AQA A-LEVEL CHEMISTRY

CHEMISTRY



EXAM QUESTION PACK

UNIT 5 OLD SPECIFICATION PAPERS

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AQA

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A-level CHEMISTRY

Unit 5 Energetics, Redox and Inorganic Chemistry

Wednesday 22 June 2016 Morning Time allowed: 1 hour 45 minutes

Materials

For this paper you must have:
- the Periodic Table/Data Sheet provided as an insert (enclosed)
- a ruler with millimetre measurements
- a calculator.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator, where appropriate.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use scientific terminology accurately.

Advice

- You are advised to spend about 75 minutes on **Section A** and about 30 minutes on **Section B**.

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Section A

Answer **all** questions in the spaces provided.

1 This question is about the elements in Period 3 from sodium to phosphorus (Na to P) and their oxides.

1 (a) Element **X** forms an oxide that has a low melting point. This oxide dissolves in water to form an acidic solution.

1 (a) (i) Deduce the type of bonding in this oxide of **X**.

[1 mark]

1 (a) (ii) Identify element **X**.

[1 mark]

1 (a) (iii) Write an equation for the reaction between this oxide of **X** and water.

[1 mark]

1 (b) Element **Y** reacts vigorously with water. An oxide of **Y** dissolves in water to form a solution with a pH of 14.

1 (b) (i) Deduce the type of bonding in this oxide of **Y**.

[1 mark]

1 (b) (ii) Identify element **Y**.

[1 mark]

1 (b) (iii) Write an equation for the reaction of element **Y** with water.

[1 mark]

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1 (b) (iv) Write an equation for the reaction of this oxide of **Y** with hydrochloric acid.

[1 mark]

1 (c) Element **Z** forms an amphoteric oxide that has a very high melting point.

1 (c) (i) Deduce the type of bonding in this oxide of **Z**.

[1 mark]

1 (c) (ii) Write the formula of this amphoteric oxide.

[1 mark]

1 (c) (iii) State the meaning of the term amphoteric.

[1 mark]

1 (c) (iv) Write two equations to show the amphoteric nature of the oxide of **Z**.

[2 marks]

12

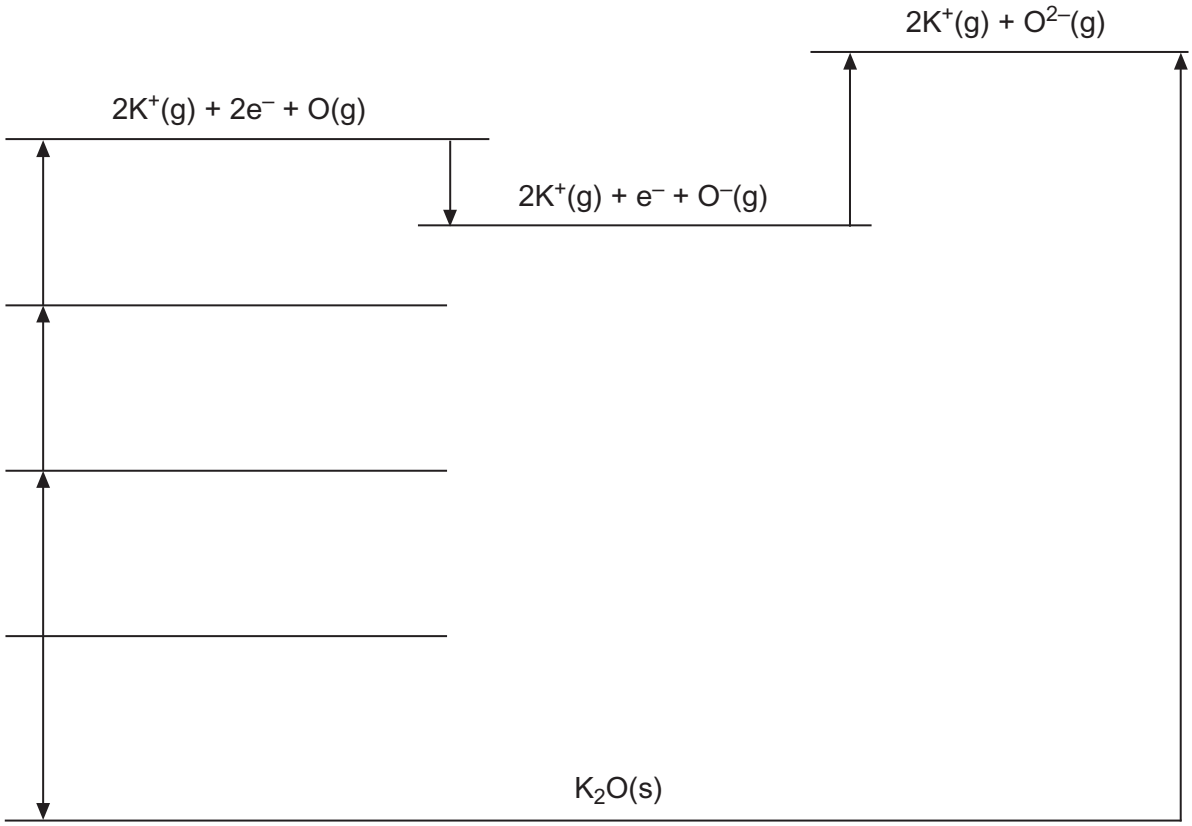
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2 (a) **Figure 1** is a Born–Haber cycle for potassium oxide, K_2O. **Figure 1** is not to scale and not fully labelled.

2 (a) (i) Complete **Figure 1** by writing the formulae, including state symbols, of the appropriate species on each of the three blank lines.

[3 marks]

Figure 1



Do not write outside the box

2 (a) (ii) **Table 1** shows some enthalpy data.

Table 1

Enthalpy change	$\Delta H^{\ominus}$ **/ kJ mol^{-1}**
Enthalpy of atomisation of potassium	+90
First ionisation enthalpy of potassium	+418
Enthalpy of atomisation of oxygen	+248
First electron affinity of oxygen	–142
Second electron affinity of oxygen	+844
Enthalpy of formation of potassium oxide	–362

Use the data in **Table 1** to calculate the enthalpy of lattice dissociation of potassium oxide, K_2O

[3 marks]

2 (b) Explain why the enthalpy of lattice dissociation of potassium oxide is less endothermic than that of sodium oxide.

[2 marks]

8

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3 This question is about magnesium chloride.

3 (a) Write the equation, including state symbols, for the process corresponding to the enthalpy of solution of magnesium chloride.

[1 mark]

3 (b) Use these data to calculate the standard enthalpy of solution of magnesium chloride.

Enthalpy of lattice dissociation of $MgCl_2$	= +2493 kJ mol^{-1}
Enthalpy of hydration of magnesium ions	= –1920 kJ mol^{-1}
Enthalpy of hydration of chloride ions	= –364 kJ mol^{-1}

[2 marks]

3 (c) Solubility is the measure of how much of a substance can be dissolved in water to make a saturated solution. A salt solution is saturated when an undissolved solid is in equilibrium with its aqueous ions.

Use your answer to part **(b)** to deduce how the solubility of $MgCl_2$ changes as the temperature is increased.
Explain your answer.

[3 marks]

6

Turn over for the next question

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ANSWER IN THE SPACES PROVIDED

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4 **Table 2** shows some standard electrode potential data.

Table 2

Electrode half-reaction	$E^{\ominus}$ / V
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	–0.76
$Co^{2+}(aq) + 2e^- \rightarrow Co(s)$	–0.28
$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l)$	+1.23
$Au^+(aq) + e^- \rightarrow Au(s)$	+1.68
$Co^{3+}(aq) + e^- \rightarrow Co^{2+}(aq)$	+1.82

4 (a) (i) Identify the weakest oxidising agent in **Table 2**.

[1 mark]

_____

4 (a) (ii) Give the conditions under which the electrode potential of the Zn^{2+}/Zn electrode is –0.76 V.

[2 marks]

_____

_____

_____

4 (b) Two half-cells, involving species in **Table 2**, are connected together to give a cell with an e.m.f. = +0.48 V.

Use data from **Table 2** to deduce the conventional representation of this cell.
Write the half-equation for the reaction that occurs at the negative electrode.

[3 marks]

Conventional representation _____

_____

Half-equation _____

Do not write outside the box

4 (c) Use data from **Table 2** to identify a cobalt species that can react with water.

Write an equation for the redox reaction that occurs and identify the oxidation product in the reaction.

[3 marks]

Cobalt species _____

Equation _____

_____

_____

Oxidation product _____

4 (d) Use data from **Table 2** to explain why gold jewellery is unreactive in moist air.

[2 marks]

_____

_____

_____

_____

_____

_____

11

Turn over for the next question

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5 A representation of a hydrogen–oxygen fuel cell that operates in alkaline conditions is

$$Pt|H_2|H_2O||O_2|OH^-|Pt$$

5 (a) (i) Write a half-equation for the reaction that occurs at each electrode.
Use the half-equations to deduce an overall equation for the cell.

[3 marks]

Half-equation at positive electrode _____

Half-equation at negative electrode _____

Overall equation _____

5 (a) (ii) State and explain the effect, if any, of increasing the pressure of oxygen on the e.m.f of this cell.

[2 marks]

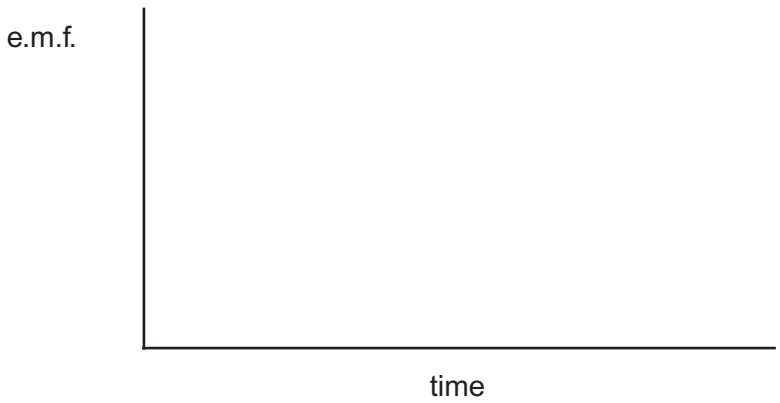
Effect on e.m.f. _____

Explanation _____

_____

5 (b) Complete the diagram to show how the e.m.f. of a hydrogen–oxygen fuel cell changes with time.

[1 mark]



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5 (c) (i) Suggest the effect, if any, on the e.m.f. of this cell if the surface area of each platinum electrode is increased.

[1 mark]

5 (c) (ii) State the main environmental advantage of using a hydrogen–oxygen fuel cell to power a car.

[1 mark]

5 (d) Suggest why the use of a hydrogen–oxygen fuel cell might not be carbon-neutral.

[1 mark]

9

Turn over for the next question

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6 In the Contact Process sulfur dioxide reacts with oxygen to form sulfur trioxide as shown in the equation.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

Table 3 shows some thermodynamic data.

Table 3

	$\Delta H_f^{\ominus}$ /kJ mol^{-1}	$S^{\ominus}$/J K^{-1} mol^{-1}
$SO_2(g)$	–297	248
$O_2(g)$	0	205
$SO_3(g)$	–395	256

6 (a) Use data from **Table 3** to calculate the standard enthalpy change for this reaction.

[2 marks]

6 (b) Use data from **Table 3** to calculate the standard entropy change for this reaction.

[2 marks]

6 (c) State what the sign of the entropy change in your answer to part **(b)** indicates about the product of this reaction relative to the reactants.

[1 mark]

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6 (d) Use your answers to parts **(a)** and **(b)** to calculate a value for the free–energy change for this reaction at 50 °C.

(If you were unable to calculate ΔH in part **(a)** assume a value of –250 kJ mol^{-1}
If you were unable to calculate ΔS in part **(b)** assume a value of –250 J K^{-1} mol^{-1}
These are not the correct values.)

[3 marks]

6 (e) Use your answer to part **(d)** to explain whether the reaction is feasible at 50 °C

[1 mark]

6 (f) Vanadium(V) oxide acts as a heterogeneous catalyst in the Contact Process.

6 (f) (i) State what is meant by the term heterogeneous.

[1 mark]

6 (f) (ii) Write **two** equations that show how this catalyst is involved in the Contact Process.

[2 marks]

Do not write outside the box

6 (f) (iii) Suggest why the vanadium(V) oxide is used in small pellet form rather than as large lumps.

[1 mark]

6 (f) (iv) State why the reactants should be purified before they come into contact with the vanadium(V) oxide.

[1 mark]

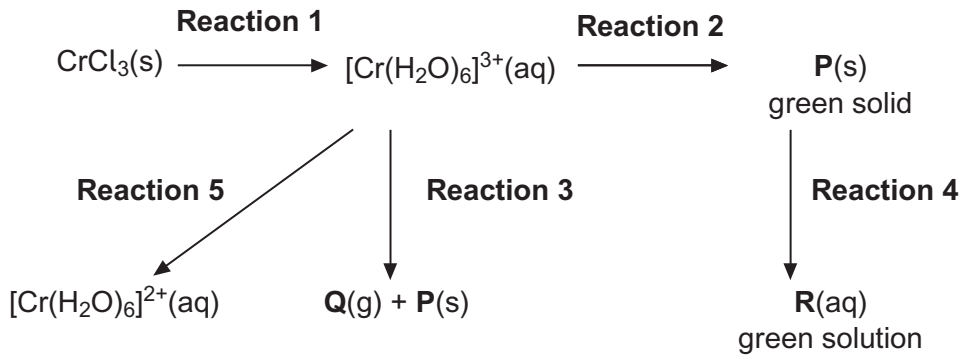
14

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7 The following scheme shows some reactions of chromium compounds.



