AQA Qualifications

A-LEVEL

Chemistry

CHEM5 Energetics, Redox and Inorganic Chemistry
Mark scheme

2420
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Version: 1.0 Final

Mark schemes are prepared by the Lead Assessment Writer and considered, together with the relevant questions, by a panel of subject teachers. This mark scheme includes any amendments made at the standardisation events which all associates participate in and is the scheme which was used by them in this examination. The standardisation process ensures that the mark scheme covers the students' responses to questions and that every associate understands and applies it in the same correct way. As preparation for standardisation each associate analyses a number of students' scripts: alternative answers not already covered by the mark scheme are discussed and legislated for. If, after the standardisation process, associates encounter unusual answers which have not been raised they are required to refer these to the Lead Assessment Writer.

It must be stressed that a mark scheme is a working document, in many cases further developed and expanded on the basis of students' reactions to a particular paper. Assumptions about future mark schemes on the basis of one year's document should be avoided; whilst the guiding principles of assessment remain constant, details will change, depending on the content of a particular examination paper.

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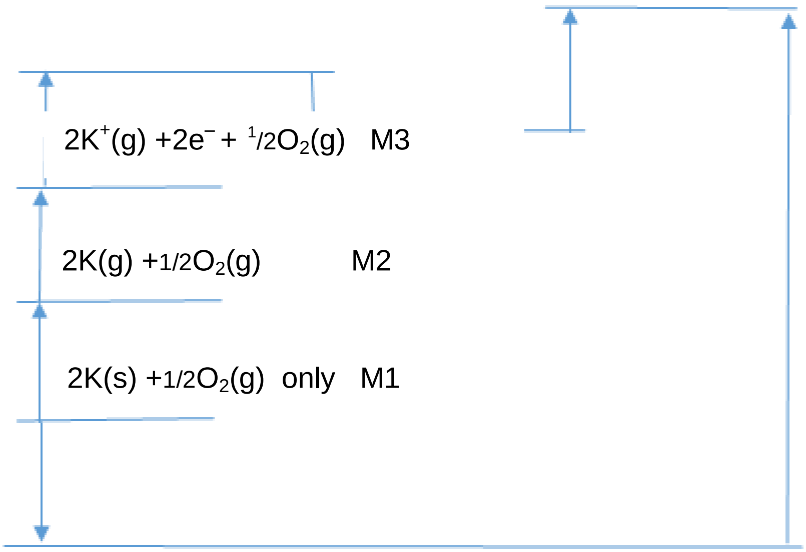
Question	Marking guidance	Mark	Comments
1ai	Covalent	1	Ignore simple / molecular Do not allow macromolecular/giant covalent/dative/dipole-dipole/Hydrogen bonds Ignore VdW
1aii	P / phosphorus / P_4	1	
1aiii	$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	1	Mark independently of 1aii Accept multiples/fractions Ignore state symbols Allow ions on the RHS ($\rightarrow 12H^+ + 4PO_4^{3-}$) Allow correct equations from P_4O_6, P_2O_3 and P_2O_5 $P_4O_6 + 6H_2O \rightarrow 4H_3PO_3$ $P_2O_3 + 3H_2O \rightarrow 2H_3PO_3$ $P_2O_5 + 3H_2O \rightarrow 2H_3PO_4$
1bi	Ionic	1	Ignore giant / lattice
1bii	Na / Sodium	1	
1biii	$2Na + 2H_2O \rightarrow 2Na^+ + 2OH^- + H_2$	1	Allow equation to form 2NaOH Accept multiples/fractions Ignore state symbols

