

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

<b>Question</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>19</b>	<b>20</b>	<b>21</b>	<b>22</b>	<b>23</b>	<b>24</b>	<b>25</b>	<b>26</b>	<b>27</b>	<b>28</b>	<b>29</b>	<b>30</b>
<b>Answer</b>	D	B	C	A	D	B	D	B	C	C	D	D	B	C	A

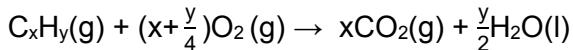
### **MCQ worked solutions**

**Q1** (Ans: A)

At r.t.p, number of moles of molecules in 1 cm<sup>3</sup> of CH<sub>4</sub> gas =  $\frac{1}{24000}$  mol

number of molecules in 1 cm<sup>3</sup> of CH<sub>4</sub> gas =  $\frac{6.02 \times 10^{23}}{24000}$

**Q2** (Ans: B)



Volume of CO<sub>2</sub> produced = 100 – 40 = 60 cm<sup>3</sup>

Volume of unreacted O<sub>2</sub> = 40 cm<sup>3</sup>

Volume of O<sub>2</sub> reacted = 130 – 40 = 90 cm<sup>3</sup>

$$\text{Hence, } x = \frac{60}{20} = 3.$$

$$(x+\frac{y}{4}) = (3+\frac{y}{4}) = \frac{90}{20}$$

$$y = 6$$

Thus, formula of the hydrocarbon is C<sub>3</sub>H<sub>6</sub>.

**Q3** (Ans: B)

Option A is incorrect as <sup>18</sup>O<sup>2-</sup> and <sup>19</sup>F<sup>-</sup> each has 10 electrons and 10 neutrons.

Option B is correct as both <sup>18</sup>O<sup>2-</sup> and <sup>19</sup>F<sup>-</sup> have 10 neutrons each.

Option C is incorrect as both ions have outer electronic configuration of 2s<sup>2</sup> 2p<sup>6</sup>.

Option D is incorrect as nucleons refer to protons and neutrons. Hence <sup>18</sup>O<sup>2-</sup> has 18 nucleons and <sup>19</sup>F<sup>-</sup> has 19 nucleons.

**Q4** (Ans: C)

After the beta decay, the mass number remains the same at 234 and the resulting species has 90 + 1 = 91 protons, which is protactinium (Pa).

**Q5** (Ans: C)

Option A is incorrect as boiling involves overcoming intermolecular forces (hydrogen bonding) and does not involve the breaking of covalent bonds. Furthermore, the F–H bond is stronger than the O–H bond.

Option B is incorrect as both H<sub>2</sub>O and HF are isoelectronic (same number of electrons).

Option C is correct as, on average, each H<sub>2</sub>O can form 2 hydrogen bonds per molecule whereas each HF only forms 1 hydrogen bond per molecule.

Option D is incorrect as the statement is not a major reason for the higher boiling point of H<sub>2</sub>O since hydrogen bonding is the predominant intermolecular force of attraction.

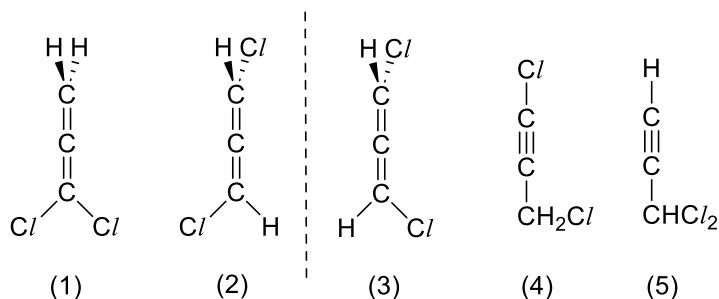
**Q6 (Ans: D)**

Option A is incorrect as ice is less dense than water due to its open structure, preventing the molecules from getting too close to one another. This also causes the same mass of H<sub>2</sub>O to occupy a larger volume.

Option B is incorrect as covalent O–H bonds are stronger than hydrogen bonds.

Option C is incorrect as each O atom forms 2 hydrogen bonds, hence 4 electrons (2 electron pairs) are involved.

Option D is correct as each H<sub>2</sub>O molecule is tetrahedrally bonded to four H atoms via covalent and hydrogen bonds.

**Q7 (Ans: B)**

Option 1 is correct to adhere to the given molecular formula and non-cyclic structure.

Option 2 is incorrect as isomers 2 and 3 are optically active as they lack an internal plane of symmetry. However, both do not contain any chiral C atom.

Option 3 is correct as there is a total of five non-cyclic isomers, including stereoisomers.

**Q8 (Ans: D)**

$$pV = nRT$$

Option A is incorrect as  $p \propto T$ , in K, at constant V. Since units of T on x-axis is °C, when  $p = 0$ ,  $T = -273$  °C. The graph should not pass through the origin.

Option B is incorrect as  $pV = nRT = \text{constant}$  at constant T. Hence, the graph should be a vertical line.

Option C is incorrect as  $V \propto 1/p$  at constant T. Hence, the graph should resemble a  $y = \frac{1}{x}$  hyperbolic graph, with asymptotes along x and y axes.

Option D is correct as  $p/T = nR/V = \text{constant}$  at constant V. Hence, the graph should be a horizontal line.

**Q9 (Ans: C)**

Atomic radius decreases across a period from sodium to chlorine.

Electronegativity increases across the period from sodium to chlorine.

The first ionisation energy of elements generally increase across a period from sodium to chlorine.

**Q10 (Ans: A)**

Only MgO dissolves sparingly in water to form Mg(OH)<sub>2</sub>. SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> are insoluble while Na<sub>2</sub>O and SO<sub>2</sub> dissolves completely in water. Hence, options A and B are possible answers.

MgCl<sub>2</sub> solution has a pH of 6.5, which is higher than that of Al<sub>2</sub>Cl<sub>3</sub> solution (pH of 3). Hence, option A is correct. NaCl has a pH of 7, and hence option B is incorrect.

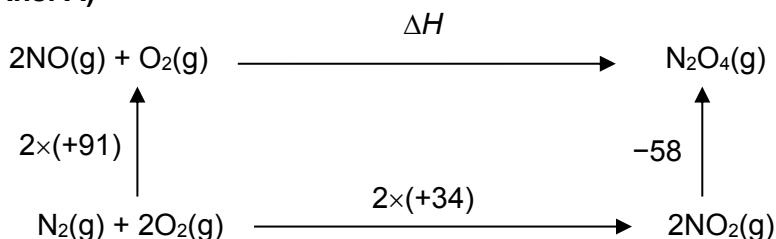
**Q11 (Ans: B)**

Option A is incorrect as the boiling point of  $X_2$  increases down the group due to stronger instantaneous dipole-induced dipole interactions between the molecules. Hence, the volatility decreases down the group.

Option B is correct as the bond length of  $X_2$  increases down the group due to increase in the size of the atom down the group.

Option C is incorrect as the bond energy of  $X_2$  decreases down the group as the electron cloud of the atoms get more diffused down the group and the effectiveness of orbital overlap decreases down the group.

Option D is incorrect as the oxidizing power of  $X_2$  decreases down the group since the tendency of  $X_2$  to gain electrons decreases down the group.

**Q12 (Ans: A)**

$$\Delta H = -2\times(+91) + 2\times(+34) + (-58) = -172 \text{ kJ mol}^{-1}$$

**Q13 (Ans: D)**

	Reaction	Sign of $\Delta H$
$\Delta H_1$	enthalpy change of reaction between sodium and hydrochloric acid $2\text{Na(s)} + 2\text{H}_2\text{O(l)} \longrightarrow 2\text{NaOH(aq)} + \text{H}_2(\text{g}) \quad \Delta H_r^\ominus < 0$ $\text{OH}^\ominus(\text{aq}) + \text{H}^\oplus(\text{aq}) \longrightarrow \text{H}_2\text{O(l)} \quad \Delta H_r^\ominus < 0$	negative
$\Delta H_2$	enthalpy change of combustion of sodium	negative
$\Delta H_3$	enthalpy change of reaction between sodium oxide and hydrochloric acid	Cannot be determined from the question
$\Delta H_4$	enthalpy change of combustion of hydrogen	negative

Option A is incorrect as  $\Delta H_1 + \Delta H_2$  is always negative.

Option B is incorrect as  $\Delta H_3 + \Delta H_4$  is not always positive since  $\Delta H_4$  is negative.

Option C is incorrect, by Hess' Law,  $\Delta H_3 - \Delta H_4 - \Delta H_1 = -\Delta H_2$ , and  $-\Delta H_2$  is positive.

Option D is correct, by Hess' Law,  $\Delta H_2 + \Delta H_3 - \Delta H_1 = \Delta H_4$  and  $\Delta H_4$  is negative.

**Q14 (Ans: A)**

Option A is correct. When  $[\text{CH}_3\text{CHO}] = c$ , the active sites of the enzymes become saturated with  $\text{CH}_3\text{CHO}$ . Further increase in  $[\text{CH}_3\text{CHO}]$  will not have any effect on the reaction rate.

Option B is incorrect. When  $[\text{CH}_3\text{CHO}] = c$ , the order of reaction with respect to  $[\text{CH}_3\text{CHO}]$  is zero.

Option C is incorrect. When  $[\text{CH}_3\text{CHO}] = c$ , the reaction rate remains constant as long as the active sites of the enzymes remain saturated with  $\text{CH}_3\text{CHO}$ .

Option D is incorrect. When  $[\text{CH}_3\text{CHO}] = c$ , the reaction rate remains constant but non-zero.

**Q15 (Ans: A)**

For  $X(g) \rightleftharpoons Y(g)$ ,  $K_c = \frac{[Y]}{[X]}$  and  $K_p = \frac{P_Y}{P_X}$

Statement 1 is correct. Given that X and Y behave as ideal gases,  $P_X V = n_X RT$  and hence  $P_X = [X]RT$ .

$$\text{Thus, } K_p = \frac{P_Y}{P_X} = \frac{[Y]RT}{[X]RT} = \frac{[Y]}{[X]} = K_c.$$

Statement 2 is correct. Under the same conditions,  $K_p$  is constant regardless if the equilibrium was achieved from 100% of  $X(g)$  or 100% of  $Y(g)$ . Thus,  $\frac{P_Y}{P_X} = K_p$  remains constant.

Statement 3 is correct. Adding more  $X(g)$  increases the concentration of  $X(g)$  and the position of equilibrium of  $X(g) \rightleftharpoons Y(g)$  shifts to the right to partially offset this increase. However, at the same temperature,  $K_p$  is constant and hence the partial pressures of both gases must increase so that  $K_p = \frac{P_Y}{P_X} = \text{constant}$ .

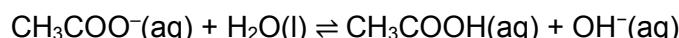
**Q16 (Ans: D)**



When  $\text{HNO}_3$  was titrated against  $\text{NH}_3$ ,  $\text{NH}_3$  is added from the burette to  $\text{HNO}_3$  in the conical flask.

vol. of $\text{NH}_3$ added / $\text{cm}^3$	remarks
10	The conical flask contains unreacted $\text{HNO}_3$ and the product, $\text{NH}_4^+$ , which does not act as a buffer.
20	All the $\text{HNO}_3$ is completely neutralised and the conical flask contains the product, $\text{NH}_4^+$ , which does not act as a buffer.
30	20 $\text{cm}^3$ of $\text{NH}_3$ is used for neutralisation and the remaining 10 $\text{cm}^3$ is in excess. The conical flask contains excess $\text{NH}_3$ and the product, $\text{NH}_4^+$ , in the ratio 1 : 2 and hence can act as a buffer but does not have maximum buffering capacity
40	20 $\text{cm}^3$ of $\text{NH}_3$ is used for neutralisation and the remaining 20 $\text{cm}^3$ is in excess. The conical flask contains excess $\text{NH}_3$ and the product, $\text{NH}_4^+$ , in the ratio 1 : 1 and hence can act as a buffer with maximum buffering capacity.

