1. Which molecule has the highest boiling point?

A. 2,3-dimethylbutane
B. 2-methylheptane
C. 2,3,4-trimethylpentane
D. 3-ethylpentane

Your answer

[1]

2. This question looks at alkanes.

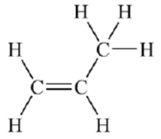
Ethane reacts with chlorine by radical substitution.

Describe fully, with equations, the mechanism for this reaction.

[5]

3. This question is about alkenes.

Propene, drawn below, contains both σ- and π-bonds. The C−H and C−C single bonds are σ-bonds. The C=C double bond is made up of a σ-bond and a π-bond.



i. Describe how a σ-bond forms.

[1]

ii. State the bond angle and shape around each carbon atom of the C=C double bond in propene.

bond angle:

shape:

[1]

4. Butane, C_4H_{10}, is a highly flammable gas, used as a fuel for camping stoves. Butane reacts with oxygen as in the equation below:

$$C_4H_{10}(g) + 6.5O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$$

i. The use of portable heaters in enclosed spaces can result in potential dangers if incomplete combustion takes place.
Explain the potential danger of incomplete combustion.

[1]

ii. A portable heater is lit to heat a room.
The heater burns 600 g of butane and consumes 1.50 m^3 of O_2, measured at room temperature and pressure.
Determine whether this portable heater is safe to use.
Show **all** your working.

conclusion, with reason: --

[3]

5. Complete combustion of 40 cm^3 of a gaseous hydrocarbon **X** requires 240 cm^3 of oxygen. 160 cm^3 of carbon dioxide forms. All gas volumes are at room temperature and pressure.

What is the formula of **X**?

A. C_4H_8
B. C_4H_{10}
C. C_6H_{12}
D. C_6H_{14}

Your answer ☐

[1]

6. * The hydrocarbon propane can be reacted with chlorine to prepare 2-chloropropane, $CH_3CHClCH_3$, by radical substitution.

Describe this reaction, including an overall equation and conditions, the mechanism with names for all steps and the limitations of this method of preparation.

[6]

7. A student carries out the following experiment to investigate the reaction between hexane and chlorine. The chlorine is made by reaction of aqueous sodium chlorate(I) with dilute hydrochloric acid.

Procedure	**Observations**
1 cm^3 of hexane is mixed with 1 cm^3 dilute aqueous sodium chlorate(I) in a test-tube.	The mixture forms two colourless layers.
1 cm^3 dilute hydrochloric acid is slowly added to the mixture.	The acid mixes with the lower layer, which turns a pale green colour.
The tube is then stoppered and shaken.	The pale green colour moves to the upper layer, leaving the lower layer colourless.
The tube is placed under a bright light and shaken at regular intervals for about 10 minutes. The stopper is loosened regularly to release any pressure.	The pale green colour slowly disappears leaving two colourless layers after about 10 minutes.

The reaction of hexane with chlorine took place when the bright light was switched on.

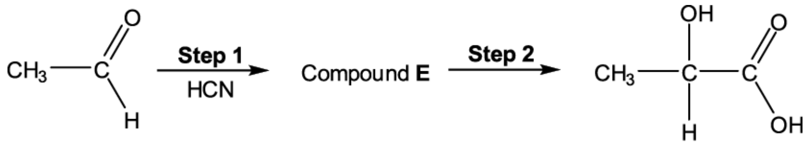
i. Give the skeletal formula of **one** possible organic product of this reaction.

[1]

ii. Explain why this type of mechanism is likely to produce a mixture of organic products.

[1]

8(a). Lactic acid is a naturally occurring chemical, which can be synthesised from ethanal, CH_3CHO, as shown in the steps below.



lactic acid

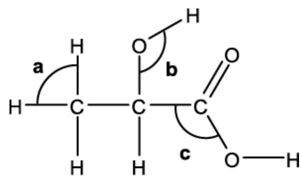
i. Draw the structure for compound **E**.

[1]

ii. Suggest a reagent that could be used for **Step 2**.

[1]

iii. The displayed formula of lactic acid is shown below.



lactic acid

Suggest a value for each bond angle **a**–**c**.

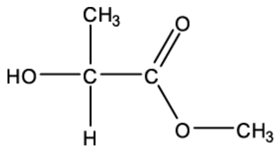
Bond angle **a**: ....

Bond angle **b**: ....

Bond angle **c**: ....

[2]

(b). Methyl lactate is an ester of lactic acid which is used as a solvent.



methyl lactate

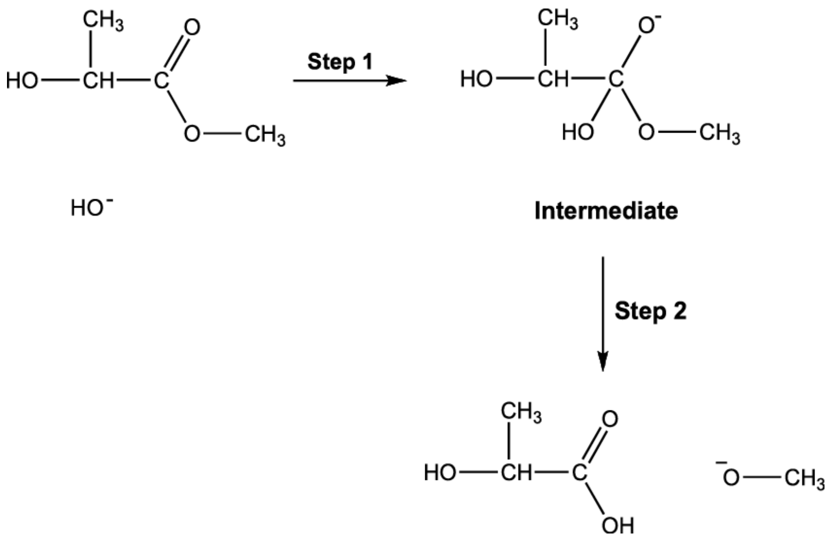
Methyl lactate can be hydrolysed by refluxing with sodium hydroxide solution.

In this reaction the hydroxide ion acts as a nucleophile.

i. Suggest how the hydroxide ion can act as a nucleophile.

[1]

ii. Part of the mechanism for the hydrolysis is shown below.

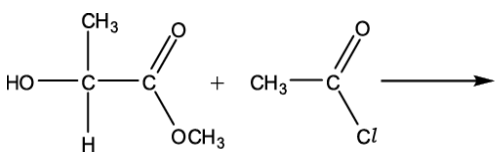


- Add relevant dipoles and curly arrows to show how the intermediate is formed in **Step 1** of the mechanism.
- Add curly arrows to show how the carboxylic acid and $^{-}OCH_3$ ion are formed from the intermediate in **Step 2** of the mechanism.

[4]

iii. Methyl lactate can also react with ethanoyl chloride.

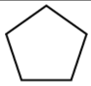
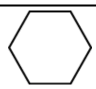
Complete the equation for this reaction.



[2]

9(a). This question is about cyclic organic compounds.

The table shows some information about cycloalkanes.

Cycloalkane	Skeletal formula	Boiling point / °C
Cyclopropane		−33
Cyclopentane		49
Cyclohexane		81

These cycloalkanes are members of the same homologous series and have the same general formula.

i. What is meant by the term *homologous series*?

[2]

ii. State the general formula for these cycloalkanes.

[1]

iii. Explain the increase in boiling points of the cycloalkanes shown in the table.

[2]

(b). The C–C–C bond angles in **cyclohexane** are 109.5°.

State and explain the shape around each carbon atom in cyclohexane.

shape ....

explanation ....

[2]

(c). In the presence of ultraviolet radiation, **cyclohexane** reacts with bromine.

A mixture of cyclic organic compounds is formed, including $C_6H_{11}Br$.

i. Complete the table below to show the mechanism of the reaction between bromine and cyclohexane to form $C_6H_{11}Br$.

Include all possible termination steps in your answer.

Step	Equation
Initiation	....
Propagation	....
Termination	....

[5]

ii. The initiation step involves homolytic fission.

Explain why the initiation step is an example of *homolytic fission.*

[1]

(d). The reaction between cyclohexane and bromine in **(f)** also forms $C_6H_{10}Br_2$.

i. Write an equation, using molecular formulae, for the reaction of cyclohexane and bromine in the presence of ultraviolet radiation to form $C_6H_{10}Br_2$.

[1]

ii. Name **one** of the structural isomers of $C_6H_{10}Br_2$ formed in the reaction between cyclohexane and bromine.

[1]

10. Give chemical explanations for the following statements.

The reaction of ethane with chlorine under UV radiation is a poor method for preparing a high yield of chloroethane.

[1]

11. Alkanes are used as fuels.

i. Construct an equation for the complete combustion of octane C_8H_{18}.

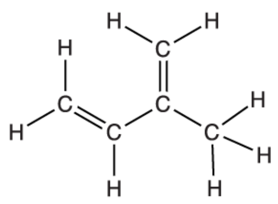
[1]

ii. Combustion of 36.48 g of octane produced 2.50 mol of carbon dioxide.

Show that this combustion was incomplete.

[2]

12. The displayed formula for a hydrocarbon is shown below.



How many σ and π bonds are present in a molecule of this hydrocarbon?

	σ bonds	**π bonds**
A	2	4
B	10	2
C	10	4
D	12	2

Your answer ☐

[1]

13. Chlorine reacts with 1-chloropropane in the presence of ultraviolet radiation via a radical substitution mechanism.

Which equation shows a propagation step in the mechanism for this reaction?

A	Cl_2	→	•Cl + •Cl
B	•Cl + •C_3H_6Cl	→	$C_3H_6Cl_2$
C	C_3H_7Cl + •Cl	→	$C_3H_6Cl_2$ + •H
D	•Cl + C_3H_7Cl	→	•C_3H_6Cl + HCl

Your answer ☐

[1]

14. At room temperature and pressure, the first four members of the alkanes are all gases but the first four alcohols are all liquids.

Explain this difference in terms of intermolecular forces.

[2]

15. Propane reacts with chlorine as shown below.

$CH_3CH_2CH_3 + Cl_2 \rightarrow CH_3CH_2CH_2Cl + HCl$

What is the mechanism of this reaction?

A Electrophilic addition

B Electrophilic substitution

C Radical substitution

D Nucleophilic substitution

Your answer

[1]

16. *Five compounds **B–F** have the boiling points shown below.

Compound	Boiling point / °C
B	−12
C	0
D	35
E	48
F	97

The structural formulae of compounds **B–F** are shown below in no particular order.

$CH_3CH_2CH_2CH_3$, $CH_3CH_2CH_2NH_2$, $CH_3CH_2CH_2OH$, $CH_3CH(CH_3)CH_3$, $CH_3CHCl\ CH_3$

Using this information, identify compounds **B–F**.

Explain your reasoning.

[6]

17. Ethane reacts with chlorine by radical substitution to form chloroethane. Which radical(s) is/are present in the mechanism?

1. H•
2. Cl•
3. C_2H_5•

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer **[1]**

18. Samples of four hydrocarbons are completely burnt under the same conditions of temperature and pressure.

Which sample produces the greatest volume of CO_2?

A 0.4 mol C_2H_6

B 0.3 mol C_3H_8

C 0.2 mol C_4H_{10}

D 0.1 mol C_5H_{12}

Your answer ☐ **[1]**

19. Which organic compound has the lowest boiling point?

A 2,3,4-trimethylpentane

B 2,3-dimethylhexane

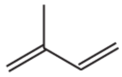
C 2-methylheptane

D octane

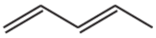
Your answer ☐ **[1]**

20. This question is about unsaturated hydrocarbons.

Compound **A** and compound **B** are isomers.



compound A



compound B

Compound **A** has a lower melting point than compound **B**.

Suggest why.

[2]

21. Within the permafrost in Arctic regions of the Earth, large amounts of methane are trapped within ice as 'methane hydrate', $CH_4{\bullet}xH_2O$. Methane makes up about 13.4% of the mass of 'methane hydrate'.

Scientists are concerned that global warming will melt the permafrost, releasing large quantities of methane into the atmosphere.

Suggest why some industries are interested in the presence of 'methane hydrate' in regions of the Earth.

[1]

22. Alkanes are saturated hydrocarbons with the general formula C_nH_{2n+2}.

A student carries out an experiment to measure the enthalpy change of combustion, $\Delta_c H$, of hexane.

The student finds that combustion of 1.29 g of hexane changes the temperature of 200 g of water from 20.5 °C to 65.5 °C.

i. Calculate the enthalpy change of combustion, Δ_cH, of hexane, in kJ mol^{-1}.

Give your final answer to an **appropriate** number of significant figures.

Δ_cH .... kJ mol^{-1} **[4]**

ii. The calculated value of Δ_cH for hexane from this experiment is different from the data book value.

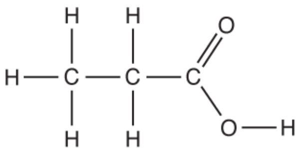
Suggest **two** reasons for this difference.

1

2

[2]

23(a). The displayed formula for propanoic acid is shown below.



i. State the shape and bond angle around a carbon atom in the alkyl group of propanoic acid. Explain the shape.

Shape

Bond angle

Explanation

[2]

ii. Suggest a value for the C–O–H bond angle in propanoic acid.

[1]

(b). 2-Chloropropanoic acid, $CH_3CHClCOOH$, can be made by reacting propanoic acid with chlorine in a radical substitution reaction.

i. State the conditions for the reaction.

[1]

ii. Write the overall equation for the reaction.

[1]

iii. The first step in the reaction mechanism involves homolytic fission of a chlorine molecule to form two chlorine radicals.

Why is this step an example of *homolytic fission*?

[1]

iv. Write **two** equations to show the propagation steps in the mechanism for this reaction.

Use dots,•, to show the unpaired electrons on radicals.

[2]

v. Draw the displayed formula of the radical formed in the first propagation step.

Use a dot,•, to show the position of the unpaired electron.

[1]

vi. Further substitution forms a mixture of organic products.

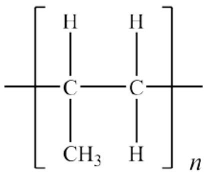
Draw the structure of an organic product formed from 2-chloropropanoic acid by further substitution.

[1]

24. A large proportion of the world's output of organic chemicals is used to make addition polymers. These polymers have a variety of uses.

Poly(propene) is used to make packaging, textiles and rope.

A repeat unit for poly(propene) is shown below.



i. Explain why poly(propene) is a *saturated* hydrocarbon.

[1]

ii. State the bond angle around each carbon atom in poly(propene).

[1]

iii. After polymers have been used for packaging, the waste polymers need to be processed to save resources, for example, by recycling.

Describe **two** other ways in which waste poly(propene) can be processed in a sustainable way.

