Achievement Standard 90932

Demonstrate understanding of aspects of carbon chemistry

CHEMISTRY

1.3

Externally assessed 4 credits

Hydrocarbons

Covalent bonds

Non-metal elements – those with 4, 5, 6 or 7 **valence** electrons – can achieve a stable electron arrangement by sharing electrons in their outer energy levels (valence electrons) with another non-metal atom. The attraction between the shared electrons and the nuclei of the two atoms is known as a **covalent bond** between two atoms.

The element carbon can form long chains of carbon atoms, with covalent bonds between the atoms.

- The C–C covalent bonds are very strong.
- Carbon-containing compounds are the basis of **organic chemistry**.
- The simplest organic compounds are **hydrocarbons** – compounds made up only of hydrogen and carbon.

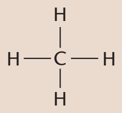
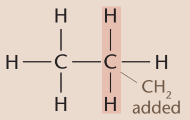
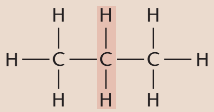
Carbon-containing compounds can be represented by either:

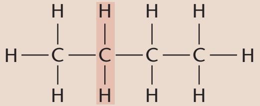
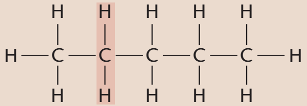
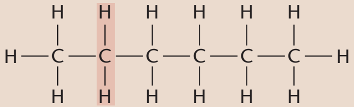
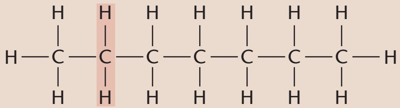
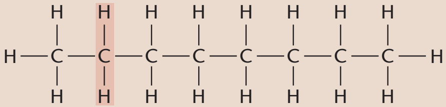
- a **molecular formula** – indicates the number and type of atoms in a molecule
- a **structural formula** – indicates the arrangement of atoms in a molecule, showing the covalent bonds between atoms.

Alkanes

The **alkanes** are a family of hydrocarbons with the general formula, C_nH_{2n+2} (*n* can be any number 1, 2, 3, 4, …, etc.).

Systematic naming of alkanes

Name	Molecular formula	Structural formula	Melting point (°C)	Boiling point (°C)	Physical state at 20 °C	Occurrence and uses
methane	CH_4		–182	–164	gas	natural gas fuel (CNG); source of hydrogen for ammonia production
ethane	C_2H_6		–183	–88	gas	natural gas; fuel (CNG)
propane	C_3H_8		–190	–42	gas	natural gas and petroleum; fuel (LPG)

Name	Molecular formula	Structural formula	Melting point (°C)	Boiling point (°C)	Physical state at 20 °C	Occurrence and uses
butane	C_4H_{10}		–139	0	gas	natural gas and petroleum; fuel (LPG)
pentane	C_5H_{12}		–130	36	liquid	petroleum; fuel (petrol)
hexane	C_6H_{14}		–95	69	liquid	petroleum; fuel (petrol)
heptane	C_7H_{16}		–91	98	liquid	petroleum; fuel (petrol)
octane	C_8H_{18}		–57	126	liquid	petroleum; fuel (petrol)

Physical state of alkanes

As the number of atoms and length of the carbon chain of an alkane increases, the mass of the molecule increases. More energy is required to separate the molecules of larger mass, so melting points and boiling points increase as the mass of the molecule increases.

As the number of carbon atoms in the molecule increases, the state at room temperature (20 °C) changes from gas to liquid to solid.

At room temperature (20 °C), the smallest alkane molecules are gases (e.g. methane, ethane, propane and butane), larger molecules are liquids (e.g. pentane, hexane, heptane and octane) and the largest molecules (e.g. those with more than 20 carbon atoms) are solids.

Sources of alkanes

Alkanes occur naturally in fossil fuels, e.g.:

- natural gas – is mainly methane but also contains ethane
- petroleum (crude oil) – is a mixture of hydrocarbons (with up to 30 carbon atoms in the molecule), which are gases, liquids and solids.

Separating the petroleum mixture for use

- **Fractional distillation** is used – a process of separation based on the different condensation (or boiling) temperatures of molecules with different sizes.
- Distillation separates the hydrocarbons into useful **fractions** (i.e. groups of alkanes with similar-sized molecules), such as petrol, diesel, kerosene, jet fuel, etc.