**Q17 (Ans: B)**



$$K_b \text{ for } \text{CH}_3\text{COO}^- = \frac{K_w}{K_a} = \frac{10^{-13.3}}{1.63 \times 10^{-5}} = 3.0748 \times 10^{-9} \text{ mol dm}^{-3}$$

At equilibrium,  $[\text{OH}^-] = [\text{CH}_3\text{COOH}]$

$$[\text{CH}_3\text{COO}^-]_{\text{eqm}} \approx [\text{CH}_3\text{COO}^-]_{\text{initial}} = 1 \text{ mol dm}^{-3}$$

since  $\text{CH}_3\text{COO}^-$  is a weak acid with a small  $K_b$ .

$$[\text{OH}^-] = \sqrt{K_b \times [\text{CH}_3\text{COO}^-]} = \sqrt{3.0748 \times 10^{-9} \times 1} = 5.5451 \times 10^{-5} \text{ mol dm}^{-3}$$

$$\text{pH} = \text{p}K_w - \text{pOH} = 13.3 - [-\lg(5.5451 \times 10^{-5})] = 9.04$$

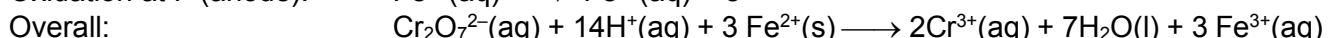
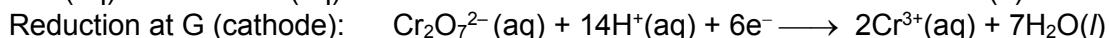
**Q18 (Ans: C)**

Option A is incorrect as there is no common ion between NaCl and MgCO<sub>3</sub>.

Option B is incorrect as the addition of H<sub>2</sub>O(l) decreases the concentration of dissolved MgCO<sub>3</sub>, causing the solution to be no longer saturated and no precipitate will form.

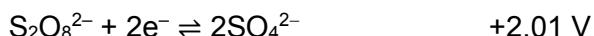
Option C is correct as K<sub>2</sub>CO<sub>3</sub>(s) will dissolve in water to form CO<sub>3</sub><sup>2-</sup>(aq), increasing the [CO<sub>3</sub><sup>2-</sup>] and causing ionic product of MgCO<sub>3</sub> = [Mg<sup>2+</sup>][CO<sub>3</sub><sup>2-</sup>] to exceed  $K_{sp}$  of MgCO<sub>3</sub>, causing the formation of MgCO<sub>3</sub> precipitate.

Option D is incorrect as HCl(aq) will react with MgCO<sub>3</sub> in an acid-base reaction to decrease the concentration of CO<sub>3</sub><sup>2-</sup> and the solution will no longer be saturated and no precipitate will form.

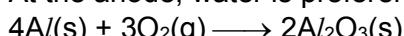
**Q19 (Ans: A)**

$$E^\ominus_{\text{cell}} = E^\ominus_{\text{cathode}} - E^\ominus_{\text{anode}} = +1.33 - (+0.77) = +0.56 \text{ V}$$

Electrons are produced at F (anode) and flows to G (cathode).

**Q20 (Ans: D)**

At the anode, water is preferentially oxidised to oxygen. Hence, option B is incorrect.



Oxygen evolved reacts with the aluminium and an inert layer of Al<sub>2</sub>O<sub>3</sub> is formed.

Hence, option D is correct.



At the cathode, hydrogen ion is preferentially reduced to hydrogen gas and there is no change in mass of the cathode. Hence, options A and C are incorrect.

**Q21 (Ans: B)**

Option A is incorrect as copper is a transition metal, and has a much higher density than potassium.

Option B is correct as potassium is not a transition metal and does not form coloured compounds while copper can form copper(I) compounds which have a fully filled 3d subshell, preventing the 3d electrons from undergoing d-d transition, thus appearing white in colour.

Option C is incorrect as potassium does not form stable compounds with oxidation state of +2 (no variable oxidation states).

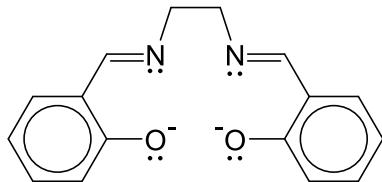
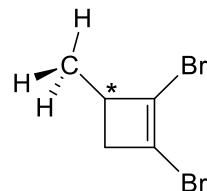
Option D is incorrect as potassium only uses electrons from the 4s subshell for metallic bonding, while copper can use electrons from both 4s and 3d subshells for metallic bonding.

**Q22 (Ans: D)**

Statement 1 is incorrect as the central Mn atom does not have six bond pairs of electrons.

Statement 2 is correct as Mn-salen metal complex has no net charge while the two nitrogen atoms in the tetridentate ligand below are uncharged and the two oxygen atoms are singly charged, together with the singly charged monodentate  $\text{Cl}^-$  ligand, Mn has an oxidation number of +3.

Statement 3 is correct as the monodentate ligand is  $\text{Cl}^-$  while the tetridentate ligand is as shown below.

**Q23 (Ans: B)**

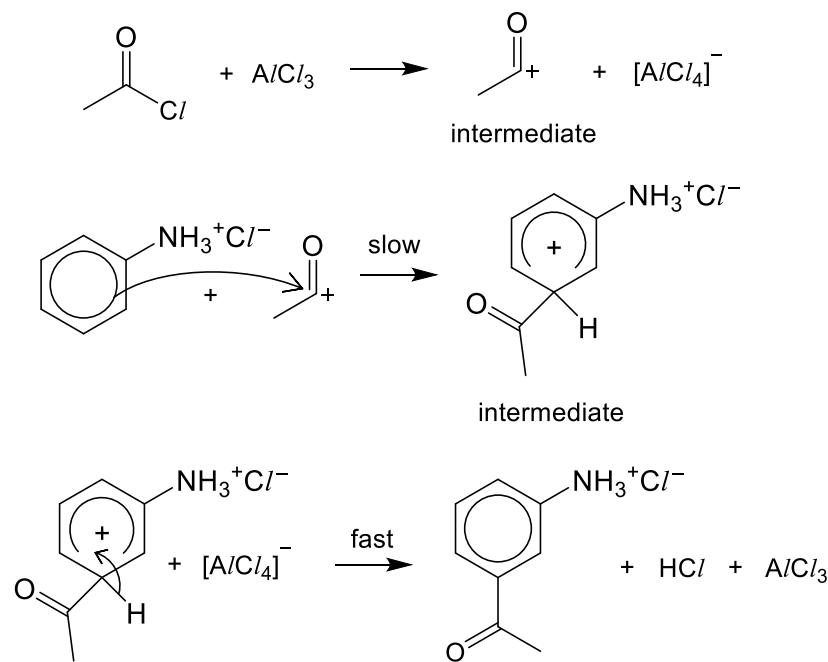
Statement 1 is incorrect as the compound contains a methyl substituent which has a tetrahedral geometry with respect to the  $-\text{CH}_3$  carbon.

Statement 2 is correct as the compound contains one chiral carbon labelled (\*).

Statement 3 is incorrect as the compound is a cyclic alkene which does not exist as cis-trans isomers. The trans-isomer does not exist due to ring strain.

**Q24 (Ans: C)**

Note that, from the *Data Booklet*,  $-\text{NH}_3^+$  is a 3-directing group.



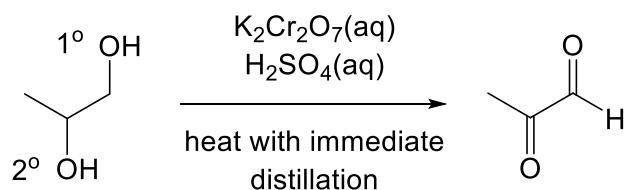
**Q25 (Ans: C)**

For elimination reactions of alcohols or halogenoalkanes to form alkenes, the major product is the alkene with the greater number of alkyl groups attached to the doubly bonded carbon atoms i.e. the more substituted alkene.

	No. of monochlorinated compounds	Major product
1	Correct 4 compounds 	Correct 
2	Incorrect 3 compounds 	Correct 
3	Correct 4 compounds 	Correct 
4	Correct 4 compounds 	Incorrect 

**Q26 (Ans: D)**

$\text{K}_2\text{Cr}_2\text{O}_7$ ,  $\text{H}_2\text{SO}_4$ , and heat with distillation will oxidise primary alcohol to aldehyde and oxidise secondary alcohol to ketone.

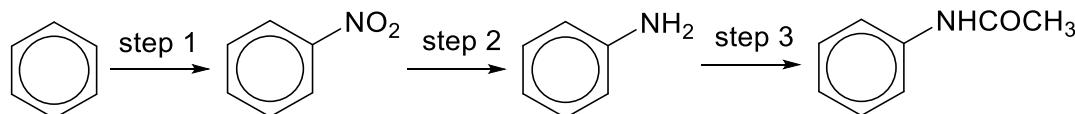


**Q27 (Ans: D)**

To substitute a nitrogen atom on the benzene ring, nitration via electrophilic substitution is needed, option A is incorrect.

Reduction of nitro group on aromatic ring should be done with Sn with  $\text{HCl}$ , and not with  $\text{LiA/H}_4$ , option B is incorrect.

Amide formation should be carried using an amine with an acyl halide and not a carboxylic acid. Hence, option C is wrong and option D is correct.



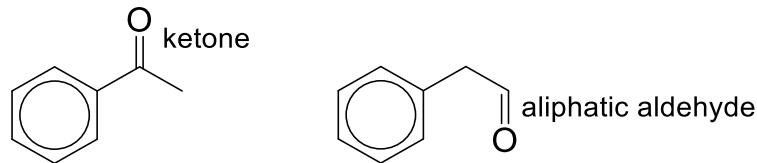
**Q28 (Ans: B)**

Option 1 is incorrect as 2,4-DNPH will give orange precipitate with both compounds as both have  $\text{C=O}$  carbonyl groups.

Option 2 is correct as Tollen's reagent will give silver mirror with the aldehyde, and not the ketone.

Option 3 is correct as Fehling's reagent will give brick-red precipitate with the aliphatic aldehyde, and not the ketone.

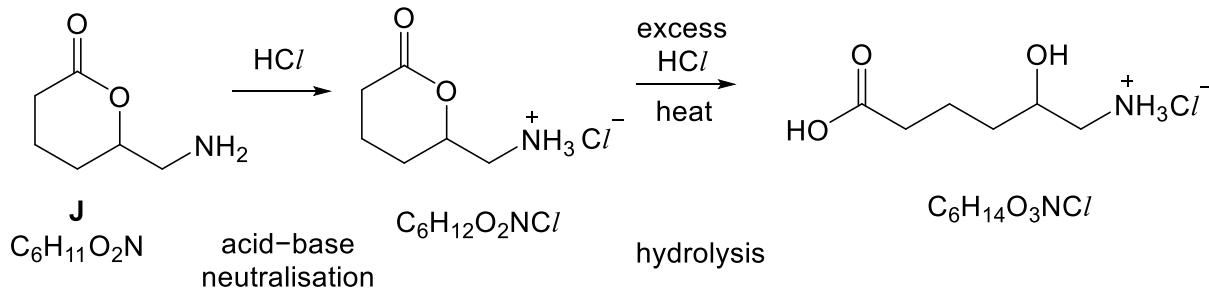
Option 4 is incorrect as purple  $\text{KMnO}_4$  will be decolourised with both compounds as side-chain oxidation will take place for both compounds.



