

A-LEVEL

Chemistry

CHEM5 Energetics, Redox and Inorganic Chemistry
Mark scheme

2420
June 2016

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.

Further copies of this Mark Scheme are available from aqa.org.uk

Question	Marking guidance	Mark	Comments
1ai	<u>Covalent</u>	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 ₄ O ₆ , P ₂ O ₃ and P ₂ O 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	<u>Ionic</u>	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	$\text{Na}_2\text{O} + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O}$	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	$\text{Al}_2\text{O}_3 + 6\text{HCl} \rightarrow 2\text{Al}^{3+} + 6\text{Cl}^- + 3\text{H}_2\text{O}$ $\text{Al}_2\text{O}_3 + 6\text{H}^+ \rightarrow 2\text{Al}^{3+} + 3\text{H}_2\text{O}$ $\text{Al}_2\text{O}_3 + 2\text{NaOH} + 3\text{H}_2\text{O} \rightarrow 2\text{Na}^+ + 2[\text{Al}(\text{OH})_4]^-$ $\text{Al}_2\text{O}_3 + 2\text{OH}^- + 3\text{H}_2\text{O} \rightarrow 2[\text{Al}(\text{OH})_4]^-$ $\text{Al}_2\text{O}_3 + 2\text{NaOH} + 7\text{H}_2\text{O} \rightarrow 2\text{Na}^+ + 2[\text{Al}(\text{OH})_4(\text{H}_2\text{O})_2]^-$ $\text{Al}_2\text{O}_3 + 2\text{OH}^- + 7\text{H}_2\text{O} \rightarrow 2[\text{Al}(\text{OH})_4(\text{H}_2\text{O})_2]^-$	1 1	Allow equation to form 2AlCl_3 (but not Al_2Cl_6) Allow equations with other acids Allow equations to form $2\text{Na}[\text{Al}(\text{OH})_4]$ or $2\text{Na}[\text{Al}(\text{OH})_4(\text{H}_2\text{O})_2]$ Allow equations with other alkalis Allow correct equations which form $[\text{Al}(\text{OH})_6]^{3-}$ Allow equations to form $[\text{Al}(\text{OH})_x(\text{H}_2\text{O})_{6-x}]^{3-x}$ etc. Ignore state symbols

Question	Marking guidance	Mark	Comments
2ai	<p> $2\text{K}^+(\text{g}) + 2\text{e}^- + \frac{1}{2}\text{O}_2(\text{g})$ M3 $2\text{K}(\text{g}) + \frac{1}{2}\text{O}_2(\text{g})$ M2 $2\text{K}(\text{s}) + \frac{1}{2}\text{O}_2(\text{g})$ only M1 </p>	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 $2\text{K}(\text{g}) + \text{O}(\text{g})$ M3 $2\text{K}(\text{g}) + \frac{1}{2}\text{O}_2(\text{g})$ M2 $2\text{K}(\text{s}) + \frac{1}{2}\text{O}_2(\text{g})$ only M1 or $2\text{K}(\text{g}) + \text{O}(\text{g})$ M3 $2\text{K}(\text{s}) + \text{O}(\text{g})$ M2 $2\text{K}(\text{s}) + \frac{1}{2}\text{O}_2(\text{g})$ only M1

2aii	$(2 \times 90) + 248 + (2 \times 418) - 142 + 844 = -362 + \text{Lattice enthalpy of dissociation}$ enthalpy of lattice dissociation = (+) 2328 (kJmol ⁻¹)	3 M1 for (<u>2 x 90</u>) and (<u>2 x 418</u>) 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.
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Question	Marking guidance	Mark	Comments
3a	$\text{MgCl}_2(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq})$	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 $[\text{Mg}(\text{H}_2\text{O})_6]^{2+}$ ions.
3b	$\Delta H_{\text{soln}} \text{MgCl}_2 = \text{LE} + (\Delta H_{\text{hyd}}\text{Mg}^{2+}) + 2(\Delta H_{\text{hyd}}\text{Cl}^{-})$ $\Delta H_{\text{soln}} \text{MgCl}_2 = 2493 - 1920 + (2 \times -364)$ $= -155 \text{ (kJ mol}^{-1}\text{)}$	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)