In the fractionating tower:

- The crude oil is heated to above the boiling point of the hydrocarbons; this means the hydrocarbons vaporise into a gas mixture.
- As the vapours pass up the tower, they are progressively cooled.

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Question Four: Crude oil

Crude oil undergoes fractional distillation in tall towers, like the ones shown in the photograph. The different fractions produced have many uses.

a. Name TWO of the fractions obtained from a fractional distillation tower, and describe ONE use for each.

Fraction	Name	Use
1		
2		

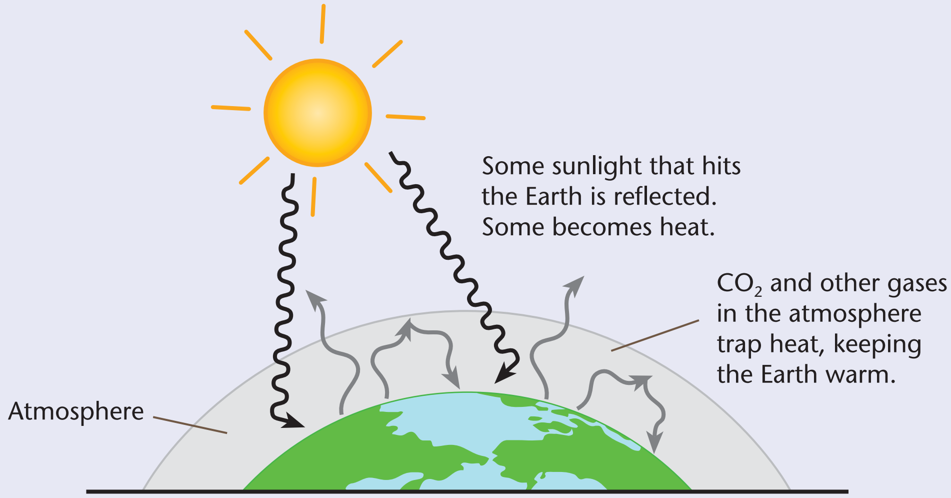
b. i. Why does crude oil need to undergo fractional distillation before it can be used?

ii. Explain why fractional distillation is carried out in tall towers.

In your answer you should link the process of fractional distillation to the physical properties and chemical structure of the hydrocarbons in crude oil.

Greenhouse effect and global warming

The **greenhouse effect** is caused by the presence of carbon dioxide (and other gases) in the atmosphere that allow heat energy from the Sun to pass through, but trap (absorb) the heat energy radiating back from the Earth's surface. The amount of carbon dioxide gas in the atmosphere is gradually increasing, which contributes to the greenhouse effect. The increased greenhouse effect results in the warming of the Earth's surface (**global warming**). Other greenhouse gases also contribute to global warming, e.g. methane released by farm animals.



Possible consequences of global warming include the following.

- Ice melting in the Earth's polar regions could cause seawater levels to rise, and some low-lying islands and shorelines could disappear below sea-level.
- Higher temperatures above the Earth's surface could cause more water to evaporate from seas and lakes. This could result in more frequent and more severe weather events, such as storms, floods and droughts.
- Diseases that occurred primarily in 'tropical' countries might spread into other regions.

Acid rain

Carbon dioxide gas dissolves in water to form a weak acidic solution of carbonic acid, H_2CO_3, which will dissolve calcium carbonate (limestone/marble): $CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$

Marble and limestone are used as building materials, which means buildings constructed from these materials are also subject to slow attack by acid rain.

Acidification of oceans

Increasing amounts of carbon dioxide gas dissolved in the oceans increases the acidity of the oceans. Increased acidity has adverse impacts on marine organisms (e.g. shells of corals and planktons contain calcium carbonate but acidity inhibits the shell-forming processes).

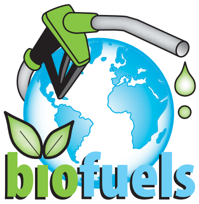
Pollution from the internal combustion engine

The internal combustion engine uses hydrocarbons, such as petrol, diesel oil and kerosene, which burn in air. If the fuel does not burn efficiently, the hydrocarbons do not undergo complete combustion. Some fuel escapes unburned, as well as the carbon monoxide gas and carbon particulates (soot) that are products of incomplete combustion. Some of the energy contained in the fuel goes to waste.

