Cambridge IGCSE · Chemistry 0620 · Notes

Fuels and alkanes

Read online at **pastopic.com/cambridge/chemistry-0620/notes/fuels-and-alkanes**

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Read first: **Organic formulae, functional groups and naming**, **Formulae and equations**

What you need to know

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

1. **Name the three fossil fuels**: coal, natural gas and petroleum.
2. **Name methane** as the main substance in natural gas.
3. **State what a hydrocarbon is**: a compound that contains carbon and hydrogen only.
4. **State that petroleum is a mixture of hydrocarbons.**
5. **Describe how fractional distillation separates petroleum** into useful fractions.
6. **Describe how the fractions change from the bottom to the top of the fractionating column**: the chains get shorter, the volatility gets higher, the boiling points get lower and the viscosity gets lower.
7. **Name the use of each fraction**: refinery gas for heating and cooking; gasoline (petrol) for cars; naphtha as a chemical feedstock; kerosene (paraffin) for jet fuel; diesel oil (gas oil) for diesel engines; fuel oil for ships and home heating; lubricating oil for lubricants, waxes and polishes; bitumen for making roads.
8. **State that alkanes are saturated hydrocarbons** whose bonds are all single covalent bonds.
9. **Describe alkanes as generally unreactive**, apart from burning (combustion) and substitution by chlorine.
10. **Extended only: state what a substitution reaction is**: one atom or group of atoms is replaced by another atom or group of atoms.
11. **Extended only: describe how alkanes react with chlorine**: a photochemical reaction in which ultraviolet light provides the activation energy, E_{a}. Draw the structural or displayed formulae of the products when one hydrogen atom is replaced (monosubstitution).

Questions on this topic also ask for the general formula of the alkanes, $\mathrm{C}_n\mathrm{H}_{2n+2}$ (from the Organic formulae note), and for the products of complete and incomplete combustion, so both are here too. Cracking is listed under the alkenes (syllabus 11.5), but it is asked inside petroleum questions, so this note teaches what those questions need: what cracking is, its conditions, its products, why it is done and how to balance its equations.

Understand it

Fuels and fossil fuels

A **fuel** is a substance that releases heat energy when it burns. Burning is exothermic: the fuel gives energy out, it does not take energy in. Methane, butane, gasoline, coal, ethanol and hydrogen are all fuels. Oxygen is **not** a fuel (it is what a fuel burns in), and nor are unreactive gases such as nitrogen, helium or argon.

Fossil fuels formed over millions of years from the remains of ancient living things. There are three: **coal** (a solid), **natural gas** and **petroleum** (crude oil, a liquid). Anything made from petroleum, such as gasoline or kerosene, is also fossil-fuel based. Ethanol (made from plants by fermentation) and hydrogen are fuels but **not** fossil fuels.

Natural gas is mostly **methane**, $\mathrm{CH_4}$. It also contains a smaller amount of other alkanes (ethane, propane) and a little of substances that are not hydrocarbons. On a bar chart or pie chart of natural gas, methane is by far the largest share.

Hydrogen is a fuel too. It burns to give only water, so it releases no carbon dioxide, but it is a gas that is hard to store. It can also react with oxygen in a fuel cell to produce an electric current (see the Electrochemistry note).

Hydrocarbons and petroleum

A **hydrocarbon** is a **compound** made of **carbon and hydrogen only**. The word "only" is the point: ethanol contains carbon and hydrogen too, but it also contains oxygen, so it is not a hydrocarbon.

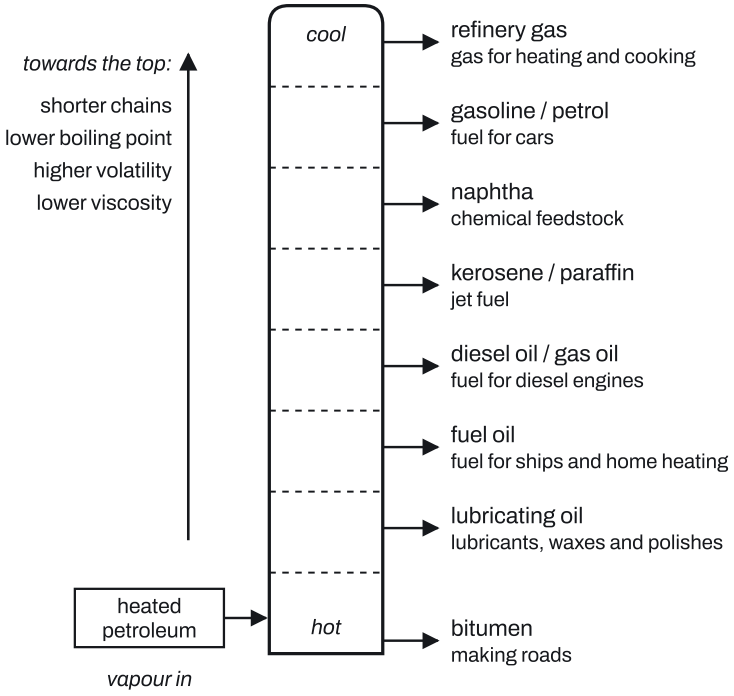
Petroleum is a mixture of many different hydrocarbons, mostly alkanes, with chains from one carbon atom to very long chains. Because it is a mixture, not one compound, it can be separated by a physical process, and every compound in it contains carbon and hydrogen.

