



AQA CHEMISTRY 7405

ALKANES

FRACTIONS • CRACKING • COMBUSTION • RADICAL SUBSTITUTION

			
SPEC	CRACK IT	TEST IT	DONE WHEN

From crude oil to useful products

Learn how the structure of alkanes explains their separation, how refineries change their molecules, why their combustion causes pollution and how chlorine substitutes for hydrogen. Each section teaches the idea, works through an example and gives you a different task to solve.

AQA SECTION	YOUR ROUTE THROUGH THE PACK
3.3.2.1	Recognise alkanes; explain boiling trends; separate petroleum by fractional distillation.
3.3.2.2	Choose thermal or catalytic cracking; explain economic demand; balance product equations.
3.3.2.3	Write combustion equations; identify pollutants; explain catalytic converters and sulfur dioxide removal.
3.3.2.4	Explain methane chlorination through initiation, propagation and termination; apply the mechanism.

BRING FORWARD Formulae and naming from Introduction to Organic Chemistry I; radicals and bond fission from Introduction II; Van der Waals forces from Bonding II. The essentials are briefly retaught here.

HOW TO USE THESE NOTES Read the worked reasoning, then attempt every TEST IT without looking at the answers. Give equations where requested and keep radical dots visible. Complete answers follow the teaching pages.

Scope: AQA 3.3.2.1–3.3.2.4 with essential links to 3.3.1.2 and 3.1.3.7. Detailed alkene reactions, halogenoalkane mechanisms and aromatic chemistry belong in later packs.

Current AQA specification checked 1 October 2026. Original teaching examples and practice questions.

1. Recognise an alkane



SPEC 3.3.2.1 Define alkanes and recognise their formulae and structures.



CRACK IT An alkane is a saturated hydrocarbon. Check the atoms present and the bonds, then use the general formula for an open chain.

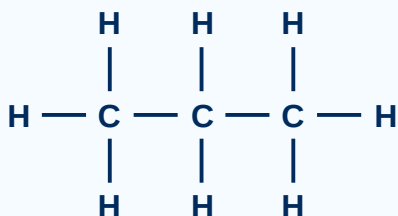
TERM	LEARNABLE DEFINITION	EXAMPLE
Hydrocarbon	A compound containing hydrogen and carbon only.	C_2H_6 is a hydrocarbon; C_2H_5OH is not.
Saturated	Contains only single carbon–carbon bonds.	$CH_3CH_2CH_3$ has no $C=C$ or $C\equiv C$ bond.
Alkane	A saturated hydrocarbon.	Propane, C_3H_8 .
Homologous series	A family with the same general formula and similar chemical properties; successive members differ by CH_2 .	Methane $\rightarrow$ ethane $\rightarrow$ propane.

Open-chain alkanes: C_nH_{2n+2}

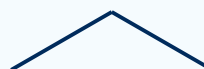
The formula applies to straight and branched open-chain alkanes. A ring changes the formula: a saturated hydrocarbon can contain a ring, so C_nH_{2n} alone does not prove a $C=C$ bond.

METHANE	ETHANE	PROPANE	BUTANE	PENTANE	HEXANE
CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	C_6H_{14}

Worked example One molecule in two representations



Displayed formula



Skeletal formula

Propane contains three carbons. C_nH_{2n+2} gives $2(3) + 2 = 8$ hydrogens. Its structural formula is $CH_3CH_2CH_3$. Every carbon in the displayed formula has four bonds.



TEST IT 1

a) Define a hydrocarbon and explain what saturated means for carbon–carbon bonding. [2 marks]

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b) Give the molecular and structural formulae of the straight-chain alkane with seven carbon atoms. [2 marks]

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✓ **DONE WHEN** you identify alkanes from their atoms and bonds and use the open-chain general formula correctly.

2. Explain boiling point trends



SPEC 3.3.2.1; link to 3.1.3.7 Use intermolecular forces to explain why alkane fractions boil at different temperatures.



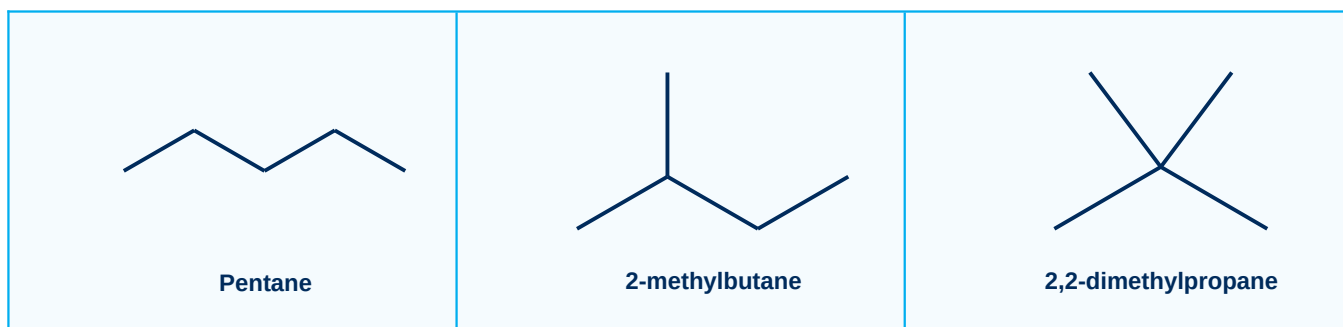
CRACK IT Boiling separates molecules. Explain the strength of Van der Waals forces between molecules, not the strength of covalent bonds inside them.