7 (a) Write an equation for **Reaction 1**.

[1 mark]

_____

7 (b) For **Reaction 2,** identify the complex **P**, state a reagent and write an equation.

[3 marks]

Identity of **P** _____

Reagent _____

Equation _____

_____

7 (c) For **Reaction 3**, identify **Q**, state a reagent and write an equation.

[3 marks]

Identity of **Q** _____

Reagent _____

Equation _____

_____

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7 (d) For **Reaction 4**, identify the complex **R**, state a reagent and write an equation for the formation of **R** from **P**.

[3 marks]

Identity of **R** _____

Reagent _____

Equation _____

_____

7 (e) For **Reaction 5** suggest the reagents and state the colour of $[Cr(H_2O)_6]^{2+}(aq)$.

[2 marks]

Reagents _____

Colour _____

12

Turn over for the next question

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Section B

Answer **all** questions in the spaces provided.

8 This question is about cobalt chemistry.

8 (a) Give the electron configuration of the Co atom and of the Co^{2+} ion.

State three characteristic features of the chemistry of cobalt and its compounds.

[5 marks]

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8 (b) Ethane-1,2-diamine can act as a bidentate ligand. When $[Co(H_2O)_6]^{2+}(aq)$ ions are treated with an excess of ethane-1,2-diamine, the water ligands are replaced.

Explain what is meant by the term bidentate ligand.

Explain, with the aid of an equation, the thermodynamic reasons why this reaction occurs.

Draw a diagram to show the structure of the complex ion formed.

[7 marks]

12

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9 A student weighed out a 2.29 g sample of impure $K_3[Fe(C_2O_4)_3].3H_2O$ and dissolved it in water.
This solution was added to a 250 cm^3 volumetric flask and made up to 250 cm^3 with distilled water.
A 25.0 cm^3 portion was pipetted into a conical flask and an excess of acid was added.
The mixture was heated to 60 ºC and titrated with 0.0200 mol dm^{-3} $KMnO_4$ solution.
26.40 cm^3 of $KMnO_4$ solution were needed for a complete reaction.

In this titration only the $C_2O_4^{2-}$ ions react with the $KMnO_4$ solution.

9 (a) The reaction between $C_2O_4^{2-}$ ions and MnO_4^- ions is autocatalysed.

Explain what is meant by the term autocatalysed and identify the catalyst in the reaction.

[2 marks]

9 (b) Select from the list the most suitable substance used to acidify the solution in the conical flask.
Put a tick (✓) in the correct box.

[1 mark]

$H_2C_2O_4$ ☐

H_2SO_4 ☐

HCl ☐

HNO_3 ☐

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9 (c) The reaction between $C_2O_4^{2-}$ ions and MnO_4^- ions is very slow at first.
Explain why the reaction is initially slow.

[3 marks]

9 (d) Write an equation for the reaction between $C_2O_4^{2-}$ ions and MnO_4^- ions in acidic solution.
Calculate the percentage purity of the original sample of $K_3[Fe(C_2O_4)_3].3H_2O$
Give your answer to 3 significant figures.

[7 marks]

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9 (e) A solution of $KMnO_4$ has an unknown concentration.

Describe briefly how colorimetry can be used to determine the concentration of this solution.

[3 marks]

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END OF QUESTIONS

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AQA Qualifications

A-LEVEL

Chemistry

CHEM5 Energetics, Redox and Inorganic Chemistry
Mark scheme

2420
June 2016

Version: 1.0 Final

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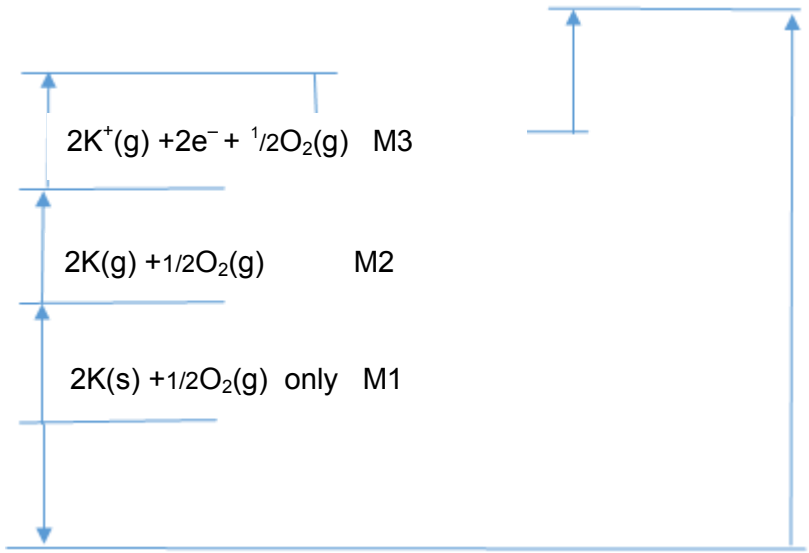
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Question	Marking guidance	Mark	Comments
1ai	Covalent	1	Ignore simple / molecular Do not allow macromolecular/giant covalent/dative/dipole-dipole/Hydrogen bonds Ignore VdW
1aii	P / phosphorus / P_4	1	
1aiii	$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	1	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_4O_6, P_2O_3 and P_2O_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	Ionic	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

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1biv	$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$	1	Accept multiples/fractions Ignore state symbols Allow ions, but do not allow H^+ only for the acid.
1ci	Ionic	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	$Al_2O_3 + 6HCl \rightarrow 2Al^{3+} + 6Cl^- + 3H_2O$ $Al_2O_3 + 6H^+ \rightarrow 2Al^{3+} + 3H_2O$ $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2Na^+ + 2[Al(OH)_4]^-$ $Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2[Al(OH)_4]^-$ $Al_2O_3 + 2NaOH + 7H_2O \rightarrow 2Na^+ + 2[Al(OH)_4(H_2O)_2]^-$ $Al_2O_3 + 2OH^- + 7H_2O \rightarrow 2[Al(OH)_4(H_2O)_2]^-$	1 1	Allow equation to form $2AlCl_3$ (but not Al_2Cl_6) Allow equations with other acids Allow equations to form $2Na[Al(OH)_4]$ or $2Na[Al(OH)_4(H_2O)_2]$ Allow equations with other alkalis Allow correct equations which form $[Al(OH)_6]^{3-}$ Allow equations to form $[Al(OH)_x(H_2O)_{6-x}]^{3-x}$ etc. Ignore state symbols

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Question	Marking guidance	Mark	Comments
2ai		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 $2K(g) + O(g)$ M3 $2K(g) + {}^1/_2O_2(g)$ M2 $2K(s) + {}^1/_2O_2(g)$ only M1 or $2K(g) + O(g)$ M3 $2K(s) + O(g)$ M2 $2K(s) + {}^1/_2O_2(g)$ only M1

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2aii	(2 x 90) + 248 + (2 x 418) – 142 + 844 = – 362 + Lattice enthalpy of dissociation enthalpy of lattice dissociation = (+) 2328 ($kJmol^{-1}$)	3	M1 for (2 x 90) and (2 x 418) 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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2b	K^+ (ion)/K ion is bigger (than Na^+ ion)	1	K^+ has lower charge density / Na^+ has higher charge density. Ignore K atom is bigger
	(Electrostatic) attraction between (oppositely charged) ions is weaker	1	If attraction is between incorrect ions, then lose M2 *Attraction between molecules/atoms or mention of intermolecular forces CE=0/2* Allow converse for Na_2O if explicit

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Question	Marking guidance	Mark	Comments
3a	$MgCl_2(s) \rightarrow Mg^{2+}(aq) + 2Cl^-(aq)$	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 $[Mg(H_2O)_6]^{2+}$ ions.
3b	$\Delta H_{soln}\ MgCl_2 = LE + (\Delta H_{hyd}Mg^{2+}) + 2(\Delta H_{hyd}Cl^-)$ $\Delta H_{soln}\ MgCl_2 = 2493 - 1920 + (2 \times -364)$ $= -155\ (kJ\ mol^{-1})$	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)

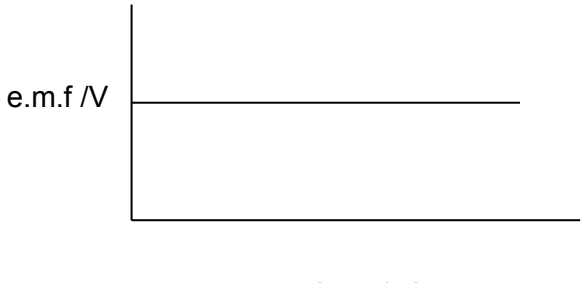
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Question	Marking guidance	Mark	Comments
4ai	Zn^{2+}	1	$Zn^{2+}(aq)$ Apply List
4aii	298 K /25°C (solutions at) unit concentration / 1 mol dm^{-3} (of Zn^{2+})	1 1	Ignore pressure Ignore standard conditions Ignore state symbols Ignore references to S.H.E
4b	Identifying it is the Zn/Zn^{2+} and Co^{2+}/Co half cells Zn $\vert$ $Zn^{2+}\vert$ $\vert$ $Co^{2+}\vert$ Co $Zn \rightarrow Zn^{2+} + 2e^{(-)}$	1 1 1	 correct order with phase boundaries and salt bridge correct, no Pt If this is correct it scores M1 and M2 *Allow double dashed line for salt bridge* *Extra phase boundaries loses M2* Ignore state symbols M3 independent Allow $-2e^{-}$ on LHS

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4c	$\underline{Co^{3+}}$ $2Co^{3+}(aq) + H_2O(l) \rightarrow 2Co^{2+}(aq) + ½ O_2(g) + 2H^+(aq)$ Oxygen /O_2	1 1 1	Mark independently. Ignore state symbols allow multiples Allow ½ O_2
4d	$E^{\ominus}$ (O_2|H_2O) electrode < $E^{\ominus}$ (Au^+|Au) OR $E^{\ominus}$ (Au^+|Au) > $E^{\ominus}$ (O_2|H_2O) OR the $E^{\ominus}$ (Au^+|Au) electrode potential is more positive than the $E^{\ominus}$ (O_2|H_2O) electrode OR The emf (for the reaction of Au and oxygen) is –0.45 V (and therefore not spontaneous) so <u>oxygen</u> is unable to oxidise gold	1 1	Mark independently Ignore references to water Allow gold cannot reduce <u>oxygen</u>

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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		1	Must start at y-axis
5ci	Unchanged	1	

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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_xH_y or unburnt hydrocarbons	1	Not fuel cell does not give out pollutants unless pollutant stated
5d	<u>CO_2 is released</u> because fossil fuels are burned to produce electricity <u>to generate hydrogen</u> OR <u>CO_2 is released</u> when methane reacts with steam <u>to produce hydrogen</u>	1	Allow CO_2 is released to produce the hydrogen

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Question	Marking guidance	Mark	Comments
6a	$\Delta H^{\ominus}$ = Σ $\Delta H_f^{\ominus}$ products - Σ $\Delta H_f^{\ominus}$ reactants or (2 × –395) – (2 × –297) = –196 (kJ mol $^{-1}$)	1 1	 Penalise incorrect units, ignore missing units
6b	$\Delta S^{\ominus}$ = $\Sigma S^{\ominus}$ products - $\Sigma S^{\ominus}$ reactants = (2 × 256) – 205 – (2 × 248) = –189 $\underline{JK^{-1}\ mol^{-1}}$	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

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6d	$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ $= -196 - 323 (-189/1000)$ $= -134.9$ kJ mol^{-1}	1 1 1	Do not insist on standard state symbol If conversion of T or ΔS incorrect, then can only score M1 Must have correct units. Allow answers in J mol^{-1} -135 kJ mol^{-1} If both alternative values used then -169(.3) kJ mol^{-1}. Allow alternative ΔH and/or alternative ΔS in calculation
6e	Feasible because ΔG is negative	1	Allow mark if a correct deduction from answer to 6d Both a reference to feasibility and to ΔG needed
6fi	(The catalyst is in) a different state or phase (from the reactants)	1	
6fii	$SO_2 + V_2O_5 \rightarrow SO_3 + V_2O_4$ $\frac{1}{2}O_2 + V_2O_4 \rightarrow V_2O_5$	1 1	allow $2VO_2$ instead of V_2O_4 allow multiples Must have equations in this order.
6fiii	Surface area is increased	1	
6fiv	So that the catalyst is not poisoned	1	Allow correct reference to the blocking active sites

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Question	Marking guidance	Mark	Comments
7a	$CrCl_3 + 6H_2O \rightarrow [Cr(H_2O)_6]^{3+} + 3Cl^-$	1	Ignore state symbols
7b	M1 **P** = $Cr(OH)_3(H_2O)_3$ M2 NaOH (not excess) or NH_3 or names M3 $[Cr(H_2O)_6]^{3+} + 3OH^- \rightarrow [Cr(OH)_3(H_2O)_3] + 3H_2O$ $[Cr(H_2O)_6]^{3+} + 3NH_3 \rightarrow [Cr(OH)_3(H_2O)_3] + 3NH_4^+$	3	Ignore state symbols Penalise charges on ligands in complex ion formulae Do not transfer M1 from equation Allow KOH do not allow OH^- /excess NaOH but mark on Equations must match reagent but if NH_3 then also allow two equations $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$ $[Cr(H_2O)_6]^{3+} + 3OH^- \rightarrow [Cr(OH)_3(H_2O)_3] + 3H_2O$ Do not allow $Cr(OH)_3$ as identity of P, or in equation

