2021 Y5 H2 Chemistry Promotion Examination – Suggested Solutions

Section A

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

1 Amount of E = $\frac{1}{24000}$ mol
(Note: 1 mole of gas occupies 24 dm^3 at room temperature and pressure.)

No. of molecules in 1 cm^3 of E = = $\frac{1}{24000} \times L = \frac{L}{24000}$

No. of atoms in 1 cm^3 of E = $\frac{L}{24000} \times 3 = \frac{3L}{24000}$
(Note: E is a triatomic molecule.)

2 Reduction half-equation: $SO_2 + 4H^+ + 4e^- \longrightarrow S + 2H_2O$
Oxidation half-equation: $H_2S \longrightarrow S + 2H^+ + 2e^-$
Overall balanced equation: $SO_2 + 2H_2S \longrightarrow 3S + 2H_2O$

After reaction is completed, the mixture contains unreacted H_2S. Hence <u>H_2S is present in excess</u> and SO_2 is the limiting reagent $\Rightarrow$ Options B and C are incorrect.

When 5 mol of H_2S reacts with 1 mol of SO_2, SO_2 is the limiting reagent. 3 mol of H_2S will remain unreacted and 3 mol of S will be formed.

3 Since the biggest jump in ionisation energy is from the 5^{th} to 6^{th} ionisation energy, element M has five valence electrons.

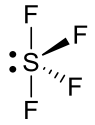
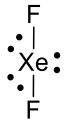
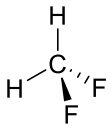
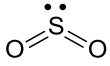
Since element M is in <u>Group 15</u>, it reacts with chlorine to form the <u>covalent</u> compound MCl_3.

4 Rb^+, Br^- and Kr are isoelectronic species (i.e. with same total number of electrons)
$\Rightarrow$ their outermost e^- experience the <u>same shielding effect</u>.
However, <u>nuclear charge of $Br^- < Kr < Rb^+$</u>.
<u>Hence, effective nuclear charge of $Br^- < Kr < Rb^+$</u>.

Electrostatic attraction between the nucleus and the outermost e^- of <u>$Br^- < Kr < Rb^+$</u>.

Energy required to remove the outermost e^- increases in the order: <u>$\Delta H_2 < \Delta H_3 < \Delta H_1$</u>

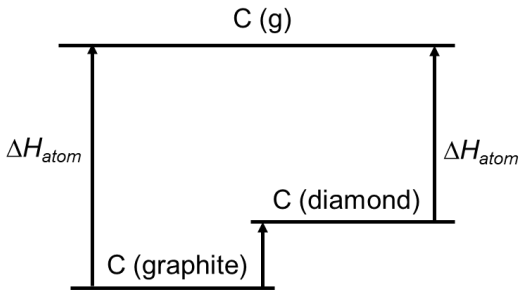
5

molecule	structure	shape	bond dipoles cancel out?	polar / non-polar
SF_4		see-saw	No	polar
XeF_2		linear	Yes	non-polar
CH_2F_2		tetrahedral	No	polar
SO_2		bent	No	polar

6

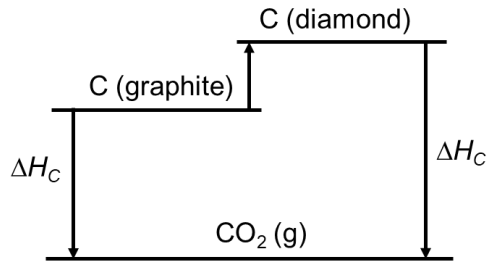
Statement 1	Incorrect. In the aldehyde group () of butanal, the <u>hydrogen atom is bonded to carbon (not oxygen)</u>. Hence there is no intermolecular hydrogen bonding in butanal. Only intermolecular instantaneous dipole-induced dipole and permanent dipole-permanent dipole interactions exist in butanal. Recall the criteria for hydrogen bonding: • A hydrogen atom covalently bonded to F, O and N. • A lone pair of electrons on a F, O and N atom in a neighboring molecule bearing a $\delta-$ which can attract the $\delta+$ charge on the H atom.
Statement 2	Incorrect. All three compounds are simple molecules. Although C=C bond is stronger and requires more energy to break compared to C−C bond, boiling of simple molecules involves <u>overcoming intermolecular forces of attraction, NOT covalent bonds</u>.
Statement 3	Correct. Butanal and 2-methylpropanal differs only in their hydrocarbon chain. Both compounds have the same aldehyde functional group and the same number of electrons (as they have the same molecular formula). Butanal is a <u>straight-chain</u> aldehyde, which has greater surface area for intermolecular interactions as compared to its <u>branched</u> isomer, 2-methylpropanal. Hence, the instantaneous dipole–induced dipole interactions in butanal are stronger than that in 2-methylpropanal.

7 The carbon atoms in graphite are sp^2 hybridised while those in diamond are sp^3 hybridised. Since sp^2 hybrid orbitals have greater s-character, there is more effective overlap between the sp^2 hybrid orbitals to form stronger carbon-carbon bond in graphite.
⇒ Statement 1 is correct.



With reference to the energy level diagram on the left, the enthalpy change of atomisation of diamond is less endothermic than that of graphite.
⇒ Statement 2 is correct.

(Note: $\Delta H_{atomisation} > 0$)



With reference to the energy level diagram on the left, the enthalpy change of combustion of diamond is more exothermic than that of graphite.
⇒ Statement 3 is correct.

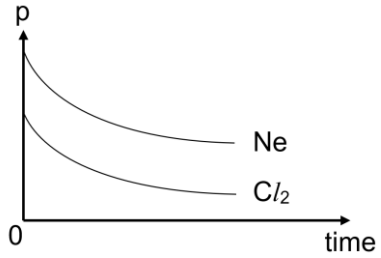
(Note: $\Delta H_{combustion} < 0$)

8 Since the amount of gas and temperature are kept constant,
pV = nRT = constant as time progresses.
⇒ The graph of pV against time is a horizontal line.

As equal masses of Cl_2 and Ne are used and Cl_2 has a higher molar mass than Ne, a smaller amount of Cl_2 is present in the syringe. Hence, the value of pV (= nRT) of Cl_2 is smaller than that of Ne.
⇒ Option A is correct.

As the volumes of the syringes are increased at the same constant rate,
$V \propto \text{time}$ and $p = \frac{nRT}{V} \propto \frac{nRT}{\text{time}}$
⇒ graph of p against time is a downward sloping curve.