Alkanes are simple molecular substances with Van der Waals forces between their molecules. For comparable unbranched alkanes, a longer chain has more electrons and stronger overall intermolecular attractions. More energy is needed to separate the molecules, so boiling point increases.

CHANGE	EXPLANATION	RESULT
Longer unbranched chain	More electrons; stronger overall Van der Waals forces.	Higher boiling point; lower volatility.
More branching at the same molecular formula	More compact shape; less effective surface contact between molecules.	Weaker overall attractions; lower boiling point.

VOLATILITY Volatility is how readily a substance vaporises. A lower boiling point generally means greater volatility.

Worked example Compare three C_5H_{12} isomers



All three have the same molecular formula and electron count. Pentane has the greatest effective surface contact and the highest boiling point. The most compact isomer, 2,2-dimethylpropane, has the lowest. Use shape to explain this comparison, not “more electrons”.

Worked contrast Butane compared with hexane

Hexane has more electrons and stronger overall Van der Waals forces than butane. Hexane therefore needs more energy to boil. No C–C or C–H bonds need to break during boiling.

EXAM TRAP Do not say that larger alkanes have stronger covalent bonds and therefore higher boiling points. The relevant attractions act between molecules.



TEST IT 2

a) Predict which has the higher boiling point, heptane or nonane, and explain your choice. [3 marks]

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b) Hexane and 2,2-dimethylbutane both have formula C_6H_{14} . Which is more volatile? Explain using molecular shape. [3 marks]

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✓ **DONE WHEN** you use electron count for chain-length comparisons and molecular shape for branching comparisons.

3. Separate crude oil into fractions

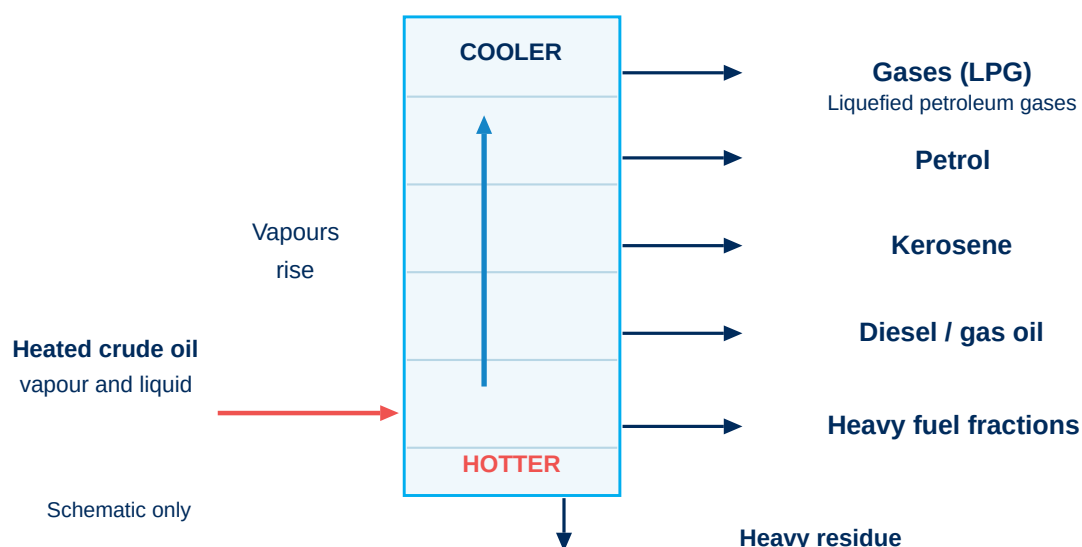


SPEC 3.3.2.1 Explain fractional distillation of petroleum using boiling points and the temperature gradient.



CRACK IT Heat the mixture, let vapours rise and cool, then collect mixtures with similar boiling ranges at different heights.

TERM	MEANING
Petroleum or crude oil	A mixture consisting mainly of alkane hydrocarbons.
Fraction	A mixture of hydrocarbons with similar boiling points, collected over a boiling range.
Fractional distillation	Separation using differences in boiling point and repeated vaporisation and condensation.



1. Heat crude oil so that much of it vaporises; feed it into the lower part of the column.
2. The column is hot at the bottom and cooler at the top. Rising vapours cool.
3. Higher-boiling components condense lower down. Lower-boiling components rise further before condensing.
4. Collect the fractions separately. Very volatile gases leave the top; a heavy residue remains at the bottom.

Worked example Why does kerosene leave below petrol?

Kerosene generally contains larger molecules with higher boiling points. They condense in a warmer, lower part of the column. Petrol components remain as vapour there and rise into a cooler region.

SEPARATION IS PHYSICAL No C–C bonds are broken in fractional distillation. A fraction is a mixture, not a single pure alkane.



TEST IT 3

a) A refinery collects fraction P near the top and fraction Q near the bottom. Explain which has the higher boiling range and why it leaves at that position. [3 marks]

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b) Explain why collecting a fraction does not produce a pure substance. [1 mark]

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✓ **DONE WHEN** you link boiling point, condensation temperature and collection height without breaking molecules.