Effects of combustion products on human health

Carbon **monoxide** gas is poisonous to the human system because it attaches to haemoglobin in the blood at the expense of oxygen. Poisoning occurs by oxygen starvation. Carbon particulates (black carbon or soot) are very small in size, and can be inhaled deep into the lungs, where they can cause asthma or lung cancer.

c. Ethanol made from sugar cane can be mixed with petrol to produce a biofuel for cars.



Ethanol burns in air with an almost invisible flame, and has some useful advantages as a biofuel compared with some hydrocarbons found in petrol, such as heptane, C_7H_{16}.

Evaluate the use of ethanol in biofuels for cars.

In your answer, you should:

- state the type of combustion reaction that ethanol usually undergoes, and name the products formed
- explain two effects that the combustion products of ethanol can have on the environment
- elaborate on the advantages of using ethanol as a biofuel compared with hydrocarbon fuels, such as those containing heptane
- include a balanced symbol equation for the combustion of ethanol.

Balanced symbol equation:

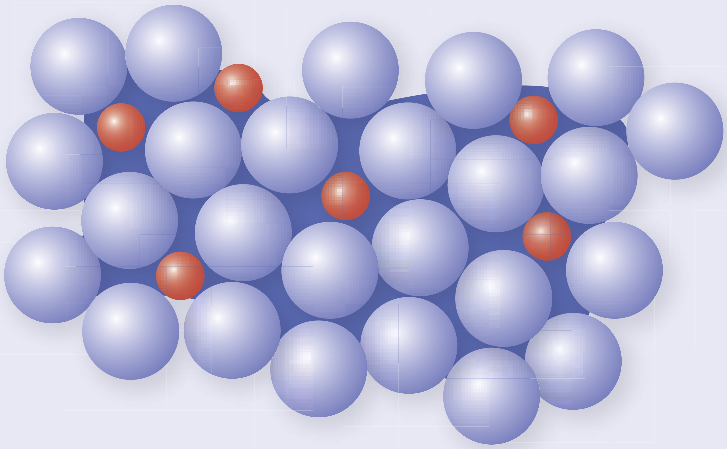
Alloys

Alloys:

- are formed by mixing two or more molten metals and allowing the mixture to cool
- do not have distinct melting points because they are a mixture of metals
- are used where their properties are more useful than those of the separate component metals.

Pure metals, such as aluminium, iron and copper, are too soft to be used for construction purposes. However, mixing them with small proportions of other elements creates an alloy with dramatically increased hardness. In the alloy, atoms of another element (with atoms of a different size) replace a small number of atoms of the parent metal in the lattice, which distorts the regular arrangement of metal atoms. The layers of atoms cannot move over each other as well, which makes the alloy harder than the pure metals alone.

Arrangement of atoms in an alloy



Common alloys, and their properties, include the following.

- Brass (copper and zinc) – does not corrode as easily as copper and retains an attractive appearance; it retains the good electrical conductivity of copper.
- Bronze (copper and tin) – protects itself with an attractive coating that lasts for centuries.
- Solder (tin and lead) – melts at a lower temperature than either tin or lead and can bond with many metals.
- Pewter (tin and lead plus small quantities of copper and antimony) – is harder than lead and does not release lead, which is a poison to human beings, when made into drinking vessels.
- Duralumin (aluminium and magnesium) – has greater strength than aluminium but retains the low density needed for aeroplane body construction.
- Cupronickel (copper and nickel) – harder than copper and will last longer.

Steel

The valuable alloy, steel, is unusual because it contains a non-metal, carbon (present in proportions of 0.5% to 2%), along with iron metal. Other metals are added to make specialist steels. There is a large variety of 'steels', all of which contain iron and carbon. Steels have high tensile strength – they can be bent and will return to their original shape without breaking. Steels resist corrosion better than iron.