1biv	$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$	1	Accept multiples/fractions Ignore state symbols Allow ions, but do not allow H^+ only for the acid.
1ci	<u>Ionic</u>	1	Allow ionic and covalent / ionic with covalent character
1cii	Al_2O_3	1	Ignore state symbols
1ciii	reacts with acids and bases	1	Allow reacts with acids and alkalis / acts as both an acid and a base / shows acidic and basic properties
1civ	$Al_2O_3 + 6HCl \rightarrow 2Al^{3+} + 6Cl^- + 3H_2O$ $Al_2O_3 + 6H^+ \rightarrow 2Al^{3+} + 3H_2O$	1	Allow equation to form $2AlCl_3$ (but not Al_2Cl_6) Allow equations with other acids
	$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2Na^+ + 2[Al(OH)_4]^-$ $Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2[Al(OH)_4]^-$ $Al_2O_3 + 2NaOH + 7H_2O \rightarrow 2Na^+ + 2[Al(OH)_4(H_2O)_2]^-$ $Al_2O_3 + 2OH^- + 7H_2O \rightarrow 2[Al(OH)_4(H_2O)_2]^-$	1	Allow equations to form $2Na[Al(OH)_4]$ or $2Na[Al(OH)_4(H_2O)_2]$ Allow equations with other alkalis Allow correct equations which form $[Al(OH)_6]^{3-}$ Allow equations to form $[Al(OH)_x(H_2O)_{6-x}]^{3-x}$ etc. Ignore state symbols

Question	Marking guidance	Mark	Comments
2ai		1 1 1	Mark each line independently, but follow one route only. Must have state symbols, but ignore s.s. on electrons. Penalise lack of state symbols each time. Alternative answers $2K(g) + O(g)$ M3 $2K(g) + 1/2O_2(g)$ M2 $2K(s) + 1/2O_2(g)$ only M1 or $2K(g) + O(g)$ M3 $2K(s) + O(g)$ M2 $2K(s) + 1/2O_2(g)$ only M1

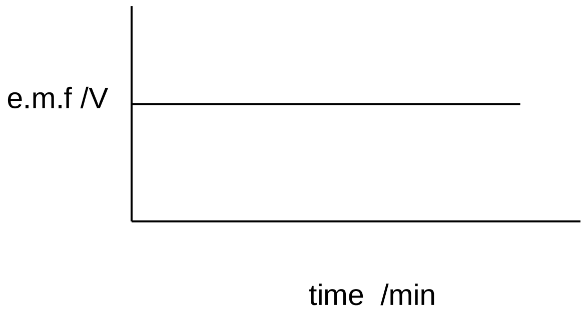
2aii	(2 x 90) + 248 + (2 x 418) – 142 + 844 = – 362 + Lattice enthalpy of dissociation enthalpy of lattice dissociation = (+) 2328 ($kJmol^{-1}$)	3	M1 for (2 x 90) and (2 x 418) M2 for a correct expression (either in numbers or with words/formulae) M3 for answer 2328 $kJmol^{-1}$ scores 3 marks. Allow answers given to 3sf. Answer of 1820, scores zero marks as two errors in calculation. Answers of 2238, 1910, 2204 max = 1 mark only since one chemical error in calculation (incorrect/missing factor of 2) Allow 1 mark for answer of -2328 ($kJmol^{-1}$) Penalise incorrect units by one mark.

2b	K^+ (ion)/K ion is bigger (than Na^+ ion) (Electrostatic) attraction between (oppositely charged) ions is weaker	1 1	K^+ has lower charge density / Na^+ has higher charge density. Ignore K atom is bigger If attraction is between incorrect ions, then lose M2 *Attraction between molecules/atoms or mention of intermolecular forces CE=0/2* Allow converse for Na_2O if explicit