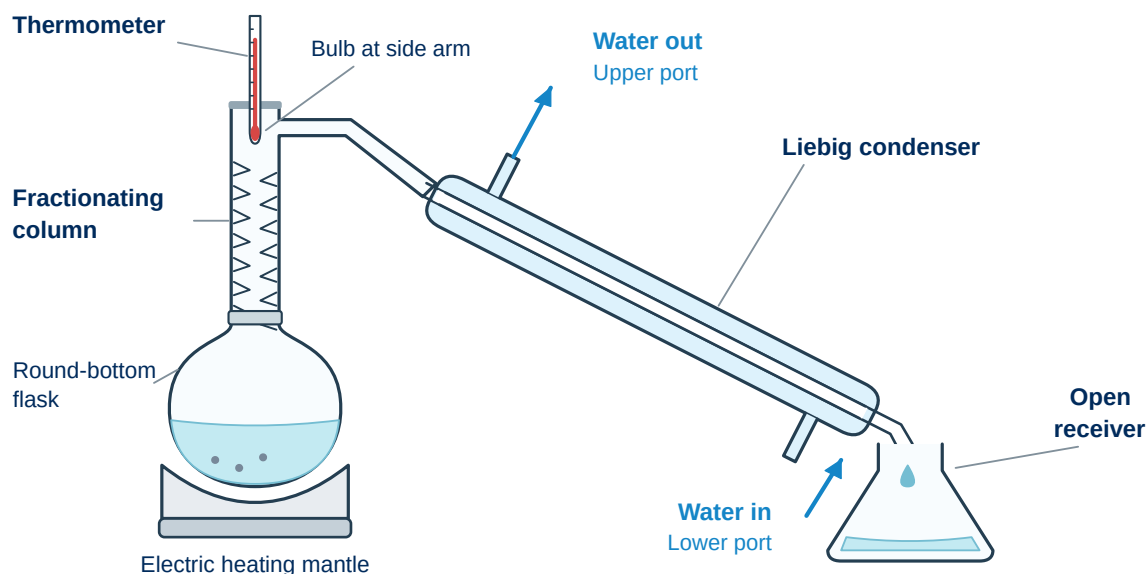
4. Understand laboratory fractional distillation



SPEC 3.3.2.1; AT a, d, k Explain the functions of the column, thermometer and condenser in a laboratory separation.



CRACK IT The column improves separation. The thermometer measures the outgoing vapour; the condenser turns that vapour into liquid.



PART	FUNCTION
Fractionating column	Repeated condensation and vaporisation enrich the rising vapour in the more volatile component.
Thermometer bulb at the side arm	Measures outgoing vapour temperature, not the temperature of liquid in the flask.
Water-cooled condenser	Cools vapour to liquid. Water always enters at the bottom and leaves at the top, keeping the jacket full for effective cooling.
Receiver	Collects distillate. Change the receiver to collect a new boiling range.

Use an electric heater for flammable hydrocarbons and keep the apparatus unsealed. Add anti-bumping granules before heating to help the liquid boil smoothly. Practical work requires the teacher's risk assessment.

Worked example A two-component model mixture

For liquids with boiling points around 70 °C and 110 °C, the first collected fraction is enriched in the lower-boiling liquid. As it is depleted, the vapour temperature rises. Collecting over a narrow temperature range improves separation, but does not guarantee absolute purity.



TEST IT 4

a) Explain why a fractionating column separates two liquids better than an empty delivery tube. [2 marks]

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b) State the correct position of the thermometer bulb and explain why water enters the lower condenser port. [2 marks]

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c) Give one reason for using electric heating instead of a naked flame. [1 mark]

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✓ **DONE WHEN** you explain each part of the apparatus and distinguish vapour temperature from liquid temperature.

5. Choose a cracking process



SPEC 3.3.2.2 Compare thermal and catalytic cracking and explain why cracking is economically useful.



CRACK IT Cracking breaks C–C bonds in larger alkanes. Choose conditions according to the products needed.

FULL-MARK DEFINITION Cracking is the breakdown of larger hydrocarbon molecules into smaller molecules by breaking carbon–carbon bonds.

A refinery may have more heavy fractions than it can sell and too little of the lighter products in demand. Cracking changes the molecules to improve the product mix. Smaller fuel molecules are useful, and alkenes provide feedstock for making other chemicals, including polymers.

FEATURE	THERMAL CRACKING	CATALYTIC CRACKING
Temperature	High temperature.	High temperature.
Pressure	High pressure.	Slight pressure.
Catalyst	No catalyst.	Zeolite catalyst.
Product emphasis	A high percentage of alkenes, plus mainly straight-chain alkanes.	Branched-chain alkanes for motor fuels, plus aromatic hydrocarbons.
Main reason to choose it	Produce alkene feedstock.	Increase useful fuel production.

A zeolite is a porous solid catalyst. It speeds up the reaction by providing an alternative pathway with a lower activation energy. Aromatic hydrocarbons are a separate class of products; their detailed structures and reactions are outside this booklet.

Worked example Select a process for an alkene plant

A company wants a high proportion of alkenes for chemical manufacture. Thermal cracking is appropriate: it uses high temperature and high pressure and favours a high percentage of alkenes. The accompanying alkanes are mainly straight-chain. Catalytic cracking produces more branched-chain alkanes, useful in motor fuels.

AQA CONDITIONS Learn the qualitative conditions above. AQA does not specify one universal numerical temperature or pressure here, and cracking mechanisms are not required.



