → colourless with a C=C; stays orange if saturated	Learn it
Extended: addition reaction: only one product is formed	Learn it
Extended: $\mathrm{C_nH_{2n}} + \mathrm{Br_2} \rightarrow \mathrm{C_nH_{2n}Br_2}$ (room temperature)	Learn it
Extended: $\mathrm{C_nH_{2n}} + \mathrm{H_2} \rightarrow \mathrm{C_nH_{2n+2}}$ (nickel catalyst, heat)	Learn it
$\mathrm{C_2H_4} + \mathrm{H_2O} \rightarrow \mathrm{C_2H_5OH}$ (steam, acid catalyst, $300\ ^\circ\mathrm{C}$, $60\ \mathrm{atm}$)	Learn it

Formula	Status
Cracking: long-chain alkane → shorter alkane + alkene (or alkene + hydrogen); high temperature, catalyst	Learn it
Complete combustion: $\mathrm{C}_n\mathrm{H}_{2n} + \frac{3n}{2}\mathrm{O}_2 \rightarrow n\mathrm{CO}_2 + n\mathrm{H}_2\mathrm{O}$	Learn it (or balance C, H, then O)
Extended: $\Delta H =$ bonds broken $-$ bonds made	Learn it

How to do it

In the questions we have tagged for this topic (104 questions, 2021–2025, on all four papers), the types came up this often. 57 of the 104 questions mix types, so the counts add up to more than 104.

Question type	Questions
Describe cracking: name, conditions, feedstock, products	34
Aqueous bromine test: describe it or give the colour change	32
Alkene formulae, names, structures and trends	28
Explain "unsaturated" and point to the C=C	23
Give the product of an addition reaction	21
Complete or choose a cracking equation	15
Pick the unsaturated compound from a set	13
Define or recognise an addition reaction	13
Conditions and catalysts for adding hydrogen or steam	12
Give a reason for cracking	5
Combustion of an alkene	5
Bond energies for an alkene addition reaction	3

1. Describe cracking: name, conditions, feedstock, products (34 questions)

1. **Name the process**: cracking. Not polymerisation, combustion, condensation or fractional distillation.
2. **State the meaning**: the breakdown of **long-chain** (large) hydrocarbons into **shorter-chain** (smaller) hydrocarbons, **by heat**. Mark schemes give a mark for each of those ideas, so say all three. Vague words like "compounds" or "substances" instead of hydrocarbons lose marks.
3. **Conditions** (a mark each): **high temperature** (not just "temperature") and a **catalyst**.
4. **Feedstock**: large alkanes from **petroleum** fractions.
5. **Products**: shorter alkanes, **alkenes** and **hydrogen**.

Variations you will meet:

- **"Describe how alkenes are made from petroleum fractions" (3–4 marks)**: large alkane molecules are heated to a high temperature with a catalyst (cracking); they break down into smaller molecules, including alkenes (and hydrogen). One point per mark.
- **"Cracking is a thermal decomposition. State what that means"**: a compound broken down (into simpler substances) by heat. "Thermal decomposition" is also accepted as the type of reaction cracking is.
- **Multiple choice: which statement or which products?** True: it needs a high temperature and a catalyst; it breaks long chains; it makes alkenes, alkanes and hydrogen. False: low temperature, excess oxygen, electricity, water or carbon dioxide as products, "only alkenes", "combining small monomers", "separating a mixture".
- **Complete the sentence** "long-chain alkanes are converted to shorter alkanes and ...": alkenes (or hydrogen).
- **Which compounds could form when a given alkane is cracked?** Only hydrocarbons with fewer carbon atoms (shorter alkanes and alkenes), and hydrogen. Not alcohols, acids or esters.
- **Classify** the compounds in a chain of reactions: the large starting hydrocarbon is an alkane; if cracking gives a hydrocarbon and hydrogen, the hydrocarbon is an alkene; the addition polymer made from that alkene is saturated and counts with the alkanes.

