Markscheme

November 2024

Chemistry

Higher level

Paper 2

20 pages

Subject Details: Chemistry higher level Paper 2 Markscheme

Candidates are required to answer **ALL** questions. Maximum total = **[90 marks]**.

1. Each row in the "Question" column relates to the smallest subpart of the question.

2. The maximum mark for each question subpart is indicated in the "Total" column.

3. Each marking point in the "Answers" column is shown by means of a tick (✓) at the end of the marking point.

4. A question subpart may have more marking points than the total allows. This will be indicated by "**max**" written after the mark in the "Total" column. The related rubric, if necessary, will be outlined in the "Notes" column.

5. An alternative word is indicated in the "Answers" column by a slash (***/***). Either word can be accepted.

6. An alternative answer is indicated in the "Answers" column by "***OR***". Either answer can be accepted.

7. An alternative markscheme is indicated in the "Answers" column under heading **ALTERNATIVE 1** *etc*. Either alternative can be accepted.

8. Words inside chevrons **« »** in the "Answers" column are not necessary to gain the mark.

9. Words that are <u>underlined</u> are essential for the mark.

10. The order of marking points does not have to be as in the "Answers" column, unless stated otherwise in the "Notes" column.

11. If the candidate's answer has the same "meaning" or can be clearly interpreted as being of equivalent significance, detail and validity as that in the "Answers" column then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by ***OWTTE*** (or words to that effect) in the "Notes" column.

12. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

13. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. When marking, indicate this by adding **ECF** (error carried forward) on the script.

14. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the "Notes" column.

15. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the "Notes" column. Similarly, if the formula is specifically asked for, do not award a mark for a correct name unless directed otherwise in the "Notes" column.

16. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the "Notes" column.

17. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the "Notes" column.

Question			Answers	Notes	Total
1.	**(a)**	**(i)**	London/dispersion forces **«**only**»** ✓ strength **«**of intermolecular forces**»** increases as size of electron cloud/number of electrons increases ✓	*Accept strength of intermolecular forces increases as mass/size of molecule increases for M2.*	**2**
1.	**(a)**	**(ii)**	boils/vaporizes ***OR*** molecules have sufficient energy to overcome intermolecular forces ✓ gaseous molecules are further apart **«**than in liquid**»** ✓	*Accept gases have a **«**much**»** lower density than liquids for M2.* *Do **not** award M2 unless a change of state is indicated.*	**2**
1.	**(a)**	**(iii)**	**«***M*r(C_3H_8) = 44.11**»** **«**n =**»** 0.146 **«**mol**»** ✓ **«**V = $\frac{0.146\times8.31\times288}{100}$ =**»** 3.49 **«**dm^3**»** ✓	*Award **[2]** for correct final answer.* *Accept answers in the range 3.49 - 3.59 **«**dm^3**»**.*	**2**
1.	**(a)**	**(iv)**	not behaving as an ideal gas **«**at very high pressure**»** ✓ ideal gas molecules have no volume ***OR*** volume of **«**propane**»** molecules is not negligible ✓	*Accept propane is a real gas for M1.*	**2**
1.	**(b)**		substitution ***AND*** **«**free**»** radical ✓		**1**

(continued…)

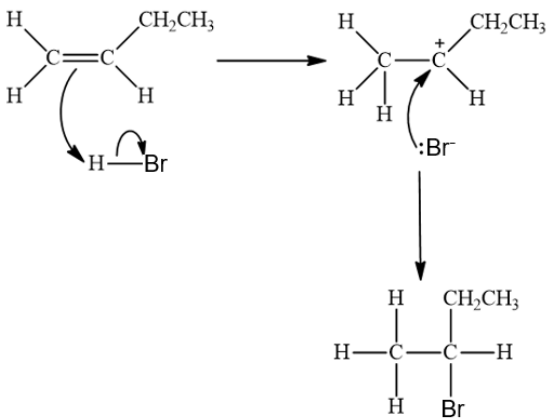
(Question 1 continued)