Questions: Metals

Question One: Ships and zamak

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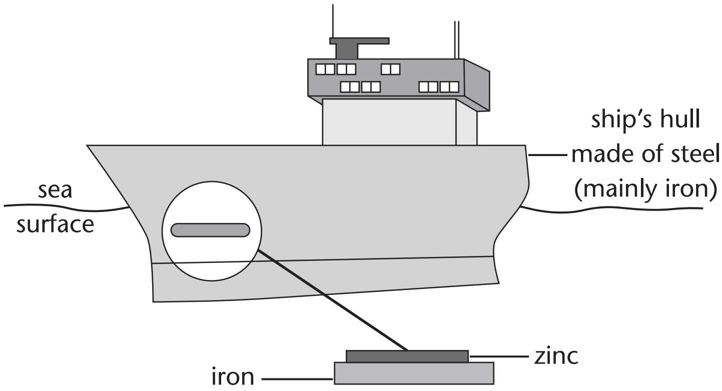
a. Give TWO physical properties for each of the elements sulfur and lead.

b. Zinc blocks are sometimes added to the hulls of steel (iron) ships, as shown in the diagram.

Blocks of zinc attached to the hull of a ship



Explain why these blocks are made from zinc and why they are used on the hull of a ship.

You may refer to the activity series on page **viii**.

c. **Zamak** is a family of alloys with a base metal of zinc, and with alloying elements of aluminium, magnesium, and copper.

i. Explain why alloys are sometimes used instead of pure metals.

ii. Zamak can be used to make jewellery.

Elaborate on the advantages of adding the elements aluminium, magnesium, and copper to zinc to make the alloy zamak.

Catalytic decomposition of hydrogen peroxide

Catalysts

A **catalyst** is a substance that increases the rate of a chemical reaction without being used up itself. A catalyst reduces the amount of energy needed for the reaction to proceed.

> ***Example***
>
> Without a catalyst, the decomposition of hydrogen peroxide at room temperature is very slow. A catalyst speeds up the reaction so that it can be observed at room temperature.
>
> Only a small amount of catalyst is needed because it does not get used up during the reaction.

Decomposition of hydrogen peroxide

Hydrogen peroxide, H_2O_2 (a colourless liquid), is stable if very pure.

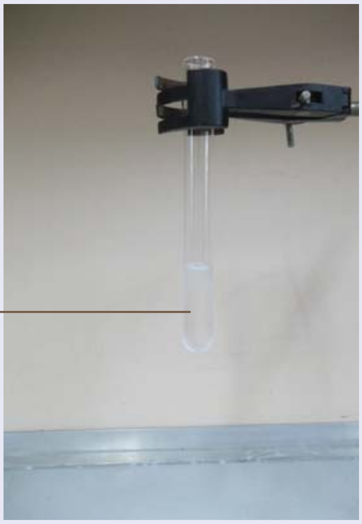
It decomposes rapidly to oxygen, O_2, and water, H_2O, at room temperature if a catalyst, such as manganese(IV) oxide, MnO_2, is present. Heat is given off during this reaction.

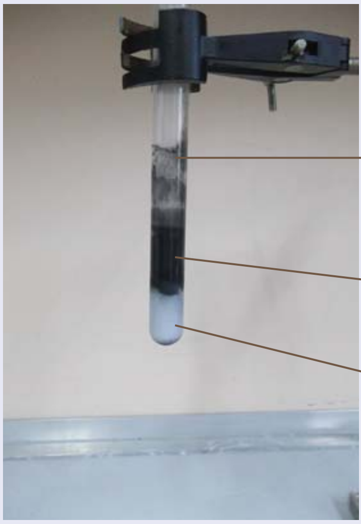
$$\text{hydrogen peroxide} \rightarrow \text{oxygen gas} + \text{water}$$

$$2H_2O_2 \rightarrow O_2 + 2H_2O$$

The presence of oxygen gas can be detected by holding a glowing splint above the test-tube. The splint will burst into flame due to the presence of oxygen.

The rate of a catalysed reaction is very rapid at first. The rate levels off after a short time as all the reactant (hydrogen peroxide) is used up.





The rate of an uncatalysed reaction is much slower than a catalysed reaction. However, the volume of oxygen produced in an uncatalysed reaction will steadily increase over time until it reaches the same volume as the catalysed reaction when all the reactant is used up.