Since there is a smaller amount of Cl_2 present in the syringe, the partial pressure of Cl_2 is also smaller. Hence the correct graph of p against time is:



9

Option A	$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(l)$ $\Delta H_{formation}^{\ominus}(H_2O(l))$ $H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(l)$ $\Delta H_{combustion}^{\ominus}(H_2(g))$ The equation that represents both processes is the <u>same</u>. Hence, the two enthalpy changes have the same value.
Option B	$\frac{1}{2}I_2$**(s)** $\longrightarrow I(g)$ $\Delta H_{atomisation}^{\ominus}(I_2(s))$ $\frac{1}{2}I_2$**(g)** $\longrightarrow I(g)$ $\frac{1}{2} \times$ BE(I–I) Since the two processes are <u>different</u>, as each involves different states of I_2, the enthalpy changes are of different values.
Option C	C**(s)** + **O₂**(g) $\longrightarrow CO_2(g)$ $\Delta H_{combustion}^{\ominus}(C(s))$ $CO_2(g) \longrightarrow$ C**(g)** + **2O**(g) $2 \times$ BE(C=O) Since the two processes are <u>different</u>, the enthalpy changes are of different values.
Option D	$O(g) \longrightarrow O^+(g) + e^-$ 1st IE of O $O(g) + e^- \longrightarrow O^-(g)$ 1st EA of O Since the two processes are <u>different</u>, the enthalpy changes are of different values. Note: The energy required to remove 1 mol of electrons from 1 mol of O(g) to form 1 mol of $O^+(g)$ is equal in magnitude to the energy released when 1 mol of electrons is gained by 1 mol of $O^+(g)$ to form 1 mol of O(g).

10

Statement 1	Correct. The equation that represents $\Delta H_{formation}^{\ominus}(KI(s))$ is: $K(s) + \frac{1}{2}I_2(s) \longrightarrow KI(s)$ The standard enthalpy change of formation of a substance is the <u>energy change</u> when <u>1 mole</u> of the <u>pure substance in a specified state</u> is formed from its <u>constituent elements in their standard states</u> under standard conditions. (Note: Standard state of I_2 is solid).
Statement 2	Correct. The equation that represents the lattice energy of potassium iodide is: $K^+(g) + I^-(g) \longrightarrow KI(s)$ The lattice energy of an ionic compound is the <u>energy released</u> when <u>1 mole</u> of the solid ionic compound is formed from its <u>constituent gaseous ions</u> under standard conditions.
Statement 3	Incorrect. The equation that represents the hydration energy of potassium iodide is: $K^+(g) + I^-(g) \longrightarrow K^+(aq) + I^-(aq)$
Statement 4	Incorrect. ΔH_2 = 1st IE of potassium **+** 1st EA of iodine

11 $\Delta G = \Delta H - T\Delta S$

For a reaction to be less spontaneous at higher temperatures, ΔG has to be less negative (or more positive) at higher temperatures. Hence, ΔS must be negative so that the $-T\Delta S$ term is more positive at higher temperatures.

The reactions in options A, B and D produce more gaseous products compared to the reactants, hence ΔS is positive.

Only the reaction in option C produces less gaseous products compared to the reactants, hence ΔS is negative.

12 At constant room temperature and pressure, $V_{gas} \propto n_{gas}$.

	$X_2(g)$ $\longrightarrow$ $2X(g)$	
Initial volume / cm^3	50	0
Change in volume /cm^3	– a	+2a
Final volume / cm^3	50 – a	2a

Total volume at time, t = 50 – a + 2a = 50 + a = 87.5

a = 37.5

Volume of $X_2(g)$ = 50 – 37.5 = 12.5 cm^3

Since $50\ cm^3 \xrightarrow{t_{½}} 25\ cm^3 \xrightarrow{t_{½}} 12.5\ cm^3$

Time taken = $2(t_{½})$ = 2(20) = 40 min

13 initial rate $\propto \frac{V_A}{t}$

Since total volume is kept constant, $V_A \propto$ [A] (same for B and C).

Expt	V_A / cm^3	V_B / cm^3	V_C / cm^3	V_{H_2O} / cm^3	t / s	$\frac{V_A}{t}$
1	10	10	5	25	10	1
2	10	10	10	20	10	1
3	10	20	10	10	5	2
4	20	10	5	15	10	2
5	30	5	5	10	y	$\frac{30}{y}$

Comparing expt 1 and 2, when volume of C $\times$ 2, initial rate is unchanged.
Hence the reaction is zero-order with respect to C.

Comparing expt 2 and 3, when volume of B $\times$ 2, initial rate $\times$ 2.
Hence the reaction is first-order with respect to B.

Comparing expt 1 and 4, when volume of A $\times$ 2, initial rate $\times$ 2.
Hence the reaction is first-order with respect to A.
$\Rightarrow$ Statement 2 is incorrect.

Hence the rate equation is rate = k[A][B].
The reaction is an overall second-order reaction.
$\Rightarrow$ Statement 3 is correct.

Comparing expts 1 and 5,

$$\frac{\text{rate}_5}{\text{rate}_1} = \frac{k(30)(5)}{k(10)(10)} = 1.5 = \frac{30}{y}$$

$y = 20 \Rightarrow$ Statement 1 is correct.

14 When the equilibrium constant of a reaction is independent of temperature, the ΔH of the reaction is zero.

This means that the total bond energy of the reactants is the same as that of the products. Hence, the activation energy of the forward and backward reaction is the same and the rate constants of both the forward and backward reaction will vary to the same extent with temperature.

15 At constant temperature and volume, p α n.
Hence initial $P_{SO_2Cl_2} : P_{Cl_2} = 5 : 3$.

	$SO_2Cl_2(g)$	$\rightleftharpoons$	$SO_2(g)$	+	$Cl_2(g)$
initial pressure	5a		0		3a
change in pressure	–y		+y		+y
equilibrium pressure	5a – y		y		3a + y

Total initial pressure = 5a + 3a = 8a
Total pressure at equilibrium = 5a – y + y + 3a + y = 8a + y

Since total equilibrium pressure is 10% greater than total initial pressure,
8a + y = (1.1)8a
y = 0.8a

Mole fraction of $Cl_2 = \frac{3a + y}{8a + y} = \frac{3.8a}{8.8a}$

Partial pressure of $Cl_2 = \frac{3.8a}{8.8a} \times p = 0.432p$

Section B

B1(a)(i) Dynamic equilibrium refers to a state in a reversible system in which the rates of the forward and backward reactions are continuing at the same rate, resulting in no net change in the macroscopic properties of the reactants and products.

Comments:
- Most students showed understanding that at dynamic equilibrium, forward rate equals backward rate. However, a handful did not mention that the forward and backward reactions are still continuing, i.e. forward and backward rates are non-zero.
- In this definition, students need to state clearly that there is no net change in the macroscopic properties (e.g. concentration) of both the reactants and products.

B1(a)(ii) Since ethanol and ethyl propanoate are volatile compounds, the mixture must be stored in a sealed container to prevent the vaporisation and loss of ethanol and ethyl propanoate. Otherwise, the concentrations of the two compounds will change continually and the reaction cannot reach dynamic equilibrium / value of K_c obtained will be inaccurate.