Question			Answers	Notes	Total
1.	**(c)**		*Reagent:* sodium hydroxide/NaOH/hydroxide ions/OH^- ✓ *Conditions:* warm/heat/reflux ***OR*** aqueous ***OR*** **«**aprotic**»** solvent ✓	*Accept any strong base for M1.* *Award **[2]** for NaOH(aq).*	**2**

Question			Answers	Notes	Total
2.	**(a)**	**(i)**	***A:*** sp^2 ***AND*** ***B:*** sp^3 ✓		**1**
2.	**(a)**	**(ii)**	σ *bonds*: orbital overlap/high electron density along internuclear axis/between nuclei ***OR*** head-on/end-to-end overlap **«**of atomic/hybridized orbitals**»** ✓ π *bonds*: **«**orbital**»** overlap/high electron density above and below internuclear/bond axis ***OR*** sideways overlap **«**of parallel p orbitals**»** ✓	*Award **[2 max]** for appropriate diagrams.*	**2**

(continued…)

(Question 2 continued)

Question			Answers	Notes	Total
2.	**(b)**	**(i)**	2-bromobutane/ $CH_3CH(Br)CH_2CH_3$ ✓ secondary carbocation is more stable than primary carbocation ***OR*** **«**secondary**»** carbocation has greater number of alkyl groups/lower charge on carbon ***OR*** alkyl groups are more electron releasing/have greater inductive effect **«**than hydrogen**»** ✓	*Do **not** award M2 for simply stating Markovnikov's rule.*	**2**
2.	**(b)**	**(ii)**	 curly arrow going from C=C to H of HBr ***AND*** curly arrow showing heterolytic fission of H-Br bond ✓ representation of carbocation ✓ curly arrow going from lone pair/negative charge on Br^- to C^+ ✓	*Do not penalise a mechanism that yields the wrong isomer, if this was given in 2(b)(i).*	**3**
2.	**(b)**	**(iii)**	polarimeter ✓		**1**

Question			Answers	Notes	Total
3.	**(a)**		*K(s):* high **«**electrical conductivity**»**/conductor ***AND*** electrons free to flow/delocalized ✓ *KCl(s)*: low **«**electrical conductivity**»**/not a conductor ***AND*** ions/charged particles are fixed in position ✓	*Award **[1 max]** for K(s) is a conductor **AND** KCl(s) is not a conductor.* *Do **not** accept just "metal" or "metallic bonding" for M1.* *Do **not** accept an explanation in terms of electrons for M2.*	**2**
3.	**(b)**	**(i)**	*Anode (positive electrode):* $H_2O(l) \rightarrow ½\ O_2 + 2H^+(aq) + 2e^-$ ***OR*** $2OH^-(aq) \rightarrow ½\ O_2 + H_2O(l) + 2e^-$ ✓ *Cathode (negative electrode):* $H_2O(l) + e^- \rightarrow ½\ H_2(g) + OH^-(aq)$ ***OR*** $H^+(aq) + e^- \rightarrow ½\ H_2(g)$ ✓	*Award **[1 max]** for correct equations at wrong electrode.* *Do **not** award a mark for reactions producing chlorine.* *Ignore reversible arrows.*	**2**
3.	**(b)**	**(ii)**	oxygen/O_2 ✓		**1**
3.	**(b)**	**(iii)**	1:1 ✓	*Accept "same".*	**1**

(continued…)

(Question 3 continued)

Question			Answers	Notes	Total
3.	**(c)**		*Protons:* 19 ***AND*** *Electrons:* 18 ***AND*** *Neutrons:* 22 ✓		**1**
3.	**(d)**		successive ionization energies ✓ 3 large increases in **«**ionization**»** energy **«**after first, ninth and seventeenth electron removed**»** ✓	*Award **[2 max]** for a labelled diagram which shows the trend in successive ionization energies.*	**2**

(continued…)

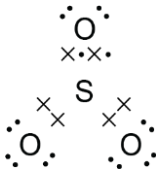
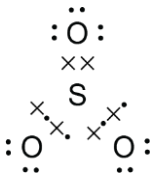
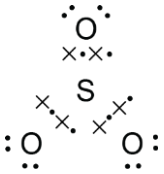
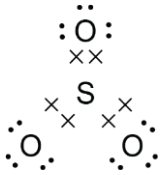
(Question 3 continued)

