# Achievement Standard 90932

## *Demonstrate understanding of aspects of carbon chemistry*

CHEMISTRY

**1.3**

**Externally assessed 4 credits**

## *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 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.

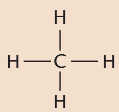
**Carbon-containing** compounds can be represented by either:

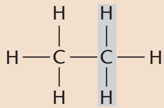
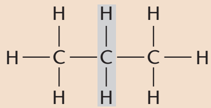
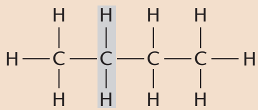
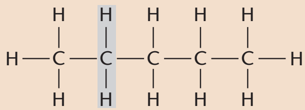
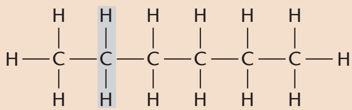
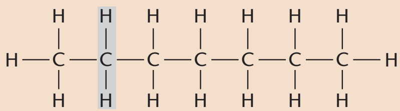
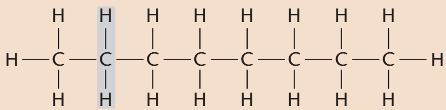
- a **molecular formula** – indicates the number and type of atoms in a molecule
- a **structural formula** – indicates the arrangement of atoms in a molecule, showing the covalent bonds between atoms.

## *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 |

| Name | Molecular formula | Structural formula | Melting point (°C) | Boiling point (°C) | Physical state at 20 °C | Occurrence and uses |
|---|---|---|---|---|---|---|
| ethane | $C_2H_6$ |  | –183 | –88 | gas | natural gas; fuel (CNG) |
| propane | $C_3H_8$ |  | –190 | –42 | gas | natural gas and petroleum; fuel (LPG) |
| 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 in 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.

## Preparing petroleum 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.
- As the vapours pass up the tower, they are progressively cooled.
- The largest molecules (which have the highest boiling point) condense first, and are removed as liquids at the bottom of the tower.
- The smaller molecules condense at lower temperatures further up the tower and are successively removed as liquids.
- The smallest molecules, such as methane, ethane, propane and butane (which have the lowest boiling points), remain as gases and are removed at the top of the tower.

## Cracking of fractions

- **Cracking** is the process by which long-chain hydrocarbon molecules are split into shorter hydrocarbons by the breaking of carbon-carbon bonds.
- Cracking uses high temperatures and pressures (or a catalyst).
- Smaller, more useful alkanes and alkenes are produced.

### Example

Butane $CH_3–CH_2–CH_2–CH_3$ can be cracked ('broken down') to form ethane $CH_3–CH_3$ and ethene $CH_2=CH_2$

# Questions: Alkanes

Year 2013
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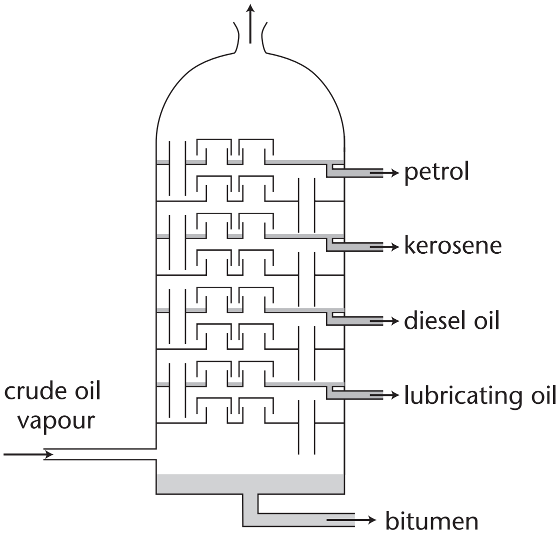
## Question One – Fractional distillation

Crude oil is fractionally distilled in tall towers, like the one shown, to obtain useful products.

(See also picture page 3.)




**a.** Explain why crude oil must be fractionally distilled before it can be used.

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

| Fraction | Name | Use |
|---|---|---|
| 1 | | |
| 2 | | |

**c.** Explain why fractional distillation is carried out in towers.

You will need to refer to the chemical structure and physical properties of the hydrocarbons that make up crude oil, and the way the fractional distillation tower operates.