**Q29 (Ans: C)**

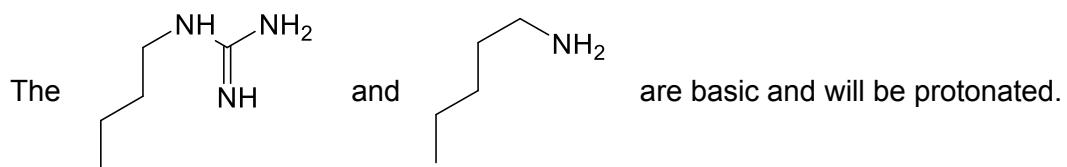
Reaction of **J**,  $\text{C}_6\text{H}_{11}\text{O}_2\text{N}$  with  $\text{HCl}$  (without heating) is an acid-base neutralization reaction to give salt  $\text{C}_6\text{H}_{12}\text{O}_2\text{NCI}$  (increase in 1 H and 1 Cl). Compound **J** is basic and contains the amine  $-\text{NH}_2$  group as in option **C**. (Option A contains neutral  $-\text{CN}$  group, while options B and D contain neutral amide groups).

Heating the mixture containing the salt  $\text{C}_6\text{H}_{12}\text{O}_2\text{NCI}$  and  $\text{HCl}$  results in hydrolysis to give  $\text{C}_6\text{H}_{14}\text{O}_3\text{NCI}$  (increase in 2 H and 1 O). Since no atoms were lost in the hydrolysis reaction, this suggests that the functional group that was hydrolysed is part of a ring structure.

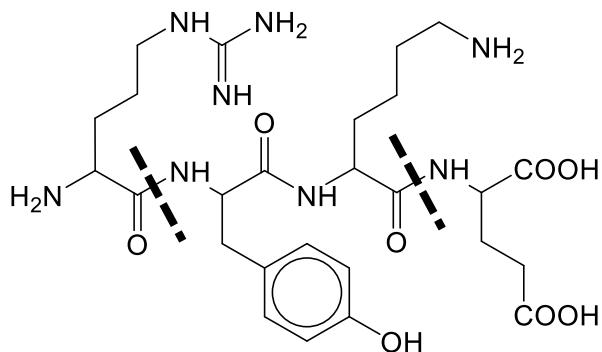


**Q30 (Ans: A)**

Amide side chains are not basic and will not be protonated.

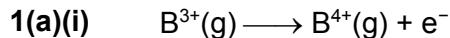


Hence, the peptide in option **A** is cleaved as shown to give 3 different products.



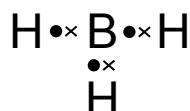
**2024 Y6 H2 Chemistry Preliminary Exams Paper 2 – Suggested Solutions**

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- 1(a)(ii)**  $B^{3+}: 1s^2$        $C^{3+}: 1s^2 2s^1$   
 $C^{3+}$  has one more electron shell than  $B^{3+}$ ; the 2s electron in  $C^{3+}$  is further away from the nucleus than the 1s electron in  $B^{3+}$ . Shielding experienced by the 2s electron in  $C^{3+}$  is greater than the 1s electron in  $B^{3+}$ .  
 Despite the greater nuclear charge in  $C^{3+}$ , electrostatic attraction between the nucleus and the 2s electron in  $C^{3+}$  is weaker than the 1s electron in  $B^{3+}$ . Less energy is required to remove the 2s electron in  $C^{3+}$  compared to the 1s electron in  $B^{3+}$ . Thus, B has a higher fourth ionisation energy than C.

**1(b)(i)**



- 1(b)(ii)** shape: trigonal planar  
 bond angle:  $120^\circ$

**1(b)(iii)**  $\Delta H_r = \text{energy required to break bonds} - \text{energy released from bonds formed}$   
 $= 3\text{BE(B-H)} + \frac{3}{2}\text{BE(O=O)} - \text{BE(B=O)} - \text{BE(B-O)} - 3\text{BE(O-H)}$   
 $= 3(330) + \frac{3}{2}(496) - 837 - 536 - 3(460)$   
 $= -1019 \text{ kJ mol}^{-1}$   
 $= \underline{-1020 \text{ kJ mol}^{-1}}$  (3 s.f.)

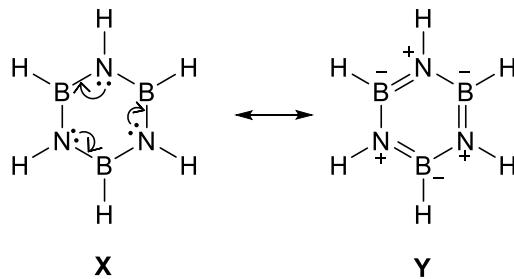
- 1(b)(iv)** The standard enthalpy change of combustion of borane is more exothermic than  $\Delta H_r$  as energy is released to condense steam to water and to convert  $\text{B}_2\text{O}_3$  from gaseous to solid state.

- 1(c)(i)** Aluminium in  $\text{AlCl}_3$  has a vacant, low-lying orbital to accept a lone pair of electrons from the chlorine atom of another  $\text{AlCl}_3$  molecule.

**1(c)(ii)**  $\text{sp}^2$  to  $\text{sp}^3$

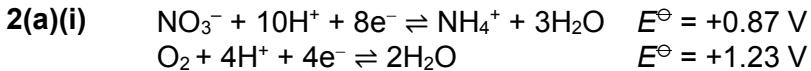
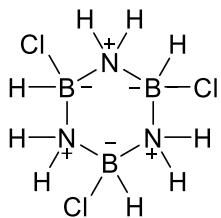
- 1(c)(iii)** There is less electron density in each  $\text{B}-\text{H}_b$  bond / fewer shared bonding electrons, hence resulting in weaker attraction to the nuclei.

**1(d)(i)**



**1(d)(ii)** N is more electronegative than B, and this reduces the extent of electron delocalisation (partially delocalised) compared to benzene.

**1(d)(iii)**



$$E^\ominus_{\text{cell}} = +1.23 - (+0.87) = +0.36 \text{ V} > 0 \text{ (reaction is spontaneous)}$$

**2(a)(ii)** The beneficial bacteria provide enzymes which act as biological catalysts to speed up the nitrification process.

**2(b)(i)** Day 9 or 10

**2(b)(ii)** Day 29

**2(b)(iii)**  $[\text{NO}_3^-]$  before water change = 35 ppm  
 $[\text{NO}_3^-]$  after water change =  $\frac{100-25}{100} \times 35 = 26.3 \text{ ppm}$

**2(b)(iv)** Using Henderson-Hasselbalch equation,  $\text{pH} = \text{p}K_a + \lg\left(\frac{[\text{NH}_3]}{[\text{NH}_4^+]}\right)$ ,

$$7.4 = 9.25 + \lg\left(\frac{[\text{NH}_3]}{[\text{NH}_4^+]}\right)$$

$$\frac{[\text{NH}_3]}{[\text{NH}_4^+]} = 10^{7.4-9.25} = 0.014125$$

$$[\text{NH}_3] = 0.014125[\text{NH}_4^+]$$

$$z = \frac{[\text{NH}_3]}{\text{TAN}} = \frac{[\text{NH}_3]}{[\text{NH}_3] + [\text{NH}_4^+]} = \frac{0.014125[\text{NH}_4^+]}{0.014125[\text{NH}_4^+] + [\text{NH}_4^+]} = \frac{0.014125}{0.014125 + 1} = 0.0139$$

OR

Let mole fraction of  $\text{NH}_3$  be  $z$ , hence mole fraction of  $\text{NH}_4^+ = 1 - z$

$$\frac{z}{1-z} = 0.014125$$

$$z = \frac{0.014125}{1 + 0.014125} = 0.0139$$

**2(c)(i)** When small amount of  $\text{OH}^-$ (aq) is added,  
 $\text{HCO}_3^-$ (aq) +  $\text{OH}^-$ (aq)  $\longrightarrow$   $\text{CO}_3^{2-}$ (aq) +  $\text{H}_2\text{O}$ (l)

When small amount of  $\text{H}_3\text{O}^+$ (aq) is added,  
 $\text{CO}_3^{2-}$ (aq) +  $\text{H}_3\text{O}^+$ (aq)  $\longrightarrow$   $\text{HCO}_3^-$ (aq) +  $\text{H}_2\text{O}$ (l)

**2(c)(ii)** Tank water with a higher carbonate hardness has a higher buffer capacity to partially offset increase in  $[\text{H}^+]$  due to the nitrification process.

**2(d)(i)**

$$n(\text{S}_2\text{O}_3^{2-}) = 13.40 / 1000 \times 0.0100$$

$$= 0.000134 \text{ mol}$$

mole ratio of  $\text{O}_2 : \text{I}_2 : \text{S}_2\text{O}_3^{2-}$

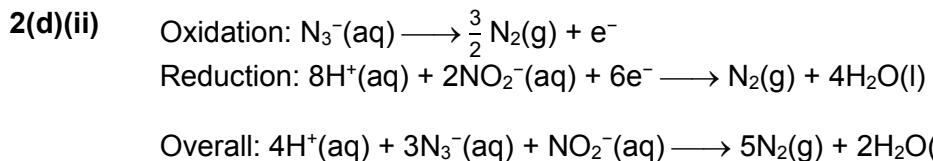
$$= 0.5 : 1 : 2$$

$$= 1 : 2 : 4$$

$$n(\text{O}_2) = 0.000134 / 4 = 0.0000335 \text{ mol}$$

$$[\text{O}_2] = 0.0000335 / 100 \times 1000$$

$$= 3.35 \times 10^{-4} \text{ mol dm}^{-3} \text{ (within recommended range)}$$

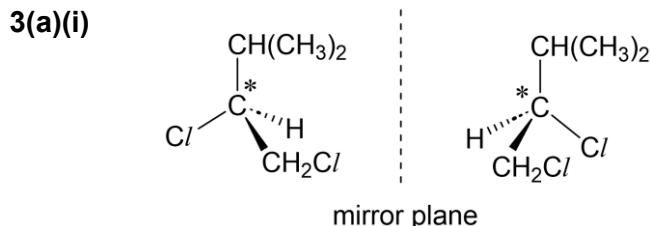


**2(e)** Decreasing basicity: N(1) > N(2) > N(3)

N(1) is a primary amine. The electron-donating  $-\text{CH}_2-$  group increases the electron density on N(1), making the lone pair of electrons on N more readily available to form a dative covalent bond with a proton.

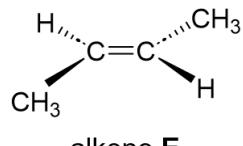
N(2) is an aromatic amine. The orbital containing the lone pair of electrons on the nitrogen atom overlaps with the  $\pi$  electron cloud of the benzene ring and the lone pair of electrons is delocalised and is less available to form a dative covalent bond with a proton.

N(3) is a sulfonamide which has similar basicity as amides. It has the lowest basicity among the three nitrogen-containing groups because the orbital containing the lone pair of electrons on the N atom overlaps with the  $\pi$  electron cloud of the adjacent S=O group and the lone pair of electrons is delocalised to a greater extent, and hence least/not available to form a dative covalent bond with a proton.

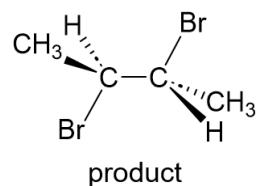


**3(a)(ii)** The carbocation that is produced in the reaction is trigonal planar with respect to the positively charged carbon.  $\text{Cl}^-$  can attack the positively charged carbon from either side of the trigonal plane with equal likelihood. This results in the formation of a racemic mixture. The optical activity of each enantiomer cancels out each other. The product mixture is unable to rotate plane-polarised light.

