



**General Certificate of Education (A-level)
June 2012**

Chemistry

CHEM5

(Specification 2420)

**Unit 5: Energetics, Redox and Inorganic
Chemistry**

Final

Mark Scheme

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Question	Marking Guidance	Mark	Comments
1(a)	To prevent it coming into contact/reacting with oxygen/air	1	Allow because it reacts with air/oxygen And because with air/oxygen it forms an oxide. (Oxide, if identified, must be correct :- P ₄ O ₁₀ , P ₂ O ₅ , P ₄ O ₆ , P ₂ O ₆)
1(b)	One molecule contains 4P and 10O/the molecular formula is P ₄ O ₁₀	1	Allow exists as P ₄ O ₁₀ Do not allow reference to combination of two P ₂ O ₅ molecules Ignore any reference to stability
1(c)	P ₄ O ₁₀ is a bigger molecule (than SO ₃)/greater M _r /more electrons/ greater surface area <u>Van der Waals / vdW forces between molecules are stronger/require more energy to break</u>	1 1	Penalise SO ₂ for one mark (max 1) CE = 0 if mention of hydrogen bonding/ionic/ giant molecule/breaking of covalent bonds Do not allow just more vdW forces Ignore any reference to dipole-dipole forces
1(d)	P ₄ O ₁₀ + 6H ₂ O → 4H ₃ PO ₄ pH must be in the range -1 to +2	1 1	Allow correct ionic equations Ignore state symbols Allow -1 to +2 Mark independently

1(e)(i)	$3\text{MgO} + 2\text{H}_3\text{PO}_4 \rightarrow \text{Mg}_3(\text{PO}_4)_2 + 3\text{H}_2\text{O}$ OR $\text{MgO} + 2\text{H}_3\text{PO}_4 \rightarrow \text{Mg}(\text{H}_2\text{PO}_4)_2 + \text{H}_2\text{O}$ OR $\text{MgO} + \text{H}_3\text{PO}_4 \rightarrow \text{MgHPO}_4 + \text{H}_2\text{O}$	1	Allow $\text{MgO} + 2\text{H}^+ \rightarrow \text{Mg}^{2+} + \text{H}_2\text{O}$ Allow magnesium phosphates shown as ions and ionic equations Ignore state symbols
1(e)(ii)	MgO is sparingly soluble/insoluble/weakly alkaline	1	Excess/unreacted MgO can be filtered off/separated
1(e)(iii)	An excess of NaOH would make the lake alkaline/toxic/kill wildlife	1	Allow pH increases

Question	Marking Guidance	Mark	Comments
2(a)	$\Delta G = \Delta H - T\Delta S$	1	Ignore e
2(b)	0.098 or 98 kJ K ⁻¹ mol ⁻¹ J K ⁻¹ mol ⁻¹ - $\Delta S/\Delta S$	1 1 1	Allow 0.097 to 0.099/97 to 99 Allow 0.1 only if 0.098 shown in working Allow in any order Unless slope is approx. 100(90-110) accept only kJ K ⁻¹ mol ⁻¹ . If no slope value given, allow either units
2(c)	ΔG becomes <u>negative</u> So reaction becomes spontaneous/feasible	1 1	Mark independently unless ΔG +ve then CE = 0 Or reaction can occur below this temperature Or reaction is not feasible above this temperature
2(d)	Ammonia liquefies (so entropy data wrong/different)	1	Allow any mention of <u>change</u> in state or implied change in state even if incorrect eg freezing/boiling