Essential exam notes

# Properties and uses of non-metals and their compounds

## Physical properties

Non-metal elements have a range of physical properties. Unlike metals, non-metals are *not* good conductors of electricity (an exception is graphite) or heat. They do *not* exhibit the properties of lustre, malleability or ductility.

| Element | Symbol/ Formula | Physical state at room temperature (20 °C) | Appearance; odour (if any) | Hardness (if applicable) |
|---|---|---|---|---|
| carbon | C | gas | dark-grey solid (graphite) or colourless crystal (diamond) | soft (graphite); extremely hard (diamond) |
| nitrogen | $N_2$ | gas | colourless | |
| oxygen | $O_2$ ($O_3$ ozone) | gas | colourless; strong smell | |
| sulfur | S | solid | yellow; faint odour | crystalline, brittle |
| chlorine | $Cl_2$ | gas | green-yellow; strong smell | |
| bromine | $Br_2$ | liquid | reddish-brown; strong smell | |
| iodine | $I_2$ | solid | blackish-violet | crystalline, brittle |

## Allotropes of elements

When two or more forms of the same element exist in the same state (solid, liquid or gas), but with different arrangements of the atoms, each form of the element is called an **allotrope**.

- Each allotrope is regarded as a different substance.
- Many non-metals have allotropic forms.

# Oxygen

The element oxygen exists as a gas at room temperature (20 °C). A molecule of oxygen is made up of two oxygen atoms, and has the formula $O_2$. Oxygen gas makes up 21% of the Earth's atmosphere. Combined with other elements, oxygen makes up 50% of the Earth's crust. Most elements combine directly with oxygen, with the release of heat and light energy (i.e. they burn), in a combustion/simple combination reaction. Elements that do not react with oxygen include the inert gases and the **noble metals** (e.g. gold and platinum).

## Ozone – an allotrope of oxygen

When energy, in the form of an electric spark, is passed through oxygen gas, some molecules of oxygen, $O_2$, are converted into molecules of ozone, $O_3$: $3O_2 \rightarrow 2O_3$

Ozone is a colourless gas with a strong smell. It is an allotrope of oxygen.

- Ozone in the lower atmosphere is regarded as a pollutant because it is harmful to the respiratory systems of animals.
- In the upper atmosphere, ozone is beneficial because it prevents harmful ultra-violet radiation from the Sun from reaching the Earth's surface.

Ozone is used at very low concentrations to purify and disinfect air and water.

- Ozone is used in swimming pools and spas to destroy bacteria and make viruses inactive. During this process, ozone decomposes to produce oxygen gas, $O_2$. It is the strong *oxidising effect* of ozone that is responsible for ozone's disinfecting properties. (Note: **oxidation** is a type of reaction during which a substance is oxidised, i.e. combines with oxygen and/or loses electrons.)
- Ozone, for water-disinfecting purposes, is produced onsite by an ozone generator, which passes an electric discharge through air.

Benefits of using ozone include: ozone kills microbes much faster than other *oxidising agents* (chemicals that oxidise other substances), such as chlorine can kill microbes; unlike chlorine, ozone leaves no harmful or smelly by-products – the only residue is oxygen gas.

Disadvantages of using ozone include: it is poisonous – must be handled carefully; it rapidly decomposes – cannot be stored and must be made on site.

1.4

# Questions: Oxygen

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## Question One – Allotropes of oxygen

oxygen has two allotropes, oxygen ($O_2$) and ozone ($O_3$).

**a.** Describe what an allotrope is.

**b.** Ozone is formed when an oxygen molecule breaks down into two atoms of oxygen. These oxygen atoms then react with oxygen molecules to form ozone.

Write the TWO balanced symbol equations for the reactions that form ozone.

Equation 1:

Equation 2:

**c.** Ozone can be used to disinfect water. Evaluate the use of ozone for disinfecting water. In your answer include explanations of:

- how ozone acts to disinfect water
- two advantages of using ozone
- one disadvantage of using ozone.

Essential exam notes

# Sulfur

The element sulfur is a pale-yellow, crystalline solid that is found near hot springs and in volcanic regions.

## Reaction with oxygen

Sulfur burns in oxygen (with a blue flame) to produce sulfur dioxide gas:

$S + O_2 \rightarrow SO_2$

Sulfur dioxide gas:

- has a strong odour and irritates the throat and lungs
- is produced by industrial processes and can dissolve in rainwater to produce 'acid rain' – acid rain is corrosive to metals and carbonates (e.g. calcium carbonate or limestone)
- is used as a preservative because of its anti-oxidant effect on micro-organisms
- is used as a bleaching agent in the wood pulp and paper industry.

## Uses of sulfur

Sulfur is mainly used for the production of sulfuric acid. Sulfuric acid has many industrial uses as well as being a laboratory chemical.

