2020 Y5 Promotional Examinations Suggested Solutions

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Answer	A	B	C	A	D	D	B	D	D	C	C	A	A	B	C

Question 1 (A)

MP: $AlCl_3$ < MgO and $MgCl_2$

$AlCl_3$ is a simple covalent compound while MgO and $MgCl_2$ are ionic compounds. Less energy is required to overcome the weak intermolecular forces of attraction between $AlCl_3$ molecules compared to the strong ionic bonds in MgO and $MgCl_2$.

MP: $MgCl_2$ < MgO

Melting involves overcoming the ionic bonds between the ions in $MgCl_2$ and in MgO. Since O^{2-} has a higher charge and smaller size than Cl^-, the lattice energy of MgO is more exothermic (has a larger magnitude) compare to the lattice energy of $MgCl_2$. Therefore, MgO has stronger ionic bonds and a higher melting point.

Question 2 (B)

1	Incorrect. Boiling involves overcoming the hydrogen bonds between H_2O molecules, the id-id interactions between CH_4 molecules and id-id interactions between $SiBr_4$ molecules. It does not involve breaking the covalent bonds within the molecules.
2	Correct.
3	Incorrect. $SiBr_4$ is a simple molecule.

Question 3 (C)

Lanthanum does not change its oxidation state in this reaction:

$$IO_3^- \rightarrow \text{periodate(VII)} + I_2 + O_2$$

Mole ratio of IO_3^- : I_2 = 5:2:

$$\mathbf{5}IO_3^- \rightarrow \text{periodate(VII)} + \mathbf{2}I_2 + O_2$$

By counting atoms on the LHS and RHS, one periodate(VII) ion contains one I. To balance the 5(1–) = 5– charge on the LHS, the RHS should have an overall 5– charge. Since I_2 and O_2 have no charge, the periodate(VII) ion has a 5– charge i.e. periodate(VII) is IO_6^{5-}.

Question 4 (A)

From the Periodic Table,

Group 15	Group 16
As	Se
Sb	Te

Method 1

The ionization energy (IE) data for As, Sb, Se and Te are not available in the Data Booklet.

For group 16 element,

$$ns^2\,np^4 \xrightarrow{IE_1} ns^2\,np^3 \xrightarrow{IE_2} ns^2\,np^2 \xrightarrow{IE_3} ns^2np^1 \xrightarrow{IE_4} ns^2$$

For group 15 element,

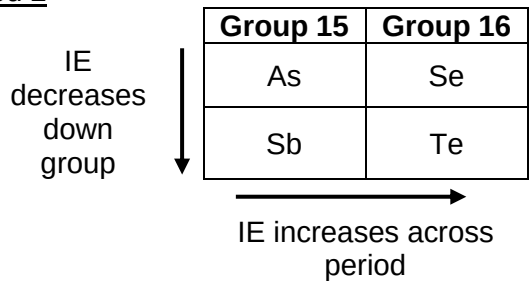
$$ns^2\,np^3 \xrightarrow{IE_1} ns^2\,np^2 \xrightarrow{IE_2} ns^2\,np^1 \xrightarrow{IE_3} ns^2 \xrightarrow{IE_4} ns^1$$

IE_4 of a Group 15 element involves the removal of e^- from the inner ns subshell, requiring a larger than expected amount of energy compared to IE_3 which involves the removal of e^- from the higher energy np subshell.

Comparing the values of IE_3 and IE_4 in the options, options A and C have large differences between IE_3 and IE_4 i.e. A and C are group 15 elements.

Since antimony is below arsenic, the IE's of antimony are lower than that of arsenic since IE's decrease down the Group. Hence, A is ~~Tellurium~~ Antimony.

Method 2



Antimony has the lowest IE out of all the four elements. Look for the option which has the lowest IEs.

Question 5 (D)

W, X, Y and Z are **consecutive** elements. It is important to check whether the elements before and after the element suggested in the options have the correct number of unpaired electrons.

A	**W**	X	Y	Z
Element	**Zn**	Ga	Ge	As
Valence shell electronic configuration	$3d^{10}\ 4s^2$	$4s^2\ 4p^1$	$4s^2\ 4p^2$	$4s^2\ 4p^3$
No. of unpaired e^-	0	1	2	3

B	W	**X**	Y	Z
Element	Ca	**Sc**	Ti	V
Valence shell electronic configuration	$4s^2$	$3d^1\ 4s^2$	$3d^2\ 4s^2$	$3d^3\ 4s^2$
No. of unpaired e^-	0	1	2	3

C	W	X	**Y**	Z
Element	Zn	Ga	**Ge**	As
Valence shell electronic configuration	$3d^{10}\ 4s^2$	$4s^2\ 4p^1$	$4s^2\ 4p^2$	$4s^2\ 4p^3$
No. of unpaired e^-	0	1	2	3

D	W	X	Y	**Z**
Element	Cr	Mn	Fe	**Co**
Valence shell electronic configuration	$3d^5\ 4s^1$	$3d^5\ 4s^2$	$3d^6\ 4s^2$	$3d^7\ 4s^2$
No. of unpaired e^-	6	5	4	3

Question 6 (D)

Equal number of moles of H_2 and O_2 means that the partial pressure of H_2 and O_2 are the same.

$$p_{oxygen} = p_{hydrogen} = \tfrac{1}{2}P \text{ Pa.}$$

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

Since H_2 is fully consumed and mole ratio of $H_2 : O_2 = 2:1$, $p_{oxygen\ reacted} = \tfrac{1}{2}(p_{hydrogen\ consumed})$
$= \tfrac{1}{4}P$ Pa

$p_{oxygen\ remaining} = \tfrac{1}{2}P - \tfrac{1}{4}P = 0.25\ P$ Pa

Alternatively

	$2H_2(g)$ +	$O_2(g)$ →	$2H_2O(l)$
Initial partial pressure / Pa	½ P	½ P	--
Since H_2 is the limiting reagent and is fully consumed,			
Change in partial pressure / Pa	–½ P	–¼P	--
Final partial pressure / Pa	0	0.25 P	--

Question 7 (B)

The definitions of the standard enthalpy change of atomisation of an element and a compound are different.

For an element: It is the energy absorbed when **1 mole of gaseous atoms** is formed from the element under standard conditions.

For a compound: It is the energy absorbed when 1 **mole of the compound** is converted to **gaseous atoms** under standard conditions.