Comments:
- It is important to read the question carefully and explain why a sealed container is needed for the system to reach equilibrium. Some students mistakenly discussed about the safety risks of the compounds used.
- Other mistakes include not referring to the properties of the compounds listed in Table 1.1 and/or discussing about possible side reactions between the compounds and atmospheric air (e.g. oxygen).

B1(b)(i) Pre-calculations

The mixture at equilibrium will be titrated against 1.00 mol dm^{-3} NaOH(aq), which reacts with both the HC*l* catalyst and propanoic acid present at equilibrium.

Amount of NaOH used = amount of propanoic acid at eqm + amount of HC*l*

Maximum amount of NaOH used occurs if there are a lot of propanoic acid left at equilibrium, i.e. negligible amount of propanoic acid was reacted. This maximum amount of NaOH cannot exceed the capacity of the burette (50.00 cm^3).

$$\text{Maximum amount of NaOH used} = \frac{50.00}{1000} \times 1.00 = 0.0500 \text{ mol}$$

Since 1.00 cm^3 of 2.00 mol dm^{-3} HC*l* was used,
0.0500 = amount of propanoic acid at eqm + amount of HC*l*

$$0.0500 = \text{amount of propanoic acid at eqm} + \frac{1.00}{1000}(2.00)$$

amount of propanoic acid at eqm = 0.0480 mol
mass of propanoic acid used = 0.0480(74.0) = 3.55 g
mass of ethanol used = 0.0480(46.0) = 2.21 g

Procedure

1) Using an electronic balance, weigh accurately about 3.55 g of propanoic acid into a clean and dry 100 cm^3 conical flask. Record the mass of propanoic acid used.
2) Using an electronic balance, weigh accurately about 2.21 g of ethanol into the same conical flask. Record the mass of ethanol used.
3) Using a 50.00 cm^3 burette, add 1.00 cm^3 of HC*l* (aq) into the same conical flask.
4) Stopper the conical flask with a rubber bung and swirl the mixture to obtain a homogeneous solution. Leave the mixture to stand at room temperature for one week.
5) Using a 50 cm^3 measuring cylinder, add 25 cm^3 of cold, deionised water into the conical flask.
6) Add a few drops of thymolphthalein indicator.
7) Titrate the mixture quickly against 1.00 mol dm^{-3} NaOH(aq), placed in a 50.00 cm^3 burette. The endpoint is reached when the mixture turns from colourless to pale blue.
8) Record the titration results in an appropriate table.

Comments:

- While most students made effort to attempt this question, a handful did not read the information given on pg 8 to plan their experimental procedure.
- The experiment involves a homogeneous reaction system – the reactants and products are all in the liquid state (see equation 1). Since Table 1.1. only gives the M_r and not the density of the compounds, students will need to determine the amount and mass of the reactants (propanoic acid and ethanol) to use.
- The key points in the experimental procedure are as follows:
    - Use of electronic balance to weigh out propanoic acid and ethanol; burette to measure 1.00 cm^3 of HC*l*
    - Mixing the reactants and acid catalyst, and storing the reaction mixture in a sealed container for one week at room temperature to achieve dynamic equilibrium
    - Quenching of the equilibrium mixture by adding a large quantity of cold, deionised water, followed by addition of thymolphthalein indicator
    - Titration of the whole reaction mixture against NaOH in the burette
    - Colour change at the end-point of titration
    - Recording of mass measurements and titration results
- In the preparation of the equilibrium mixture, there should not be any addition of water (e.g. transfer of washings from rinsing of apparatus) as liquid water is a product of this homogeneous reaction system. Otherwise, any liquid water added will need to be considered in the determination of K_c.
- The purpose of the titration is to obtain an accurate determination of the total amount of acid (made up of the HC*l* catalyst and propanoic acid at equilibrium). Hence, the volume of HC*l* used must be measured using an apparatus of high precision, e.g. burette. Use of measuring cylinder or dropper is not accepted. Note that any equipment/apparatus used must be found in a normal school laboratory.

B1(b)(ii) Any one of the following:

- As propanoic acid is corrosive, safety gloves should be worn to prevent any direct contact of the chemical with our skin.
- As propanoic acid and ethanol are eye irritants, safety goggles should be worn to prevent direct contact of the chemicals with our eyes.
- As propanoic acid, ethanol and ethyl propanoate are flammable, there should not be any naked flame near the experiment.
- As ethanol and ethyl propanoate are volatile compounds, the experiment should be carried out in a fumehood to prevent inhalation of chemical vapours.

Comments:

- Generally well done. Students need to state clearly the safety risk and the corresponding safety precaution (e.g. wearing of safety gloves to prevent skin irritation when coming into contact with corrosive acids used).

B1(c)(i) ① *Absence of acid catalyst:*

Since a catalyst lowers the activation energy of both the forward and backward reactions to the same extent (or increases the rates of both the forward and backward reactions to the same extent), it has no effect on the value of K_c.

OR

Since a catalyst increases the rates of both the forward and backward reactions, equilibrium is reached more quickly. In the absence of the dilute strong acid catalyst, the mixture may not have reached dynamic equilibrium after leaving to stand for one week. Hence, there will be more reactants and less products, and the value of K_c obtained will be lower.

Comments:

- Generally well done. Several students correctly stated that K_c is unaffected as K_c only changes with temperature.
- A common mistake is to state that K_c is unaffected as the catalyst does not appear in the K_c expression.
- Note that a catalyst does not affect the equilibrium position and composition of the mixture as the forward and backward reaction rates are increased to the same extent. Hence, K_c remains unchanged.

② *Large quantity of cold, deionised water not added prior to titration:*

The reaction is not slowed down and as the concentration of propanoic acid decreases during the titration, the equilibrium position would shift towards the reactants side, resulting in a lower K_c obtained.

OR

The rate of reaction in equation 1 is too slow compared to the acid-base titration reaction. Hence, even without the addition of cold deionised water, the shift in equilibrium position is negligible. Therefore, the value of K_c will be unaffected.

Comments:

- The actual K_c is unchanged if the temperature at which dynamic equilibrium is established is kept constant. However, the K_c obtained from this experiment will be affected once the equilibrium position shifts during the titration, as the titre value will be inaccurate.
- Students need to show understanding that the large quantity of cold, deionised water is added to <u>quench / slow down</u> both the forward and backward reactions (in equation 1), and NOT to prevent vaporisation of compounds in the mixture. Without the large quantity of cold, deionised water added, the equilibrium position may shift during the titration as the propanoic acid is neutralised by NaOH.
- Some students mistakenly stated that K_c will increase as the forward reaction can proceed to form more products, without considering the shift in equilibrium position to counteract the decrease in concentration of propanoic acid.
- Another common mistake was to state that temperature will be higher due to neutralisation releasing heat when cold water is not added, and that equilibrium position will shift to favour the endothermic reaction. However, there is insufficient information in the question as to which direction is endothermic. Furthermore, incorrect answers of this type failed to consider the shift in equilibrium position to counteract the decrease in concentration of propanoic acid.