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7c	M1 **Q** = CO_2 M2 Na_2CO_3 or $NaHCO_3$ or K_2CO_3 M3 $2[Cr(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2[Cr(OH)_3(H_2O)_3] + 3CO_2 + 3H_2O$	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_2CO_3 but mark on. Do not allow equations that give $Cr(OH)_3$ allow $[Cr(H_2O)_6]^{3+} + 3HCO_3^{-} \rightarrow [Cr(OH)_3(H_2O)_3] + 3CO_2 + 3H_2O$

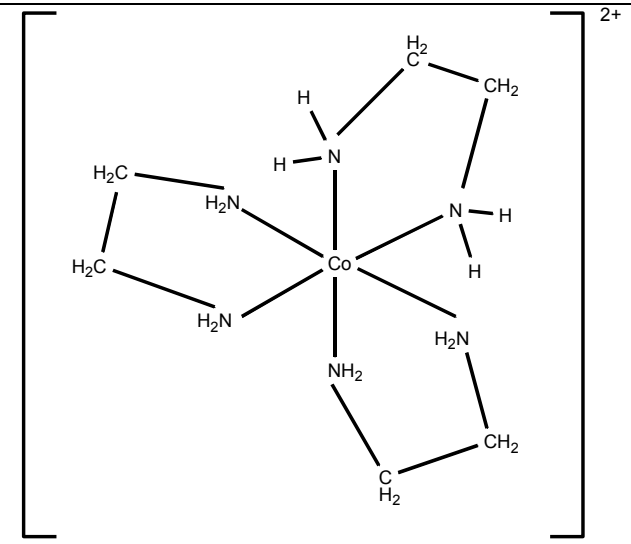
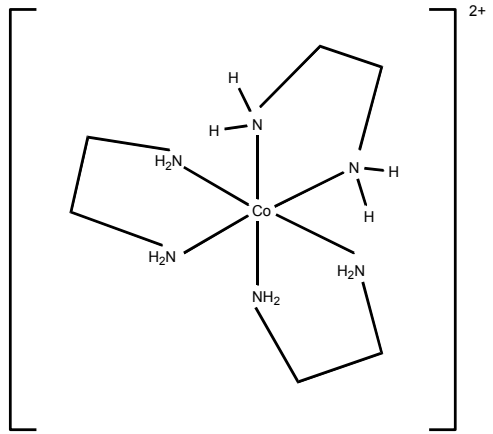
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7d	Either **M1** **R** = $[Cr(OH)_6]^{3-}$ **M2** NaOH or KOH **M3** $[Cr(OH)_3(H_2O)_3] + 3OH^- \rightarrow [Cr(OH)_6]^{3-} + 3H_2O$ OR **M1** **R** = $[Cr(H_2O)_6]^{3+}$ **M2** HCl or any named acid **M3** $[Cr(OH)_3(H_2O)_3] + 3H^+ \rightarrow [Cr(H_2O)_6]^{3+}$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

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Question	Marking guidance	Mark	Comments
8a	[Ar] $4s^2\ 3d^7$ or $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^7$ [Ar] $3d^7$ or $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7$ Any 3 Variable oxidation state Act as catalysts Form complexes Form coloured ions/compounds	1 1 3	Allow 4s and 3d in either order
8b	Two atoms that each donate a lone pair (of electrons) / coordinate bonds from two atoms Formula of ethane-1,2- diamine: $NH_2CH_2CH_2NH_2$ $[Co(H_2O)_6]^{2+} + 3NH_2CH_2CH_2NH_2 \rightarrow [Co(NH_2CH_2CH_2NH_2)_3]^{2+} + 6H_2O$ There is an increase in the number of particles / the reaction goes from 4 moles to 7 moles disorder/entropy increases / ΔS is positive ΔG negative	1 1 1 1 1 1	M2 gained from equation or structure Equation must be balanced inc charges Allow en or $C_2H_8N_2$ in equation for ethane-1,2-diamine . Allow increase number of molecules/moles. Allow numbers that match an incorrect equation

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	 Or 	1	Mark for correct structure (ignore charges -even if wrong) NH_2 can be shown in either way – see structure

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Question	Marking guidance	Mark	Comments
9a	A reaction that produces its own catalyst/ one of the products is the catalyst Mn^{2+}	1 1	 Allow Mn^{3+}
9b	H_2SO_4	1	
9c	There is no/very little catalyst at the start OR the reaction only speeds up when the catalyst is produced Two negative ions (MnO_4^- and $C_2O_4^{2-}$) <u>repel</u> The <u>activation energy</u> for the reaction is high / heat is required to overcome the <u>activation energy</u>	1 1 1	 Reference to molecules loses M2

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9d	M1 5 $C_2O_4^{2-}(aq)$ + 2 $MnO_4^-(aq)$ + 16 $H^+(aq)$ → 10 $CO_2(g)$ + 2 $Mn^{2+}(aq)$ + 8 $H_2O(l)$	1	Ignore state symbols
	M2 $n(MnO_4^-) = \frac{26.40 \times 0.02}{1000}$ OR $n(MnO_4^-) = 5.28 \times 10^{-4}$	1	
	M3 $n(C_2O_4^{2-}) = \frac{5}{2} \times 5.28 \times 10^{-4} = 1.32 \times 10^{-3}$	1	M3 is for M2 x 5/2 If wrong ratio used then can only score M2, M4, M5 and M6
	M4 $n(C_2O_4^{2-}$ in flask originally) = $1.32 \times 10^{-3} \times 10 = 1.32 \times 10^{-2}$	1	M4 is for M3 x 10
	M5 $n(K_3[Fe(C_2O_4)_3].3H_2O) = \frac{1.32 \times 10^{-2}}{3} = 4.40 \times 10^{-3}$ (*Mr* $K_3[Fe(C_2O_4)_3].3H_2O$ = 491.1)	1	M5 is for M4 ÷ 3
	M6 Mass of $K_3[Fe(C_2O_4)_3].3H_2O$ reacted = $4.40 \times 10^{-3} \times 491.1$ = 2.16 g	1	M6 is for M5 x 491(.1)
	M7 % purity = $\frac{2.16}{2.29} \times 100$ = 94.3 or 94.4%	1	Answer must be to 3 s.f. Correct answer scores 6 marks; mark equation separately Alternative method using ratio by moles: M5 $n(C_2O_4^{2-}) = 4.66 \times 10^{-3} \times 3 = 0.0140$ moles in $250cm^3$ M6 n(complex) = 2.29/491.1 = 4.66×10^{-3} moles in $250cm^3$ M7 % = 0.0132/0.0140 x 100 = 94.3 or 94.4%

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9e	Make some known 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

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Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
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TOTAL	

AQA

General Certificate of Education
Advanced Level Examination
June 2015

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Monday 15 June 2015 1.30 pm to 3.15 pm

For this paper you must have:
- the Periodic Table/Data Sheet, provided as an insert (enclosed)
- a ruler with millimetre measurements
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator, where appropriate.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use scientific terminology accurately.

Advice
- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.

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Section A

Answer **all** questions in the spaces provided.

1 (a) Define the term **electron affinity** for chlorine.

[2 marks]

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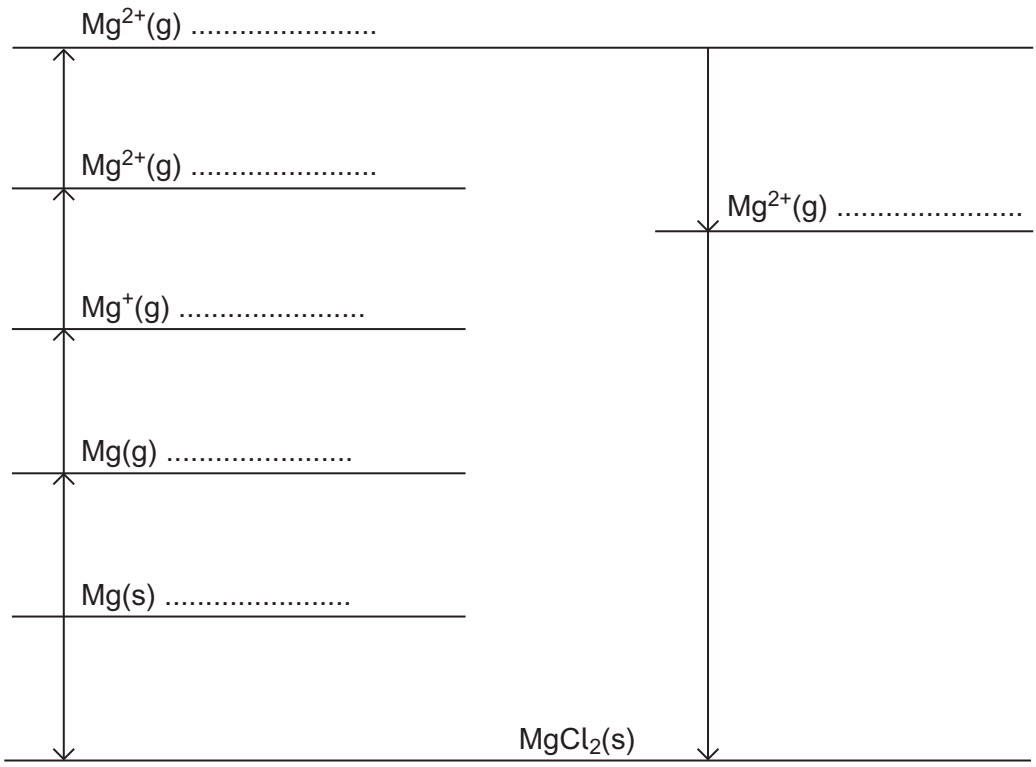
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1 (b) Complete this Born–Haber cycle for magnesium chloride by giving the missing species on the dotted lines. Include state symbols where appropriate.

The energy levels are **not** drawn to scale.

[6 marks]



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1 (c) **Table 1** contains some enthalpy data.

Table 1

	Enthalpy change / kJ mol^{-1}
Enthalpy of atomisation of magnesium	+150
Enthalpy of atomisation of chlorine	+121
First ionisation energy of magnesium	+736
Second ionisation energy of magnesium	+1450
Enthalpy of formation of magnesium chloride	–642
Lattice enthalpy of formation of magnesium chloride	–2493

Use your Born–Haber cycle from Question **1 (b)** and data from **Table 1** to calculate a value for the electron affinity of chlorine.

[3 marks]

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Question 1 continues on the next page

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1 (d) **Table 2** contains some more enthalpy data.

Table 2

	Enthalpy change / kJ mol^{-1}
Enthalpy of hydration of Mg^{2+} ions	–1920
Enthalpy of hydration of Na^{+} ions	–406
Enthalpy of hydration of Cl^{-} ions	–364

1 (d) (i) Explain why there is a difference between the hydration enthalpies of the magnesium and sodium ions.

[2 marks]

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1 (d) (ii) Use data from **Table 1** and **Table 2** to calculate a value for the enthalpy change when one mole of magnesium chloride dissolves in water.

[2 marks]

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Turn over for the next question

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2 **Table 3** contains some bond enthalpy data.

Table 3

Bond	H—H	O=O	H—O
Bond enthalpy / kJ mol^{-1}	436	496	464

2 (a) The value for the H—O bond enthalpy in **Table 3** is a mean bond enthalpy.

State the meaning of the term **mean bond enthalpy** for the H—O bond.

[2 marks]

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2 (b) Use the bond enthalpies in **Table 3** to calculate a value for the enthalpy of formation of water in the gas phase.

[3 marks]

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2 (c) The standard enthalpy of combustion of hydrogen, forming water in the gas phase, is almost the same as the correct answer to Question **2 (b)**.

2 (c) (i) Suggest **one** reason why you would expect the standard enthalpy of combustion of hydrogen to be the same as the answer to Question **2 (b)**.

[1 mark]

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2 (c) (ii) Suggest **one** reason why you would expect the standard enthalpy of combustion of hydrogen to differ slightly from the answer to Question **2 (b)**.

[1 mark]

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Turn over for the next question

Do not write outside the box

3 Hydrogen can be manufactured from the reaction of steam with methane.

$$CH_4(g) + H_2O(g) \longrightarrow CO(g) + 3H_2(g)$$

3 (a) **Table 4** contains some enthalpy of formation and entropy data.

Table 4

Substance	**$\Delta H^{\ominus}_f$ / kJ mol^{-1}**	**$S^{\ominus}$ / J K^{-1} mol^{-1}**
$CH_4(g)$	–75	186
$H_2O(g)$	–242	189
$CO(g)$	–111	198
$H_2(g)$	0	131
$CO_2(g)$	–394	214

3 (a) (i) Use data from **Table 4** to calculate the enthalpy change, ΔH, for the reaction of steam with methane.

[3 marks]

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3 (a) (ii) Use data from **Table 4** to calculate the entropy change, ΔS, for the reaction of steam with methane.

[2 marks]

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3 (b) Use your values of ΔH and ΔS from Questions **3 (a) (i)** and **3 (a) (ii)** to calculate the temperature above which this reaction is feasible.

[4 marks]

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3 (c) The temperature used for this manufacture of hydrogen is usually about 1300 K.