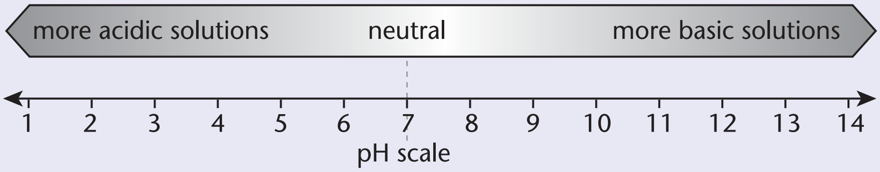
pH scale and acid or base nature of solutions

pH is used as a measure of how acidic or basic a solution is. The range usually worked with is an acid to base scale going from 1 to 14, with neutral solutions at the mid-point of pH 7.

All solutions contain some amount of *both* the acidic species hydrogen ions (H^+) and the base species hydroxide ions (OH^-).

- When acidic substances form a solution with water (neutral, pH 7), they add to, and increase, the H^+ ion concentration relative to the OH^- ion concentration – the result is a lowering of the pH to below 7. Strong acids have relatively very much higher H^+ ion concentrations, and so have a pH in the lowest values of 1–3.
- When basic substances form a solution with water (neutral, pH 7), they add to, and increase, the OH^- ion concentration relative to the H^+ ion concentration – the result is a raising of the pH to above 7. Strong bases have relatively very much higher OH^- ion concentrations, and so have a pH in the highest values of 10–14.
- Neutral substances have an **equal concentration** of both H^+ ions and OH^- ions. Pure water, as well as many salt solutions, have H^+ ions and OH^- ions in equal concentration – the result is a pH of 7.

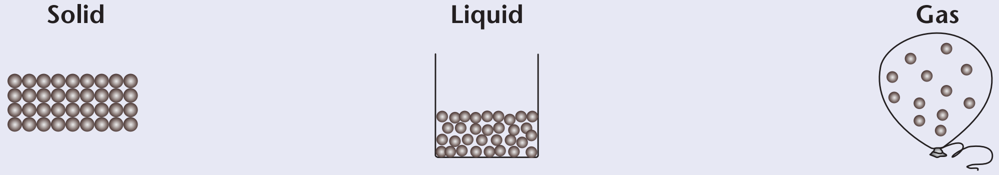
Indicators



Litmus paper	blue turns red		no change		red turns blue
Universal indicator	red in strong acid	orange/yellow in weak acid	green in neutral	blue in weak base	purple in strong base

Rates of reaction

The *particle theory* (*'kinetic theory'*) of matter states that all matter is made up of tiny particles which are in a constant state of motion. The particles can be atoms, ions, molecules. The amount of movement of the particles depends on the *state* of matter.



Particles have low-energy vibration movement only

Particles have some movement energy, so can slide past one another

Particles have high energy and rapid movement in all directions

Collision theory

Particles constantly collide as a result of their movement. A **chemical reaction** occurs when the particles collide with *sufficient kinetic energy*, E_K, to break the bonds that hold the particles together. The reaction rate depends upon the number of **effective** collisions that occur between particles per unit of time. Reaction rate can be increased by the following.

- **Higher temperatures** – higher E_K of particles causes more frequent collisions, so more effective collisions.
- **Higher concentrations** – more particles in a volume available for collisions (e.g. concentrated HCl has more particles than the same volume of dilute HCl).
- **Increasing the surface area (SA)** – more particles exposed to each other (e.g. a solid that is a powder has greater SA than a solid that is a lump; mixing/stirring increases SA; solutions have more SA than solids).

Reaction rate (*how fast* a chemical reaction occurs) can be measured in a school lab by the following.

- How fast reactants are used up (e.g. time for a solid to disappear, or colour to disappear or change).
- How fast products are formed (e.g. time for colour to change or form, time for bubbles of gas to form).