4c	<p><u>Co³⁺</u></p> <p>$2\text{Co}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{Co}^{2+}(\text{aq}) + \frac{1}{2} \text{O}_2(\text{g}) + 2\text{H}^+(\text{aq})$</p> <p>Oxygen /O₂</p>	<p>1</p> <p>1</p> <p>1</p>	<p>Mark independently.</p> <p>Ignore state symbols allow multiples</p> <p>Allow $\frac{1}{2} \text{O}_2$</p>
4d	<p>$E^\ominus (\text{O}_2 \text{H}_2\text{O})$ electrode $< E^\ominus (\text{Au}^+ \text{Au})$ OR $E^\ominus (\text{Au}^+ \text{Au}) > E^\ominus (\text{O}_2 \text{H}_2\text{O})$ OR the $E^\ominus (\text{Au}^+ \text{Au})$ electrode potential is more positive than the $E^\ominus (\text{O}_2 \text{H}_2\text{O})$ electrode OR The emf (for the reaction of Au and oxygen) is -0.45 V (and therefore not spontaneous)</p> <p>so <u>oxygen</u> is unable to oxidise gold</p>	<p>1</p> <p>1</p>	<p>Mark independently</p> <p>Ignore references to water Allow gold cannot reduce <u>oxygen</u></p>

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 / $E^{\ominus} O_2 OH^{-}$ half cell moves to the right
5b	e.m.f /V  time /min	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 _x H _y or unburnt hydrocarbons	1	Not fuel cell does not give out pollutants unless pollutant stated
5d	<u>CO₂ is released</u> because fossil fuels are burned to produce electricity <u>to generate hydrogen</u> OR <u>CO₂ 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	$\Delta H^\ominus = \sum \Delta H_f^\ominus \text{ products} - \sum \Delta H_f^\ominus \text{ reactants}$ or $(2 \times -395) - (2 \times -297)$ $= -196 \text{ (kJ mol}^{-1}\text{)}$	1 1	Penalise incorrect units, ignore missing units
6b	$\Delta S^\ominus = \sum S^\ominus \text{ products} - \sum S^\ominus \text{ reactants}$ $= (2 \times 256) - 205 - (2 \times 248)$ $= -189 \text{ JK}^{-1} \text{ mol}^{-1}$	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

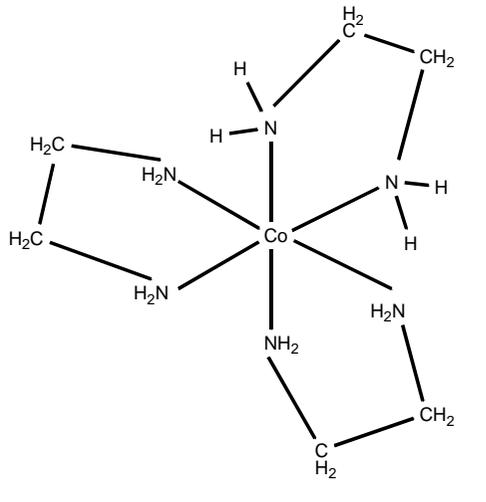
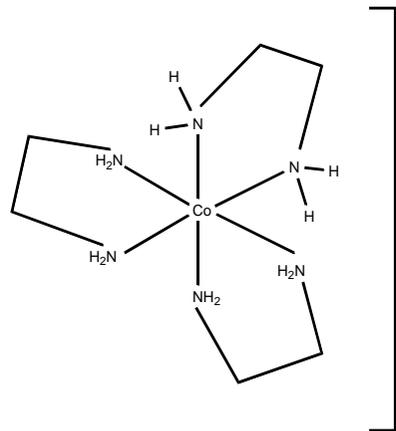
6d	$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus$ $= -196 - 323 (-189/1000)$ $= -134.9 \text{ kJ mol}^{-1}$	1 1 1	<p>Do not insist on standard state symbol</p> <p>If conversion of T or ΔS incorrect, then can only score M1</p> <p>Must have correct units. Allow answers in J mol^{-1} -135 kJ mol^{-1}</p> <p>If both alternative values used then $-169(.3) \text{ kJ mol}^{-1}$. Allow alternative ΔH and/or alternative ΔS in calculation</p>
6e	Feasible because ΔG is negative	1	<p>Allow mark if a correct deduction from answer to 6d</p> <p>Both a reference to feasibility and to ΔG needed</p>
6fi	(The catalyst is in) a different state or phase (from the reactants)	1	
6fii	$\text{SO}_2 + \text{V}_2\text{O}_5 \rightarrow \text{SO}_3 + \text{V}_2\text{O}_4$ $\frac{1}{2} \text{O}_2 + \text{V}_2\text{O}_4 \rightarrow \text{V}_2\text{O}_5$	1 1	<p>allow 2VO_2 instead of V_2O_4</p> <p>allow multiples</p> <p>Must have equations in this order.</p>
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	$\text{CrCl}_3 + 6\text{H}_2\text{O} \rightarrow [\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{Cl}^-$	1	Ignore state symbols
7b	<p>M1 P = $\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3$</p> <p>M2 NaOH (not excess) or NH_3 or names</p> <p>M3 $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \rightarrow [\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3] + 3\text{H}_2\text{O}$</p> <p>$[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{NH}_3 \rightarrow [\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3] + 3\text{NH}_4^+$</p>	3	<p>Ignore state symbols Penalise charges on ligands in complex ion formulae Do not transfer M1 from equation</p> <p>Allow KOH do not allow OH^- /excess NaOH but mark on</p> <p>Equations must match reagent but if NH_3 then also allow two equations $\text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4^+ + \text{OH}^-$ $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \rightarrow [\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3] + 3\text{H}_2\text{O}$</p> <p>Do not allow $\text{Cr}(\text{OH})_3$ as identity of P, or in equation</p>