3(a)(iii)

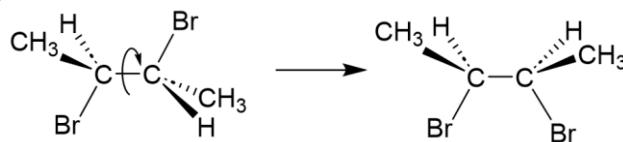


alkene E



product

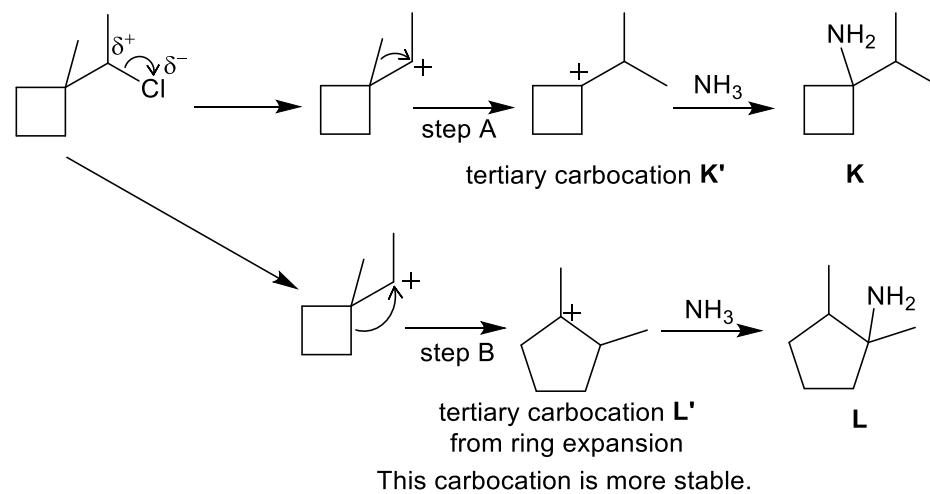
For visualization,



3(b)(i)

In this reaction, a secondary carbocation, **F'**, rearranges to form a tertiary carbocation, **G'** which is more stable because it has more electron donating alkyl groups bonded to the positively charged carbon. This helps to disperse the positive charge. **G** will be formed in a larger proportion.

3(b)(ii)

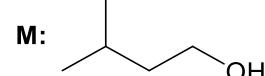


This carbocation is more stable.

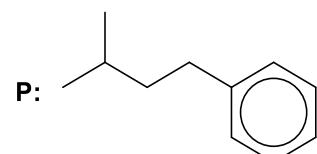
3(b)(iii)

Although both carbocations are tertiary carbocations, **L'** is more stable as there is less repulsion between bond pairs of electrons in the cyclopentane ring, compared to **K'**. **L'** is formed faster and hence, **L** is the major product.

3(c)(i)



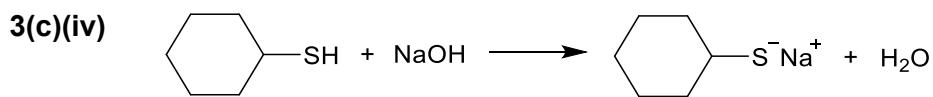
Step 2:  $\text{PCl}_5 / \text{PCl}_3 / \text{SOCl}_2$ , or dry  $\text{HCl}$ ,  $\text{ZnCl}_2$ , heat



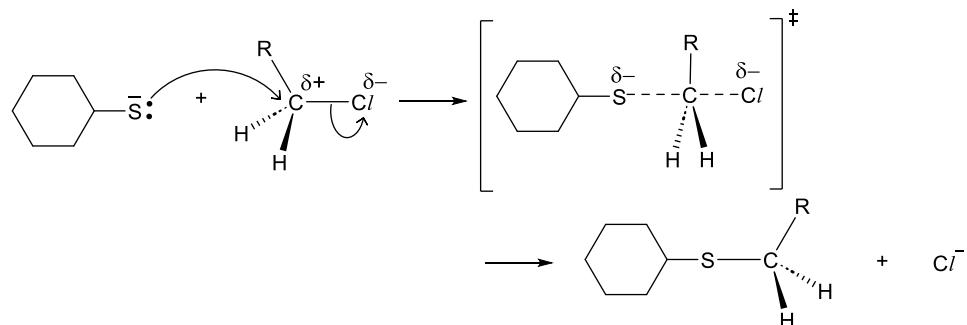
3(c)(ii)

1-chloro-3-methylbutane

**3(c)(iii)** Electrophilic substitution



**3(c)(v)** S<sub>N</sub>2



**3(c)(vi)** To 1 cm<sup>3</sup> of each compound, add 1 cm<sup>3</sup> NaOH(aq), followed by 2 to 3 drops of KMnO<sub>4</sub>. Heat the solution.

**S:** Purple KMnO<sub>4</sub> is decolourised. Black solid MnO<sub>2</sub> is formed.

**T:** Purple KMnO<sub>4</sub> remains.

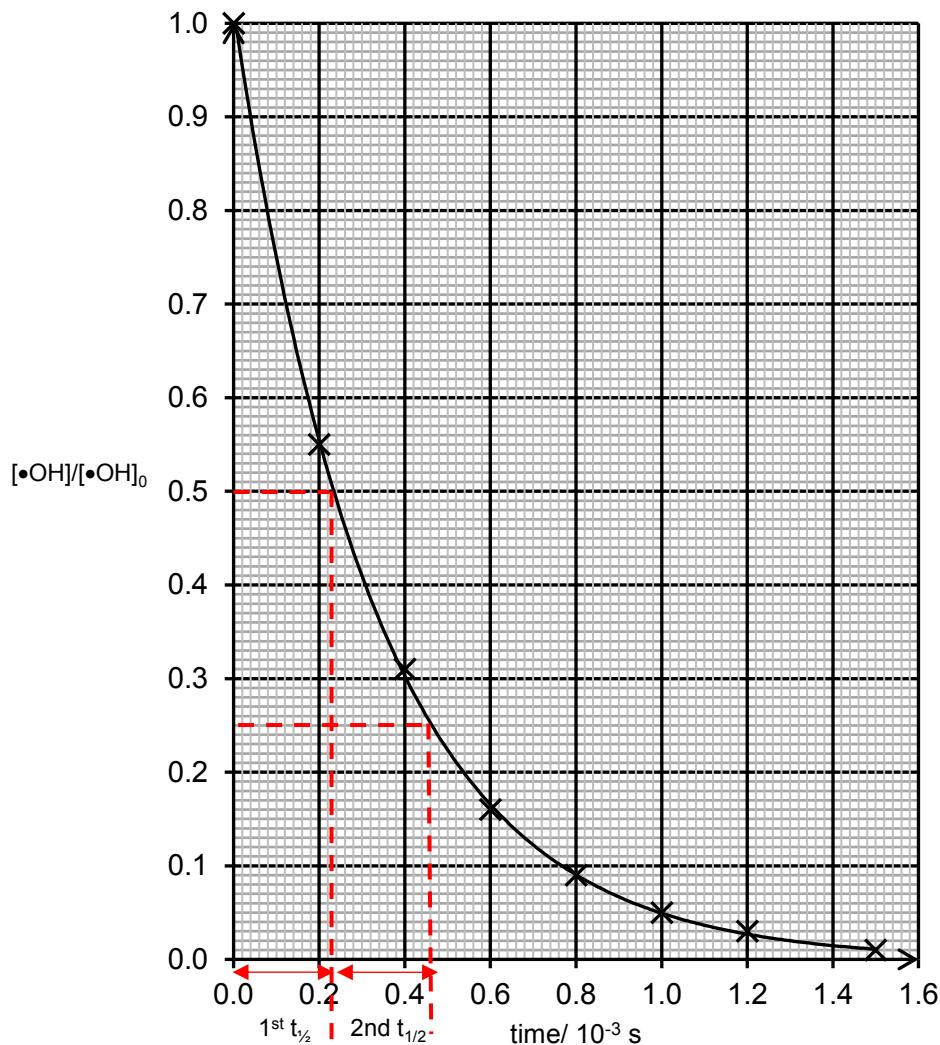
**3(d)(i)** CFCs contain C–Cl bonds which undergo homolytic fission in the presence of UV light to form chlorine radicals which catalyse the decomposition of ozone.

**3(d)(ii)** HFCs have higher GWP than CFCs. Hence, HFCs trap more heat and cause global warming to a larger extent than CFCs.

**4(a)(i)** The order of reaction with respect to a particular reactant is the power to which the concentration of that reactant is raised in the rate equation.

The rate constant, *k*, is a constant of proportionality in the rate equation. It is constant for a particular reaction at a given temperature.

- 4(a)(ii)** From Fig. 3.1, first  $t_{1/2} = 2^{\text{nd}} t_{1/2} = 2.3 \times 10^{-4} \text{ s}$   
 $\therefore$  reaction is first order with respect to  $\bullet\text{OH}$ .



**Fig. 3.1**

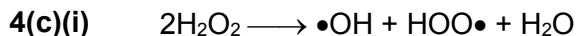
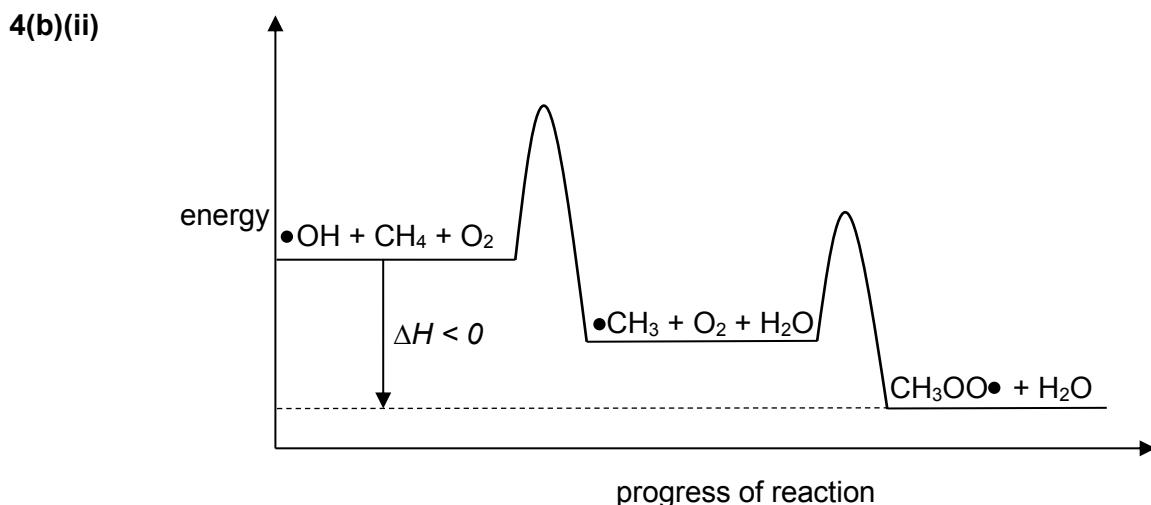
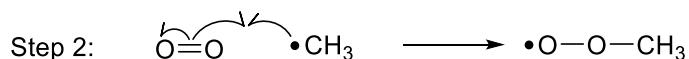
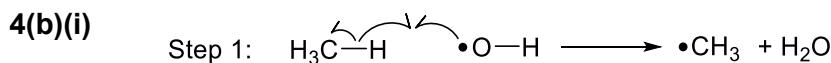
- 4(a)(iii)**  $K' = k[\text{CH}_3\text{CHO}]^n$   
A straight line graph with positive gradient passing through the origin is obtained for the graph of  $K'$  vs  $[\text{CH}_3\text{CHO}]$ , OR  $K' \propto [\text{CH}_3\text{CHO}]$ , OR  $k'$  is directly proportional to  $[\text{CH}_3\text{CHO}]$ .  
The reaction is first order with respect to  $\text{CH}_3\text{CHO}$ .

$$k = \text{gradient} = \frac{(4.0 - 0.0) \times 10^3}{(4.5 - 0.0) \times 10^7} = 8.89 \times 10^9$$

- 4(a)(iv)** rate =  $k[\bullet\text{OH}] [\text{CH}_3\text{CHO}]$

**4(a)(v)** Yes I agree, since equation 1 shows a bimolecular reaction involving 1 •OH reacting with 1 ethanal which agrees with the rate equation in (a)(iv) showing that the reaction is first order with respect to both •OH and CH<sub>3</sub>CHO.

