

**General Certificate of Education (A-level)  
June 2013**

**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)	Enthalpy change (to separate) 1 mol of an (ionic) substance into its <u>ions</u>  Forms <u>ions</u> in the gaseous state	1    1	If ionisation or hydration / solution, CE = 0 If atoms / molecules / elements mentioned, CE = 0 Allow heat energy change but not energy change alone. If forms 1 mol ions, lose M1 If lattice formation not dissociation, allow M2 only. Ignore conditions. Allow enthalpy change for $MX(s) \rightarrow M^+(g) + X^-(g)$ (or similar) for M1 and M2
1(b)	Any <b>one</b> of: <ul style="list-style-type: none"> <li>• Ions are point charges</li> <li>• Ions are perfect spheres</li> <li>• Only electrostatic attraction / bonds (between ions)</li> <li>• No covalent interaction / character</li> <li>• Only ionic bonding / no polarisation of ions</li> </ul>	1 max	If atoms / molecules mentioned, CE = 0
1(c)	(Ionic) radius / distance between ions / size  (Ionic) charge / charge density	1   1	Allow in any order. Do not allow charge / mass or mass / charge. Do not allow 'atomic radius'.

1(d)	$\Delta H_L = \Delta H_a(\text{chlorine}) + \Delta H_a(\text{Ag}) + \text{I.E}(\text{Ag}) + \text{EA}(\text{Cl}) - \Delta H_f^\ominus$ $= 121 + 289 + 732 - 364 + 127$ $= (+) 905 \text{ (kJ mol}^{-1}\text{)}$	1  1  1	Or cycle If $\text{AgCl}_2$ , CE=0/3  Allow 1 for -905 Allow 1 for (+)844.5 (use of 121/2) Ignore units even if incorrect.
1(e)	<b>M1</b> Greater <b>M2</b> (Born-Haber cycle method allows for additional) covalent interaction  <b>OR</b>  <b>M1</b> Equal <b>M2</b> AgCl is perfectly ionic / no covalent character	1  1	Do not penalise $\text{AgCl}_2$ Allow AgCl has covalent character. Only score M2 if M1 is correct.

Question	Marking Guidance	Mark	Comments
2(a)	<p>Chloride <u>ions</u> are smaller (than bromide <u>ions</u>)</p> <p>So the force of attraction between chloride ions and water is stronger</p> <p>Chloride <u>ions</u> attract the <math>\delta+</math> on H of water / electron deficient H on water</p>	<p>1</p> <p>1</p> <p>1</p>	<p>Must state or imply ions.</p> <p>Allow chloride has greater charge density (than bromide).</p> <p>Penalise <u>chlorine ions</u> once only (max 2/3).</p> <p>This can be implied from M1 and M3 but do not allow intermolecular forces.</p> <p>Allow attraction between ions and polar / dipole water.</p> <p>Penalise <math>H^+</math> (ions) and mention of hydrogen bonding for <b>M3</b></p> <p>Ignore any reference to electronegativity.</p> <p>Note: If water not mentioned can score M1 only.</p>
2(b)	<p><math>\Delta H_{\text{solution}} = \Delta H_{\text{L}} + \Delta H_{\text{hyd}} K^+ \text{ ions} + \Delta H_{\text{hyd}} Br^- \text{ ions} / = 670 - 322 - 335</math></p> <p><math>= (+)13 \text{ (kJ mol}^{-1}\text{)}</math></p>	<p>1</p> <p>1</p>	<p>Allow <math>\Delta H_{\text{solution}} = \Delta H_{\text{L}} + \sum \Delta H_{\text{hyd}}</math></p> <p>Ignore units even if incorrect.</p> <p>+13 scores M1 and M2</p> <p>-13 scores 0</p> <p>-16 scores M2 only (transcription error).</p>