B1(c)(ii) The reaction mixture can be placed in a <u>water bath maintained at room temperature</u> to achieve dynamic equilibrium before quenching by addition of large quantity of cold, deionised water.

OR

The experiment can be <u>repeated</u> several times using <u>different initial ratios of reactants</u> each time to obtain an <u>average value</u> for K_c.

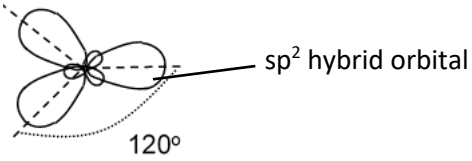
OR

The experiment can be <u>repeated</u> several times using the <u>same amount of each reactant</u> to get <u>an average titre value</u> for the determination of K_c.

Comments:

- While most students recognised the need to repeat the experiment a few times, some did not elaborate on finding the average values to increase reliability of the K_c obtained.
- Some students proposed using aliquots of the equilibrium mixture for titration until consistent results are obtained. While this improves the reliability of the titration results, it may not necessarily improve the reliability of the K_c obtained (i.e. whether similar values of K_c can be obtained from repeated experiments conducted under similar conditions, e.g. temperature).

B2(a)(i)

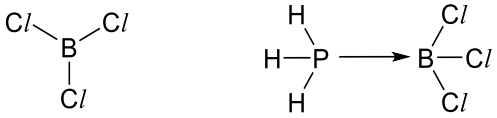


Comments:
- Common mistakes include incorrect representation of sp^2 (e.g. Sp^2 and sp_2 were commonly used).
- Many students did not draw the small lobe directly opposite the big lobe, while some did not draw the intersection of the nodes. Students should try their best to draw hybrid orbitals of approximately equal sizes and about 120° apart.
- Some students incorrectly determined that the B atom in BCl_3 is sp^3 hybridised.

B2(a)(ii) The boron atom in BCl_3 contains a <u>low lying/energetically accessible, vacant (2p) orbital</u> to accept a lone pair of electrons to form a dative bond.

Comments:
- Many students either left out low-lying/energetically accessible or vacant orbitals in their answers. Atoms can have vacant orbitals that are not low-lying or energetically accessible.
- Many students simply mentioned that boron is short of two electrons or is electron deficient. This is insufficient because a low lying/energetically accessible, vacant orbital is required for dative bonding.
- Some students discussed about the ability of the Cl atom to expand its octet configuration instead. This is incorrect as boron is the electron pair acceptor.

B2(a)(iii) There are <u>three bond pairs</u> around boron in BCl_3. To minimise repulsion between the bond pairs, the Cl–B–Cl bond angle is <u>120°</u>. There are <u>four bond pairs</u> around the boron atom in $PH_3 \cdot BCl_3$. To minimise repulsion, the Cl–B–Cl bond angle is <u>109.5°</u>.



Comments:
- Some students incorrectly deduced that BCl_3 has 4 regions of electron density, where it has an additional lone pair on top of the three bond pairs. Instead, it should be an empty p-orbital.
- Some students incorrectly deduced that the dative bond is a lone pair of electrons, hence B has three bond pairs and one lone pair. A dative bond is considered a bond pair.
- Many students used the number of regions of electron density instead of the specific number of bond pairs in their explanation. Regions of electron density include both bond pairs and lone pairs. Having four regions of electron density does not necessarily mean it has four bond pairs.

B2(b) Since the $–C_6H_5$ and $–C_6F_5$ groups are bulky, it prevents the lone pair on the phosphorous atom from getting close enough to the boron atom to form a dative covalent bond.

Comments:
- Many students correctly identified that the difference in the structure is the large/bulky $–C_6H_5$ and $–C_6F_5$ groups. However, some students did not go further to explain how the bulky groups do not allow the P–B dative bond to form.

B2(c) In borazine, boron and nitrogen atom each has an unhybridised p-orbital which overlaps (side-on) continuously, resulting in resonance/delocalised π electrons. Hence, this results in boron–nitrogen bond lengths in borazine being identical and intermediate between that of B–N and B=N.

Comments:
- Many students did not mention about the continuous side-on overlap of p-orbitals. Many simply stated that the molecule exhibits resonance. It is important to state the reason how resonance occurs.
- Most students need to improve their phrasing of answers. Some students incorrectly used the phrases “electrons overlap” and “orbitals delocalise”. Instead, only π electrons can delocalise, while orbitals can overlap. Also, students need to recognise that the p orbitals of **both** B and N atoms overlap side-on, not just that of N atoms. Phrases such as ‘delocalisation of electrons’ should be correctly written as ‘delocalisation of π electrons’, and ‘π orbitals overlap’ should be correctly written as ‘p orbitals overlap’.
- Some students incorrectly explained that the B–N bond length is constant since all boron and nitrogen atoms are sp^2 hybridised. This is incorrect as not all atoms with sp^2 hybridisation form bonds with equal bond lengths.

B2(d) Boron nitride has a giant molecular lattice structure with strong covalent bonds between boron and nitrogen atoms while borazine has a simple molecular structure with weak intermolecular forces of attraction between borazine molecules. Since more energy is required to break the stronger covalent bonds in boron nitride, it has a higher boiling point than borazine.

Comments:
- Many students did not consider the structure of borazine (simple molecular structure) in their answers.
- Many students misinterpreted the word "structure" and discussed about the instantaneous dipole – induced dipole interactions between layers of boron nitride. Instead, melting boron nitride requires the breaking of covalent bonds.
- Some students incorrectly deduced that boron nitride exists as discrete B≡N molecules. The question mentioned that boron nitride has a similar structure as graphite, which meant that it has a giant molecular structure.
- Since we are comparing the types of structure between boron nitride and borazine, a more accurate phrasing will be "giant molecular structure and simple molecular structure" instead of "giant molecular structure and simple molecule".
- Some students incorrectly stated that both boron nitride and borazine require the breaking of strong covalent bonds.
- Some students used s-character and hybridisation to explain the difference in boiling point. This is incorrect as the covalent bonds in borazine are not broken during melting.
- Since this is a comparison between a giant (molecular) structure and a simple molecular structure, we can simply compare strong covalent bonds to weak intermolecular forces of attraction. When we compare two simple molecular structures, it is a requirement to state/identify the type of intermolecular interaction.

B3(a) advantage:
At room temperature, methanol is a liquid whereas methane is a gas. Hence, methanol can be transported more easily.

disadvantage:
Methanol releases smaller amount of energy per gram of fuel combusted compared to methane. Hence, higher mass of methanol is required to produce the same amount of energy.

Comments:
- Students are required to show understanding of how having a higher boiling point (or being less volatile) lead to easier storage/transportation by identifying the physical state of methanol.

B3(b)(i) At 1000 K, K_p is very small and equilibrium position will lie very much to the left. Hence, $\Delta G_r^{\ominus}$ has a large magnitude and is positive.