Question			Answers	Notes	Total
3.	**(e)**	**(i)**	***Alternative 1:*** **«**$\Delta H_f(H_2O(l))$ **=»** −285.8 **«**kJ mol^{-1}**»** ✓ **«**$\Delta H_{reaction} = \Sigma\Delta H_f$(products) – $\Sigma\Delta H_f$(reactants)**»** **«**$\Delta H_{reaction}$ = (2(−481.8) +0) – (0 + 2(−285.8))**»** **«**$\Delta H_{reaction}$ **=»** −392.0 **«**kJ**»** ✓ **«**ΔH **=»** −196.0 **«**kJ mol^{-1}**»** ✓ ***Alternative 2:*** **«**$\Delta H_f(H_2O(l))$ **=»** −285.8 **«**kJ mol^{-1}**»** ✓ $K(s) + H_2O(l) \rightarrow KOH(aq) + \frac{1}{2}H_2(g)$ ***OR*** **«**$\Delta H_{reaction} = \Sigma\Delta H_f$(products) – $\Sigma\Delta H_f$(reactants)**»** **«**$\Delta H_{reaction}$ **=»** (−481.8) – (−285.8) ✓ **«**$\Delta H_{reaction}$ **=»** −196.0 **«**kJ**»** ✓	*Award **[3]** for correct final answer.* *M1 may be awarded from working.*	**3**

(continued…)

(Question 3 continued)

Question			Answers	Notes	Total
3.	**(e)**	**(ii)**	sodium reaction is slower/less vigorous/produces less heat ✓	*Accept sodium yellow **AND** potassium lilac flame.* *Accept hydrogen gas does not ignite with sodium.* *Do **not** accept answers such as "sodium is less reactive" that do not describe the difference in the reaction with water.*	**1**
3.	**(e)**	**(iii)**	$K_2O(s) + H_2O(l) \rightarrow 2K^+(aq) + 2OH^-(aq)$ ✓	*Accept $K_2O(s) + H_2O(l) \rightarrow 2\ KOH(aq)$.* *Accept an equation for a neutralization reaction of K_2O with an acid e.g.* $K_2O(s) + 2H^+(aq) \rightarrow 2K^+(aq) + H_2O(l)$.	**1**

Question			Answers	Notes	Total
4.	**(a)**	**(i)**	*Obeys octet rule:*  ***OR*** other resonance structures ✓ *Does not obey octet rule:*  ***OR***  ***OR*** other resonance structures ✓	*Accept any combination of dots or crosses to represent electrons, or lines to represent electron pairs.* *Do **not** accept delocalized structures.* *For M2 accept:* 	**2**

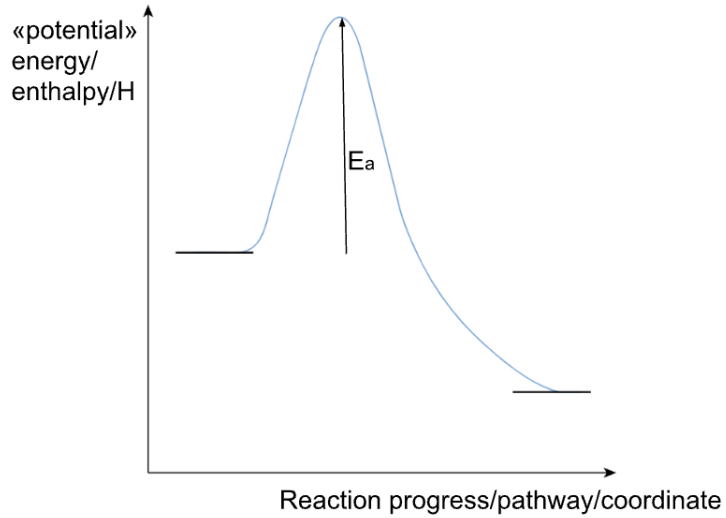
(continued…)