A **Incorrect** : $O_2(g) \rightarrow 2O(g)$
[Corrected : $\tfrac{1}{2}O_2(g) \rightarrow O(g)$]

B $Hg(l) \rightarrow Hg(g)$

C $CO_2(g) \rightarrow C(g) + O_2(g)$
[Corrected : $CO_2(g) \rightarrow C(g) + 2O(g)$]

D $C_2H_4(g) \rightarrow 2C(s) + 4H(g)$
[Corrected : $C_2H_4(g) \rightarrow 2C(g) + 4H(g)$]

Question 8 (D)

Heat absorbed by coffee = $mc\Delta T$
$= (205)(4.18)(42)$
$= 35990$ J

Since reaction is 80% efficient,
heat released by reaction = 35990 / 0.8 = 44990 J

$$\Delta H = -\frac{q}{n}$$

$$-64500 = -\frac{44990}{n}$$

$$n = 0.6975 \text{ mol}$$

Mass of CaO = 0.6975 x (40.1 + 16.0) = 39.1 g

Question 9 (D)

1	Incorrect. The diagram shows an endothermic reaction where the reaction takes in energy from the surroundings. Hence, there is a decrease in the temperature of the surroundings.
2	Correct. Since the products are of higher energy than the reactants, the products are energetically less stable than the reactants.
3	Correct. For the reaction to be spontaneous, ΔG must be less than 0. Since ΔH is positive and $\Delta G = \Delta H - T\Delta S$, ΔG will be less than 0 only if a negative $-T\Delta S$ term outweighs the positive ΔH term. For $-T\Delta S$ to be negative, ΔS must be positive.

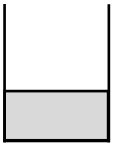
Question 10 (C)

We can infer from the information provided that the reaction rate is slow at the beginning but is increased later in the titration. This describes an autocatalytic reaction where the reaction rate is slow initially, but is faster after some reaction has taken place because one of the products formed (Mn^{2+} in this case) acts a catalyst for the reaction i.e. **C** is correct.

A	Incorrect. Since MnO_4^- is a titrant, it is consumed immediately after each drop is added to the solution in the conical flask. The concentration of MnO_4^- does not "accumulate", hence there is no concentration of MnO_4^- to speak of.
B	Incorrect. The phenomenon described involves the rate of the reaction, not the position of equilibrium.
D	Incorrect. CO_2 gas escaping has no effect on the rate of the reaction.

Question 11 (C)

Conditions for experiment 1 leading to graph 1

$V(Mn^{2+})$ / cm^3	$V(H_2O_2)$ / cm^3	$[H_2O_2]$ / mol dm^{-3}	
1	25	0.1	 1 cm^3 Mn^{2+} 25 cm^3 0.1 mol dm^{-3} H_2O_2

From the graph, the reaction for graph 2

- has twice the rate of production of O_2
- produces double the O_2

compared to that of graph 1.

W

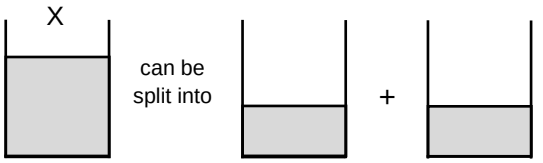
$V(Mn^{2+})$ / cm^3	$V(H_2O)$ / cm^3	$[H_2O_2]$ / mol dm^{-3}
1	25	0.2

Correct. $[H_2O_2]$ in W is twice that in experiment 1 with the same volume of solutions. Hence, the rate of reaction is double and the rate of production of O_2 is also doubled. This also doubles the amount (and hence volume) of O_2 produced.

X

$V(Mn^{2+})$ / cm^3	$V(H_2O)$ / cm^3	$[H_2O_2]$ / mol dm^{-3}
1	50	0.1

Incorrect. X has double the volume of H_2O_2 at the same concentration compared to experiment 1. Hence, the amount of H_2O_2 in X is double that of experiment 1 and will produce double the amount (hence volume) of O_2 eventually.



1 cm^3 Mn^{2+} 50 cm^3 0.1 mol dm^{-3} H_2O_2

0.5 cm^3 Mn^{2+} **25 cm^3** 0.1 mol dm^{-3} H_2O_2

0.5 cm^3 Mn^{2+} **25 cm^3** 0.1 mol dm^{-3} H_2O_2

X can be split into two containers, each containing the same volume and concentration of H_2O_2 compared to **experiment 1**, but with **half the amount of Mn^{2+} catalyst** ⇒ each smaller container produces O_2 at half the rate of experiment 1. Combining the effects of the two split containers, the total rate of production of O_2 is the same as that of experiment 1.

Y

$V(Mn^{2+})$ / cm^3	$V(H_2O)$ / cm^3	$[H_2O_2]$ / mol dm^{-3}
2	25	0.2

Incorrect. With the same volume of H_2O_2,

- $[H_2O_2]$ in Y is twice that in experiment 1
  ⇒ rate of reaction and hence rate of production of O_2 is doubled

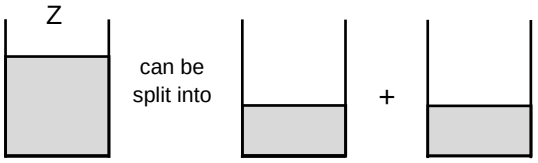
⇒ amount (and hence volume) of O_2 produced is doubled.

- double the amount of catalyst is used which doubles the rate of reaction and rate of production of O_2.

Overall, the rate of production of O_2 is 4 times that of experiment 1 and the amount (and hence volume) of O_2 produced is double that of experiment 1.

Z

$V(Mn^{2+})$ / cm^3	$V(H_2O)$ / cm^3	$[H_2O_2]$ / mol dm^{-3}
2	50	0.1



2 cm^3 Mn^{2+} 50 cm^3 0.1 mol dm^{-3} H_2O_2

1 cm^3 Mn^{2+} **25 cm^3** 0.1 mol dm^{-3} H_2O_2

1 cm^3 Mn^{2+} **25 cm^3** 0.1 mol dm^{-3} H_2O_2

Correct. Z can be split into two containers, each container being the same as experiment 1. Combining the effects of the two split containers, the total rate of production of O_2 will be double that of experiment 1 (since Z is the same as two experiments 1 running concurrently). The total amount (hence volume) of O_2 produced is double that of experiment 1.

Question 12 (A)

Y is a product, not a reactant.

From each graph, as temperature increase, %Y (i.e. the percentage of product) increases ⇒ the forward reaction is favoured. By LCP, an increase in temperature favours the endothermic reaction i.e. the forward reaction is endothermic ⇒ options **A** and **B**.