2(c)(i)	<p>The entropy change is positive / entropy increases</p> <p>Because 1 mol (solid) → 2 mol (aqueous ions) / no of particles increases</p> <p>Therefore <math>T\Delta S &gt; \Delta H</math></p>	1  1  1	<p><math>\Delta S</math> is negative loses M1 and M3</p> <p>Allow the aqueous ions are more disordered (than the solid). Mention of atoms / molecules loses M2</p>
2(c)(ii)	<p>Amount of KCl = <math>5/M_r = 5/74.6 = \underline{0.067(0)}</math> mol</p> <p>Heat absorbed = <math>17.2 \times 0.0670 = 1.153</math> kJ</p> <p>Heat absorbed = mass × sp ht × <math>\Delta T</math> <math>(1.153 \times 1000) = 20 \times 4.18 \times \Delta T</math></p> <p><math>\Delta T = 1.153 \times 1000 / (20 \times 4.18) = 13.8</math> K</p> <p><math>T = 298 - 13.8 = 284(.2)</math> K</p>	1  1  1  1  1	<p>If moles of KCl not worked out can score M3, M4 only (answer to M4 likely to be 205.7 K)</p> <p>Process mark for M1 × 17.2</p> <p>If calculation uses 25 g not 20, lose M3 only (M4 = 11.04, M5 = 287)</p> <p>If 1000 not used, can only score M1, M2, M3</p> <p>M4 is for a correct <math>\Delta T</math> Note that 311.8 K scores 4 (M1, M2, M3, M4).</p> <p>If final temperature is negative, M5 = 0</p> <p>Allow no units for final temp, penalise wrong units.</p>

Question	Marking Guidance	Mark	Comments
3(a)(i)	(At 0 K) particles are stationary / not moving / not vibrating	1	Allow have zero energy.
	No disorder / perfect order / maximum order	1	Ignore atoms / ions. Mark independently.
3(a)(ii)	As $T$ increases, particles start to move / vibrate	1	Ignore atoms / ions. Allow have more energy. If change in state, CE = 0
	<u>Disorder / randomness</u> increases / order decreases	1	
3(a)(iii)	Mark <u>on temperature axis</u> vertically below second 'step'	1	Must be marked as a line, an 'x', $T_b$ or 'boiling point' <u>on the temperature axis.</u>
3(a)(iv)	L <sub>2</sub> corresponds to boiling / evaporating / condensing / l → g / g → l And L <sub>1</sub> corresponds to melting / freezing / s → l / l → s	1	There must be a clear link between L <sub>1</sub> , L <sub>2</sub> and the change in state.
	Bigger change in <u>disorder</u> for L <sub>2</sub> / boiling compared with L <sub>1</sub> / melting	1	M2 answer must be in terms of changes in state and not absolute states eg must refer to change from liquid to gas not just gas. Ignore reference to atoms even if incorrect.

3(b)(i)	$\Delta G = \Delta H - T\Delta S$ $\Delta H = c \text{ and } (-)\Delta S = m / \Delta H \text{ and } \Delta S \text{ are constants (approx)}$	1	
		1	Allow $\Delta H$ is the intercept, and $(-)\Delta S$ is the slope / gradient. Can only score M2 if M1 is correct.
3(b)(ii)	Because the entropy change / $\Delta S$ is positive / $T\Delta S$ gets bigger	1	Allow $-T\Delta S$ gets more negative.
3(b)(iii)	<u>Not</u> feasible / <u>un</u> feasible / <u>not</u> spontaneous	1	
3(c)(i)	+ 44.5 J K <sup>-1</sup> mol <sup>-1</sup>	1	Allow answer without units but if units given they must be correct (including mol <sup>-1</sup> )
3(c)(ii)	At 5440 $\Delta H = T\Delta S$ $= 5440 \times 44.5 = 242\,080$ ( <b>OR</b> using given value = $5440 \times 98 = 533\,120$ )  $\Delta H = 242 \text{ kJ mol}^{-1}$ ( <b>OR</b> using given value $\Delta H = 533 \text{ kJ mol}^{-1}$ )	1	Mark is for answer to (c)(i) $\times 5440$  Mark is for correct answer to M2 with correct units (J mol <sup>-1</sup> or kJ mol <sup>-1</sup> ) linked to answer. If answer consequentially correct based on (c)(i) except for incorrect sign (eg -242), max 1/3 provided units are correct.



