Section A

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

Question 1 (C)

$A_r = \left(\frac{60.9}{100}\right) \times 20 + \left(\frac{1.2}{100}\right) \times 21 + \left(\frac{37.9}{100}\right) \times 22$

$= 20.8$

Question 2 (D)

Method 1: comparing mol ratio

$C_xH_y \xrightarrow{O_2} xCO_2 + \frac{y}{2}H_2O$

0.06 mol 0.04 mol

$x : \frac{y}{2} = 0.06 : 0.04$

$= 6 : 4$

$x : y = 6 : 8$

$= 3 : 4$

$= 9 : 12$

Method 2: trial and error

$CO_2 : H_2O = 0.06 \text{ mol} : 0.04 \text{ mol}$

$= 6 : 4$

$= 3 : 2$

	equations	$CO_2 : H_2O$
A	$C_3H_6 \xrightarrow{O_2} 3CO_2 + 3H_2O$	3:3
B	$C_6H_{10} \xrightarrow{O_2} 6CO_2 + 5H_2O$	6:5
C	$C_6H_{12} \xrightarrow{O_2} 6CO_2 + 6H_2O$	6:6
D	$C_9H_{12} \xrightarrow{O_2} 9CO_2 + 6H_2O$	9:6 = 3:2

Question 3 (B)

Atomic number of Sr = 38

Number of neutrons in Sr, W, X and Y

= 84 – 38 = 46

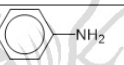
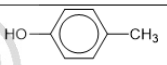
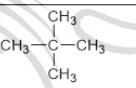
Number of electrons in Sr^{2+}, W, X^-, Y^{2-}

= 38 – 2 = 36

	W	X	Y
proton number	36	35	34
nucleon number	82	81	80

Note: W = Kr, X = Br, Y = Se

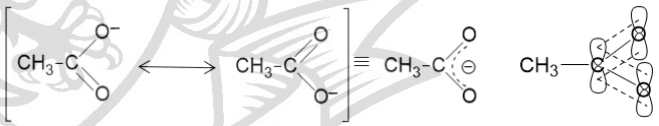
Question 4 (C)

	first substance	second substance
A	K (Lower boiling point) Larger cationic radius, weaker metallic bonding	Na (Higher boiling point) Smaller cationic radius, stronger metallic bonding
B	CO_2 (Lower boiling point) Simple molecular structure, weaker instantaneous-dipole induced-dipole interactions	SiO_2 (Higher boiling point) Giant molecular structure, stronger Si–O covalent bonds
C	 (Higher boiling point) Forms, on average, 3 hydrogen bonds per molecule, more extensive inter-molecular hydrogen bonding	 (Lower boiling point) Forms, on average, 1 hydrogen bond per molecule, less extensive inter-molecular hydrogen bonding
D	 (Lower boiling point) Branched-chained hydrocarbon has smaller surface area, weaker instantaneous-dipole induced-dipole interactions	$CH_3CH_2CH_2CH_2CH_3$ (Higher boiling point) Straight-chained hydrocarbon has greater surface area, stronger instantaneous-dipole induced-dipole interactions

Question 5 (D)

Option **A** is incorrect: Ion is not planar as it is tetrahedral about C in $–CH_3$.

Option **B** is incorrect: The π electrons are delocalised over the $–COO^-$ group.



Option **C** is incorrect: In the resonance hybrid, the two C−O bonds lengths are identical.

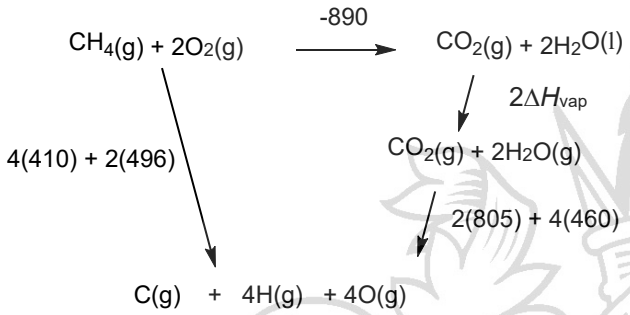
Option **D** is correct:

The H−C−H bond angle (109.5°) is smaller than the C−C−O bond angle (120°).

Question 6 (C)

Definition of Bond Energy: The **bond energy** of a X–Y bond is the average energy required to break **1 mole of the X–Y bonds** in the **gaseous state**.

To use the average bond energies in the table, we need to have the molecules be converted to the gaseous state. To convert 2 mol of $H_2O(l)$ to $H_2O(g)$, that is 2 x enthalpy change of vaporisation of water.



By Hess' Law,
$-890 + 2\Delta H_{vap} + 2(805) + 4(460) = 4(410) + 2(496)$
$2\Delta H_{vap} = +72$ kJ mol^{-1}
$\Delta H_{vap} = +36$ kJ mol^{-1}

Question 7 (B)

Graph A
pV = nRT, constant n and T
pV = constant

Graph of V against pV should be vertical (not horizontal). Graph is incorrect.

Graph B
pV = nRT, constant n and V
p = constant × T, hence p α T

Graph of p against T is correct.

Graph C
pV = nRT, constant n and T
p = constant/V, hence p α 1/V

Graph of p against $\frac{1}{V}$ is incorrect.
It should be a y = kx graph.

Graph D
pV = nRT, constant V and T
p = constant × n, hence p α n

Graph of p against n is incorrect.
It should be a y = kx graph.

Question 8 (B)

The **lattice energy** (LE) of an ionic compound is the energy released when 1 **mole** of the **solid ionic compound** is formed from **its constituent gaseous ions** under standard conditions.

Question 9 (A)

$\Delta H > 0$ and $\Delta S > 0$ for this reaction.

The entropy change is positive because the reaction results in an increase in the number of moles of gaseous particles in the system (from 0 to 1 mol of gas).

Hence, only at high temperatures can the negative $-T\Delta S$ term outweighs the positive ΔH, causing the ΔG to be negative.

Question 10 (C)

Comparing Expt 1 to 3, rate = $k[I^-][S_2O_8^{2-}]$.

The total volume of Expt 4 is double that of all the other experiments (e.g. Expt 2).

In Expt 4 (compared to Expt 2), when the volume of I^- used is doubled, initial $[I^-]$ in the mixture of Expt 4 is the same as Expt 2.

In Expt 4 (compared to Expt 2), when the volume of $S_2O_8^{2-}$ used x 4, initial $[S_2O_8^{2-}]$ in the mixture of Expt 4 is double that of Expt 2.

When $[S_2O_8^{2-}]$ is doubled, rate of reaction for Expt 4 is double that of Expt 2.

rate $\propto$ 1/t,
time taken for Expt 4 (compared to Expt 2)
$= \frac{42.5}{2} = 21.3$ s

Question 11 (A)

From the slow step, rate $\propto$ [CO][C*l*],
rate = k' [CO][C*l*] --- ①

$K_{step\ 1} = \frac{[Cl]^2}{[Cl_2]}$

$\sqrt{K_{step\ 1}\ [Cl_2]} = [Cl]$ --- ②
Sub ② into ①,
rate = k' $K_{step\ 1}{}^{½}$ [CO][Cl_2]^{½}
rate = k [CO][Cl_2]^{½}

Statement 1 (correct)
Overall order of reaction = 1 + ½ = 1.5.