At a fixed temperature, %Y (i.e. the percentage of product) is lower at a higher pressure i.e. the backward reaction is favoured at higher pressure. By LCP, an increased pressure favours the reaction which produces fewer gaseous particles. The equilibrium should be such that the backward reaction produces fewer gaseous particles ⇒ option **A**.

Question 13 (A)

Option 1 (incorrect)

	$H_2(g)$ +	$I_2(g)$ →	$2HI(g)$
Initial conc / mol dm^{-3}	$\frac{0.1}{1} = 0.1$	$\frac{0.2}{1} = 0.2$	0
Change in conc / mol dm^{-3}	$-\frac{1}{2}x$	$-\frac{1}{2}x$	$+x$
	Ratio of H_2 : HI = 1 : 2 Ratio of I_2 : HI = 1 : 2		
Eqm conc / mol dm^{-3}	$0.1 - 0.5x$	$0.2 - 0.5x$	$\frac{x}{1} = x$

Therefore, $K_c = \dfrac{x^2}{(0.1-0.5x)(0.2-0.5x)}$

Option 2 (Correct)

$$K_p = \frac{p_{HI}^{\ 2}}{p_{H_2} p_{I_2}}$$

Since pV = nRT , $p = \frac{n}{V}RT = conc(RT)$

$$K_p = \frac{([HI]RT)^2}{([H_2]RT)([I_2]RT)} = \frac{[HI]^2}{[H_2][I_2]} = K_c$$

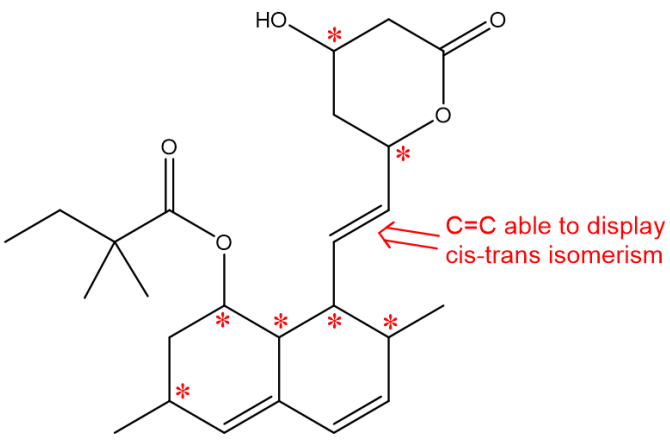
Option 3 (Correct)

If the cooling and dissolving of the equilibrium mixture was done slowly, the position of equilibrium would shift during the cooling, changing the composition of the mixture i.e. the concentrations of the species will not be what it was at 700 K.

Option 4 (Incorrect)

The addition of a catalyst speeds up the rate of both the forward and backward reactions. There is no change in the amount of substance formed at equilibrium.

Question 14 (B)



With 7 chiral centres and one C=C capable of displaying cis-trans isomerism, there are $2^{7+1} = 2^8$.

Question 15 (C)
The reaction intermediates in the free radical substitution reaction between chlorine and methane are C*l*● and ●CH_3.

A Incorrect. The reaction intermediates (C*l*● and ●CH_3) combine to from CH_3Cl. H*Cl* is formed in the first propagation step and involves the reaction between CH_4 (a reactant) and C*l*● (a reaction intermediate).

B Incorrect. The reaction intermediates are C*l*● and ●CH_3 radicals which do not bear any charge.

C Correct. The reaction intermediates are C*l*● and ●CH_3 radicals, each of which contains an unpaired electron.

D Incorrect. The radical intermediates have higher energy than the products.

B1(a)(i) Mass of condensed gas = 7.5387 – 7.5228 = **0.0159 g**

Examiner Comments
- Students should be careful to keep the precision of the instrument (in this case, 4 d.p.) in your answers. Take note of this, especially for practical papers!

B1(a)(ii) $M = \frac{mRT}{PV}$ where *m* is the mass of the gas

$$M = \frac{(0.0159)(8.31)(99+273)}{(100\times10^3)(8.6\times10^{-6})} = 57.2 \text{ g mol}^{-1}$$

The M_r of the gas is 57.2.

Examiner Comments
- Generally well done with most students converting the data to the correct units. However, there were quite a number of students who forgot to give the expression for *M* (with *M* as the subject), or gave their answers as 57.1 (rounding error).
- Students should also note that molar mass, *M*, is not the same as relative molecular mass, M_r. They have the same numerical value, but M_r has no units while *M* has units of g mol^{-1}. Rearranging the ideal gas equation gives the expression for *M* and not M_r.

B1(a)(iii) At a higher T and same P and V, there will be less moles of vapour in the test-tube in step 5 and hence, a lower mass will be measured.

OR

At higher T, the gaseous molecules of G possess higher kinetic energy and more vapour of G will escape from the test tube. This results in a lower mass measured.

OR

According to the expression from **(ii)**, at higher T while P and V are constant, the mass measured will be lower since *M* is constant.

Examiner Comments
- Students should have realised that changing the experiment to an oil bath instead of a water bath resulted in a higher temperature in step 5, while P and V are kept constant. In your answer, it is important for you to state the conditions which were kept constant.
- Many students compared the heat capacity of oil to water but this experiment does not involve heat energy being absorbed / released, nor does the rate at which vapourisation takes place matter. In step 5, all of G has already vapourised.

B1(b) Amount of $Cr_2O_7^{2-}$ in **FA2** = $0.0169 \times 0.250 = 4.225 \times 10^{-3}$ mol

Amount of $Cr_2O_7^{2-}$ that reacted with **G** = $(0.0500 \times 0.400) - 4.225 \times 10^{-3} = 0.01578$ mol

Amount of **G** that reacted = $\frac{3}{2} \times 0.01578 = 0.02365$ mol (in 1.5g)

$M_r = 1.500 \div 0.02365 = 63.4$

Examiner Comments

- Most students were able to apply their understanding of back titration here to obtain the correct answers. A common mistake was to use 50 cm^3 for the volume of **FA2** instead of 250 cm^3.
- Some students applied the mole ratio given wrongly. A simple way to understand the mole ratio is to express it in the following manner.

$$\frac{\text{Amt of G}}{\text{Amt of } K_2Cr_2O_7} = \frac{3}{2}$$

- Students are reminded to express your final answer in 3 s.f. and with the correct units. Intermediate steps can be expressed in 4 s.f. with units.