Question	Marking Guidance	Mark	Comments
4(a)	MgO is ionic	1	If not ionic, CE = 0
	Melt it	1	If solution mentioned, cannot score M2 or M3
	(Molten oxide) conducts electricity	1	Allow acts as an electrolyte. Cannot score M3 unless M2 is correct.
4(b)	Macromolecular	1	CE = 0 if ionic, metallic or molecular. Allow giant molecule.
	Covalent bonding	1	Giant covalent scores M1 and M2
	Water cannot (supply enough energy to) break the covalent bonds / lattice	1	Hydration enthalpy < bond enthalpy.
4(c)	(Phosphorus pentoxide's melting point is) lower	1	If M1 is incorrect, can only score M2
	<u>Molecular</u> with <u>covalent</u> bonding	1	M2 can be awarded if molecular mentioned in M3
	Weak / easily broken / not much energy to break intermolecular forces <b>OR</b> weak vdW / dipole-dipole forces of attraction <u>between molecules</u>	1	Intermolecular / IMF means same as between molecules.

4(d)	Reagent (water or acid)  Equation eg $\text{MgO} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2\text{O}$	1  1	Can be awarded in the equation.  $\text{MgO} + \text{H}_2\text{O} \rightarrow \text{Mg}(\text{OH})_2$ Equations can be ionic but must show all of the reagent eg $\text{H}^+ + \text{Cl}^-$ Simplified ionic equation without full reagent can score M2 only. Allow $6\text{MgO} + \text{P}_4\text{O}_{10} \rightarrow 2\text{Mg}_3(\text{PO}_4)_2$
4(e)	$\text{P}_4\text{O}_{10} + 12\text{NaOH} \rightarrow 4\text{Na}_3\text{PO}_4 + 6\text{H}_2\text{O}$	1	Allow $\text{P}_2\text{O}_5$ and acid salts. Must be NaOH not just hydroxide ions.

Question	Marking Guidance	Mark	Comments
5(a)	It has mobile ions / ions can move through it / free ions	1	Do not allow movement of electrons. Allow specific ions provided they are moving but do not react.
5(b)	<u>Chloride</u> ions react with <u>copper ions</u> / <u>Cu<sup>2+</sup></u> <b>OR</b> [CuCl <sub>4</sub> ] <sup>2-</sup> formed	1	If incorrect chemistry, mark = 0
5(c)	The Cu <sup>2+</sup> ions / CuSO <sub>4</sub> in the <u>left-hand</u> electrode more concentrated  So the reaction of Cu <sup>2+</sup> with 2e <sup>-</sup> will occur (in preference at) <u>left-hand</u> electrode / Cu → Cu <sup>2+</sup> + electrons at <u>right-hand</u> electrode	1  1	Allow converse.  Allow <u>left-hand</u> electrode positive / <u>right-hand</u> electrode negative.  Also reduction at <u>left-hand</u> electrode / oxidation at <u>right-hand</u> electrode.  Also <u>left-hand</u> electrode has oxidising agent / <u>right-hand</u> electrode has reducing agent.  Allow <i>E</i> left-hand side > <i>E</i> right-hand side
5(d)	(Eventually) the copper ions / CuSO <sub>4</sub> in each electrode will be at the same concentration	1	
5(e)(i)	-3.05 (V)	1	Must have minus sign. -3.05 only.

5(e)(ii)	<p><math>\text{LiMnO}_2 \rightarrow \text{Li} + \text{MnO}_2</math> correct equation</p> <p>Correct direction</p>	<p>1</p> <p>1</p>	<p>Allow 1 for reverse equation.</p> <p>Allow multiples.</p> <p>If <math>\text{Li}^+</math> not cancelled but otherwise correct, max = 1</p> <p>If electrons not cancelled, CE = 0</p> <p><math>\text{LiMnO}_2 \rightarrow \text{Li} + \text{MnO}_2</math> scores 2</p> <p><math>\text{Li}^+ + \text{LiMnO}_2 \rightarrow \text{Li}^+ + \text{Li} + \text{MnO}_2</math> scores 1</p> <p><math>\text{Li} + \text{MnO}_2 \rightarrow \text{LiMnO}_2</math> scores 1</p>
5(e)(iii)	<p>Electricity for recharging the cell may come from power stations <u>burning</u> (fossil) fuel</p>	<p>1</p>	<p>Allow any reference to <u>burning</u> (of carbon-containing) fuels.</p> <p>Note combustion = burning.</p>