2. Aqueous bromine test: describe it or give the colour change (32 questions)

1. **Test**: add **aqueous bromine** (bromine water) and shake. Name the reagent; "bromination" or "add bromine and see" is not a description.
2. **Result with an unsaturated compound**: **orange to colourless** (decolourised). A mark scheme has accepted "brown to colourless", but orange is the safe word.
3. **Result with a saturated compound**: **stays orange** (no colour change).

Variations you will meet:

- **"Describe the colour change when excess X is added to aqueous bromine" (2 marks)**: "from orange" (1) "to colourless" (1). Excess means all the bromine reacts, so it ends colourless. Any compound with a C=C does this, including unfamiliar acids and alcohols.
- **"Describe a test to distinguish a saturated from an unsaturated compound" (3 marks)**: the reagent, then **both** results, saying which is which.
- **"State the colour of aqueous bromine"**: orange (not red).
- **Multiple choice with two or three hydrocarbons**: work out which have a C=C. Those go orange → colourless; alkanes (and methane) stay orange. Reject any row with the change the wrong way round (colourless → orange or brown).
- **Reverse reasoning**: a hydrocarbon that decolourises aqueous bromine is an **alkene**, **unsaturated**, with general formula $\mathrm{C}_n\mathrm{H}_{2n}$. It is not an alkane, not $\mathrm{C}_2\mathrm{H}_6$, not saturated.

3. Alkene formulae, names, structures and trends (28 questions)

1. **Draw ethene** (the most common Core part): C=C with two H on each carbon, every bond drawn.

2. **General formula**: $\mathrm{C}_n\mathrm{H}_{2n}$. **Name the series**: alkenes (the answer is the series, not one member).
3. **Name an alkene** from its formula or structure: count the carbons (eth-, prop-, but-); for four carbons give the position (but-1-ene, but-2-ene).

Variations you will meet:

- **Extended: why two compounds are in the same homologous series** (two marks): the same general formula ($\mathrm{C}_n\mathrm{H}_{2n}$), and the same functional group (C=C). Other characteristics: each differs from the next by CH_2; similar chemical properties; a trend in physical properties.
- **"State the term for a family of similar compounds"**: homologous series.
- M_r **difference between one member and the next**: 14 (one CH_2). M_r **of ethene**: 28.
- **Extended: empirical formula** of any alkene: CH_2.
- **Extended: draw or name an isomer** of a butene: but-1-ene ↔ but-2-ene (move the C=C), or the branched methylpropene if the question asks for a branched one. The isomer must still be $\mathrm{C}_4\mathrm{H}_8$ with one C=C, and each carbon must have four bonds.
- **Name an alkene with a given number of H atoms**: $2n = 6$ gives $n = 3$, propene.
- **Complete a structure** of an alkene: add the missing C=C or H so that every carbon has four bonds and hydrogen one.
- **Trends from a table**: boiling point increases as the number of carbon atoms increases; predict a missing value between its neighbours; the state at a temperature comes from the melting and boiling points (liquid if between them).
- **Words that describe ethene**: hydrocarbon, unsaturated, monomer; not saturated, not unreactive.

4. Explain "unsaturated" and point to the C=C (23 questions)

1. **"State what is meant by unsaturated"** or **"explain why X is unsaturated"**: it contains a **carbon–carbon double bond** (C=C). The mark schemes also accept "a carbon–carbon bond that is not a single bond".
2. Always say **carbon–carbon**. "A double bond" or "a carbon double bond" alone has been rejected, and a C=O does not count.
3. **"Draw a circle around the part that shows it is unsaturated"**: ring the C=C only (the two carbon atoms and the double bond), even in a large molecule with other groups.

Variations you will meet:

- **Multiple-choice statements**: true: "contains both single and double bonds"; "$\mathrm{CH_3CH_2CH{=}CHCH_3}$ is unsaturated". False: "double bonds between carbon and hydrogen"; "propene is saturated"; "propene contains only single bonds"; "ethene has more H atoms than ethane".
- **Explain why alkenes are hydrocarbons**: they contain carbon and hydrogen **only**.

5. Give the product of an addition reaction (21 questions)

Mostly Extended; Core meets ethene + steam → ethanol.

1. **Find the C=C.** The two carbons of the double bond are where the new atoms go.