Statement 2 (incorrect)
An increase in the partial pressure (hence concentration) of Cl_2 will increase the reaction rate since the order of reaction w.r.t. Cl_2 is ½.

Statement 3 (incorrect)
The units of rate constant ((mol $dm^{-3})^{-½}$ $time^{-1}$) are different from the units for equilibrium constant of step 1 (mol dm^{-3}).

Question 12 (D)
Given that the mole fraction of HI is $2x$,
mol fraction of H_2 + mol fraction of I_2 = 1 – 2x,

Given H_2 and I_2 are equimolar,
mole fraction of H_2 = mole fraction of I_2 = ½(1–2x)

Let the total pressure of the system at equilibrium be P_T.

partial pressure of HI = $2x(P_T)$
partial pressure of H_2 = partial pressure of I_2
$= \frac{1-2x}{2}(P_T)$

$$K_p = \frac{P_{HI}^2}{P_{H_2}P_{I_2}} = (2x(P_T))^2 \div \left(\frac{1-2x}{2}(P_T)\right)^2 = \frac{16x^2}{(1-2x)^2}$$

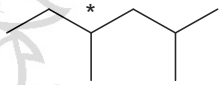
Question 13 (C)
Option **A** is incorrect. Adding a catalyst will increase the rate of both forward and backward reaction to the same extent. Hence equilibrium position is not shifted and percentage composition of NH_3 is not increased.

Option **B** is incorrect. Decreasing the temperature will cause the equilibrium position to shift right to favour the forward exothermic reaction and increase the percentage composition of NH_3. However, decreasing the temperature will reduce the rate of formation of NH_3 as the rate of reaction will be reduced.

Option **C** is correct. Reducing the total volume at constant temperature leads to an increase in total pressure, which will shift the equilibrium position to the right, favouring the forward reaction as it produces less gaseous molecules. This results in the increase in the percentage composition of NH_3. Also, the partial pressures of the individual reactants increase, resulting in the increase in the rate of formation of NH_3.

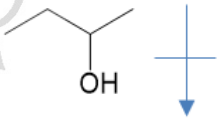
Option **D** is incorrect. Since argon is added at constant volume, the partial pressure of the reacting gases remains the same. Hence, the rate of formation of NH_3 and percentage composition of NH_3 will remain the same.

Question 14 (A)
Only **A** has a chiral centre as shown below.



Note: **C** has 2 chiral centres while **B** and **D** have none.

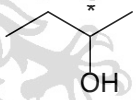
Question 15 (B)
Statement 1 (correct)
Both E & F are polar.



Note: In E, the region around O is not linear.

Statement 2 (correct)
They have the same molecular formula ($C_4H_{10}O$) but different structural formula.

Statement 3 (incorrect)
Only F has a chiral carbon.

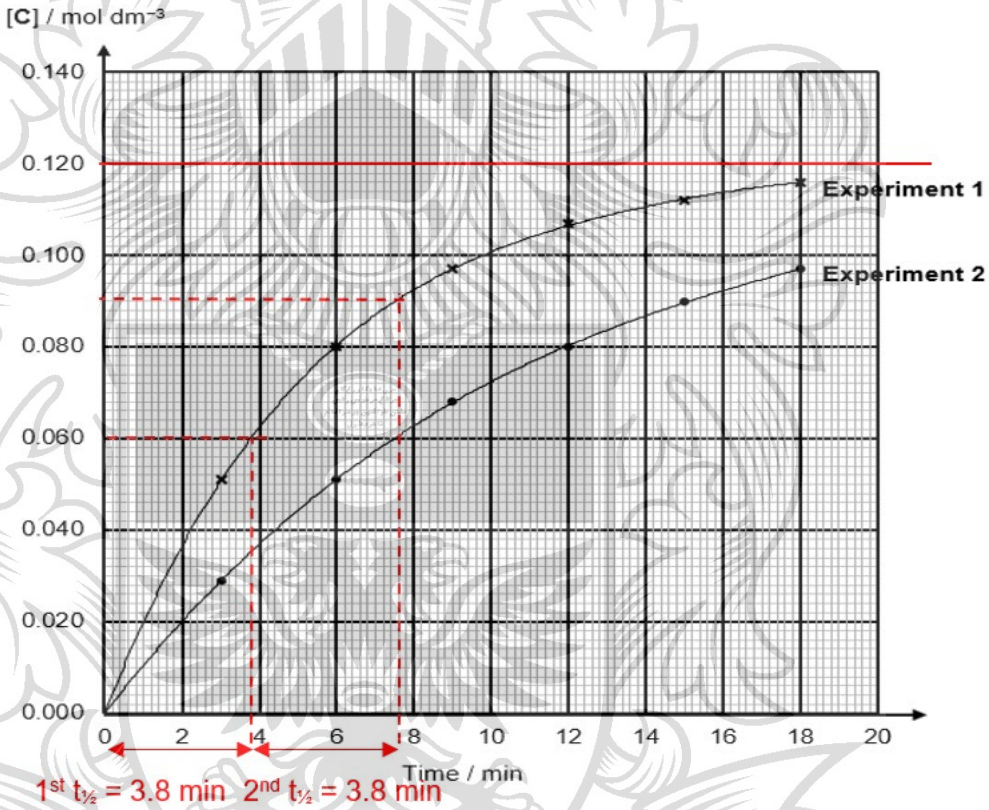


Section B

B1 (a) (i) [**B**] remains approximately constant so that the order of reaction with respect to **A** can thus be found.

Examiners' Comments
- A handful of students gave an incomplete answer. Note that there are two parts to this answer.
- Examiners accepted answers that described a pseudo *first*-order reaction wrt **A**. However, in actual fact, when **B** is added in excess, we do not yet know if the reaction is a pseudo first-order or a pseudo second-order reaction. It would be more accurate to simply describe the reaction as a pseudo-order reaction.
- While it is true that using excess **B** allows all the **A** to react, it is not a valid answer here as the kinetics of the reaction can be studied without monitoring till the completion of the reaction.

(ii) If the reaction were to go to completion, final [**C**] = initial [**A**] = 0.120 mol dm^{-3}