Fractional distillation of petroleum

The hydrocarbons in petroleum have **different boiling points**: the longer the chain, the stronger the forces between the molecules and the higher the boiling point. Fractional distillation uses this difference. It does not separate every compound; it gives **fractions**, groups of hydrocarbons with similar chain lengths and boiling points.

1. The petroleum is **heated** until most of it turns to **vapour**, and the vapour enters near the bottom of a tall **fractionating column**.
2. The column has a **temperature gradient**: it is **hot at the bottom and cool at the top**.
3. The vapour rises. As it rises it cools, and each hydrocarbon **condenses** (turns back to a liquid) when it reaches a height where the temperature is below its boiling point.
4. The liquids collect on trays at different heights and are **piped off** as the fractions.

5. The molecules with the **shortest chains and lowest boiling points** stay as gases all the way up and leave at the **top** (refinery gas). The **longest chains**, with the highest boiling points, never boil and leave at the **bottom** as a thick liquid (bitumen).



How the fractions change up the column

From the **bottom to the top** of the column:

Property	Change towards the top	What it means
chain length	decreases	fewer carbon atoms per molecule, smaller molecules
boiling point	lower	the fraction boils (and condenses) at a lower temperature
volatility	higher	it evaporates more easily
viscosity	lower	it is runnier and flows more easily

All four go together: short chains mean weak forces between molecules, so a low boiling point, easy evaporation and a runny liquid. Read the table the other way for the bottom: bitumen has the longest chains, the highest boiling point, the lowest volatility and the highest viscosity.

Learn the order of the eight fractions from the top: **refinery gas, gasoline, naphtha, kerosene, diesel oil, fuel oil, lubricating oil, bitumen**. One way is a sentence made from the first letters, such as "**R**eal **G**ardeners **N**ever **K**eep **D**ead **F**lowers **L**ying **B**ehind". Everything else (which is more volatile, which has longer chains) follows from the order.

Alkanes

The **alkanes** are the homologous series of hydrocarbons with the general formula $\mathrm{C}_n\mathrm{H}_{2n+2}$: methane CH_4, ethane $\mathrm{C}_2\mathrm{H}_6$, propane $\mathrm{C}_3\mathrm{H}_8$, butane $\mathrm{C}_4\mathrm{H}_{10}$, and so on. Their names end in **-ane**.

- **Bonding:** every bond is a **single covalent bond** (C–C and C–H). There are no double bonds and no ionic bonds. A methane molecule has four C–H single bonds; an ethane molecule has seven single bonds, so 14 shared electrons.
- **Saturated:** all their carbon–carbon bonds are single, so alkanes are **saturated hydrocarbons**. Unsaturated hydrocarbons (alkenes, names ending in **-ene**, formula $\mathrm{C}_n\mathrm{H}_{2n}$) have a C=C double bond.
- **Reactivity:** alkanes are **generally unreactive**. They have no functional group. They do **not** decolourise aqueous bromine (it stays orange), and they do not form polymers. The only reactions you need are **combustion** and **substitution by chlorine**.
- **Physical properties:** the small alkanes (methane to butane) are gases at room temperature; all alkanes are insoluble in water. As the chain gets longer, the boiling point, melting point and viscosity increase and the volatility decreases.

Combustion

Complete combustion happens in plenty of oxygen (air). The carbon ends up in **carbon dioxide** and the hydrogen in **water**:

$$\mathrm{methane} + \mathrm{oxygen} \rightarrow \mathrm{carbon\ dioxide} + \mathrm{water}$$

$$\mathrm{CH_4} + 2\mathrm{O_2} \rightarrow \mathrm{CO_2} + 2\mathrm{H_2O}$$

To balance the equation for any hydrocarbon: balance C first (that many CO_2), then H (half as many $\mathrm{H}_2\mathrm{O}$ as H atoms), then O last. If you need an odd number of O atoms, double everything. For propane: $\mathrm{C}_3\mathrm{H}_8 + 5\mathrm{O}_2 \rightarrow 3\mathrm{CO}_2 + 4\mathrm{H}_2\mathrm{O}$.

Incomplete combustion happens when there is **not enough oxygen** (a limited supply of air). Some carbon ends up as **carbon monoxide**, a toxic gas, or as **carbon** (soot); water still forms. For example, $2\mathrm{CH}_4 + 3\mathrm{O}_2 \rightarrow 2\mathrm{CO} + 4\mathrm{H}_2\mathrm{O}$. Hydrogen gas is never a product.

The carbon dioxide from burning fuels is a greenhouse gas: it adds to **global warming and climate change**. Fuels that contain carbon (methane, gasoline, coal, ethanol) all release carbon dioxide; hydrogen does not.

Cracking

Fractional distillation gives more of the long-chain fractions than people need, and not enough of the short-chain ones such as gasoline. **Cracking** fixes this: it **breaks down long-chain alkanes into shorter-chain molecules**.

- **Conditions:** a **high temperature** and a **catalyst**.
- **Products:** shorter-chain **alkanes**, **alkenes** (such as ethene) and sometimes **hydrogen**.