2. **Put one new atom or group on each of those two carbons**: Br and Br; H and H; H and OH. The double bond becomes single.
3. **Copy the rest of the molecule unchanged**, then check each carbon has four bonds.
4. **Name it**: dibromo + the alkane name with the Br positions (1,2-dibromoethane, 1,2-dibromopropane, 2,3-dibromobutane); the alkane for hydrogen; the alcohol for steam.

Variations you will meet:

- **Multiple choice with four structures**: reject any with both Br on one carbon, a Br on a carbon that was not in the C=C, only one Br, or a C=C still present. For propene + bromine the answer is $\mathrm{CH_3CHBrCH_2Br}$.
- **Molecular formula of the product**: add the reagent's atoms: propene + bromine gives $\mathrm{C_3H_6Br_2}$.
- **Symbol equation**: $\mathrm{C_4H_8 + Br_2 \rightarrow C_4H_8Br_2}$; $\mathrm{C_2H_4 + H_2O \rightarrow C_2H_5OH}$ (Core: complete the equation for ethanol from ethene).
- **Word equations and "which products?"**: ethene + steam → ethanol (not ethanoic acid); ethene + bromine → 1,2-dibromoethane (dibromoethane, not bromoethane); ethene + hydrogen → ethane ($\mathrm{CH_3CH_3}$, not $\mathrm{CH_2CH_2}$).
- **Two products with steam**: an alkene whose C=C ends differ (propene, but-1-ene) gives two alcohols; name and draw both (propan-1-ol and propan-2-ol; butan-1-ol and butan-2-ol), one mark for each drawing and each name.
- **Chlorine** adds exactly like bromine: propene gives $\mathrm{CH_3CHClCH_2Cl}$.
- **Identify the alkene** from its products: a substance that gives ethanol with steam, 1,2-dibromoethane with bromine and ethane with hydrogen is ethene.

6. Complete or choose a cracking equation (15 questions)

1. **Count** C and H in the alkane on the left.
2. **Take away** what is already on the right (multiply any formula by its number first).
3. **What is left** is the missing product. Check it fits $\mathrm{C_nH_{2n}}$ (an alkene), $\mathrm{C_nH_{2n+2}}$ (an alkane) or is $\mathrm{H_2}$.

For $\mathrm{C_{19}H_{40} \rightarrow C_{12}H_{26} + ?}$: C $19 - 12 = 7$; H $40 - 26 = 14$; so $\mathrm{C_7H_{14}}$, an alkene.

Variations you will meet:

- **A mole ratio is given**, e.g. "an alkane and propene in a 1 : 2 ratio": write $\mathrm{2C_3H_6}$ first, take its 6 C and 12 H away, and what is left is the one alkane. A mark is usually for the right formula and a mark for the balanced equation.
- **Only the products' names are given** (e.g. propane and propene only): write their formulae, then find how many alkene molecules balance: $\mathrm{C_9H_{20} \rightarrow C_3H_8 + 2C_3H_6}$.
- **Several products, one missing**: take all the given ones away together.
- **Multiple choice: which equation is cracking?** An alkane on the left breaking into smaller hydrocarbons (and perhaps $\mathrm{H_2}$), and atoms balancing. Not small molecules joining (that is polymerisation), not adding $\mathrm{H_2}$ (that is addition), not breaking into carbon and hydrogen.

- **Multiple choice: which equations are possible?** Check the H count of each; the "exactly one alkane or H_2" rule in "Understand it" finds the wrong ones fast.
- **Deduce a product's identity**: if one product is hydrogen, the other is an alkene; if one is an alkane, the other is an alkene (it decolourises aqueous bromine and can make a polymer).

7. Pick the unsaturated compound from a set (13 questions)

1. Write down beside each structure or name what it is (alkane, alkene, alcohol, acid).
2. **"Unsaturated hydrocarbon"** or **"a member of the alkene series"**: the one with a C=C **and** only C and H. **"Decolourises aqueous bromine"**: any with a C=C. **"Saturated hydrocarbon"**: only C and H, all single bonds.
3. In a list of names, look for **-ene** (ethene, propene); ethane, ethanol and ethanoic acid are not unsaturated hydrocarbons.