TEST IT 5

a) A refinery wants more motor fuel from a surplus heavy fraction. Name the appropriate cracking process and state its catalyst and pressure condition. [3 marks]

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b) Give two economic reasons for cracking long-chain alkanes. [2 marks]

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c) State the type of covalent bond that must break during cracking. [1 mark]

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✓ **DONE WHEN** you distinguish the two processes and connect cracking to demand and product value.

6. Write balanced cracking equations



SPEC 3.3.2.2; equation skills Deduce missing cracking products while conserving every carbon and hydrogen atom.



CRACK IT Count carbon first, then hydrogen. Check that the proposed product formula belongs to a plausible hydrocarbon.

A cracking reaction produces a mixture. A written equation shows one possible route, not the only product combination. Many simple examples show an alkane plus an alkene. The alkene contains a C=C bond and, for an open chain with one C=C, has formula C_nH_{2n} .

Worked example 1 One missing product



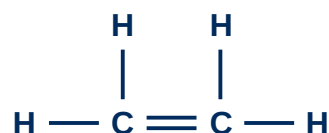
1. Carbon remaining: $10 - 8 = 2$.
2. Hydrogen remaining: $22 - 18 = 4$.
3. The missing product is C_2H_4 , ethene. The totals are C = 10 and H = 22 on each side.



Products from worked example 1



+



Alkane: all C–C bonds single

Alkene: C=C present

Worked example 2 More than two product molecules



Carbon: $8 + 2(3) = 14$. Hydrogen: $18 + 2(6) = 30$. The coefficient 2 multiplies the entire propene formula. Do not change a subscript just to balance an equation.

PHYSICAL OR CHEMICAL Fractional distillation separates existing molecules.
Cracking makes new molecules because covalent bonds break and form.



TEST IT 6

a) Complete $C_{11}H_{24} \rightarrow C_7H_{16} + X$ by giving the molecular formula of X. Show the subtraction of atoms. [2 marks]

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b) Find a and x in the balanced equation $C_{16}H_{34} \rightarrow aC_2H_4 + C_xH_{18}$. Show your atom counts. [3 marks]

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c) Explain why cracking is a chemical change but fractional distillation is a physical change. [2 marks]

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✓ **DONE WHEN** you balance all atoms and explain why several cracking product combinations are possible.

7. Balance complete combustion



SPEC 3.3.2.3 Write complete combustion equations and explain why alkanes are useful fuels.



CRACK IT For complete combustion, send all carbon to CO_2 and all hydrogen to H_2O . Balance oxygen last.

A fuel releases useful energy when it burns. With enough oxygen and effective mixing, complete combustion of an alkane produces carbon dioxide and water. It is exothermic: more energy is released by forming product bonds than is needed to break reactant bonds.

Worked example 1 Propane

1. Write the skeleton: $\text{C}_3\text{H}_8 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$.
2. Balance carbon and hydrogen: $\text{C}_3\text{H}_8 + \text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O}$.
3. Count 10 oxygen atoms on the right, requiring 5O_2 on the left.



Worked example 2 A fractional oxygen coefficient



There are seven product oxygen atoms, so one ethane molecule needs $3\frac{1}{2} \text{O}_2$ in the equation ratio. Multiply every coefficient by 2 for whole numbers.



The general equation is a check, not a substitute for counting atoms. State symbols depend on the conditions: water is vapour in hot exhaust and may condense on cooling.

CARBON DIOXIDE STILL MATTERS Complete combustion avoids CO and soot in this idealised equation, but CO_2 emissions contribute to the enhanced greenhouse effect.



TEST IT 7

- a) Write the complete combustion equation for butane, C_4H_{10} , using the smallest whole-number coefficients. State symbols are not required. [3 marks]

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- b) Write the complete combustion equation for pentane, C_5H_{12} . State symbols are not required. [2 marks]

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- c) Explain why an alkane releases energy overall when it burns. [2 marks]

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✓ **DONE WHEN** you balance C, then H, then O and explain the overall energy release.

8. Explain incomplete combustion and pollutants



SPEC 3.3.2.3 Identify engine pollutants, explain their sources and write incomplete combustion equations.



CRACK IT Limited oxygen can produce CO or carbon. Nitrogen oxides form from air at high engine temperatures.

Incomplete combustion occurs when oxygen supply or mixing is insufficient for complete combustion. The exhaust can contain a mixture of CO₂, CO, carbon particles and unburned hydrocarbons. The following equations show idealised routes.

Worked examples Methane with restricted oxygen



POLLUTANT	SOURCE	WHY IT MATTERS
Carbon monoxide, CO	Incomplete combustion.	Toxic: binds to haemoglobin and reduces oxygen transport in blood.
Carbon particles, soot	Incomplete combustion.	Particulates damage respiratory health.
Unburned hydrocarbons	Fuel escapes complete combustion.	Contribute to photochemical smog; some are harmful.
Nitrogen oxides, NO _x	N ₂ and O ₂ from air react at high engine temperatures.	Cause respiratory harm and contribute to acid deposition and photochemical smog.
Sulfur dioxide, SO ₂	Sulfur-containing impurities burn.	Causes respiratory harm and acid deposition.



NO can be oxidised further to NO₂. NO_x is a collective label for nitrogen oxides, not the formula of one particular compound. Pure alkanes contain neither nitrogen nor sulfur.