[2]

25(a). The relative molecular masses and boiling points of some fuels are shown in **Table 22.1**.

Fuel	Relative molecular mass	Boiling point / °C
hexane	86	69
pentan-1-ol	88	138
heptane	100	98

Table 22.1

Write an equation for the incomplete combustion of heptane.

[1]

(b). Explain the difference in the boiling points of the fuels in **Table 22.1**.

[4]

26. 1 mol of a compound reacts with 8 mol O_2 for complete combustion.

What is the formula of the compound?

A C_4H_8

B C_4H_9OH

C $C_5H_{11}OH$

D C_5H_{12}

Your answer **[1]**

27. This question is about energy changes and rate of reaction.

Magnesium reacts with aqueous silver nitrate, $AgNO_3$(aq), as in **equation 23.1.**

$$Mg(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Mg(NO_3)_2(aq)$$ **Equation 23.1**

A student carries out an experiment to determine the enthalpy change of this reaction, $\Delta_r H$.

- The student adds 25.0 cm_3 of 0.512 mol dm^{-3} $AgNO_3$ to a polystyrene cup.
- The student measures the temperature of the solution.
- The student adds a small spatula measure of magnesium powder, stirs the mixture and records the maximum temperature

Temperature readings

Initial temperature	= 19.5 °C
Maximum temperature	= 47.5 °C

i. Calculate $\Delta_r H$, in kJ mol^{-1}, for the reaction shown in **equation 23.1**.

Give your answer to an **appropriate** number of significant figures.

Assume that the density and specific heat capacity, *c*, of the solution are the same as for water and that all the aqueous silver nitrate has reacted.

$\Delta_r H$ = ______________________ kJ mol^{-1} **[4]**

ii. At the end of the experiment, the student adds a few drops of aqueous sodium chloride to the reaction mixture in the polystyrene cup to test whether all the aqueous silver nitrate has reacted.

Explain how the results would show whether all the aqueous silver nitrate has reacted. Include an equation with state symbols in your answer.

____

____

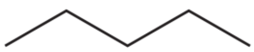
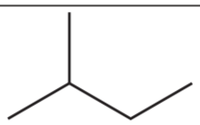
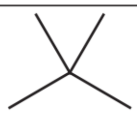
____

[2]

28(a). This question is about saturated hydrocarbons.

Compounds **A**, **B** and **C** are saturated hydrocarbons.

The structures and boiling points of **A**, **B** and **C** are shown below.

	Isomer	Boiling point / °C
A		36
B		28
C		9

- Use the structures to explain what is meant by the term structural isomer.
- Explain the trend in boiling points shown by **A**, **B** and **C** in the table.

[5]

(b). Compounds **A**, **B** and **C** all react with chlorine in the presence of ultraviolet radiation to form organic compounds with the formula $C_5H_{11}Cl$.

i. Name the mechanism for this reaction.

[1]

ii. Complete the table to show the number of structural isomers of $C_5H_{11}Cl$ that could be formed from the reaction of chlorine with **A** and **B**.

	A	**B**
Number of structural isomers	....	....

[2]

iii. The reaction of compound **A** with excess chlorine forms a compound **D**, which has a molar mass of 175.5 g mol^{-1}.

Draw a possible structure for compound **D** and write the equation for its formation from compound **A**. Use molecular formulae in the equation.

Compound D

Equation   **[2]**

29. Which alkane has the highest boiling point?

A $CH_3(CH_2)_5CH_3$

B $(CH_3)_3CCH(CH_3)_2$

C $CH_3(CH_2)_3CH(CH_3)_2$

D $(CH_3)_2CHCH_2CH(CH_3)_2$

Your answer   **[1]**

30. Butane reacts with chlorine in the presence of ultraviolet radiation to form a mixture of organic products.

Which equation shows a propagation step in the mechanism for this reaction?

A $Cl_2 \rightarrow \bullet Cl + \bullet Cl$

B $\bullet Cl + \bullet C_4H_8Cl \rightarrow C_4H_8Cl_2$

C $C_4H_9Cl + \bullet Cl \rightarrow C_4H_8Cl_2 + \bullet H$

D $\bullet Cl + C_4H_9Cl \rightarrow \bullet C_4H_8Cl + HCl$

Your answer   **[1]**

31. Under suitable conditions, butane, C_4H_{10}, reacts with chlorine by radical substitution. A mixture of organic compounds is formed, including C_4H_9Cl , and compounds **D** and **E**.

i. Complete the table below to show the mechanism for the initiation and propagation stages of the reaction of C_4H_{10} with chlorine to form C_4H_9Cl .

In your equations, use molecular formulae and 'dots' (·) with any radicals.

Initiation	Equation Conditions
Propagation	→ →

[3]

ii. Organic compound **D** is formed by substitution of **all** the H atoms in butane by C*l* atoms.

Write the equation for the formation of compound **D** from butane.

Use molecular formulae.

[1]

iii. Organic compound **E** is formed by the substitution of **some** of the H atoms in butane by C*l* atoms.

A chemist found that 0.636 g of compound **E** has a volume of 78.0 cm^3.
Under the conditions used, the molar gas volume is 32.5 $dm^3\ mol^{-1}$.

Determine the molecular formula of compound **E**.

molecular formula = ... **[3]**

32. Which property explains the low reactivity of alkanes?

A Electron pair repulsion between σ-bonds

B Free rotation about σ-bonds

C High C–C bond enthalpy

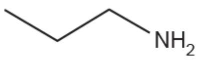
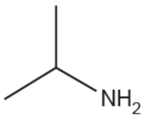
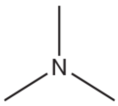
D High polarity of the C–H bonds

Your answer ☐ **[1]**

33. This question is about organic chemistry.

This part is about amines.

i. The table shows the structures and boiling points of three amines, which are structural isomers of C_3H_9N.

Amine	$CH_3CH_2CH_2NH_2$	$(CH_3)_2CHNH_2$	$(CH_3)_3N$
Skeletal formula			
Boiling point / °C	48–49 °C	33–34 °C	3–4 °C

Explain the difference in the boiling points of the three amines.

[4]

ii. Amine **A** is a liquid at room temperature and pressure.

When vaporised, 0.202 g of the amine produces 72.0 cm^3 of gas at 1.00×10^5 Pa and 100 °C. The ^{13}C NMR spectrum of amine **A** has 3 peaks.

Determine the molecular formula of **A** and suggest a possible structure for amine **A**.

Molecular formula of **A** ....

Structure of A

[6]

34. Which statement about bonds is correct?

A The C=C bond in ethene is more polar than the C−C bond in ethane.

B A σ-bond is stronger than a π-bond.

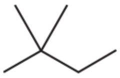
C The H−C−H bond angle in ethane is greater than the H−C−H bond angle in ethene.

D A σ-bond is formed from sideways overlap of p orbitals.

Your answer

[1]

35(a). The structure of hydrocarbon **A** is shown below.



A

Complete the table to show the mechanism for the reaction of hydrocarbon **A** with Br_2 to form $(CH_3)_3CCHBrCH_3$.

Use skeletal formulae for all organic compounds.

Use 'dots' (●) to show the position of unpaired electrons.

Initiation ....
Propagation  + ... → .... + ... + ... → .... + ...

[3]

(b). State **two** limitations of using radical substitution in organic synthesis.

1 ____

____

2 ____

____

[2]

36. Which structural isomer of C_7H_{16} has the weakest induced dipole–dipole interactions (London forces)?

A 2,3-dimethylpentane

B 3-ethylpentane

C 2-methylhexane

D 2,2,3-trimethylbutane

Your answer ☐ **[1]**

37. Which compound contains the smallest bond angle?

A bromoethane

B ethanol

C ethane

D ethene

Your answer [ ] **[1]**

38. 2-Methylbutane is reacted with chlorine by radical substitution.

What is the number of structural isomers with the molecular formula $C_5H_{11}Cl$ that could be formed?

A 2

B 3

C 4

D 5

Your answer [ ] **[1]**

39(a). But-1-ene, $H_2C{=}CHCH_2CH_3$, and buta-1,3-diene, $H_2C{=}CH–CH{=}CH_2$, are unsaturated compounds used to make many organic products.

But-1-ene and buta-1,3-diene have σ-bonds and π-bonds.

i. Explain what is meant by the terms **σ-bond** and **π-bond**.

σ-bond ____

π-bond ____

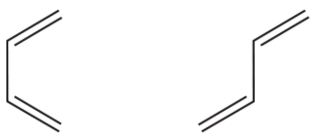
[2]

ii. How many σ- and π-bonds are in one molecule of buta-1,3-diene?

σ-bonds: .... π-bonds: .... **[2]**

(b). A student thought that buta-1,3-diene can show stereoisomerism.

The student drew out skeletal formulae for the stereoisomers of buta-1,3-diene:



i. Explain the term **stereoisomerism**.

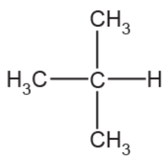
[1]

ii. Explain, with a reason, whether the student is correct or incorrect.

[1]

40(a). Alkane **A**, shown below, reacts with bromine in a radical substitution reaction.

Alkane A



In this reaction with bromine, monosubstitution of alkane **A** forms a mixture of organic products.

Show the structures of **two** monosubstituted organic products that are formed.

[2]

(b). With excess bromine, further substitution takes place.

Write an equation for the reaction of alkane **A** with excess bromine to produce 1,3-dibromo-2-methylpropane.

Use structures for the organic compounds.

[2]

41. Internal combustion engines have historically used fuels obtained from crude oil as a source of power.

The environmental effects of fossil fuel use can be reduced by blending petrol with biofuels such as ethanol.

A fuel is being developed using a 1:1 molar ratio of octane and ethanol.

i. Write the equation for the complete combustion of this fuel.

[1]

ii. Calculate the energy released, in kJ, by the complete combustion of 8.00 kg of this fuel.
$\Delta_c H(C_8H_{18}) = -5470 \text{ kJ mol}^{-1}$; $\Delta_c H(C_2H_5OH) = -1367 \text{ kJ mol}^{-1}$.

energy released = ... kJ **[3]**

42(a). 2-Bromobutane, $CH_3CH_2CHBrCH_3$, can be prepared by several different methods.

The relative molecular mass, M_r, of 2-bromobutane is 136.9.

2-Bromobutane can be prepared by reacting butane with bromine (**Reaction 5.1**).

$CH_3CH_2CH_2CH_3 + Br_2 \rightarrow CH_3CH_2CHBrCH_3 + HBr$ **Reaction 5.1**

The reaction is initiated by the formation of bromine radicals from bromine.

i. State the conditions for the formation of bromine radicals from bromine.

[1]

ii. Write two equations for the propagation steps in the mechanism for **Reaction 5.1**.

Use structural formulae for organic species and dots (·) for unpaired electrons on radicals.

$CH_3CH_2CH_2CH_3$ + ... → .... + ...

.... + ... → .... + ...

[2]

iii. The yield of $CH_3CH_2CHBrCH_3$ is only 30%.

Suggest **two** reasons why the yield of $CH_3CH_2CHBrCH_3$ is so low.

1

2

[2]

(b). 2-Bromobutane can also be prepared by reacting but-2-ene, $CH_3CH{=}CHCH_3$, with hydrogen bromide, HBr (**Reaction 5.2**).

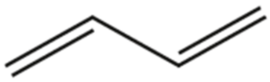
$CH_3CH{=}CHCH_3 + HBr \rightarrow CH_3CH_2CHBrCH_3$ **Reaction 5.2**

Explain, in terms of atom economy, why **Reaction 5.2** is more sustainable than **Reaction 5.1**.

Include calculations to justify your answer.

[2]

43. What is the number of σ-bonds in the molecule below?



A 1

B 3

C 7

D 9

Your answer **[1]**

44. Complete combustion of an alkane forms 30 cm^3 of carbon dioxide and 40 cm^3 of water vapour, under the same conditions of temperature and pressure.

Which alkane has undergone complete combustion?

A butane

B ethane

C heptane

D propane

Your answer **[1]**

45. What is the number of sigma bonds in a molecule of methylbenzene?

A 7

B 10

C 12

D 15

Your answer [ ] **[1]**

46. Which equation(s) could be part of the propagation step in the radical substitution of C_5H_{12} to form $C_5H_{11}Cl$?

1 $C_5H_{11}\bullet + Cl_2 \rightarrow C_5H_{11}Cl + Cl\bullet$

2 $C_5H_{12} + Cl\bullet \rightarrow C_5H_{11}Cl + H\bullet$

3 $C_5H_{11}\bullet + Cl\bullet \rightarrow C_5H_{11}Cl$

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer [ ] **[1]**

47. For complete combustion, 0.100 mol of an alkane requires 22.8 dm^3 of O_2, measured at RTP.

Which alkane has undergone complete combustion?

A pentane

B hexane

C heptane

D octane

Your answer ☐ **[1]**

48(a). This question is about hydrocarbons.

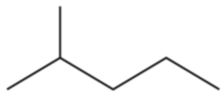
The boiling points of some hydrocarbons containing 6 carbon atoms are shown below.

Hydrocarbon	**Boiling point / ºC**
2,2-dimethylbutane	50
2-methylpentane	60
hexane	69

State and explain the trend in boiling points shown by these hydrocarbons.

[4]

(b). 2-methylpentane reacts with bromine by radical substitution.



2-methylpentane

A mixture of organic products is formed, including 3-bromo-2-methylpentane, and compounds **A** and **B**.

i. Complete the table below to show the mechanism for the formation of 3-bromo-2-methylpentane and **three** possible equations for termination.

In your equations, use **structural or skeletal formulae** and 'dots' (•) for the position of radicals.

Initiation	Equation: .... Conditions: ....
Propagation	⟶ ⟶
Termination	⟶ ⟶ ⟶

[6]

ii. Organic compound **A** is formed by the substitution of **all** 14 H atoms in 2-methylpentane by Br atoms.

Write the equation, using **molecular formulae**, for the formation of compound **A** from 2-methylpentane.

[2]

iii. Organic compound **B** is formed by the substitution of **some** of the 14 H atoms in 2-methylpentane by Br atoms.

0.8649 g of compound **B** is heated until it is vaporised.

Under the conditions used:

- compound **B** has a volume of 72.0 cm^3
- the molar gas volume is 40.0 dm^3 mol^{-1}.

Determine a possible molecular formula of compound **B**.

molecular formula = ... **[3]**

49. This question is about enthalpy changes.

In a petrol engine, alkanes undergo combustion.

i. Heptane is one of the alkanes in petrol.

Write the equation for the complete combustion of heptane.

State symbols are **not** required.

[2]

ii. In a petrol engine, polluting gases such as CO and NO are formed. These are mostly removed before being emitted from the exhaust.

The equation for the removal of CO and NO is shown below.