Variations you will meet:

- **"Explain your answer"**: it has a C=C (and contains only carbon and hydrogen).
- **"Give all the letters"**: there may be more than one alkene. Check every structure.
- **Two structures side by side** (for example an alkane and an alkene with four carbons): the alkene decolourises aqueous bromine; the alkane does not.

8. Define or recognise an addition reaction (13 questions)

Extended only.

1. **"State why this is an addition reaction"** or **"what is meant by addition"**: **only one product is formed**. Not "a double bond breaks" or "bromine is added".
2. **Name the type of reaction** for an alkene with bromine, hydrogen or steam: **addition** (steam also accepts "hydration"). Not substitution, condensation or oxidation.

Variations you will meet:

- **Pick the addition equation** from four: the one with two reactants and **one** product, e.g. $\mathrm{A} + \mathrm{B} \rightarrow \mathrm{C}$. Reject any with two products (substitution gives two; cracking gives two or more; a decomposition starts from one reactant).
- **"Which type of compound reacts with hydrogen in an addition reaction?"**: alkenes.
- **Letter questions**: "propene + bromine → 1,2-dibromopropane" is the addition; "methane + chlorine → chloromethane + hydrogen chloride" is substitution.

9. Conditions and catalysts for adding hydrogen or steam (12 questions)

1. **Hydrogen** (to make an alkane): **nickel** catalyst, heated. For "reagent and conditions": hydrogen, nickel catalyst, high temperature.

2. **Steam** (to make an alcohol): an **acid** catalyst (phosphoric acid), $300\ ^\circ\mathrm{C}$ and $60\ \mathrm{atm}$ ($6000\ \mathrm{kPa}$). Write **steam**, not water: water is a liquid at room temperature, and the reaction needs gaseous water.

Variations you will meet:

- **Multiple choice**: nickel goes with hydrogen, acid with steam. Reject iron (Haber process), vanadium(V) oxide (Contact process), yeast (fermentation) and an alkaline catalyst.
- **Core**: "state the temperature and pressure" ($300\ ^\circ\mathrm{C}, 60\ \mathrm{atm}$); "circle the type of catalyst": acid.
- **"Give one condition"**: any one of $300\ ^\circ\mathrm{C}, 60\ \mathrm{atm}$ or phosphoric acid. When 2 or 3 marks are available, give the reagent and all of them.

10. Give a reason for cracking (5 questions)

One mark, any one of: the shorter-chain products are **in greater demand** (more useful) than the long-chain fractions; to make more **petrol** (fuel); to make **alkenes**, which are used to make polymers; to make **hydrogen**. In multiple choice, "cracking produces petrol" and "produces alkenes used to make polymers" are true; "only produces alkenes" is false.

11. Combustion of an alkene (5 questions)

1. **Complete combustion**: carbon dioxide and water only.
2. **Balance** C, then H, then O; double if you need a half: $\mathrm{C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O}$. Mark schemes give one mark for $\mathrm{CO_2}$ + $\mathrm{H_2O}$ as the only products and one for the balancing.
3. **Incomplete combustion** (limited oxygen): carbon monoxide and/or carbon, plus water. "State the meaning of incomplete combustion": burning in a limited supply of oxygen (air).

12. Bond energies for an alkene addition reaction (3 questions)

Extended only; the bond energies are given in the question.

1. **Bonds broken**: list every bond in the reactants from the displayed formulae (for ethene + a halogen: 4 C–H, 1 C=C, 1 X–X), multiply and add.
2. **Bonds made**: every bond in the product (4 C–H, 1 C–C, 2 C–X).
3. **ΔH = broken – made**, with its sign (negative: exothermic).
4. **Shortcut**: leave out the C–H bonds on both sides; you get the same ΔH (mark schemes accept this too).

Variation: working backwards to a bond energy. Given ΔH, find the total energy released making bonds: made $=$ broken $-\Delta H$. Take away the bonds you know; divide what is left by how many of the unknown bond there are (for $\mathrm{CH_2XCH_2X}$, two C–X bonds).

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

A long-chain alkane, $\mathrm{C_{17}H_{36}}$, is cracked.

