Version 1.1

**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<br>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 $P_4O_{10}$<br>Do not allow reference to combination of two $P_2O_5$ molecules<br>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<br>Van der Waals / vdW forces between molecules are stronger/require more energy to break | 1<br>1 | Penalise $SO_2$ for one mark (max 1)<br>CE = 0 if mention of hydrogen bonding/ionic/ giant molecule/breaking of covalent bonds<br>Do not allow just more vdW forces<br>Ignore any reference to dipole-dipole forces |
| 1(d) | $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$<br>pH must be in the range -1 to +2 | 1<br>1 | Allow correct ionic equations<br>Ignore state symbols<br>Allow -1 to +2<br>Mark independently |

| | | | |
|---|---|---|---|
| 1(e)(i) | $3MgO + 2H_3PO_4 \rightarrow Mg_3(PO_4)_2 + 3H_2O$<br>OR $MgO + 2H_3PO_4 \rightarrow Mg(H_2PO_4)_2 + H_2O$<br>OR $MgO + H_3PO_4 \rightarrow MgHPO_4 + H_2O$ | 1 | Allow $MgO + 2H^+ \rightarrow Mg^{2+} + H_2O$<br>Allow magnesium phosphates shown as ions and ionic equations<br>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 | 1 | Allow 0.097 to 0.099/97 to 99<br>Allow 0.1 only if 0.098 shown in working |
| | kJ $K^{-1}$ $mol^{-1}$ J $K^{-1}$ $mol^{-1}$ | 1 | Allow in any order<br>Unless slope is approx. 100(90-110) accept only kJ $K^{-1}$ $mol^{-1}$. If no slope value given, allow either units |
| | $-\Delta S/\Delta S$ | 1 | |
| 2(c) | $\Delta G$ becomes <u>negative</u> | 1 | Mark independently unless $\Delta G$ +ve then CE = 0 |
| | So reaction becomes spontaneous/feasible | 1 | Or reaction can occur below this temperature<br>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<br>eg freezing/boiling |

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

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|---|---|---|---|
| 3(d)(i) | $\Delta H$(solution) = LE + $\Sigma$(hydration enthalpies) / correct cycle<br><br>*LE* = -20 -(-464 + -506)<br>= (+) 950 kJ $mol^{-1}$ | 1<br><br>1<br>1 | $AgF_2$ or other wrong formula CE = 0<br>Ignore state symbols in cycle<br><br>Ignore no units, penalise M3 for wrong units<br>-950 scores max 1 mark out of 3<br>990 loses M3 but M1 and M2 may be correct<br>808 is transfer error (AE) scores 2 marks<br>848 max 1 if M1 correct<br>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<br>Do not penalise reference to atoms/molecules<br>Ignore incorrect reference to liquid rather than solution |
| 3(d)(iii) | Entropy change is positive/entropy increases and enthalpy change negative/exothermic<br>So $\Delta G$ is (always) negative | 1<br>1 | |