- **Why it is done:** the shorter-chain products are **more in demand** and **more useful**: shorter alkanes are used as fuels such as gasoline, and alkenes are used to make polymers (plastics) and other chemicals such as ethanol.
- Cracking is a **thermal decomposition**: a substance broken down into two or more simpler substances by heating.

No atoms are gained or lost, so the carbon and hydrogen atoms on each side of a cracking equation must balance:

$$\mathrm{C_{14}H_{30}} \rightarrow \mathrm{C_6H_{14}} + 4\mathrm{C_2H_4}$$

C: $14 = 6 + 8$; H: $30 = 14 + 16$. The alkane that goes in fits $\mathrm{C}_n\mathrm{H}_{2n+2}$; at least one product is an alkene, $\mathrm{C}_n\mathrm{H}_{2n}$. Alkenes are unsaturated, which is what makes them reactive enough to be turned into plastics (see the Alkenes note).

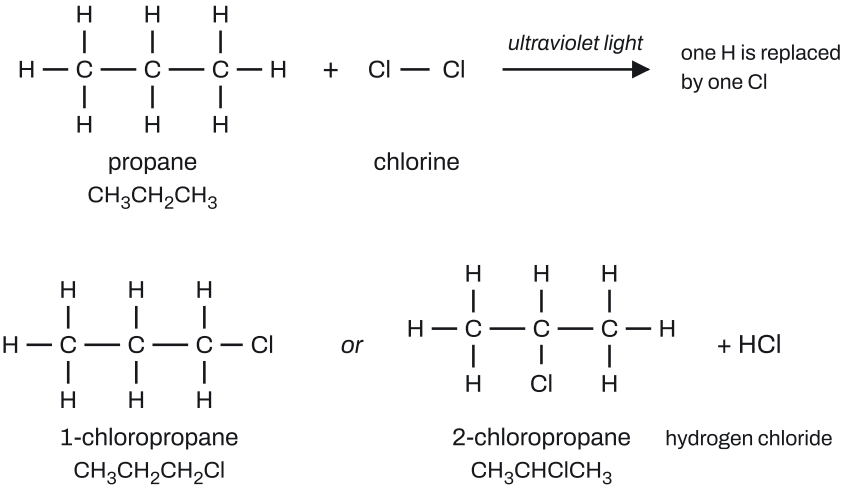
Substitution by chlorine

In ultraviolet light (sunlight works too), an alkane reacts with chlorine. One hydrogen atom in the alkane is **replaced** by a chlorine atom, and the hydrogen atom that was removed joins the other chlorine atom as **hydrogen chloride**:

$$\mathrm{CH_4} + \mathrm{Cl_2} \rightarrow \mathrm{CH_3Cl} + \mathrm{HCl} \qquad \mathrm{C_2H_6} + \mathrm{Cl_2} \rightarrow \mathrm{C_2H_5Cl} + \mathrm{HCl}$$

- It is a **substitution** reaction: a hydrogen atom is replaced by a chlorine atom. It is **not** addition; there are two products, and nothing is added across a double bond.
- The condition is **ultraviolet light**. No acid or nickel catalyst is used.
- **Extended only:** the definition: in a substitution reaction one atom or group of atoms is replaced by another atom or group of atoms.
- **Extended only:** it is a **photochemical** reaction: it needs light. The **ultraviolet light provides the activation energy**; it is not a catalyst.
- The products are a **chloroalkane** and **hydrogen chloride**, HCl. Hydrogen, $\mathrm{H_2}$, is never formed. In a dry gas HCl is hydrogen chloride, not hydrochloric acid.
- The reaction can carry on and replace more hydrogen atoms: methane can go on to $\mathrm{CH_2Cl_2}$, $\mathrm{CHCl_3}$ and $\mathrm{CCl_4}$, with one HCl each time. So methane gives **four** different chlorine compounds with one carbon atom. For drawing, the syllabus asks only for monosubstitution (one Cl).

Extended only: where can the chlorine go? In a chain of three or more carbons, the Cl can replace a hydrogen on an end carbon or on a middle carbon, and these give **structural isomers**: compounds with the **same molecular formula** but **different structural formulae**. Propane gives two.



A Cl on the **left** end carbon and one on the **right** end carbon give the **same** compound, just drawn the other way round. To count the different monosubstituted products of an unbranched alkane, count the different carbon positions from one end to the middle:

Alkane	Different places for Cl	Products $C_nH_{2n+1}Cl$
methane, ethane	1 (all H alike)	1
propane, butane	2 (end carbon, next carbon in)	2
pentane, hexane	3	3

Key facts and formulas

Nothing in this topic is given in the exam (the paper gives only the Periodic Table), so everything below is to learn.

Formula	Status
Alkanes: C_nH_{2n+2}, so $M_r = 14n + 2$	Learn it
Complete combustion: hydrocarbon + oxygen → carbon dioxide + water	Learn it
Alkane complete combustion: $C_nH_{2n+2} + \frac{3n+1}{2} O_2 \rightarrow n\,CO_2 + (n+1)\,H_2O$ (double it when n is even)	Learn it (or balance C, H, then O)
Incomplete combustion (limited oxygen): carbon monoxide and/or carbon, and water	Learn it
Extended: $C_nH_{2n+2} + Cl_2 \rightarrow C_nH_{2n+1}Cl + HCl$ (ultraviolet light)	Learn it
Fractions from the top: refinery gas, gasoline, naphtha, kerosene, diesel oil, fuel oil, lubricating oil, bitumen	Learn it
Up the column: shorter chains, lower boiling point, higher volatility, lower viscosity	Learn it

Formula	Status
Hydrocarbon: a compound of carbon and hydrogen only	Learn it
Saturated: all C–C bonds single	Learn it

How to do it

In the questions we have tagged for this topic (156 questions, 2021–2025, on all four papers), the types came up this often. 39 of the 156 questions mix types, so the counts add up to more than 156.