Comments:
- Students are required to use the magnitude of the K_p values given in the table to explain their answers.
- Students are not required to memorise the equation $\Delta G = -RT \ln K$. However, they are required to show understanding of the relationship between ΔG and K.

B3(b)(ii) As temperature increases, K_p decreases. This shows that the equilibrium position shift left to favour the backward endothermic reaction to absorb heat energy. Hence, the forward reaction is exothermic.

Comments:
- Students are required to identify that the increase in temperature favours the backward endothermic reaction based on the decreasing values of K_p.

B3(c)(i) $$K_p = \frac{P_{CH_3OH}}{P_{H_2}^2 P_{CO}}$$

Comments:
- K_p expression should be represented by the partial pressures of the species present in the equilibrium, and not by their concentrations (represented using square brackets).

B3(c)(ii) $$K_p = \frac{P_{CH_3OH}}{P_{H_2}^2 P_{CO}} = \frac{0.4P_T}{(0.4^2P_T^2)(0.2P_T)} = 1.78 \times 10^{-9}\ Pa^{-2}$$

$P_T = 8.38 \times 10^4$ Pa

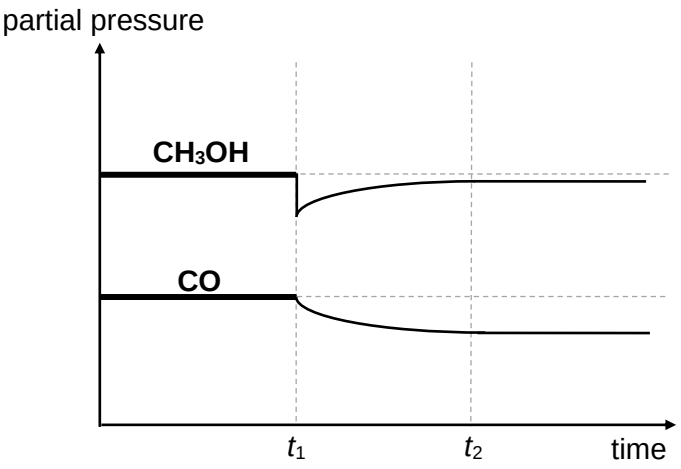
Comments:
- Since the molar ratio of CO and H_2 (1 : 2) present in the initial mixture is the same as the reaction stoichiometric ratio, at equilibrium the molar ratio of CO : H_2 remains the same at 1 : 2.
- Students are required to use the information that the mole fraction of CH_3OH at equilibrium is 0.4.
  Hence, mole fraction of CO = $\frac{1}{3}(1 - 0.6) = 0.2$
  and mole fraction of mole fraction of H_2 = $\frac{2}{3}(1 - 0.6) = 0.4$
- Students are also required to use the K_p value at 373 K in Table 3.2.

B3(c)(iii) $P_{CH_3OH} = 0.4 \times 8.38 \times 10^4 = 3.352 \times 10^4$ Pa

Amount of CH_3OH = $(3.352 \times 10^4 \times 1) / (8.31 \times 373) = 10.8$ mol

Comments:
- Students are required to calculate the equilibrium amount and not equilibrium pressure. Do read the question carefully.

B3(c)(iv)



When a small amount of $CH_3OH(g)$ was removed, P_{CH_3OH} initially decreases and the system is no longer at equilibrium. The equilibrium position will shift right to partially offset the decrease in P_{CH_3OH}. Hence, P_{CH_3OH} increases and P_{CO} decreases until equilibrium is re-established at t_2.

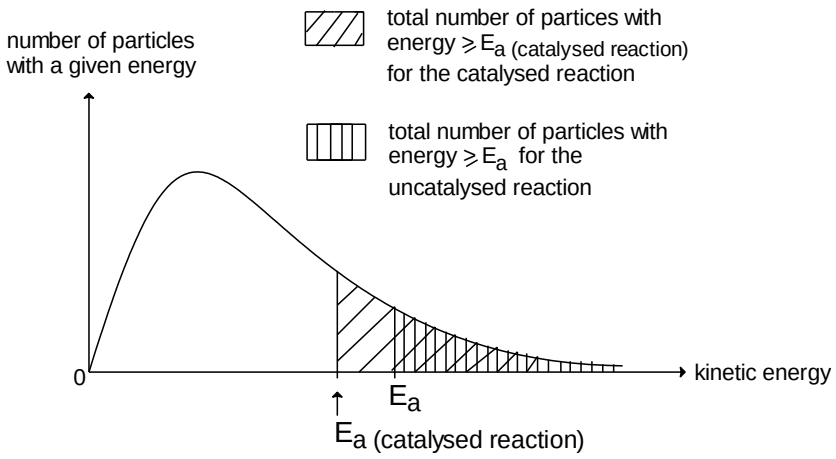
Comments:

- Students are required to show the initial dip in P_{CH_3OH} as a small amount of CH_3OH is removed.
- Students are to show that the system re-establishes equilibrium at t_2 by showing that the partial pressures of CH_3OH and CO remains constant after t_2.
- Students are required to state what happens to the equilibrium position after the change or which reaction (forward or backward) is favoured.
- Do note that the shift in equilibrium position only partially offset the decrease in partial pressure of CH_3OH. Hence, the final partial pressure of CH_3OH at t_2 will still be lower than its initial value.

Section C

C1(a)(i) Platinum catalyst increases the rate of a reaction by providing an alternative reaction pathway of lower activation energy.

In the catalysed reaction, since the activation energy ($E_{a\ (catalysed\ reaction)}$) is lower than that of the uncatalysed reaction (E_a), more reactant particles have energy greater than or equal to the activation energy than in the uncatalysed reaction. This is shown by the larger shaded area for the catalysed reaction in the diagram below.



The frequency of effective collision increases accordingly, and hence the reaction rate increases.

A lower activation energy also results in the reaction having a larger rate constant, and hence an increase in the reaction rate.

Comments:

- Many students failed to draw a reasonable Boltzmann distribution curve. Students need to note the shape of the curve, where it
  - should start from the origin
  - is a convex shape from origin to the apex of the curve
  - is asymmetrical with the peak towards the left side
  - tapers off with x-axis as the asymptote
- The axes need to be labelled correctly.
- The keyword "frequency" of effective collisions needs to be present.
- Some students failed to use the term "activation energy" but instead use "energy required for reaction".

C1(a)(ii) The platinum disc catalyses the decomposition reaction by providing active sites for reaction to take place.

At low [H_2O_2], not all of the active sites on the platinum surface are occupied.
In this case, rate α [H_2O_2] and reaction is first-order with respect to H_2O_2.

At high [H_2O_2], all the active sites on the platinum surface become saturated / are fully occupied by molecules of H_2O_2.
In this case, any increase in [H_2O_2] will not have any effect on the reaction rate / reaction is zero-order with respect to H_2O_2 / rate is independent of [H_2O_2].