$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)\ \Delta H = -746\ kJ\ mol^{-1}$

Complete the enthalpy profile diagram in **Fig. 23.1** for this reaction.

On your diagram:

- Label the enthalpy change of reaction, Δ*H*.
- Include the formulae of the reactants and products.
- Label the activation energy, E_a.

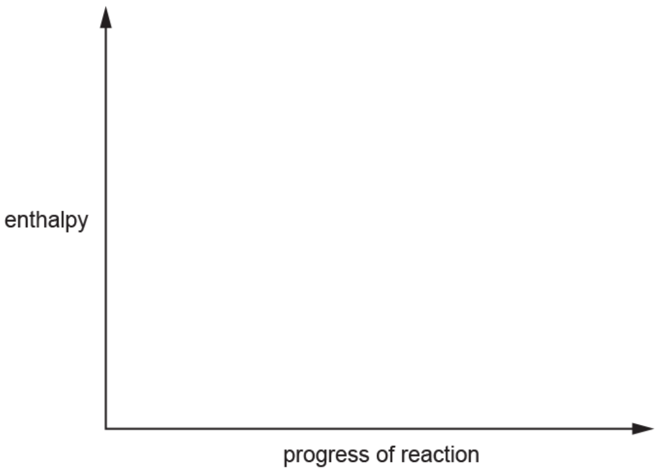


Fig. 23.1

[2]

iii. CO and NO are removed by use of a catalyst.

Explain the role of the catalyst.

Refer to your enthalpy profile diagram in **Fig. 23.1** in your answer.

[2]

50. This question is about hydrocarbons.

Butane reacts with bromine by radical substitution to form a mixture of organic products.

The reaction needs UV radiation for the initiation stage.

Write equations for the propagation stage that follows to form 2-bromobutane.

Use skeletal formulae and 'dots' (•) to show the position of any radicals.

Propagation	→ →

51. Which property explains the low reactivity of alkanes?

A Low C–C bond enthalpy.

B Low bond enthalpy of π- bonds.

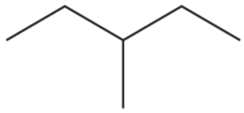
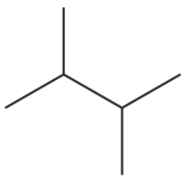
C Low polarity of σ- bonds.

D Low reactivity of carbon and hydrogen.

Your answer **[1]**

52(a). This question is about hydrocarbons.

The skeletal formulae and boiling points of three isomers of C_6H_{14} are shown in the table below.

Isomer	**Molecular formula**	**Skeletal formula**	**Boiling point/°C**
A	C_6H_{14}		69
B	C_6H_{14}		63
C	C_6H_{14}		58

State and explain the trend in the boiling points shown in the table.

Refer to the isomers **A**, **B** and **C** in your answer.

[4]

(b). The hydrocarbon C_2H_6 reacts with bromine, Br_2, to form C_2H_5Br under suitable conditions.

Complete the table below to show the mechanism for the three stages of the reaction of C_2H_6 with Br_2 to form C_2H_5Br.

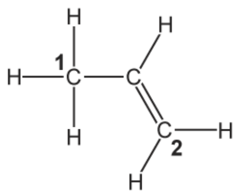
The equation for one of the possible reactions for termination has been completed.

In your equations, use molecular formulae and 'dots' (·) with any radicals.

Initiation	Conditions .... Equation .... → ....
Propagation	**1** .... → .... **2** .... → ....
Termination	**1** Br· + Br· → Br_2 **2** .... → .... **3** .... → ....

[5]

(c). Propene, C_3H_6, has different bond angles and shapes around the carbon atoms. The displayed formula of a propene molecule is shown below.



Predict the bond angles and the names of the shapes around the C atoms **1** and **2** above, and explain why the bond angles and shapes are different.

Carbon atom	Bond angle	Name of shape
1		
2		

Explanation:

[5]

53. Hydrogen reacts much more readily with alkenes than with alkanes.

Why is this?

A Alkenes are polar molecules whereas alkanes are not.

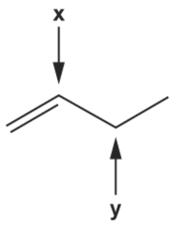
B All atoms in an alkane have a full outer shell of electrons.

C The bond enthalpy of C–C σ bonds is **higher** than that of **π** bonds.

D The bond enthalpy of C–C σ bonds is **lower** than that of **π** bonds.

Your answer ☐ **[1]**

54. The structure of but-1-ene is shown below.



Which row has the correct **shape** around carbon atoms labelled **x** and **y**?

	x	**y**
A	Tetrahedral	Pyramidal
B	Trigonal planar	Tetrahedral
C	Trigonal planar	Pyramidal
D	Pyramidal	Tetrahedral

Your answer ☐ **[1]**

55. Haloalkanes can be synthesised by reacting alkanes with halogens in the presence of ultraviolet radiation.

An alkane reacts with bromine to form 2-bromo-2-methylpropane.

i. Write the equation for this reaction, showing the structures of the organic compounds.

Name the reaction mechanism and the type of bond fission that occurs.

Equation

Name of reaction mechanism

Type of bond fission

[3]

ii. Describe **two** limitations of the synthesis of 2-bromo-2-methylpropane from an alkane and bromine.

1

2

[2]

END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			B	1	
			Total	**1**	
2			Initiation $Cl_2 \rightarrow 2Cl\cdot$ (1) Propagation $C_2H_6 + Cl\cdot \rightarrow C_2H_5\cdot + HCl$ (1) $C_2H_5\cdot + Cl_2 \rightarrow C_2H_5Cl + Cl\cdot$ (1) Termination $Cl\cdot + Cl\cdot \rightarrow Cl_2$ **OR** $C_2H_5\cdot + Cl\cdot \rightarrow C_2H_5Cl$ **OR** $C_2H_5\cdot + C_2H_5\cdot \rightarrow C_4H_{10}$ (1) Initiation, propagation, termination used in correct context (1)	5	If the structure of the ethyl radical is drawn, the lone electron must be attached to a C atom
			Total	**5**	
3		i	Overlap of orbitals directly between the bonding atoms	1	**allow** a correct diagram
		ii	120° **AND** trigonal planar	1	**allow** planar triangle
			Total	**2**	
4		i	CO is toxic	1	**allow** responses linked to effect of CO in blood
		ii	*Calculation:* *n*(butane) = 600/58.0 = 10.34 (mol) **AND** *n*(O_2) required = 6.5 × 10.34 = 67.2 (mol) (1) *n*(O_2) consumed = 1.50 × 10^3 / 24.0 = 62.5 (mol) **OR** volume O_2 required for complete combustion = 67.2 × 24.0/1000 = 1.61 m^3 (1) *Conclusion:* incomplete combustion / stove not safe to use	3	using 1 : 6.5 ratio **allow** number rounding to 67

<table>
<tr><td></td><td></td><td></td><td>AND
62.5 < 67.2 OR 1.61 > 1.50 (1)</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>4</td><td></td></tr>
<tr><td>5</td><td></td><td></td><td>A</td><td>1</td><td></td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>1</td><td></td></tr>
<tr><td>6</td><td></td><td></td><td>Please refer to the marking instruction point 10 for guidance on how to mark this question.

Level 3 (5–6 marks)
A comprehensive description with all three scientific points explained thoroughly with few omissions.

There is a well-developed and detailed description, including correct names of all steps and radicals identified using • consistently; limitations illustrated with examples.

Level 2 (3–4 marks)
Attempts to describe all three scientific points but explanations may be incomplete.
OR
Explains two scientific points thoroughly with few omissions.

The description has some structure including names of some steps linked to correct equations and some radicals identified using •.

Level 1 (1–2 marks)
A simple description based on at least two of the main scientific points.
OR
Explains one scientific point thoroughly with few omissions.

The description is communicated in an unstructured way, including some use of names or dots.

0 marks
No response or no response worthy of credit.</td><td>6</td><td>Indicative scientific points may include:

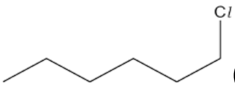
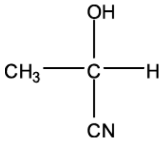
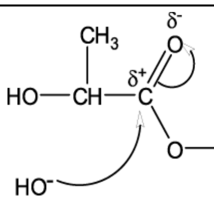
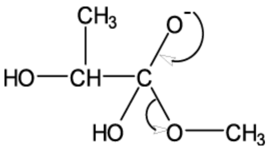
1. Overall equation and conditions
• $C_3H_8 + Cl_2 \rightarrow C_3H_7Cl + HCl$
• Conditions: UV
• Initiation: $Cl_2 \rightarrow 2Cl\bullet$

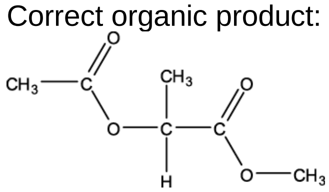
2. Propagation and termination

<table><tr><th>Step names</th><th>Equation</th></tr><tr><td>Propagation</td><td>$C_3H_8 + Cl\bullet \rightarrow C_3H_7\bullet + HCl$
$C_3H_7\bullet + Cl_2 \rightarrow C_3H_7Cl + Cl\bullet$</td></tr><tr><td>Termination</td><td>$C_3H_7\bullet + Cl\bullet \rightarrow C_3H_7Cl$
$C_3H_7\bullet + C_3H_7\bullet \rightarrow C_6H_{14}$
$Cl\bullet + Cl\bullet \rightarrow Cl_2$</td></tr></table>3. Limitations

• Further substitution, e.g. $C_3H_6Cl_2$
• Substitution at different positions on chain, e.g. $CH_3CH_2CH_2Cl$

IGNORE state symbols throughout</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>6</td><td></td></tr>
</table>

7		i	any mono or multiple substituted chlorohexane – e.g.  (1)	1	
		ii	(because) substitution can replace any H atom / multiple substitution *owtte* (1)	1	**ignore** vague statements about free radical reactions being random **allow** termination can join alkyl radicals to form larger hydrocarbons *owtte*
			Total	**2**	
8	a	i		1	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
		ii	**aqueous** acid **OR** H^+ / $\mathbf{H_2O}$	1	**ALLOW** $H^+(aq)$ / $H_2SO_4(aq)$ / HC*l*(aq)
		iii	Angle a = 109.5° Angle b = 104.5° Angle c = 120° **Two** correct All **three** correct	2	**ALLOW** 109–110° **ALLOW** 104–105°
	b	i	It is an electron pair donor **OR** donates a lone pair	1	
		ii	 Curly arrow from HO^- to carbon atom of C=O bond Correct dipole **AND** curly arrow from C=O bond to $O^{\delta-}$ ....  Curly arrow from negative charge on oxygen to C–O bond (to reform carbonyl π-bond)	4	Curly arrow must come from lone pair on O of HO^- **OR** OH^- **OR** from minus sign on HO^- ion (No need to show lone pair if curly arrow came from negative charge on O) **IGNORE** dipole on C–O single bond

			Curly arrow from C–O single bond to oxygen atom (to form methoxide ion)		Curly arrow must come from lone pair on O **OR** from minus sign on O^- ion (No need to show lone pair if curly arrow came from negative charge on O)
		iii	Correct organic product:  HC*l*	2	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
			Total	**11**	
9	a	i	(series of compounds with the) same functional group **OR** same / similar chemical properties **OR** same / similar chemical reactions ✓ each **successive/subsequent** member differing by CH_2 ✓	2	**IGNORE** references to physical properties **IGNORE** has same general formula (in question) **DO NOT ALLOW** have the same empirical formula **OR** have the same molecular formula **Examiner's Comments** Many candidates were able to score both marks by specifying the same functional group and that each successive member varies by a CH_2 group. Some responses were imprecise and referred to just members differing by CH_2 group.
		ii	C_nH_{2n} ✓	1	**Examiner's Comments** Most candidates were able to state the general formula for the cycloalkanes.
		iii	More carbons (in ring) **OR** more (surface area of) contact	2	**Both answers need to be comparisons** **ALLOW** ORA throughout **ALLOW** has more electrons **OR** larger (carbon) ring **OR** higher molecular mass

			AND **more van der Waals** forces **OR stronger van der Waals** forces ✓ More energy needed to break the intermolecular forces ✓		**IGNORE** bigger molecule **IGNORE** chain instead of ring **DO NOT ALLOW** 'more contact between atoms' **ALLOW** 'VDW' for van der Waals 'More intermolecular forces' is **not** sufficient **ALLOW** it is harder to overcome the intermolecular forces **ALLOW** intermolecular bonds / van der Waals bonds **ALLOW** more energy is needed to separate molecules **IGNORE** more energy is needed to break bonds **Examiner's Comments** This was a well answered question and many candidates could relate the difference in boiling point to the increase in points of contact and stronger van derWaals' forces. A significant number of candidates referred to the breaking of bonds rather than intermolecular forces.
	b		tetrahedral ✓ four **bonding** pairs repel **OR** four **bonds** repel ✓	2	**Mark each point independently** **IGNORE** surrounded by four atoms **IGNORE** four areas of electron charge repel **IGNORE** four electron pairs repel (*one could be lp*) **DO NOT ALLOW** atoms repel **Examiner's Comments** Most candidates were able to state the shape required. Explanations for the bond angle often focused on the four bond pairs around the carbon atom, however candidates did not always refer to repulsion between these electron pairs.
	c	i	| Step | Equation |	5	**IGNORE** state symbols **IGNORE** dots