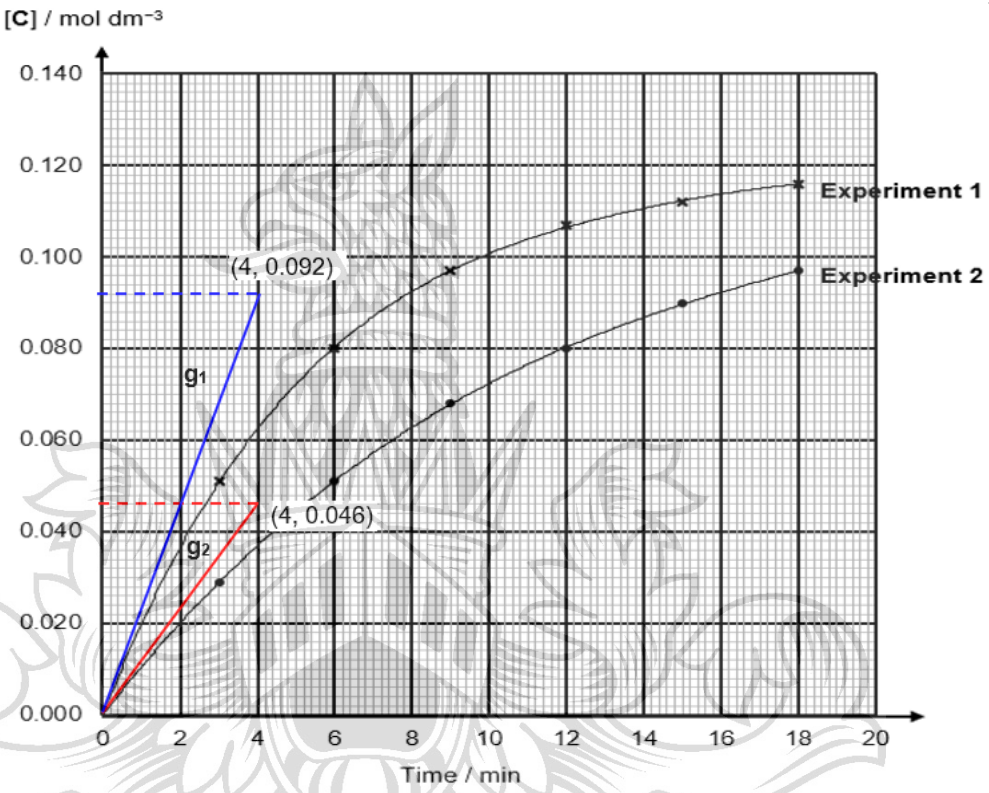
1st $t_{½}$ is time taken for [**C**] to increase from 0.00 to 0.06 mol dm^{-3} while 2nd $t_{½}$ is time taken for [**C**] to increase from 0.06 to 0.09 mol dm^{-3}.

From Experiment 1 graph, 1st $t_{½}$ = 3.8 min and 2nd $t_{½}$ = 3.8 min.
Since 1st $t_{½}$ = 2nd $t_{½}$, $t_{½}$ is constant, the reaction is first-order with respect to **A**.

(Note: Results from Expt 2 can also be used.)

Examiners' Comments
- Students must learn how to determine order wrt a reactant given a [product]-time graph. Revisit Section 5 of Kinetics lecture notes.
- Clear working includes showing all construction lines & labelling at least two $t_{½}$ on the graph.

(iii)



Method 1: Compare initial rates of experiments 1 and 2.

initial rate of experiment 1 = $g_1 = \frac{0.092 - 0}{4 - 0} = 0.0230$ mol dm^{-3} min^{-1}

initial rate of experiment 2 = $g_2 = \frac{0.046 - 0}{4 - 0} = 0.0115$ mol dm^{-3} min^{-1}

(Show, on the graph, the tangent and construction lines to obtain coordinates for g_1 and g_2 calculations)

Since initial rate is halved when initial [**B**] is halved, the reaction is first order with respect to **B**.

Method 2: Compare half-lives of experiments 1 and 2.

Let order of reaction with respect to B be y.

rate = k[A][B]^y = k'[A] where $k' = k$[B]^y

Since B is used in large excess, [B]^y is approximately constant such that the reaction is a pseudo first-order reaction.

$$t_{\frac{1}{2}} = \frac{\ln 2}{k'} = \frac{\ln 2}{k[B]^y} \Rightarrow t_{\frac{1}{2}} \propto \frac{1}{[B]^y} \Rightarrow t_{\frac{1}{2}} \times [B]^y \text{ is a constant}$$

For experiment 1, $t_{½}$ = 3.8 min and [B] = 2.00 mol dm^{-3}

For experiment 2, $t_{½}$ = 7.6 min and [B] = 1.00 mol dm^{-3}

$3.8(2.00)^y = 7.6(1.00)^y$

$\frac{3.8}{7.6} = \left(\frac{1.00}{2.00}\right)^y \Rightarrow y = 1 \Rightarrow$ reaction is first order with respect to B.

Examiners' Comments

- Majority of students could use **Method 1** to obtain the answer. Some students who used **Method 2** did not show clearly how the half-life is related to [**B**].
- The initial rate is obtained by drawing a tangent to a curve at t = 0 and finding the gradient of that tangent. Students should show how the value of the gradient was determined by including construction lines to obtain coordinates on the graph and calculation working.
- Tips on choosing coordinates for gradient determination: **(1)** For convenient reading, extend the tangent line to cut the edge of the grid and use (0,0) as one of the points. **(2)** Choose coordinates that are far apart.
- Misreading of coordinates and writing the wrong units for time were common.
- Students should note that initial concentrations are being compared here and therefore should compare initial rates and not average rates. In this case, average rate is not a good approximation for the initial rate given the long time-interval.

(iv) rate = k[**A**][**B**]

Examiners' Comments

- Generally well done.

(v) **Method 1**: Using initial rate

Using results from experiment 1 in **(a)(iii)**,

initial rate of experiment 1 = 0.0230 mol dm^{-3} min^{-1}

Since rate = k[**A**][**B**], at t = 0 min, 0.0230 = k(0.12)(2.00)

$$\Rightarrow k = \frac{0.0230}{(0.12)(2.00)} = 0.0958 \text{ mol}^{-1} \text{ dm}^3 \text{ min}^{-1}$$

Method 2: Using half-life

Using results from experiment 1 in **(a)(iii)**,

$$t_{\frac{1}{2}} = \frac{\ln 2}{k'} = \frac{\ln 2}{k(2.00)} = 3.8$$

$$k = \frac{\ln 2}{(3.8)(2.00)} = 0.0912 \text{ mol}^{-1} \text{ dm}^3 \text{ min}^{-1}$$

Examiners' Comments

- Majority of students could use **Method 1** to obtain the answer. Some students who used **Method 2** did not realise that it is a pseudo first-order reaction and that half-life is related to [**B**].
- Units for k were often incorrectly written as mol^{-1} dm^3 s^{-1}. Students are advised to check the time axis of the graph and see that it is in minutes (min). It is also unnecessary to convert time in minutes to seconds.

(b) A heterogeneous catalyst increases the rate of reaction by providing active sites for reaction to take place.

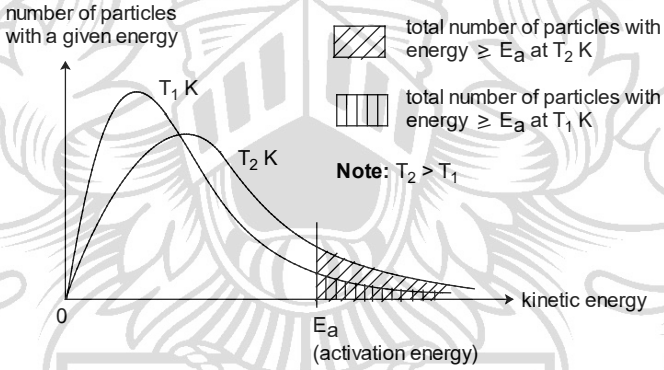
At low [**A**], not all of the active sites on catalyst are occupied.
In this case, rate $\propto$ [**A**] and reaction is first order with respect to **A**.

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

Examiners' Comments

- This question was not well answered.
- Students need to use the proper terminology of 'active sites' found on the heterogeneous catalyst and describe the shape of the graph.
- Do recognise that this is a rate−[**A**] graph, obtained by carrying out multiple reactions with varying [**A**] and a fixed addition of heterogeneous catalyst. Students should explain why **(1)** at low [**A**], increasing [**A**] increases rate and **(2)** at high [**A**], rate becomes constant.
- Detailed explanation of how a heterogeneous catalyst works to increase rate is unnecessary as no part of the graph was obtained without addition of catalyst.