7c	M1 Q = CO ₂ M2 Na ₂ CO ₃ or NaHCO ₃ or K ₂ CO ₃ M3 $2[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{CO}_3^{2-} \rightarrow 2[\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3] + 3\text{CO}_2 + 3\text{H}_2\text{O}$	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 ₂ CO ₃ but mark on. Do not allow equations that give Cr(OH) ₃ allow $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{HCO}_3^- \rightarrow [\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3] + 3\text{CO}_2 + 3\text{H}_2\text{O}$
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7d	<p>Either</p> <p>M1 $R = [Cr(OH)_6]^{3-}$</p> <p>M2 NaOH or KOH</p> <p>M3 $[Cr(OH)_3(H_2O)_3] + 3OH^- \rightarrow [Cr(OH)_6]^{3-} + 3 H_2O$</p> <p>OR</p> <p>M1 $R = [Cr(H_2O)_6]^{3+}$</p> <p>M2 HCl or any named acid</p> <p>M3 $[Cr(OH)_3(H_2O)_3] + 3H^+ \rightarrow [Cr(H_2O)_6]^{3+}$</p>	3	<p>Ignore state symbols Penalise charges on ligands in complex ion formulae</p> <p>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</p> <p>allow equations to form $[Cr(OH)_4(H_2O)_2]^-$ and $[Cr(OH)_5(H_2O)]^{2-}$ Do not allow equations from $Cr(OH)_3$</p> <p>OR</p> <p>Allow $R = [Cr(H_2O)_5(OH)]^{2+}$ or $[Cr(H_2O)_4(OH)_2]^+$ Do not allow H^+ etc, but mark on.</p> <p>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 $Cr(OH)_3$</p>
7e	<p>Zn/ HCl , Sn/ HCl, etc</p> <p>Blue</p>	1 1	<p>Allow H_2SO_4 instead of HCl Ignore H_2</p> <p>Mark independently</p>

Question	Marking guidance	Mark	Comments
8a	<p>[Ar] 4s² 3d⁷ or 1s²2s²2p⁶3s²3p⁶4s²3d⁷</p> <p>[Ar] 3d⁷ or 1s²2s²2p⁶3s²3p⁶3d⁷</p> <p>Any 3</p> <p>Variable oxidation state</p> <p>Act as catalysts</p> <p>Form complexes</p> <p>Form coloured ions/compounds</p>	<p>1</p> <p>1</p> <p>3</p>	<p>Allow 4s and 3d in either order</p>
8b	<p><u>Two atoms</u> that each donate a lone pair (of electrons) / coordinate bonds from <u>two atoms</u></p> <p>Formula of ethane-1,2- diamine: NH₂CH₂CH₂NH₂</p> <p>[Co (H₂O)₆]²⁺ + 3NH₂CH₂CH₂NH₂ → [Co(NH₂CH₂CH₂NH₂)₃]²⁺ + 6H₂O</p> <p>There is an increase in the number of particles / the reaction goes from 4 moles to 7 moles</p> <p>disorder/entropy increases / ΔS is positive</p> <p>ΔG negative</p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>M2 gained from equation or structure</p> <p>Equation must be balanced inc charges</p> <p>Allow en or C₂H₈N₂ in equation for ethane-1,2-diamine</p> <p>Allow increase number of molecules/moles. Allow numbers that match an incorrect equation</p>