Question	Marking Guidance	Mark	Comments
3(a)	<p><u>Enthalpy change</u>/heat energy change when <u>one mole</u> of <u>gaseous atoms</u></p> <p>Form (one mole of) gaseous negative ions (with a single charge)</p>	<p>1</p> <p>1</p>	<p>Allow explanation with an equation that includes state symbols</p> <p>If ionisation/ionisation energy implied, CE=0 for both marks</p> <p>Ignore conditions</p>
3(b)	<p>Fluorine (atom) is smaller than chlorine/shielding is less/ outer electrons closer to nucleus</p> <p>(Bond pair of) electrons attracted more strongly <u>to the nucleus/protons</u></p>	<p>1</p> <p>1</p>	<p>Fluorine molecules/ions/charge density CE=0 for both marks</p>
3(c)	<p><u>Fluoride</u> (ions) smaller (than chloride) / have larger charge density</p> <p>So (negative charge) attracts ($\delta+$ hydrogen on) water more strongly</p>	<p>1</p> <p>1</p>	<p>Any reference to electronegativity CE=0</p> <p>Allow H on water, do not allow O on water</p> <p>Allow F⁻ hydrogen bonds to water, chloride ion does not</p> <p>Mark independently</p>

3(d)(i)	$\Delta H(\text{solution}) = LE + \Sigma(\text{hydration enthalpies}) / \text{correct cycle}$ $LE = -20 - (-464 + -506)$ $= (+) 950 \text{ kJ mol}^{-1}$	1 1 1	AgF ₂ or other wrong formula CE = 0 Ignore state symbols in cycle Ignore no units, penalise M3 for wrong units -950 scores max 1 mark out of 3 990 loses M3 but M1 and M2 may be correct 808 is transfer error (AE) scores 2 marks 848 max 1 if M1 correct 1456 CE=0 (results from AgF ₂)
3(d)(ii)	There is an increase in the number of particles / more disorder / less order	1	Allow incorrect formulae and numbers provided number increases Do not penalise reference to atoms/molecules Ignore incorrect reference to liquid rather than solution
3(d)(iii)	Entropy change is positive/entropy increases and enthalpy change negative/exothermic So ΔG is (always) negative	1 1	

Question	Marking Guidance	Mark	Comments
4(a)	$\Delta H = \Sigma(\Delta H_f \text{ products}) - \Sigma(\Delta H_f \text{ reactants})$ /= +34 - +90 = -56 kJ mol ⁻¹	1	Allow correct cycle
		1	Ignore no units, penalise incorrect units
4(b)	$\Delta S = \Sigma(S \text{ products}) - \Sigma(S \text{ reactants})$ /= 240 - (205 + 211/2) = -70.5 J K ⁻¹ mol ⁻¹ / -0.0705 kJ K ⁻¹ mol ⁻¹	1	
		1	Ignore no units, penalise incorrect units Allow -70 to -71/-0.070 to -.071
4(c)	$T = \Delta H/\Delta S$ / $T = (\text{Ans to part(a)} \times 1000)/\text{ans to part(b)}$ /= -56/(-70.5 ÷ 1000) = 794 K (789 to 800 K)	1	Mark consequentially on answers to parts (a) and (b)
		1	Must have correct units Ignore signs; allow + or – and –ve temps
4(d)	Temperatures exceed this value	1	
4(e)	$\text{N}_2 + \text{O}_2 \rightarrow 2\text{NO}$	1	Allow multiples
4(f)	there is no change in the number of moles (of gases) So entropy/disorder stays (approximately) constant / entropy/disorder change is very small / $\Delta S=0$ / $T\Delta S=0$	1	Can only score these marks if the equation in (e) has equal number of moles on each side
		1	Numbers, if stated must match equation

Question	Marking Guidance	Mark	Comments
5(a)	Electron acceptor / gains electrons / takes electrons away	1	Do not allow electron pair acceptor / gain of electrons / definition of redox (QWC)
5(b)	Cd(OH) ₂ Species (on LHS) with the least positive/most negative electrode potential / lowest <i>E</i> / smallest <i>E</i>	1 1	Do not allow 'Cd(OH) ₂ /Cd' Only allow this mark if M1 answer given correctly or blank Do not allow negative emf
5(c)(i)	1.5 (V) / 1.50	1	
5(c)(ii)	$2\text{MnO}_2 + 2\text{H}_2\text{O} + \text{Zn} \rightarrow 2\text{MnO(OH)} + 2\text{OH}^- + \text{Zn}^{2+}$	1	Ignore state symbols e ⁻ must be cancelled (take care that Zn ²⁺ is on RHS)
5(c)(iii)	Allows <u>ions</u> to pass (through it) or words to that effect	1	Penalise passage of electrons Allow mention of particular ions
5(c)(iv)	Allows electrons to flow / makes electrical contact / conductor	1	Allow acts as an (inert) electrode / anode / cathode
5(c)(v)	Zn is 'used up' / has reacted / oxidised	1	Allow idea that zinc <u>reacts</u> Do not allow just zinc corrodes