Question	Marking guidance	Mark	Comments
3a	$MgCl_2(s) \rightarrow Mg^{2+}(aq) + 2Cl^{-}(aq)$	1	State symbols essential Do not allow this equation with H_2O on the LHS Ignore + aq on the LHS Allow H_2O written over the arrow / allow equation written as an equilibrium, Allow correct equations to form $[Mg(H_2O)_6]^{2+}$ ions.
3b	ΔH_{soln} $MgCl_2$ = LE + ($\Delta H_{hyd} Mg^{2+}$) + 2($\Delta H_{hyd} Cl^{-}$) ΔH_{soln} $MgCl_2$ = 2493 – 1920 + (2 x -364) = –155 (kJ mol^{-1})	1 1	M1 for expression in words or with correct numbers Ignore units, but penalise incorrect units
3c	M1: Solubility decreases (as temp increases) M2: the enthalpy of solution is exothermic / reaction is exothermic / backwards reaction is endothermic M3: (According to Le Chatelier) the equilibrium moves to absorb heat/reduce temperature/oppose the increase in temperature (in the endothermic direction)	1 1 1	If M1 is incorrect then CE=0/3 If answer to 3b is a +ve value, allow: M1: Solubility increases (as temp increases) M2: Enthalpy of solution is endothermic etc. M3: (According to Le Chatelier) the equilibrium moves to absorb heat/reduce the temperature/oppose the increase in temperature (in the endothermic direction)

Question	Marking guidance	Mark	Comments
4ai	Zn^{2+}	1	$Zn^{2+}(aq)$ Apply List
4aii	298 K /25°C (solutions at) unit concentration / 1 mol dm^{-3} (of Zn^{2+})	1 1	Ignore pressure Ignore standard conditions Ignore state symbols Ignore references to S.H.E
4b	Identifying it is the Zn/Zn^{2+} and Co^{2+}/Co half cells $Zn \mid Zn^{2+} \mid \mid Co^{2+} \mid Co$ $Zn \rightarrow Zn^{2+} + 2e^{(-)}$	1 1 1	correct order with phase boundaries and salt bridge correct, no Pt If this is correct it scores M1 and M2 *Allow double dashed line for salt bridge* *Extra phase boundaries loses M2* Ignore state symbols M3 independent Allow $-2e^{-}$ on LHS

4c	<u>Co^{3+}</u> $2Co^{3+}(aq) + H_2O(l) \rightarrow 2Co^{2+}(aq) + \frac{1}{2} O_2(g) + 2H^+(aq)$ Oxygen /O_2	1 1 1	Mark independently. Ignore state symbols allow multiples Allow ½ O_2
4d	$E^{\ominus}$ (O_2(|H_2O)) electrode < $E^{\ominus}$ (Au^+(|Au)) OR $E^{\ominus}$ (Au^+(|Au)) > $E^{\ominus}$ (O_2(|H_2O)) OR the $E^{\ominus}$ (Au^+|Au) electrode potential is more positive than the $E^{\ominus}$ (O_2|H_2O) electrode OR The emf (for the reaction of Au and oxygen) is –0.45 V (and therefore not spontaneous) so <u>oxygen</u> is unable to oxidise gold	1 1	Mark independently Ignore references to water Allow gold cannot reduce <u>oxygen</u>

Question	Marking guidance	Mark	Comments
5ai	M1 Positive electrode $O_2 + 2H_2O + 4e^{(-)} \rightarrow 4OH^-$ M2 Negative electrode $H_2 + 2OH^- \rightarrow 2H_2O + 2e^{(-)}$ $2H_2 + O_2 \rightarrow 2H_2O$	1 1 1	Allow multiples, ignore state symbols If equations both correct but at the wrong electrodes allow 1 mark Mark independently Must be this way round
5aii	Increase (emf) $2H_2 + O_2 \rightarrow 2H_2O$ will move to the right or overall equation moves to the right	1 1	If decrease/no change then CE=0/2; if blank then mark on Allow $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ will move to the right / oxygen half equation moves to the RHS / $\boldsymbol{E}^{\ominus}$ O_2|OH^- half cell moves to the right
5b		1	Must start at y-axis
5ci	Unchanged	1	

5cii	Water is the <u>only</u> product / fuel cell does not give out pollutants such as NO_x or CO_2 or SO_2 or C or CO or C_xH_y or unburnt hydrocarbons	1	Not fuel cell does not give out pollutants unless pollutant stated
5d	<u>CO_2 is released</u> because fossil fuels are burned to produce electricity <u>to generate hydrogen</u> OR <u>CO_2 is released</u> when methane reacts with steam <u>to produce hydrogen</u>	1	Allow CO_2 is released to produce the hydrogen