	<p style="text-align: right;">2+</p>  <p style="text-align: center;">Or</p> <p style="text-align: right;">2+</p> 	<p>1</p>	<p>Mark for correct structure (ignore charges -even if wrong)</p> <p>NH₂ can be shown in either way – see structure</p>
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Question	Marking guidance	Mark	Comments
9a	A reaction that produces its own catalyst/ one of the products is the catalyst	1	Allow Mn ³⁺
	Mn ²⁺	1	
9b	H ₂ SO ₄	1	
9c	There is no/very little catalyst at the start OR the reaction only speeds up when the catalyst is produced	1	Reference to molecules loses M2
	Two negative ions (MnO ₄ ⁻ and C ₂ O ₄ ²⁻) <u>repel</u>	1	
	The <u>activation energy</u> for the reaction is high / heat is required to overcome the <u>activation energy</u>	1	

9d	<p>M1 $5 \text{C}_2\text{O}_4^{2-}(\text{aq}) + 2 \text{MnO}_4^{-}(\text{aq}) + 16 \text{H}^{+}(\text{aq}) \rightarrow 10 \text{CO}_2(\text{g}) + 2 \text{Mn}^{2+}(\text{aq}) + 8 \text{H}_2\text{O}(\text{l})$</p> <p>M2 $n(\text{MnO}_4^{-}) = \frac{26.40 \times 0.02}{1000}$ OR $n(\text{MnO}_4^{-}) = 5.28 \times 10^{-4}$</p> <p>M3 $n(\text{C}_2\text{O}_4^{2-}) = \frac{5}{2} \times 5.28 \times 10^{-4} = 1.32 \times 10^{-3}$</p> <p>M4 $n(\text{C}_2\text{O}_4^{2-} \text{ in flask originally}) = 1.32 \times 10^{-3} \times 10 = 1.32 \times 10^{-2}$</p> <p>M5 $n(\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3] \cdot 3\text{H}_2\text{O}) = \frac{1.32 \times 10^{-2}}{3} = 4.40 \times 10^{-3}$</p> <p>(Mr $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3] \cdot 3\text{H}_2\text{O} = 491.1$)</p> <p>M6 Mass of $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3] \cdot 3\text{H}_2\text{O}$ reacted = $4.40 \times 10^{-3} \times 491.1 = 2.16 \text{ g}$</p> <p>M7 % purity = $\frac{2.16}{2.29} \times 100 = \underline{94.3 \text{ or } 94.4\%}$</p>	1 1 1 1 1 1 1	<p>Ignore state symbols</p> <p>M3 is for M2 x 5/2 If wrong ratio used then can only score M2, M4, M5 and M6</p> <p>M4 is for M3 x 10</p> <p>M5 is for M4 ÷ 3</p> <p>M6 is for M5 x 491(.1)</p> <p>Answer must be to 3 s.f. Correct answer scores 6 marks; mark equation separately</p> <p>Alternative method using ratio by moles: M5 $n(\text{C}_2\text{O}_4^{2-}) = 4.66 \times 10^{-3} \times 3 = 0.0140 \text{ moles in } 250\text{cm}^3$ M6 $n(\text{complex}) = 2.29/491.1 = 4.66 \times 10^{-3} \text{ moles in } 250\text{cm}^3$ M7 % = $0.0132/0.0140 \times 100 = \underline{94.3 \text{ or } 94.4\%}$</p>
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9e	Make <u>some known</u> concentrations (of the coloured solution and read the absorbance of each one using a colorimeter) Plot a graph of absorbance vs concentration Read/compare unknown concentration from calibration curve/graph (and hence the concentration from the graph)	1 1 1	Ignore addition of suitable ligand Not just “plot a calibration curve” / reference to Beer-Lambert graph is insufficient Do not allow transmittance in M2 M3 can only be scored if graph/curve mentioned