# Commercial preparation of sulfuric acid – the Contact Process

Annually, millions of tonnes of sulfuric acid are produced worldwide from sulfur using the Contact Process. The name of the process comes from the fact that the reacting gases of sulfur dioxide and oxygen come in *contact* with the **catalyst**.

| Stage | | Process | Equation(s) | Conditions |
|---|---|---|---|---|
| 1 | Sulfur dioxide is produced from sulfur (or a mineral containing sulfur). | Sulfur is burned in air. | $S + O_2 \rightarrow SO_2$ | Burn sulfur in air. |
| 2 | Sulfur dioxide is converted into sulfur trioxide, $SO_3$. | Sulfur dioxide is mixed with air (oxygen) and passed over a catalyst of vanadium pentoxide. | $2SO_2 + O_2 \rightarrow 2SO_3$ | A temperature of 400 °C is used to melt the catalyst to increase its efficiency.<br>(The catalyst provides a surface on which the reaction takes place – this lowers the energy needed for the reaction.) |
| 3 | Sulfur trioxide is dissolved in sulfuric acid to make oleum, $H_2S_2O_7$. | Sulfur trioxide is absorbed in pure sulfuric acid. | $SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ | The process is carried out at room temperature.<br>(Directly dissolving $SO_3$ in water is not practical due to the large amount of heat given off in the reaction between sulfur trioxide and water. The reaction forms corrosive droplets, which would fill the surroundings.) |
| 4 | The oleum is diluted with water to produce pure sulfuric acid, $H_2SO_4$. | The oleum is carefully mixed with water in the correct proportions to produce sulfuric acid. | $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$ | The process gives off heat so the mixture must be cooled. |

Sulfuric acid is manufactured in industrial plants made of steel components. Since *pure* sulfuric acid does not attack metals, there is no corrosion of the plant components by the sulfuric acid.

## Properties of sulfuric acid

Sulfuric acid is referred to as the 'king of the acids' because its varied properties make it an extremely useful chemical in many industries. More sulfuric acid is made each year than is made of any other manufactured chemical.



The chemical properties of sulfuric acid include the following.

- It has acidic properties (forms hydrogen ions) when in aqueous (water) solution.
  Example: $H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$
- It is a 'strong acid' and ionises completely in water.
- It turns blue litmus red.
- It releases hydrogen gas when magnesium (and other reactive metals) is added to it.
  Example: $H_2SO_4 + Mg \rightarrow MgSO_4 + H_2$
- It neutralises bases to form salts. Example: $H_2SO_4 + NaOH \rightarrow Na_2SO_4 + H_2O$
- It **dehydrates** (removes water from) other chemical substances.
- It oxidises (remove electrons from) metals and non-metals.
- It sulfonates organic molecules (to make detergents).
- It acts as a catalyst in many chemical reactions.

## Uses of sulfuric acid

Sulfuric acid has widely varied uses and plays some part in the production of nearly all manufactured goods.

The major use of sulfuric acid is in the production of fertilisers – for example, superphosphate and ammonium sulfate. Superphosphate is a very important fertiliser, used to supply phosphorus, P, to soils. Superphosphate is calcium dihydrogen phosphate mixed with calcium sulfate. It is called superphosphate because it has a much greater solubility in water than rock phosphate (calcium phosphate).

Superphosphate is made by treating rock phosphate with concentrated sulfuric acid:

$$Ca_3(PO_4)_2 \quad + \quad 2H_2SO_4 \quad \rightarrow \quad Ca(H_2PO_4)_2 \quad + \quad 2CaSO_4$$

Sulfuric acid is also:

- widely used in the manufacture of chemicals – for example, in making hydrochloric acid, nitric acid, sulfate salts, synthetic detergents, dyes and pigments, explosives and drugs
- used in petroleum refining to wash impurities out of gasoline and other refinery products
- used in processing metals – for example, in cleaning iron and steel before plating them with tin or zinc
- used in the manufacture of synthetic fibres, such as terylene and rayon
- used as the electrolyte in the lead-acid storage battery commonly used in motor vehicles (the acid for this use, containing about 33% $H_2SO_4$, is often called battery acid).

# Questions: Sulfur

## Question One – Sulfur and sulfuric acid

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Ans. p. 113

1.4

Sulfur in its pure form reacts with oxygen.

a. Describe an observation made of the product formed in the reaction of sulfur with oxygen.

b. Write a balanced equation for this reaction.