**4(a)(vi)** A catalyst will increase the magnitude of the rate constant, k, and decrease the magnitude of the activation energy, E<sub>a</sub>.



**4(c)(ii)** Fe<sup>2+</sup> is a homogeneous catalyst as it is in the same phase as H<sub>2</sub>O<sub>2</sub>. It is used in equation 2 and regenerated in equation 3.

**4(c)(iii)** Add aq. NaOH/aq. Na<sub>2</sub>CO<sub>3</sub> to precipitate out Fe(OH)<sub>2</sub> / Fe(OH)<sub>3</sub>.  
OR  
Add aq. Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> (or other known reducing agent of H<sub>2</sub>O<sub>2</sub>) to react with H<sub>2</sub>O<sub>2</sub>.  
OR  
Add a large volume of water (dilution).

**Section A**

1(a)(i)  $K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]} \text{ mol}^{-1} \text{ dm}^3$

1a(ii) 
$$\begin{aligned} K_c &= \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]} \\ &= \frac{\frac{4.60^2}{1.00}}{\frac{(0.500)^2(0.100)}{1.00}} \\ &= 846.4 \text{ mol}^{-1} \text{ dm}^3 \\ &= \underline{846 \text{ mol}^{-1} \text{ dm}^3} \text{ (3 s.f.)} \end{aligned}$$

1(a)(iii)  $pV = nRT$   
 $p = \frac{(0.5+0.1+4.6)(8.31)(273+450)}{1000} = 31.24 \times 10^6 \text{ Pa}$   
 $p = \underline{31.2 \text{ MPa}}$

1(a)(iv) Partial pressure of  $\text{SO}_3$   
 $= \frac{4.60}{0.5+0.1+4.6} \times (31.24 \times 10^6) = \underline{27.6 \text{ MPa}}$

1(a)(v) Let  $y$  be the amount of  $\text{O}_2$  added into the system

	2 $\text{SO}_2$	+	$\text{O}_2$	$\rightleftharpoons$	2 $\text{SO}_3$
Initial amt / mol	0.500		0.1 + y		4.6
Change in amt / mol	-0.1		-0.05		+0.1
Equilibrium / mol	0.400		0.05 + y		4.7

$K_c$  is a constant as temperature remained constant

At equilibrium,  $\frac{\frac{4.70^2}{1.00}}{\frac{(0.400)^2(0.05+y)}{1.00}} = 846.4 \text{ mol}^{-1} \text{ dm}^3$

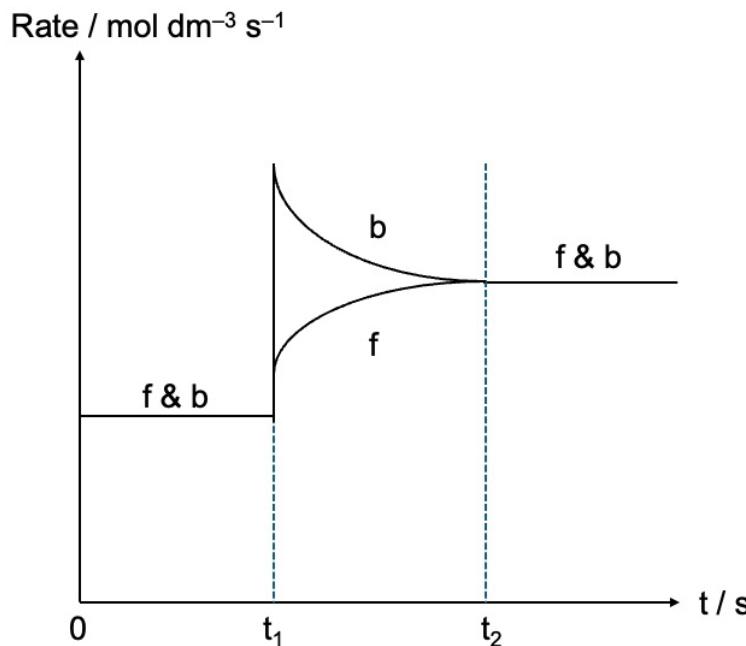
$4.7^2 = 846.4(0.4)^2(0.05 + y)$

$0.05 + y = 0.1631$

$y = \underline{0.113 \text{ mol}}$

- 1(b)(i) When temperature increases, equilibrium position shifts left to favour the backward endothermic reaction to counteract the increase in temperature. Hence, the amount of  $\text{SO}_2$  will increase.

1(b)(ii)



1(c)(i) 800 K

1(c)(ii) As temperature increases,  $\Delta G_r$  of reaction 1 becomes more positive.

Thus, position of equilibrium of reaction 1 lies more to the left, causing the positions of equilibrium for both reactions 2 and 3 to shift to the left, which result in a lower proportion of  $H_2SO_4$ .

1(d)(i)

- An ideal gas consists of particles of negligible volume. The size of the gas particles is negligible compared to the volume of the container.
- The gas particles exert negligible attractive forces on one another.
- Collisions between gas particles are perfectly elastic.

1(d)(ii) At moderately high pressure, the gas particles come closer together and intermolecular attractive forces between the gas particles become significant.  
OR

At very high pressure, the gas particles are much closer together and the gas occupies a smaller volume. As such, the volume of the gas particles is not negligible as compared to the volume of the container.

1(e)(i) Above  $T_c$ , kinetic energy of the gas particles is so high such that the intermolecular forces of attraction are overcome at all pressures.

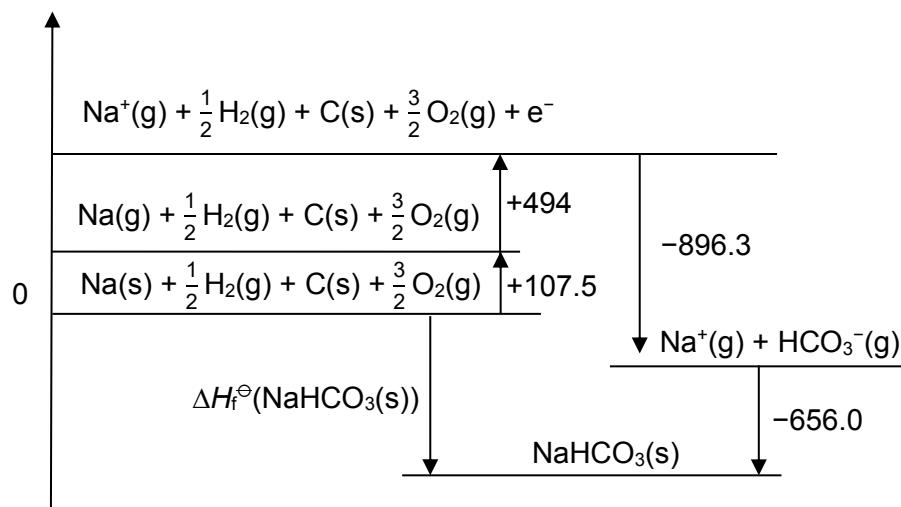
1(e)(ii) The intermolecular forces of attraction present in steam are stronger hydrogen bonds compared to the weaker instantaneous dipole-induced dipole interactions (id-id) between carbon dioxide molecules.

More energy is required to overcome the stronger hydrogen bonds as compared to weaker id-id, hence steam has a higher critical temperature.

- 2(a)(i)** Standard enthalpy change of formation is the 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 of 1 bar and 298 K.

- 2(a)(ii)**

energy / kJ mol<sup>-1</sup>



By Hess' Law,

$$(+107.5) + (+494) + (-896.3) + (-656.0) = \Delta H_f^\ominus(\text{NaHCO}_3(\text{s}))$$

$$\Delta H_f^\ominus(\text{NaHCO}_3(\text{s})) = -951 \text{ kJ mol}^{-1} \text{ (3 s.f.)}$$

- 2(a)(iii)**

$$\text{amount of sodium hydrogencarbonate} = \frac{11.2}{84.0} = 0.1333 \text{ mol}$$

$$q = -(+18.7 \times 0.1333) = -2.493 \text{ kJ}$$

$$\Delta T = \frac{-2.493 \times 1000}{(100)(4.18)} = -5.96 \text{ }^\circ\text{C or K}$$

- 2(a)(iv)**

$$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$$

Since  $\Delta G_{\text{solution}}^\ominus < 0$ , and  $\Delta H_{\text{solution}}^\ominus > 0$ ,  $-T\Delta S_{\text{solution}}^\ominus$  must be less than 0. Hence, the sign for  $\Delta S_{\text{solution}}^\ominus$  is also positive.

- 2(a)(v)**

The hydroxide ion is smaller than hydrogencarbonate ion, while having the same charge. Therefore, the hydroxide ion has a higher charge density.

Hence, the standard enthalpy change of hydration of hydroxide is more exothermic.

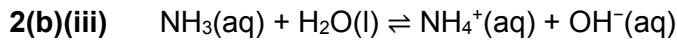
- 2(b)(i)**

$$K_{\text{sp}} = [\text{Cu}^{2+}][\text{CO}_3^{2-}] \quad \text{units} = \text{mol}^2 \text{ dm}^{-6}$$

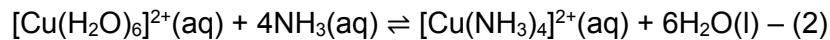
**2(b)(ii)**  $[CO_3^{2-}]$  to precipitate  $PbCO_3 = \frac{7.40 \times 10^{-14}}{\frac{1}{2}(0.1)} = 1.48 \times 10^{-12} \text{ mol dm}^{-3}$

$$[CO_3^{2-}] \text{ to precipitate } CuCO_3 = \frac{1.40 \times 10^{-10}}{\frac{1}{2}(0.2)} = 1.40 \times 10^{-9} \text{ mol dm}^{-3}$$

Since  $[CO_3^{2-}]$  needed to precipitate  $PbCO_3 < CuCO_3$ ,  $PbCO_3$  will be precipitated first.



Upon addition of aqueous ammonia, a weak base,  $[OH^-]$  increases and shift the position of equilibrium of (1) to the right, resulting in the formation of a light blue precipitate of  $Cu(OH)_2$  since ionic product of  $Cu(OH)_2 > K_{sp}(Cu(OH)_2)$ .

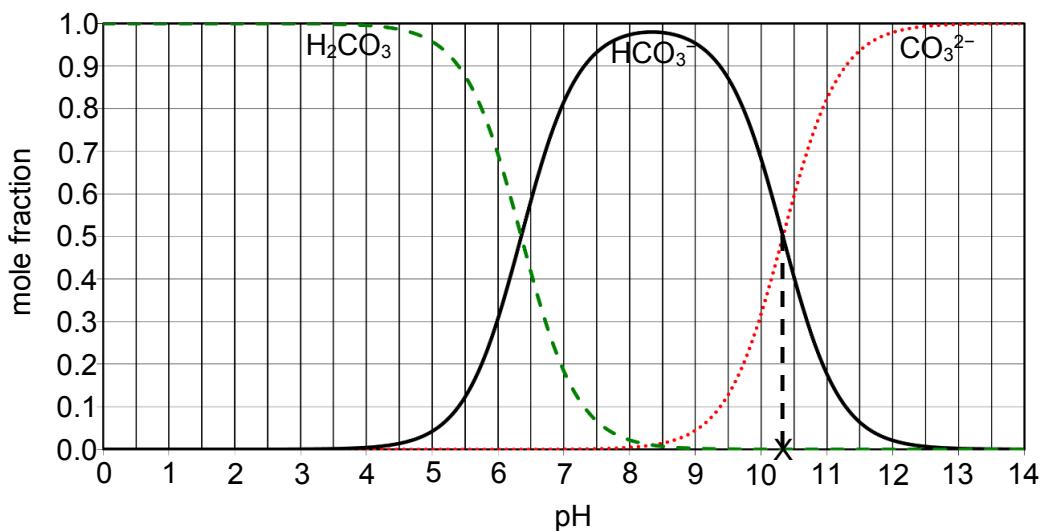


Upon addition of excess aqueous ammonia,  $[NH_3]$  increases and shifts the position of equilibrium of (2) shifts to the right and decreases the concentration of  $[Cu(H_2O)_6]^{2+}$ . Hence, the position of equilibrium of (1) shifts to the left, causing the blue precipitate of  $[Cu(OH)_2(H_2O)_4](s)$  to dissolve since ionic product  $Cu(OH)_2 < K_{sp}(Cu(OH)_2)$ , giving a dark blue solution.