			<table><tr><td>**Initiation** (1 mark)</td><td>$Br_2 \rightarrow 2Br\bullet$ ✓</td></tr><tr><td>**Propagation** (2 marks)</td><td>$C_6H_{12} + Br\bullet \rightarrow C_6H_{11}\bullet + HBr$ ✓ $C_6H_{11}\bullet + Br_2 \rightarrow C_6H_{11}Br + Br\bullet$ ✓</td></tr><tr><td>**Termination** (2 marks)</td><td>$C_6H_{11}\bullet + Br\bullet \rightarrow C_6H_{11}Br$ $C_6H_{11}\bullet + C_6H_{11}\bullet \rightarrow C_{12}H_{22}$ $Br\bullet + Br\bullet \rightarrow Br_2$ **Two** correct ✓ All **three** correct ✓✓</td></tr></table>		If an incorrect hydrocarbon with **six** C atoms is used: **DO NOT ALLOW** any marks for the propagation steps but **ALLOW** ECF for termination steps *(i.e. 3 max)* **Examiner's Comments** This question required candidates to apply their knowledge of the radical substitution mechanism and those who had prepared well scored full marks. A common misconception was to have hydrogen radicals being formed and reacted in propagation and termination steps.
		ii	The breaking of a (Br-Br) bond **AND** forms (two) radicals **OR** the breaking of a (Br-Br) bond **AND** one electron (from the bond pair) goes to each atom / bromine ✓	1	**ALLOW** 'the breaking of a covalent bond' **ALLOW** the splitting of the bond in bromine **ALLOW** the breaking of a covalent bond where each atom keeps one of the bonding electrons **IGNORE** particle for atom **ALLOW** one electron goes to each product / species **DO NOT ALLOW** molecule or compound for atom **IGNORE** homolytic fission equations **Examiner's Comments** This question was better attempted than in previous sessions. Although many candidates were able to identify that radicals were formed, a significant number did not refer to the breaking of the covalent bond in Br_2.
	d	i	$C_6H_{12} + 2Br_2 \rightarrow C_6H_{10}Br_2 + 2HBr$ ✓	1	**ALLOW** molecular formula only. **Examiner's Comments** This question proved quite difficult for the vast majority of candidates who failed to apply their knowledge of radical substitution to an unfamiliar example. The most common

					incorrect answer was $C_6H_{12} + Br_2 \longrightarrow C_6H_{10}Br_2 + H_2$.
		ii	1,1-dibromocyclohexane **OR** 1,2-dibromocyclohexane **OR** 1,3-dibromocyclohexane **OR** 1,4-dibromocyclohexane ✓	1	Locant numbers **MUST** lowest possible e.g. **DO NOT ALLOW** 2,4-dibromocyclohexane etc. **IGNORE** structures **Examiner's Comments** Candidates were required to name one of the dibromocyclohexane compounds that could be formed from cyclohexane and the more able candidates were able to apply their understanding of nomenclature successfully. Common incorrect responses included straight chain dibromo compounds e.g. 1,2—dibromohexane and incorrect use of locant numbers e.g. 2,3—dribromocyclohexane.
			Total	**15**	
10			Further substitution occurs	1	**ALLOW** multiple substitution occurs **ALLOW** examples of further substitution products
			Total	**1**	
11		i	$C_8H_{18} + 12½O_2 \rightarrow 8CO_2 + 9H_2O$ ✓	1	**ALLOW** multiples e.g. $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$ **IGNORE** state symbols **Examiner's Comments** Almost all candidates could provide a correctly balanced equation for the complete combustion of octane.
		ii	(n(C_8H_{18}) burned) = 0.32 (mol) ✓ (n(CO_2) from complete combustion) = 2.56 **or** 2.6 mol **OR** (ratio nCO_2 / nC_8H_{18}) = 7.8(125) **OR** (n C_8H_{18} produce 2.5 mol CO_2) = 0.31(25) ✓	2	**DO NOT ALLOW ECF** from an incorrect moles of octane **DO NOT ALLOW ECF** from incorrect ratio from equation in **(i)**

					ALLOW the following alternate methods
					Method 1 (mass CO_2 produced) = 110 g ✓ (mass CO_2 from complete combustion) = 8 × 0.32 × 44 = 112.64 **or** 112.6 **or** 113 g ✓
					Method 2 (*n* C_8H_{18} to produce 2.5 mol CO_2) = 0.31(25) ✓ (mass of octane required to produce 2.50 mol CO_2) = 35.6 **OR** 35.63 **OR** 35.625 g ✓ **Examiner's Comments** Candidates coped well with this unfamiliar question. Almost all candidates recognised the need to calculate the number of moles of octane combusted and received the first mark. The majority of candidates were able to process this to show that 2.56 moles of carbon dioxide should have been produced. It was encouraging to see a range of alternative approaches adopted by candidates. For example, some used the calculated moles of octane and the amount of CO_2 given in the question to show that the reacting ratio was less than 8. The mark scheme allowed full marks for all valid responses.
			Total	**3**	
12			D	1	**Examiner's Comments** B was a common incorrect answer

					with the sigma bond not counted as part of a double bond.
			Total	**1**	
13			D	1	**Examiner's Comments** Generally scored well.
			Total	**1**	
14			Alcohols have hydrogen bonds (and van der Waals' forces) ✓ Hydrogen bonds are stronger than van der Waals' forces (in alkanes) ✓	2	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **ALLOW** reference to specific compounds e.g. comparing methane and methanol Second marking point requires **BOTH** types of intermolecular forces in response i.e comparison of hydrogen bonds **AND** van der Waals is **essential** **DO NOT ALLOW** the second mark for a comparison of van der Waals' and hydrogen bonds between alcohols and water **ALLOW** more energy required to break hydrogen bonds than van der Waals' forces **ALLOW** it is harder to overcome the hydrogen bonds than van der Waals' forces **IGNORE** more energy is needed to break bonds **Examiner's Comments** Many candidates attributed the difference in boiling point between alkanes and alcohols to the relative strength of hydrogen bonds compared with van der Waals' forces. Weaker responses simply identified alcohols as being able to form hydrogen bonds, but failed to compare these with van der Waals' forces.
			Total	**2**	

15			C	1	
			Total	**1**	
16			**Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.* **Level 3 (5–6 marks)** Identifies most of the compounds. **AND** A comprehensive explanation with most of the scientific points and few omissions. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated* **Level 2 (3–4 marks)** Identifies some of the compounds. **AND** Explanation covers some of the scientific points and few omissions. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1–2 marks)** Attempts to identify a few of the compounds. **AND** A basic explanation based on intermolecular forces. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	6	**Indicative scientific points may include:** **<u>Compounds B-F</u>** • **B** is $CH_3CH(CH_3)CH_3$ • **C** is $CH_3CH_2CH_2CH_3$ • **D** is $CH_3CHClCH_3$ • **E** is $CH_3CH_2CH_2NH_2$ • **F** is $CH_3CH_2CH_2OH$ **<u>Intermolecular forces</u>** • $CH_3CH(CH_3)CH_3$ and $CH_3CH_2CH_2CH_3$ have London dispersion/induced dipole-dipole forces. • $CH_3CHClCH_3$ has permanent dipole-dipole (and London dispersion/induced dipole-dipole forces). • $CH_3CH_2CH_2NH_2$ and $CH_3CH_2CH_2OH$ have hydrogen bonding (and London dispersion/induced dipole-dipole forces). • The stronger the intermolecular force, the higher the boiling point as more energy is required to overcome intermolecular forces. • Relative strength: hydrogen bonds > permanent dipole-dipole > London dispersion forces. **<u>Affect of structure</u>** • $CH_3CH(CH_3)CH_3$ is branched and $CH_3CH_2CH_2CH_3$ is straight chain. • $CH_3CH(CH_3)CH_3$ has less points of contact.

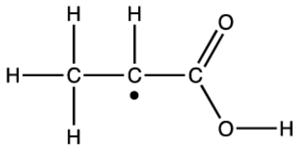
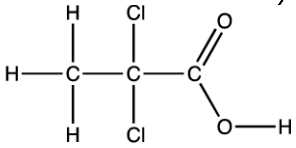
					• London dispersion/induced dipole-dipole forces are weaker in branched structures. • $CH_3CH_2CH_2OH$ has stronger H bonds than $CH_3CH_2CH_2NH_2$ **OR** more H bonds than $CH_3CH_2CH_2NH_2$ • O is more electronegative than N **OR** O has two lone pairs (and N has one)
			Total	**6**	
17			C	1	**Examiner Comments** Once the Candidates had realised that hydrogen radicals do not appear in the mechanism for a radical substitution reaction of an alkane, the answer C was given. Almost 90% of candidates scored this mark.
			Total	**1**	
18			B	**1**	**Examiner's Comments** Able candidates answered this question correctly, with answer option A being a common distractor.
			Total	**1**	
19			A	**1**	**Examiner's Comments** The majority of candidates correctly identified answer option A as the lowest boiling point alkane. The common incorrect answer was D, the complete opposite as it is the least branched and longest chain.
			Total	**1**	
20			Compound **A** (is branched so) has less points of contact / less surface interaction between molecules ✓	**2**	**Both answers need to be comparisons** **ALLOW ORA** throughout **DO NOT ALLOW** 'more contact between atoms'

			Induced dipole–dipole interactions **/** London (dispersion) forces are weaker. **AND** Require less energy to break (these interactions / forces) ✓		**IGNORE** van der Waals' forces/VDW for induced dipole–dipole interactions (ambiguous as this term refers to both permanent dipole – dipole and induced dipole–dipole forces) **ALLOW** fewer induced dipole-dipole interactions. **IGNORE** it is easier to break the induced dipole-dipole / London forces. (reference to energy required) **IGNORE** less energy required to separate molecules **IGNORE** less energy is needed to break the bonds. **Examiner Comments** This question was less well answered than on the more traditional legacy papers with only 30% of candidates gaining both marking points. Common mistakes included the use of surface area without reference to points of contact, reference to van der Waal's forces previously accepted but not in the new specification and failing to mention more energy being required to break the intermolecular forces. For clarification on the use of van der Waal's forces please refer to page 20 of the current specification.
			Total	**2**	
21			For fuel **OR** energy ✓	**1**	**ALLOW** responses linked with energy. e.g. • to generate electricity • for burning / heat **ALLOW** (chemical) feedstock **IGNORE** cooking **Examiner's Comment:** Most candidates correctly identified that industry might use methane as a fuel or for production of energy. Credit was also allowed for use as a chemical feedstock. A small number effectively rewrote

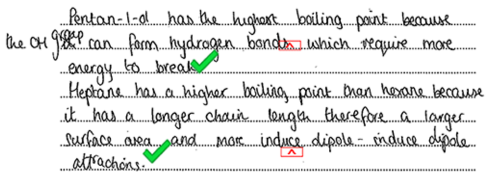
					the question without stating how industry could use the methane.
			Total	**1**	
22		i	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = −2510 (kJ mol^{-1}) award 4 marks** **IF answer = 2508 / 2507 (kJ mol^{-1}) award 3 marks** *(not rounded to 3SF, ignore sign)* **IF answer = + 2510 (kJ mol^{-1}) award 3 marks** *(incorrect sign)* **IF answer = −2510000 (kJ mol^{-1}) award 3 marks** *(used J instead of kJ)* .... *Moles* n(C_6H_{14}) = 0.0150 mol ✓ *Energy* q calculated correctly = 37620 (J) **OR** 37.620 (kJ) ✓ *Calculating ΔH* Correctly calculates ΔH in kJ mol^{-1} **AND** to **3 or more SF** ✓ *Rounding **AND** sign* calculated value of Δ*H* rounded **to 3 SF** **AND** '-'sign ✓	**4**	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** moles = 1.29/86.0 **IGNORE** trailing zeros *q* = 200 × 4.18 × 45.0 **ALLOW** correctly rounded to 3 sig figs: 37.6 kJ **ALLOW** ECF from incorrect q **ALLOW ECF** from incorrect molar mass or incorrect moles of hexane to 3 SF or more correctly rounded **IGNORE** sign at this intermediate stage **IGNORE** working Δ*H* = 37.62/0.015 = 2508 (kJ mol^{-1}) Δ*H* = 37.6/0.015 = 2507 (kJ mol^{-1}) Δ*H* = −2510 (kJ mol^{-1}) Final answer must have '−' **sign** and **3 SF** **Examiner's Comments** A high proportion of candidates lost marks on this question for a variety of reasons including errors in the calculation of moles and / or energy

					change. Many candidates did not express their final answer to three significant figures and so failed to score the final mark. An incorrect or missing sign also resulted in loss of the final mark.
		ii	**Any two from the following:** ✓✓ • Heat released to the surroundings • Incomplete combustion • Non-standard conditions	**3**	**ALLOW** heat loss **ALLOW** incomplete reaction **OR** not everything burns **IGNORE** reference to evaporation **Examiner's Comment:** Almost all candidates scored at least one mark for this well-rehearsed practical question. There was some confusion regarding the use of average bond enthalpy values obtained from a data book which was not relevant to this question.
			Total	**6**	
23	a	i	Tetrahedral **AND** 109.5(°) ✓ four **bonded** pairs repel **OR** four **bonds** repel ✓	**2**	**Mark each point independently** **ALLOW** range 109 – 110° **IGNORE** surrounded by four atoms **IGNORE** four areas of electron charge repel **IGNORE** four electron pairs repel (*one could be lp*) **DO NOT ALLOW** atoms repel **Examiner's Comments** This question was poorly answered. Many candidates ignored the instruction to give the shape around the carbon atom in the alkyl group and instead focussed on the bond angle and shape around the carbonyl carbon. Even candidates who could identify the correct shape and bond angle did not explain that it is due to

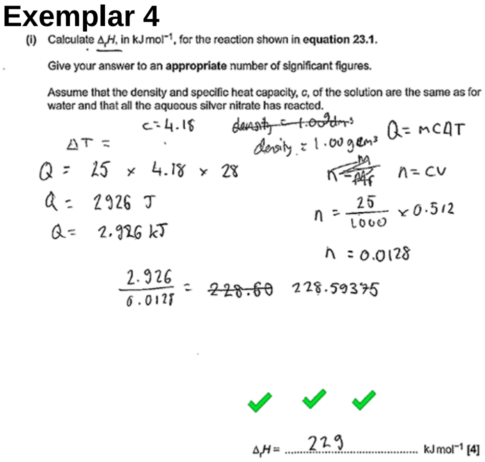
		iv			the repulsion between four bonding pairs.
		ii	104.5(°) ✓	**1**	**ALLOW** range 104 – 105° **Examiner's Comments** Generally well answered but many examples of incorrect bond angles including 107, 120 and 180 were seen here.
	b	i	Ultraviolet (radiation)/UV ✓	**1**	**ALLOW** sunlight **IGNORE** temperature **Examiner's Comments** Most candidates scored this mark.
		ii	$CH_3CH_2COOH + Cl_2 \rightarrow CH_3CHClCOOH + HCl$ ✓	**1**	**ALLOW** $C_2H_5COOH + Cl_2 \rightarrow C_2H_4ClCOOH + HCl$ **ALLOW** $C_3H_6O_2 + Cl_2 \rightarrow C_3H_5ClO_2 + HCl$ **Examiner's Comments** Many candidates could write the overall equation but there was some confusion with propagation steps and some equations contained radicals or missed out HC*l* as a product.
		iii	one electron from the bond (pair) goes to each atom / chlorine/radical ✓	**1**	**ALLOW** the breaking of a covalent bond where each atom keeps one of the bonding electrons **IGNORE** particle for atom **ALLOW** one electron from the bond goes to each product / species **DO NOT ALLOW** molecule or compound for atom **IGNORE** homolytic fission equations **Examiner's Comments** Homolytic fission is described in the specification in terms of each bonding atom receiving one electron from the bonded pair forming two radicals. A large proportion of candidates failed to match the essential points in this definition.
		iv	*Propagation step 1*	**2**	**ALLOW** 1. $Cl\cdot + C_3H_6O_2 \rightarrow C_3H_5O_2\cdot + HCl$

			$Cl\cdot + CH_3CH_2COOH \rightarrow CH_3CHCOOH\cdot$ + HCl ✓ *Propagation step 2* $CH_3CHCOOH\cdot + Cl_2 \rightarrow$ $CH_3CHClCOOH + Cl\cdot$ ✓		2. $C_3H_5O_2\cdot + Cl_2 \rightarrow C_3H_5ClO_2 + Cl\cdot$ **ALLOW** dot at any position on the radical **ALLOW** 1 mark if both equations correct but any dots omitted from radicals **Examiner's Comments** Generally well answered. Candidates took note of the instruction in the question and it was very rare to see radicals without their unpaired electron.
		v	 ✓	1	Dot shown in correct position **ALLOW** –OH **Examiner's Comments** Unfortunately, candidates who were not able to attempt equations for the propagation steps in part (iv) were then unable to suggest the structure of the radical formed in the first step. Many candidates did not present a fully displayed formula. However, formulae showing –OH were given credit in this question.
		vi	Any structure with two or more Cl atoms on alkyl chain (provided that one Cl is at C–2)  e.g.✓	1	**ALLOW** correct structural **OR** skeletal **OR** displayed formula **OR** mixture of the above **DO NOT ALLOW** $C_3H_4Cl_2O_2$ **ALLOW** further substitution into any or all of the 4 positions occupied by H atoms in the alkyl group, provided that at least one Cl is at C–2 **Examiner's Comment:** Generally well answered but it was clear from some of the structures drawn that some candidates did not understand what is meant by further substitution.