(c) As temperature increases from T_1 to T_2 K, the average kinetic energy of the reactant particles increases. As such, significantly more reactant particles have energy greater than or equal to the activation energy of the reaction. This is shown by the larger shaded area at a higher temperature in the diagram below.



Consequently, the frequency of effective collisions increases, and hence the rate of reaction rate increases.

This also results in a higher rate constant, *k*.

Examiners' Comments

- When drawing the Maxwell Boltzmann distribution curve, the asymmetric curve must start from the origin and the asymptotic behaviour must be shown, i.e. the lines should not touch the x-axis. The legend should be indicated clearly, corresponding to the shaded areas.
- A fully labelled diagram included the relative temperatures of each graph. Also note that the "peak" of the **higher temperature graph** is broader (shifts downwards) and has a larger energy value (shifts to the right).
- Accurate explanations stated "energy greater than or equal to activation energy", though many students did not include "equal to".
- Explanations that concluded with "more effective collision" were not accepted. The word "frequency" was necessary to indicate a time factor, corresponding to the increase in rate of reaction.

B2 **(a)** Methylcyclopentane is generally unreactive due to the following two reasons:

1. Methylcyclopentane is non-polar and thus does not attract electrophilic or nucleophilic reagents. (Alternatively: Methylcyclopentane does not contain regions of high or poor electron density.)

2. Methylcyclopentane comprises relatively strong C–C **and** C–H bonds which do not break under normal conditions.

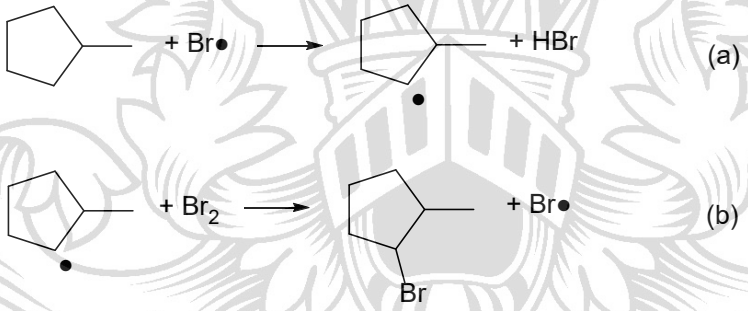
Examiners' Comments

- Students should use proper terminologies in describing regions of "high electron density" in alkane. For example, "electron dense" was not accepted. The phrase, "region of electron density", is ambiguous as all molecules have regions of electron density.
- Negative answers were also not accepted, for instance, "alkanes lack double bonds".

(b) (i) Free radical substitution mechanism

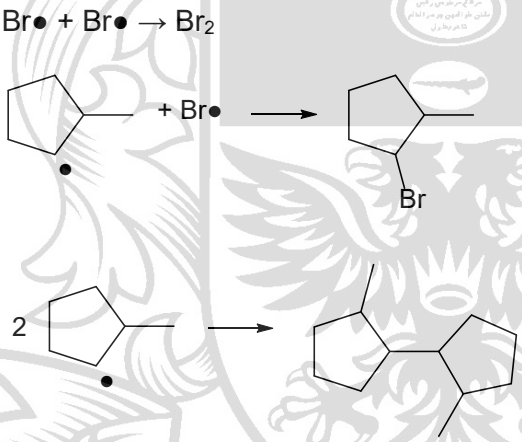
Initiation

Propagation



then (a), (b), (a), (b), …

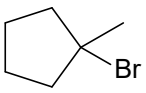
Termination



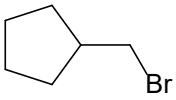
Examiners' Comments

- Students are reminded that "describing the mechanism" refers to drawing the full mechanism, including labels such as the name of the mechanism and each step, as well as the condition(s), "uv light". Refer to the checklist in your lecture notes for all necessary marking points.
- The product of the termination step involving the two alkyl radicals was often drawn wrongly, with a reduction of one carbon atom. Some students also omitted this equation in the termination step.
- Students are not required to indicate fish-hook arrows for the propagation or termination steps. For those who indicated, many were drawn wrongly.

(ii)



or



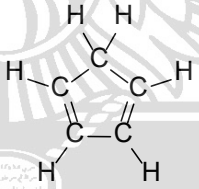
1-bromo-1-methylcyclopentane (bromomethyl)cyclopentane

Examiners' Comments
- Most students were able to identify the correct structure.
- When naming (bromomethyl)cyclopentane, the parentheses are necessary to indicate that the bromine atom is substituted on the methyl side chain, which is then a substituent (the bromomethyl group) on the cyclopentane ring. Thus, the "1-" prefix is not required as the ring only has one substituent.
  Punctuation was often used wrongly in the naming of 1-bromo-1-methylcyclopentane. Since the bromine atom and methyl group are different substituents, both must be numbered and arranged alphabetically.

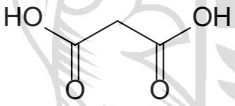
(c) **(i)**

bond type present	total number of each bond type
σ	11
π	2

Examiners' Comments
- Many students did not include the C–H σ bonds in the cyclopentane ring.



(ii)



Examiners' Comments
- Some answers included ethanedioic acid as a product. However, ethanedioic acid is further oxidised into carbon dioxide and water and hence, not the organic product of the oxidation reaction.
- Similarly, CO_2 and H_2O should not be included as they are not organic products.
- When drawing skeletal formulae, students should be careful when drawing a bond to the –OH group; the bond should end at the O atom.

- Correct: Incorrect:
- Skeletal formulae should also reflect accurate bond angles. For example, the C in the –COOH group has a trigonal planar geometry.

(d) **(i)** Electrophilic addition

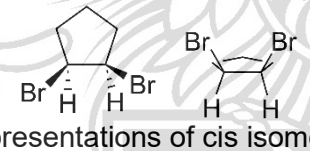
Examiners' Comments
- "Addition" was not accepted as the specific type of reaction that alkenes undergo is **electrophilic** addition. Similarly, "bromination" (or "halogenation") are generic names of reactions where bromine (or a halogen) was a reactant and hence, not accepted.

(ii) Reaction 1: Br_2(aq) at room temperature
Reaction 2: Br_2 in CCl_4 / Br_2(l) in the dark at room temperature

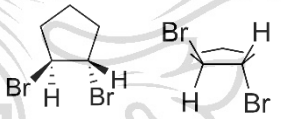
Examiners' Comments
- When alkenes react with Br_2 in CCl_4, the reaction must be conducted in the absence of uv light or heat to ensure free radical substitution does not take place.
- Contradicting answers for reaction 2, e.g. Br_2(aq) in CCl_4, were not accepted.

(iii) **L** exhibits cis-trans isomerism due to the restricted rotation about C-C bond in the cyclopentane ring, and the adjacent C atoms have two different groups attached to them.

Examiners' Comments
- A common wrong answer was that cis-trans isomerism is only possible in the presence of a C=C double bond. This is not true as cis-trans isomerism arises due to the restricted rotation about a bond, which can be due to C=C double bond **or** a ring structure. Hence, a complete answer should include discussing the cyclopentane ring.
- When considering the ring on its side, the cis isomer of the compound can be viewed as having both Br atoms on the same side of the ring, while the trans isomer has the Br atoms on opposite sides of the ring.