(Question 4 continued)

Question			Answers	Notes	Total
4.	**(a)**	**(ii)**	**«**lowest**»** formal charge ✓		**1**
4.	**(a)**	**(iii)**	**«**all bonds**»** less than 161 **«**pm**»** ✓	*Accept any value less than 161 pm and above 121 pm (actual value is 142 pm).* *Do **not** award the mark if two bond length values are given.* *Do **not** apply ECF from the Lewis structures in (a)(i).*	**1**
4.	**(b)**		**«**reacts with water and forms sulfuric**»** acid rain/deposition ***OR*** is highly corrosive ✓	*Do **not** accept health problems caused by SO_3 such as irritant/poisonous/toxic.* *Accept "forms smog" **OR** "causes global dimming".* *Accept any specific environmental problem caused by acid deposition or smog.*	**1**
4.	**(c)**		flue gas desulfurization ***OR*** **«**alkaline**»** scrubbing ✓	*Accept injection of/neutralization with $CaCO_3$/basic oxide **«**into flue gas**».*** *Do **not** accept just neutralization.*	**1**

(continued…

(Question 4 continued)

Question			Answers	Notes	Total
4.	**(d)**	**(i)**	 x-axis labelled reaction progress/pathway/coordinate ***AND*** y-axis labelled **«**potential**»** energy/enthalpy/H ✓ curve showing exothermic reaction ✓ labelled arrow/line showing E_a ✓	*Do **not** accept just "reaction" or "time" for x-axis label.* *Accept double-headed arrow for E_a but do **not** accept a downward arrow.* *Accept more complex diagrams showing an intermediate.*	**3**

(continued…)

(Question 4 continued)

Question			Answers	Notes	Total
4.	**(d)**	**(ii)**	more molecules/collisions have energy ≥ E_a ✓ frequency/probability of **«**successful**»** collisions increases ✓	*Do **not** accept **"**more collisions" in M2 without reference to time or probability.*	**2**
4.	**(d)**	**(iii)**	**«**provides**»** alternative reaction pathway/mechanism ✓ lowers E_a ***OR*** more molecules/collisions have sufficient energy/energy ≥ E_a ✓	*Accept description of how catalyst lowers E_a such as "reactants adsorb on surface **«**of catalyst**»**", "reactant bonds weaken **«**when adsorbed**»**" for M1.*	**2**
4.	**(d)**	**(iv)**	V_2O_5 : +5 ***AND*** V_2O_4 : +4 ✓	*Do **not** accept 5+ or 4+.*	**1**
4.	**(d)**	**(v)**	**«**K_c =**»** $\frac{[SO_3]}{[SO_2][O_2]^{1/2}}$ ✓		**1**
4.	**(d)**	**(vi)**	**«**$\Delta S^{\ominus}$ = 256.8 – (248.2 + ½ (205.2) =**»** −94.0 **«**J K^{-1} mol^{-1}**»** ✓		**1**
4.	**(d)**	**(vii)**	fewer moles/molecules **«**of gas**»** in products ✓	*Apply ECF, so do **not** award mark if answer to 4(d)vi is positive.*	**1**
4.	**(d)**	**(viii)**	**«**$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ » **«** = −98.5 – (773 x (−94.0 x 10^{-3})) =**»** −25.8 **«**kJ mol^{-1}**»** ✓	*Award **[1]** for − 21.2 **«**kJ mol^{-1}**»** if −100 J K^{-1} mol^{-1} was used.*	**1**

(continued…)

(Question 4 continued)

Question			Answers	Notes	Total
4.	**(d)**	**(ix)**	**«**−25.8 x 10^3 = −8.31 x 773 x ln*K***»** ln*K* = **«**$\frac{-25.8\times10^3}{-8.31\times773}$ **=»** 4.016 ✓ *K* = 55.5 ✓	*Award **[2]** for correct final answer.* Accept answers in the range 55 – 60. *Award **[2]** for K = 49.0 if −25.0 kJ mol^{-1} was used.*	**2**
4.	**(d)**	**(x)**	**«** $\frac{0.150}{0.120\times0.050^{1/2}}$ **=»** 5.6 ✓ **«**not at equilibrium and proceeds in**»** forward/right/products/SO_3 direction ✓	*Do **not** award M2 if no working is shown.*	**2**