B1(c) In experiment 1, some of the compound G vapour may have escaped from the test-tube during cooling. Therefore, the mass of G measured is lower than the actual mass of the vapour. This leads to a smaller M_r value.

OR

In experiment 2, the alcohol (compound G) may not be completely oxidised by the acidified $K_2Cr_2O_7$. This leads to a greater concentration of $K_2Cr_2O_7$ present in FA2. Therefore, the amount of G calculated is smaller and hence, a larger M_r value.

Examiner Comments

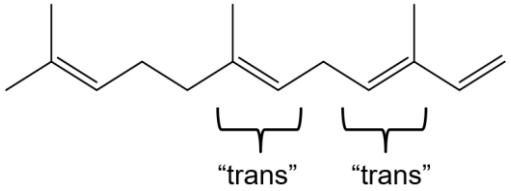
- Students need to realise that the lower M_r obtained in experiment 1 was due to some G vapour escaping from the test-tube particularly during cooling, and not during heating (where some vapour of G is supposed to escape to keep pressure constant).
- Students need to explicitly state the effect of the vapour escaping on the measured quantities (in this case, mass), leading to the lower M_r value calculated.
- Many students suggested that experiment 1 was inaccurate due to the non-ideal behaviour of the vapour. While this is a valid point, the temperature and pressure used in this experiment are near r.t.p. and the assumptions for ideal gas behaviour are applicable.

B2(a) *Cis-trans* isomerism arises because the given hydrocarbons are alkenes with restricted rotation about the C=C bonds, and each hydrocarbon contains at least 1 C=C bond with each doubly bonded C atom bonded to 2 different atoms or groups of atoms.

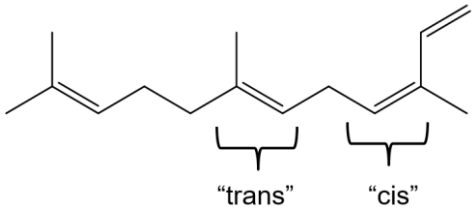
Examiner Comments

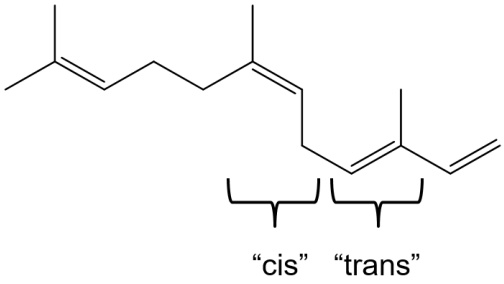
- Students are expected to use concise scientific terminology to accurately reflect the concepts involved. Examples of weaker responses which are not accepted include phrases like "restricted or limited *movement* of the C=C" or "the C atoms bonded to 2 different *functional groups*". Students ought to realise that the above phrases lead to misconception and do not represent the concepts accurately.

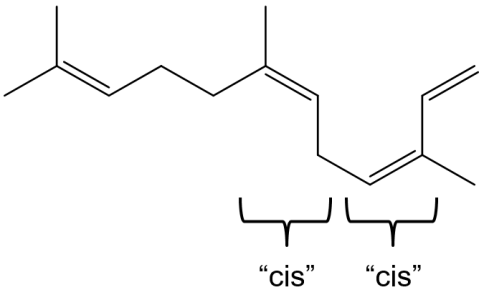
B2(b) Original stereoisomer given:



Any 1 of the following stereoisomers can be drawn:



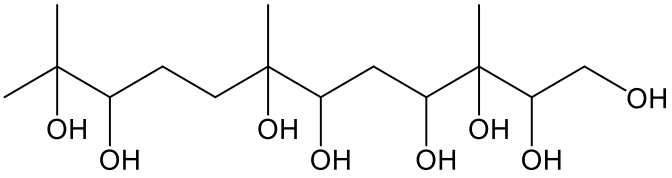




Examiner Comments

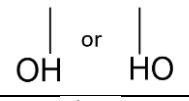
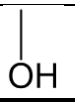
- Students should be aware that cis-trans isomers are to be represented clearly with trigonal planar geometry with respect to the doubly bonded carbon atoms.
- Quite a number of students end up drawing the same structure as the one given in the question. This shows that these students either did not check their structures or lack the skills needed to check for cis-trans isomerism.
- There is also a considerable number of students who still do not know how to draw skeletal formulae properly.

2(c)(i) **V**:



Examiner Comments

- Students need to ensure that that the correct number of carbon atoms are drawn to avoid having extra/missing $–CH_2–$ in the structure.
- Students should be aware that mild oxidation involves the addition of two –OH groups across the C=C of an alkene and not only one –OH group.
- Students are encouraged to put in effort to draw the structures clearly. In this case, there are a number of structures which do not explicitly show the C-O bonds. Instead, ambiguous C-H bonds are shown in the structures of diols.
- Students should take note of the following:

	**Incorrect**. These are **not accepted**. The C atom should not be bonded to the H atom.
	**Correct**. The C atom should bonded to the O atom.

2(c)(ii) $KMnO_4(aq)$, NaOH(aq), cold

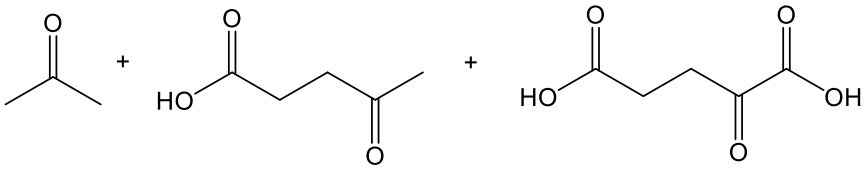
Examiner Comments

- Students should preferably use alkaline medium (e.g. using aqueous NaOH) for the mild oxidation of alkenes. Acidic medium (e.g. using dilute H_2SO_4) is not commonly used for mild oxidation.
- Students should be aware of the cold conditions necessary for mild oxidation instead of room/high temperature.

2(c)(iii) The organic products are:

CH_3COCH_3, $HO_2C\text{-}CH_2CH_2COCH_3$, $HO_2C\text{-}CH_2CH_2COCO_2H$

Or



Examiner Comments

- Students need to ensure that the –H on the C=C is replaced with –OH to form carboxylic acids under strong oxidation conditions.
- Students should be aware that carbon can only form 4 bonds and the structures drawn should reflect this accordingly.
- Students should only include organic products in their answer for this question. CO_2 should be excluded unless the question asks for all carbon-containing products of the reaction.