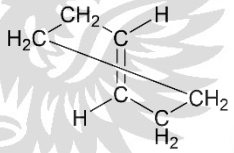


representations of cis isomer



representations of trans isomer

- Some students were confused and mistook cyclopentane for cyclopentene, stating that the trans isomer cannot exist as the ring will be highly strained. This is true for cyclic **alkenes**, for example, cyclohexene: the trans isomer of cyclohexene cannot exist due to ring strain. Hence, despite the presence of the C=C double bond, cyclohexene does not exhibit cis-trans isomerism.



"trans" isomer does not exist

B3 **(a)** **(i)** $n_{I_2 \text{ reacted with vitamin C}}$
$= n_{\text{vitamin C}}$
$= \frac{0.090}{176.0}$
$= 5.11 \times 10^{-4}$ mol

Examiners' Comments
- Students are required to be familiar with units conversion. 1 mg is equivalent to 10^{-3} g.

(ii) Assume 25.00 cm^3 of $Na_2S_2O_3$ as the titre value.
$n_{S_2O_3^{2-}} = 0.010 \times \frac{25.00}{1000}$ $= 2.50 \times 10^{-4}$ mol

$n_{I_2 \text{ in } 25.0 \text{ cm}^3 \text{ of diluted solution}} = \frac{2.50 \times 10^{-4}}{2}$

$= 1.25 \times 10^{-4}$ mol

$n_{I_2 \text{ in } 250 \text{ cm}^3 \text{ of diluted solution}} = (1.25 \times 10^{-4}) \times \frac{250}{25.0}$

$= 1.25 \times 10^{-3}$ mol

$= n_{I_2 \text{ unreacted}}$

total n_{I_2}added = $n_{I_2 \text{ reacted with vitamin C}} + n_{I_2 \text{ unreacted}}$

$= (5.11 \times 10^{-4}) + (1.25 \times 10^{-3})$

$= 1.761 \times 10^{-3}$ mol

Volume of aq $I_2 = \frac{1.761 \times 10^{-3}}{0.10} = 0.0176$ dm^3 = 17.6 cm^3

Examiners' Comments

- To perform the calculations correctly, students need to understand the concept of back titration, which is described in the question. By working backwards from a suggested titre value, students can proceed to calculate the volume of I_2(aq) which should be added.
- Many students missed out on the additional step to calculate the amount of unreacted iodine in 250 cm^3 of diluted reaction mixture from 25 cm^3 of diluted reaction mixture.
- Key considerations for the calculations include:
  - the I_2 added is used to react with the vitamin C, and there must be sufficient unreacted I_2 for its subsequent titration with $S_2O_3^{2-}$
  - dilution is performed on the reaction mixture before the titration
  - a suitable titre value of $S_2O_3^{2-}$ is 25.00 cm^3 (10.00 – 30.00 cm^3)

(b) Procedure:

1. Using a burette, transfer 17.60 cm^3 of aqueous iodine into the 100 cm^3 beaker containing the health syrup and stir the contents with a glass rod.
2. Transfer the final reaction mixture quantitatively into a 250 cm^3 volumetric flask with the aid of a funnel and a glass rod. Rinse the beaker a few times with deionised water and transfer all the washings into the 250 cm^3 volumetric flask.
3. Fill the volumetric flask to the 250 cm^3 mark with more deionised water. Use a dropping pipette (or dropper) to add the deionised water dropwise when nearing the mark.
4. Stopper the volumetric flask and shake the diluted mixture thoroughly to ensure that it is homogeneous.
5. Fill the burette with aqueous sodium thiosulfate provided.
6. Pipette 25.0 cm^3 of the diluted mixture into a 250 cm^3 conical flask.
7. Titrate the mixture against aqueous sodium thiosulfate until the reaction mixture turns pale-yellow. Then add 3 drops of starch solution and carry on titration until the deep blue colour is just discharged.
8. Record the titration results using an appropriate table.
9. Repeat the titration until at least two consistent results are obtained (i.e. the two titre volumes are within 0.10 cm^3 of each other).

Key points to be included in the procedure:

- ✓ Accurate volume of aqueous iodine added to health syrup in beaker
  - use of burette
- ✓ Preparation of diluted reaction mixture
  - quantitative transfer of reaction mixture to graduated flask
  - rinsing and transferring of washings

- top to the 250 cm^3 mark with deionised water
- stopper and shake graduated flask

✓ Titration of diluted reaction mixture against sodium thiosulfate
- fill burette with aqueous sodium thiosulfate
- pipette 25.0 cm^3 diluted reaction mixture into 250 cm^3 conical flask

✓ End-point colour change
- addition of starch near the end-point (pale yellow)
- end-point colour change of dark blue to colourless

✓ Recording of titration results and repeat titration until at least two consistent results are obtained

Examiners' Comments
- Students are reminded to read the question carefully. The 10 cm^3 sample of health syrup is already in the 100 cm^3 beaker, therefore there is no need to transfer the health syrup to another container.
- While there were many good attempts to describe the procedure of quantitative transfer, a few students did not mention the solution (i.e. deionised water) that they are rinsing the apparatus with and topping up the graduated flask with.
- Many students recognised that they needed to add starch indicator for the titration but gave incorrect colour change at end-point. When deducing colour change at end-point, students need to consider what substance is in the conical flask prior to the end-point, followed by at the end-point.
- Students are also required to be clear in the description of procedures. For example, when describing the part on repeat of titration until consistent results, vague descriptions are "repeat experiment" and "repeat until consistent results".

(c) When exposed to air, some Vitamin C would be <u>oxidised</u> by atmospheric oxygen. As there is less Vitamin C in the health syrup, there would be <u>more unreacted I_2</u> and hence a higher titre value of sodium thiosulfate.

Examiners' Comments
- Students are required to identify the important clue in the question – "exposed to the air" which is associated to some chemical reaction with the gases in the air. Since equation 1 shows that vitamin C can be oxidised, students will need to suggest that vitamin C can also be oxidised by atmospheric O_2 when exposed to air for a long period of time.
- Several common <u>incorrect</u> responses are listed below
  - some H_2O in health syrup evaporated, resulting in a higher concentration of vitamin C – while this is true, the number of mol of vitamin C in the sample remains the same and therefore this will not affect the titre value
  - some vitamin C evaporated – this is incorrect because there is insufficient data in the question to suggest vitamin C is volatile
  - I^- is oxidised back to I_2 by atmospheric O_2 – this is incorrect because the health syrup is exposed to air before the introduction of I_2, therefore there is no I^- to begin with

Section C

C1 **(a)** **(i)** The standard enthalpy change of combustion of $C_6H_{12}O_6(s)$ is the energy released when 1 mole of $C_6H_{12}O_6(s)$ is completely burnt in excess oxygen at 1 bar and 298 K.

Examiners' Comments
- Some students used generic terms such as "energy change" instead of energy release.
- Some students did not state the standard conditions or wrongly stated the pressure as 1 atm and temperature as 273 K.
- Some students added statements such as "to form carbon dioxide and water" which were irrelevant to the definition.