(a) State two conditions needed for cracking. **[2]**

(b) One molecule of $\mathrm{C_{17}H_{36}}$ breaks down into one molecule of $\mathrm{C_{11}H_{24}}$ and one molecule of a hydrocarbon Z. Deduce the molecular formula of Z. **[1]**

(c) Z is an alkene. State why Z is described as unsaturated. **[1]**

(d) Describe a test to show that Z is unsaturated but $\mathrm{C_{11}H_{24}}$ is not. Give the result for each. **[3]**

(e) Give one reason why large alkanes are cracked. **[1]**

(a) A high temperature **B1**; a catalyst **B1**.

(b) C: $17 - 11 = 6$; H: $36 - 24 = 12$. Z is $\mathrm{C_6H_{12}}$. **B1** (It fits $\mathrm{C_nH_{2n}}$, as an alkene should.)

(c) Its molecules contain a carbon–carbon double bond, C=C. **B1**

(d) Shake each with aqueous bromine (bromine water) **B1**. With Z: the orange colour turns colourless **B1**. With $\mathrm{C_{11}H_{24}}$ (saturated): it stays orange **B1**.

(e) The shorter molecules are in greater demand than the long-chain alkanes, for example as petrol, or alkenes to make polymers. **B1**

Example 2 (Extended)

Compound W has the structural formula $\mathrm{CH_3CH_2CH{=}CHCH_2CH_3}$.

(a) Give the molecular formula of W and show that it fits the general formula of the alkenes. **[1]**

(b) W reacts with bromine.

(i) Give the structural formula of the product. **[1]**

(ii) State why this is an addition reaction. **[1]**

(c) W reacts with hydrogen. Name the catalyst and name the organic product. **[2]**

(d) W reacts with steam.

(i) State the conditions used. **[2]**

(ii) Give the structural formula of the product, and explain why only one product forms. **[2]**

(e) Write the balanced symbol equation for the complete combustion of W. **[2]**

(a) $\mathrm{C_6H_{12}}$: with $n = 6$, $2n = 12$, which matches $\mathrm{C_nH_{2n}}$. **B1**

(b)(i) One Br on each carbon of the C=C: $\mathrm{CH_3CH_2CHBrCHBrCH_2CH_3}$. **B1**

(ii) Only one product is formed. **B1**

(c) Nickel **B1**; hexane **B1**.

(d)(i) An acid catalyst (phosphoric acid) **B1**; $300\ ^\circ\mathrm{C}$ and $60\ \mathrm{atm}$ **B1**.

(ii) $\mathrm{CH_3CH_2CH(OH)CH_2CH_2CH_3}$ **B1**. The two carbons of the C=C are carbons 3 and 4 of a six-carbon chain, each with an ethyl group on the other side, so putting the OH on either of them gives the same molecule **B1**.

(e) C: $6\mathrm{CO_2}$; H: $12 \div 2 = 6\mathrm{H_2O}$; O needed $12 + 6 = 18$ atoms $= 9\mathrm{O_2}$:

$$\mathrm{C_6H_{12} + 9O_2 \rightarrow 6CO_2 + 6H_2O}$$

M1 for $\mathrm{CO_2}$ and $\mathrm{H_2O}$ as the only products, **A1** for the balancing.

Example 3 (Extended)

Propene reacts with hydrogen to form propane.

$$\mathrm{CH_2{=}CHCH_3 + H{-}H \rightarrow CH_3CH_2CH_3}$$

Bond	C–H	C–C	C=C	H–H
Bond energy in kJ/mol	412	348	612	436

(a) Use the bond energies to calculate the enthalpy change of the reaction. **[3]**

(b) State whether the reaction is exothermic or endothermic. **[1]**

(a) Propene has 6 C–H, 1 C–C and 1 C=C; propane has 8 C–H and 2 C–C.

Bonds broken: $6(412) + 348 + 612 + 436 = 3868$ kJ **M1**

Bonds made: $8(412) + 2(348) = 3992$ kJ **M1**

$\Delta H = 3868 - 3992 = -124$ kJ/mol **A1** (the sign is part of the answer)

Shortcut check: broken $612 + 436 = 1048$; made $348 + 2(412) = 1172$; $1048 - 1172 = -124$.