Suggest **one** reason, other than changing the position of equilibrium, why this temperature is used rather than the value that you calculated in Question **3 (b)**.

[1 mark]

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Question 3 continues on the next page

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3 (d) Hydrogen can also be obtained by reaction of carbon monoxide with steam.

$$CO(g) + H_2O(g) \longrightarrow CO_2(g) + H_2(g) \qquad \Delta H = -41 \text{ kJ mol}^{-1}, \ \Delta S = -42 \text{ J K}^{-1} \text{ mol}^{-1}$$

3 (d) (i) Explain, using a calculation, why this reaction should **not** occur at 1300 K.

[3 marks]

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3 (d) (ii) Explain how the conditions for the reaction could be changed to allow this reaction to take place.

[2 marks]

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4 (a) Write an equation for the reaction that occurs when magnesium is heated in steam. Describe what you would observe when this reaction occurs.

[3 marks]

Equation .....

Observations .....

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4 (b) Write an equation for the reaction that occurs when sodium is heated in oxygen. Describe what you would observe when this reaction occurs.

[3 marks]

Equation .....

Observations .....

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Turn over for the next question

Do not write outside the box

5 (a) **Table 5** contains data that show a trend in the melting points of some oxides of the Period 3 elements.

Table 5

Oxide	Sodium oxide	Magnesium oxide	Aluminium oxide	Silicon(IV) oxide	Phosphorus(V) oxide	Sulfur(IV) oxide
Melting point / K		3125	2345	1883	573	

5 (a) (i) Use data from **Table 5** to predict an approximate melting point for sodium oxide.

Tick (✓) **one** box.

[1 mark]

250 K ☐

500 K ☐

1500 K ☐

3500 K ☐

5 (a) (ii) Explain, in terms of structure and bonding, why sodium oxide has a high melting point.

[2 marks]

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Do not write outside the box

5 (a) (iii) Use data from **Table 5** to predict a value for the melting point of sulfur(IV) oxide.

Suggest, in terms of structure and bonding, why the melting point of sulfur(IV) oxide is different from that of phosphorus(V) oxide.

[3 marks]

Predicted melting point of sulfur(IV) oxide .....

Why the melting point is different from phosphorus(V) oxide .....

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5 (b) Write an equation for the reaction of sulfur(IV) oxide with water.

Suggest the pH value of the resulting solution.

[2 marks]

Equation

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pH value .....

5 (c) Silicon(IV) oxide is insoluble in water.

Explain, using an equation, why silicon(IV) oxide is classified as an acidic oxide.

[2 marks]

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Turn over ▶

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6 **Table 6** contains some standard electrode potential data.

Table 6

Electrode half-equation	$E^{\ominus}$ / V
$F_2 + 2e^- \longrightarrow 2F^-$	+2.87
$Au^+ + e^- \longrightarrow Au$	+1.68
$2HOCl + 2H^+ + 2e^- \longrightarrow Cl_2 + 2H_2O$	+1.64
$Cl_2 + 2e^- \longrightarrow 2Cl^-$	+1.36
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.23
$Ag^+ + e^- \longrightarrow Ag$	+0.80
$Fe^{3+} + e^- \longrightarrow Fe^{2+}$	+0.77
$2H^+ + 2e^- \longrightarrow H_2$	0.00
$Fe^{2+} + 2e^- \longrightarrow Fe$	–0.44

6 (a) In terms of electrons, explain the meaning of the term **oxidising agent**.

[1 mark]

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6 (b) Identify the weakest oxidising agent in **Table 6**.
Explain your choice.

[2 marks]

Weakest oxidising agent .....

Explanation .....

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Do not write outside the box

6 (c) Write the conventional representation of the cell used to measure the standard electrode potential for the Ag^+/Ag electrode.

State the conditions necessary when measuring this value.

[4 marks]

Conventional representation .....

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Conditions .....

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6 (d) Use data from **Table 6** to explain, in terms of redox, what happens when a soluble gold(I) compound containing Au^+ ions is added to water.

State what you would observe.

Write an equation for the reaction that occurs.

[4 marks]

Explanation .....

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Observation .....

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Equation .....

Question 6 continues on the next page

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Table 6 is repeated below to help you answer these questions.

Table 6

Electrode half-equation	$E^{\ominus}$ / V
$F_2 + 2e^- \longrightarrow 2F^-$	+2.87
$Au^+ + e^- \longrightarrow Au$	+1.68
$2HOCl + 2H^+ + 2e^- \longrightarrow Cl_2 + 2H_2O$	+1.64
$Cl_2 + 2e^- \longrightarrow 2Cl^-$	+1.36
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.23
$Ag^+ + e^- \longrightarrow Ag$	+0.80
$Fe^{3+} + e^- \longrightarrow Fe^{2+}$	+0.77
$2H^+ + 2e^- \longrightarrow H_2$	0.00
$Fe^{2+} + 2e^- \longrightarrow Fe$	–0.44

6 (e) A cell is made by connecting Fe^{2+}/Fe and Ag^+/Ag electrodes with a salt bridge.

6 (e) (i) Calculate the e.m.f. of this cell.

[1 mark]

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Answer = ...

6 (e) (ii) Suggest why potassium chloride would **not** be suitable for use in the salt bridge of this cell.

[1 mark]

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6 (f) Use data from **Table 6** to explain what happens when a solution of iron(II) chloride is exposed to the air.

[2 marks]

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Section B

Answer **all** questions in the spaces provided.

7 (a) A sample of solid chromium(III) hydroxide displays amphoteric character when treated separately with dilute hydrochloric acid and with dilute aqueous sodium hydroxide.

Write an ionic equation for each of these reactions. Include the formula of each complex ion formed.
Describe the changes that you would observe in each reaction.

[5 marks]

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7 (b) Aqueous solutions of copper(II) sulfate and cobalt(II) sulfate undergo ligand substitution reactions when treated separately with an excess of dilute aqueous ammonia.

Write equations for these reactions. Include the formulae for any complex ions. Describe the changes that you would observe in each reaction.

[6 marks]

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Turn over for the next question

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8 A green solution, **X**, is thought to contain $[Fe(H_2O)_6]^{2+}$ ions.

8 (a) The presence of these ions can be confirmed by reacting separate samples of solution **X** with aqueous ammonia and with aqueous sodium carbonate.

Write equations for each of these reactions and describe what you would observe.

[4 marks]

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8 (b) A 50.0 cm^3 sample of solution **X** was added to 50 cm^3 of dilute sulfuric acid and made up to 250 cm^3 of solution in a volumetric flask.

A 25.0 cm^3 sample of this solution from the volumetric flask was titrated with a 0.0205 mol dm^{-3} solution of $KMnO_4$
At the end point of the reaction, the volume of $KMnO_4$ solution added was 18.70 cm^3.

8 (b) (i) State the colour change that occurs at the end point of this titration and give a reason for the colour change.

[2 marks]

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8 (b) (ii) Write an equation for the reaction between iron(II) ions and manganate(VII) ions.

Use this equation and the information given to calculate the concentration of iron(II) ions in the original solution **X**.

[5 marks]

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Turn over for the next question

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9 The redox reaction, in aqueous solution, between acidified potassium manganate(VII) and sodium ethanedioate is autocatalysed.

9 (a) Write an equation for this redox reaction.

Identify the species that acts as the catalyst.

Explain how the properties of the species enable it to act as a catalyst in this reaction.

[6 marks]

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9 (b) Sketch a graph to show how the concentration of MnO_4^- ions varies with time in this reaction.
Explain the shape of the graph.

[4 marks]

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END OF QUESTIONS

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AQA Qualifications

A-LEVEL CHEMISTRY

CHEM5 Energetics, Redox and Inorganic Chemistry
Mark scheme

2420
June 2015

Version 1: Final

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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.

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Question	Marking Guidance	Marks	Comments
1(a)	The <u>enthalpy change / heat energy change/ ΔH</u> for the formation of <u>one mole</u> of (chloride) ions from (chlorine) atoms	1	Allow enthalpy change for $Cl + e^- \rightarrow Cl^-$ Do not allow energy change ionisation energy description is CE=0 Allow enthalpy change for the addition of 1 mol of electrons to Chlorine atoms penalise Cl_2 and chlorine molecules CE=0 allow chlorine ions
	Atoms and ions in the gaseous state	1	Or state symbols in equation Cannot score M2 unless M1 scored except allow M2 if energy change rather than enthalpy change ignore standard conditions

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1 (b)	$Mg^{2+}(g) + 2e^- + 2Cl(g)$ (1) (M5) $Mg^{2+}(g) + 2e^- + Cl_2(g)$ (1) (M4) $Mg^{2+}(g) + 2Cl^-(g)$ (1) (M6) $Mg^+(g) + e^- + Cl_2(g)$ (1) (M3) $Mg(g) + Cl_2(g)$ (1) (M2) $Mg(s) + Cl_2(g)$ (1) (M1) $MgCl_2(s)$	6	Allow e for electrons (i.e no charge) State symbols essential If no electrons allow M5 but not M3,M4 If incorrect 1/2 Cl_2 used allow M3 and M4 for correct electrons (scores 2/6)

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1(c)	$-\Delta H_f(MgCl_2) + \Delta H_a(Mg) + 1^{st}$ IE(Mg) + 2nd IE(Mg) $+2\Delta H_a(Cl)$ $= -2EA(Cl) - LE(MgCl_2)$ $-2EA(Cl) = 642 + 150 + 736 + 1450 + 242 - 2493 = 727$ $EA(Cl) = -364$ (kJ mol^{-1})	1 1 1	Allow Enthalpy of Formation = sum of other enthalpy changes (incl lattice formation) Allow –363 to –364 Allow M1 and M2 for -727 Allow 1 (1 out of 3) for +364 or +363 but award 2 if due to arithmetic error after correct M2 Also allow 1 for –303 Units not essential but penalise incorrect units Look for a transcription error and mark as AE-1

1(d)(i)	Magnesium (ion) is smaller **and** more charged (than the sodium ion) OR magnesium (ion) has higher charge to size ratio / charge density (magnesium ion) attracts water more strongly	1 1	Do not allow wrong charge on ion if given Do not allow similar size for M1 Do not allow mass/charge ratio Mark independently Mention of intermolecular forces, (magnesium) atoms or atomic radius CE=0

1(d)(ii)	Enthalpy change = $-LE(MgCl_2) + \Sigma(\Delta H_{hyd}$ions)		
	$= 2493 + (-1920 + 2 \times -364)$	1	
	$= -155$ (kJ mol^{-1})	1	Units not essential but penalise incorrect units

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Question	Marking Guidance	Mark	Comments
2(a)	The enthalpy (change) to break <u>1 mol</u> of H—O / bonds Averaged over a range of compounds / molecules	1 1	Allow heat energy Penalise energy but mark on ignore states CE=0 for ionic bonds
2(b)	$H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$ ΔH = (H–H) + $\frac{1}{2}$(O=O) – 2(H–O) / sum of(bonds broken) - sum of (bonds formed) = 436 + 496/2 – 2 × 464 = –244 (kJ mol^{-1})	 1 1 1	 Allow 1 mark only for +244 and –488 Units not essential but penalise incorrect units
2(c)(i)	same reaction / same equation / same number / same reactants and same products / same number and type of bonds broken and formed	1	Do not allow similar

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2(c)(ii)	There must be a slight difference between the actual bond enthalpy (in water) and mean bond enthalpies for the O–H bond (in other molecules)	1	Allow bond enthalpy value for enthalpy of formation may not be under standard conditions. Allow reference to bond energy rather than bond enthalpy Do not allow heat loss or experimental error Do not allow mean bond enthalpies are not accurate

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Question	Marking Guidance	Mark	Comments
3(a)(i)	ΔH = Σ(enthalpies formation products) – Σ(enthalpies formation reactants)	1	Or correct cycle with enthalpy changes labelled
	= –111 –(–75 – 242)	1	
	= (+)206 (kJ mol^{-1})	1	–206 scores 1 only Units not essential if ans in kJ mol^{-1} but penalise incorrect units
3(a)(ii)	ΔS = Σ(entropies of products) – Σ(entropies reactants)		
	= 198 + 3 × 131 – (186 + 189)	1	
	= (+) 216 (J K^{-1} mol^{-1}) OR 0.216 kJ K^{-1} mol^{-1}	1	Units not essential but penalise incorrect units

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3(b)	When $\Delta G = 0$ OR $\Delta H = T\Delta S$ $T = \Delta H/\Delta S$ $= 206 \times 1000/216$ $= 954$ K	1 1 1 1	 M2 also scores M1 Allow error carried forward from (a)(i) and (a)(ii) Ignore unexplained change of sign from – to + Allow 953 – 955, Units of K essential, must be +ve If values from (a)(i) and (a)(ii) lead to negative value in M3 allow M1 to M3 but do not allow negative temperature for M4 If negative value changed to positive for M4, allow M4
3(c)	To speed up the rate of reaction OR wtte	1	Allow so that more molecules have energy greater than the activation energy IF T in 3(b) > 1300 allow answers such as; to reduce energy cost to slow down reaction do NOT allow to increase rate