Equation:

c. i. Complete the following table for the reactions of sulfuric acid, $H_2SO_4$, with a cleaned piece of lead metal and a cleaned piece of zinc metal. You may refer to the activity series on page **vi** at the front of this book.

| Metal | Observations of any reaction with sulfuric acid | Balanced equation |
|---|---|---|
| lead | | |
| zinc | | |

**ii.** Pure water is a poor conductor of electricity, but a solution of sulfuric acid in water is a good electrical conductor. Explain why the sulfuric acid solution conducts electricity so well. Include a balanced equation in your answer.

Balanced equation:

# Answers and explanations

## Assessment criteria

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

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

## 1.3 Alkanes

### *Question One – Fractional distillation*

p. 4

**a.** Crude oil is a mixture of different-sized hydrocarbon molecules which have a variety of different properties. Long-chain hydrocarbons are inefficient as fuels.

**b.** Possible answers (name and use – *two* answers required):

- Petrol – fuel for cars.
- Kerosene – jet fuel / lighting / heating.
- Diesel oil – fuel for trucks, trains / heating.
- Lubricating oil – lubrication of moving parts in machinery.

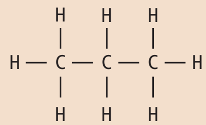
**c.** The fractional distillation tower varies in temperature from high temperatures at the bottom to low temperatures at the top. Crude oil vapour enters at the bottom of the tower. The larger, heavier hydrocarbon molecules (highest numbers of atoms) have the highest boiling points and will condense to liquids at or near the bottom of the tower. The smaller, lighter molecules (with fewer atoms) have lower boiling points and so condense to liquids towards the top of the tower where it is cooler. This process allows the separation of molecules of different masses due to the different temperatures within the tower.

(**A** – describes the composition of crude oil, names two fractions with one use for each, describes the fractional distillation process;
**M** – explains why crude oil must be fractionally distilled before use, links the physical properties or chemical structure of hydrocarbons to the fractional distillation process;
**E** – explains why the fractional distillation process is carried out in towers and links the process to the physical properties *and* chemical structure of hydrocarbons)

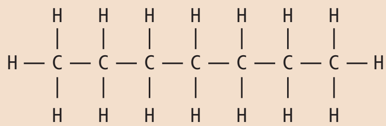
### *Question Two – Properties of hydrocarbons*

p. 5

**a.** propane



heptane



**b.** The boiling points increase as the number of carbon atoms in the molecule increases.

Explanation:

- as the number of carbon atoms in the molecule increases, the mass of the molecule increases
- as the mass increases, more energy is required to separate the molecules in the liquid state and allow them to escape into the gas state (to boil)
- the increase in energy required means that a higher temperature must be reached before the liquid boils.

(**A** – writes correct structural formulae with correct names, identifies the trend in boiling points; **M** – **A** plus identifies trend in boiling points with *two* points of explanation; **E** – **M** plus has *three* points of explanation)

### *Question Three – Cracking*

p. 6

The *process of cracking* involves reducing the size of large-chain hydrocarbon molecules to form smaller molecules by breaking the carbon-carbon bonds.

- High temperatures and a catalyst are needed for cracking to occur.
- *Large-chain molecules are not useful* as fuels because they do not vaporise easily (i.e. difficult to ignite) and burn by incomplete combustion, giving smoky black (carbon-containing) combustion products.

The *products of hexane cracking* are butane and ethene.

The hexane molecule contains six carbon atoms in a straight chain …

$CH_3–CH_2–CH_2–CH_2–CH_2–CH_3$

… when this molecule is cracked, a carbon-carbon bond is broken, and two smaller molecules are formed – butane with four carbon atoms, $CH_3–CH_2–CH_2–CH_3$, and ethene with two carbon atoms and a double bond, $CH_2 = CH_2$. The total number of carbon and hydrogen atoms stays the same.

*Uses of products that form*:

- butane – fuel
- ethene – manufacture of polythene (polymer).

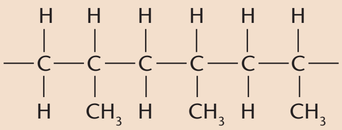
(**A** – describes the cracking process, states conditions required, names *one* product of hexane cracking, gives use of butane *or* ethene; **M** – **A** plus names *both* products of hexane cracking, gives correct use for each of butane and ethene, explains why large-chain molecules are not useful as fuels *or* explains why products are formed in terms of their structure; **E** – **M** plus explains why large-chain molecules are not useful as fuels *and* explains why products are formed in terms of their structure)

## 1.3 Alkenes

### Question One – Polypropylene

p. 8

**a.**



**b.** Polymers are very large molecules made up of many small repeating units. Alkenes contain a carbon-to-carbon double bond. This double bond can be broken, using heat and a catalyst, allowing the small alkene molecules to link together to form a polymer.