Example

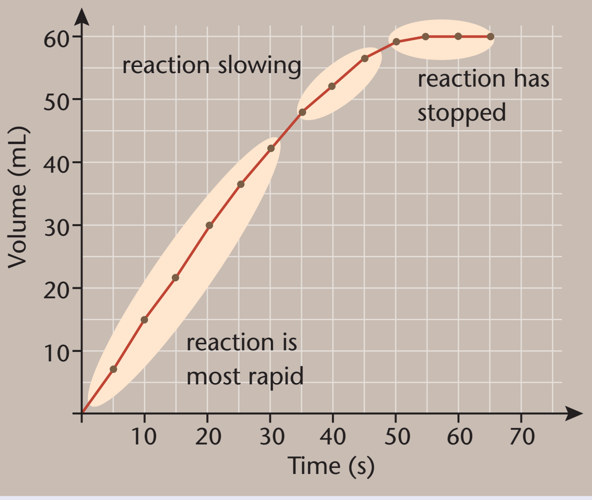
Calcium carbonate (marble chips) reacts with hydrochloric acid to form calcium chloride, water, and carbon dioxide.

The rate of this reaction could be measured by timing how long it takes for:

- the marble chips to disappear
- CO_2 bubbles to form.

If the CO_2 gas is collected and measured over time to find the reaction rate, the line graph shown could be produced.

Volume of carbon dioxide gas produced by adding calcium carbonate to hydrochloric acid



A reaction begins *rapidly* (many reactant particles in the reaction system, i.e. high concentration) then *slows* as reactants are used up (concentration decreases) and *stops* when one of the reactants is used up.

Catalysts increase the rate of some reactions. A catalyst does not get used up in the reaction or become part of the products. *Enzymes* are catalysts found in living things; without them, chemical reactions would take place too slowly for life to exist. Catalysts lower the energy needed for a successful collision – therefore more successful collisions occur, increasing the reaction rate.

Answers and explanations

Assessment criteria

Achievement	Merit	Excellence
Demonstrate understanding will typically involve: • describing, identifying, naming, drawing, giving an account of, or defining aspects • using chemistry vocabulary, symbols and conventions, including names and formulae • completing word equations.	*Demonstrate in-depth understanding* will typically involve: • explaining aspects • using chemistry vocabulary, symbols and conventions, including names and formulae • writing word equations or completing given symbol equations.	*Demonstrate comprehensive understanding* will typically involve: • linking aspects when elaborating, justifying, relating, evaluating, comparing and contrasting, or analysing • using chemistry vocabulary, symbols and conventions consistently • writing balanced symbol equations.

Achievement Standard 90932 (Chemistry 1.3): Demonstrate understanding of aspects of carbon chemistry

1.3 Hydrocarbons

Question One: Crude oil processing

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a. i. Crude oil is a mixture of different carbon compounds, each of which have different uses. Fractional distillation separates the mixture into each usable fraction/component.

ii. Smaller hydrocarbons have very low boiling points due to weak forces between molecules. As the crude oil vapour mixture moves up the tower it cools and each fraction condenses out of the gas mixture. However, the smaller hydrocarbons remain as vapour, even at the coolest top of the tower, and so are collect from the top in the gas state.

b. $C_{10}H_{22} \rightarrow C_5H_{12} + C_3H_6 + C_2H_4$

> Cracking produces at least one alkane and at least one alkene.
>
> Ethene, C_2H_4, is nearly always an alkene product from cracking; it is made up of 2 C atoms and 4 H atoms.
>
> The other product given is pentane, C_5H_{12}; it is made up of 5 C atoms and 12 H atoms.
>
> Decane is $C_{10}H_{22}$; it is made up of 10 C atoms and 22 H atoms.
>
> Now, ethene, C_2H_4, and pentane, C_5H_{12}, represent a total of 2 + 5 = 7 C atoms and 4 + 12 = 16 H atoms.
>
> This means 10 – 7 = 3 C atoms and 22 – 16 = 8 H atoms need to be accounted for. Since there is only one more product, it must have the formula C_3H_6 (propene).

c. Fractional distillation is a physical process used for separation of a mixture, there are no changes to the properties of the products or new compounds being created. Fractional distillation utilises the physical property of different boiling points of the molecules in the mixture.

Cracking is a chemical reaction that involves heating a large, long-chain hydrocarbon over a silica catalyst such that the long-chain hydrocarbon breaks down to produce smaller molecules; these new compounds – at least one alkane and at least one alkene – have lower boiling points and different chemical properties to the reactant molecule.