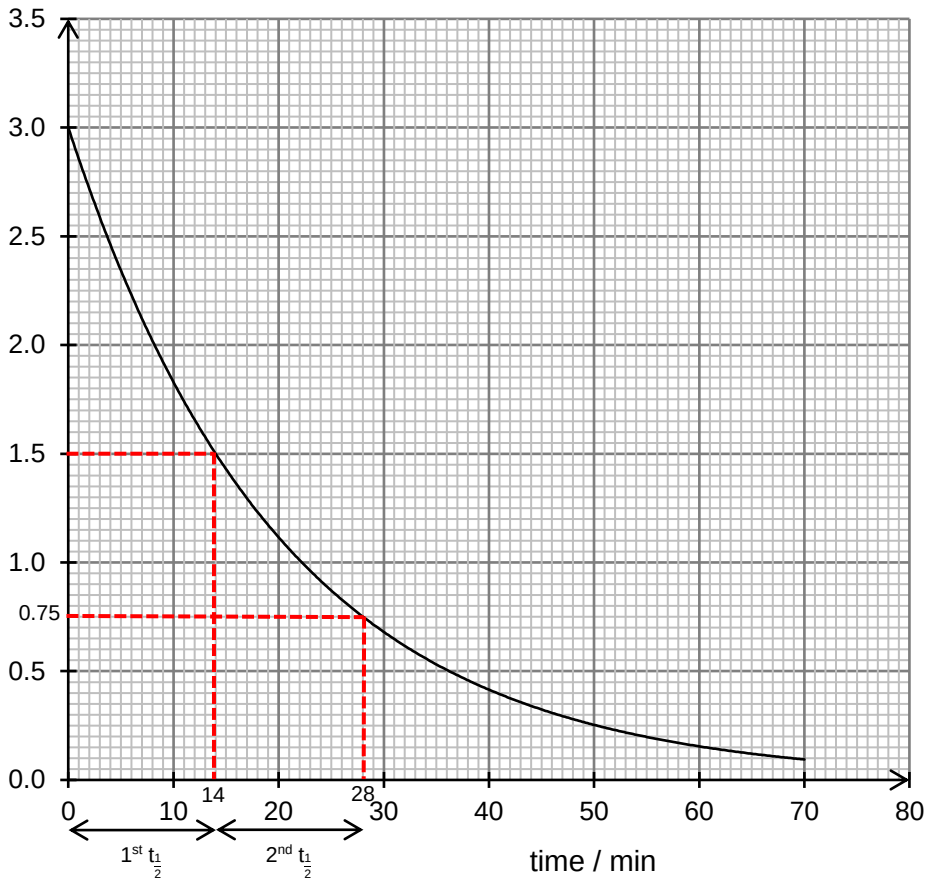
Comments:
- Students need to clearly state the orders of the reaction with respect to H_2O_2 at both low and high concentrations of H_2O_2.
- Many students focused on accounting for the shape of the curve to the order of reaction with respect to H_2O_2, without explaining the reasons why it is so (i.e. due to the active sites being available or saturated).

C1(b)(i) In mechanism A, the slow step (also the rate-determining step) is a bimolecular elementary reaction involving one molecule of H_2O_2 and one I^- ion. The rate equation is rate = $k[H_2O_2][I^-]$.
$\Rightarrow$ Mechanism A fits the rate equation.

In mechanism B, the slow step (also the rate-determining step) is a termolecular elementary reaction involving two molecules of H_2O_2 and one I^- ion. The rate equation is rate = $k[H_2O_2]^2[I^-]$.
$\Rightarrow$ Mechanism B does not fit the rate equation.

Comments:
- As the mechanism is at the molecular level, students need to discuss about the slow step in terms of number of H_2O_2 molecules and number of I^- ions, before stating the rate equation determined from the slow step and concluding which is the correct mechanism.
- The use of stoichiometry or mole ratio of H_2O_2 : I^- (i.e. 1 : 1) in the explanation is unacceptable.
- Students are to take note of how rate equations are written. Examples of incorrect rate equations are $k[H_2O_2][I^-]$ or $k[H_2O_2]^2[I^-]$.

C1(b)(ii)



From graph,
time taken for $[H_2O_2]$ to decrease from 3.00 mol dm^{-3} to 1.50 mol dm^{-3} = 14 min
time taken for $[H_2O_2]$ to decrease from 1.50 mol dm^{-3} to 0.75 mol dm^{-3} = 28 – 14
=14 min

Since there is a <u>constant half-life</u> of <u>14 min</u>, reaction is first-order with respect to H_2O_2.

rate = $k[H_2O_2][I^-]$
Since I^- is a catalyst, its concentration remains constant at 0.80 mol dm^{-3}.
Hence,
rate = $k'[H_2O_2]$, where $k' = k[I^-]$

$$t_{½} = \frac{\ln 2}{k'} = \frac{\ln 2}{k[I^-]} = \frac{\ln 2}{k(0.80)} = 14 \text{ min}$$

$k = 6.19 \times 10^{-2}$ mol^{-1} dm^3 min^{-1}

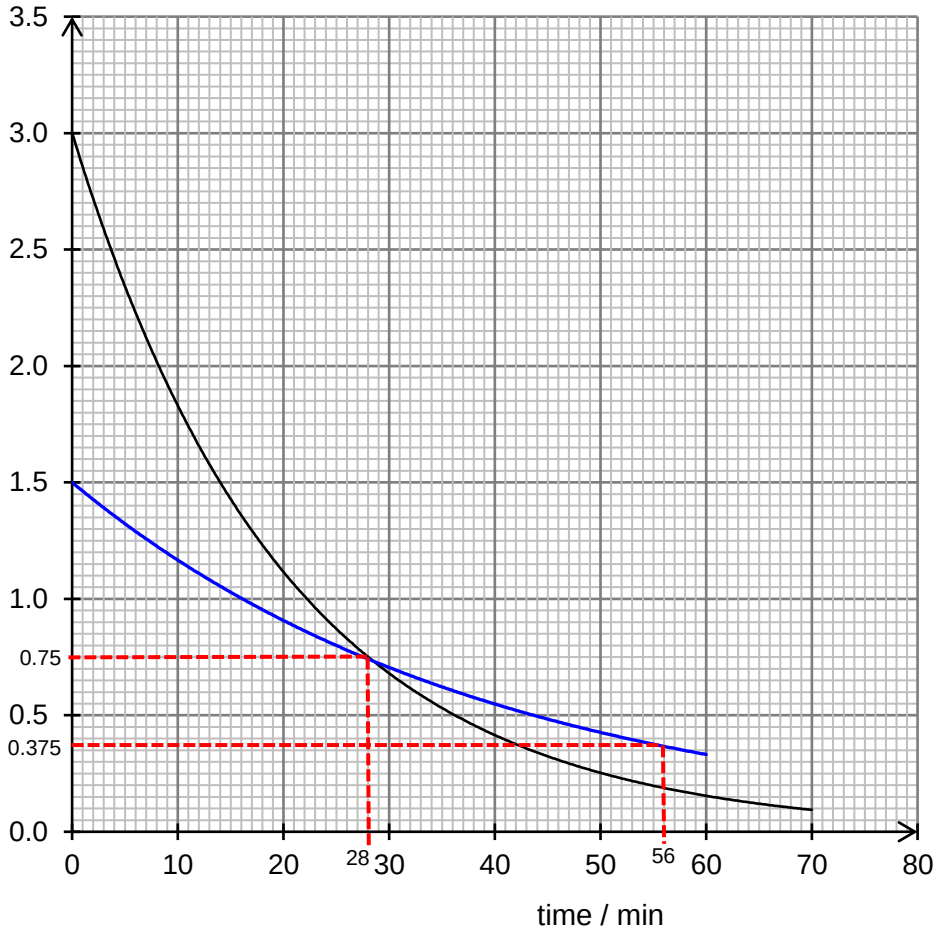
Comments:

- Students need to show working by drawing construction lines or writing down the two $t_{1/2}$ values on the graph.
- The time-axis is in min, hence there is a constant half-life of 14 min.
- There is no need to convert from min to s.
- Many students did not read the question carefully and failed to realise that this is a pseudo first-order reaction. Hence, many incorrectly obtained

$$k = \frac{\ln 2}{t_{½}} = \frac{\ln 2}{14} = 0.0495 \text{ min}^{-1}$$

  Since rate = $k'[H_2O_2]$, $\frac{\ln 2}{t_{½}}$ gives the value for k', and not k.
- Note that 2nd $t_{1/2}$ should only refer to the time taken for $[H_2O_2]$ to decrease from 1.50 mol dm^{-3} to 0.75 mol dm^{-3} and not for any time taken when any selected $[H_2O_2]$ is halved. Students should avoid using overlapping half-lives where possible.
- Some even mentioned that 1st $t_{1/2}$ = 14 min and 2nd $t_{1/2}$ = 28 min and concluded that $t_{1/2}$ is constant, which is contradictory.

C1(b)(iii) $[H_2O_2]$ / mol dm^{-3}



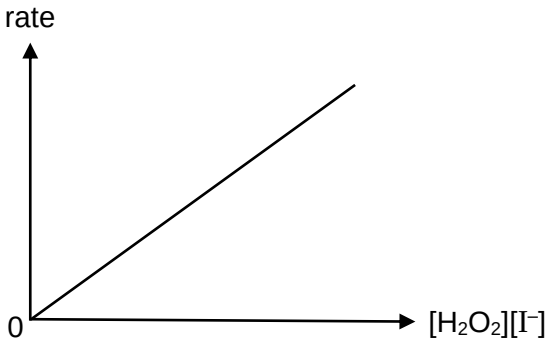
initial $[H_2O_2]$ = 1.50 mol dm^{-3}

$t_{½} = \frac{\ln 2}{k'} = \frac{\ln 2}{k[I^-]} \Rightarrow$ Since $[I^-] = \frac{1}{2} \times 0.80$, $t_{½} = 2 \times 14$ min = 28 min

Both curves should intersect at $[H_2O_2]$ = 0.75 mol dm^{-3} at 28 min.

Comments:
- Many students did not show that when $[I^-] \times \frac{1}{2}$ from 0.80 mol dm^{-3} to 0.40 mol dm^{-3}, the $t_{½}$ becomes 14 min × 2 = 28 min.

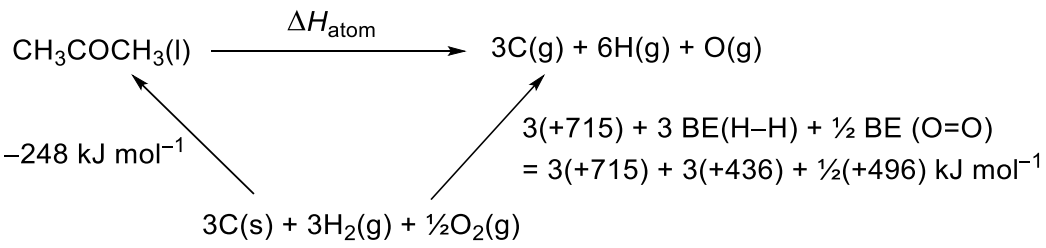
C1(b)(iv) rate = $k[H_2O_2][I^-]$



Comments:
- As the reaction is first order with respect to $[H_2O_2]$ and first order with respect to $[I^-]$, the overall order of reaction is 2. This graph is similar to sketching rate against $[A]^2$.

$\underbrace{\text{rate}}_{y} = k\underbrace{[H_2O_2][I^-]}_{x}$ (straight line passing through origin)

C2(a)(i)



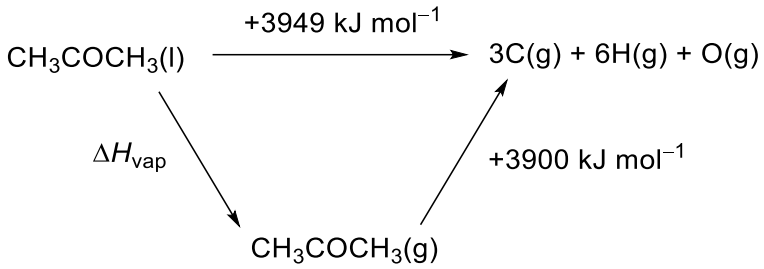
By Hess' Law,

$\Delta H_{atom}(CH_3COCH_3(l))$ = – (–248) + 3(715) + 3(436) + ½(496)
= +3949 kJ mol^{-1}
= +3950 kJ mol^{-1} (3 s.f.)

Comments:

- A sizeable number of students confused ΔH_{atom} with ΔH_{vap}. Vaporisation involves a change of the compound/element (usually in the liquid state) to its gaseous state whereas atomisation involves a change of the compound/ element being broken into its constituent gaseous atoms.
- A number of students used the wrong coefficients for the atomisation of carbon and bond energies of H_2 and O_2. To avoid such mistakes, students are advised to have a good grasp of the definitions of the enthalpy changes.

C2(a)(ii) $\Delta H_{atom}(CH_3COCH_3(g)) = 6\ BE(C–H) + 2\ BE(C–C) + BE(C=O)$
$= 6(410) + 2(350) + 740$
$= +3900\ kJ\ mol^{-1}$



$\Delta H_{vap}\ (CH_3COCH_3(l)) = +3949 – (+3900) = +49\ kJ\ mol^{-1}$

Comments:

- Some students erroneously thought that there are 3 C–C bonds in CH_3COCH_3.