Alkanes do not contain a double bond so are unable to link together in the same way.

**c.** Uses: any two of – rope, plastic chairs, textiles, containers, hinges, mouldings (may be other answers).

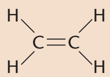
Properties: any two for each use – flexible, tough, lightweight, chemically unreactive, heat resistant (may be other answers).

(**A** – draws the structure of one or more repeating units for polypropylene, describes a polymer, describes an alkene as containing a double bond, gives two uses of polypropylene and two physical or chemical properties;
**M** – links polymer formation to the presence of a double bond in alkenes, links uses of polypropylene to physical or chemical properties;
**E** – links polymer formation to the presence of a double bond in alkenes *and* explains why alkanes do not form polymers, links the properties of polypropylene to the long chains present)

### Question Two – Polymers

p. 9

**a.** ethene



**b.** LDPE is used to make plastic food wrap because:

- it is light – so easy to carry
- it is flexible – so suitable for wrapping
- it has high chemical resistance – so does not react with any chemical substances in the food
- it is insoluble in water – so does not dissolve in any moisture (water) in the food
- the loosely packed chains allow some movement of particles through the polymer – so it is 'breathable'.

HDPE is used to make plastic drink bottles because:

- it is light – so is easy to carry
- it is not flexible – so the bottle holds its shape
- it has high chemical resistance – so does not react with any chemical substances in the drink
- it is insoluble in water – so does not dissolve in drinks which contain water
- the chains are packed closely together – so it does not allow any movement of liquid particles through the polymer.

**c.** Polyethene is non-biodegradable because:

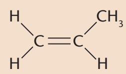
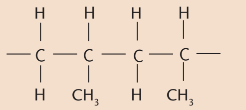
- the single covalent bonds between carbon atoms in the long carbon chains are very strong and are not easily broken by reaction with other substances
- there are strong attractive (intermolecular) forces between the long polymer chains which link the polymer molecules together to form a physically tough substance.

(**A** – gives correct structure of ethene, links use of LDPE to *one* property, links use of HDPE to *one* property, gives *one* reason why polyethene is non-biodegradable; **M** – **A** plus use of LDPE and HDPE have an explanation each, explains why polyethene is non-biodegradable; **E** – **M** plus LDPE and HDPE have *two* properties with explanations, fully explains why polyethene non-biodegradable)

### Question Three – Making polymers

p. 10

**a.**

| Structure of propene: | Structure of polypropene: |
|---|---|
|  |  |

**b.** **Chemical reaction**: In the presence of a catalyst and heat, the C = C double bonds in the propene molecules are broken and form single covalent bonds between these carbons and the carbons of neighbouring molecules. This allows many small propene molecules to join to form long-chain polypropene molecules.

**c.** **Uses of polypropene** (linked to properties): TWO of: ropes, textiles, 'plastic' chairs, re-useable containers, hinges and mouldings (may be others). Properties: chemically stable, tough/strong, flexible, lightweight, plasticity (can be moulded or drawn into threads).

(**A** – *two* of: draws the structure of a propene molecule and a section of a polypropene molecule; states that the small propene molecules are joined to form the long-chain polypropene molecule; states one of the conditions needed for polymerisation; describes one use of polypropene and links this to a property;
**M** – *two* of: explains how propene molecules are linked to form polypropene molecules; states heat and a catalyst needed for polymerisation; describes two uses of polypropene and links each use to a chemical *and* a physical property;
**E** – fully explains the process of the polymerisation of propene into polypropene, linking conditions required to how the ethene molecules react to join to form polyethene)

## 1.3 Properties of alkanes and alkenes

### Question One – Properties of hydrocarbons

p. 12

The *oil formed a layer on top of water* because:

- hydrocarbons are insoluble (do not dissolve) in water
- hydrocarbons are generally less dense than water.

The *oil lasted for a long time* because hydrocarbons are chemically stable, so do not react readily with other chemical substances.

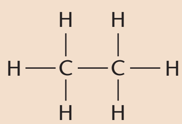
(**A** – gives *one* reason why oil forms layer on top of water; **M** – gives *two* reasons why oil forms layer on top of water *and* explains why oil is long-lasting))

## 1.3 Alcohols – methanol and ethanol

### Question One: Ethane and ethanol

p. 15

**a.** ethane:



ethanol: