



**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 :- $P_4O_{10}$ , $P_2O_5$ , $P_4O_6$ , $P_2O_6$ )
1(b)	One molecule contains 4P and 10O/the molecular formula is $P_4O_{10}$	1	Allow exists as $P_4O_{10}$ Do not allow reference to combination of two $P_2O_5$ molecules Ignore any reference to stability
1(c)	$P_4O_{10}$ 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)	$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$  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 <sup>-1</sup> mol <sup>-1</sup> J K <sup>-1</sup> mol <sup>-1</sup>  - $\Delta S/\Delta S$	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 <sup>-1</sup> mol <sup>-1</sup> . If no slope value given, allow either units
2(c)	$\Delta G$ becomes <u>negative</u>  So reaction becomes spontaneous/feasible	1  1	Mark independently unless $\Delta G$ +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)	<u>Enthalpy change</u> /heat energy change when <u>one mole</u> of <u>gaseous atoms</u> Form (one mole of) gaseous negative ions (with a single charge)	1	Allow explanation with an equation that includes state symbols
		1	If ionisation/ionisation energy implied, CE=0 for both marks Ignore conditions
3(b)	Fluorine (atom) is smaller than chlorine/shielding is less/ outer electrons closer to nucleus (Bond pair of) electrons attracted more strongly <u>to the nucleus/protons</u>	1	Fluorine molecules/ions/charge density CE=0 for both marks
		1	
3(c)	Fluoride (ions) smaller (than chloride) / have larger charge density So (negative charge) attracts ( $\delta+$ hydrogen on) water more strongly	1	Any reference to electronegativity CE=0
		1	Allow H on water, do not allow O on water Allow F <sup>-</sup> hydrogen bonds to water, chloride ion does not Mark independently

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

Question	Marking Guidance	Mark	Comments
4(a)	$\Delta H = \Sigma(\Delta H_f \text{ products}) - \Sigma(\Delta H_f \text{ reactants})$ $\neq +34 - +90$ $= -56 \text{ kJ mol}^{-1}$	1	Allow correct cycle
		1	Ignore no units, penalise incorrect units
4(b)	$\Delta S = \Sigma(S \text{ products}) - \Sigma(S \text{ reactants})$ $\neq 240 - (205 + 211/2)$ $= -70.5 \text{ J K}^{-1} \text{ mol}^{-1} / -0.0705 \text{ kJ K}^{-1} \text{ mol}^{-1}$	1	
		1	Ignore no units, penalise incorrect units Allow -70 to -71/-0.070 to -0.071
4(c)	$T = \Delta H/\Delta S \quad / \quad T = (\text{Ans to part(a)} \times 1000)/\text{ans to part(b)}$ $\neq -56/(-70.5 \div 1000)$ $= 794 \text{ K} \quad (789 \text{ to } 800 \text{ K})$	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)	$\text{Cd}(\text{OH})_2$ Species (on LHS) with the least positive/most negative electrode potential / lowest $E$ / smallest $E$	1 1	Do not allow ' $\text{Cd}(\text{OH})_2/\text{Cd}$ ' 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)	$2\text{MnO}_2 + 2\text{H}_2\text{O} + \text{Zn} \rightarrow 2\text{MnO}(\text{OH}) + 2\text{OH}^- + \text{Zn}^{2+}$	1	Ignore state symbols $e^-$ must be cancelled (take care that $\text{Zn}^{2+}$ 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 $\text{H}_2\text{O}$ missing and $\text{OH}^-$ 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 $\text{CO}_2$ 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><math>\text{CO}_2</math></u> released by combustion / fermentation / fuel cell / reaction with water (atmospheric) <u><math>\text{CO}_2</math></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 $FeC_2O_4$ reacts with 3 $MnO_4^-$	1	Can be equation showing correct ratio

6(d)(ii)	<p><b>M1</b> Moles of <math>\text{MnO}_4^-</math> per titration = <math>22.35 \times 0.0193/1000 = 4.31 \times 10^{-4}</math></p> <p>Method marks for each of the next steps (no arithmetic error allowed for M2):</p> <p><b>M2</b> moles of <math>\text{FeC}_2\text{O}_4 =</math> ratio from (d)(i) used correctly <math>\times 4.31 \times 10^{-4}</math></p> <p><b>M3</b> moles of <math>\text{FeC}_2\text{O}_4</math> in <math>250 \text{ cm}^3 = \text{M2 ans} \times 10</math></p> <p><b>M4</b> Mass of <math>\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = \text{M3 ans} \times 179.8</math></p> <p><b>M5</b> % of <math>\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = (\text{M4 ans}/1.381) \times 100</math></p> <p>(OR for M4 max moles of <math>\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = 1.381/179.8 (= 7.68 \times 10^{-3})</math></p> <p>for M5 % of <math>\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = (\text{M3 ans}/\text{above M4ans}) \times 100</math>)</p> <p>eg using correct ratio 5/3:</p> <p>Moles of <math>\text{FeC}_2\text{O}_4 = 5/3 \times 4.31 \times 10^{-4} = 7.19 \times 10^{-4}</math></p> <p>Moles of <math>\text{FeC}_2\text{O}_4</math> in <math>250 \text{ cm}^3 = 7.19 \times 10^{-4} \times 10 = 7.19 \times 10^{-3}</math></p> <p>Mass of <math>\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}</math></p> <p>% of <math>\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = 1.29 \times 100/1.381 = 93.4</math> (allow 92.4 to 94.4)</p> <p>Note correct answer ( 92.4 to 94.4) scores 5 marks</p>	<div> <div>1</div> <div>Allow <math>4.3 \times 10^{-4}</math> ( 2 sig figs)</div> </div> <div> <div>1</div> <div>Allow other ratios as follows: eg from given ratio of 7/3</div> </div> <div> <div>1</div> <div><b>M2</b> = <math>7/3 \times 4.31 \times 10^{-4} = 1.006 \times 10^{-3}</math></div> </div> <div> <div>1</div> <div><b>M3</b> = <math>1.006 \times 10^{-3} \times 10 = 1.006 \times 10^{-2}</math></div> </div> <div> <div>1</div> <div><b>M4</b> = <math>1.006 \times 10^{-2} \times 179.8 = 1.81 \text{ g}</math></div> </div> <div> <div></div> <div><b>M5</b> = <math>1.81 \times 100/1.381 = 131 \%</math> (130 to 132)</div> </div> <div> <div></div> <div>Allow consequentially on candidates ratio eg <b>M2</b> = <math>5/2 \times 4.31 \times 10^{-4} = 1.078 \times 10^{-3}</math></div> </div> <div> <div></div> <div><b>M3</b> = <math>1.0078 \times 10^{-3} \times 10 = 1.078 \times 10^{-2}</math></div> </div> <div> <div></div> <div><b>M4</b> = <math>1.078 \times 10^{-2} \times 179.8 = 1.94 \text{ g}</math></div> </div> <div> <div></div> <div><b>M5</b> = <math>1.94 \times 100/1.381 = 140 \%</math> (139 to 141)</div> </div> <div> <div></div> <div>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)</div> </div>
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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 $\text{Cr}^{2+}$ Ignore additional steps e.g. formation of $\text{CrO}_4^{2-}$
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 $E_{(cell)} = 1.67$ 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><b>Reaction 1</b> ammonia solution <b>W</b> is <math>[\text{Co}(\text{NH}_3)_6]^{2+}</math> <math>[\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}</math></p> <p><b>Reaction 2</b> <math>\text{H}_2\text{O}_2</math> <b>X</b> is <math>[\text{Co}(\text{NH}_3)_6]^{3+}</math> <math>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}^-</math></p> <p><b>Reaction 3</b> <math>\text{HCl}</math> <b>Y</b> is <math>[\text{CoCl}_4]^{2-}</math> <math>[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O}/</math> <math>[\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}^+</math></p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>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 <math>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}^-</math> Correct equations score all 3 marks</p> <p>Do not allow <math>\text{Cl}^-</math> but mark on</p> <p>Correct equation scores previous mark This equation scores all three marks</p>

	<b>Reaction 4</b> $\text{Na}_2\text{CO}_3$ Or $\text{NaOH}/\text{NH}_3$ <b>Z</b> is $\text{CoCO}_3$ $\text{Co}(\text{OH})_2/\text{Co}(\text{H}_2\text{O})_4(\text{OH})_2$ $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + \text{CO}_3^{2-} \rightarrow \text{CoCO}_3 + 6\text{H}_2\text{O}$ $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow$ $\text{Co}(\text{H}_2\text{O})_4(\text{OH})_2 + 2\text{H}_2\text{O}$ etc Or $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + \text{Na}_2\text{CO}_3 \rightarrow \text{CoCO}_3 + 6\text{H}_2\text{O} + 2\text{Na}^+$	1 1 1	Do not allow $\text{CaCO}_3$ as a reagent but mark on  Allow waters to stay co-ordinated to Co. This mark also previous mark  Allow $\text{Co}^{2+} + \text{CO}_3^{2-} \rightarrow \text{CoCO}_3$
8(b)	$\text{SO}_3^{2-} + \frac{1}{2}\text{O}_2 \rightarrow \text{SO}_4^{2-}$ The activation energy is lower (for the catalysed route) $\frac{1}{2}\text{O}_2 + 2\text{Co}^{2+} + 2\text{H}^+ \rightarrow \text{H}_2\text{O} + 2\text{Co}^{3+}$ $2\text{Co}^{3+} + \text{SO}_3^{2-} + \text{H}_2\text{O} \rightarrow 2\text{Co}^{2+} + \text{SO}_4^{2-} + 2\text{H}^+$	1 1 1 1	Allow multiples  Or $\text{Co}^{3+}$ attracts $\text{SO}_3^{2-}$ / $\text{Co}^{2+}$ attracts $\text{SO}_3^{2-}$ / oppositely charged ions attract  Allow these equations in either order