(**A** – 3 of: states crude oil is a mixture in **a. i.**, identifies the smaller hydrocarbons are in gas state at the top in **a. ii.**, has the correct formula for the pentane product in **b.**, describes fractional distillation as separating a mixture in **c.**, describes cracking as breaking off a small molecule in **c.**; **M** – 3 of: explains separation needed for different uses in **a. i.**, links the gas state of smaller hydrocarbons to low b.p. in **a. ii.**, equation correct in **b.**, fully explains the process of fractional distillation or cracking in **c.**; **E** – **M** with: explanation of how smaller hydrocarbons have been separated and remain a gas linked to low b.p. in **a. ii.**, and correct comparison of both fractional distillation and cracking linking the relevant properties to the changes that have occurred for each process in **c.**)

Question Two: Propane and propene

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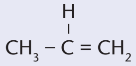
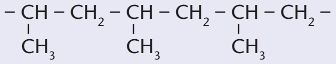
a. **Propane**

$CH_3 - CH_2 - CH_3$

Propene



b. 

> Use dashes (or 3 dots) at each end of the diagram to show that the molecule continues.

c. Propene is a bigger molecule with a larger mass than ethene. This means a greater amount of attractive forces can occur between adjacent propene molecules compared with ethene molecules, and these greater attractive forces in propene require more energy to separate the molecules during boiling of the substance. Hence, propene has a higher b.p. than ethene.

d. Polymers form from the addition reaction between propene monomer molecules. This can occur because propene has a C=C double bond. One of these bonds can be broken while the other bond keeps the molecule still joined; this then allows the C atom at the end of the molecule to form a new bond with the C atom on an adjacent molecule that has similarly had its double bond broken – this repeats in a recurring way so that the long molecule keeps breaking the double bonds at its ends to form a long-chain polymer.

Propane only contains single C–C bonds which cannot be broken without breaking the molecule itself – this means the C atoms within the propane are not able to form more bonds with adjacent molecules so cannot make a polymer.

(**A** – 3 of: both correct diagrams in **a.**, **b.** correct, stating stronger forces between propene molecules in **c.**, describes addition reaction or identifies the C=C presence in **d.**; **M** – 2 of: both **a.** and **b.** correct, explains propene has bigger mass so more energy required for boiling in **c.**, explains how addition reaction occurs in terms of bonding to make polypropene; **E** – **M** with: linking of propene's larger mass to more attraction forces, energy and b.p. in **c.**, and explanation for both why propene can and propane cannot form polymers correct in **d.**)

Question Three: 3 and 4 carbon molecules

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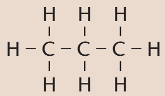
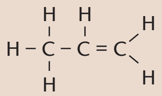
a.

Propane	Propene
	

b. i. Type of bonding present: Covalent.

Reason: The H and C atoms are both non-metal elements that bond by sharing pairs of valence electrons to attain the stability of a full outer shell of electrons.

ii. Propene is unsaturated which means that it contains a C=C double bond.

c. Complete combustion occurs in excess O_2; the butane fully burns to produce only CO_2 and water. Incomplete combustion occurs in a limited supply of O_2; the butane does not fully burn and forms a mixture of carbon products that include pure carbon (soot), carbon monoxide and carbon dioxide. In the environment:

- CO_2 contributes towards the greenhouse layer, which is a layer of gas in the atmosphere that reflects heat from the Earth back towards the ground and so increases global temperatures which in turn can melt polar ice to raise sea levels
- CO is a toxic gas that replaces O_2 in the bloodstream and so poisons animals
- C (soot) is a black deposit that can cause sites for cancer growth in the lungs when inhaled, and also builds up as a dirty black deposit on buildings and structures in the environment.

Complete combustion:

$$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$$

Incomplete combustion:

$$C_4H_{10} + 5O_2 \rightarrow CO + C + 2CO_2 + 5H_2O$$

The exact ratio of each carbon product from incomplete combustion is varied, depending the extent of the combustion that occurs.