(b) Exothermic, because ΔH is negative (more energy is released making bonds than is needed to break them). **B1**

Example 4 (multiple choice)

(a) An alkene has a relative molecular mass of 70. What is its molecular formula? (A_r: C = 12, H = 1) **[1]**

A C_5H_{12} B C_6H_{12} C C_5H_{10} D C_4H_{10}

(b) Which equation shows a possible cracking reaction? **[1]**

- A $C_{11}H_{24} \rightarrow C_5H_{12} + C_6H_{14}$
- B $C_{11}H_{24} \rightarrow C_9H_{20} + C_2H_4$
- C $C_{11}H_{24} \rightarrow C_5H_{10} + C_6H_{12}$
- D $C_{11}H_{24} + H_2 \rightarrow C_5H_{12} + C_6H_{14}$

(c) Which statement about a hydrocarbon with the formula C_4H_8 is correct? **[1]**

- A It is saturated.
- B It decolourises aqueous bromine.
- C It reacts with steam to form butanoic acid.
- D It is formed when butane reacts with hydrogen.

(a) For an alkene $M_r = 14n = 70$, so $n = 5$ and the formula is C_5H_{10}. (A and D are alkanes; B has M_r 84.) **Answer C.**

(b) A and C fail the H count: $12 + 14 = 26$ and $10 + 12 = 22$, not 24 (two alkanes or two alkenes can't balance). D adds hydrogen, which is not cracking. B balances: C $9 + 2 = 11$, H $20 + 4 = 24$. **Answer B.**

(c) C_4H_8 fits C_nH_{2n}, so it is an alkene with a C=C: unsaturated (not A). Steam gives an alcohol, not an acid (not C). Hydrogen adds to alkenes, not alkanes (not D). **Answer B.**

Common mistakes

- **Writing "double bond" without "carbon–carbon".** Examiners reject "it has a double bond" and "a carbon double bond" as the reason for unsaturation. Write "a C=C (carbon–carbon double bond)".
- **Getting the bromine colour wrong.** Aqueous bromine is orange, not red, and it goes **orange to colourless**. Reversing it (colourless to orange) is the favourite multiple-choice trap. "Clear" is not "colourless".
- **Describing the test with one word.** "Bromination" earns nothing. Name aqueous bromine and give the observation for each compound.
- **Vague cracking answers.** "Breaking substances", "breaking bonds" or just "temperature" lose marks. Say long-chain hydrocarbons, shorter-chain hydrocarbons, high temperature and catalyst.

- **Calling cracking polymerisation**, or naming polymerisation as the way alkenes are made from alkanes. Cracking breaks big molecules; polymerisation joins small ones.
- **Leaving out the balancing** of a cracking equation, or writing products that don't add up. Count C and H on both sides.
- **"Water" instead of "steam"**, and confusing ethanol from ethene (steam, acid catalyst, $300\ ^\circ\mathrm{C}$, $60\ \mathrm{atm}$) with fermentation (yeast, 25–$35\ ^\circ\mathrm{C}$).
- **Mixing up the catalysts.** Nickel is for hydrogen; an acid is for steam. Iron, vanadium(V) oxide and yeast belong to other processes.
- **Naming butenes as "butene"** when the position is needed. Give but-1-ene or but-2-ene. Likewise "dibromobutane" or "bromide butane" for 2,3-dibromobutane.
- **Putting the new atoms in the wrong place**: both Br on one carbon, or a Br on a carbon that was not in the C=C. One on each C=C carbon, always.
- **Explaining "addition" with the mechanism.** "The double bond breaks" or "bromine is added" is not the answer. Addition means only one product is formed.
- **Confusing ethene and ethane.** Ethene ($\mathrm{C_2H_4}$, C=C) decolourises aqueous bromine; ethane ($\mathrm{C_2H_6}$) does not. Its polymer is poly(ethene), not poly(ethane).
- **Thinking alkenes contain ionic bonds**, or that a polymer of an alkene is still unsaturated. All the bonds are covalent, and the polymer chain has only single C–C bonds.