2(d)(i) 2,6,10-trimethyldodecane

Examiner Comments

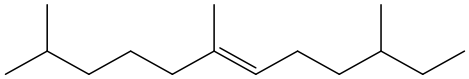
- Students should ensure the lowest possible numbering in the prefix and use "tri" to indicate the presence of 3 methyl substituents.

2(d)(ii) Free radical substitution

Examiner Comments

- Students are required to be specific in their answer for the type of reaction. Overly general answers like "substitution" was not given the credit.

2(d)(iii) **X**:



Reaction (2): ethanolic KOH (or NaOH), heat

Examiner Comments

- Students need to ensure that that the correct number of carbon atoms are drawn to avoid having extra/missing methyl substituents in the structure.
- Students are reminded that the dehydrohalogenation reaction (and other elimination reactions in general) require heating.

2(d)(iv) Reaction (3): DC*l*(g)

Reaction (4): cold concentrated D_2SO_4 followed by heating with D_2O

Examiner Comments

- Students need to realise the deuterium in the products originate from the reagents and hence the reagents should be in their corresponding deuterated forms.
- Students are reminded to read the question carefully to ensure that the reagents and conditions for the reactions are written in their respective answering spaces.

B3(a)(i) $K_p = \frac{p_{NO}^2}{p_{N_2} \times p_{O_2}}$

Examiner Comments

- Students should avoid using the symbol [ ] in K_p expressions as [ ] represents concentration in mol dm^{-3}.

B3(a)(ii) Let the equilibrium pressure of NO be 2*x*.

	$N_2(g)$ +	$O_2(g)$ ⇌	$2NO(g)$
Initial p/atm	1.5	1.5	0
Change in p/atm	–*x*	–*x*	+2*x*
Eqm p/atm	1.5– *x*	1.5–*x*	2*x*

$K_p = \frac{p_{NO}^2}{p_{N_2} \times p_{O_2}} = 4.5 \times 10^{-11}$

$\frac{(2x)^2}{(1.5-x)^2} = 4.5 \times 10^{-11}$

$\frac{2x}{1.5-x} = 6.708 \times 10^{-6}$

$2x = 1.006 \times 10^{-5} - 6.708 \times 10^{-6} x$

$x = 5.03 \times 10^{-6} \Rightarrow$ Eqm pressure of NO = $2x$ = $\underline{1.01 \times 10^{-5} \text{ atm}}$

Examiner Comments

- Students need to refer to the balanced equation in the ICE table to deduce the change in partial pressure. ~~A significant number of students incorrectly wrote 2x for change in partial pressure of NO_2, instead of x.~~ Note that the change in partial pressure of NO should be +2x, not +x. Hence, the equilibrium partial pressure of NO should be 2x, not x.
- Students have to realize that they can square root both sides of

$$\frac{(2x)^2}{(1.5-x)^2} = 4.5 \times 10^{-11}$$

to avoid having to solve a quadratic equation.

B3(a)(iii) An increase in the volume of the container decreases the total pressure of the reaction mixture.

However, the position of equilibrium remains unchanged, as the number of gaseous particles on both sides of the equation are the same.

Examiner Comments

- A significant number of students did not indicate that equal moles of particles on both side of the equation are in the **gaseous** state.

B3(b)(i) From the graph, lg K_p increases with increase in temperature, hence K_p also increases, indicating a larger extent of formation of products. This suggests that with increase in temperature, the forward reaction is favoured to remove the excess heat. Hence the forward reaction to form NO is endothermic.

Examiner Comments

- This question requires deductions to be made from the graph. Hence, we need to use the graph to discuss how lg K_p, and thus K_p, changes with temperature. It is insufficient to simply state that lg K_p is negative even though the conclusion may be right.
- The idea of "shifting of equilibrium position to the **right**" or "larger **extent** of formation of products" must be clearly expressed.

B3(b)(ii) Increase amount/partial pressure/concentration of N_2 / O_2
Decrease amount/partial pressure/concentration NO

Examiner Comments

- Mostly well done.
- Note that the factor stated has to **favour** the formation of NO, hence vague answers that only state "pressure" without mentioning an increase / decrease in pressure of the appropriate species are not answering the question.

B3(b)(iii) Since lg K_p is negative, K_p is less than 1. Hence, $\Delta G^{\ominus}$ is **positive and decreases in magnitude** from 500 K to 2000 K.

Examiner Comments

- Your answer should address two points – sign and magnitude. Please make sure these are clearly and obviously stated.
- Though no explanation was required, the following shows the thought process to derive the answer.
- From the graph, lg K_p is negative from 500 K to 2000 K
  - ⇒ K_p is less than 1 (denominator is larger than numerator)
  - ⇒ Reactants favoured over products
  - ⇒ Position of equilibrium lies to the left (i.e. forward reaction less favoured)
  - ⇒ $\Delta G^{\ominus}$ is positive.
- From 500 K to 2000 K, lg K_p changes from −30 to −5 i.e. becomes less negative.
  - ⇒ K_p is less than 1 but increasing
  - ⇒ Position of equilibrium shifting toward the right (i.e. forward reaction becomes more favoured though position of equilibrium still lies to the left)
  - ⇒ $\Delta G^{\ominus}$ is positive but becomes less positive i.e. decreases in magnitude.

Alternatively, you may choose to use the formula $\Delta G^{\ominus} = -RT \ln K_p$ (*not in syllabus*).
Since $\Delta G^{\ominus} = -RT \ln K_p$, and ln K_p is negative, the **sign** for $\Delta G^{\ominus}$ is **positive**.

- From 500 K to 2000 K, lg K_p changes from −30 to −5, hence its magnitude decreases. According to $\Delta G^{\ominus} = -RT \ln K_p$, the **magnitude** for $\Delta G^{\ominus}$ correspondingly **decreases**, since the magnitude of ln K_p also decreases.

B3(c)(i) $2NO(g) + 2CO(g) \longrightarrow 2CO_2(g) + N_2(g)$

Examiner Comments

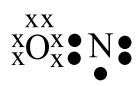
- Your syllabus requires you to know how oxides of nitrogen are catalytically removed from the exhaust gases produced by the car engine. Details can be found in your Kinetics notes.
- Rh is a heterogeneous catalyst which should not be included in the equation.
- It is not specified that air/oxygen is a reactant – O_2 should not be included in the equation.
- Care should be taken to balance the equation.