Question type	Questions
Alkanes and chlorine: substitution	34
Match a petroleum fraction to its use	32
Combustion of alkanes and other fuels	31
Describe or identify alkanes	28
Fossil fuels, natural gas and what counts as a fuel	27
Trends down the fractionating column	19
Cracking and the route from petroleum to plastics	19
General formula and trends in the alkane series	13
Describe or name fractional distillation	12
Define a hydrocarbon	7

1. Alkanes and chlorine: substitution (34 questions)

Core questions (multiple choice on Paper 1, short answers on Paper 3) ask for the type of reaction, the condition, the products and a drawing of chloromethane or chloroethane. Extended questions add the definition, "photochemical", what the light does, equations and isomers.

1. **Type of reaction**: substitution (a hydrogen atom is replaced by a chlorine atom). Never addition.
2. **Condition**: ultraviolet light (sunlight is accepted). Not a catalyst, not an acid, not heat alone.
3. **Extended only: what the light does**: it provides the activation energy. A reaction that needs light is **photochemical**; "it needs (ultraviolet) light" is the meaning.
4. **Products**: the chloroalkane and **hydrogen chloride**. Write the name "hydrogen chloride" when a name is asked.
5. **Equation**: take one H off the alkane and put one Cl on; the other Cl pairs with the H: $\mathrm{C_4H_{10} + Cl_2 \rightarrow C_4H_9Cl + HCl}$.

Variations you will meet:

- **Pick the right equation** from four. Reject any with H_2 as a product, any with an alkene (C_nH_{2n}) as the reactant, any with HCl as the reactant, and any that is not balanced.
- **"Which substance is not produced?"** Hydrogen, H_2. Chloroalkanes with more than one Cl can form, and so can HCl.
- **"How many products with one carbon atom?"** Four: CH_3Cl, CH_2Cl_2, $CHCl_3$ and CCl_4.
- **"Which reagent reacts with this alkane, and how?"** Chlorine, by substitution (steam and bromine react with alkenes by addition, not with alkanes).
- **Draw the product** (Core: chloromethane or chloroethane): the alkane's displayed formula with one H swapped for Cl.
- **Extended: draw and name two isomers** from propane or butane. Put the Cl on an end carbon, then on the second carbon: 1-chloropropane $CH_3CH_2CH_2Cl$ and 2-chloropropane $CH_3CHClCH_3$; 1-chlorobutane and 2-chlorobutane. Mark schemes give a mark for each correct structure and each correct name. Don't draw the same isomer twice (Cl on the other end) and don't add a branch.
- **Extended: count the isomers** (the table in "Understand it"), and **define structural isomers**: the same molecular formula but different structural formulae.
- **Mixed questions**: a statement that the Cl in a chloroalkane is covalently bonded is correct; HCl gas turns damp blue litmus red, not red litmus blue.

2. Match a petroleum fraction to its use (32 questions)

1. Learn the eight pairs in "What you need to know" word for word: they are exactly what the mark scheme wants.
2. Use the words **as the syllabus puts them**: "fuel for cars", not just "fuel" or "cars"; "jet fuel", not "fuel for planes" when kerosene is the answer; "making chemicals" or "chemical feedstock" for naphtha.

Variations you will meet:

- **Multiple-choice rows**: check every row; distractors swap uses between fractions (bitumen as ship fuel, kerosene for waxes, refinery gas for lubrication).
- **Line matching**: three fractions, three uses; all three right is 2 marks, one or two right is 1.
- **Fill a table**: given the use, name the fraction ("waxes and polishes" → lubricating oil), or given the fraction, give its use.
- **"Using only the fractions shown"**: the question lists some fractions. Pick from that list only.
- **Two uses at once**: reducing friction in engines (lubricating oil) and fuel in cars (gasoline).

3. Combustion of alkanes and other fuels (31 questions)

1. **Complete combustion** (excess or plenty of oxygen): carbon dioxide **and** water. Two marks: one for each product.
2. **Word equation**: alkane + oxygen → carbon dioxide + water.
3. **Symbol equation**: balance C, then H, then O; double if you need half an O_2.

4. **Incomplete combustion** (not enough oxygen): carbon monoxide and/or carbon (soot), and water. "Define incomplete combustion": burning in a **limited supply of oxygen** (or air).