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3(d)(i)	**Method 1** $\Delta G = \Delta H - T\Delta S$ ΔG = –41 – (1300 × –42/1000) (M1) = +13.6 kJ mol^{-1} ΔG must be negative for the reaction to be feasible. OR ΔG is positive so reaction is not feasible **Method 2** For reaction to be feasible ΔG must be negative or zero T when $\Delta G = 0 = \Delta H / \Delta S$ = 976*K* ΔS is -ve so ΔG must be +ve at temperatures above 976K / at 1300 *K*	 1 1 1 1 1 1	If 42 and not 42/1000 used can score M3 only but allow ΔG = –41 x 1000 – (1300 × –42) (M1) =13600 J mol^{-1} (M2) Units essential
3(d)(ii)	If the temperature is lowered (Ignore reference to catalyst and/or pressure) ΔG will become (more) negative because the $-T\Delta S$ term will be less positive/ $T\Delta S > \Delta H$	1 1	Alternative mark scheme (if T is calculated) Allow T reduced to 976 K or lower M1 At this temperature (the reaction becomes feasible because) ΔG <= 0 M2

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Question	Marking Guidance	Mark	Comments
4(a)	$Mg + H_2O \rightarrow MgO + H_2$	1	ignore state symbols
	White solid/powder/ash/smoke	1	ignore precipitate ignore fumes
	(Bright) <u>white</u> light/flame	1	allow glow penalise effervescence under list principle
4(b)	$2Na + \frac{1}{2}O_2 \rightarrow Na_2O$ / $4Na + O_2 \rightarrow 2Na_2O$	1	Allow multiples, ignore state symbols Allow $2Na + O_2 \rightarrow Na_2O_2$
	white / yellow solid/ash/smoke	1	ignore precipitate ignore fumes
	orange / yellow flame	1	

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Question	Marking Guidance	Mark	Comments
5(a)(i)	1500	1	
5(a)(ii)	Ionic lattice / giant ionic	1	Mention of vdW / covalent bonding / molecules / atoms / metal etc CE=0
	Strong <u>attraction</u> between <u>oppositely charged ions</u> / Na^+ and O^{2-} OR lots of energy required to separate/ overcome attraction between oppositely charged ions / Na^+ and O^{2-}	1	Do not allow incorrect formulae for ions.
5(a)(iii)	200 (K)	1	Allow range 10–273 (K) CE = 0 if temperature >573 K, otherwise mark on Allow correct answers in ^oC but units must be given.
	SO_2 smaller (molecule) (than P_4O_{10}) (or converse)	1	also SO_2 has lower M_r / less surface area/less polarisable / fewer electrons penalise SO_3 and P_2O_5 for M2 only
	vdW forces <u>between molecules</u> are weaker / require less energy to separate molecules	1	ignore dipole-dipole If covalent bonds broken lose M2 and M3 but can gain M1

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5(b)	$SO_2 + H_2O \rightarrow H_2SO_3 / H^+ + HSO_3^- / 2H^+ + SO_3^{2-}$	1	can be equilibrium sign instead of arrow
	1	1	Allow values between 1–3 mark independently
5(c)	Reacts with / neutralises bases / alkalis	1	Allow any given base or alkali including OH^-
	$SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O$	1	Allow $CaO + SiO_2 \rightarrow CaSiO_3$ or equation with any suitable base M2 can score M1 even if equation unbalanced or incorrect

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Question	Marking Guidance	Mark	Comments
6(a)	Electron acceptor / gains electrons	1	do not allow electron pair acceptor
6(b)	Fe^{2+} ions	1	
	Fe^{2+}/Fe or Fe^{2+} or it has smallest / most negative <u>electrode potential</u> / <u>E^{o}</u>	1	Do not allow Fe/Fe^{2+} Cannot score M2 if M1 incorrect
6(c)	$Pt\|H_2\|H^+\|\|Ag^+\|Ag$	1	M1 for H_2 H^+ Ag^+ Ag in correct order
	allow dashed phase boundaries	1	M2 for Pt correct and correct phase boundaries
	$2H^+$ loses one mark (M2)		Ignore state symbols. M1 must be correct to score M2
			If answer correct but all in reverse order allow 1 mark out of two
	Any **two** correct conditions • 298 K /25 ^{o}C • 100 kPa • both solutions of unit concentration • zero current	2	Allow 1 bar Do not apply list principle, mark correct answers.

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6(d)	E Au^+(/Au) > E O_2 (/ H_2O) OR e.m.f. / *E*cell = 0.45 V	1	If both species in electrode given, must be in correct order i.e. Au^+/Au
	<u>Au^+ (ions) oxidise water</u> OR <u>water reduces Au^+</u> (ions)	1	Allow water donates electrons to Au+
	<u>Gold</u> metal/solid/precipitate **OR** <u>bubbles</u> / effervescence of (oxygen gas) / gas produced	1	Penalise incorrect observations
	$2Au^+ + H_2O \rightarrow 2Au + 2H^+ + \frac{1}{2}O_2$ OR $4Au^+ + 2H_2O \rightarrow 4Au + 4H^+ + O_2$	1	Allow multiples
6(e)(i)	1.24 (V)	1	Do not allow -1.24
6(e)(ii)	Chloride ions / Cl^- react with / form a precipitate with silver ions/ Ag+ / form AgCl	1	Penalise reaction of chloride ions with iron ions or iron
6(f)	E O_2 (/H_2O) > E Fe^{3+} (/Fe^{2+}) (or e.m.f / *E*cell = 0.46 V)	1	Species in electrode if all given must be in correct order
	Therefore the <u>iron(II)</u> ions are oxidised (or converted) into <u>iron(III)</u> ions (by oxygen)	1	If chloride ions oxidised to chlorine, lose M2 M2 can be obtained or lost from equation. Ignore observations.

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M

Question	Marking Guidance	Mark	Comments
7(a)	$Cr(OH)_3 + 3H_2O + 3H^+ \rightarrow [Cr(H_2O)_6]^{3+}$	1	Can start with $Cr(H_2O)_3(OH)_3$ for each equation Ignore any unnecessary preliminary preparation of $Cr(OH)_3$
	Green / grey-green solid	1	Mark colours independently from equations Allow green ppt.
	Forms green / purple / ruby / violet <u>solution</u>	1	ignore shades of colours
	$Cr(OH)_3 + 2H_2O + OH^- \rightarrow [Cr(H_2O)_2(OH)_4]^-$	1	Allow with 5 or 6 OH^- provided complex has co-ordination number of 6 Penalise complex ions with incorrect charges overall or or if shown on ligand.
	Forms green <u>solution</u>	1	Note that for each equation final complex must be 6 co-ordinate

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7(b)	$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 4H_2O$	1	Allow two correct equations via intermediate hydroxide in both cases even if first equation uses OH^- instead of NH_3
	Blue (solution)	1	Mark colours independently from equations
	Dark/deep/royal blue <u>solution</u>	1	
	$[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$	1	
	pink/red (solution)	1	
	Brown / straw / yellow <u>solution</u>	1	ignore darkens in air/with time

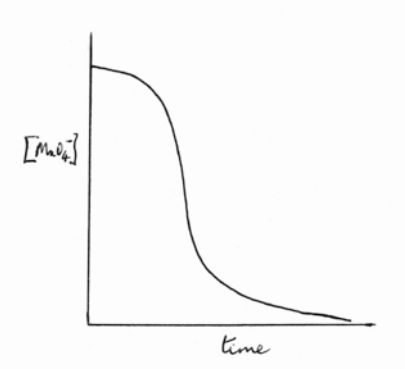
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Question	Marking Guidance	Mark	Comments
8(a)	$[Fe(H_2O)_6]^{2+} + 2NH_3 \rightarrow Fe(H_2O)_4(OH)_2 + 2NH_4^+$	1	Allow equation with OH^- provided equation showing formation of OH^- from NH_3 given
	Green precipitate	1	
	$[Fe(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow FeCO_3 + 6H_2O$	1	
	Green precipitate	1	effervescence incorrect so loses M4
8(b)(i)	Colourless/(pale) green changes to pink/purple (solution)	1	Do not allow pale pink to purple
	Just after the end-point MnO_4^- is in excess/present	1	
8(b)(ii)	$MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H_2O + 5Fe^{3+}$	1	
	Moles $KMnO_4 = 18.7 \times 0.0205/1000 = (3.8335 \times 10^{-4})$	1	Process mark
	Moles $Fe^{2+} = 5 \times 3.8335 \times 10^{-4} = 1.91675 \times 10^{-3}$	1	Mark for M2 x 5
	Moles Fe^{2+} in 250 $cm^3 = 10 \times 1.91675 \times 10^{-3} =$ 0.0191675 moles in 50 cm^3	1	Process mark for moles of iron in titration (M3) x10
	Original conc $Fe^{2+} = 0.0191675 \times 1000/50 = 0.383$ $\underline{\text{mol dm}^{-3}}$	1	Answer for moles of iron (M4) x 1000/50 Answer must be to at least 2 sig. figs. (0.38)

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Question	Marking Guidance	Mark	Comments
9(a)	$2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$	1	
	Mn^{2+} OR Mn^{3+}	1	If catalyst incorrect can only score M1 and M3
	(Possible because) Mn can exist in variable oxidation states	1	
	E_a lowered because oppositely charged ions attract	1	These marks can be gained in any order
	Mn^{3+} (reduced) to Mn^{2+} by $C_2O_4^{2-}$ / equation		
	Mn^{2+} (oxidised (back)) to Mn^{3+} by MnO_4^- / equation	1	M5 may appear before M2
		1	M5 and M6 can be scored in unbalanced equations or in words showing: $Mn^{3+} + C_2O_4^{2-} \rightarrow Mn^{2+}$ $Mn^{2+} + MnO_4^- \rightarrow Mn^{3+}$

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9(b)	**Graph marks**  S-shaped curve must not rise significantly and must not fall rapidly initially. Starts on concentration axis **and** is levelling out (can level out on time axis or above but parallel to time axis) **Explanation marks** Slope / rate increases as catalyst (concentration) forms Slope / rate decreases as (concentration) of MnO_4^- ions /reactant(s) decreases (OR reactants are being used up)	1 1 1 1	Cannot score graph marks (M1 and M2) if no axes and/or no labels Explanation marks can be awarded independent of graph.

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CHEM5 Mark scheme instructions to examiners

1. General

The mark scheme for each question shows:

- the marks available for each part of the question
- the total marks available for the question
- the typical answer or answers which are expected
- extra information to help the Examiner make his or her judgement and help to delineate what is acceptable or not worthy of credit or, in discursive answers, to give an overview of the area in which a mark or marks may be awarded.

The extra information is aligned to the appropriate answer in the left-hand part of the mark scheme and should only be applied to that item in the mark scheme.

At the beginning of a part of a question a reminder may be given, for example: where consequential marking needs to be considered in a calculation; or the answer may be on the diagram or at a different place on the script.

In general the right-hand side of the mark scheme is there to provide those extra details which confuse the main part of the mark scheme yet may be helpful in ensuring that marking is straightforward and consistent.

2. Emboldening

2.1 In a list of acceptable answers where more than one mark is available 'any **two** from' is used, with the number of marks emboldened. Each of the following bullet points is a potential mark.

2.2 A bold **and** is used to indicate that both parts of the answer are required to award the mark.

2.3 Alternative answers acceptable for a mark are indicated by the use of **or**. Different terms in the mark scheme are shown by a / ; eg allow smooth / free movement.

3. Marking points

3.1 Marking of lists

This applies to questions requiring a set number of responses, but for which candidates have provided extra responses. The general principle to be followed in such a situation is that 'right + wrong = wrong'.

Each error / contradiction negates each correct response. So, if the number of error / contradictions equals or exceeds the number of marks available for the question, no marks can be awarded.

However, responses considered to be neutral (often prefaced by 'Ignore' in the mark scheme) are not penalised.

3.2 Marking procedure for calculations

Full marks can be given for a correct numerical answer, without any working shown unless the question states 'Show your working'.

However, if the answer is incorrect, mark(s) can usually be gained by correct substitution / working and this is shown in the 'extra information' column or by each stage of a longer calculation.

3.3 Interpretation of 'it'

Answers using the word 'it' should be given credit only if it is clear that the 'it' refers to the correct subject.

3.4 Errors carried forward, consequential marking and arithmetic errors

Allowances for errors carried forward are most likely to be restricted to calculation questions and should be shown by the abbreviation e.c.f. or conseq in the marking scheme.

An arithmetic error should be penalised for one mark only unless otherwise amplified in the marking scheme. Arithmetic errors may arise from a slip in a calculation or from an incorrect transfer of a numerical value from data given in a question.

3.5 Phonetic spelling

The phonetic spelling of correct scientific terminology should be credited **unless** there is a possible confusion with another technical term.

3.6 Brackets

(…..) are used to indicate information which is not essential for the mark to be awarded but is included to help the examiner identify the sense of the answer required.

3.7 Ignore / Insufficient / Do <u>not</u> allow

Ignore or insufficient is used when the information given is irrelevant to the question or not enough to gain the marking point. Any further correct amplification could gain the marking point.

Do **not** allow means that this is a wrong answer which, even if the correct answer is given, will still mean that the mark is not awarded.

Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
TOTAL	

General Certificate of Education
Advanced Level Examination
June 2014

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Tuesday 17 June 2014 1.30 pm to 3.15 pm

For this paper you must have:
- the Periodic Table/Data Sheet provided as an insert (enclosed)
- a ruler with millimetre measurements
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator, where appropriate.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use scientific terminology accurately.

Advice
- You are advised to spend about 75 minutes on **Section A** and about 30 minutes on **Section B**.

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Section A

Answer **all** questions in the spaces provided.

1 (a) Write an equation for the process that has an enthalpy change equal to the electron affinity of chlorine.

[1 mark]

.....