B3(c)(ii) CO and NO are adsorbed onto the active sites of the catalyst surface. This increases the concentration of CO and NO at the catalyst surface and also weakens the covalent bonds within the molecules. After reaction, the product molecules desorb from the surface of the catalyst.

Examiner Comments

- An explanation of **how** a **heterogeneous** catalyst works is required, thus a full description of the process is necessary, including the process of **adsorption** (note the correct spelling) and its consequences.
- Many students described generally why catalysts speeded up reactions, which is insufficient in this question.

B3(d)(i)



Examiner Comments

- The number of valence electron on each atom should be correct.
- There should not be more than 8 valence electrons on N or O atom.

B3(d)(ii) NO has an unpaired electron on the N atom. Hence, 2 NO molecules can form N_2O_2 with N-N bond formation. Hence Step 1 is exothermic.

Examiner Comments

- Student need to use answer in **(i)** to explain clearly that the NO free radicals form N-N bonds with each other to form N_2O_2. Merely stating that NO have unpaired electrons is insufficient.

C1(a)(i) $\frac{1}{4}\ S_8(s) + Cl_2(g) \longrightarrow S_2Cl_2(l)$

Examiner Comments

- Students are reminded that standard enthalpy change of formation is defined as energy change when **1 mole of the pure substance in a specified state** is formed from its **constituent elements in their standard states** under standard conditions (1 bar and 298 K).
- Students are expected to know that at standard conditions, elemental sulfur (S_8) exists as a yellow solid (not a gas).
- The chemical formula of S_8 was given in the question so students are expected to use S_8 in writing the chemical equation instead of S(s).

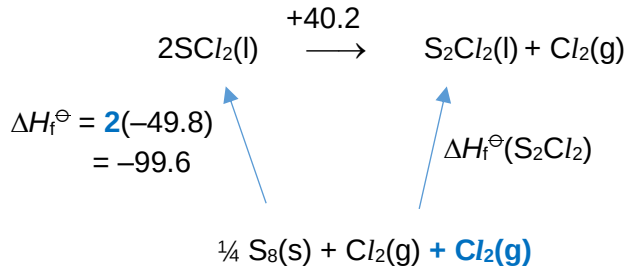
C1(a)(ii) IE generally increases across the period.

Across the period, nuclear charge increases while shielding effect remains relatively constant (as electrons are being added to the same shell). The effective nuclear charge increases and thus, the IE generally increases.

Examiner Comments

- Students are expected to use concise scientific terminology to accurately reflect the concepts involved.
- Both factors, **nuclear charge** and **shielding effect**, are to be discussed separately. Merely stating 'effective nuclear charge' is insufficient.
- In the discussion for shielding effect, many students omitted the important word "**relatively**" or "**approximately**" or "**effectively" constant** and hence demonstrated wrong understanding about the shielding effect across a period. Many wrong answers described "shielding effect remains constant due to same number of inner shells" – this is conceptually incorrect when applied to answering this question. The reason why shielding effect remains **relatively constant** across a period is because the electrons are added to the same valence shells and these electrons in the same shell exert negligible shielding effect on one another as compared to inner shell electrons. The shielding does not remain constant across a period.

C1(b)(i)



$\Delta H_f^{\ominus}$ (S_2Cl_2) = 2(–49.8) + 40.2 = **–59.4 kJ mol^{-1}**

Examiner Comments

- This is a relatively straightforward energy cycle that is generally well attempted.
- Students need to ensure that all the chemical equations in the energy cycle
  - are balanced with the correct state symbols shown,
  - with correct direction of the arrows,
  - with correct stoichiometry on the relevant ΔH.
- Many students forgot to multiply the ΔH_f (SCl_2) by 2 to reflect the correct understanding in forming 2 mol of SCl_2.

C1(b)(ii) The sign of $\Delta S^{\ominus}$ is **positive**.

Disorder of the system increases due to **increase in the number of gaseous particles** from 0 to 1 due to the formation of Cl_2(g).

Examiner Comments

- This question is very well attempted.
- Students are encouraged to phrase their answer clearly and concisely. It is the 'entropy **change'** that is positive, not the 'entropy'. Some answers merely stated the formation of 1 mol of chlorine molecules but did not explicitly link the formation of gaseous products to the increase in disorder, such answers were not given full credit.
- Some students wrongly assumed that the decomposition reaction is spontaneous and therefore deduced the sign of $\Delta S^{\ominus}$ from the assumption. Marks were not awarded for such an answer despite the right sign being derived as there is no information provided on the spontaneity of the decomposition reaction in the question.

C1(b)(iii) Since $\Delta S^{\ominus}$ and $\Delta H^{\ominus}$ are both positive, the reaction is spontaneous under **high temperatures** as the **negative $-T\Delta S^{\ominus}$ term will outweigh the positive $\Delta H^{\ominus}$ term such that $\Delta G^{\ominus} < 0$**.

Examiner Comments

- Students need to state the conditions of the temperature as required in the question.
- Students should use concise scientific terminology to accurately reflect the concepts involved. Weaker responses made use of unclear and ambiguous phrases like "the factor of T and $\Delta S^{\ominus}$ should be greater than $\Delta H^{\ominus}$". No credit was award for such responses.
- Students are reminded that entropy (S) and enthalpy (H) are not the same as entropy **change** ($\Delta S^{\ominus}$) and enthalpy **change** ($\Delta H^{\ominus}$).
- It is important to specify the signs of $\Delta S^{\ominus}$ and $\Delta H^{\ominus}$ clearly before going into the reasoning. The understanding of $\Delta G^{\ominus} < 0$ for a reaction to be spontaneous should be reflected in the whole answer.

C1(c)(i) Bond angle ***a***: 105° Bond angle ***b***: 109.5°

Examiner Comments

- This question is generally well attempted.
- Some students failed to recognise that there are 2 lone pairs of electrons on the S in S_2Cl_2 and gave wrong angles such as 180° thinking that the molecule is linear about S.
- Some students did not realise that the central C atom in mustard gas with bond angle ***b*** is bonded to 4 other atoms (one carbon atom, one chlorine atom and two hydrogen atoms) and hence adopts a tetrahedral arrangement with bond angle of 109.5°.

C1(c)(ii) There are 2 bond pairs and 2 lone pairs around S. Repulsion between the two lone pairs is stronger than repulsion involving the two bond pairs, resulting in the bond angle of Cl–S–S bond to be smaller than 109.5°.