DO NOT CONFUSE SOURCES Nitrogen oxides mainly form from nitrogen and oxygen in the intake air. Sulfur dioxide comes from sulfur-containing fuel impurities.



TEST IT 8

a) Write a balanced equation for incomplete combustion of ethane forming carbon monoxide and water only. [2 marks]

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b) Write a balanced equation for incomplete combustion of propane forming carbon and water only. [2 marks]

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c) Explain how a nitrogen-free fuel can still produce NO in a car engine. [2 marks]

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✓ **DONE WHEN** you distinguish pollutants from products and identify the correct source of each pollutant.

9. Remove pollutants from exhaust and flue gases



SPEC 3.3.2.3 Explain catalytic converters and removal of SO₂ using calcium oxide or calcium carbonate.



CRACK IT Use chemical equations to show the pollutant becoming a less harmful product. Each device tackles particular pollutants.

Catalytic converters in vehicles

Hot exhaust passes over a large catalyst surface, commonly using metals such as platinum, palladium and rhodium. CO and unburned hydrocarbons are oxidised; nitrogen oxides are reduced to nitrogen. The catalyst provides lower-activation-energy pathways and is not used up overall.



For the first equation, count C = 2, N = 2 and O = 4 on each side. CO gains oxygen; NO loses oxygen. A converter does not remove CO₂, and conversion is less effective before the catalyst reaches its working temperature. Soot needs particulate control rather than this gas-conversion explanation.

Sulfur dioxide in industrial flue gas

Flue gas is waste gas leaving a combustion plant. SO₂ is an acidic oxide, so it reacts with basic CaO or with CaCO₃. The sulfur is captured in a solid calcium compound.



These equations represent sulfite formation. If oxygen is also supplied, calcium sulfite can be oxidised to calcium sulfate:



METHOD	MAIN TARGET	LIMITATION
Catalytic converter	CO, NO _x and unburned hydrocarbons.	Does not eliminate CO ₂ emissions.
CaO or CaCO ₃ treatment	SO ₂ in flue gases.	The calcium reagent is consumed; solid material must be handled.

REAGENT OR CATALYST CaO reacts and is used up. Do not call it a catalyst in sulfur dioxide removal.



TEST IT 9

a) Balance the converter equation using the smallest whole-number coefficients: $\text{CO} + \text{NO}_2 \rightarrow \text{CO}_2 + \text{N}_2$. [2 marks]

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b) MgO is a basic oxide. Explain why it could remove SO₂ and write the equation forming magnesium sulfite, MgSO₃. [2 marks]

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c) Write the overall equation for CaCO₃ removing SO₂ when oxygen converts the captured sulfur to sulfate. State symbols are not required. [2 marks]

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✓ **DONE WHEN** you support pollution-control explanations with balanced equations and recognise their limits.



TERM	PRECISE MEANING
Free radical	A species containing an unpaired electron. Show that electron with a dot.
Homolytic fission	Breaking a covalent bond so that each bonded atom receives one electron from the bonding pair.
Initiation	A step that creates radicals from non-radical species and starts the chain.



11. Follow the two propagation steps



SPEC 3.3.2.4 Write the propagation steps for methane chlorination and show how the radical is regenerated.



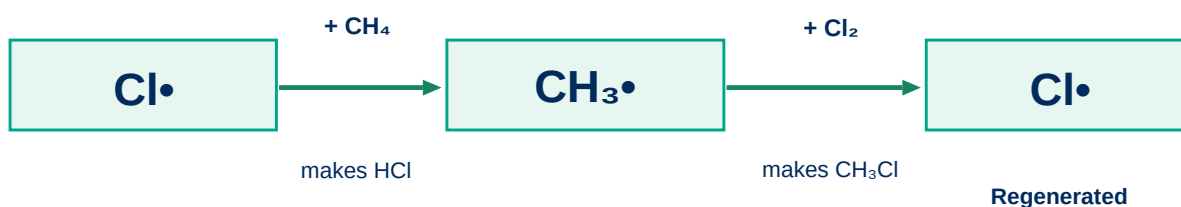
CRACK IT One radical reacts and another radical is formed. Add the two steps to recover the overall substitution equation.

Worked example Methane to chloromethane



One hydrogen atom in methane is replaced by chlorine. This is substitution: an atom or group in a molecule is replaced by another atom or group. The overall equation is not the mechanism; the following steps explain it.

STEP	BALANCED EQUATION	WHAT CHANGES
Propagation 1	$\text{Cl}\cdot + \text{CH}_4 \rightarrow \text{HCl} + \text{CH}_3\cdot$	A chlorine radical removes H; a methyl radical forms.
Propagation 2	$\text{CH}_3\cdot + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}\cdot$	The methyl radical reacts with chlorine; a chlorine radical is regenerated.



$\text{CH}_3\cdot$ is an intermediate: it is made in one step and consumed in the next. $\text{Cl}\cdot$ is consumed in step 1 and regenerated in step 2, so the chain can continue. Each propagation step has one radical on each side.

Worked check Add and cancel

Add both equations. Cancel $\text{CH}_3\cdot$ and $\text{Cl}\cdot$ because each appears once on each side. The net change is $\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}$. This explains why one initiation event can lead to many substitution events.