Question			Answers	Notes	Total
5.	**(a)**	**(i)**	**«**n(NaOH) = n(H^+) = 0.150 x 20.0 x 10^{-3} **=»** 3.00×10^{-3} **«**mol**»** ***OR*** **«**volume at equivalence point **=»** 18.0 **«**cm^3**»** ✓ **«**[NaOH] =$\frac{3.00\times10^{-3}}{18.0\times10^{-3}}$ **»** = 0.167 **«**mol dm^{-3}**»** ✓	*Award **[2]** for correct final answer.*	**2**
5.	**(a)**	**(ii)**	**«**pK_a **=»** 4.8 ✓	*Accept answers in the range 4.7 – 4.9.*	
5.	**(a)**	**(iii)**	**«**conjugate**»** acid and base pair/forms **«**of phenolphthalein**»** have different colours ✓	*Do **not** accept just colorless in acid and pink in alkali.*	**1**

(continued…)

(Question 5 continued)

Question			Answers	Notes	Total
5.	**(a)**	**(iv)**	equivalence point falls within endpoint/pH range of indicator ***OR*** pH range of phenolphthalein is 8.3-10.0 ***AND*** pH at equivalence is within this range ***OR*** endpoint/pK_a «of phenolphthalein» is within vertical section of curve ✓		**1**
5.	**(b)**		***Alternative 1*:** *Method:* measure pH **«**of both acids**»** ✓ *Observation:* weak acid has higher pH ✓ ***Alternative 2:*** *Method:* react **«**both acids**»** with metal/metal oxide/hydroxide/hydrogen carbonate/carbonate ✓ *Observation:* weak acid reacts more slowly/less vigorously ✓ ***Alternative 3:*** *Method:* measure **«**electrical» conductivity ✓ *Observation:* weak acid has lower **«**electrical» conductivity ✓	*Accept specific examples for Alternative 2.* *Accept other suitable methods such as titration, indicator/pH paper, or enthalpy change and corresponding observations such as shape of curve/pH at equivalence point, colour, or enthalpy change/amount of heat released upon neutralization.*	**2**

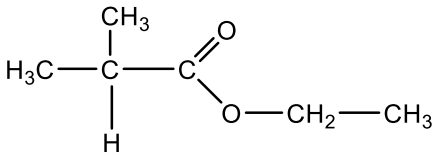
(continued…)

(Question 5 continued)

Question			Answers	Notes	Total
5.	**(c)**	**(i)**	dissociation of water is endothermic ✓		**1**
5.	**(c)**	**(ii)**	**«**K_w = $[H^+][OH^-]$**»** **«**[H+] = $(9.55 \times 10^{-14})^{½}$ = 3.09×10^{-7}**»** pH = 6.51 ✓ pOH = 6.51 ✓	*Accept pOH = pH for M2.* *Award **[2]** for 6.51 without specifying whether it is pH or pOH.*	**2**
5.	**(d)**	**(i)**	*Number of signals:* 3 ✓ *Ratio of areas:* 6:1:1 ✓	*Accept ratio in any order.*	**2**
5.	**(d)**	**(ii)**	doublet ✓	*Accept "2".*	**1**
5.	**(d)**	**(iii)**	*Any one of:* chemical shift/signal outside range of common chemical shifts/signals ✓ all 12 H atoms in same environment ✓ singlet/no splitting of signal ✓ volatile/easily separated/easily removed ✓ inert/stable ✓	*Accept strong signal.* *Do **not** accept chemical shift = 0.*	**1 Max**
5.	**(e)**	**(i)**	^{13}C/carbon-13 ✓	*Accept isotope.*	**1**