Examiner Comments

- Students need to state clearly the number of bond pairs and lone pairs around the S atom.
- Students are also expected to be specify clearly the relative strength of repulsion between the lone pairs and bond pairs to account for the deviation in the bond angle. Merely stating "to minimise the repulsion between the electron pairs" in a generic manner is insufficient.

C1(c)(iii)

sp^2  Three sp^2 hybrid orbitals arranged in trigonal planar

Examiner Comments

- Students are reminded to be careful of the notation for hybrid orbital. The "sp" is written in small letter instead of capital letter (such as "Sp" or "SP") while the "2" in sp^2 has to be written in superscript.
- Students are expected to draw the hybrid orbitals clearly (each hybrid orbital with one big lobe and one small lobe), show the correct shape and arrangements of the orbitals as well as clear overlapping at one single node at the center.
- Students must illustrate clearly the trigonal planar shape in the drawing. If side view is shown, the answers should include the indication of 120° as the angle between the hybrid orbitals to show understanding of the trigonal planar shape.
- Some students included unhybridised p-orbitals in the drawing. This is unnecessary.

C1(d) Being a period 3 element, the p orbitals of S are large and diffuse, hence the overlap between them in the formation of π bond is not effective.

Examiner Comments

- Students have to state clearly the reason as to why the side-on overlap of p-orbitals of **sulfur atoms** is not effective instead of merely giving generic answers (without making specific reference to the S atom in this context) that compare the strength of sigma bond formation to π bond formation.
- Students should explain why the formation of π bond is not effective (as required by the question) instead of looking at the effect by neighbouring atoms such as C*l* after the bond is formed. Many wrong answers made reference to C*l* atoms being electronegative and hence draw electrons away from the π bond. This is incorrect because the difference in electronegativity between S and C*l* is not significant enough to cause substantial weakening of the π bond in S=S.

C2(a) $2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$

Examiner Comments

- Generally well done.

C2(b) Comparing experiments 1 and 2, when volume of $K_2S_2O_8$ is halved, 1/t is halved.
$\Rightarrow$ 1/t $\propto$ volume of $K_2S_2O_8$
$\Rightarrow$ rate $\propto [S_2O_8^{2-}]$
Therefore, the reaction is 1st order with respect to $S_2O_8^{2-}$.

Comparing experiments 1 and 3, when volume of KI is halved, 1/t is halved.
$\Rightarrow$ 1/t $\propto$ volume of KI
$\Rightarrow$ rate $\propto [I^-]$
Therefore, the reaction is 1st order with respect to I^-.

Examiner Comments

- A handful of students deduced the orders of reaction incorrectly because the relative rate was wrongly determined. Note that rate $\propto$ 1/t.
- Students must compare rate or 1/t across 2 experiments, and not merely the time taken.

C2(c) Rate = $k[I^-][S_2O_8^{2-}]$

Examiner Comments

- Generally well done.

C2(d) $n(S_2O_3^{2-}) = 10/1000 \times 0.1 = 0.001$mol; $n(I_2) = ½ \times 0.001 = 0.0005$ mol

Hence, rate = $d[I_2]/dt = [(0.0005/50)x1000]/139 = 7.19 \times 10^{-5}$ mol dm^{-3} s^{-1}

From experiment 1: $7.19 \times 10^{-5} = k\,[0.4 \times 12.50/50][0.2 \times 12.50/50]$

$k = 0.0144$ mol^{-1} dm^3 s^{-1}

Examiner Comments

- Students who attempted to determine "the amount of I_2 formed in each experiment when the blue-black complex first appears" thinking that different amounts of I_2 were formed across all 3 experiments showed poor understanding of how this "clock reaction" works.

  The iodine being produced by the reaction between $K_2S_2O_8$ and KI (reaction 1) will immediately react with $S_2O_3^{2-}$ (reaction 2).

  At the point when the $S_2O_3^{2-}$ is completely used up, reaction (2) stops but reaction (1) continues. The free iodine produced from reaction (1) will cause the appearance of a blue-black complex (starch-iodine complex).

  Therefore, "the amount of I_2 formed in each experiment when the blue-black complex first appears" is controlled by the amount of $S_2O_3^{2-}$ added (10.0 cm^3 of 0.1 mol dm^{-3} of $Na_2S_2O_3$)**, which is the same for all 3 experiments.**

- Rate is the change in concentration of a particular reactant or product per unit time.
  Rate = $d[I_2]/dt$
  Rate ≠ d(amount of I_2)/dt
  Rate ≠ 1/t
- When applying the rate equation to solve for value of rate constant, $[I^-]$ and $[S_2O_8^{2-}]$ are concentrations in the mixture of total volume of 50 cm^3. Mixing results in dilution!

C2(e) Fe^{2+} and $S_2O_8^{2-}$ are involved in the rate determining step of experiment 4.
Since the addition of a small amount of Fe^{2+} led to a substantial increase in rate, Fe^{2+} acts as a catalyst.
It can be attributed to the fact that there is electrostatic attraction / no repulsion between the oppositely charged Fe^{2+} and $S_2O_8^{2-}$ ions, and this lowers the activation energy.
Therefore, the frequency of effective collisions increases.

Examiner Comments

- "By considering the species involved in the rate determining step"… students must mention clearly in their answer Fe^{2+} and $S_2O_8^{2-}$ are the species involved in the rate determining step since investigation showed that rate $\propto [S_2O_8^{2-}][Fe^{2+}]$.
- Fe^{2+} replaces I^- to participate in the rate determining step with $S_2O_8^{2-}$. A small number of students were able to provide an explanation why this reaction pathway has a lower activation energy. This point adds value to the answer and is a marking point.

C2(f) In the proposed mechanism, the rate determining step involves one $S_2O_8^{2-}$ ion and two Fe^{2+} ions, whereas the rate determining step based on the observed kinetic data involves one $S_2O_8^{2-}$ ion and one Fe^{2+} ion.

OR

The rate equation based on the mechanism would be rate = $k[S_2O_8^{2-}][Fe^{2+}]^2$, whereas the rate equation based on the observed kinetic data would be rate = $k[S_2O_8^{2-}][Fe^{2+}]$.

AND

Thus the mechanism is inconsistent with the kinetics data.

Examiner Comments

- Rate being directly proportional to the concentrations of aqueous Fe^{2+} and $S_2O_8^{2-}$ meant rate $\propto [S_2O_8^{2-}][Fe^{2+}]$.
- For a proposed mechanism to be consistent with observed kinetic data, other than having the reactants that participate in the slow step appear in the rate equation**, the order of reaction with respect to a reactant X is the number of X particles that participates in the slow step**. Many students failed to consider the **second point** and gave the wrong conclusion.