KEEP THE DOT $\text{CH}_3\cdot$ is a methyl radical, not CH_3^+ . Cl_2 is the molecule in the second propagation step; writing $\text{Cl}\cdot$ there would describe a termination step instead.



TEST IT 11

a) Write both propagation equations for chlorination of ethane to chloroethane. Show every radical dot. [4 marks]

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b) Identify the intermediate in your ethane mechanism and explain why the chain continues. [2 marks]

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✓ **DONE WHEN** you write both propagation steps with balanced atoms and one radical on each side.

12. Terminate the chain and audit the mechanism



SPEC 3.3.2.4 Write termination equations and distinguish initiation, propagation and termination.



CRACK IT Termination removes radicals: two radicals combine to form a non-radical product.

Worked example Three methane termination possibilities



The methyl radicals join through their carbon atoms, forming a new C–C bond. This explains a small amount of ethane in a methane chlorination mixture. Any one such event terminates a chain by removing radicals; it does not instantly stop every chain in the vessel.

STAGE	RADICAL COUNT	IDENTIFY IT BY
Initiation	0 → 2	Radicals are created, for example by UV homolysis.
Propagation	1 → 1	A radical reacts and another radical is produced.
Termination	2 → 0	Two radicals combine; no radical is regenerated.

Worked correction A tempting wrong label



This makes chloromethane, but it is termination. Classify the step by its radical change, not by the name of its product. Propagation producing chloromethane uses Cl_2 and also produces $\text{Cl}\cdot$.

MECHANISM AUDIT Check atoms, radical dots and the named stage. Use ordinary reaction arrows in these equations; do not use full-headed electron-pair curly arrows for radical steps.



TEST IT 12

a) Write two termination equations in ethane chlorination: one forming chloroethane and one formed by combining two ethyl radicals. Name the hydrocarbon in the second equation. [3 marks]

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b) Classify each step and explain your choice: (i) $\text{Br}\cdot + \text{C}_2\text{H}_6 \rightarrow \text{HBr} + \text{C}_2\text{H}_5\cdot$; (ii) $\text{Br}\cdot + \text{Br}\cdot \rightarrow \text{Br}_2$. [2 marks]

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✓ **DONE WHEN** you recognise a step by the radical count and combine carbon radicals without losing atoms.

13. Explain why chlorination gives mixtures



SPEC 3.3.2.4; application Explain further substitution and different substitution positions in larger alkanes.



CRACK IT One substitution does not make the product unreactive. Remaining C–H bonds can react, and larger alkanes may have different H environments.

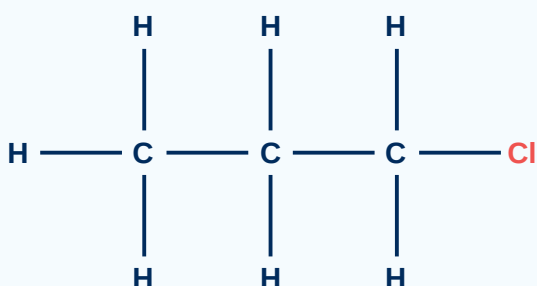
Worked example Further substitution of methane products



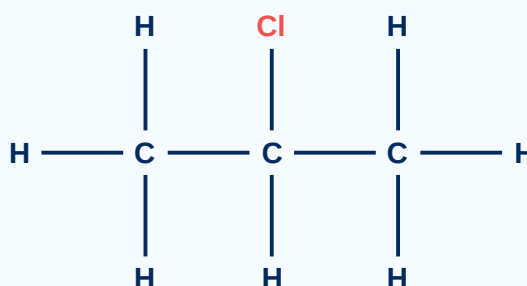
Each arrow above represents one further substitution using Cl_2 under UV light and producing HCl . Chloromethane, dichloromethane, trichloromethane and tetrachloromethane can all occur. A large excess of methane relative to chlorine favours monosubstitution, but does not guarantee a pure product.



Worked example Two positions in propane



1-chloropropane



2-chloropropane

The two end carbons of propane are equivalent, so replacing an H at either end gives 1-chloropropane. Replacing H at the middle carbon gives 2-chloropropane. Counting differently oriented drawings as different compounds would duplicate the same connectivity.

LIMITED SYNTHETIC USE Further substitution and different substitution positions can produce mixtures that need separation. Do not assume all possible products occur in equal amounts.



TEST IT 13

a) Name the two different monochloro products obtainable from butane. Ignore stereoisomers. [2 marks]

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b) Write the overall equation for one further substitution of chloroethane, $\text{C}_2\text{H}_5\text{Cl}$, by chlorine. Give the molecular formula of the organic product and the inorganic product. [2 marks]

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c) Explain how using excess alkane affects monosubstitution and why it does not guarantee purity. [2 marks]

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✓ **DONE WHEN** you explain mixtures using further substitution and distinct carbon positions.

14. Apply the refinery and fuel ideas



SPEC 3.3.2.1–3.3.2.3 Link separation, cracking, combustion and pollution control in a single context.



CRACK IT Name the process first. Then connect the observation to the molecules, the products or a balanced equation.

Worked example Build a linked explanation

A refinery has surplus high-boiling material but needs more alkene feedstock. First isolate suitable heavy fractions by fractional distillation, using boiling-point differences. Then use thermal cracking to break C–C bonds at high temperature and pressure. The high alkene proportion meets the feedstock demand. These are separate physical and chemical operations.