			Total	**10**	
24		i	(because) molecule contains only single C–C bonds (1)	1	**allow** no multiple bonds / no double or triple bonds **allow** contains single bonds only
		ii	109.5°	1	
		iii	Combustion for energy production (alternative to fossil fuels) (1) Use as an organic feedstock (1)	2	
			Total	**4**	
25	a		$C_7H_{16} + 7^1/_2O_2 \rightarrow 7CO + 8H_2O$ **OR** $C_7H_{16} + 4O_2 \rightarrow 7C + 8H_2O$ ✓	**1**	**ALLOW** multiples **IGNORE** state symbols **ALLOW** equations for incomplete combustion that give CO and/or C with CO_2 e.g $C_7H_{16} + 9O_2 \rightarrow 4CO + 3CO_2 + 8H_2O$ $C_7H_{16} + 6O_2 \rightarrow 4CO + 3C + 8H_2O$ **<u>Examiner's Comments</u>** The majority of candidates were able to provide a correct equation for the incomplete combustion of heptane.
	b		**Heptane compared to hexane** heptane (has a longer chain so) has more points of contact / more surface interaction (between molecules) ✓ heptane has stronger/more induced dipole(–dipole) interactions ✓ **Pentan-1-ol compared to heptane and/or hexane** pentan-1-ol has hydrogen bonds that are strong(er than induced dipole–dipole interactions) **OR** (alcohols have) hydrogen bonds and induced dipole(-dipole) interactions/London forces ✓ **Energy required to break forces** More energy is required to break induced	**4**	**ANNOTATE WITH TICKS AND CROSSES** **ALLOW ORA** throughout **ALLOW** heptane has more electrons **IGNORE** IDID **ALLOW** stronger/more London forces **IGNORE** van der Waals' forces/VDW for induced dipole–dipole interactions *(ambiguous as this term refers to both permanent dipole–dipole interactions and induced dipole–dipole interactions)* **IGNORE** 'pentan-1-ol can form hydrogen bonds with water' **ALLOW** 'more energy to break intermolecular forces' if intermolecular forces are not stated.

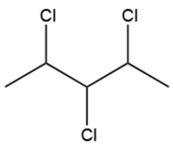
			dipole(–dipole) interactions in heptane than hexane **OR** More energy is required to break hydrogen bonds ✓		**IGNORE** it is harder to break the intermolecular forces *no reference to energy)* **IGNORE** more energy needed to separate molecules **IGNORE** more energy is needed to break bonds **<u>Examiner's Comments</u>** This question was answered well with most candidates scoring three or four marks. Examiners were impressed by the number of responses that accurately referred to induced dipole-dipole interactions or London forces rather than van der Waals' forces, which is ambiguous. Some responses lacked detail, as demonstrated in Exemplar 10. **Exemplar 10**  This response attributes the higher boiling point of pentan-1-ol to the amount energy required to break hydrogen bonds. However, it does not refer the relative strength of this type of interaction. Consequently, the first paragraph only scores marking point four and not marking point three. The higher boiling point of heptane compared to hexane is explained by a correct comparison of the induced dipole-dipole interactions present in these compounds, so marking point two was achieved. However, the justification for the difference in intermolecular forces lacks precision. Candidates should be encouraged to focus on surface contact or surface interaction between molecules rather than referring to surface area alone.

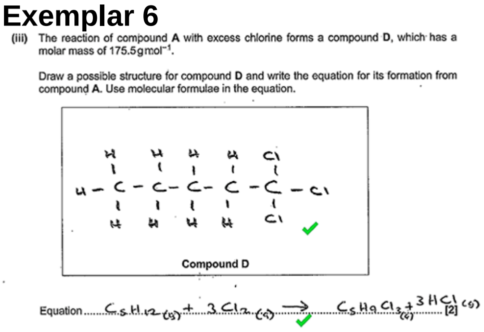
			Total	**5**	
26			**D**	**1**	**Examiner's Comments** Most candidates selected A or D, with D being the correct option. Presumably, A was chosen by halving the '8' in C_4H_8 without considering that each H_2O molecule contains two H atoms. The successful answer of D usually resulted from the candidate constructing equations.
			Total	**1**	
27		i	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF Δ_rH = −457 OR −458 (kJ mol^{-1}) award 4 marks** **IF Δ_rH = ±229 OR 457 (kJ mol^{-1}) award 3 marks** ------------------------------------ ***Energy released in J OR kJ*** = 25.0 × 4.18 × 28.0 = 2926 (J) **OR** 2.926 (kJ)✓ ***Correctly calculates n($AgNO_3$)*** $= 0.512 \times \frac{25.0}{1000} = 1.28 \times 10^{-2}$ (mol) ✓ **ΔH per mole $AgNO_3$ in kJ AND 3 SF** *Answer **MUST** divide energy by n($AgNO_3$)* $\pm \frac{2.926}{1.28 \times 10^{-2}}$ = ±228.59375 = ±229 (kJ) ✓ **3 SF** needed Sign **NOT** needed **ΔH for 2 mol $AgNO_3$ AND – sign AND** 3 SF ΔHr = 2 × −228.59375 = −457 (kJ mol^{-1}) OR 2 × −229 = −458 (kJ mol^{-1}) ✓	**4**	***FULL ANNOTATIONS MUST BE USED*** -- **ALLOW ECF** throughout --------------------------------------- **ALLOW** 2930 J **OR** 2.93 kJ **DO NOT ALLOW** < 3 SF **IGNORE** any sign **and** units *i.e. **ALLOW** correctly calculated number in J **OR** kJ* -- ---- **Alternative approach** using 1 mol Mg Energy released = 2926 (J) OR 2.926 (kJ) ✓ n($AgNO_3$) = 1.28×10^{-2} (mol) ✓ $n(\text{Mg}) = \frac{1.28 \times 10^{-2}}{2}$ = 6.4×10^{-3} (mol) ✓ $\Delta H_r = \frac{2.926}{6.4 \times 10^{-3}}$ = –457 (kJ mol^{-1}) **– sign AND** 3 SF needed **Examiner's Comments**

					Candidates are well-versed with the relationship q = mcΔT and most were able to calculate that 2.926 kJ of energy was released in this reaction. It was also common to see the amount of $AgNO_3$ correctly calculated as 1.28×10^{-3} mol. Candidates were expected to determine the amount of energy released from 1 mol AgNO3 as 229 kJ and finally to multiply this value by 2 for the molar quantities in the equation to match the 'enthalpy change of reaction'. It was common to see −229 given as the final answer but this was rarely multiplied by 2. The question also required the final answer to be given to an appropriate number of significant figures. Many candidates seemed to be unaware that this reflects the least significant figure provided in the data, in this case 3 significant figures. The exemplar shows a typical response for 3 of the available 4 marks. Many omitted the negative sign in their Δ*H* value to consider the exothermicity of the reaction. Candidates are also advised to only round at the end of a multi-step calculation. Rounding of intermediate values introduces rounding errors in the final answer. Answer = −457 kJ mol^{-1} **Exemplar 4** 
		ii	$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$ ✓ **State symbols required**	**2**	**ALLOW** $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

			White precipitate **AND** $AgNO_3/Ag^+$ **NOT ALL** reacted **OR** **NO** white precipitate **AND** AgNO3/Ag^+ **ALL** reacted ✓		Observation needs to be linked to conclusion **<u>Examiner's Comments</u>** Most candidates recognised that silver nitrate and chloride ions react together to form a white precipitate, but many did not make the link between this observation and whether any silver nitrate was left unreacted. Many candidates did not give a correct equation, with missing or incorrect state symbols being common. This question discriminated extremely well.
			Total	**6**	
28	a		**Structural isomers:** *1 mark* Different structural formulae AND same molecular formula ✓ **Common molecular formula:** *1 mark* C_5H_{12} for all 3 hydrocarbons ✓	**5**	For 'structural': **ALLOW** different structure **OR** different displayed/ skeletal formula **DO NOT ALLOW** any reference to spatial/space/3D Same formula is **not** sufficient (no 'molecular') Different arrangement of atoms is **not** sufficient (no 'structure'/'structural') **ALLOW** 5 carbons and 12 hydrogens **ALLOW** for 2 marks: Different structural formulae **AND** same molecular formula ✓ of C_5H_{12} ✓ **Comparisons** needed throughout **ORA** throughout **ALLOW** comparison between any alcohols, e.g. **A** is least branched and has highest

			Boiling point and branching: *1 mark* Boiling point decreases with more branching **OR** more methyl/alkyl groups/side chains **OR** shorter carbon chain ✓ **Branching and London forces:** *1 mark* *Could be seen anywhere within response* More branching gives less (surface) contact **AND** fewer/weaker London forces ✓ **Energy and intermolecular forces:** *1 mark* Less energy to break London forces/ intermolecular forces/intermolecular bonds/ ✓		b pt **C** is most branched and has lowest b pt **ALLOW** induced dipole(−dipole) interactions **IGNORE** van der Waals'/vdw forces **ALLOW** SA for surface area **ALLOW** 'harder to overcome intermolecular forces **ALLOW** more energy to separate the molecules **IGNORE** just 'bonds' ***intermolecular/London forces*** *required* **Examiner's Comments** This question discriminated well and resulted in a full range of marks. Most candidates were aware that structural isomers have different structural formulae but the same molecular formulae. It was common though for candidates to refer to different arrangements of atoms in space, clearly confusing with stereoisomerism. The best candidates used the structures (as in the question) to show that the common molecular formula was C5H12. Candidates were expected to link the amount of surface contact between molecules with induced dipole–dipole forces or London forces. 'Contact' or the name of the intermolecular forces was often omitted. Finally, candidates were expected to link the amount of branching to the strength of the intermolecular forces and the energy needed to change state. Lower ability candidates often let themselves down by being unable to construct a well-reasoned response. There was often a gulf between the clear responses of able candidates and those of lower ability candidates.

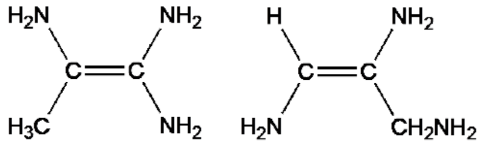
	b		Enter text here.	Enter text here.	Enter text here.
		i	Radical substitution ✓	**1**	**ALLOW** Free radical substitution **<u>Examiner's Comments</u>** Most candidates identified this reaction as radical substitution.
		ii	<table><tr><th>A</th><th>B</th></tr><tr><td>3 ✓</td><td>4 ✓</td></tr></table>	**2**	**<u>Examiner's Comments</u>** Most candidates achieved at least one mark, particularly for isomer **A**. Successful candidates often drew structures of the isomers alongside the table to help with their response.
		iii	**Structure of D** Structure of a trichloro isomer of **A**, e.g.  ✓ **ALLOW** any trichloro isomer of A **CHECK** carefully **Equation** $C_5H_{12} + 3Cl_2 \rightarrow C_5H_9Cl_3 + 3HCl$ ✓ **Molecular formulae required** **NO ECF** from incorrect structure of **D**	**2**	**ALLOW** correct structural **OR** displayed **OR** skeletal formula **OR** mixture of the above (as long as unambiguous) **IGNORE** molecular formula **ALLOW** multiples, e.g. $2C_5H_{12} + 6Cl_2 \rightarrow 2C_5H_9Cl_3 + 6HCl$ **<u>Examiner's Comments</u>** Many candidates correctly drew the structure of compound D but comparatively few were able to construct a correct equation. For this equation, candidates needed to apply their knowledge and understanding of monosubstitution of alkanes to substitution of three H atoms by three Cl atoms. This task proved to be one of the most difficult

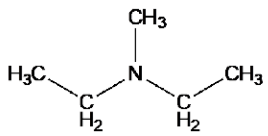
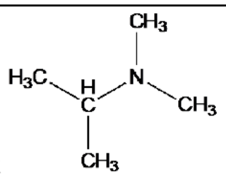
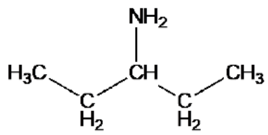
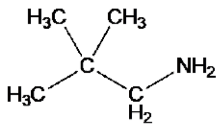
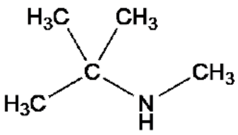
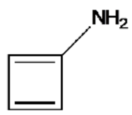
					questions on this paper. The exemplar shows an excellent response. The candidate has drawn a trisubstituted structure that fits the molar mass of 175.5 g mol^{-1} and a correct equation for its formation. Many attempts at this equation showed H2 as the second product rather than HCl. **Exemplar 6** 
			Total	**10**	
29			**A**	1 (AO 1.2)	
			Total	**1**	
30			**D**	1 (AO 2.1)	
			Total	**1**	
31		i	**Initiation** $Cl_2 \rightarrow 2Cl\cdot$ **AND** UV ✓ **Propagation** $C_4H_{10} + Cl\cdot \rightarrow C_4H_9\cdot + HCl$ ✓ $C_4H_9\cdot + Cl_2 \rightarrow C_4H_9Cl + Cl\cdot$ ✓	3 (AO1.1) (AO2.5) (AO2.5)	Dots **NOT** required for initiation **IGNORE** temperature **OR** pressure Dots **required** in each propagation equation **ALLOW** 1 mark for **BOTH** propagation equations with any dots missing or extra dots e.g. $C_4H_{10} + Cl \rightarrow C_4H_9 + HCl$ $C_4H_9\bullet + Cl_2\bullet \rightarrow C_4H_9Cl + Cl$ **DO NOT ALLOW** charges **<u>Examiner's Comments</u>** A minority of Many candidates scored all 3 marks for this part, showing that most had thoroughly learnt the mechanism for radical substitution. The equation and