**2(c)(i)** When mole fraction of  $CO_3^{2-} = 0.05$ , pH is about 9 – 9.25.

$$[H^+] = 1.00 \times 10^{-9} \text{ mol dm}^{-3}$$

2(c)(ii)

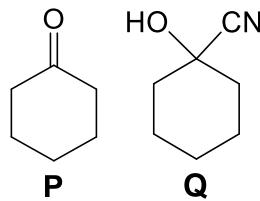


2(c)(iii) As carbon dioxide emission increases, concentration of  $\text{H}_2\text{CO}_3$  in seawater increases. pH of seawater decreases.

From Fig. 2.1, the mole fraction of carbonate ions decreases with decreasing pH, Hence, it is more difficult for the marine creatures to build their shells.

3(a) Since C/I is more electronegative than I, the C/I atom is more electron-withdrawing than the I atom and the negative charge is dispersed to a greater extent in  $\text{CH}_3\text{CHC}/\text{COO}^-$  ion than in  $\text{CH}_3\text{CHICOO}^-$  ion. Hence  $\text{CH}_3\text{CHC}/\text{COO}^-$  ion is more stable. The greater stability of the conjugate base anion explains the higher acidity of  $\text{CH}_3\text{CHC}/\text{COOH}$ .

3(b)(i)



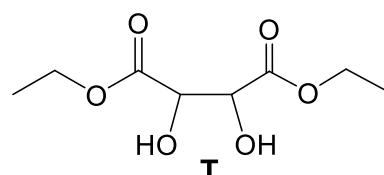
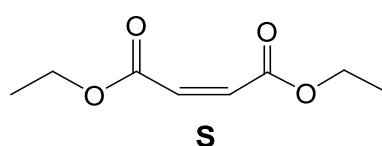
3(b)(ii)

Step 1:  $\text{H}_2\text{SO}_4$ (aq),  $\text{K}_2\text{Cr}_2\text{O}_7$ (aq) and heat

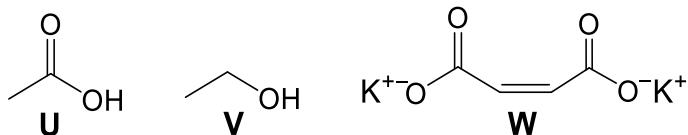
Step 2: HCN with trace KCN

Step 3:  $\text{H}_2\text{SO}_4$ (aq), heat

3(c)

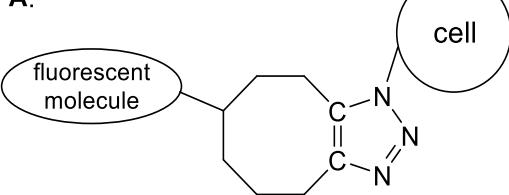


*trans* isomer acceptable



- 3(d) The  $\text{C}\equiv\text{C}$  group in alkynes do not have a partial positive charge to attract nucleophiles.  
OR  
The alkyne is electron rich and repels electron rich nucleophiles.

3(e)(i)



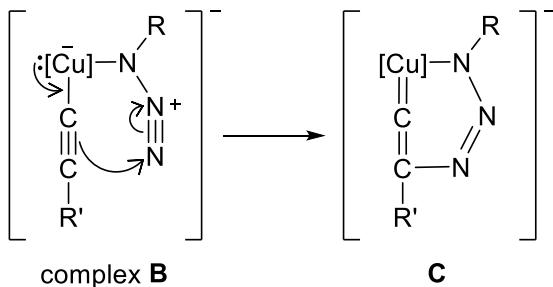
- 3(e)(ii) Due to ring strain/ bond strain, making cyclooctyne less stable and lowering the activation energy required for reaction.

Note: The alkyne  $-\text{C}\equiv\text{C}-$  carbon atoms are *sp* hybridized and the ideal VESPR bond angle to minimise repulsion is  $180^\circ$ . In the ring structure of cyclooctyne, the bond angles from the  $-\text{C}\equiv\text{C}-$  are less than  $180^\circ$ .

- 3(f)(i) The azide group has a net positive charge OR lost electron density coordinating to Cu. Thus, it is more electron deficient and a better electrophile.

The alkyne group is next to the Cu and sideways overlap between the Cu orbital with the lone-pair electrons is possible with the alkyne  $\pi$  electron cloud. Hence the Cu lone pair electrons can be delocalised with the alkyne group, making it more electron rich and susceptible to electrophilic attack.

3(f)(ii)  
and  
3(f)(iii)



## **Section B**

- 4(a)** Aqueous Cu<sup>2+</sup> exists as [Cu(H<sub>2</sub>O)<sub>6</sub>]<sup>2+</sup> complex and Cu<sup>2+</sup> has an electronic configuration of [Ar]3d<sup>9</sup>. The presence of H<sub>2</sub>O ligands split the 3d orbitals into two sets of slightly different energy levels.

Since the 3d subshell in Cu<sup>2+</sup> is partially filled, electrons in the lower energy d orbitals can absorb energy corresponding to certain wavelengths from the visible spectrum and get promoted to the higher-energy d orbitals (d-d transition). The colour observed is the complement of the colour absorbed.

Even though aqueous Zn<sup>2+</sup> exists as [Zn(H<sub>2</sub>O)<sub>6</sub>]<sup>2+</sup> complex, Zn<sup>2+</sup> has an electronic configuration of [Ar]3d<sup>10</sup>. Hence, Zn<sup>2+</sup> has a full 3d subshell and d-d transitions cannot occur. Thus, visible light is not absorbed and aqueous solution containing Zn<sup>2+</sup> is colourless.

- 4(b)** React bromine and iodine separately with aq Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>.
- $$S_2O_3^{2-}(aq) + 4Br_2(aq) + 5H_2O(l) \longrightarrow 2SO_4^{2-}(aq) + 8Br^-(aq) + 10H^+(aq)$$
- The average oxidation state of S increases from +2 to +6.
- $$2S_2O_3^{2-}(aq) + I_2(aq) \longrightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$
- The average oxidation state of S increases from +2 to +2.5.
- I<sub>2</sub>, being a weaker oxidising agent than Br<sub>2</sub>, oxidises S<sub>2</sub>O<sub>3</sub><sup>2-</sup> to a lesser extent.
- OR
- React bromine and iodine separately with aqueous iron(II) sulfate.
- Fe<sup>2+</sup> is oxidised to Fe<sup>3+</sup> by Br<sub>2</sub> but no reaction occurs between Fe<sup>2+</sup> and I<sub>2</sub>.
- $$2Fe^{2+} + Br_2 \longrightarrow 2Fe^{3+} + 2Br^-$$
- (This example shows that Br<sub>2</sub> can be shown to be a stronger oxidising agent (OA) than iodine by reacting the two halogens separately with a reducing agent which has E<sup>⊖</sup> greater than +0.54 V but less than +1.07 V.)
- OR
- React bromine with aqueous potassium iodide.
- $$Br_2 + 2I^- \longrightarrow 2Br^- + I_2$$
- Br<sub>2</sub> is a stronger oxidising agent than I<sub>2</sub> as Br<sub>2</sub> is able to oxidise I<sup>-</sup> but I<sub>2</sub> is unable to oxidise Br<sup>-</sup>.

- 4(c)(i)** The standard cell potential, E<sup>⊖</sup><sub>cell</sub>, is the potential difference between two half-cells under standard conditions (298 K, 1 bar of gases and 1 mol dm<sup>-3</sup> of aqueous species).



$$E^{\ominus}_{\text{cell}} = +1.00 - 0.34 = +0.66 \text{ V}$$

$$\Delta G^{\ominus} = -nFE^{\ominus}_{\text{cell}} = -2 \times 96500 \times 0.66 = -127380 \text{ J mol}^{-1} = -127 \text{ kJ mol}^{-1}$$

- 4(c)(iii)** ① Solid sodium carbonate is added to the Cu<sup>2+</sup>/Cu half-cell
- $$E^{\ominus}_{\text{cell}} = E^{\ominus}(VO_2^+/VO^{2+}) - E^{\ominus}(Cu^{2+}/Cu)$$
- Na<sub>2</sub>CO<sub>3</sub>(s) dissolves to form CO<sub>3</sub><sup>2-</sup>(aq) which reacts with Cu<sup>2+</sup>(aq) to form CuCO<sub>3</sub>(s). This causes the [Cu<sup>2+</sup>(aq)] to decrease.



Hence position of equilibrium shifts left and  $E(\text{Cu}^{2+}/\text{Cu})$  will then be less positive than  $E^\ominus(\text{Cu}^{2+}/\text{Cu})$ .

Hence,  $E_{\text{cell}} = E^\ominus(\text{VO}_2^+/\text{VO}^{2+}) - E(\text{Cu}^{2+}/\text{Cu})$  is more positive than  $E^\ominus_{\text{cell}}$

② Water is added to the  $\text{VO}_2^+/\text{VO}^{2+}$  half-cell.



Addition of water dilutes the mixture and favours the direction of reaction to produce more aqueous ions.

Hence position of equilibrium shifts left and  $E(\text{VO}_2^+/\text{VO}^{2+})$  becomes less positive than  $E^\ominus(\text{VO}_2^+/\text{VO}^{2+})$ .

Thus,  $E_{\text{cell}} = E(\text{VO}_2^+/\text{VO}^{2+}) - E^\ominus(\text{Cu}^{2+}/\text{Cu})$  is less positive than  $E^\ominus_{\text{cell}}$ .

**4(d)** To ensure that electrical neutrality is maintained.

**4(e)(i)** BCA is added to prevent the volatile/ toxic  $\text{Br}_2$  formed from escaping.

**4(e)(ii)** Even though complex **A** is ionic, its ions have low charge density.

Hence, the ion-dipole interactions with water are weak and insufficient to overcome the strong hydrogen bonding between water molecules/ ionic bonds in A, causing complex **A** to be immiscible with the aqueous electrolyte.

**4(f)**  $\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}$

$$n(\text{e}^-) = 2 \times n(\text{Zn}) = 2 \times \frac{1000}{65.4} = 30.58 \text{ mol}$$

$$\text{Quantity of charge} = 30.58 \times 96500 \text{ C} = 2.951 \times 10^6 \text{ C}$$

Since the process is only 80.0 % efficient,

$$\text{Quantity of charge required} = 2.951 \times 10^6 \times 100/80 = 3.689 \times 10^6 \text{ C}$$

$$Q = It,$$

$$\text{Time} = \frac{Q}{I} = \frac{3.689 \times 10^6}{32} \text{ s} = \frac{1.153 \times 10^5}{60 \times 60} = 32.0 \text{ h}$$

**5(a)** The 3d and 4s electrons in Ni are close in energy, hence both its 3d and 4s electrons are available for delocalisation into the sea of electrons. Thus, Ni has more delocalised electrons as compared to s-block elements.

**5(b)(i)** Ni(s) possesses a partially filled 3d subshell.

**5(b)(ii)** Ni(s) provides sites on which alkene(g) and H<sub>2</sub>(g) can be adsorbed.

The adsorption leads to an increase in reaction rate as

- it weakens the covalent bonds in alkene and H<sub>2</sub> thus reducing the activation energy for the reaction.
- it increases the concentration of the reactant molecules at the Ni surface. Hence, the reactant molecules can come into close contact, with proper orientation, for reaction.