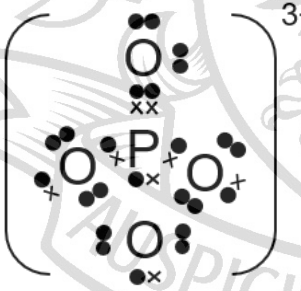
(ii) Heat absorbed by water = mcΔT = 775 x 4.18 x (42.4 – 30.6) = 38226 J
Heat absorbed by calorimeter = 893 x (42.4 – 30.6) = 10537 J
Total heat energy released = 38226 + 10537 = 48763 J
Amt of glucose burnt = $\frac{3.12}{180}$ = 0.01733 mol
ΔH_c= $\frac{-48763}{0.01733}$ = **–2810** kJ mol^{-1}

Examiners' Comments
- Some students mistook the temperature change as (11.8+ 273).
- Some students did not include the heat absorbed by the calorimeter.
- Students should not round the intermediate working of heat energy released or no. of moles of glucose to 3 s.f., but only the final answer to this part, to 3 s.f. Ensure the negative sign in front of the value for exothermic enthalpy change.

(iii) The experimental data to calculate ΔH_c in **(ii)** were not obtained under standard conditions.

Examiners' Comments
- Some students wrongly stated that bond energies are average values when the previous part does not require bond energy values in the calculation.
- Some students had answers in (ii) that are more exothermic than -2900 but still wrote a contradicting answer that there was heat lost to the surroundings.

(b) **(i)**

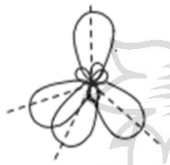


There are 4 electron regions consisting of 4 bond pairs and 0 lone pair.
To minimise repulsion between electron pairs, shape is tetrahedral.

Examiners' Comments
- For the dot-and-cross diagram, in addition to three single bonds, students should draw a double bond instead of a dative covalent bond between P and O atoms. Students should also indicate clearly the external electrons, using contrasting notation of dots or crosses only, gained by O atoms.

- Many students left out the number of lone pairs in their explanation.
- Students should include 'to minimise repulsion' in their answer since the question required them to make use of VSEPR theory.
- Unless otherwise instructed, only dots (not circles) and crosses should be used. No other symbol is needed and please do not add your own.
- Some forgot to use the large brackets with the ionic charge.
- Many stated the expected bond angle, which was not required by the question. Candidates should always write concisely and focus on what the question requires, and to not include any irrelevant parts.

(ii) **sp^3** hybrid orbitals



Examiners' Comments
- Students should take note of the correct presentation of their answers for hybridisation, with 3 as the superscript and not the subscript.
- When drawing the four sp^3 hybridised orbitals, students should ensure that the four orbitals show a tetrahedral shape, and all the four small lobes are shown clearly.

(iii) It will be the same as there is resonance across C_1–N_1–C_2 bonds / π electrons are delocalised across continuous overlapping p orbitals C_1–N_1–C_2 atoms.

Examiners' Comments
- Just stating the term "resonance" without any elaboration / description is insufficient.
- Some students wrongly identified the type of hybridisation and mentioned the % of s character and/or effective overlaps.
- Some students also wrongly mentioned about C_1 and N_1 having double bond having a π bond, hence it will have more effective overlap and thus a shorter bond.
- Quite a number were able to correctly point out the overlapping p orbitals as well as the delocalisation of the π electrons – well done!

(iv) The like charges / negatively charged phosphate groups in ATP are in close proximity to each other, hence they repel each other.

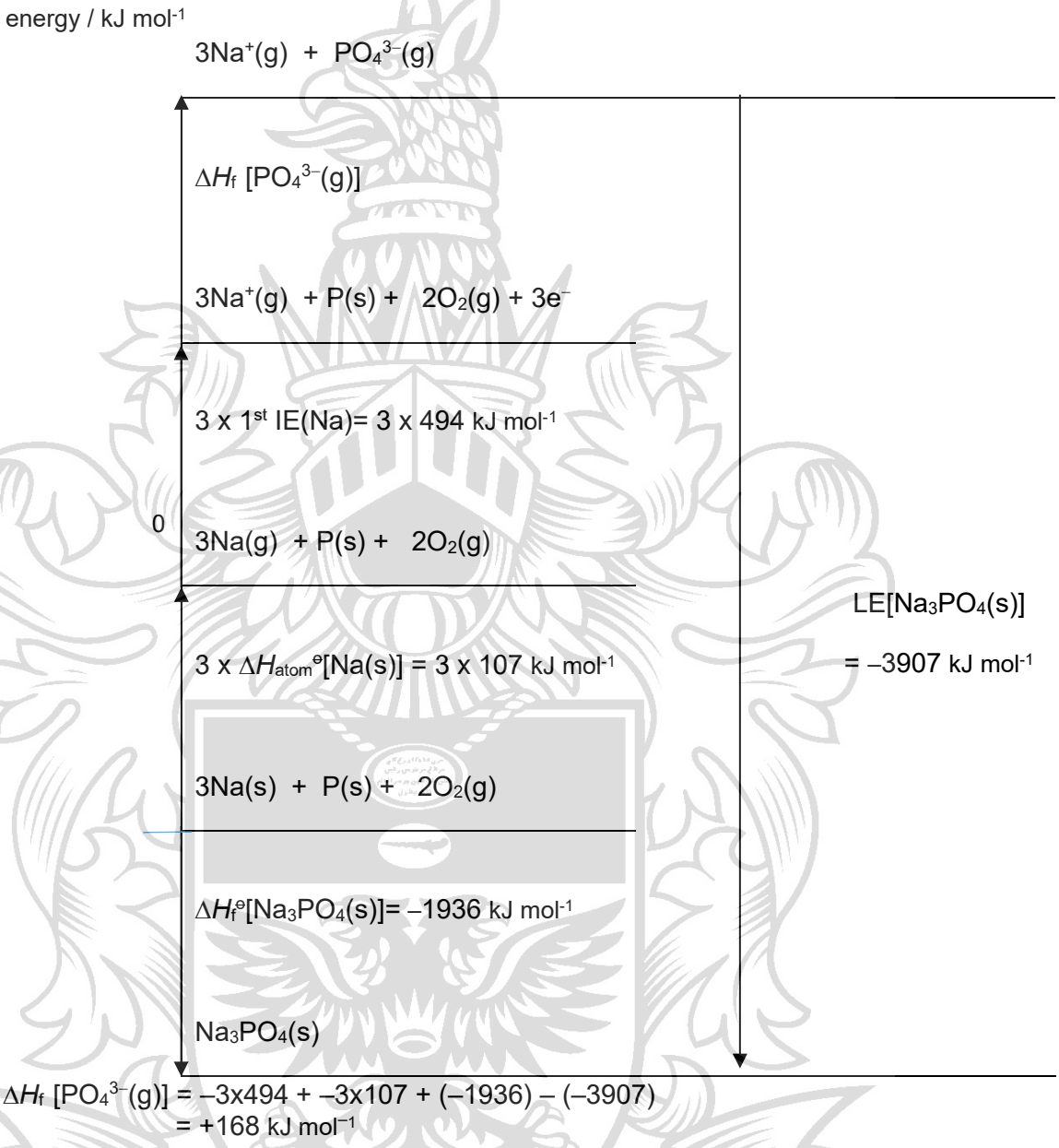
Examiners' Comments
- Many students missed out on answering this question.
- Some students merely mentioned that ATP has higher energy level hence it is less stable, which is not relevant to the question.
- Some students also talked about phosphate group being bulky hence there will be strain thus it is relatively unstable.
- Some students also wrongly stated that there is strain in the ring, hence making ATP unstable.