| Question | Marking Guidance | Mark | Comments |
|---|---|---|---|
| 4(a) | $\Delta H = \Sigma(\Delta H_f$ products) - $\Sigma(\Delta H_f$ reactants)<br>/= +34 - +90<br>= -56 kJ $mol^{-1}$ | 1<br><br>1 | Allow correct cycle<br><br>Ignore no units, penalise incorrect units |
| 4(b) | $\Delta S = \Sigma(S$ products) - $\Sigma(S$ reactants)<br>/= 240 - (205 +211/2)<br>= -70.5 J $K^{-1}$ $mol^{-1}$ / -0.0705 kJ $K^{-1}$ $mol^{-1}$ | 1<br><br>1 | <br><br>Ignore no units, penalise incorrect units<br>Allow -70 to -71/-.070 to -.071 |
| 4(c) | $T = \Delta H/\Delta S$ / $T$ = (Ans to part(a) $\times$1000)/ans to part(b)<br>/= -56/(-70.5 $\div$ 1000)<br>= 794 K (789 to 800 K) | 1<br><br>1 | Mark consequentially on answers to parts (a) and (b)<br>Must have correct units<br>Ignore signs; allow + or – and –ve temps |
| 4(d) | Temperatures exceed this value | 1 | |
| 4(e) | $N_2 + O_2 \rightarrow 2NO$ | 1 | Allow multiples |
| 4(f) | there is no change in the number of moles (of gases)<br><br>So entropy/disorder stays (approximately) constant / entropy/disorder change is very small / $\Delta S$=0 / $T\Delta S$=0 | 1<br><br>1 | Can only score these marks if the equation in (e) has equal number of moles on each side<br>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) | $Cd(OH)_2$<br>Species (on LHS) with the least positive/most negative electrode potential / lowest *E* / smallest *E* | 1<br>1 | Do not allow '$Cd(OH)_2$/Cd'<br>Only allow this mark if M1 answer given correctly or blank<br>Do not allow negative emf |
| 5(c)(i) | 1.5 (V) / 1.50 | 1 | |
| 5(c)(ii) | $2MnO_2 + 2H_2O + Zn \rightarrow 2MnO(OH) + 2OH^- + Zn^{2+}$ | 1 | Ignore state symbols<br>$e^-$ must be cancelled<br>(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<br>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><br>Do not allow just zinc corrodes |

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| 5(d)(i) | 3 / +3 / III<br>$2Ni(OH)_2 + Cd(OH)_2 \rightarrow 2NiO(OH) + Cd + 2H_2O$ | 1<br>1<br>1 | <br>For correct nickel and cadmium species in correct order (allow $H_2O$ missing and $OH^-$ not cancelled)<br>For balanced equation (also scores M2)<br>Allow max 1 for M2 and M3 if correct balanced equation but reversed.<br>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<br>Do not allow less $CO_2$ unless explained |
| 5(e)(i) | $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ | 1 | Allow $C_2H_6O$ |
| 5(e)(ii) | $C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 12H^+ + 12e^-$ | 1 | Allow $C_2H_6O$ |
| 5(e)(iii) | (+)0.23 (V) | 1 | |
| 5(e)(iv) | $\underline{CO_2}$ released by combustion / fermentation / fuel cell / reaction with water<br>(atmospheric) $\underline{CO_2}$ taken up in <u>photosynthesis</u> | 1<br>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><br>forms co-ordinate bond with <u>Fe</u> / donates electron pair to <u>Fe</u> | 1<br>1 | If co-ordination to $O^{2-}$, CE=0<br>'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<br>Do not allow 120 or any other incorrect angle<br>Ignore units eg $^{o}C$ |
| 6(d)(i) | 3 : 5 / 5 $FeC_2O_4$ reacts with 3 $MnO_4^-$ | 1 | Can be equation showing correct ratio |

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|---|---|---|---|
| 6(d)(ii) | **M1** Moles of $MnO_4^-$ per titration = $22.35 \times 0.0193/1000 = \underline{4.31 \times 10^{-4}}$<br>Method marks for each of the next steps (no arithmetic error allowed for M2):<br>**M2** moles of $FeC_2O_4$= ratio from (d)(i) used correctly $\times 4.31 \times 10^{-4}$<br>**M3** moles of $FeC_2O_4$ in 250 $cm^3$ = M2 ans $\times$ 10<br>**M4** Mass of $FeC_2O_4.2H_2O$ = M3 ans $\times$ 179.8<br>**M5** % of $FeC_2O_4.2H_2O$ = (M4 ans/1.381) $\times$ 100<br>(OR for M4 max moles of $FeC_2O_4.2H_2O$ = 1.381/179.8 (= $7.68\times 10^{-3}$)<br>for M5 % of $FeC_2O_4.2H_2O$ = (M3 ans/above M4ans) $\times$ 100)<br>eg using correct ratio 5/3:<br>Moles of $FeC_2O_4 = 5/3 \times 4.31 \times 10^{-4} = 7.19 \times 10^{-4}$<br>Moles of $FeC_2O_4$ in 250 $cm^3 = 7.19 \times 10^{-4} \times 10 = 7.19 \times 10^{-3}$<br>Mass of $FeC_2O_4.2H_2O = 7.19 \times 10^{-3} \times 179.8 = 1.29$ g<br>% of $FeC_2O_4.2H_2O$ = $1.29 \times 100/1.381 = 93.4$ (allow 92.4 to 94.4)<br>Note correct answer ( 92.4 to 94.4) scores 5 marks | 1<br><br><br>1<br>1<br>1<br>1 | Allow $\underline{4.3 \times 10^{-4}}$ ( 2 sig figs)<br>Allow other ratios as follows:<br>eg from given ratio of 7/3<br><br>**M2** = $7/3 \times 4.31 \times 10^{-4} = 1.006 \times 10^{-3}$<br>**M3** = $1.006 \times 10^{-3} \times 10 = 1.006 \times 10^{-2}$<br>**M4** = $1.006 \times 10^{-2} \times 179.8 = 1.81$ g<br>**M5** = $1.81 \times 100/1.381 = 131$ % (130 to 132)<br><br>Allow consequentially on candidates ratio<br>eg **M2** = $5/2 \times 4.31 \times 10^{-4} = 1.078 \times 10^{-3}$<br>**M3** = $1.0078 \times 10^{-3} \times 10 = 1.078 \times 10^{-2}$<br>**M4** = $1.078 \times 10^{-2} \times 179.8 = 1.94$ g<br>**M5** = $1.94 \times 100/1.381 = 140$ % (139 to 141)<br>Other ratios give the following final % values<br>1:1 gives 56.1% (55.6 to 56.6)<br>5:1 gives 281% (278 to 284)<br>5:4 gives 70.2% (69.2 to 71.2) |

| Question | Marking Guidance | Mark | Comments |
|---|---|---|---|
| 7(a) | Orange dichromate | 1 | Allow max 2 for three correct colours not identified to species but in correct order |
| | Changes to purple / green / ruby / red-violet / violet Chromium(III) | 1 | |
| | (Note green complex can be $[Cr(H_2O)_5Cl]^{2+}$ etc) | | Do not allow green with another colour |
| | That changes further to blue Chromium(II) | 1 | Allow max 1 for two correct colours not identified but in correct order |
| | $[Cr_2O_7]^{2-} + 14H^+ + 3Zn \rightarrow 2Cr^{3+} + 3Zn^{2+} + 7H_2O$ | 1 | Ignore any further reduction of $Cr^{2+}$ |
| | $2Cr^{3+} + Zn \rightarrow 2Cr^{2+} + Zn^{2+}$ / | 1 | Ignore additional steps e.g. formation of $CrO_4^{2-}$ |
| | $[Cr_2O_7]^{2-} + 14H^+ + 4Zn \rightarrow 2Cr^{2+} + 4Zn^{2+} + 7H_2O$ | | |
| 7(b) | Green precipitate | 1 | |
| | (Dissolves to form a) green solution | 1 | Solution can be implied if 'dissolves' stated |
| | $[Cr(H_2O)_6]^{3+} + 3OH^- \rightarrow Cr(H_2O)_3(OH)_3 + 3H_2O$ | 1 | Penalise $Cr(OH)_3$ once only |
| | $Cr(H_2O)_3(OH)_3 + 3OH^- \rightarrow [Cr(OH)_6]^{3-} + 3H_2O$ | 1 | Allow $[Cr(H_2O)_6]^{3+} + 6OH^- \rightarrow [Cr(OH)_6]^{3-} + 6H_2O$ |
| | | | Allow formation of $[Cr(H_2O)_2(OH)_4]^-$ and $[Cr(H_2O)(OH)_5]^{2-}$ in balanced equations |
| | | | Ignore state symbols, mark independently |

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| 7(c) | (ligand) substitution / replacement / exchange | 1 | Allow nucleophilic substitution |
| | The energy levels/gaps of the <u>d</u> electrons are <u>different</u> (for each complex) | 1 | |
| | So a <u>different</u> wavelength/frequency/colour/energy of light is absorbed (when d electrons are excited) | 1 | Ignore any reference to emission of light |
| | OR light is absorbed and a different wavelength/frequency/colour/energy (of light) is transmitted/reflected | | |