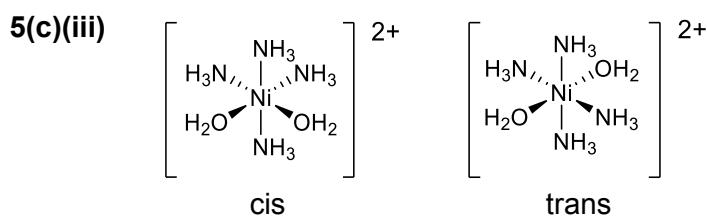
Once formed, alkane molecules can easily desorb from the Ni(s) surface so that the active sites are exposed for further reaction (regeneration of catalyst).

**5(c)(i)** Acid-base reaction

**5(c)(ii)** Down the group, cationic radius increases, resulting in a lower charge density and weaker polarising power of the cations.

Consequently, there is decreasing extent of distortion of the electron cloud of the CO<sub>3</sub><sup>2-</sup> anion and hence decreasing extent of weakening of covalent bonds within the CO<sub>3</sub><sup>2-</sup> anion.

More heat energy is required to break the covalent bonds within the CO<sub>3</sub><sup>2-</sup> anion, causing the decomposition temperature / thermal stability to increase down the group.



**5(c)(iv)** NH<sub>3</sub> is added in excess to ensure that all H<sub>2</sub>O ligands are exchanged with NH<sub>3</sub> ligands.

**B** is [Ni(NH<sub>3</sub>)<sub>6</sub>]<sup>2+</sup>.

**5(c)(v)** Both [Ni(H<sub>2</sub>O)<sub>6</sub>]<sup>2+</sup> and **B** ([Ni(NH<sub>3</sub>)<sub>6</sub>]<sup>2+</sup>) are complex ions with Ni<sup>2+</sup> as the central metal ion with an electronic configuration of [Ar]3d<sup>8</sup>. The presence of the ligands causes the splitting of the five originally degenerate 3d orbitals in the Ni<sup>2+</sup> ion into two sets of slightly different energy levels.

Since the 3d subshell is partially filled, the electrons from the lower energy d orbitals can absorb energy corresponding to certain wavelengths from the visible spectrum and get promoted to the higher energy d orbitals. Such d-d transitions are responsible for the colour observed. The colour observed is the complement of the colour absorbed.

H<sub>2</sub>O and NH<sub>3</sub> are different ligands of different strength. The d orbitals of Ni<sup>2+</sup> are hence split into two sets of slightly different energy levels to different extents, creating different energy gaps for different complexes, which in turn absorb energies of different wavelengths from the visible light spectrum for d-d transitions, thus displaying different colours.

**5(d)(i)**     $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8$

**5(d)(ii)** In an octahedral environment, the six ligands in octahedral complexes approach the central metal ion along the x, y and z axes.

$3d_{x^2-y^2}$  and  $3d_z^2$  orbitals have their greatest electron density along the co-ordinate axes. Hence electrons in these orbitals are pointing towards the lone pairs of ligands and will be repelled by them.

$3d_{xy}$ ,  $3d_{yz}$ ,  $3d_{xz}$  orbitals have their greatest electron density in between the co-ordinate axes. Hence the repulsion between electrons in these orbitals and those of the approaching ligands will be less compared to electrons in  $3d_{x^2-y^2}$  or  $3d_z^2$  orbitals.

Hence, the  $3d_{x^2-y^2}$  and  $3d_z^2$  orbitals are at a higher energy level while  $3d_{xy}$ ,  $3d_{yz}$ ,  $3d_{xz}$  orbitals are at a lower energy level

**5(d)(iii)**     $3d_{x^2-y^2}$

**2024 RI H2 Chemistry Paper 4 – Suggested Solutions**

**1(a)(i)**

**Table 1.1**

temperature of room temperature water, $T_1 / ^\circ\text{C}$	30.4
temperature of hot water, $T_2 / ^\circ\text{C}$	70.1
maximum temperature of combined water, $T_3 / ^\circ\text{C}$	48.2

**1(a)(ii)** Heat energy lost by the hot water      Heat energy gained by the room temperature water =  $mc\Delta T$   
 $= mc\Delta T$   
 $= 50 \times 4.18 \times (T_2 - T_3)$   
 $= 50 \times 4.18 \times (70.1 - 48.2)$   
 $= 4577.1 \text{ J}$   
 $= \underline{\underline{4580 \text{ J}}}$  (3 s.f.)      =  $mc\Delta T$   
 $= 50 \times 4.18 \times (T_3 - T_1)$   
 $= 50 \times 4.18 \times (48.2 - 30.4)$   
 $= 3720.2 \text{ J}$   
 $= \underline{\underline{3720 \text{ J}}}$  (3 s.f.)

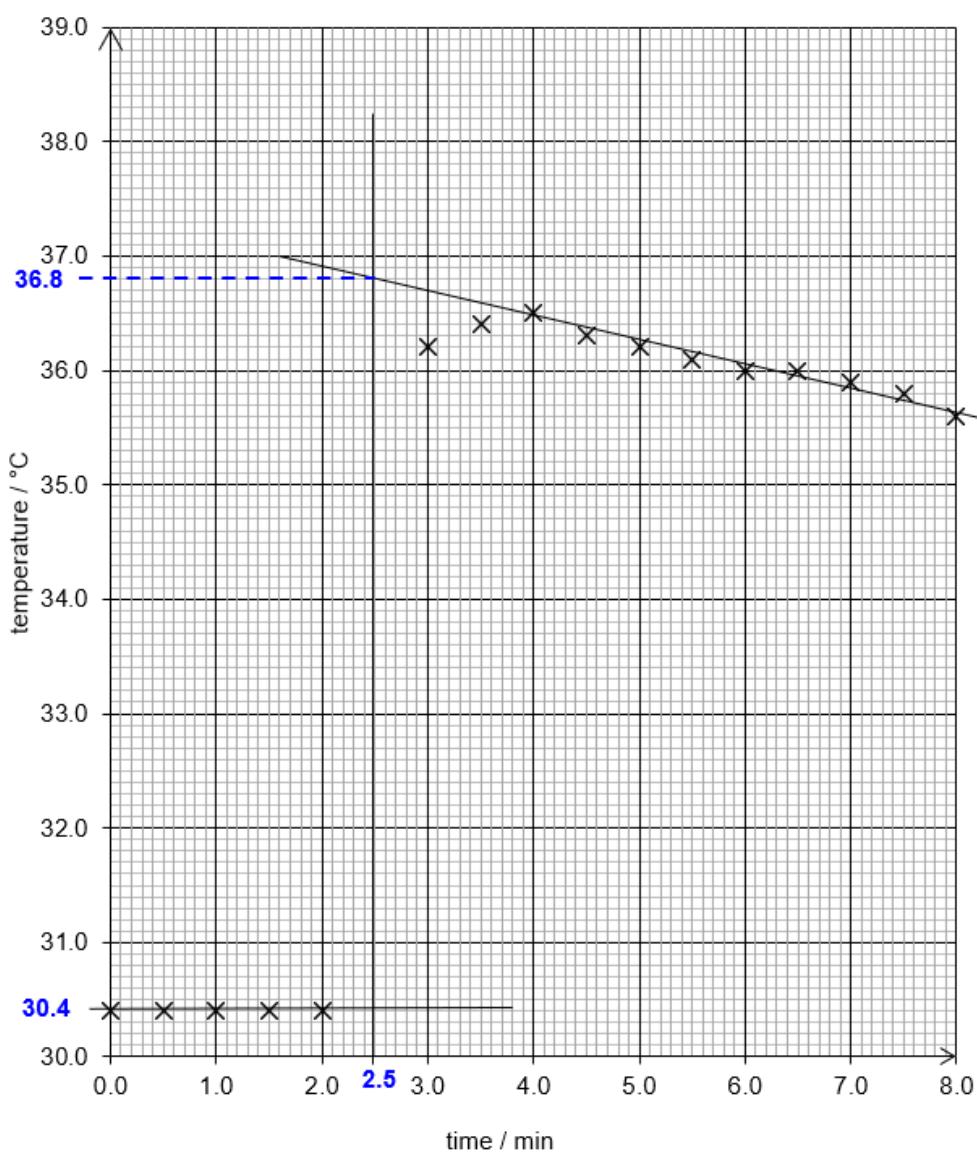
**1(a)(iii)** Heat energy absorbed by the calorimeter      Heat capacity of calorimeter,  $C_{\text{cal}}$   
 $= \text{heat energy lost by hot water}$   
 $= \frac{856.9}{T_3 - T_1} = \frac{856.9}{48.2 - 30.4}$   
 $- \text{heat energy gained by room temp water}$   
 $= 4577.1 - 3720.2$   
 $= 48.14 \text{ J } ^\circ\text{C}^{-1}$   
 $= 856.9 \text{ J}$   
 $= \underline{\underline{857 \text{ J}}}$  (3 s.f.)      =  $48.1 \text{ J } ^\circ\text{C}^{-1}$  (3 s.f.)

**1(b)(i)**

mass of capped weighing bottle and <b>FA 1</b> / g	8.782
mass of capped weighing bottle after emptying <b>FA 1</b> / g	4.745
mass of <b>FA 1</b> used / g	4.037

time / min	temperature / $^\circ\text{C}$
0.0	30.4
0.5	30.4
1.0	30.4
1.5	30.4
2.0	30.4
2.5	—
3.0	36.2
3.5	36.4
4.0	36.5
4.5	36.3
5.0	36.2
5.5	36.1
6.0	36.0
6.5	36.0
7.0	35.9
7.5	35.8
8.0	35.6

**1(b)(ii)**



**1(b)(iii)**  $T_{\min} = 30.4 \text{ }^{\circ}\text{C}$

$T_{\max} = 36.8 \text{ }^{\circ}\text{C}$

$\Delta T = +6.4 \text{ }^{\circ}\text{C}$

**1(b)(iv)** Total heat change,  $q$

= heat absorbed by solution + heat absorbed by calorimeter

$$= (mc\Delta T) + (C_{\text{cal}} \Delta T)$$

$$= (100 \times 4.18 \times 6.4) + (48.14 \times 6.4)$$

$$= +2983 \text{ J}$$

$$= +2980 \text{ J (3 s.f.)}$$

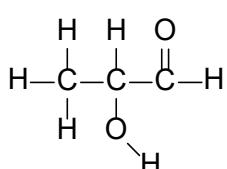
**1(b)(v)** Amount of  $\text{MgSO}_4$  used

$$\frac{4.037}{24.3 + 32.1 + 4(16.0)} \\ = 0.03353 \text{ mol}$$

$$\Delta H_{\text{sol}} = -\frac{q}{n(\text{MgSO}_4)} = -\frac{+2983}{0.03353} = -89000 \text{ J mol}^{-1} \text{ (or } -89.0 \text{ kJ mol}^{-1} \text{)} \text{ (3 s.f.)}$$

- 1(c)** The heat energy absorbed by and heat capacity of calorimeter obtained in **(a)(iii)** is higher than expected. Hence, the  $\Delta H_{\text{sol}}$  of **FA 1** obtained in **(b)(v)** is more exothermic than expected (or the magnitude of  $\Delta H_{\text{sol}}$  of **FA 1** obtained in **(b)(v)** is higher than expected).

tests		observations
1	<p>Add 1 cm depth of <b>FA 2</b> into a clean test-tube.</p> <p>To this test-tube add 10 drops of sodium hydroxide followed by iodine solution, dropwise, until a permanent orange colour is present.</p> <p>Warm the test-tube in the beaker of hot water for 2 minutes.</p>	<u>(pale) Yellow ppt</u> formed.
2	<p>Add 1 cm depth of <b>FA 2</b> into a clean test-tube.</p> <p>Add 8 drops of Fehling's solution.</p> <p>Warm the test-tube in the beaker of hot water for 3 minutes.</p>	<u>Brick-red ppt</u> formed.
3	Test solution <b>FA 2</b> with Universal Indicator paper.	Universal Indicator paper turned <u>dark yellow-green</u> . pH is <u>7</u> .