(c) **(i)** $P(s) + 2O_2(g) + 3e^- \longrightarrow PO_4^{3-}(g)$

Examiners' Comments
- Many students wrote wrong formula for phosphorus element as P_2, P_5 or P_8.
- Many also wrote the wrong state symbol for P and wrote it as P(g).

- Many students missed out the $3e^-$ in this equation, which must be included for charge balance.
- A handful wrote the definition instead of giving the equation.

(ii)



ΔH_f $[PO_4^{3-}(g)]$ = –3x494 + –3x107 + (–1936) – (–3907)
= +168 kJ mol^{-1}

Examiners' Comments

- Some students went to atomise $2O_2(g)$ to get $4O(g)$ which is not necessary for the formation of $PO_4^{3-}(g)$. This could have been avoided by applying the definition for "formation" closely (i.e. "form from constituent elements").
- Some students drew the wrong direction for the arrow for the formation of $PO_4^{3-}(g)$. The direction of the arrow should correspond to their calculated value (exo as downwards and endo as upwards.)
- Some students missed out the coefficient for Na and did not multiply the atomisation energy and the first IE of Na.

- Quite a handful missed out the $3e^-$ formed after the formation of $3Na^+$.
- Students should also remember to include state symbols for the chemical species written in the energy level diagram.
- All enthalpy terms should bear either the "+" or "–" sign.

C2 **(a)** **(i)** $pV = nRT$

$50 \times 10^5 \times 2 \times 10^{-3} = n \times 8.31 \times (1200 + 273)$

$n = 0.817$ mol

maximum amount of **M** = 0.817 mol

Examiners' Comments

- Students who did not obtain the correct answer by making one or more of the following mistakes:
  - Not converting the units of pressure to Pa, volume to m^3, or temperature to K.
  - Using the wrong conversion factor for pressure. 50 bar is equal to (50×10^5) Pa, and not (50 x 101325) Pa, which would only be true if the safety limit was 50 atm.
  - Incorrect rearrangement of the ideal gas equation to n = RT/pV (note: it should be n = pV/RT)

(ii) At constant n and T,

$p_1V_1 = p_2V_2$

$P \times 2 = p_2 \times 5$

$p_2 = 0.4P$ bar

Examiners' Comments

- Many students did not answer this question correctly because of the use of 50 bar in their working. This question deals with the initial pressure of ***P*** bar, and is unrelated to the safety limit of 50 bar meant for question part (a)(i).

(b) **(i)** The gas particles exert negligible intermolecular attractive forces on one another.
The volume of gas particles is negligible compared to the volume of container/gas.

Examiners' Comments

- Most students were able to give these two assumptions which are most relevant to the discussion of non-ideal behaviour that follows. The most common mistake was not clearly referring to the **gas particles** having negligible volume. A gas always occupies the entire space of the container, so it is not correct to say that a "gas has negligible volume compared to the volume of the container".
- While factors such as elastic collisions between gas particles are assumptions of ideal gases, they are not the main assumptions. The main assumptions are critical to explain the deviation from ideal gas behaviour at different temperatures and pressures.

(ii)

Examiners' Comments
- Most students were able to correctly draw the graph showing a constant pV value.
- Some students attempted to label the y-intercept value as 1, which is incorrect. It should be RT (since n = 1). However, such mistakes were not penalised in this question.

(iii) See **(ii)**.

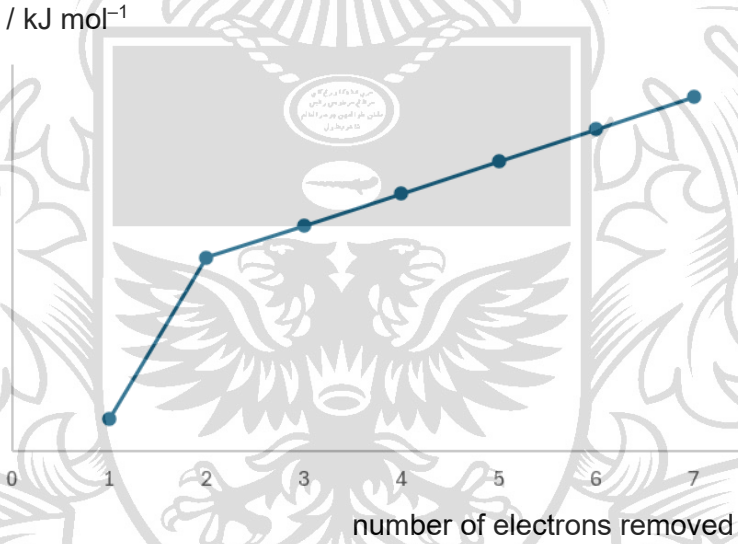
The volume of $\mathbf{M}^+(g)$ will be <u>larger</u> than the volume of the same amount of an ideal gas at moderate pressure as $\mathbf{M}^+$ ions will <u>repel</u> one another.

Examiners' Comments
- An overwhelming number of students presented the typical non-ideal gas graph containing a negative deviation at moderately high pressures, complete with an explanation related to the presence of intermolecular forces of attraction between the M^+ ions. This is **incorrect** because this would be only valid for neutral gas particles. Between positively charged M^+ ions, only repulsion occurs between the like charges.

(c) **(i)** **M** is Na.

Examiners' Comments
- This was generally well answered. Potassium is not an acceptable answer as it would mean that the three elements after **M** would have a proton number of 20 and above.

(ii)



Examiners' Comments
- Students who identified the wrong element could still earn full credit if they were able to identify the correct position of the big jump in ionisation energy (IE). However, students who selected elements from group 17 or 18 would not be able to fulfil this requirement as only the first seven IEs were to be plotted.
- Successive IEs for a given element <u>always increase</u>, as the amount of shielding experienced by the outermost electron decreases when there are fewer remaining electrons. A sizeable number of students included a few irregularities (drops in IEs) in their graph, revealing confusion with what is observed in a graph of IEs across a period.
- Some incorrect graphs included a gradual decrease in IE after a large increase – this is only correct for a graph of atomic radii in successive elements involving a change in the number

of electron shells. Some graphs showed a big decrease in IE – it is unclear what the contributing reasons are.
- As there are numerous graphs introduced in this topic, understanding the reasons behind their shapes is essential. The reasons generally involve the key factors of (1) nuclear charge, (2) shielding, and (3) distance of the outermost electron from the nucleus.

C3 **(a)** **(i)** $K_c = [SO_3]$
mol dm^{-3}

Examiners' Comments
- Students need to understand that solids have fixed density and hence, fixed concentration. Therefore, the concentrations of solids, $[CuSO_4]$ and [CuO] are constant. Hence, K_c is only dependent on $[SO_3(g)]$.
- Many students were able to obtain the correct units for K_c expression.

(ii) $[SO_3] = 1.38 \times 10^{-3}$ mol dm^{-3}
$n_{SO_3} = 1.38 \times 10^{-3} \times 0.5 = 6.90 \times 10^{-4}$ mol
mass of $SO_3 = 6.90 \times 10^{-4} \times 80.1 = 0.05526$ g ≈ 0.0553 g

Examiners' Comments
- From the value of K_c of reaction 1, students should be able to determine the amount of SO_3 present at equilibrium in the 0.5 dm^3 vessel.
- To determine the mass of SO_3 at equilibrium, students should multiply the molar mass of SO_3 and the amount of SO_3 at equilibrium.