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|---|---|---|---|
| 7(d) | *E* $O_2$ (/ $H_2O$) > *E* $Cr^{3+}$ (/ $Cr^{2+}$) / e.m.f = 1.67 V | 1 | Allow E(cell) = 1.67 |
| | So $Cr^{2+}$ ions are oxidised by oxygen/air | 1 | Allow any equation of the form: $Cr^{2+} + O_2 \rightarrow Cr^{3+}$ |
| | With $[Cr(H_2O)_6]^{2+}$ get $CrCO_3$ | 1 | If named must be chromium(II) carbonate |
| | with $[Cr(H_2O)_6]^{3+}$ get $Cr(H_2O)_3(OH)_3$ / $Cr(OH)_3$ | 1 | Allow 0 to 3 waters in the complex |
| | and $CO_2$ | 1 | Can score M3, M4, M5 in equations even if unbalanced |
| | Cr(III) differs from Cr(II) because it is acidic / forms $H^+$ ions | 1 | |
| | because $Cr^{3+}$ ion polarises <u>water</u> | 1 | Ignore charge/size ratio and mass/charge |

| Question | Marking Guidance | Mark | Comments |
|---|---|---|---|
| 8(a) | | | For reactions 1 to 3 must show complex ions as reactants and products<br>Take care to look for possible identification on flow chart |
| | **Reaction 1** | | |
| | ammonia solution | 1 | |
| | **W** is $[Co(NH_3)_6]^{2+}$ | 1 | |
| | $[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$ | 1 | Correct equation scores all 3 marks |
| | **Reaction 2** | | Allow oxygen, Do not allow air |
| | $H_2O_2$ | 1 | |
| | **X** is $[Co(NH_3)_6]^{3+}$ | 1 | |
| | $2[Co(NH_3)_6]^{2+} + H_2O_2 \rightarrow 2[Co(NH_3)_6]^{3+} + 2OH^-$ | 1 | Allow $2[Co(NH_3)_6]^{2+} + {}^1/_2O_2 + H_2O \rightarrow 2[Co(NH_3)_6]^{3+} + 2OH^-$<br>Correct equations score all 3 marks |
| | **Reaction 3** | | |
| | HCl | 1 | Do not allow $Cl^-$ but mark on |
| | **Y** is $[CoCl_4]^{2-}$ | 1 | |
| | $[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$/ | 1 | Correct equation scores previous mark |
| | $[Co(H_2O)_6]^{2+} + 4HCl \rightarrow [CoCl_4]^{2-} + 6H_2O + 4H^+$ | | This equation scores all three marks |

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|---|---|---|---|
| | **Reaction 4**<br>$Na_2CO_3$ Or $NaOH/NH_3$<br>**Z** is $CoCO_3$ $Co(OH)_2/Co(H_2O)_4(OH)_2$<br>$[Co(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow CoCO_3 + 6H_2O$ $[Co(H_2O)_6]^{2+}+2OH^- \rightarrow Co(H_2O)_4(OH)_2+2H_2O$ etc<br>Or $[Co(H_2O)_6]^{2+} + Na_2CO_3 \rightarrow CoCO_3 + 6H_2O + 2Na^+$ | 1<br>1<br>1 | Do not allow $CaCO_3$ as a reagent but mark on<br>Allow waters to stay co-ordinated to Co. This mark also previous mark<br>Allow $Co^{2+} + CO_3^{2-} \rightarrow CoCO_3$ |
| 8(b) | $SO_3^{2-} + {}^1/_2O_2 \rightarrow SO_4^{2-}$<br>The activation energy is lower (for the catalysed route)<br>${}^1/_2O_2 + 2Co^{2+} + 2H^+ \rightarrow H_2O + 2Co^{3+}$<br>$2Co^{3+} + SO_3^{2-} + H_2O \rightarrow 2Co^{2+} + SO_4^{2-} + 2H^+$ | 1<br>1<br>1<br>1 | Allow multiples<br>Or $Co^{3+}$ attracts $SO_3^{2-}$/$Co^{2+}$ attracts $SO_3^{2-}$ /oppositely charged ions attract<br>Allow these equations in either order |