Question	Marking guidance	Mark	Comments
6a	$\Delta H^{\ominus} = \Sigma\ \Delta H_f^{\ominus}$ products - $\Sigma\ \Delta H_f^{\ominus}$ reactants or (2 × –395) – (2 × –297) = –196 (kJ mol $^{-1}$)	1 1	 Penalise incorrect units, ignore missing units
6b	$\Delta S^{\ominus} = \Sigma S^{\ominus}$ products - $\Sigma S^{\ominus}$reactants = (2 × 256) – 205 – (2 × 248) = –189 <u>JK^{-1} mol $^{-1}$</u>	1 1	 Allow -0.189 kJ K^{-1} mol^{-1} Units must be given and must match value
6c	causes an increase in order / a decrease in disorder	1	Allow products more ordered / products less disordered If answer to 6b is +ve, allow products are less ordered / causes an increase in disorder / causes a decrease in order

6d	$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ $= -196 - 323\ (-189/1000)$ $= -134.9\ kJ\ mol^{-1}$	1 1 1	Do not insist on standard state symbol If conversion of T or ΔS incorrect, then can only score M1 Must have correct units. Allow answers in $J\ mol^{-1}$ $-135\ kJ\ mol^{-1}$ If both alternative values used then -169(.3) $kJ\ mol^{-1}$. Allow alternative ΔH and/or alternative ΔS in calculation
6e	Feasible because ΔG is negative	1	Allow mark if a correct deduction from answer to 6d Both a reference to feasibility and to ΔG needed
6fi	(The catalyst is in) a different state or phase (from the reactants)	1	
6fii	$SO_2 + V_2O_5 \rightarrow SO_3 + V_2O_4$ $\frac{1}{2}O_2 + V_2O_4 \rightarrow V_2O_5$	1 1	allow $2VO_2$ instead of V_2O_4 allow multiples Must have equations in this order.
6fiii	Surface area is increased	1	
6fiv	So that the catalyst is not poisoned	1	Allow correct reference to the blocking active sites

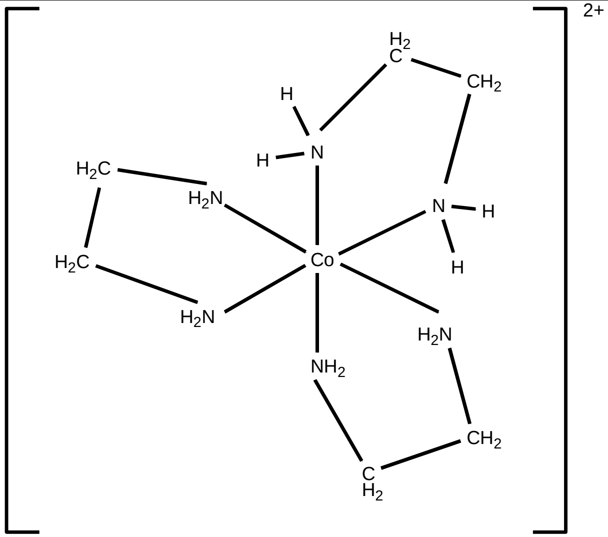
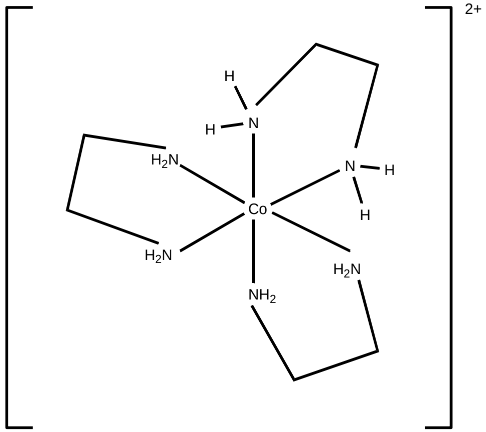
Question	Marking guidance	Mark	Comments
7a	$CrCl_3$ + $6H_2O$ → $[Cr(H_2O)_6]^{3+}$ + $3Cl^-$	1	Ignore state symbols
7b	M1 **P** = $Cr(OH)_3(H_2O)_3$ M2 NaOH (not excess) or NH_3 or names M3 $[Cr(H_2O)_6]^{3+}$ + $3OH^-$ → $[Cr(OH)_3(H_2O)_3]$ + $3H_2O$ $[Cr(H_2O)_6]^{3+}$ + $3NH_3$ → $[Cr(OH)_3(H_2O)_3]$ + $3NH_4^+$	3	Ignore state symbols Penalise charges on ligands in complex ion formulae Do not transfer M1 from equation Allow KOH do not allow OH^- /excess NaOH but mark on Equations must match reagent but if NH_3 then also allow two equations NH_3 + H_2O → NH_4^+ + OH^- $[Cr(H_2O)_6]^{3+}$ + $3OH^-$ → $[Cr(OH)_3(H_2O)_3]$ + $3H_2O$ Do not allow $Cr(OH)_3$ as identity of P, or in equation