1 (b) In terms of electrostatic forces, suggest why the electron affinity of fluorine has a negative value.

[2 marks]

.....

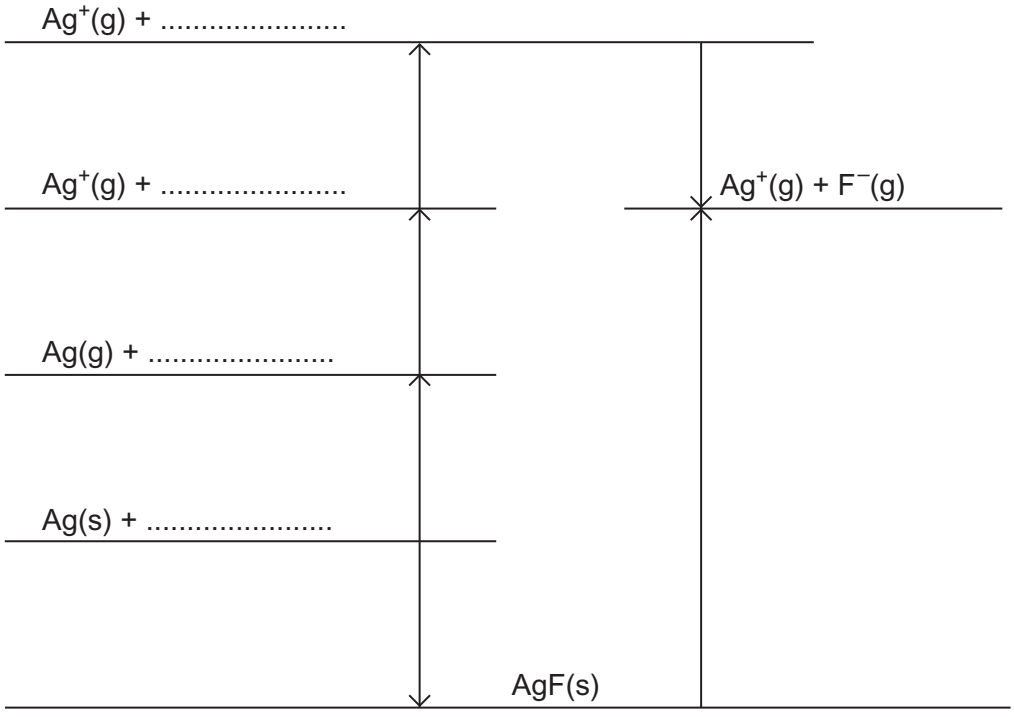
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1 (c) (i) Complete the Born–Haber cycle for silver fluoride by adding the missing species on the dotted lines.

[3 marks]



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1 (c) (ii) Use the cycle in Question **1 (c) (i)** and the data in **Table 1** to calculate a value, in kJ mol^{-1}, for the bond enthalpy of the fluorine–fluorine bond.

[2 marks]

Table 1

Enthalpy change	**Value / kJ mol^{-1}**
Enthalpy of atomisation for silver	+289
First ionisation energy for silver	+732
Electron affinity for fluorine	–348
Experimental enthalpy of lattice dissociation for silver fluoride	+955
Enthalpy of formation for silver fluoride	–203

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Question 1 continues on the next page

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1 (d) A theoretical value for enthalpy of lattice dissociation can be calculated using a perfect ionic model.

The theoretical enthalpy of lattice dissociation for silver fluoride is +870 kJ mol^{-1}.

1 (d) (i) Explain why the theoretical enthalpy of lattice dissociation for silver fluoride is different from the experimental value that can be calculated using a Born–Haber cycle.

[2 marks]

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[Extra space] .....

.....

1 (d) (ii) The theoretical enthalpy of lattice dissociation for silver chloride is +770 kJ mol^{-1}.

Explain why this value is less than the value for silver fluoride.

[2 marks]

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[Extra space] .....

.....

12

Turn over for the next question

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ANSWER IN THE SPACES PROVIDED

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2 **Table 2** shows some enthalpy change and entropy change data.

Table 2

	ΔH / kJ mol^{-1}	ΔS / J K^{-1} mol^{-1}
$AgCl(s) \longrightarrow Ag^+(g) + Cl^-(g)$	+905	
$AgCl(s) \longrightarrow Ag^+(aq) + Cl^-(aq)$	+77	+33
$AgF(s) \longrightarrow Ag^+(aq) + F^-(aq)$	–15	to be calculated
$Ag^+(g) \longrightarrow Ag^+(aq)$	–464	

2 (a) Define the term **enthalpy of hydration** of an ion.

[2 marks]

.....

.....

.....

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2 (b) Use data from **Table 2** to calculate a value for the enthalpy of hydration of the chloride ion.

[2 marks]

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2 (c) Suggest why hydration of the chloride ion is an exothermic process.

[2 marks]

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2 (d) Silver chloride is insoluble in water at room temperature.

Use data from **Table 2** to calculate the temperature at which the dissolving of silver chloride in water becomes feasible.
Comment on the significance of this temperature value.

[4 marks]

Calculation of temperature .....

.....

.....

.....

.....

.....

Significance of temperature value .....

.....

.....

2 (e) When silver fluoride dissolves in water at 25 ºC, the free-energy change is –9 kJ mol^{-1}.

Use this information and data from **Table 2** to calculate a value, with units, for the entropy change when silver fluoride dissolves in water at 25 ºC.

[3 marks]

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13

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3 This question is about some Period 3 elements and their oxides.

3 (a) Describe what you would observe when, in the absence of air, magnesium is heated strongly with water vapour at temperatures above 373 K.
Write an equation for the reaction that occurs.

[3 marks]

Observations .....

.....

.....

.....

.....

Equation .....

3 (b) Explain why magnesium has a higher melting point than sodium.

[2 marks]

.....

.....

.....

.....

[Extra space] .....

.....

3 (c) State the structure of, and bonding in, silicon dioxide.
Other than a high melting point, give **two** physical properties of silicon dioxide that are characteristic of its structure and bonding.

[4 marks]

Structure .....

Bonding.....

Physical property 1.....

Physical property 2.....

Do not write outside the box

3 (d) Give the formula of the species in a sample of solid phosphorus(V) oxide. State the structure of, and describe fully the bonding in, this oxide.

[4 marks]

Formula .....

Structure .....

Bonding .....

.....

.....

.....

3 (e) Sulfur(IV) oxide reacts with water to form a solution containing ions.

Write an equation for this reaction.

[1 mark]

.....

3 (f) Write an equation for the reaction between the acidic oxide, phosphorus(V) oxide, and the basic oxide, magnesium oxide.

[1 mark]

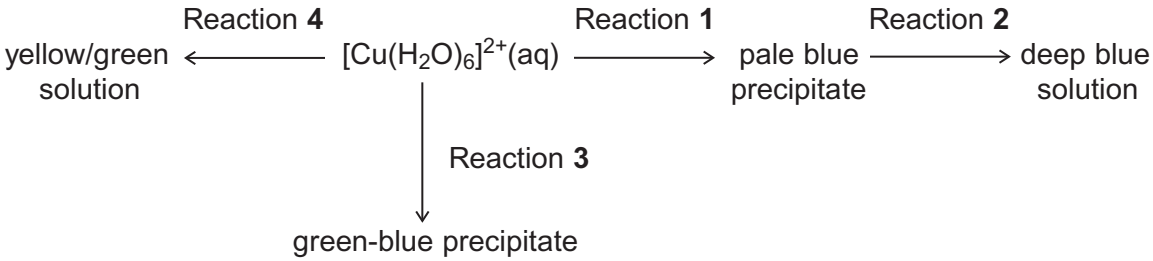
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15

Turn over for the next question

Do not write outside the box

4 Consider the following reaction scheme that starts from aqueous $[Cu(H_2O)_6]^{2+}$ ions.



For each of the reactions **1** to **4**, identify a suitable reagent, give the formula of the copper-containing species formed and write an equation for the reaction.

4 (a) Reaction **1**

[3 marks]

Reagent .....

Copper-containing species .....

Equation .....

4 (b) Reaction **2**

[3 marks]

Reagent .....

Copper-containing species .....

Equation .....

4 (c) Reaction **3**

[3 marks]

Reagent .....

Copper-containing species .....

Equation .....

Do not write outside the box

4 (d) Reaction **4**

[3 marks]

Reagent .....

Copper-containing species .....

Equation .....

12

Turn over for the next question

Do not write outside the box

5 **Table 3** shows some standard electrode potential data.

Table 3

	$E^{\ominus}$ / V
$ZnO(s) + H_2O(l) + 2e^- \longrightarrow Zn(s) + 2OH^-(aq)$	–1.25
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	–0.44
$O_2(g) + 2H_2O(l) + 4e^- \longrightarrow 4OH^-(aq)$	+0.40
$2HOCl(aq) + 2H^+(aq) + 2e^- \longrightarrow Cl_2(g) + 2H_2O(l)$	+1.64

5 (a) Give the conventional representation of the cell that is used to measure the standard electrode potential of iron as shown in **Table 3**.

[2 marks]

.....

5 (b) With reference to electrons, give the meaning of the term **reducing agent**.

[1 mark]

.....

.....

5 (c) Identify the weakest reducing agent from the species in **Table 3**.

Explain how you deduced your answer.

[2 marks]

Species .....

Explanation .....

.....

Do not write outside the box

5 (d) When HOCl acts as an oxidising agent, one of the atoms in the molecule is reduced.

5 (d) (i) Place a tick (✓) next to the atom that is reduced.

[1 mark]

Atom that is reduced	Tick (✓)
H	
O	
Cl	

5 (d) (ii) Explain your answer to Question **5 (d) (i)** in terms of the change in the oxidation state of this atom.

[1 mark]

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.....

5 (e) Using the information given in **Table 3**, deduce an equation for the redox reaction that would occur when hydroxide ions are added to HOCl

[2 marks]

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Question 5 continues on the next page

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5 (f) **Table 3** is repeated to help you answer this question.

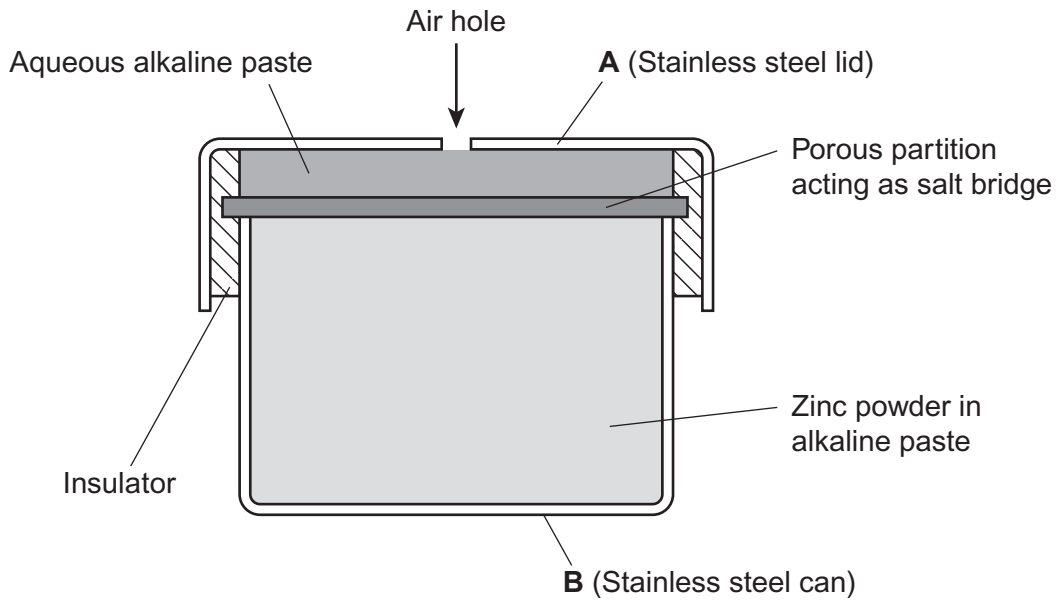
Table 3

	$E^{\ominus}$ / V
$ZnO(s) + H_2O(l) + 2e^- \longrightarrow Zn(s) + 2OH^-(aq)$	–1.25
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	–0.44
$O_2(g) + 2H_2O(l) + 4e^- \longrightarrow 4OH^-(aq)$	+0.40
$2HOCl(aq) + 2H^+(aq) + 2e^- \longrightarrow Cl_2(g) + 2H_2O(l)$	+1.64

The half-equations from **Table 3** that involve zinc and oxygen are simplified versions of those that occur in hearing aid cells.

A simplified diagram of a hearing aid cell is shown in **Figure 1**.

Figure 1



5 (f) (i) Use data from **Table 3** to calculate the e.m.f. of this cell.

[1 mark]

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Answer = ...

Do not write outside the box

5 (f) (ii) Use half-equations from **Table 3** to construct an overall equation for the cell reaction.

[1 mark]

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5 (f) (iii) Identify which of **A** or **B**, in **Figure 1**, is the positive electrode. Give a reason for your answer.

[2 marks]

Positive electrode .....

Reason .....

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5 (f) (iv) Suggest **one** reason, other than cost, why this type of cell is **not** recharged.

[1 mark]

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14

Turn over for the next question

Do not write outside the box

6 Hydrogen–oxygen fuel cells are used to provide electrical energy for electric motors in vehicles.

6 (a) In a hydrogen–oxygen fuel cell, a current is generated that can be used to drive an electric motor.