2(b)(i)	tests	observations
1	<p>Using a 10 cm<sup>3</sup> measuring cylinder, add 2 cm<sup>3</sup> of <b>FA 3</b> into a clean boiling tube.</p> <p>Using another 10 cm<sup>3</sup> measuring cylinder, measure out 7 cm<sup>3</sup> of aqueous sodium hydroxide. Slowly with shaking, add this completely to <b>FA 3</b>.</p> <p>Stir the contents of the boiling tube with a glass rod.</p> <p>Filter the mixture into a clean test-tube. The filtrate will be used for test <b>4</b>.</p> <p>While waiting, proceed to test <b>2</b> and <b>3</b>.</p>	<p><b><u>Off-white ppt. rapidly turned brown on contact with air.</u></b></p> <p>Ppt. is insoluble in excess NaOH(aq).</p> <p><b><u>Brown residue.</u></b></p> <p><b><u>Colourless filtrate.</u></b></p>

tests		observations
2	<p>Add 1 cm depth of <b>FA 3</b> into a clean test-tube.</p> <p>Add 2 cm depth of aqueous sodium carbonate.</p>	<u>Off-white/ white ppt.</u> <u>Effervescence was observed.</u> <u><math>\text{CO}_2</math> gas evolved gave a white ppt. with limewater.</u>
3	<p>Add 1 cm depth of <b>FA 3</b> into a clean test-tube.</p> <p>Add 1 cm depth of aqueous silver nitrate.</p> <p>Filter the mixture and discard the filtrate.</p> <p>Wash the residue by pouring deionised water through it. Discard the washings.</p> <p>Place the filter funnel containing the residue into a test-tube containing 1 cm depth of dilute nitric acid.</p> <p>Carefully add aqueous ammonia to the filter funnel until it covers the residue.</p> <p>The filtrate will collect in the test-tube containing the dilute nitric acid.</p>	<u>White ppt formed.</u> White residue obtained.  Colourless filtrate.  <u>White ppt formed.</u>
4	<p>Add 1 cm depth of the filtrate from test 1 into a clean test-tube.</p> <p>Add dilute sulfuric acid drop-wise, until in excess.</p>	<u>White ppt.</u> formed, <u>soluble in excess dilute <math>\text{H}_2\text{SO}_4</math></u> to give a colourless solution.

cation	evidence
$\text{Mn}^{2+}$	In <u>test 1</u> , FA 3 reacted with $\text{NaOH(aq)}$ to give <u>an off-white ppt. of <math>\text{Mn(OH)}_2</math></u> which was insoluble in excess $\text{NaOH(aq)}$ . On contact with air, $\text{Mn(OH)}_2$ was oxidised <u>to brown <math>\text{Mn(OH)}_3</math></u> .
$\text{Al}^{3+}$	In <u>test 2</u> , FA3 reacted with $\text{Na}_2\text{CO}_3(\text{aq})$ to give a <u>white ppt. of <math>\text{Al(OH)}_3</math></u> together with the effervescence of <u><math>\text{CO}_2</math> gas</u> .
anion	evidence
$\text{Cl}^-$	In <u>test 3</u> , FA 3 reacted with $\text{AgNO}_3(\text{aq})$ to form a <u>white ppt. of <math>\text{AgCl}</math></u> . White ppt of $\text{AgCl}$ soluble in excess ammonia to form colourless solution of $[\text{Ag}(\text{NH}_3)]^+$ .

3(a)(i)	Titration number	1	2
	Final burette reading / cm <sup>3</sup>	21.90	41.80
	Initial burette reading / cm <sup>3</sup>	0.00	20.00
	Volume of FA 4 used / cm <sup>3</sup>	21.90	21.80
	Values used (✓)	✓	✓

3(a)(ii) Average volume of FA 4 used =  $\frac{21.90 + 21.80}{2} = 21.85 \text{ cm}^3$

3(b)(i) Amount of Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> =  $\frac{21.85}{1000} \times 0.100$

$$= 2.185 \times 10^{-3} \text{ mol}$$

$$\text{Amount of I}_2 \text{ produced} = (\frac{1}{2}) (2.185 \times 10^{-3})$$

$$= 1.093 \times 10^{-3} \text{ mol}$$

$$= \underline{1.09 \times 10^{-3} \text{ mol}}$$

3(b)(ii) Amount of KMnO<sub>4</sub> reacted =  $(2/5) (1.093 \times 10^{-3})$

$$= 4.372 \times 10^{-4} \text{ mol}$$

$$= \underline{4.37 \times 10^{-4} \text{ mol}}$$

3(b)(iii) Amount of KMnO<sub>4</sub> in 25.0 cm<sup>3</sup> FA 7 =  $4.372 \times 10^{-4} \text{ mol}$

Amount of KMnO<sub>4</sub> in 250 cm<sup>3</sup> FA 7

$$= \text{Amount of KMnO}_4 \text{ in } 34.50 \text{ cm}^3 \text{ P}$$

$$= 4.372 \times 10^{-4} \times 10 = 4.372 \times 10^{-3} \text{ mol}$$

$$\text{Conc. of KMnO}_4 \text{ in P} = \frac{4.372 \times 10^{-3}}{34.5 \times 10^{-3}} = 0.1267 \text{ mol dm}^{-3} = \underline{0.127 \text{ mol dm}^{-3}} \text{ (3sf)}$$

3(b)(iv) Mass of KMnO<sub>4</sub> =  $0.1267 \times (39.1 + 54.9 + 4 \times 16.0) = 20.02 \text{ g} = \underline{20.0 \text{ g}}$  (3sf)

3(c)(i) Percentage =  $\frac{21.0 - 20.0}{21.0} \times 100 = \underline{4.76\%}$  (3sf)

3(c)(ii) I do not agree with the student, as KI used was in excess, hence the precision of the apparatus used is not relevant.

4(a) Excess H<sub>2</sub>NCH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub>(aq) must be used so that the equilibrium position of equation 4 lies to the right and the reaction mixture contains mainly [Ni(en)<sub>3</sub>]<sup>2+</sup>(aq).

OR

Excess H<sub>2</sub>NCH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub>(aq) must be used to ensure complete ligand exchange.

4(b) Dilution of FA 8,  $2.00 \times 10^{-3} \text{ mol dm}^{-3} [\text{Ni}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$

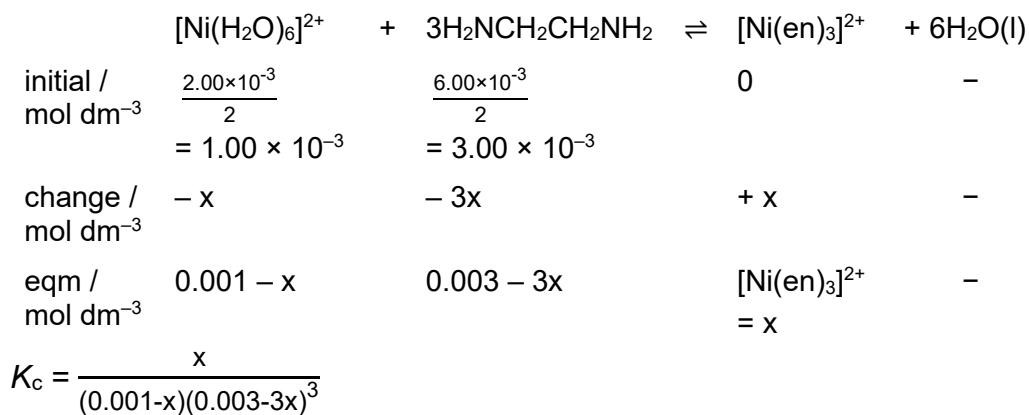
- Using a burette, transfer 50.00 cm<sup>3</sup> of FA 8 to a 100 cm<sup>3</sup> volumetric flask.
- Top up to the mark with deionised water, stopper the volumetric flask and shake this solution to obtain a homogeneous solution. Label this solution as solution 1.
- Repeat steps 1 to 2 using the volumes of FA 8 shown in the table below to prepare solution 2 to solution 5.

Solution	Volume of FA 8 / cm <sup>3</sup>	[Ni(H <sub>2</sub> O) <sub>6</sub> ] <sup>2+</sup> / mol dm <sup>-3</sup>
1	50.00	$1.00 \times 10^{-3}$
2	40.00	$8.00 \times 10^{-4}$
3	30.00	$6.00 \times 10^{-4}$
4	20.00	$4.00 \times 10^{-4}$
5	10.00	$2.00 \times 10^{-4}$

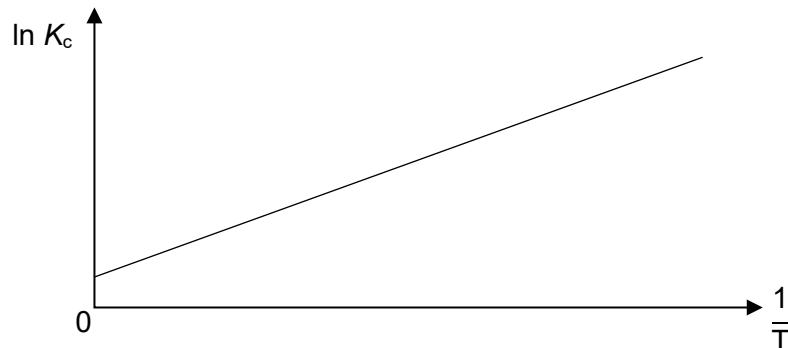
**4(c) Procedure**

1. Using separate  $25.0 \text{ cm}^3$  pipettes, transfer  $25.0 \text{ cm}^3$  of  $2.00 \times 10^{-3} \text{ mol dm}^{-3}$  FA 8 and  $25.0 \text{ cm}^3$  of  $6.00 \times 10^{-3} \text{ mol dm}^{-3}$  FA 9 into a  $100 \text{ cm}^3$  conical flask/ beaker.
2. Shake/Swirl the conical flask/ beaker to ensure a homogeneous solution.
3. Place the conical flask/ beaker in a thermostatically controlled water bath maintained at  $80^\circ\text{C}$  for about 5 min.
4. Measure and record the temperature of the solution using a thermometer.
5. Remove the solution in conical flask/ beaker from the water bath and use the spectrometer to immediately measure and record the absorbance.
6. Repeat steps 3 – 5 at  $70^\circ\text{C}$ ,  $60^\circ\text{C}$ ,  $50^\circ\text{C}$  and  $40^\circ\text{C}$ .
7. For each absorbance obtained, read off the calibration line to determine the corresponding concentration of  $[\text{Ni}(\text{en})_3]^{2+}(\text{aq})$  at each temperature.
8. Calculate the  $K_c$  for each temperature according to the following method.

Let the concentration of  $[\text{Ni}(\text{en})_3]^{2+}(\text{aq})$  obtained from the calibration line be  $x \text{ mol dm}^{-3}$



**4(d)(i)**



Compare the equation given to  $y = mx + c$ , gradient =  $-\Delta H / R$ .  
As  $\Delta H < 0$  and  $R > 0$ , gradient is a positive constant

**4(d)(ii)**

$$\ln K_c = -\frac{\Delta H}{R}\left(\frac{1}{T}\right) + \frac{\Delta S}{R}$$

$\uparrow$        $\uparrow$        $\uparrow$        $\uparrow$   
 $y =$      $m$      $x$  +  $c$

$$\text{gradient} = -\Delta H / R$$

Hence,  $\Delta H = -\text{gradient} \times R$

$$\text{y-intercept} = \Delta S / R$$

Hence,  $\Delta S = \text{y-intercept} \times R$