C2(a)(iii) $CH_3COCH_3(l) + 4O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(l)$

Comments:

- When writing the equation that represents standard enthalpy change of combustion, all species must be in their standard states (at 298 K and 1 bar). Hence, water must be in the liquid and not gaseous state.
- The enthalpy change of combustion must be based on one mole of $CH_3COCH_3(l)$. Hence, the following answer is not accepted:

$$2CH_3COCH_3(l) + 8O_2(g) \longrightarrow 6CO_2(g) + 6H_2O(l)$$

- A sizeable number of students also forgot the O present in CH_3COCH_3 and hence incorrectly used 4.5 mol of O_2 to balance the equation.

C2(a)(iv) $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus} = -219 - 298(-168/1000) = -169$ kJ mol^{-1} (3 s.f.)

Comments:
- Generally well done.
- Students who got an incorrect answer need to consider that the given entropy change is in **J** mol^{-1} K^{-1} while the enthalpy change is in **kJ** mol^{-1}.
- A few students showed correct working but forgot to include the negative sign in front of the entropy change.

C2(a)(v) Though the reaction is feasible, energy equal to or greater than the activation energy has to be supplied for the reaction to proceed. The spark provides the activation energy needed for CH_3COCH_3 and O_2 to react.

Comments:
- General well done.

C2(a)(vi) At 400 K, both CH_3COCH_3 and water are in the gaseous state. Now, the combustion reaction proceeds to give an increase in the number of moles of gaseous molecules (from 5 mol to 6 mol of gas), causing an increase in entropy. Hence the $\Delta S^{\ominus}$ has a positive value.

Comments:
- Note that 400 K is above the boiling points of both CH_3COCH_3 and water. Hence the combustion reaction at 400 K is:

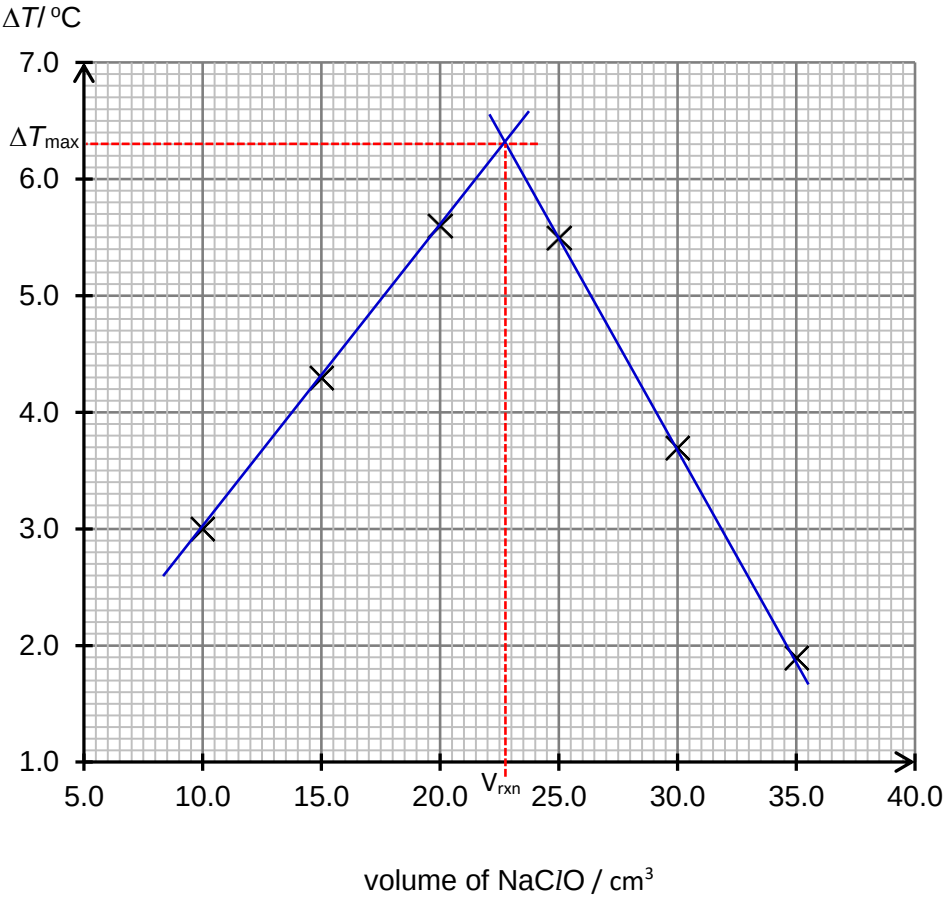
$$CH_3COCH_3\mathbf{(g)} + 4O_2(g) \rightarrow 3CO_2(g) + 3H_2O\mathbf{(g)}$$

- Answers involving the broadening of the Boltzmann distribution caused by the temperature rise are rejected.

$$CH_3COCH_3(l) + 4O_2(g) \rightarrow 3CO_2(g) + 3H_2O(l)$$

  For example, with a temperature rise (without any change in states), the above reaction still proceeds to give a decrease in the number of moles of gaseous molecules (from 4 mol to 3 mol of gas), leading to a decrease in entropy, despite having a broadening of the Boltzmann distribution.

C2(b)(i)



ΔT_{max} = +6.3 °C
volume of NaC*l*O required for complete reaction = 22.75 cm^3

Comments:
- Based on the given plotted points, each best-fit line should cut through <u>three</u> plotted points.
- Students can only read to half the smallest square, i.e. 22.55 cm^3 is not a possible value for volume. For students who wrote 22.8 cm^3, benefit of the doubt was accorded, assuming that 22.75 cm^3 was read and rounded off to 3 s.f.

C2(b)(ii) Volume of $S_2O_3^{2-}$ ions = 40.0 – 22.75 = 17.25 cm^3

Amount of $S_2O_3^{2-}$ ions = $\frac{17.25}{1000} \times 0.100 = 0.00173$ mol

$q = 40.0 \times 4.18 \times (+6.3) = +1053.4$ J

$\Delta H_1 = -\frac{+1053.4}{0.00173}$ J mol^{-1} = −609 kJ mol^{-1}

Comments:

- When calculating ΔH_1, students need to realise that the enthalpy change is based on <u>per mole of $Na_2S_2O_3$</u> (see equation below), not per mole of NaC*l*O.

$$4NaCIO(aq) + Na_2S_2O_3(aq) + 2NaOH(aq) \xrightarrow{\Delta H_1} 4NaCl(aq) + 2Na_2SO_4(aq) + H_2O(l)$$

- Students who were unable to calculate the amount/volume of $Na_2S_2O_3$ correctly may have failed to realise that the question stated that the total volume (vol. of $Na_2S_2O_3$ + vol. of NaC*l*O) of solution was kept constant at <u>40.0 cm^3</u> for all experiments.
- When using the formula, $q = mc\Delta T$, m is the mass of the substance (usually water or solution) to which the temperature change occurs. The temperature change was measured by placing the thermometer into <u>40.0 cm^3</u> of solution, not 22.75 cm^3. Hence, m should be 40.0 g.
- ΔT of 1 °C = ΔT of 1 K. Students must not add 273 to the ΔT in °C to get a ΔT in K.