7c	M1 **Q** = CO_2 M2 Na_2CO_3 or $NaHCO_3$ or K_2CO_3 M3 $2[Cr(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2[Cr(OH)_3(H_2O)_3] + 3CO_2 + 3H_2O$	3	Ignore state symbols Penalise charges on ligands in complex ion formulae Do not allow incorrect formulae or CO_3^{2-} but mark on. Do not allow insoluble carbonates or H_2CO_3 but mark on. Do not allow equations that give $Cr(OH)_3$ allow $[Cr(H_2O)_6]^{3+} + 3HCO_3^- \rightarrow [Cr(OH)_3(H_2O)_3] + 3CO_2 + 3H_2O$

7d	Either **M1** **R** = $[Cr(OH)_6]^{3-}$ **M2** NaOH or KOH **M3** $[Cr(OH)_3(H_2O)_3]$ + $3OH^- \rightarrow$ $[Cr(OH)_6]^{3-}$ + $3 H_2O$ OR **M1** **R** = $[Cr(H_2O)_6]^{3+}$ **M2** HCl or any named acid **M3** $[Cr(OH)_3(H_2O)_3]$ + $3H^+ \rightarrow$ $[Cr(H_2O)_6]^{3+}$	3	Ignore state symbols Penalise charges on ligands in complex ion formulae Allow **R** = $[Cr(OH)_4(H_2O)_2]^-$ or $[Cr(OH)_5(H_2O)]^{2-}$ do not allow OH^- but mark on, ignore excess/conc allow equations to form $[Cr(OH)_4(H_2O)_2]^-$ and $[Cr(OH)_5(H_2O)]^{2-}$ Do not allow equations from $Cr(OH)_3$ OR Allow **R** = $[Cr(H_2O)_5(OH)]^{2+}$ or $[Cr(H_2O)_4(OH)_2]^+$ Do not allow H^+ etc, but mark on. Allow equations to form $[Cr(H_2O)_5(OH)]^{2+}$ or $[Cr(H_2O)_4(OH)_2]^+$ or $[Cr(H_2O)_5Cl]^{2+}$ or $[Cr(H_2O)_4Cl_2)]^+$ but not $[Cr(H_2O)_3Cl_3]$ Do not allow equations from $Cr(OH)_3$

7e	Zn/ HCl , Sn/ HCl, etc Blue	1 1	Allow H_2SO_4 instead of HCl Ignore H_2 Mark independently