6 (a) (i) Deduce half-equations for the electrode reactions in a hydrogen–oxygen fuel cell.

[2 marks]

Half-equation 1 .....

Half-equation 2 .....

6 (a) (ii) Use these half-equations to explain how an electric current can be generated.

[2 marks]

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6 (b) Explain why a fuel cell does **not** need to be recharged.

[1 mark]

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6 (c) To provide energy for a vehicle, hydrogen can be used either in a fuel cell or in an internal combustion engine.

Suggest the main advantage of using hydrogen in a fuel cell rather than in an internal combustion engine.

[1 mark]

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Do not write outside the box

6 (d) Identify **one** major hazard associated with the use of a hydrogen–oxygen fuel cell in a vehicle.

[1 mark]

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7

Turn over for the next question

Do not write outside the box

Section B

Answer **all** questions in the spaces provided.

7 The characteristic properties of transition metals include coloured ions, complex formation and catalytic activity.

7 (a) Consider the chromium complexes **P** and **Q**.

$[Cr(H_2O)_6]^{3+}(aq)$ ⟶ $[Cr(H_2O)_5Cl]^{2+}(aq)$

red-violet — green

P — **Q**

Explain, with reference to oxidation states and electron configurations, why the chromium ions in complexes **P** and **Q** contain the same number of d electrons. You should **not** consider the electrons donated by the ligands.

Explain, in terms of electrons, why the complexes are **different** colours. (You are **not** required to explain why the observed colours are red-violet and green.)

[6 marks]

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Do not write outside the box

7 (b) Write an equation to show how the $[Co(NH_3)_6]^{2+}(aq)$ ion reacts with 1,2-diaminoethane. Explain the thermodynamic reasons why this reaction occurs.

[5 marks]

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Question 7 continues on the next page

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7 (c) The toxic complex cisplatin is an effective anti-cancer drug because it reacts with the DNA in cancer cells, preventing cell division.

7 (c) (i) Draw the **displayed** structure of cisplatin.
On your structure, show the value of one of the bond angles at platinum.
State the charge, if any, on the complex.

[3 marks]

7 (c) (ii) When cisplatin is ingested, an initial reaction involves one of the chloride ligands being replaced by water.

Write an equation for this reaction.

[1 mark]

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7 (c) (iii) Suggest how the risk associated with the use of this drug can be minimised.

[1 mark]

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Do not write outside the box

7 (d) Explain, with the aid of equations, how and why vanadium(V) oxide is used in the Contact Process.

[4 marks]

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20

Turn over for the next question

Do not write outside the box

8 A student carried out an experiment to find the mass of $FeSO_4.7H_2O$ in an impure sample, **X**.
The student recorded the mass of **X**. This sample was dissolved in water and made up to 250 cm^3 of solution.
The student found that, after an excess of acid had been added, 25.0 cm^3 of this solution reacted with 21.3 cm^3 of a 0.0150 mol dm^{-3} solution of $K_2Cr_2O_7$

8 (a) Use this information to calculate a value for the mass of $FeSO_4.7H_2O$ in the sample of **X**.

[5 marks]

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Do not write outside the box

8 (b) The student found that the calculated mass of $FeSO_4.7H_2O$ was greater than the actual mass of the sample that had been weighed out. The student realised that this could be due to the nature of the impurity.

Suggest **one** property of an impurity that would cause the calculated mass of $FeSO_4.7H_2O$ in **X** to be greater than the actual mass of **X**.
Explain your answer.

[2 marks]

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7

END OF QUESTIONS

There are no questions printed on this page

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AQA Qualifications

A-LEVEL
CHEMISTRY

CHEM5 Energetics, Redox and Inorganic Chemistry
Mark scheme

2420
June 2014

Version 1.1 Final

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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.

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Question	Marking Guidance		Comments
1(a)	$Cl(g) + e^- \rightarrow Cl^-(g)$	1	State symbols essential Allow e with no charge This and all subsequent equations must be balanced
1(b)	There is an <u>attraction</u> between the <u>nucleus / protons</u> and (the added) electron(s)	1	
	Energy is released (when the electron is gained)	1	Allow product more stable / product has lower energy Allow reaction exothermic / heat released Allow reference to chlorine rather than fluorine Wrong process eg ionisation, boiling CE = 0
1(c)(i)	Top line: $+ e^- + F(g)$	1	Penalise missing / wrong state symbols one mark only Penalise Fl or Cl one mark only
	Second line from top : $+ e^- + \frac{1}{2}F_2(g)$	1	Mark independently Allow e with no charge
	Bottom two lines: $+ \frac{1}{2}F_2(g)$	1	Penalise each lack of an electron in M1 and M2 each time

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1(c)(ii)	$\frac{1}{2}$E(F–F) + 732 + 289 + +203 = 348 + 955 $\frac{1}{2}$E(F–F) = 79 E(F–F) = 158 (kJ mol^{-1})	 1 1	 Award one mark (M2) if M1 wrong but answer = M1 × 2 Ignore no units, penalise wrong units but allow kJ mol^{-} Any negative answer, CE = 0

1(d)(i)	Experimental lattice enthalpy value allows for / includes covalent interaction / non–spherical ions / distorted ions / polarisation OR AgF has covalent character Theoretical lattice enthalpy value assumes only ionic interaction / point charges / no covalent / perfect spheres / perfectly ionic OR AgF is not perfectly ionic	1 1	Allow discussion of AgCl instead of AgF CE = 0 for mention of molecules, atoms, macromolecular, mean bond enthalpy, intermolecular forces (imf), electronegativity

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1(d)(ii)	Chloride ion larger (than fluoride ion) / fluoride ion smaller (than chloride ion)	1	Penalise chlorine ion once only Allow Cl^- and F^- instead of names of ions Allow chloride ion has smaller charge density / smaller charge to size ratio but penalise mass to charge ratio
	Attraction between Ag^+ and Cl^- weaker / attraction between Ag^+ and F^- stronger	1	For M2 Cl^- and F^- can be implied from an answer to M1 Mark M1 and M2 independently provided no contradiction CE = 0 for mention of chlorine not chloride ion, molecules, atoms, macromolecular, mean bond enthalpy, intermolecular forces (imf), electronegativity

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Question	Marking Guidance	Mark	Comments
2(a)	Enthalpy change/ΔH when 1 mol of a gaseous ion	1	Enthalpy change for $X^{+/-}(g) \rightarrow X^{+/-}(aq)$ scores M1 and M2
	forms aqueous ions	1	Allow heat energy change instead of enthalpy change Allow 1 mol applied to aqueous or gaseous ions If substance / atoms in M1 CE = 0 If wrong process (eg boiling) CE = 0
2(b)	ΔH(solution) = ΔH(lattice) + Σ(ΔH hydration) OR +77 = +905 – 464 + ΔH(hydration, Cl^-) OR ΔH(hydration, Cl^-) = +77 –905 + 464	1	Allow any one of these three for M1 even if one is incorrect
	= –364 (kJ mol^{-1})	1	Allow no units, penalise incorrect units, allow kJ mol^- Allow lower case j for J (Joules) +364 does not score M2 but look back for correct M1

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2(c)	Water is polar / water has Hδ+	1	
	(Chloride ion) attracts (the H in) water molecules (note chloride ion can be implied from the question stem)	1	Idea that there is a force of <u>attraction</u> between the chloride ion and water Do not allow H bonds / dipole–dipole / vdW / intermolecular but ignore loose mention of bonding Do not allow just chlorine or chlorine atoms / ion Mark independently

2(d)	$\Delta G = \Delta H - T\Delta S$	1	Look for this equation in 2(d) and/or 2(e); equation can be stated or implied by correct use. Record the mark in 2(d)
	($\Delta G = 0$ so) $T = \Delta H/\Delta S$	1	
	T = 77 × 1000/33 = 2333 <u>K</u> (allow range 2300 to 2333.3)	1	Units essential, allow lower case k for K (Kelvin) Correct answer with units scores M1, M2 and M3 2.3 (K) scores M1 and M2 but not M3
	Above the boiling point of water (therefore too high to be sensible) / water would evaporate	1	Can only score this mark if M3 >373 K

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2(e)	$\Delta S = (\Delta H - \Delta G)/T$ OR $\Delta S = (\Delta G - \Delta H)/-T$ = ((–15 + 9) × 1000)/298 OR (–15 + 9)/298 = –20 J K^{-1} mol^{-1} OR –0.020 kJ K^{-1} mol^{-1} (allow –20 to –20.2) (allow –0.020 to –0.0202)	1 1 1	Answer with units must be linked to correct M2 For M3, units must be correct Correct answer with appropriate units scores M1, M2 and M3 and possibly M1 in 2(d) if not already given Correct answer without units scores M1 and M2 and possibly M1 in 2(d) if not already given Answer of –240 / –0.24 means temperature of 25 used instead of 298 so scores M1 only If ans = +20 / +0.020 assume AE and look back to see if M1 and possibly M2 are scored

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Question	Marking Guidance	Mark	Comments
3(a)	<u>White</u> powder / solid / ash / smoke	1	Ignore ppt / fumes
	Bright / white light / flame	1	Allow glows white / glows bright
	$Mg + H_2O \rightarrow MgO + H_2$	1	Ignore state symbols Ignore reference to effervescence or gas produced
3(b)	Mg^{2+} / magnesium ion has higher charge than Na^+	1	Allow Mg^{2+} ions smaller / greater charge density than Na^+ ions Allow Mg atoms smaller than Na (atoms) Allow magnesium has more delocalised electrons Must be a comparison Ignore reference to nuclear charge
	Attracts <u>delocalised / free / sea of</u> electrons more strongly / metal–metal bonding stronger / metallic bonding stronger	1	Wrong type of bonding (vdW, imf), mention of molecules CE = 0

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3(c)	**Structure**: Macromolecular / giant molecule / giant covalent	1	Mark independently
	Bonding: Covalent / giant covalent	1	
	Physical Properties:		
	Any **two** from: Hard	2	Ignore correct chemical properties
	Brittle / not malleable		Ignore strong, high boiling point, rigid
	Insoluble		
	Non conductor		

3(d)	**Formula**: P_4O_{10}	1	Mention of ionic or metallic, can score M1 only
	Structure: Molecular	1	If macromolecular, can score M1 & M3 only
	Bonding: Covalent / shared electron pair	1	
	van der Waals' / dipole–dipole forces <u>between molecules</u>	1	Allow vdW, imf and dipole–dipole imf but do not allow imf alone

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3(e)	$SO_2 + H_2O \rightarrow H^+ + HSO_3^-$	1	Products must be ions Allow $SO_2 + H_2O \rightarrow 2H^+ + SO_3^{2-}$ Allow two equations showing intermediate formation of H_2SO_3 that ends up as ions Ignore state symbols Allow multiples

3(f)	$P_4O_{10} + 6MgO \rightarrow 2Mg_3(PO_4)_2$ OR $P_4O_{10} + 6MgO \rightarrow 6Mg^{2+} + 4PO_4^{3-}$ OR $P_2O_5 + 3MgO \rightarrow Mg_3(PO_4)_2$ etc	1	Ignore state symbols Allow multiples

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Question	Marking Guidance	Mark	Comments
4(a)	**Reaction 1**		**General principles in marking this question** Square brackets are not essential Penalise charges on individual ligands rather than on the whole complex Reagent and species can be extracted from the equation Ignore conditions such as dilute, concentrated, excess Reagent must be a compound NOT just an ion Equations must start from $[Cu(H_2O)_6]^{2+}$ except in 4(b) Mark reagent, species and equation independently
	ammonia (NH_3) (solution) / NaOH	1	
	$[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow [Cu(H_2O)_4(OH)_2] + 2NH_4^+$ / $[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow [Cu(H_2O)_4(OH)_2] + 2H_2O$	2	Do not allow OH^- for reagent Product 1, balanced equation 1 Allow either equation for ammonia
4(b)	**Reaction 2**		
	Ammonia (conc/xs)	1	
	$[Cu(H_2O)_4(OH)_2] + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 2H_2O + 2OH^-$	2	Product 1, balanced equation 1 Note that the equation must start from the hydroxide $[Cu(H_2O)_4(OH)_2]$

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4(c)	**Reaction 3** Na_2CO_3 / any identified soluble carbonate / $NaHCO_3$	1	Do not allow $NaCO_3$ or any insoluble carbonate but mark on
	$[Cu(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow CuCO_3 + 6H_2O$ OR $[Cu(H_2O)_6]^{2+} + Na_2CO_3 \rightarrow CuCO_3 + 6H_2O + 2Na^+$ OR $2[Cu(H_2O)_6]^{2+} + 2CO_3^{2-} \rightarrow Cu(OH)_2.CuCO_3 + 11H_2O + CO_2$ OR with $NaHCO_3$ $[Cu(H_2O)_6]^{2+} + HCO_3^- \rightarrow CuCO_3 + 6H_2O + H^+$	2	Product 1, balanced equation 1

4(d)	**Reaction 4** HCl (conc/xs) / NaCl	1	Allow any identified soluble chloride
	$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$	2	Product 1, balanced equation 1