Question	Marking Guidance	Mark	Comments
6(a)	$\Delta E = h\nu$  $\nu = \Delta E / h = 2.84 \times 10^{-19} / 6.63 \times 10^{-34} = 4.28 \times 10^{14} \text{ s}^{-1} / \text{Hz}$	1  1	Allow = $hf$  Allow $4.3 \times 10^{14} \text{ s}^{-1} / \text{Hz}$ Answer must be in the range: $4.28 - 4.30 \times 10^{14}$
6(b)	(One colour of) light is absorbed (to excite the electron)  The remaining colour / frequency / wavelength / energy is transmitted (through the solution)	1  1	If light emitted, CE = 0  Allow light reflected is the colour that we see.
6(c)	Bigger  Blue light would be absorbed <b>OR</b> light that has greater energy than red light would be absorbed <b>OR</b> higher frequency (of light absorbed / blue light) leads to higher $\Delta E$	1  1	Can only score M2 if M1 is correct.

6(d)	Any <b>three</b> from: <ul style="list-style-type: none"><li>• (Identity of the) metal</li><li>• Charge (on the metal) / oxidation state / charge on complex</li><li>• (Identity of the) ligands</li><li>• Co-ordination number / number of ligands</li><li>• Shape</li></ul>	3 max	
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Question	Marking Guidance	Mark	Comments
7(a)	<p>Iron(II): green (solution) gives a green precipitate</p> $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + \text{CO}_3^{2-} \rightarrow \text{FeCO}_3 + 6\text{H}_2\text{O}$ <p>Iron(III):: yellow / purple / brown / lilac / violet (solution) gives a brown / rusty precipitate</p> <p>Effervescence / gas / bubbles</p> $2[\text{Fe}(\text{H}_2\text{O})_6]^{3+} + 3\text{CO}_3^{2-} \rightarrow 2[\text{Fe}(\text{H}_2\text{O})_3(\text{OH})_3] + 3\text{CO}_2 + 3\text{H}_2\text{O}$	<p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Apply list principle throughout if extra colours and/or extra observations given. Ignore state symbols in equations.</p> <p>Not blue-green ppt.</p> <p>Must start from <math>[\text{Fe}(\text{H}_2\text{O})_6]^{2+}</math></p> <p>Allow equations with <math>\text{Na}_2\text{CO}_3</math></p> <p>Allow <math>\text{CO}_2</math> evolved but not just <math>\text{CO}_2</math></p>
7(b)	<p>Copper(II): blue (solution) gives a green / yellow solution <b>OR</b> blue solution (turns) to green / yellow / olive green</p> $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CuCl}_4]^{2-} + 6\text{H}_2\text{O}$ <p>Cobalt(II): pink (solution) gives a blue solution <b>OR</b> pink solution turns blue</p> $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O}$	<p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Apply list principle throughout if extra colours and/or extra observations given. Ignore state symbols in equations.</p> <p>Allow equations with HCl</p>

7(c)	<p>Iron(II): green (solution) gives a green precipitate</p> $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2 + 2\text{H}_2\text{O}$ <p>Chromium(III): green / ruby / purple / violet / red-violet (solution) gives a green solution <b>OR</b> green / ruby / purple / violet / red-violet solution turns green</p> $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 6\text{OH}^- \rightarrow [\text{Cr}(\text{OH})_6]^{3-} + 6\text{H}_2\text{O}$	1  1  1  1	<p>Apply list principle throughout if extra colours and/or extra observations given. Ignore state symbols in equations.</p> <p>Allow equations with NaOH</p> <p>Ignore green ppt.</p> <p>Allow also with 4 or 5 OH balanced with 2 or 1 waters.</p> <p>Also allow two correct equations showing <math>\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3</math> as intermediate.</p>
7(d)	<p>Al: colourless (solution) gives a white ppt</p> $[\text{Al}(\text{H}_2\text{O})_6]^{3+} + 3\text{NH}_3 \rightarrow \text{Al}(\text{H}_2\text{O})_3(\text{OH})_3 + 3\text{NH}_4^+$ <p>Ag: colourless (solution) remains a colourless solution / no visible change</p> $[\text{Ag}(\text{H}_2\text{O})_2]^+ + 2\text{NH}_3 \rightarrow [\text{Ag}(\text{NH}_3)_2]^+ + 2\text{H}_2\text{O}$	1  1  1  1	<p>Apply list principle throughout if extra colours and/or extra observations given. Ignore state symbols in equations.</p> <p>Allow <math>+ 3\text{OH}^- \rightarrow 3\text{H}_2\text{O}</math> if <math>\text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4^+ + \text{OH}^-</math> also</p> <p>Ignore brown ppt.</p> <p>Allow 2 / 3 equations involving <math>\text{Ag}_2\text{O}</math> or <math>\text{Ag}(\text{OH})_2</math></p>