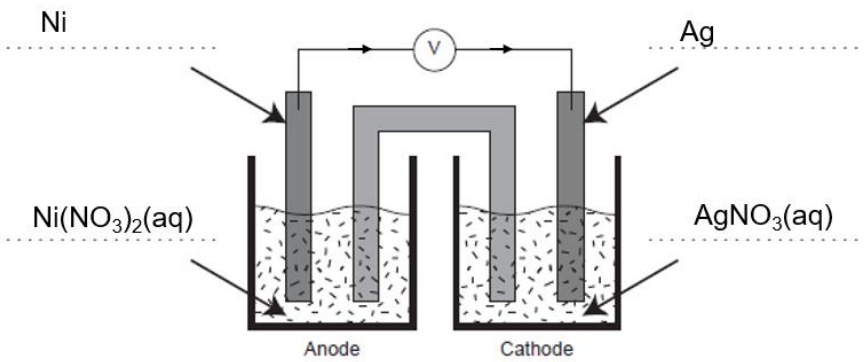
(continued…)

(Question 5 continued)

Question			Answers	Notes	Total
5.	**(e)**	**(ii)**	*m/z 73:* $CH_3CHCOOH^+$ / $C_3H_5O_2^+$ ✓ *m/z 43:* $(CH_3)_2CH^+$ / $C_3H_7^+$ ✓	*Penalize missing + sign once only.* *Award **[1 max]** for loss of CH_3 **AND** loss of COOH.*	**2**
5.	**(f)**		2500-3000 **«**cm^{-1}**»** ***OR*** 1700-1750 **«**cm^{-1}**»** ***OR*** 1050-1410 **«**cm^{-1}**»** ✓	*Accept any value within these ranges.* *Do **not** accept 2850-3090 **«**cm^{-1}**»**.*	**1**
5.	**(g)**		*Structural formula:*  correct representation of ester group ✓ rest of the structure correct ✓ *Empirical formula:* C_3H_6O ✓	*Accept unambiguous abbreviated structural formulas, such as $(CH_3)_2CHCOOC_2H_5$.*	**3**

Question			Answers	Notes	Total
6.	**(a)**	**(i)**	change in **«**brown**»** colour with time ***OR*** change in **«**gas**»** pressure **«**at constant volume**»** with time ***OR*** change in **«**gas**»** volume **«**at constant pressure**»** with time ✓	*Do **not** accept changes without reference to time.*	**1**
6.	**(a)**	**(ii)**	first order with respect to O_2 ***AND*** second order with respect to NO ✓ rate = $k[NO]^2[O_2]$ ✓	*Award **[2]** for correct rate expression.*	**2**
6.	**(a)**	**(iii)**	k = **«**$\frac{0.227}{0.020\times(0.040)^2}$ **=»** 7.1×10^3 ✓ $mol^{-2}\ dm^6\ s^{-1}$ ✓		**2**
6.	**(b)**		*Type of bonding:* coordinate/dative **«**covalent**»** ✓ *Role of NO_2:* Lewis base ✓		**2**

Question			Answers	Notes	Total
7.	(a)		oxygen/O_2 ***AND*** gains electrons ***OR*** oxygen/ O_2 ***AND*** oxidation state decreases/changes from 0 to −2 ✓		**1**
7.	(b)		«n(O_2) = ¼ n(I^-) =» 1.2 x 10^{-3} «mol» ✓		**1**
7.	(c)		«$\frac{1.2\times10^{-3}\times32.00}{200\times10^{-3}}$» = 0.19 «g dm^{-3}» ✓	*Award **[1]** for 0.32 «g dm^{-3}» if 2.0 x 10^{-3} mol was used.*	**1**

Question			Answers	Notes	Total
8.	(a)		 anode to have Ni ***AND*** $Ni(NO_3)_2/Ni^{2+}$ ***AND*** cathode to have Ag ***AND*** $AgNO_3/Ag^+$ ✓ electrons to flow from anode to cathode/left to right ✓	*Electron flow must be clearly through the external circuit for M2.*	**2**
8.	(b)		balances charges/keeps each half-cell «electrically» neutral ***OR*** completes circuit/allows ion flow «between cells» ✓		**1**