Question	Marking guidance	Mark	Comments
8a	[Ar] $4s^2$ $3d^7$ or $1s^22s^22p^63s^23p^64s^23d^7$	1	Allow 4s and 3d in either order
	[Ar] $3d^7$ or $1s^22s^22p^63s^23p^63d^7$	1	
	Any 3 Variable oxidation state Act as catalysts Form complexes Form coloured ions/compounds	3	
8b	Two atoms that each donate a lone pair (of electrons) / coordinate bonds from two atoms	1	
	Formula of ethane-1,2- diamine: $NH_2CH_2CH_2NH_2$	1	M2 gained from equation or structure
	$[Co(H_2O)_6]^{2+}$ $+ 3NH_2CH_2CH_2NH_2 \rightarrow [Co(NH_2CH_2CH_2NH_2)_3]^{2+} + 6H_2O$	1	Equation must be balanced inc charges Allow en or $C_2H_8N_2$ in equation for ethane-1,2-diamine
	There is an increase in the number of particles / the reaction goes from 4 moles to 7 moles	1	. Allow increase number of molecules/moles. Allow numbers that match an incorrect equation
	disorder/entropy increases / ΔS is positive	1	
	ΔG negative	1	

	 Or 	1	Mark for correct structure (ignore charges -even if wrong) NH_2 can be shown in either way – see structure

Question	Marking guidance	Mark	Comments
9a	A reaction that produces its own catalyst/ one of the products is the catalyst Mn^{2+}	1 1	 Allow Mn^{3+}
9b	H_2SO_4	1	
9c	There is no/very little catalyst at the start OR the reaction only speeds up when the catalyst is produced Two negative ions (MnO_4^- and $C_2O_4^{2-}$) <u>repel</u> The <u>activation energy</u> for the reaction is high / heat is required to overcome the <u>activation energy</u>	1 1 1	 Reference to molecules loses M2

9d	M1 $5\ C_2O_4^{2-}(aq) + 2\ MnO_4^-(aq) + 16\ H^+(aq) \rightarrow 10\ CO_2(g) + 2\ Mn^{2+}(aq) + 8\ H_2O(l)$	1	Ignore state symbols
	M2 $n(MnO_4^-) = \frac{26.40 \times 0.02}{1000}$ OR $n(MnO_4^-) = 5.28 \times 10^{-4}$	1	
	M3 $n(C_2O_4^{2-}) = \frac{5}{2} \times 5.28 \times 10^{-4} = 1.32 \times 10^{-3}$	1	M3 is for M2 x 5/2 If wrong ratio used then can only score M2, M4, M5 and M6
	M4 $n(C_2O_4^{2-}$ in flask originally$) = 1.32 \times 10^{-3} \times 10 = 1.32 \times 10^{-2}$	1	M4 is for M3 x 10
	M5 $n(K_3[Fe(C_2O_4)_3].3H_2O) = \frac{1.32 \times 10^{-2}}{3} = 4.40 \times 10^{-3}$	1	M5 is for M4 ÷ 3
	(*M*r $K_3[Fe(C_2O_4)_3].3H_2O$ = 491.1)		
	M6 Mass of $K_3[Fe(C_2O_4)_3].3H_2O$ reacted = $4.40 \times 10^{-3} \times 491.1$ = 2.16 g	1	M6 is for M5 x 491(.1)
	M7 % purity = $\frac{2.16}{2.29}$ x100 = 94.3 or 94.4%	1	Answer must be to 3 s.f. Correct answer scores 6 marks; mark equation separately Alternative method using ratio by moles: M5 $n(C_2O_4^{2-}) = 4.66 \times 10^{-3} \times 3 = 0.0140$ moles in $250cm^3$ M6 n(complex) = 2.29/491.1 = 4.66×10^{-3} moles in $250cm^3$ M7 % = 0.0132/0.0140 x 100 = 94.3 or 94.4%

9e	Make <u>some known</u> concentration<u>s</u> (of the coloured solution and read the absorbance of each one using a colorimeter)	1	Ignore addition of suitable ligand
	Plot a graph of absorbance vs concentration	1	Not just "plot a calibration curve" / reference to Beer-Lambert graph is insufficient Do not allow transmittance in M2
	Read/compare unknown concentration from calibration curve/graph (and hence the concentration from the graph)	1	M3 can only be scored if graph/curve mentioned