Variations you will meet:

- **Pick the balanced equation** for complete combustion: the reactant must be the alkane named, the products $\mathrm{CO_2}$ and $\mathrm{H_2O}$ only (not CO, not $\mathrm{H_2}$), and every element must balance. $2\mathrm{C_2H_6} + 7\mathrm{O_2} \rightarrow 4\mathrm{CO_2} + 6\mathrm{H_2O}$ is the ethane one.
- **Which fuels release carbon dioxide?** Any fuel containing carbon (methane, gasoline, coal); not hydrogen.
- **Which fuel is a gas and gives two products?** Read the boiling points: a gas at room temperature has a boiling point below room temperature; hydrogen gives only one product (water), so a gaseous hydrocarbon such as methane is the answer.
- **An alcohol fuel** (ethanol, hexanol) burns completely to carbon dioxide and water too.
- **Adverse effect of the carbon dioxide**: it causes (increased) global warming or climate change. Of carbon monoxide: it is toxic.
- **Letter questions**: an equation such as methane + oxygen → carbon monoxide + water is **incomplete** combustion.

4. Describe or identify alkanes (28 questions)

1. **Type of bonding** in an alkane: (single) covalent.
2. **Why saturated**: all the carbon–carbon bonds are single bonds.
3. **Reactions**: unreactive except combustion and substitution by chlorine. "State two types of reaction of alkanes": combustion and substitution.
4. **Why a structure is an alkane**: it contains only carbon and hydrogen **and** has only single bonds (fits $\mathrm{C}_n\mathrm{H}_{2n+2}$).

Variations you will meet:

- **Multiple-choice statements**: true ones are "saturated", "burn in oxygen", "react with chlorine by substitution", "only single bonds", "four single covalent bonds in methane"; false ones are "contain oxygen", "contain double bonds", "ionic bonds", "very reactive", "decolourise aqueous bromine", "form polymers", "longer chains are more volatile".
- **Pick the alkane** (or "the compound in the same series as ethane", or "the saturated hydrocarbon", or "unreactive except for burning") from displayed formulae: only C and H, only single bonds.
- **Draw ethane**: two carbons joined by a single bond, three H on each, every bond drawn.
- **Identify the unsaturated hydrocarbon** in a table: its name ends in **-ene**, or its formula fits $\mathrm{C}_n\mathrm{H}_{2n}$ instead of $\mathrm{C}_n\mathrm{H}_{2n+2}$. Give that as the reason.
- **Properties of methane**: a gas, insoluble in water, no colour change with aqueous bromine.
- **Count shared electrons**: count the single bonds and double: ethane has 7 bonds, so 14 shared electrons. An alkane $\mathrm{C}_n\mathrm{H}_{2n+2}$ has $3n + 1$ bonds.

5. Fossil fuels, natural gas and what counts as a fuel (27 questions)

Almost all Core.

1. **Fossil fuels**: coal, natural gas, petroleum (and fuels made from petroleum, such as gasoline and kerosene). Not ethanol, not hydrogen.
2. **Main constituent of natural gas**: methane. On a chart, the biggest bar or sector. Not hydrogen and not nitrogen: those answers come from confusing natural gas with air.
3. **Why a substance is used as a fuel**: it releases heat energy when it burns.

Variations you will meet:

- **Which are fuels?** Methane, butane, hydrogen, coal, ethanol. Not oxygen, argon, helium or nitrogen.
- **A solid fuel**: coal. **A gaseous fuel**: methane (or hydrogen).
- **Statements about fuels**: hydrogen is a fuel but hard to store; hydrogen and oxygen can give an electric current in a fuel cell; burning releases energy (it is not taken in); radioactive isotopes are **not** burned; heat is not only produced by burning fuels; methane gives carbon dioxide as well as water.
- **Letter questions** ("which structure is the main constituent of natural gas?"): the displayed formula of methane, $\mathrm{CH_4}$.

6. Trends down the fractionating column (19 questions)

1. Put the fractions in order, top to bottom: refinery gas, gasoline, naphtha, kerosene, diesel oil, fuel oil, lubricating oil, bitumen.
2. **Higher up** means shorter chains, lower boiling point, higher volatility, lower viscosity. **Lower down** means the opposite.
3. Answer the comparison from the order.

Variations you will meet:

- **"Name the fraction with the highest/lowest boiling point, longest/shortest chains, most/least volatile, most viscous"**: the bottom or top of the list you are **given**. If refinery gas is not in the list, the top one is gasoline; if bitumen is missing, the bottom one is lubricating oil.
- **"Draw an X where …"**: highest boiling point, lowest volatility, highest viscosity or longest chains all mean the **bottom** of the column (where bitumen leaves). Put the X inside the column at that level.
- **"Name the fraction labelled A"**: find the gap in the order, for example the fraction between naphtha and diesel oil is kerosene.
- **Put fractions in order of increasing boiling point**: read the order from the top down.
- **Statements comparing two fractions**: fuel oil is more viscous than diesel oil (true); refinery gas is less volatile than gasoline (false).
- **Three unnamed fractions described in words** ("X is more viscous than Z; Y has a higher boiling point than X"): rank them from bottom to top (here Y, X, Z), then read off the longest chains (Y) and the most volatile (Z).

- **Compounds and their boiling points**: the lowest boiling point condenses at the top; the highest at the bottom.
- **Molecules at the top**: small, with low boiling points. A molecule of methane (in refinery gas) has five atoms.