Question	Marking Guidance	Mark	Comments
8(a)	<p>Cobalt has variable oxidation states</p> <p>(It can act as an intermediate that) lowers the activation energy</p> $\text{CH}_3\text{CHO} + 2\text{Co}^{3+} + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{COOH} + 2\text{Co}^{2+} + 2\text{H}^+$ $\frac{1}{2}\text{O}_2 + 2\text{Co}^{2+} + 2\text{H}^+ \rightarrow 2\text{Co}^{3+} + \text{H}_2\text{O}$	<p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Allow exists as Co(II) and Co(III)</p> <p>Allow (alternative route with) lower <math>E_a</math></p> <p>Allow multiples; allow molecular formulae</p> <p>Allow equations with <math>\text{H}_3\text{O}^+</math></p>
8(b)(i)	$[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 3\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2 \rightarrow [\text{Co}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_3]^{2+} + 6\text{H}_2\text{O}$ <p>The number of particles increases / changes from 4 to 7</p> <p>So the entropy change is positive / disorder increases / entropy increases</p>	<p>1</p> <p>1</p> <p>1</p>	<p>Do not allow en in equation, allow <math>\text{C}_2\text{H}_8\text{N}_2</math></p> <p>Can score M2 and M3 even if equation incorrect or missing provided number of particles increases.</p>
8(b)(ii)	<p>Minimum for <b>M1</b> is 3 bidentate ligands bonded to Co</p> <p>Ligands need not have any atoms shown but diagram must show 6 bonds from ligands to Co, 2 from each ligand</p> <p>Minimum for <b>M2</b> is one ligand identified as <math>\text{H}_2\text{N}-\text{NH}_2</math></p> <p>Minimum for <b>M3</b> is one bidentate ligand showing two arrows from separate nitrogens to cobalt</p>	<p>1</p> <p>1</p> <p>1</p>	<p>Ignore all charges for M1 and M3 but penalise charges on any ligand in M2</p> <p>Allow linkage as -C-C- or just a line.</p>

8(c)	<p>Moles of cobalt = <math>(50 \times 0.203)/1000 = \underline{0.01015}</math> mol</p> <p>Moles of AgCl = <math>4.22/143.4 = 0.0294</math></p> <p>Ratio = Cl<sup>-</sup> to Co = 2.9 : 1</p> <p>[Co(NH<sub>3</sub>)<sub>6</sub>]Cl<sub>3</sub> (square brackets not essential)</p> <p>Difference due to incomplete oxidation in the preparation</p>	1	Allow 0.0101 to 0.0102
		1	Allow 0.029 If not AgCl (eg AgCl <sub>2</sub> or AgNO <sub>3</sub> ), lose this mark and can only score <b>M1</b> , <b>M4</b> and <b>M5</b>
		1	Do not allow 3 : 1 if this is the only answer but if 2.9:1 seen somewhere in answer credit this as <b>M3</b>
		1	Allow incomplete reaction. Allow formation [Co(NH <sub>3</sub> ) <sub>5</sub> Cl]Cl <sub>2</sub> etc. Some chloride ions act as ligands / replace NH <sub>3</sub> in complex. Do not allow 'impure sample' or reference to practical deficiencies.