5(d)(i)	3 / +3 / III $2\text{Ni}(\text{OH})_2 + \text{Cd}(\text{OH})_2 \rightarrow 2\text{NiO}(\text{OH}) + \text{Cd} + 2\text{H}_2\text{O}$	1 1 1	For correct nickel and cadmium species in correct order (allow H_2O missing and OH^- not cancelled) For balanced equation (also scores M2) Allow max 1 for M2 and M3 if correct balanced equation but reversed. Ignore state symbols
5(d)(ii)	Metal / metal compounds are re-used / supplies are not depleted / It (the cell) can be re-used	1	Allow does not leak / no landfill problems / less mining / less energy to extract metals / less waste Do not allow less CO_2 unless explained
5(e)(i)	$\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$	1	Allow $\text{C}_2\text{H}_6\text{O}$
5(e)(ii)	$\text{C}_2\text{H}_5\text{OH} + 3\text{H}_2\text{O} \rightarrow 2\text{CO}_2 + 12\text{H}^+ + 12\text{e}^-$	1	Allow $\text{C}_2\text{H}_6\text{O}$
5(e)(iii)	(+)0.23 (V)	1	
5(e)(iv)	<u>CO_2</u> released by combustion / fermentation / fuel cell / reaction with water (atmospheric) <u>CO_2</u> taken up in <u>photosynthesis</u>	1 1	Can be answered with the aid of equations

Question	Marking Guidance	Mark	Comments
6(a)	Co-ordinate / dative / dative covalent / dative co-ordinate	1	Do not allow covalent alone
6(b)	(lone) pair of electrons on <u>oxygen/O</u> forms co-ordinate bond with <u>Fe</u> / donates electron pair to <u>Fe</u>	1 1	If co-ordination to O ²⁻ , CE=0 'Pair of electrons on O donated to Fe' scores M1 and M2
6(c)	180° / 180 / 90	1	Allow any angle between 85 and 95 Do not allow 120 or any other incorrect angle Ignore units eg °C
6(d)(i)	3 : 5 / 5 FeC ₂ O ₄ reacts with 3 MnO ₄ ⁻	1	Can be equation showing correct ratio