7. Cracking and the route from petroleum to plastics (19 questions)

1. **Name it**: the process that breaks **long-chain** hydrocarbons into **shorter-chain** molecules is **cracking**. It is not fractional distillation, which only separates.
2. **"State the meaning of cracking"**: breaking down long-chain hydrocarbons (alkanes) into shorter-chain hydrocarbons, using heat. Say "long-chain" and "shorter-chain"; "breaking down petroleum" is not enough.
3. **Conditions** (1 mark each): high temperature, and a catalyst.
4. **Products**: shorter-chain alkanes, alkenes and hydrogen. A "complete the sentence" question wants alkenes or hydrogen.
5. **Reason**: the products are more in demand, or more useful (shorter alkanes as fuels, alkenes to make polymers).
6. **Balance or complete the equation**: count C and H on the left, take away what is already on the right, and what is left is the missing product. For $\mathrm{C_{18}H_{38}} \rightarrow \mathrm{C_{10}H_{22}} + ?$: C $18 - 10 = 8$, H $38 - 22 = 16$, so $\mathrm{C_8H_{16}}$, an alkene. If the only products are named (for example an alkane and ethene), write their formulae, then choose the number of ethene molecules that balances C and H.

Variations you will meet:

- **"Cracking is an example of thermal decomposition. State the meaning"**: a substance broken down into simpler substances by heating. Define both words: "heat" and "break down".
- **Name the process** that makes alkenes and hydrogen from large alkanes: cracking.
- **The route to a plastic** such as poly(ethene): petroleum → **fractional distillation** (gives a fraction of saturated, long-chain alkanes) → **cracking** (gives an unsaturated alkene such as ethene) → **polymerisation** (gives the plastic).
- **Which compounds could form when an alkane is cracked?** Only ones with fewer carbon atoms, made of C and H only: shorter alkanes, alkenes, hydrogen. Not alcohols, acids or esters.

8. General formula and trends in the alkane series (13 questions)

1. **State** the general formula: $\mathrm{C_nH_{2n+2}}$, with "2n+2" as one subscript.
2. **Use it**: an alkane with n carbons has $2n + 2$ hydrogens. With 20 carbons: $\mathrm{C_{20}H_{42}}$.
3. **Trend**: boiling point (and melting point) increases as the chain gets longer. **Extended**: viscosity also increases and volatility decreases.
4. **Predict a missing value** from a table: give a value **between** its two neighbours, not equal to either.

Variations you will meet:

- **Pick the pair of alkanes** from formula pairs: check $H = 2C + 2$ for both formulae.
- **Name the alkane with a given number of H atoms**, for example six H: $2n + 2 = 6$, so $n = 2$, ethane.
- **Extended: characteristics of the series** (other than any listed in the question): the same general formula, and each member differs from the next by a $-\mathrm{CH_2}-$ unit. Also a trend in physical properties and similar chemical properties. Alkanes have no functional group.
- **The next member of a table**: add $\mathrm{CH_2}$ to the formula, and pick a boiling point **higher** than the last one given.

9. Describe or name fractional distillation (12 questions)

1. **Name** the process: fractional distillation. Not cracking, filtration, chromatography or "distillation" alone. Petroleum is a **mixture**, so it can be separated.
2. **The property** it depends on: the hydrocarbons have **different boiling points**.
3. **Describe how it works.** Mark schemes list these points and give 1 or 2 marks for them (one 4-mark version gave 1 mark for the name and 1 mark each for any three points), so give all four:
   - the petroleum is **heated / vaporised**;
   - the column has a **temperature gradient**: hot at the bottom, cool at the top;
   - each fraction **condenses** at the height where the temperature matches its boiling point; smaller molecules rise further up;
   - the fractions are **piped off** as liquids at different heights.

Variation: a four-mark "outline" asks for the technique, the property and a description; answer in that order, one point per line, so each mark is easy to find.

10. Define a hydrocarbon (7 questions)

1. **Definition**: a **compound** containing **carbon and hydrogen only**. "Only" is always needed. When the definition is worth 2 marks, "compound" earns the second one, so always write both.
2. **Why both alkanes and alkenes are hydrocarbons**: they contain only carbon and hydrogen atoms.
3. **Which elements are in every compound in petroleum?** Carbon and hydrogen (not oxygen).

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

Hexane, $\mathrm{C_6H_{14}}$, is one of the hydrocarbons in gasoline.

(a) Use the general formula of the alkanes to show that hexane is an alkane. **[1]**

(b) Hexane burns completely in a plentiful supply of air. Write the balanced symbol equation for this reaction. **[2]**

(c) In a car engine some of the hexane burns in a limited supply of air.

(i) Name the toxic gas that can form. **[1]**

(ii) Name one other product of this incomplete combustion. **[1]**

(d) State one environmental problem caused by the carbon dioxide produced when fuels such as hexane burn. **[1]**

(a) For $n = 6$ the general formula $\mathrm{C_nH_{2n+2}}$ gives $2(6) + 2 = 14$ hydrogen atoms, which matches $\mathrm{C_6H_{14}}$. **B1**

(b) Products carbon dioxide and water: **M1** for $\mathrm{CO_2}$ and $\mathrm{H_2O}$ as the only products.

Balance C: $6\mathrm{CO_2}$. Balance H: $14 \div 2 = 7\mathrm{H_2O}$. Oxygen atoms needed: $12 + 7 = 19$, which is $9\frac{1}{2}\ \mathrm{O_2}$, so double everything:

$$2\mathrm{C_6H_{14}} + 19\mathrm{O_2} \rightarrow 12\mathrm{CO_2} + 14\mathrm{H_2O}$$

A1 for the balanced equation.