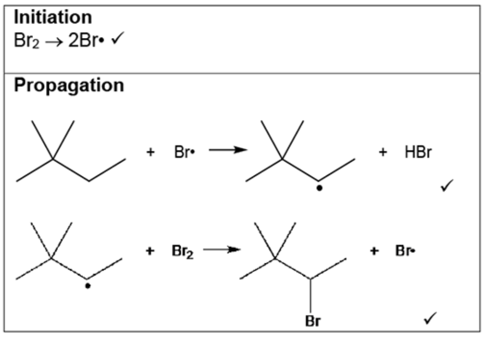
					conditions for the initiation step were well-known but the equations for the propagation steps often included errors. It was common for dots to be omitted for some radicals and $C_4H_9Cl\cdot$, rather than $C_4H_9\cdot$, was often shown for one of the products in the first propagation stage. H· was then shown as the other product.
		ii	$C_4H_{10} + 10\ Cl_2 \rightarrow C_4Cl_{10} + 10\ HCl$ ✓	1 (AO2.6)	**ALLOW** structural formulae, e.g. $CH_3CH_2CH_2CH_3 + 10Cl_2$ $\rightarrow CCl_3CCl_2CCl_2CCl_3 + 10HCl$ **Examiner's Comments** Only the highest attaining candidates were able to write the correct equation. Although most candidates did identify the organic product as C_4Cl_{10}, the other product was usually seen as $5H_2$ rather than 10HCl.
		iii	$n(\mathbf{E}) = \frac{78.0}{32500} = 2.4(0) \times 10^{-3}$ (mol) ✓ $M(\mathbf{E}) = \frac{0.636}{2.4(0) \times 10^{-3}}$ **OR** 265 ✓ Molecular formula = $C_4H_4Cl_6$ ✓	3 (AO3.1×2) (AO3.2)	**ALLOW ECF** from incorrect n(**E**) **ALLOW ECF** from incorrect M(**E**) from n(**E**) -- **COMMON ERROR** $n(\mathbf{E}) = \frac{78.0}{24000} = 3.25 \times 10^{-3}$ (mol) × $M(\mathbf{E}) = \frac{0.636}{3.25 \times 10^{-3}} = 195.69$ **OR** 196 ✓ *(3SF or more)* Molecular formula = $C^4H^6Cl^4$ ✓ **ALLOW ECF** for molecular formula but must be derived from a calculated value for M(**E**) **Examiner's Comments**

					A minority of This question discriminated very well. It was encouraging to see the number of candidates who used 32.5 dm^3 mol^{-1} as the molar gas volume under the experimental conditions to obtain 2.40 × 10^{-3} mol of gas. Many though used 24.0 dm3 mol^{-1} for RTP and obtained 3.25 × 10^{-3} mol. Error carried forward allowed such candidates to still secure the final 2 of the 3 marks available. Lower attaining candidates were unsure where to start and tried to do anything with the number provided. The result was often n unusable number.
			Total	**7**	
32			**C**	1 (AO1.1)	**Examiner's Comments** Less than half the candidates selected the correct response of C for this direct recall question. There was no key distractor, suggesting that many candidates may have guessed.
			Total	**1**	
33		i	***Comparison of branching and points of contact*** e.g. $CH_3CH_2CH_2NH_2$ has longer chain / straight chain / no branches **AND** e.g. $CH_3CH_2CH_2NH_2$ has more points of contact / more surface interaction (between molecules) ✓ ***Relative strength of force*** e.g. $CH_3CH_2CH_2NH_2$ has stronger/more	5 → 4 max (AO 1.2) (AO 2.1)	**ANNOTATE WITH TICKS AND CROSSES, etc.** -- -- **ALLOW ORA** throughout **ALLOW** 'The straighter the chain, the more points of contact ….' **IGNORE** comparison using 'primary', 'secondary' and 'tertiary'. *Comparison of branching is required.* For London forces, • **ALLOW** induced dipole(–dipole) interactions • **IGNORE** IDID **OR** van der Waals' forces/VDW

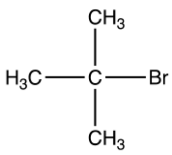
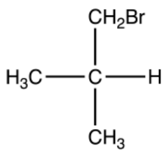
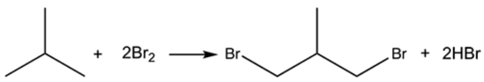
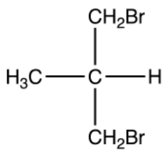
			induced dipole(–dipole) interactions **OR** London forces ✓ -- ***Hydrogen bonds*** $CH_3CH_2CH_2NH_2$ **OR** $(CH_3)_2CHNH_2$ have hydrogen/H bonds **OR** $(CH_3)_3N$ has no hydrogen/H bonds ✓ ***Relative strength of force*** Hydrogen bonds are stronger than London forces /permanent dipole interactions ✓ -- ***Comparison of energy required to break force*** e.g. More energy to break/overcome London forces/intermolecular forces in $CH_3CH_2CH_2NH_2$ **OR** More energy is needed to break H bonds (than London forces) ✓	(AO 1.2) (AO 2.1)	**DO NOT ALLOW** $CH_3CH_2CH_2NH_2$ has more electrons *(number of electrons are the same)* **DO NOT ALLOW** 'more energy to break covalent bonds **ALLOW** little energy is required to break London forces (compared with H bonds) **<u>Examiner's Comments</u>** Candidates were expected to explain the different boiling points of three amines. Most candidates linked increased branching with less surface contact between molecules, leading to weaker induced dipole interactions (London forces). Fewer candidates linked the decreasing boiling points to less energy being required to break the intermolecular bonds. The highest performing candidates recognised the large difference between the boiling points of the primary and tertiary amines. They then identified the cause: primary amines form hydrogen bonds but tertiary amines do not. This question was answered reasonably well with fewer candidates than in the past describing relative strengths of covalent bonds, a common misconception.
		ii	**FIRST CHECK MOLECULAR FORMULA and STRUCTURE**	6	

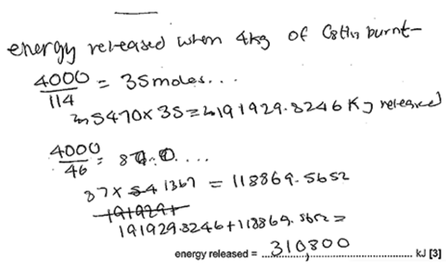
			IF molecular formula = $C_5H_{13}N$ **AND** correct structure **AND** evidence of ideal gas equation → **6 marks** Correct up to 87 **AND** $C_5H_{13}N$ → **5 marks** Correct up to 87 → **4 marks** --- -- ***Rearranging ideal gas equation*** $n = \frac{pV}{RT}$ ✓ ***Unit conversion AND substitution into*** $\boldsymbol{n = \frac{pV}{RT}}$***:*** • *R = 8.314* ***OR*** *8.31* • *V* = 72(.0) × 10^{-6} • *T in K: 373 K* *e.g.* $\frac{1.00 \times 10^{5} \times 72.0 \times 10^{-6}}{8.314 \times 373}$ ✓	(AO 2.2×4)	**IF** $n = \frac{pV}{RT}$ is omitted, **ALLOW** when values are substituted into rearranged ideal gas equation. Calculator: *n* = 2.321740325 × 10^{-3} from 8.314 *From 8.31, n = 2.322857889 ×* 10^{-3}
			Calculation of n *n* = 2.32 × 10^{-3} (mol) ✓ ***Calculation of M*** $M = \frac{0.202}{2.32 \times 10^{-3}} = 87$ ✓	(AO 3.2)	**ALLOW** elements in any order **ALLOW** molecular formula = $C_3H_9N_3$ **ALLOW** other molecular formulae of an amine that has *M* = 87, e.g. C_4H_9NO
			Molecular formula $C_5H_{13}N$ ✓ **Molecular formula required** ***Structure of amine A from*** $\boldsymbol{C_5H_{13}N}$ ✓	(AO 3.2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** structures below from molecular formula = $C_3H_9N_3$  **ALLOW ECF** but only if structure has calculated M_r **AND** has 3 peaks in ^{13}C NMR

			 OR  OR  OR  OR  **Use of 24000** 3 marks max possible for use of 72.0 cm^3 **OR** 0.720 dm^3 by **ECF** **Calculation** e.g. $n = \frac{72.0}{24000} = 3.00 \times 10^{-3}$ **No mark** *(calculation much simpler)* $M = \frac{0.202}{3.00 \times 10^{-3}} = 67.3$ **OR** 67 ✓ **ECF** **Molecular formula** = C_4H_5N ✓ **ECF** **Structure**  ✓ **ECF**		spectrum. **Examiner's Comments** Most candidates rearranged the ideal gas equation correctly to make *n* the subject. They then substituted correct values for *p*, *V*, *R* and *T* into the equation, with correct unit conversions. Most candidates then calculated *n* correctly as 2.32×10^{-3} and combined this value with the mass of 0.202 g to derive the molecular formula as 87. Lower-attaining candidates often made an error in their conversion of cm^3 into m^3, by multiplying by 10^{-3} rather than 10^{-6}. This error resulted in a value of *n* as 2.32 and the unrealistic molecular mass of 8.7×10^{-3}, from which a molecular formula is impossible. Candidates in this position are advised to check back at the unit conversions in the working. Very few candidates did not convert 100°C into 373 K. Candidates with the correct molecular formula of 87 usually suggested C5H13N as the molecular formula. A significant number quoted $C_5H_{11}NH_2$. This response was not credited as it is not a 'molecular' formula. There are several possible structures of $C_5H_{13}N$ with three ^{13}C NMR peaks and any were credited. Error carried forward was applied from a different molecular mass for both the molecular formula and a structure. This emphasises the importance of working within calculation; credit will always be given for a correct method. Instead of using the ideal gas equation, some candidates used the molar gas constant at room temperature and pressure, 24.0 dm3, which gives a molecular mass of 67. This simplified approach could only

					gain the final 2 marks for this question: a molecular formula (with an error carried forward value of 67, e.g. C_4H_5N) and a structure of an amine with this molecular formula and 3 peaks in the ^{13}C NMR spectrum.
			Total	**10**	
34			**B**	1 (AO1.1)	
			Total	**1**	
35	a			3 (AO1.2) (AO2.5×2)	**ALLOW** $Br_2 \rightarrow Br• + Br•$ **IGNORE** dots for initiation step, i.e. **ALLOW** $Br_2 \rightarrow Br + Br$ **OR** $Br_2 \rightarrow 2Br$ **DOT REQUIRED** at correct position on chain. **ALLOW 1 mark** if both propagation equations are correct by atom but dot(s) missing or on incorrect C in chain **ALLOW 1 mark** if both propagation equations are correct including position of dot(s) but structures are not shown using skeletal formula **ALLOW** ECF from incorrect intermediate **<u>Examiner's Comments</u>** Often candidates did not use skeletal formula, as required by the question, and did not place the radical dot in the correct position.
	b		further substitution/s **OR** produces different termination products **OR** More than one termination step **OR** Mixture of products are formed ✓	2 (AO1.1×2)	**ALLOW** dibromo/multibromo compounds formed **OR** an example of a further substitution product **OR** an example of a different termination product **ALLOW** more than one hydrogen (atom) can be replaced **ALLOW** radicals react with each other to form other products

			substitution at different positions along chain ✓		**IGNORE** references to separation of products **IGNORE** references to atom economy or yield **ALLOW** a hydrogen (atom) on a different carbon (atom) can be replaced
			Total	**5**	
36			**D**	1 AO2.1	
			Total	**1**	
37			**B**	1 AO1.2	
			Total	**1**	
38			**C**	1 (AO2.1)	**ALLOW** 4 (This is the number of structural isomers)
			Total	**1**	
39	a	i	σ-bond: Overlap of **orbitals** between (bonding) atoms ✓ π-bond: **Sideways** overlap of (adjacent) **p-orbitals** ✓	2 (AO1.1×2)	**ALLOW** labelled diagrams **IGNORE** the type of orbital for σ-bond **DO NOT ALLOW** pi-orbital **<u>Examiner's Comments</u>** These definitions were known by few candidates. Many did not mention orbitals in their response.
		ii	σ-bonds: 9 ✓ π-bonds: 2 ✓	2 (AO1.2×2)	
	b	i	Same structural formula **AND** Different arrangement (of atoms) in space **OR** different spatial arrangement (of atoms) ✓	1 (AO1.1)	**ALLOW** structure/displayed/skeletal formula **DO NOT ALLOW** same empirical formula **OR** same general formula **IGNORE** same molecular formula Reference to *E/Z* isomerism or optical isomerism is **not** sufficient
		ii	Student is **not** correct **AND** 2 groups on one carbon atom (of C=C) are the same	1 (AO3.1)	**DO NOT ALLOW** one side of C=C