C3(a)(i) Positional / constitutional isomerism

Examiner Comments

- Generally well done

C3(a)(ii) The instantaneous dipole-induced dipole (id-id) interactions between **J** and water does not release sufficient energy to compensate for the energy needed to overcome the hydrogen bonding between water molecules and the id-id interactions in **J**.

OR

The instantaneous dipole-induced dipole (id-id) interactions between **J** and water is weaker than the hydrogen bonding between water molecules and the id-id interactions in **J**.

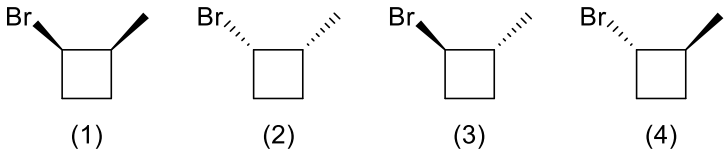
Examiner Comments

- This question is simple but not well-attempted. Common problems were
  - Incomplete considerations. Many students discussed interactions in J and in water but not between J and water, which is an important factor in this question! Your answer

should consider and discuss the interactions between <u>solute-solute, solvent-solvent, and solute-solvent</u>.

- Vague descriptions of interactions. These interactions must be clear and specific e.g. <u>id-id interactions</u> <u>between J and water</u>.
- J is considered non-polar as the bonds in J are non-polar. Hence, J forms id-id interactions (not pd-pd) with other molecules of J.

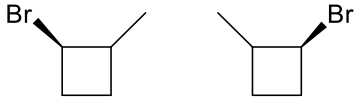
C3(a)(iii)



1 & 2 or 3 & 4: enantiomers
1 & 3 or 2 &4 : cis-trans isomers

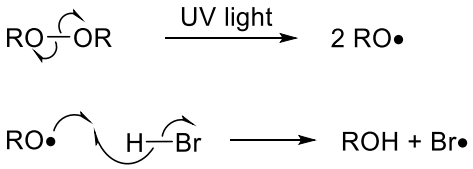
<u>Examiner Comments</u>

- Many incorrect answers involved not defining the configuration about <u>both</u> chiral centres, in the structures drawn. This leaves the stereochemical relationship ambiguous.

e.g. 

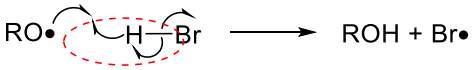
cannot be confirmed to display cis-trans isomerism or enantiomerism, as the methyl groups could be pointing either above or below the plane.

C3(b)(i)



<u>Examiner Comments</u>

- The positioning of the curly arrows were frequently imprecise. For example, in the first step, arrow heads were sometimes incorrectly pointing towards the R groups, instead of directly at the oxygen atoms. There is also a need to draw a curly arrow originating from the lone electron of the alkoxy radical in the second step to show its involvement in the formation of the O–H bond.
- Curly arrows for the second step were sometimes omitted, possibly due to an incorrect assumption based on what the students had been practising in their standard alkanes mechanism. Answer to the question requirements.
- The following arrow pushing presentation (circled) is conceptually **invalid**:



In this **incorrect** example, one electron from the H–Br bond goes to the hydrogen atom, and *another* electron is donated by the hydrogen atom to form the O–H bond, *simultaneously*. A bonded hydrogen atom does not have any extra non-bonded electron to allow for such an overall movement of electrons. Therefore, this is a timely reminder that all arrows drawn in a single mechanistic step refer to a simultaneous movement of electrons leading to bond breaking/formation.

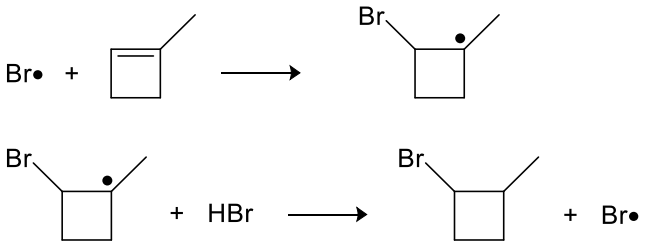
C3(b)(ii) Bond energy for O–O : 150 kJ mol^{-1} and for H–Br : 366 kJ mol^{-1} i.e. O–O bond is much weaker than H–Br.

As the O–O bond is very weak compared to H–Br, the UV light does not supply sufficient energy to break the H–Br bond directly. However, it provides sufficient energy to break the O–O bond to generate alkoxy radicals. The alkoxy radicals lead to the generation of bromine radicals as the formation of the strong O–H bond now compensates for the energy absorbed in breaking the H–Br bond.

Examiner Comments

- Students need to take the hint from the questions ("…considering the bonds in…", "Use of Data Booklet…") and infer that the use and quoting of relevant bond energy values are necessary.
- It was common to see a lack of elaboration on why it was *necessary* to have ROOR aid in the breaking of H–Br – it is because UV alone was insufficient in doing so. General statements like "it is easier to break O–O than H–Br, thus ROOR was needed" does not adequately address the necessity.
- A number of answers compared O–H and H–Br bond energies without mention of O–O bond energy, though the question specifically prompted the consideration of "*bonds in dlalkyl peroxide* (which does not contain O–H bonds) *and hydrogen bromide*".
- A number of students gave a good account on how the alkoxy radical actually leads to a favourable H–Br bond breaking, which was good to see.

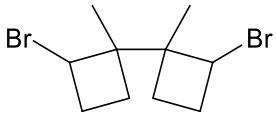
C3(b)(iii)



Examiner Comments

- Students are reminded that the *structures* of organic molecules need to be shown even in a balanced equation.
- Some students are unfamiliar with skeletal formula and did not realise that there is a $–CH_3$ on the ring.
- The position of the unpaired electron was sometimes placed on the incorrect carbon atom. Some incorrect intermediates "suddenly" transformed into the correct product, which was not possible if the second step of the described mechanism was to be followed strictly – basically, only hydrogen abstraction from HBr occurred.

C3(b)(iv)



Examiner Comments

- Students need to understand that, frequently in Chemistry, the questions have a flow where every part builds on the previous part or is part of a bigger picture. This perspective helps students understand that this termination product is formed from the radical from (b)(iii).
- There were occasional incorrect placements of the methyl groups and bromine atoms which were inconsistent with the expected product arising from the radical intermediate generated in the previous part.