(c)(i) Carbon monoxide. **B1**

(ii) Water (or carbon, as soot). **B1**

(d) It adds to global warming, causing climate change. **B1**

Example 2

Petroleum is separated into fractions in an oil refinery.

(a) Explain why petroleum can be separated by fractional distillation. **[2]**

(b) Describe how the fractionating column separates the petroleum into fractions. **[3]**

(c) One fraction is collected just below the kerosene fraction. Name this fraction and give its use. **[2]**

(d) Compare the fuel oil fraction with the gasoline fraction. State which one is more viscous and which one is more volatile. **[2]**

(a) Petroleum is a mixture of hydrocarbons **B1**, which have different boiling points. **B1**

(b) Any three of: the petroleum is heated so that it vaporises **B1**; the column is hot at the bottom and cool at the top **B1**; each fraction condenses when it reaches the height where the temperature is below its boiling point **B1**; the liquid fractions are piped off at different heights **B1**.

(c) Diesel oil (gas oil) **B1**, used as fuel for diesel engines. **B1**

(d) Fuel oil leaves lower down the column, so its chains are longer: fuel oil is more viscous **B1**; gasoline leaves higher up, so it is more volatile. **B1**

Example 3 (Extended)

Pentane, $\mathrm{C_5H_{12}}$, is an unbranched alkane. It reacts with chlorine.

(a) State the condition needed and explain why the condition is needed. **[2]**

(b) One hydrogen atom in pentane is replaced by one chlorine atom. Write the symbol equation for this reaction. **[2]**

(c) Name this type of reaction. **[1]**

(d) Determine how many different organic products with the formula $\mathrm{C_5H_{11}Cl}$ can form, and give the structural formula of each. **[3]**

(a) Ultraviolet light **B1**, which provides the activation energy for the reaction **B1**.

(b) $\mathrm{C_5H_{12} + Cl_2 \rightarrow C_5H_{11}Cl + HCl}$. **M1** for HCl as the second product, **A1** for the whole equation.

(c) Substitution (it is also photochemical). **B1**

(d) The chain is $\mathrm{C1–C2–C3–C4–C5}$. Carbon 1 is the same as carbon 5, and carbon 2 is the same as carbon 4, so there are **three** different places: **B1** for 3.

$\mathrm{CH_2ClCH_2CH_2CH_2CH_3}$, $\mathrm{CH_3CHClCH_2CH_2CH_3}$ and $\mathrm{CH_3CH_2CHClCH_2CH_3}$. **B1** for any two correct, **B1** for the third. (A Cl on carbon 4 is the same as the second one drawn from the other end.)

Example 4 (multiple choice)

(a) Which fraction has molecules with longer chains than the kerosene fraction but a lower boiling point than the fuel oil fraction? **[1]**

A diesel oil B gasoline C lubricating oil D naphtha

(b) Which equation shows the complete combustion of propane? **[1]**

- A $\mathrm{C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O}$
- B $\mathrm{2C_3H_8 + 7O_2 \rightarrow 6CO + 8H_2O}$
- C $\mathrm{C_3H_8 + 3O_2 \rightarrow 3CO_2 + 4H_2}$
- D $\mathrm{C_3H_8 + 4O_2 \rightarrow 3CO_2 + 4H_2O}$

(c) An alkane has a relative molecular mass of 212. What is its molecular formula? (A_r: C = 12, H = 1) **[1]**

A $C_{15}H_{30}$ B $C_{15}H_{32}$ C $C_{14}H_{30}$ D $C_{16}H_{34}$

(a) Longer chains than kerosene means lower in the column; a lower boiling point than fuel oil means higher than fuel oil. The only fraction between them is diesel oil. **Answer A.**

(b) B makes carbon monoxide (incomplete combustion) and C makes hydrogen, which never forms. D has the right products but only 8 oxygen atoms on the left and $6 + 4 = 10$ on the right. A balances: C $3 = 3$, H $8 = 8$, O $10 = 10$. **Answer A.**

(c) $M_r = 12n + (2n + 2) = 14n + 2 = 212$, so $n = 15$ and the formula is $C_{15}H_{32}$. (A is an alkene, M_r 210; C and D are the alkanes before and after, M_r 198 and 226.) **Answer B.**

Common mistakes

- **Leaving "only" out of the hydrocarbon definition.** "Contains carbon and hydrogen" also describes ethanol. Write "a compound of carbon and hydrogen atoms only"; don't write "carbon and hydrogen bonds".
- **Muddling the fraction uses.** Examiners often see naphtha put with waxes and polishes, the lubricating fraction put with making chemicals, bitumen as a ship fuel, and gasoline or diesel as jet fuel. Learn the eight syllabus pairs exactly, and don't give a vague use such as "fuel" or "cars".
- **Mixing up volatility and viscosity.** Volatility is how easily a liquid evaporates (higher at the top). Viscosity is how thick it is (higher at the bottom). Several multiple-choice questions turn on this.
- **Naming the wrong separation process.** Petroleum is separated by fractional distillation, not "distillation", "cracking", "filtration" or "fractionating column" (that is the apparatus).
- **Thin descriptions of fractional distillation.** "It is heated and separated" earns little. Give the temperature gradient, condensing at different heights, and piping off.
- **Saying natural gas is mostly hydrogen or nitrogen.** That is confusing natural gas with air. Natural gas is mostly methane.
- **Wrong products of incomplete combustion.** Many answers give hydrogen, or nitrogen dioxide. The products are carbon monoxide and/or carbon, with water. Define incomplete combustion as burning in a limited supply of oxygen; "not burning completely" repeats the question.
- **Calling HCl "hydrochloric acid".** In the substitution reaction the product is hydrogen chloride gas. When a name is asked, write the name, not just "HCl".
- **Not knowing what the ultraviolet light does.** It provides the activation energy. "Photochemical" means the reaction needs light; it is not "photosynthesis".
- **Mixing up substitution with addition or displacement.** Alkanes substitute; alkenes add. A halogen swapping places with a halide ion in solution is displacement, not substitution.
- **Drawing one isomer twice.** A Cl on either end carbon of propane is the same molecule, 1-chloropropane. Draw the Cl on different carbons, keep the chain unbranched, and put one Cl only if the question says one H is replaced.