			OR C–C bond can rotate ✓		
			Total	**6**	
40	a		 ✓  ✓	2 (AO2.5 × 2)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous
	b		 Structure of organic product ✓ Complete balanced equation ✓	2 (AO2.5) (AO2.6)	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous, e.g. 
			Total	**4**	
41		i	C_8H_{18} + C_2H_5OH + 15½ O_2 → 10 CO_2 + 12 H_2O ✓	1 (AO2.6)	**ALLOW** multiples e.g. 2 C_8H_{18} + 2 C_2H_5OH + 31 O_2 → 20 CO_2 + 24 H_2O **ALLOW** $C_{10}H_{24}O$ for C_8H_{18} + C_2H_5OH *Combining ethanol and octane!* **<u>Examiner's Comments</u>** Most candidates attempted to write an equation for the combustion of the 1:1 molar mixture of octane and ethanol. The formulae of C_8H_{18} and C_2H_5OH were usually seen although some candidates combined these as a 'mixture formula' of $C_{10}H_{24}O$ (which was accepted). The balancing of the equation using 15½O_2 was the hardest part of the equation and many different balancing numbers for O2 were seen (10CO_2 and 12H_2O where usually correct). Less successful responses often attempted a combustion equation using octane OR ethanol, but not both. This is not an easy equation to

					construct, and the context was novel. Overall candidates made a good attempt at this question.
		ii	**FIRST CHECK ANSWER ON THE ANSWER LINE If answer = 341850 to 2 SF or more award 3 marks** --- *M*(C_8H_{18}) = 114 **AND** *M*(C_2H_5OH) = 46 **OR** 1 mol C_8H_{18} + 1 mol C_2H_5OH has mass of 160 g ✓ 50 mol C_8H_{18} **OR** 50 mol C_2H_5OH **OR** 50 mol (C_8H_{18} + C_2H_5OH) **OR** 8.00 kg fuel contains 50 mol C_8H_{18} + 50 mol C_2H_5OH ✓ Energy = (50 × 5470) + (50 × 1367) **OR** 50 × (5470 + 1367) **OR** 50 × 6837 **OR** 273500 + 68350 **=341850(kJ)✓**	3 (3 ×AO2.2)	**IGNORE** sign throughout **ALLOW** approach based on mass for 2nd mark *m*(C_8H_{18}) = (114/160) × 8000 = 5700 g **AND** *m*(C_2H_5OH) = (46/160) × 8000 = 2300 g Energy = 5700/114 × 5470 + 2300/46 × 1367 = 341850 (kJ) **ALLOW 2 SF or more** correctly rounded -- **<u>Common errors</u>** **310800 → 2 marks** *Use of equal masses (4 kg) of C_8H_{18} & C_2H_5OH (rather than equal moles)* **Example**  **<u>Examiner's Comments</u>** This question took the novel context introduced in 5b a stage further by considering the energy released during the combustion of this fuel. Most candidates were able to obtain some credit, and many obtained the correct energy of 341,850 kJ. The commonest error was for candidates to assume that the 8 kg mixture would contain 4 kg of octane and 4 kg of ethanol, rather than an equal moles of each. Such an approach could still be partly given marks by ECF, provided that the method was sound and clear.
			Total	**4**	

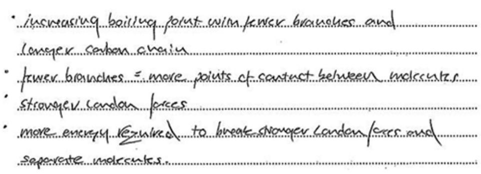
42	a	i	UV **OR** ultraviolet ✓	1 (AO1.1)	**ALLOW** Sunlight **IGNORE** Temperature **Examiner's Comments** Most candidates gave the correct response to this question. Incorrect responses included use of high temperatures and/or catalyst.
		ii	$CH_3CH_2CH_2CH_3$ + Br • → $CH_3CH_2\dot{C}HCH_3$ + HBr ✓ $CH_3CH_2\dot{C}HCH_3$ + Br_2 → $CH_3CH_2CHBrCH_3$ + Br • ✓	2 (AO 2.5 × 2)	**ALLOW** Displayed or Skeletal formulae **ALLOW 1 mark** if **BOTH** equations are 'correct' using molecular formulae, i.e. $CH_3CH_2CH_2CH_3$ + Br • → C_4H_9 • + HBr C_4H_9 • + Br_2 → C_4H_9Br + Br • ✓ **IGNORE** position of • within $CH_3CH_2CHCH_3$ • **ALLOW 1 mark** if incorrect structure of intermediate radical is used, e.g. CH_3CH_2**CH_2CH_2** • for CH_3CH_2**$CHCH_3$** • ✓ **Examiner's Comments** Candidates always find radical mechanisms tricky and this one had the added complexity of forming 2-bromo isomer. However, a majority of students still gained marks. Many candidates formed the incorrect radical removing H from C-1 i.e. $CH_3CH_2CH_2CH_2$ · therefore scoring only 1 mark. Some responses were a little messy making it very easy to miss off a dot or H or Br. Many candidates reacted with Br· in the first step but added Br to the radical intermediate (as well as forming HBr). Candidates should always check equations so that they balance in terms of atoms.

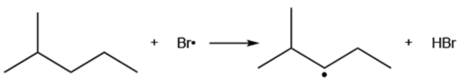
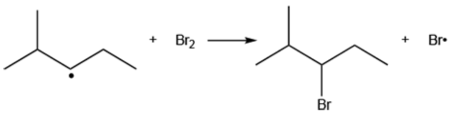
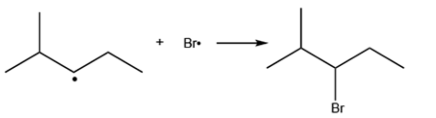
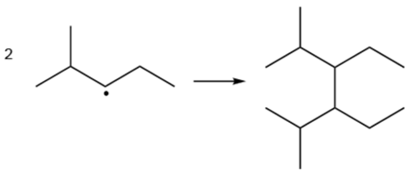
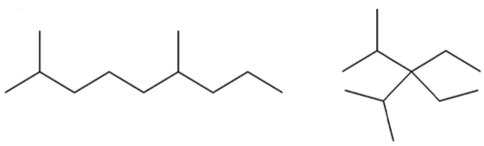
		iii	Further substitution **OR** formation of di/ tri / etc. bromobutanes **OR** produces different termination products **OR** more than one termination step ✓ Formation of 1-bromobutane **OR** (Br) subsitution in a different position ✓	2 (AO 3.2 × 2)	**ALLOW** multisubstitutation, including examples **ALLOW** an example of a different termination product **ALLOW** more than one hydrogen (atom) can be replaced **ALLOW** radicals react with each other to form other products **<u>Examiner's Comments</u>** Candidates found this question very challenging and few scored both marks. Many responses considered only the formation of HBr (other product) and/or general statements about other products with no indication of how they were formed. Some described losses due to the purification method or incomplete reaction (due to conditions such as T and P) or low atom economy. Some referred to the stability of the radical intermediate, showing possible confusion with electrophilic addition. Candidates who understood the mechanism were more confident in answering this question, at least recognising that further substitution was possible.
	b		% atom economy for butane and bromine (5.1) $= \frac{136.9}{217.8} \times 100 = 62.9\%$ ✓ atom economy for but-2-ene and HBr (5.2) is 100% ✓	2 (AO 2.2) (AO1.2)	Calculator: 62.85583104 **ALLOW** calculation for 5.2 **ALLOW** Calculations not expressed as a % i.e. 0.629 and 1. **<u>Examiner's Comments</u>** Despite the question asking for calculations to be included, many candidates didn't include them and so lost both marks. Some gained

					one mark as recognised that 5.1 has 100% atom economy but either didn't or incorrectly calculated for 5.2 (30% was seen frequently). Care needs to be taken with rounding of final values.
			Total	**7**	
43			**D**	1(AO1.2)	**ALLOW** 9 **Examiner's Comments** Candidates found this question difficult with very many choosing option B rather than the correct option D. Candidates are advised to draw out all bonds displayed when tackling such as question as the answer of B (3) results from considering just the three bonds shown in the skeletal formula and omitting the other 6 C–H bonds.
			Total	**1**	
44			**D**	1(AO2.6)	**Examiner's Comments** This question discriminated extremely well with most candidates choosing the correct option. Most candidates showed some working. The key to success was to identify the balanced equation that produced CO_2 and H_2O in a 3 : 4 molar ratio.
			Total	**1**	
45			D	1 (AO1.2)	**ALLOW** 15 (correct number of sigma bonds) **Examiner's Comments** This question discriminated well, with higher ability candidates correctly identifying D. Often students overlooked the sigma bonds in the aromatic ring and selected B.
			Total	**1**	
46			D	1 (AO1.1)	

					Examiner's Comments Most candidates identified D (only 1) for an equation that could be part of a propagation step.
			Total	**1**	
47			**B**	1 (AO2.2)	**Examiner's Comments** This was a demanding question. Candidates needed to calculate the moles of oxygen and then determine the ratio of alkane to oxygen to find the correct response. The majority of successful candidates clearly showed their working to help them to arrive at the correct answer. The most common incorrect answer was C.
			Total	**1**	
48	a		**Trend for all 3 hydrocarbons (1 mark):** Boiling point increases with less branching **OR** less methyl/alkyl groups/side chains ✓ **Explanation with comparison (3 marks):** **Branching and surface contact** (Less branching gives) more (surface) contact / interaction (between molecules) ✓ **Surface contact and London forces** (More surface contact) gives more /stronger induced dipole(–dipole) interactions/ London forces ✓ **Energy and intermolecular forces** More energy to break induced dipole(–dipole) interactions/ London	4 (AO1.1) (AO1.2 X3)	**ANNOTATE WITH TICKS AND CROSSES** **Comparisons** needed throughout **ORA** throughout Must have link between rank order of branching and boiling point for all 3. **ALLOW** Hexane is least branched/straight chain and has highest bp **AND** 2,2-dimethylbutane is most branched and has lowest bp. **IGNORE** Chain length Surface area alone is **not** sufficient, must have idea of contact. **DO NOT ALLOW** arguments comparing different numbers of electrons (as all have the same number). **IGNORE** van der Waals'/vdW forces **OR** IDID **OR** IDD **ALLOW** 'more energy to break intermolecular forces' if intermolecular forces are not identified or incorrect.

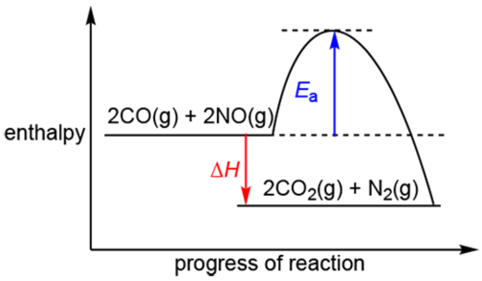
			forces/intermolecular forces/intermolecular bonds (with less branching) ✓		**IGNORE** harder to overcome/break intermolecular forces (no reference to energy) **IGNORE** just 'bonds' intermolecular/London forces required **Examiner's Comments** Most candidates attempted this question, gaining at least 1 mark, with over half scoring 3 or more marks. Responses often lacked clarity as many candidates struggled to articulate their ideas. It was common to see lengthy responses often with unnecessary repetition and sometimes even contradictions. A good strategy adopted by some was to draw skeletal formulae for the compounds next to the data provided. This enabled them to focus their response more easily on the extent of branching. Many candidates were unable to give a clear trend for the first marking point, as asked for in the question, but were able gain credit by a lengthier comparison of all three as indicated in the extra guidance. However, this mark was often lost through incomplete explanation, not referring to boiling point at all or an attempt to compare just chain length. The most common error for the second mark was omission of 'contact' or 'interaction' with reference only to surface area or 'packing' of molecules. Some lost this mark for a change in number of electrons. The third marking point was the most frequently awarded. Some candidates lost the mark for not explicitly naming the intermolecular forces as London forces/induced dipole-dipole interactions or for incorrectly using van der Waals. Some lost the mark for not explicitly indicating how increased or decreased contact would affect the strength or

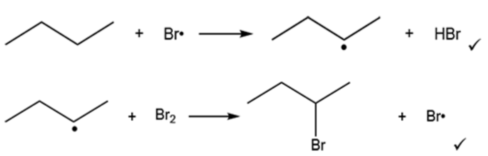
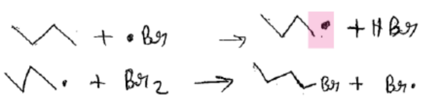
					magnitude of London forces, e.g. ‘less contact to form London forces’. The final mark was harder to obtain as it needed to be clear that **energy** was required to break **intermolecular** forces. For example, ‘less energy to break bonds’ or ‘easier to separate the molecules’ or ‘more energy to boil’ were not sufficient. **Misconception** Responses often highlighted that candidates lacked understanding about what London forces are, e.g. indicating that they form ‘between atoms’ or referring to induced dipole-dipole forces as something else. Intermolecular forces are difficult to fully comprehend as they can’t be visualised making this a challenging topic to teach. OCR have produced a ‘Bonding’ teaching guide with lots of useful suggestions and resources. This includes a link to this Salters A Level chemistry revision activity on intermolecular bonding Exemplar 1  • increasing boiling point with fewer branches and longer carbon chain • fewer branches = more points of contact between molecules • stronger London forces • more energy required to break stronger London forces and separate molecules. This exemplar shows a clear, concise response. The candidate has drawn skeletal structures next to the table. The trend is stated first followed by a detailed explanation,

					presented as a bullet point list, with all 4 marking points awarded.
	b	i	**Initiation** $Br_2 \rightarrow 2Br•$ **AND** ultraviolet / UV ✓ **Propagation** ✓ ✓ **Termination** $2Br• \rightarrow Br_2$ ✓ ✓ ✓	6 (AO1.1) (AO2.5) (AO2.5) (AO2.5) (AO3.1)	**DOT REQUIRED** throughout **IGNORE** temperature and pressure **ALLOW ECF** for use of Cl• (from Cl2) in subsequent propagation and termination steps **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW** 1 mark for propagation for 2 'correct' equations but with dot omitted or in wrong position **DO NOT ALLOW ECF** from incorrect radical intermediate for termination steps **<u>Examiner's Comments</u>** Many candidates tackled this question confidently, especially when using skeletal formula following the format of the structure given in the question. Over half the candidates scored 5 or 6 marks. Only the highest attaining candidates were able to provide all three correct termination steps. Many lost a mark for the combination of the two alkyl radicals, typically either by simply joining the ends of the chains or by missing the connecting C-C bond.  Those that attempted to use structural formula often lost marks due to missing Hs. Other common errors included the incorrect positioning of the radical dot, most

					typically on the terminal carbon, addition of Br in the first propagation step or use of molecular formula. Lower attaining candidates were often able to score a mark for the initiation step and the termination step involving two Br radicals. However, for some this was not a well-known mechanism, with attempts to break up the chain or form hydrogen radicals or charged species. Errors were also seen with correct balancing of equations such as truncated C chains or extra Br atoms added.
		ii	C_6Br_{14} ✓ Correct balanced equation $C_6H_{14} + 14\ Br_2 \rightarrow C_6Br_{14} + 14\ HBr$ ✓	2 (AO2.6 ×2)	**ALLOW** 1 mark for correct balanced equation using any combination of skeletal **OR** structural **OR** displayed formula **<u>Examiner's Comments</u>** Most responses gained at least 1 mark for this question giving the correct molecular formula of C_6Br_{14}. However many hadn't assimilated that when a hydrogen atom is substituted in an alkane it requires one mole of a halogen and produces one mole of the hydrogen halide. So many gave this incorrect equation instead: $C_6H_{14} + 7Br_2 \rightarrow C_6Br_{14} + 7H_2$. Some lost marks for C_5H_{14} or for use of structural formulae.
		iii	$n(\mathbf{B}) = \frac{72.0}{40000}$ **OR** $\frac{0.072}{40}$ **OR** $1.8(0) \times 10^{-3}$ (mol) ✓ $M(\mathbf{B}) = \frac{0.8649}{1.8(0) \times 10^{-3}} = 480.5$ ✓ Molecular formula = $C_6H_9Br_5$ ✓	3 (AO2.2 ×2) (AO3.2)	**ALLOW 2SF** up to calculator value **ALLOW ECF** from incorrect n**(B)** **ALLOW ECF** from incorrect M(**B**) from n(**B**) -- **COMMON ERROR** $n(\mathbf{B}) = \frac{72.0}{24000} = 3 \times 10^{-3}$ (mol) ✗ $M(\mathbf{B}) = \frac{0.8649}{3 \times 10^{-3}} = 288.3$ ....✓