IF THE QUESTION ASKS ABOUT...	USE THIS IDEA
A fraction's position	Temperature gradient → boiling range → condensation height.
Changing the product mix	Cracking conditions → desired products → economic demand.
An equation	Conserve each element; distinguish complete and incomplete combustion.
Cleaner exhaust	Name the pollutant, its source and the relevant removal reaction.

USE THE DATA The table below gives invented refinery data for practice. Use it as evidence rather than reciting an unrelated list of fractions.

FRACTION	BOILING RANGE / °C	SUPPLY / ARBITRARY UNITS	DEMAND / ARBITRARY UNITS
A	40–160	20	35
B	180–280	25	25
C	320–450	55	30



TEST IT 14

a) Which fraction is collected highest in the column? Explain using the data and the temperature gradient. [3 marks]

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b) Use the supply and demand figures to explain why the refinery might crack C. Name the cracking process most appropriate for increasing motor-fuel production. [3 marks]

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c) A sample of $C_{18}H_{38}$ cracks to C_8H_{18} and one type of alkene, C_5H_{10} . Write the balanced equation. [1 mark]

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✓ **DONE WHEN** you build explanations from the supplied evidence and choose the correct process.

15. Apply and check a radical mechanism



SPEC 3.3.2.4; 3.3.1.2 Use the radical mechanism in a new context and correct common errors.



CRACK IT Label the stage, conserve atoms and show every unpaired electron. The number of radical dots helps diagnose the step.

Worked check Why an equation can be balanced but wrong



Atoms balance, but charge does not: neutral reactants cannot give a net negative product here. The chain also needs a chlorine radical to continue. Replace Cl^- with $\text{Cl}\bullet$. An atom count alone is not a complete mechanism check.

MASTERY CHECK	WHAT YOU SHOULD BE ABLE TO DO
Alkanes and fractions	Define saturated hydrocarbon; explain boiling trends and fractional distillation.
Cracking	Compare thermal and catalytic conditions; explain demand; balance products.
Combustion	Balance complete and incomplete equations; explain pollutants and controls.
Chlorination	Explain UV initiation, both propagation steps, termination and mixtures.

For TEST IT 15, focus only on formation of 2-chloropropane from propane. The radical at the middle carbon is written $\text{CH}_3\text{C}\bullet\text{HCH}_3$: the dot belongs to that carbon. Other substitution routes exist, but are not requested here.



TEST IT 15

a) Write the initiation equation and state the condition needed to start chlorination of propane. [2 marks]

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b) Write both propagation equations that form 2-chloropropane, $\text{CH}_3\text{CHClCH}_3$, from propane. Use $\text{CH}_3\text{C}\bullet\text{HCH}_3$ for the intermediate. [4 marks]

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c) Write a termination equation in which this intermediate combines with a chlorine radical. Explain why it is termination. [2 marks]

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d) A student calls the overall reaction "addition". Correct the description and justify it. [2 marks]

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✓ **DONE WHEN** you can explain and apply the entire topic, including an unfamiliar radical substitution.

Answers for TEST IT 1 to 5

Check the explanation as well as the final equation. The marking points below guide these original questions; chemically equivalent wording is acceptable.

TEST IT 1 | 4 marks

- a) A hydrocarbon contains carbon and hydrogen only [1]. Saturated means that all carbon–carbon bonds are single bonds [1].
- b) Molecular: C_7H_{16} [1]. Structural: $CH_3CH_2CH_2CH_2CH_2CH_2CH_3$ or $CH_3(CH_2)_5CH_3$ [1].

TEST IT 2 | 6 marks

- a) Nonane [1]. Its larger molecules have more electrons and stronger overall Van der Waals forces [1], so more energy is needed to overcome these attractions [1].
- b) 2,2-Dimethylbutane is more volatile [1]. Greater branching makes it more compact, with less effective surface contact [1], so its intermolecular attractions are weaker and its boiling point is lower [1].

TEST IT 3 | 4 marks

- a) Q has the higher boiling range [1]. The bottom is hotter than the top [1], and Q condenses at higher temperatures while lower-boiling components remain gaseous and rise further [1].
- b) Several hydrocarbons with similar boiling points are collected together [1].

TEST IT 4 | 5 marks

- a) Repeated condensation and vaporisation occur in the column [1], increasing the proportion of the more volatile component in the vapour reaching the top [1].
- b) The bulb is at the side-arm entrance, in the outgoing vapour [1]. Water enters at the lower port so the jacket fills completely and cools the vapour effectively [1].
- c) Hydrocarbon vapour is flammable; a naked flame could ignite it [1].

TEST IT 5 | 6 marks

- a) Catalytic cracking [1]; a zeolite catalyst [1]; slight pressure [1].
- b) It converts surplus heavy fractions into more valuable products in greater demand [1]. It supplies useful smaller fuel molecules or alkene feedstock for chemical manufacture [1].
- c) A carbon–carbon bond [1].

Answers for TEST IT 6 to 10

TEST IT 6 | 7 marks

- a) Carbon: $11 - 7 = 4$; hydrogen: $24 - 16 = 8$ [1]. X is C_4H_8 [1].
- b) Hydrogen: $34 = 4a + 18$, so $a = 4$ [1]. Carbon: $16 = 2(4) + x$, so $x = 8$ [1]. $C_{16}H_{34} \rightarrow 4C_2H_4 + C_8H_{18}$ [1].
- c) Cracking changes molecular connectivity by breaking and forming covalent bonds [1]. Fractional distillation separates existing molecules without changing their identities [1].