- **Giving a series name when a member is asked.** "Name a member of this series" wants "methane", not "alkanes".

How to get the marks

- **"State" and "Name"** need the exact word: fractional distillation, methane, substitution, photochemical, ultraviolet light, hydrogen chloride, cracking.
- **"Define" or "State the meaning of"**: hydrocarbon (compound, carbon and hydrogen only); saturated (all carbon–carbon bonds single); substitution (one atom or group replaced by another); photochemical (needs light); incomplete combustion (burning in limited oxygen); structural isomers (same molecular formula, different structural formulae). Each key idea is a mark.
- **"Describe" fractional distillation**: separate points, each a step (heated, temperature gradient, condense at different heights, piped off). Name the property, different boiling points, when asked.
- **Uses**: the syllabus wording, one use per fraction. If the question lists fractions, choose from that list only.
- **Trends**: say which way the property changes and compared with what, for example "viscosity increases as the chain length increases". A prediction from a table must lie between the neighbouring values.
- **Equations**: correct formulae first, then balance. For complete combustion the only products are $\mathrm{CO_2}$ and $\mathrm{H_2O}$; for substitution they are the chloroalkane and HCl.
- **"Explain why it is unsaturated"** (a hydrocarbon in a table): the name ends in -ene, or the formula fits $\mathrm{C}_n\mathrm{H}_{2n}$, or it has a C=C bond. "It has a double bond" alone is not enough.
- **Letter questions** ("each letter may be used once, more than once or not at all"): write what each structure is beside it first, then answer.
- **Draw displayed formulae** with every atom and every bond; for a chloroalkane check that each carbon still has four bonds.

Quick check

1. Name the fraction used for: (a) fuel for ships, (b) making roads, (c) gas for cooking, (d) making other chemicals.
2. Butane, $\mathrm{C_4H_{10}}$, is a fuel. Write the balanced equation for its complete combustion, and name two products of its incomplete combustion.
3. In a fractionating column, fraction P is collected higher up than fraction Q. Which fraction has (a) the longer chains, (b) the higher boiling point, (c) the higher volatility, (d) the higher viscosity?
4. Pentadecane, $\mathrm{C_{15}H_{32}}$, is cracked to give nonane, $\mathrm{C_9H_{20}}$, and one other hydrocarbon. (a) Give the formula of the other hydrocarbon and name its homologous series. (b) State the two conditions needed. (c) Give one reason why cracking is done.
5. (Extended) Hexane, $\mathrm{C_6H_{14}}$, reacts with chlorine in ultraviolet light to replace one hydrogen atom. Write the equation, and state how many different unbranched products $\mathrm{C_6H_{13}Cl}$ can form.

Answers

1. (a) fuel oil; (b) bitumen; (c) refinery gas; (d) naphtha.
2. $2\mathrm{C_4H_{10}} + 13\mathrm{O_2} \rightarrow 8\mathrm{CO_2} + 10\mathrm{H_2O}$ (C: $8 = 8$; H: $20 = 20$; O: $26 = 16 + 10$). Incomplete combustion gives carbon monoxide (or carbon) and water.
3. Higher up means shorter chains. (a) Q; (b) Q; (c) P; (d) Q.
4. (a) C: $15 - 9 = 6$; H: $32 - 20 = 12$, so $\mathrm{C_6H_{12}}$. It fits $\mathrm{C_nH_{2n}}$, so it is an alkene. (b) A high temperature and a catalyst. (c) The shorter-chain products are more in demand (for example as fuels), and alkenes are needed to make polymers.
5. $\mathrm{C_6H_{14}} + \mathrm{Cl_2} \rightarrow \mathrm{C_6H_{13}Cl} + \mathrm{HCl}$. The chain C1–C6 has three different positions (C1 = C6, C2 = C5, C3 = C4), so **3** products.

Past questions to try

- **0620/32/M/J/25 Q4**: defining a hydrocarbon, outlining fractional distillation, and matching three fractions to their uses.
- **0620/31/O/N/25 Q4**: the fraction with the lowest boiling point or highest viscosity from a given list, and a missing formula and melting point.
- **0620/42/M/J/23 Q5**: substitution of propane: its name, what the ultraviolet light does, "photochemical" and the equation.
- **0620/22/M/J/23 Q37**: how many one-carbon products methane and chlorine can make.