					Molecular formula = $C_6H_{12}Br_2$ **OR** $C_6H_{11}Br_3$ ✓ **ALLOW ECF** for viable molecular formula with C_6 but must be derived from a calculated value for *M*(**B**) **<u>Examiner's Comments</u>** Overall, this question was well answered with over half of candidates gaining all 3 marks. The use of a different molar volume confused some candidates. Some attempted to use PV=nRT or different combinations of the figures given with varying degrees of success. Lower attaining candidates typically struggled with unit conversions and were unable to make use of the units to help them work out the methodology to use.
			Total	**15**	
49		i	$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ Correct species ✓ Balanced ✓	2 (AO2.6 ×2)	**ALLOW** multiples **IGNORE** state symbols For heptane formula, **ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **ALLOW 1 mark** for balanced combustion equation for a different alkane (**ECF**) e.g. $C_6H_{14} + 9½O_2 \rightarrow 6CO_2 + 7H_2O$ **<u>Examiner's Comments</u>** Most candidates were able to construct a balanced equation for the combustion of heptane. Most were aware that CO_2 and H_2O would be the products although some generated CO, C_6H_{12} or unusual compounds such as $C_7H_{14}O$. The hardest part was the formula of heptane itself with use of hexane instead being a common error; candidates who made this error were

					given 1 mark, provided that their equation was balanced.
		ii	 **Reactants, products and Δ*H*** **2CO + 2NO** on LHS **AND** **$2CO_2$ + N_2** on RHS **AND** Δ*H* labelled with products **below** reactants **AND** **Arrow downwards** ✓ ***E_a* (independent of ΔH)** curve with arrow from reactants to top of curve **AND** *E_a* labelled ✓ **IF** endothermic diagram shown, **ALLOW ECF** for E_a using MS criteria	2 (AO2.1) (AO1.2)	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **IGNORE** state symbols **Δ*H* DO NOT ALLOW –Δ*H*** **DO NOT ALLOW** double headed arrow on Δ*H* **ALLOW** Δ*H* arrow even with small gap at the top and bottom, i.e. line does not quite reach reactant or product line. **ALLOW** –746 for Δ*H* ***E_a* ALLOW** AE **OR** A_E **ALLOW 2** arrowheads at **each** end of E_a line **OR** no arrowhead **BUT DO NOT ALLOW** arrowhead down E_a line must reach maximum (or near to maximum) on curve **<u>Examiner's Comments</u>** Most candidates obtained 1 or 2 of the available marks, the commonest errors being use of a doubleheaded arrow for Δ*H* or a –Δ*H* label. Some candidates showed endothermic profiles and these could

					create issues with positioning of the ΔH and E_a arrows. Generally, positioning of ΔH and E_a arrows was imprecise and candidates are advised to start and finish the positions of their arrows accurately. The mark scheme did allow for some leeway but positioning of arrows could generally be improved.
		iii	Catalyst lowers activation energy **OR** Catalyst increases rate without itself changing ✓ Reaction proceeds via a different route/pathway **OR** More molecules/particles exceed activation energy ✓	2 (AO1.2 ×2)	**ALLOW** 2nd labelled curve on profile diagram in **23(a)(ii)** with lower activation energy/E_c with catalyst **ALLOW** E_c needs less energy to start reaction **ALLOW** E_c curve is lower than E_a curve **IGNORE** 'shorter route' for alternative route **IGNORE** more successful collisions **<u>Examiner's Comments</u>** Almost all candidates knew that a catalyst lowered activation energy and most were aware that an alternative pathway was made possible by a catalyst.
			Total	**6**	
50			**Skeletal formulae required** 	2 (AO3.1 ×2)	**ALLOW** 1 mark (**ECF**) for 2 'correct' equations with dot omitted or incorrectly positioned **ALLOW** 1 mark for forming 1-bromobutane with dots correct for 1-bromobutane e.g.  **No credit for responses using molecular formulae for organic**

					structures **<u>Examiner's Comments</u>** This question discriminated very well at the top end of the ability range, but many ignored the instruction to use skeletal formula and obtained no marks as a result. Of those that did use skeletal formula, many placed the dot on the wrong carbon atom or produced 1-brombutane, rather than 2-bromobutane, stated in the question. A mark was still available by ECF for misplaced or absent dots or formation of 1-brombutane with dots. This question was aimed to be demanding and so it proved to be.
			Total	**2**	
51			**C**	1	**<u>Examiner's Comments</u>** Some candidates chose B as the correct option. The other options were chosen randomly, suggesting that many had not learnt this specification content and had guessed.
			Total	**1**	
52	a		**CHECK FOR RESPONSES ON TABLE** **Trend** Boiling point decreases with more branching **OR** fewer methyl/alkyl groups/side chains ✓ **Branching and surface contact** *Could be seen anywhere within response*	4	ANNOTATE WITH TICKS AND CROSSES Comparisons needed throughout **<u>ORA</u>** <u>throughout</u> **ALLOW** comparison between 2 alkanes, e.g. **C** has greatest branching **AND** lowest boiling point **A** has no branching **AND** highest boiling point **IGNORE** Chain length Surface area alone is **not** sufficient

			Branching linked to the amount of (surface) contact / interaction/overlap (between molecules) ✓ **Type and strength of intermolecular force** *Could be seen anywhere within response* Branching/ boiling points/contact linked to strength of London forces **OR** induced dipole(-dipole) interactions **OR** extent of surface contact ✓ **Energy and intermolecular forces** *Linked to **energy** seen anywhere* More energy to break intermolecular forces with less branching ✓ **IGNORE** just 'bonds' *intermolecular or type of forces required*		*must have idea of contact*. **DO NOT ALLOW** responses comparing different numbers of electrons (as all have the same number). **ALLOW** more branching results in fewer London forces **ORA** **IGNORE** van der Waals'/vdW forces. **OR** IDID **OR** IDD **ALLOW** more **energy** to break/overcome London forces **OR** induced dipole(−dipole) interactions **OR** vdW forces **IGNORE** harder to overcome/break intermolecular forces (**no reference to energy**) **<u>Examiner's Comments</u>** Most candidates were given 3 or 4 marks. The most common omission was the idea of surface contact. Most candidates identified London forces or induced dipole interactions as the relevant intermolecular force. A few candidates gave a general comment in terms of 'intermolecular' forces without specifying the type of intermolecular forces. There has been a general improvement in candidate responses to this type of question with fewer candidates than in previous exams suggesting the breaking of hydrogen bonds or covalent bonds. Exemplar 2

					Refer to the isomers **A**, **B** and **C** in your answer. Isomers A, B and C have the same molecular formulae but different structural formulae. Boiling point decreases down the table from A to C because there is more branching so fewer surface points of contacts. This results in fewer London forces between the molecules so less energy is required to overcome these London forces. (All going down the table from A to C) Exemplar 2 shows an excellent response. The explanation is clear and the candidate is aware of the main factors responsible for the trend in boiling points. This response was given the full 4 marks.
	b		**CORRECT DOTS REQUIRED FOR ALL MARKS** **Initiation** ultraviolet / UV **AND** $Br_2 \rightarrow 2Br\cdot$ **OR** $Br_2 \rightarrow Br\cdot + Br\cdot$ **OR** $Br{-}Br \rightarrow 2Br\cdot$, etc ✓ **Propagation** **1** $C_2H_6 + Br\cdot \rightarrow C_2H_5\cdot + HBr$ ✓ **2** $C_2H_5\cdot + Br_2 \rightarrow C_2H_5Br + Br\cdot$ ✓ **Termination** In either order: $C_2H_5\cdot + C_2H_5\cdot \rightarrow C_4H_{10}$ **OR** $2C_2H_5\cdot \rightarrow C_4H_{10}$ ✓ $C_2H_5\cdot + Br\cdot \rightarrow C_2H_5Br$ ✓	5	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **DO NOT ALLOW** charged formulae **IGNORE** position of dots within a formula **DO NOT ALLOW** if reagents also present, e.g..steam **ALLOW** $\cdot CCH_5$ for $C_2H_5\cdot$ **ALLOW** $C_2H_5C_2H_5$ for C_4H_{10} ✓ **Examiner's Comments** This question was answered extremely well with most candidates obtaining the full 5 marks. It was encouraging to see the widespread correct use of dots to indicate radicals, with relatively few omissions. Of the three steps, initiation and termination were answered better than the equations for propagation.
	c			5	**ALLOW** 109−110 for **C1** **ALLOW** 118−122 for **C2** **ALLOW** planar triangle

Carbon atom	Bond angle	Name of shape
1	109.5	tetrahedral
2	120	trigonal planar

2 OR 3 correct ✓

4 correct ✓

Number of electron pairs

In **C1**/109.5°, **4** bonded pairs/bonding regions/bonds ✓

In **C2**/120°, **3** bonded regions/bonds ✓

Electron pair repulsion

Electron pairs/bonded pairs repel (as far apart as possible) ✓

Electron pairs/bonded pairs essential

DO NOT ALLOW 'bonded atoms' for this mark

ALLOW table responses if in wrong columns

IGNORE areas of electron density

For bonded pairs

ALLOW bp, **bonded** groups, **bonded** atoms

Bonded/bonding *essential*

For C2, ALLOW

- 3 bonded areas/environments
- 3 bonded pairs/groups/atoms
- 2 bonded pairs and 1 double bond
- 2 bonded pairs and 1 bonded region

DO NOT ALLOW 'atoms repel'

IGNORE

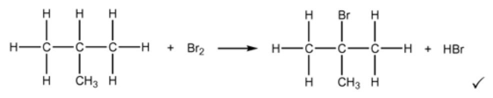
- electrons repel
- bonds repel
- electron region **OR** electron density
- lone pairs repel more *irrelevant here*
- shapes, even if wrong

Examiner's Comments

The bond angles and shapes rewarded the well-prepared candidates, with many being given both available marks for this part of the question. This part discriminated very well.

For the explanation, most candidates identified 4 and 3 for C1 and C2, but candidates often linked 4 and 3 to

					atoms, rather than to electron pairs or bonded pairs for C1 and to bonding regions for C2. A mark was available for stating that 'electron pairs repel', but this important fact was often omitted despite being the main principle that determines molecular shapes. The question discriminated well, giving a good spread of marks across the five available. ? **Misconception** Many students think that molecular shapes are determined solely by lone pairs or by repulsion between bonded atoms. The principle behind molecular shapes is called electron pair repulsion theory because it is based on repulsion between electron pairs, which may be bonded pairs or lone pairs, but **not** atoms.
			Total	**14**	
53			**C**	1	**<u>Examiner's Comments</u>** Approximately two thirds of candidates gave the correct answer C. The most common incorrect response seen was D, confusing the strength of the σ and π bonds, possibly as a C=C bond is stronger than C-C. Some gave D assuming alkenes are polar due to their reactivity and showing a misunderstanding of the term 'polar'.
			Total	**1**	
54			**B**	1	**<u>Examiner's Comments</u>**

					A large majority of candidates were able to correctly identify shape at x as being trigonal planar and y as being tetrahedral. The most common incorrect responses seen were for getting one of these incorrect i.e. D incorrect for x or C incorrect for y.
			Total	1	
55		i	**Equation**  **Name** Radical substitution ✓ **Bond fission** homolytic (fission) ✓	3	**ALLOW** any combination of skeletal **OR** structural **OR** displayed formula as long as unambiguous **IGNORE** mechanism, need overall equation **<u>Examiner's Comments</u>** This question differentiated well, with a wide mix of responses given. Just over 40% scored all 3 marks. **Equation:** The most common error was to omit HBr as a product. Some gave H_2 or just Br as a product. Some misunderstood the question and attempted to give either a partial mechanism, such as the propagation step or a complete mechanism, rather than the overall equation. Some gave molecular formula rather than structures as asked for. Those using structural or displayed formula were more prone to errors, such as missing hydrogens or incorrect chain length, than those that were confident using skeletal formula. Candidate should avoid giving equations in two formats, e.g. skeletal and structural because slips in one will lose marks. **Mechanism:** Many candidates were able to identify the radical substitution mechanism, but a significant number did not score here. Most common incorrect responses were electrophilic or nucleophilic substitution but there were also those that thought it was an addition reaction.

					Bond fission: A significant number identified this as heterolytic, even if the recognised mechanism was radical. Some struggled with the spelling or even suggested homogeneous or heterogenous. ? **Misconception** Many struggled to identify the mechanism and then to link to bond fission. Try to introduce key terminology early on in teaching organic chemistry so that it can then revisited with each topic. Relevant mechanism terminology: - substitution / addition / elimination - electrophile / nucleophile / radical - homolytic / heterolytic
		ii	Further substitution/s **OR** Different termination products **OR** More than one termination step Substitution at different positions along (carbon) chain ✓	2	**ALLOW** dibromo/multibromo compounds formed **OR** example of further substitution product e.g $CH_2BrCBr(CH_3)_2$ / $C_4H_8Br_2$ / 1,2-dibromo-2-methylpropane **OR** example of different organic termination product e.g.C_8H_{18} **ALLOW** more than one H (atom) can be replaced **ALLOW** radicals react with each other to form other products **ALLOW** a hydrogen (atom) on a different carbon (atom) can be replaced **ALLOW** Substitutions can occur at other carbons (along the chain) **ALLOW** example of substitution at different position on chain e.g.

					$CH_2BrCH(CH_3)_2$ / 1-bromo-2-methylpropane **IGNORE** references to separation of products **IGNORE** references to atom economy or yield **<u>Examiner's Comments</u>** Most candidates scored one mark here, with approximately a third of candidates scoring both marks. Most recognised that further or multiple substitution would occur or that there would be a variety of termination products. The second mark was harder to achieve as although many responses suggested a different position, it was not always clearly conveyed that a hydrogen on a different carbon along the chain was being substituted, e.g. 'substitution can occur anywhere in the molecule'. The best responses gave examples to clarify their point, e.g. 'the bromine radical can be substituted anywhere along the hydrocarbon chain making other products such as 1-bromo-2-methylpropane'. However, many gave vague answers such as poor yield or mixture of products, without explanation of how or what they might be. Some focused on HBr being formed as a product, suggesting it is toxic, or lowers the atom economy. Others highlighted ultraviolet radiation as being a limitation due to it being 'expensive', 'hard to achieve', 'lack of sources' or 'hazardous'. Others suggested that the reaction needed 'high temperatures'.
			Total	**5**	