6(d)(ii)	<p>M1 Moles of MnO_4^- per titration = $22.35 \times 0.0193/1000 = 4.31 \times 10^{-4}$</p> <p>Method marks for each of the next steps (no arithmetic error allowed for M2):</p> <p>M2 moles of $\text{FeC}_2\text{O}_4 =$ ratio from (d)(i) used correctly $\times 4.31 \times 10^{-4}$</p> <p>M3 moles of FeC_2O_4 in $250 \text{ cm}^3 = \text{M2 ans} \times 10$</p> <p>M4 Mass of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = \text{M3 ans} \times 179.8$</p> <p>M5 % of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = (\text{M4 ans}/1.381) \times 100$</p> <p>(OR for M4 max moles of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = 1.381/179.8 (= 7.68 \times 10^{-3})$</p> <p>for M5 % of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = (\text{M3 ans}/\text{above M4ans}) \times 100$)</p> <p>eg using correct ratio 5/3:</p> <p>Moles of $\text{FeC}_2\text{O}_4 = 5/3 \times 4.31 \times 10^{-4} = 7.19 \times 10^{-4}$</p> <p>Moles of FeC_2O_4 in $250 \text{ cm}^3 = 7.19 \times 10^{-4} \times 10 = 7.19 \times 10^{-3}$</p> <p>Mass of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = 7.19 \times 10^{-3} \times 179.8 = 1.29 \text{ g}$</p> <p>% of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = 1.29 \times 100/1.381 = 93.4$ (allow 92.4 to 94.4)</p> <p>Note correct answer (92.4 to 94.4) scores 5 marks</p>	1 1 1 1	<p>Allow 4.3×10^{-4} (2 sig figs)</p> <p>Allow other ratios as follows: eg from given ratio of 7/3</p> <p>M2 = $7/3 \times 4.31 \times 10^{-4} = 1.006 \times 10^{-3}$</p> <p>M3 = $1.006 \times 10^{-3} \times 10 = 1.006 \times 10^{-2}$</p> <p>M4 = $1.006 \times 10^{-2} \times 179.8 = 1.81 \text{ g}$</p> <p>M5 = $1.81 \times 100/1.381 = 131 \%$ (130 to 132)</p> <p>Allow consequentially on candidates ratio eg M2 = $5/2 \times 4.31 \times 10^{-4} = 1.078 \times 10^{-3}$</p> <p>M3 = $1.0078 \times 10^{-3} \times 10 = 1.078 \times 10^{-2}$</p> <p>M4 = $1.078 \times 10^{-2} \times 179.8 = 1.94 \text{ g}$</p> <p>M5 = $1.94 \times 100/1.381 = 140 \%$ (139 to 141)</p> <p>Other ratios give the following final % values 1:1 gives 56.1% (55.6 to 56.6) 5:1 gives 281% (278 to 284) 5:4 gives 70.2% (69.2 to 71.2)</p>
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Question	Marking Guidance	Mark	Comments
7(a)	Orange dichromate Changes to purple / green / ruby / red-violet / violet Chromium(III) (Note green complex can be $[\text{Cr}(\text{H}_2\text{O})_5\text{Cl}]^{2+}$ etc) That changes further to blue Chromium(II) $[\text{Cr}_2\text{O}_7]^{2-} + 14\text{H}^+ + 3\text{Zn} \rightarrow 2\text{Cr}^{3+} + 3\text{Zn}^{2+} + 7\text{H}_2\text{O}$ $2\text{Cr}^{3+} + \text{Zn} \rightarrow 2\text{Cr}^{2+} + \text{Zn}^{2+}$ / $[\text{Cr}_2\text{O}_7]^{2-} + 14\text{H}^+ + 4\text{Zn} \rightarrow 2\text{Cr}^{2+} + 4\text{Zn}^{2+} + 7\text{H}_2\text{O}$	1 1 1 1 1	Allow max 2 for three correct colours not identified to species but in correct order Do not allow green with another colour Allow max 1 for two correct colours not identified but in correct order Ignore any further reduction of Cr^{2+} Ignore additional steps e.g. formation of CrO_4^{2-}
7(b)	Green precipitate (Dissolves to form a) green solution $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \rightarrow \text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3 + 3\text{H}_2\text{O}$ $\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3 + 3\text{OH}^- \rightarrow [\text{Cr}(\text{OH})_6]^{3-} + 3\text{H}_2\text{O}$	1 1 1 1	Solution can be implied if 'dissolves' stated Penalise $\text{Cr}(\text{OH})_3$ once only Allow $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 6\text{OH}^- \rightarrow$ $[\text{Cr}(\text{OH})_6]^{3-} + 6\text{H}_2\text{O}$ Allow formation of $[\text{Cr}(\text{H}_2\text{O})_2(\text{OH})_4]^-$ and $[\text{Cr}(\text{H}_2\text{O})(\text{OH})_5]^{2-}$ in balanced equations Ignore state symbols, mark independently