(iii) total mass of $SO_2(g)$ and $O_2(g)$ = 0.400 – 0.05526 = 0.3447 = 0.345 g (3 s.f.)

<u>If students use 0.0400 g</u>
total mass of $SO_2(g)$ and $O_2(g)$ = 0.400 – 0.0400 = 0.360 g (3 s.f.)

Examiners' Comments
- As both reactions 1 and 2 are taking in a sealed vessel, the conservation of mass is ensured. The decrease in the total mass of solids ($CuSO_4$ and CuO) is equal to the increase in the total mass of gases (SO_3, SO_2 and O_2). Since the total mass of solids in the vessel was found to have decreased by 0.400 g, this means that 0.400 g of gases (SO_3, SO_2 and O_2) are formed at equilibrium.
- From **(a)(ii)**, the mass of SO_3 formed was found to be 0.0553 g. To determine the total mass of gases, SO_2 and O_2, formed, students need to subtract the mass of SO_3 formed at equilibrium from the total mass of gases formed at equilibrium.

(iv) $n_{SO_2} = 2 \times n_{O_2}$
$(64.1)n_{SO_2} + (32.0)n_{O_2} = 0.345$

$n_{SO_2} = 4.307 \times 10^{-3}$ mol ≈ 4.31×10^{-3} mol
$n_{O_2} = 2.153 \times 10^{-3}$ mol ≈ 2.15×10^{-3} mol

<u>If students use 0.0400 g</u>
$n_{SO_2} = 2 \times n_{O_2}$
$(64.1)n_{SO_2} + (32.0)n_{O_2} = 0.360$

$n_{SO_2} = 4.494 \times 10^{-3}$ mol ≈ 4.49×10^{-3} mol

$n_{O_2} = 2.247 \times 10^{-3}$ mol ≈ 2.25×10^{-3} mol

Examiners' Comments
- From the equation of reaction 2, SO_2 and O_2 are formed in 2:1 ratio at equilibrium. Using this molar ratio and total mass of SO_2 and O_2 formed at equilibrium, students should be able to calculate the amount of both SO_2 and O_2.

(v)

$$K_c \text{ for reaction 2} = \frac{[SO_2][O_2]^{\frac{1}{2}}}{[SO_3]}$$

$$y = \frac{[\frac{4.307 \times 10^{-3}}{0.5}][\frac{2.153 \times 10^{-3}}{0.5}]^{\frac{1}{2}}}{[\frac{6.90 \times 10^{-4}}{0.5}]} = 0.4096 \approx 0.410$$

<u>If students use 0.0400 g</u>

$n_{SO_3} = 0.0400/80.1 = 4.993 \times 10^{-4}$ mol

$$y = \frac{[\frac{4.494 \times 10^{-3}}{0.5}][\frac{2.247 \times 10^{-3}}{0.5}]^{\frac{1}{2}}}{[\frac{4.993 \times 10^{-4}}{0.5}]} = 0.6034 \approx 0.603$$

Examiners' Comments
- Most students are able to write the expression of K_c for reaction 2 correctly.
- For the K_c expression, the concentrations of the reactants and products are raised to their stoichiometric ratios as given in the chemical equation.
- Students should substitute the concentrations values (not amounts or masses) of the reactants and products into the K_c expressions, considering the volume of vessel to be 0.5 dm^3.

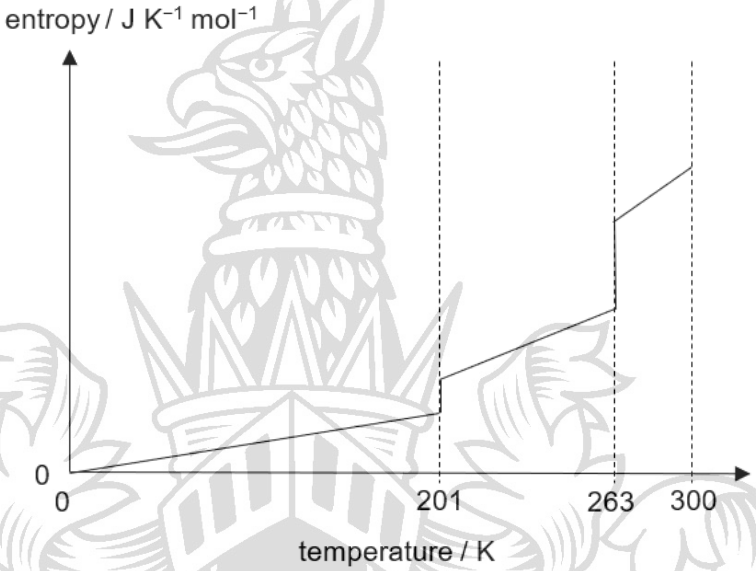
(b) Both SO_2 and SO_3 exist as <u>simple molecular</u> compounds.
SO_3 consists of molecules held together by <u>instantaneous dipole-induced dipole interactions</u> while SO_2 consists of molecules held together by <u>instantaneous dipole-induced dipole interactions as well as permanent dipole-permanent dipole interactions</u>.

SO_3 has a <u>larger electron cloud</u> compared to SO_2. A larger electron cloud is more easily polarised, hence, the intermolecular interactions found in SO_3 is significantly <u>stronger</u> than those found in SO_2 which has a much smaller electron cloud. This results in the higher boiling point of SO_3, despite the lack of permanent dipole-permanent dipole interactions.

Examiners' Comments
- Students are required to identify the type of structure (e.g. giant ionic, giant metallic, simple molecular etc) present in both SO_2 and SO_3.
- Some students wrongly identified SO_3 as polar and SO_2 as non-polar. Students should determine and specify correctly the type of intermolecular forces of attraction for both SO_2 and SO_3, given that SO_2 is polar (bent) and SO_3 is non-polar (trigonal planar).
- Based on the information given that SO_3 is a liquid and SO_2 is a gas at room temperature and pressure, students should deduce that SO_3 is less volatile and has a higher boiling point than SO_2. This means that the intermolecular forces of attraction between SO_3 molecules are stronger than that between SO_2 molecules.

- With this, students should focus on explaining why the instantaneous dipole-induced dipole interaction of SO_3 is stronger than the instantaneous dipole-induced dipole and permanent dipole-permanent dipole interactions in SO_2.

(c)



Entropy generally increases from 0 K to 300 K as there is a broadening of the energy distribution of the particles. Thus, there are more possible energy states in which the particles can adopt at a higher temperature.

At 201 K and 263 K, there are sharp increase in entropy of SO_2 due to state changes from solid to liquid and liquid to gas respectively. The increase at 263 K is larger than that at 201 K as $SO_2(g)$ has significantly higher entropy than $SO_2(l)$.

Examiners' Comments
- Students should understand that the entropy of a system increases as temperature increases, due to the broadening of the Boltzmann energy distribution, and hence, more ways of arranging energy quanta in hotter systems.
- Students should note that stating the increase in average kinetic energy is NOT sufficient.
- At 201 K and 263 K, change of physical state of SO_2 takes place. Hence, there will be a sharp increase at 201 K and 263 K, until the change of physical state has completed.
- Some students incorrectly labelled the y-axis as entropy change (ΔS) rather than entropy.