How to get the marks

- **"State" and "Name"** want the exact word: cracking, addition, nickel, steam, acid catalyst, homologous series, alkenes, poly(ethene).
- **"Define" or "State the meaning of"**: unsaturated (contains a carbon–carbon double bond); addition reaction (only one product is formed); cracking (long-chain hydrocarbons broken into shorter ones by heat); thermal decomposition (breakdown by heat); hydrocarbon (carbon and hydrogen only). Each key idea is a mark.
- **"Describe a test"**: the reagent, then the observation, and for "distinguish" the observation for each compound. Give colours as "from ... to ...".
- **"Describe" cracking or its conditions**: separate points, one per mark: high temperature, catalyst, large alkanes, smaller molecules including alkenes (and hydrogen).
- **Draw displayed formulae** with every atom and every bond. Check each carbon has four bonds, each hydrogen one, and that a C=C is drawn as two lines.
- **Equations**: formulae first, then balance. For addition, the product is alkene + reagent in one formula; for cracking, C and H must add up; for combustion, only $\mathrm{CO_2}$ and $\mathrm{H_2O}$.
- **Bond-energy calculations**: show the bonds-broken total, the bonds-made total and the subtraction, and give the sign. Each step is a mark, so a slip in one total still lets you earn the others.
- **"Suggest"** (e.g. the name of a polymer): apply the pattern: poly(propene) from propene.
- **Letter and list questions**: label every structure first, then answer; a letter may be used more than once.

Quick check

1. Which of these is an unsaturated hydrocarbon: $\mathrm{C_3H_8}$, $\mathrm{C_5H_{10}}$, $\mathrm{C_2H_5OH}$, $\mathrm{CH_3COOH}$? Explain your choice.
2. $\mathrm{C_{20}H_{42}}$ is cracked to give one alkane molecule and ethene in a $1:4$ ratio. Write the equation.
3. Describe what is seen when excess of an unsaturated compound, and separately excess of an alkane, is added to aqueous bromine.
4. (Extended) But-1-ene, $\mathrm{CH_2{=}CHCH_2CH_3}$, reacts separately with bromine and with hydrogen. Give the structural formula and name of each product, and name the catalyst needed with hydrogen.
5. (Extended) Propene reacts with bromine: $\mathrm{CH_2{=}CHCH_3 + Br{-}Br \rightarrow CH_2BrCHBrCH_3}$. Using C=C 612, C–C 348, Br–Br 193 and C–Br 276 kJ/mol, calculate the enthalpy change.

Answers

1. $\mathrm{C_5H_{10}}$. It contains only carbon and hydrogen, and it fits $\mathrm{C_nH_{2n}}$, so it has a C=C double bond. ($\mathrm{C_3H_8}$ is a saturated alkane; the other two contain oxygen; the C=O in $\mathrm{CH_3COOH}$ does not count.)
2. $\mathrm{4C_2H_4}$ has 8 C and 16 H. Left: C $20 - 8 = 12$, H $42 - 16 = 26$, so $\mathrm{C_{20}H_{42} \rightarrow C_{12}H_{26} + 4C_2H_4}$.
3. With the unsaturated compound the orange colour disappears: orange to colourless. With the alkane the solution stays orange.
4. Bromine: $\mathrm{CH_2BrCHBrCH_2CH_3}$, 1,2-dibromobutane. Hydrogen: $\mathrm{CH_3CH_2CH_2CH_3}$, butane, with a nickel catalyst (heated).
5. The C–H bonds cancel, so use the shortcut. Broken: $612 + 193 = 805$ kJ. Made: $348 + 2(276) = 900$ kJ. $\Delta H = 805 - 900 = -95$ kJ/mol (exothermic).

Past questions to try

- **0620/42/M/J/23 Q5**: propene with chlorine and with steam, including both alcohols named and drawn.
- **0620/43/M/J/24 Q7**: a cracking equation from a mole ratio, and the monomer of an alkene polymer.
- **0620/41/O/N/22 Q5**: the colour change, "addition", and a bond-energy calculation for ethene and bromine.
- **0620/22/M/J/22 Q37**: which cracking equations for one alkane are possible.