(**A** – 3 of: both diagrams in **a.**, correct bonding in **b. i.**, identifies C=C in **b. ii.**, correctly identifies excess oxygen for complete combustion and limited oxygen for incomplete combustion in **c.**, correct complete combustion symbols but balancing wrong in **c.**; **M** – 2 of: bonding explained correctly in **b. ii.**, one carbon combustion product identified and linked to combustion type and environment effect, either symbol equation fully correct in **c.**; **E** – 2 of: **b.** both **i.** and **ii.** all correct, **c.** two carbon combustion products identified and linked to combustion type and environment effects, both symbol equations correct)

Question Four: Crude oil

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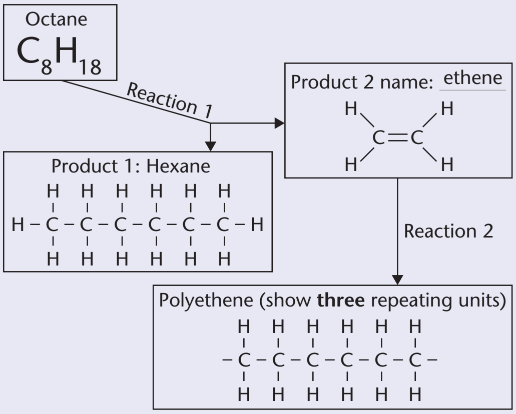
a.

Name	Use
Natural gas	Fuel gas, manufacture of methanol
Petroleum	Vehicle fuel
Diesel	Truck, heavy transport or machinery
Kerosene	Jet plane fuel
Tar/Bitumen	Roading

b. i. To separate the mixture into its component carbon compounds of different sizes, which are each used separately in different ways.

ii. The height of the tower is needed to allow the fractions to separate. The crude oil liquid mixture is heated up into a gas mixture which rises up the tower. As the gas mixture is moving up it cools, and each fraction of the mixture condenses out of the gas at different heights when the temperature reduces below that fraction's boiling point. Smaller, short-chain hydrocarbons with the lowest boiling point remain in the gas state the longest and are collected at the top of the tower; the larger, or longer-chain a hydrocarbon is the higher its boiling point is so the more easily it condenses out of the gas mixture. So, the mixture gets separated at different levels in the tower depending on a hydrocarbon's size.

c. i.



Use 3 dots (…) or a dash (–) on each end of a polymer diagram to show that the polymer continues.

ii. Reaction 1 is cracking. The octane is heated over a silica catalyst to break off 2-carbon-long units of ethene.

Reaction 2 is polymerisation. The ethene molecules are heated with a Ziegler-Natta/titanium chloride catalyst which causes one of the C=C double bonds to break and then from a new single C–C bond with an adjacent ethene, which in turn breaks one of its C=C bonds to then bond with the adjacent ethene; this 'adding on' is repeated until the molecule that forms is several hundred molecules long. In this way, the ethenes add together to form very long polyethene molecules.

(**A** – 3 of: both boxes of name and use correct in **a.**, states the mixture that needs to be separated in **b. i.**, identifies the different heights relate to different temperatures in **b. ii.**, 3/4 correct answers in **c. i.**, correct names for both processes in **c. ii.**; **M** – 2 of: links temperature at different heights to different boiling points in **b. ii.**, 3/4 correct answer in **c. i.** correct, both reaction types and one set of conditions all correct in **c. ii.**; **E** – **b. ii.** all correct with links of temperature at different heights to different boiling points and molecule size/structure, **c. ii.** both reactions correctly named with conditions, and description of the polyethene formation correct)

Question Five: Hydrocarbon fuels

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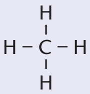
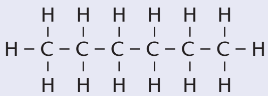
a. i. 

ii. 

iii. propene

b. i. Gas.

Propane would have boiled into gas at any temperature that is higher than its b.p. of –42 °C.

ii. Boiling point of butane would be: **higher**

Reason: Butane has a longer carbon chain and a greater mass than propane. This causes more attractive forces to occur between the butane molecules and so will require more energy to overcome these additional forces to separate the molecules from each other during boiling. Thus butane has a higher boiling point.

Use the general trend that melting and boiling points of hydrocarbons increase with chain length and reference to the examples in the question.

c. In limited oxygen there is incomplete combustion of propane. This causes a mixture of carbon, C, and carbon monoxide, CO, to form as well as water as the combustion products. When incomplete combustion is occurring the flame colour is seen as yellow/orange and black soot is released due to the C present. The CO produced is toxic as it replaces O_2 in the blood and causes shortness of breath and dizziness. The C produced is a carcinogen which can get lodged in the respiratory system.

Answers