7(c)	(ligand) substitution / replacement / exchange The energy levels/gaps of the <u>d</u> electrons are <u>different</u> (for each complex) So a <u>different</u> wavelength/frequency/colour/energy of light is absorbed (when d electrons are excited) OR light is absorbed and a different wavelength/frequency/colour/energy (of light) is transmitted/reflected	1 1 1	Allow nucleophilic substitution Ignore any reference to emission of light
7(d)	$E_{O_2} (/ H_2O) > E_{Cr^{3+}} (/ Cr^{2+}) / e.m.f = 1.67 V$ So Cr^{2+} ions are oxidised by oxygen/air With $[Cr(H_2O)_6]^{2+}$ get $CrCO_3$ with $[Cr(H_2O)_6]^{3+}$ get $Cr(H_2O)_3(OH)_3 / Cr(OH)_3$ and CO_2 Cr(III) differs from Cr(II) because it is acidic / forms H^+ ions because Cr^{3+} ion polarises <u>water</u>	1 1 1 1 1 1 1	Allow $E(\text{cell}) = 1.67$ Allow any equation of the form: $Cr^{2+} + O_2 \rightarrow Cr^{3+}$ If named must be chromium(II) carbonate Allow 0 to 3 waters in the complex Can score M3, M4, M5 in equations even if unbalanced Ignore charge/size ratio and mass/charge

Question	Marking Guidance	Mark	Comments
8(a)	<p>Reaction 1 ammonia solution W is $[\text{Co}(\text{NH}_3)_6]^{2+}$ $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 6\text{NH}_3 \rightarrow [\text{Co}(\text{NH}_3)_6]^{2+} + 6\text{H}_2\text{O}$</p> <p>Reaction 2 H_2O_2 X is $[\text{Co}(\text{NH}_3)_6]^{3+}$ $2[\text{Co}(\text{NH}_3)_6]^{2+} + \text{H}_2\text{O}_2 \rightarrow 2[\text{Co}(\text{NH}_3)_6]^{3+} + 2\text{OH}^-$</p> <p>Reaction 3 HCl Y is $[\text{CoCl}_4]^{2-}$ $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O}/$ $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{HCl} \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O} + 4\text{H}^+$</p>	<p>1 1 1</p> <p>1 1 1</p> <p>1 1 1</p>	<p>For reactions 1 to 3 must show complex ions as reactants and products Take care to look for possible identification on flow chart</p> <p>Correct equation scores all 3 marks</p> <p>Allow oxygen, Do not allow air</p> <p>Allow $2[\text{Co}(\text{NH}_3)_6]^{2+} + \frac{1}{2}\text{O}_2 + \text{H}_2\text{O} \rightarrow 2[\text{Co}(\text{NH}_3)_6]^{3+} + 2\text{OH}^-$ Correct equations score all 3 marks</p> <p>Do not allow Cl^- but mark on</p> <p>Correct equation scores previous mark This equation scores all three marks</p>

	<p>Reaction 4</p> <p>Na₂CO₃ Or NaOH/NH₃</p> <p>Z is CoCO₃ Co(OH)₂/Co(H₂O)₄(OH)₂</p> <p>[Co(H₂O)₆]²⁺ + CO₃²⁻ → CoCO₃ + 6H₂O [Co(H₂O)₆]²⁺ + 2OH⁻ → Co(H₂O)₄(OH)₂ + 2H₂O etc</p> <p>Or [Co(H₂O)₆]²⁺ + Na₂CO₃ → CoCO₃ + 6H₂O + 2Na⁺</p>	<p>1</p> <p>1</p> <p>1</p>	<p>Do not allow CaCO₃ as a reagent but mark on</p> <p>Allow waters to stay co-ordinated to Co. This mark also previous mark</p> <p>Allow Co²⁺ + CO₃²⁻ → CoCO₃</p>
<p>8(b)</p>	<p>SO₃²⁻ + 1/2O₂ → SO₄²⁻</p> <p>The activation energy is lower (for the catalysed route)</p> <p>1/2O₂ + 2Co²⁺ + 2H⁺ → H₂O + 2Co³⁺</p> <p>2Co³⁺ + SO₃²⁻ + H₂O → 2Co²⁺ + SO₄²⁻ + 2H⁺</p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Allow multiples</p> <p>Or Co³⁺ attracts SO₃²⁻/Co²⁺ attracts SO₃²⁻ /oppositely charged ions attract</p> <p>Allow these equations in either order</p>