TEST IT 7 | 7 marks

- a) $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$. Correct products [1], carbon and hydrogen balance [1], oxygen balance with smallest whole-number coefficients [1].
- b) $C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$. Correct carbon and hydrogen coefficients [1]; oxygen coefficient [1].
- c) Breaking reactant bonds requires energy [1], but making the product bonds releases more energy than this, giving a net release [1].

TEST IT 8 | 6 marks

- a) $2C_2H_6 + 5O_2 \rightarrow 4CO + 6H_2O$. Correct carbon/hydrogen balance [1]; correct oxygen balance [1].
- b) $C_3H_8 + 2O_2 \rightarrow 3C + 4H_2O$. Correct carbon/hydrogen balance [1]; correct oxygen balance [1].
- c) N_2 and O_2 enter with the air [1] and react at the high engine temperature [1].

TEST IT 9 | 6 marks

- a) $4CO + 2NO_2 \rightarrow 4CO_2 + N_2$. Carbon and nitrogen balanced [1]; oxygen balanced [1].
- b) Basic MgO reacts with acidic SO_2 [1]. $MgO + SO_2 \rightarrow MgSO_3$ [1].
- c) $2CaCO_3 + 2SO_2 + O_2 \rightarrow 2CaSO_4 + 2CO_2$. Correct products [1]; balanced equation [1].

TEST IT 10 | 5 marks

- a) $Br_2 \rightarrow 2Br\cdot$ [1], using UV light [1].
- b) A radical is a species with an unpaired electron [1]. Each bonded atom receives one electron from the shared pair [1].
- c) This shows heterolytic fission into ions, not homolytic fission into radicals [1].

Answers for TEST IT 11 to 15

TEST IT 11 | 6 marks

a) $\text{Cl}\cdot + \text{CH}_3\text{CH}_3 \rightarrow \text{HCl} + \text{CH}_3\text{CH}_2\cdot$ [2: correct species and balanced radical notation]. $\text{CH}_3\text{CH}_2\cdot + \text{Cl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{Cl} + \text{Cl}\cdot$ [2: correct species and balanced radical notation].

b) $\text{CH}_3\text{CH}_2\cdot$ is the intermediate [1]. A chlorine radical is regenerated in the second propagation step and can react with another ethane molecule [1].

TEST IT 12 | 5 marks

a) $\text{CH}_3\text{CH}_2\cdot + \text{Cl}\cdot \rightarrow \text{CH}_3\text{CH}_2\text{Cl}$ [1]. $\text{CH}_3\text{CH}_2\cdot + \cdot\text{CH}_2\text{CH}_3 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ [1], butane [1].

b) (i) Propagation: one radical reacts and another forms [1]. (ii) Termination: two radicals combine with no radical product [1].

TEST IT 13 | 6 marks

a) 1-Chlorobutane and 2-chlorobutane [1 each]. Positions 3 and 4 duplicate positions 2 and 1.

b) $\text{C}_2\text{H}_5\text{Cl} + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_4\text{Cl}_2 + \text{HCl}$. Correct organic formula [1]; HCl and balanced equation [1]. Different dichloro isomers are possible.

c) It favours reaction with the original alkane rather than with substituted products [1], but further substitution can still occur, so other products may remain [1].

TEST IT 14 | 7 marks

a) A [1], because it has the lowest boiling range [1] and condenses in the coolest, upper region while higher-boiling fractions condense lower down [1].

b) C has surplus supply of 25 units, while A has a shortage of 15 units [1]. Cracking can convert some heavy material into more valuable smaller fuel molecules [1]. Catalytic cracking [1].

c) $\text{C}_{18}\text{H}_{38} \rightarrow \text{C}_8\text{H}_{18} + 2\text{C}_5\text{H}_{10}$ [1].

TEST IT 15 | 10 marks

a) $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$ [1]; UV light [1].

b) $\text{Cl}\cdot + \text{CH}_3\text{CH}_2\text{CH}_3 \rightarrow \text{HCl} + \text{CH}_3\dot{\text{C}}\text{HCH}_3$ [2]. $\text{CH}_3\dot{\text{C}}\text{HCH}_3 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CHClCH}_3 + \text{Cl}\cdot$ [2]. Each equation must conserve atoms and show one radical on each side.

c) $\text{CH}_3\dot{\text{C}}\text{HCH}_3 + \text{Cl}\cdot \rightarrow \text{CH}_3\text{CHClCH}_3$ [1]. Two radicals are consumed and no radical is produced [1].

d) It is free-radical substitution [1]: a hydrogen atom in propane is replaced by chlorine [1].

Your final checks

Every equation conserves atoms. Propagation regenerates a radical; termination removes radicals. Cracking changes molecules; fractional distillation separates them. Boiling overcomes Van der Waals forces between molecules.

Specification reference

This pack covers AQA 7405 sections 3.3.2.1–3.3.2.4. Introductory radical notation links to 3.3.1.2. Branching and boiling explanations connect to 3.1.3.7. Larger-alkane and bromine questions apply the taught method; methane chlorination is the named AQA example.

<https://www.aqa.org.uk/subjects/chemistry/a-level/chemistry-7405/specification/subject-content/organic-chemistry>