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Question	Marking Guidance	Mark	Comments
5(a)	$Pt\|H_2\|H^+\|\|Fe^{2+}\|Fe$ Note, allow one mark only for correct symbol in reverse: $Fe\|Fe^{2+}\|\|H^+\|H_2\|Pt$	2	Allow 1 for correct order of symbols but lose second mark for a wrong phase boundary(s) / Pt missing / extra Pt on RHS, additional phase boundary Allow dashed lines for salt bridge Ignore state symbols Ignore 2 if used before H^+
5(b)	Electron donor	1	Allow (species that) loses electrons Do not allow reference to electron pairs
5(c)	Cl_2 / chlorine (Species on RHS / electron donor) has most positive / largest $E^{\ominus}$ / has highest potential	1 1	If M1 blank or incorrect cannot score M2 Do not allow reference to e.m.f. or E(cell)
5(d)(i)	Cl / chlorine	1	
5(d)(ii)	Chlorine +1 to chlorine 0	1	CE if chlorine not identified in 5(d)(i) Allow chlorine +1 to chlorine –1 (in Cl^-) Allow oxidation state decreases by one OR two Allow oxidation state changes by –1 OR –2

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5(e)	$4HOCl + 4H^+ + 4OH^- \rightarrow 2Cl_2 + O_2 + 6H_2O$ OR $4HOCl \rightarrow 2Cl_2 + O_2 + 2H_2O$	2	Allow one mark for any incorrect equation that shows $HOCl \rightarrow Cl_2 + O_2$ Allow multiples Ignore state symbols Penalise one mark for uncancelled or uncombined species (eg $H_2O + H_2O$ instead of $2H_2O$)
5(f)(i)	e.m.f. = 0.40 – (–1.25) = <u>1.65</u> (V) / <u>+1.65</u> (V)	1	Allow –1.65 (V)
5(f)(ii)	$2Zn + O_2 \rightarrow 2ZnO$	1	Allow multiples Ignore state symbols Do not allow uncancelled species If more than one equation given, choose the best
5(f)(iii)	**A /** stainless lid <u>O_2</u> (electrode) has a more positive <u>$E^\ominus$</u> / <u>oxygen</u> (electrode) requires / gains electrons from external circuit OR <u>Zinc</u> (electrode) has more negative $E^\ominus$	1 1	If M1 incorrect or blank CE=0 Or reference to the overall equation and a link to electrons going into A Allow oxygen is reduced and reduction occurs at the positive electrode Do not allow reference to e.m.f. or *E*(cell)
5(f)(iv)	(Cell) reaction(s) cannot be reversed / zinc oxide cannot be reduced to zinc by passing a current through it / zinc cannot be regenerated	1	Allow danger from production of gas / oxygen produced / hydrogen produced

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Question	Marking Guidance	Mark	Comments
6(a)(i)	$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ / $H_2 \rightarrow 2H^+ + 2e^-$	1	Any order
	$O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$ / $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	1	
6(a)(ii)	Hydrogen (electrode) produces electrons	1	Ignore reference to salt bridge Do not allow at negative / positive electrode – must identify hydrogen and oxygen
	Oxygen (electrode) accepts electrons	1	Allow electrons flow to the oxygen electrode
6(b)	Hydrogen / the fuel / reactants supplied continuously / fed in	1	Do not accept oxygen supplied as the only statement
6(c)	In the fuel cell, a greater proportion of the energy available from the hydrogen–oxygen reaction is converted into useful energy	1	Allow less energy wasted / more efficient Do not allow reference to safety
6(d)	Hydrogen is flammable / H^+ corrosive / OH^- corrosive / hydrogen explosive	1	

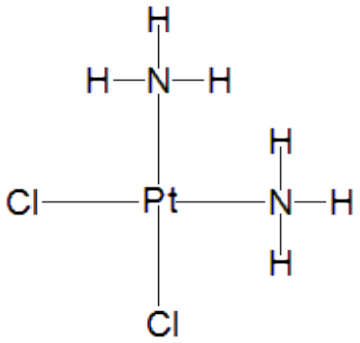
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Question	Marking Guidance	Mark	Comments
7(a)	In each of **P** and **Q** the oxidation state of Cr is +3 / both contain Cr^{3+}	1	If oxidation states are different lose M1 and M2
	In each of **P** and **Q** the electron configuration is the same / d^3 / $3d^3$	1	Do not allow just same number of electrons
	Ligands are different	1	
	Different energies of (d) electrons / different split of (d) electron energy levels / different energy gap of (d) electrons / different (d) orbital energy	1	
	Different wavelengths / frequencies / energies of light / colours (of light) are absorbed (by the d electrons)	1	Reference to emission and/or uv light but not to visible loses M5 and M6
	Different wavelengths / frequencies / energies of light / colours (of light) are transmitted / reflected	1	

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7(b)	$[Co(NH_3)_6]^{2+}$ + $3NH_2CH_2CH_2NH_2$ $\rightarrow$ $[Co(NH_2CH_2CH_2NH_2)_3]^{2+}$ + $6NH_3$	1	Allow $NH_2C_2H_4NH_2$ and $CH_2NH_2CH_2NH_2$ Allow partial substitution Do not allow en or other formulae for M1 but can score M2
	4 particles form 7 particles / increase in number of particles	1	Allow molecules, entities, ions, moles instead of particles Do not allow atoms Can score M2 if numbers match candidates incorrect equation provided number of particles increases
	disorder / entropy increases / ΔS positive	1	Cannot score M3 if number of particles stated or in equation is the same or decreases
	ΔH is approx. zero / no net change in bond enthalpies	1	Allow same number and type of bonds broken and formed
	ΔG is negative / $\Delta G <= 0$	1	Mark M4 and M5 independently

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7(c)(i)	 Bond angle 90°	1 1	Correct displayed structure Must show all three N–H bonds on each N Ignore arrows and lone pairs, attempt to show shape Ignore charges on atoms in structure for M1 Allow 87 to 93 degrees Allow this angle for any complex with 4 ligands eg if NH_2 or Cl used instead of NH_3
	Charge of zero	1	Award this mark if no charge shown on structure but if charges shown on ligands in M1 must state that overall charge = 0 Allow M3 only if cisplatin is correct OR if trans form OR if NH_3 not displayed OR if NH_2 used instead of NH_3

7(c)(ii)	$(NH_3)_2PtCl_2 + H_2O \rightarrow [(NH_3)_2PtCl(H_2O)]^+ + Cl^-$	1	If formula of cisplatin is incorrect, mark consequentially provided H_2O replaces Cl^- and charge on complex increases by one

7(c)(iii)	Use in small amounts / short bursts / target the application / monitor the patients	1	Allow: Give patient time between doses

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7(d)	$V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ / $V_2O_5 + SO_2 \rightarrow 2VO_2 + SO_3$	1	Allow multiples
	$V_2O_4 + \frac{1}{2}O_2 \rightarrow V_2O_5$ / $2VO_2 + \frac{1}{2}O_2 \rightarrow V_2O_5$	1	
	Acts as a catalyst / lowers the activation energy	1	
	Speeds up the (overall) reaction (between SO_2 and oxygen)	1	

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Question	Marking Guidance	Mark	Comments
8(a)	moles of $Cr_2O_7^{2-}$ per titration = 21.3 × 0.0150/1000 = $\underline{3.195 \times 10^{-4}}$	1	
	($Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$) $Cr_2O_7^{2-}$:Fe^{2+} = 1:6	1	If 1:6 ratio incorrect cannot score M2 or M3
	moles of Fe^{2+} = 6 × 3.195 × 10^{-4} = 1.917 × 10^{-3}	1	Process mark for M1 × 6 (also score M2)
	original moles in 250 cm^3 = 1.917 × 10^{-3} × 10 = 1.917 × 10^{-2}	1	Process mark for M3 × 10
	mass of $FeSO_4.7H_2O$ = 1.917 × 10^{-2} × 277.9 = 5.33 (g) (allow 5.30 to 5.40)	1	Mark for answer to M4 × 277.9 Answer **must** be to at least 3 sig figs Note that an answer of 0.888 scores M1, M4 and M5 (ratio 1:1 used)
8(b)	(Impurity is a) reducing agent / reacts with dichromate / impurity is a version of $FeSO_4$ with fewer than 7 waters (not fully hydrated)	1	Allow a reducing agent or compound that that converts Fe^{3+} into Fe^{2+}
	Such that for a given mass, the impurity would react with more dichromate than a similar mass of $FeSO_4.7H_2O$ OR for equal masses of the impurity and $FeSO_4.7H_2O$, the impurity would react with more dichromate.	1	Must compare mass of impurity with mass of $FeSO_4.7H_2O$

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Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
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7	
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TOTAL	

General Certificate of Education
Advanced Level Examination
June 2013

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Wednesday 19 June 2013 9.00 am to 10.45 am

For this paper you must have:
- the Periodic Table/Data Sheet provided as an insert (enclosed)
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator, where appropriate.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use scientific terminology accurately.

Advice
- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.

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Section A

Answer **all** questions in the spaces provided.

1 (a) Define the term *lattice enthalpy of dissociation*.

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(2 marks)

1 (b) Lattice enthalpy can be calculated theoretically using a perfect ionic model.

Explain the meaning of the term *perfect ionic model*.

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(1 mark)

(Extra space) .....

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1 (c) Suggest **two** properties of ions that influence the value of a lattice enthalpy calculated using a perfect ionic model.

Property 1 .....

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Property 2 .....

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(2 marks)

Do not write outside the box

1 (d) Use the data in the table to calculate a value for the lattice enthalpy of dissociation for silver chloride.

Enthalpy change	**Value / kJ mol^{-1}**
Enthalpy of atomisation for silver	+289
First ionisation energy for silver	+732
Enthalpy of atomisation for chlorine	+121
Electron affinity for chlorine	–364
Enthalpy of formation for silver chloride	–127

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(3 marks)

1 (e) Predict whether the magnitude of the lattice enthalpy of dissociation that you have calculated in part **(d)** will be less than, equal to or greater than the value that is obtained from a perfect ionic model. Explain your answer.

Prediction compared with ionic model .....

Explanation .....

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(2 marks)

10

Turn over ▶

Do not write outside the box

2 The enthalpy of hydration for the chloride ion is –364 kJ mol^{-1} and that for the bromide ion is –335 kJ mol^{-1}.

2 (a) By describing the nature of the attractive forces involved, explain why the value for the enthalpy of hydration for the chloride ion is more negative than that for the bromide ion.

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(3 marks)

2 (b) The enthalpy of hydration for the potassium ion is –322 kJ mol^{-1}. The lattice enthalpy of dissociation for potassium bromide is +670 kJ mol^{-1}.

Calculate the enthalpy of solution for potassium bromide.

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(2 marks)

Do not write outside the box

2 (c) The enthalpy of solution for potassium chloride is +17.2 kJ mol^{-1}.

2 (c) (i) Explain why the free-energy change for the dissolving of potassium chloride in water is negative, even though the enthalpy change is positive.

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(3 marks)

(Extra space) .....

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2 (c) (ii) A solution is formed when 5.00 g of potassium chloride are dissolved in 20.0 g of water. The initial temperature of the water is 298 K.

Calculate the final temperature of the solution.

In your calculation, assume that only the 20.0 g of water changes in temperature and that the specific heat capacity of water is 4.18 J K^{-1} g^{-1}.

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(5 marks)

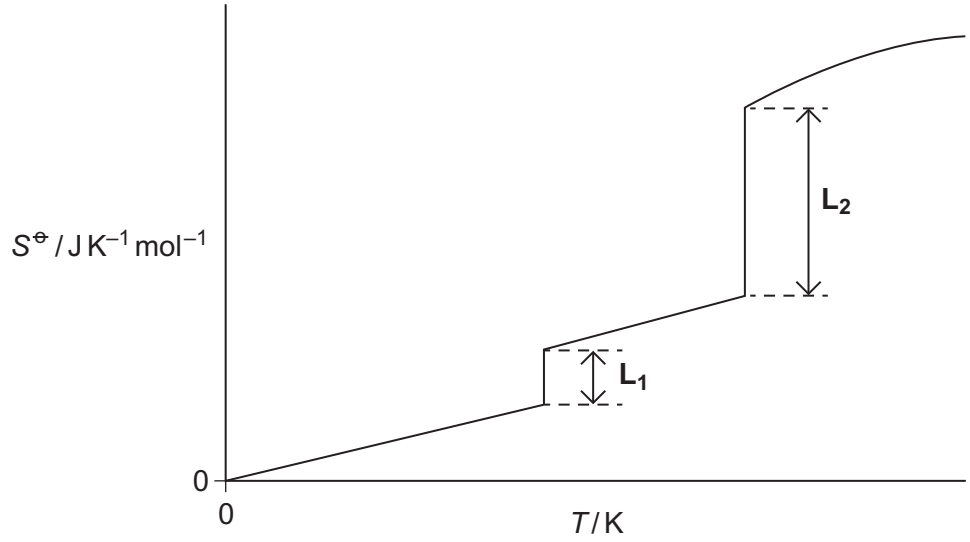
13

Turn over ▶

Do not write outside the box

3 (a) **Figure 1** shows how the entropy of a molecular substance **X** varies with temperature.

Figure 1



3 (a) (i) Explain, in terms of molecules, why the entropy is zero when the temperature is zero Kelvin.

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(2 marks)

(Extra space) .....

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3 (a) (ii) Explain, in terms of molecules, why the first part of the graph in **Figure 1** is a line that slopes up from the origin.

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(2 marks)

(Extra space) .....

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Do not write outside the box

3 (a) (iii) On **Figure 1**, mark on the appropriate axis the boiling point (T_b) of substance **X**.

(1 mark)

3 (a) (iv) In terms of the behaviour of molecules, explain why $\mathbf{L_2}$ is longer than $\mathbf{L_1}$ in **Figure 1**.

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(2 marks)

(Extra space) .....

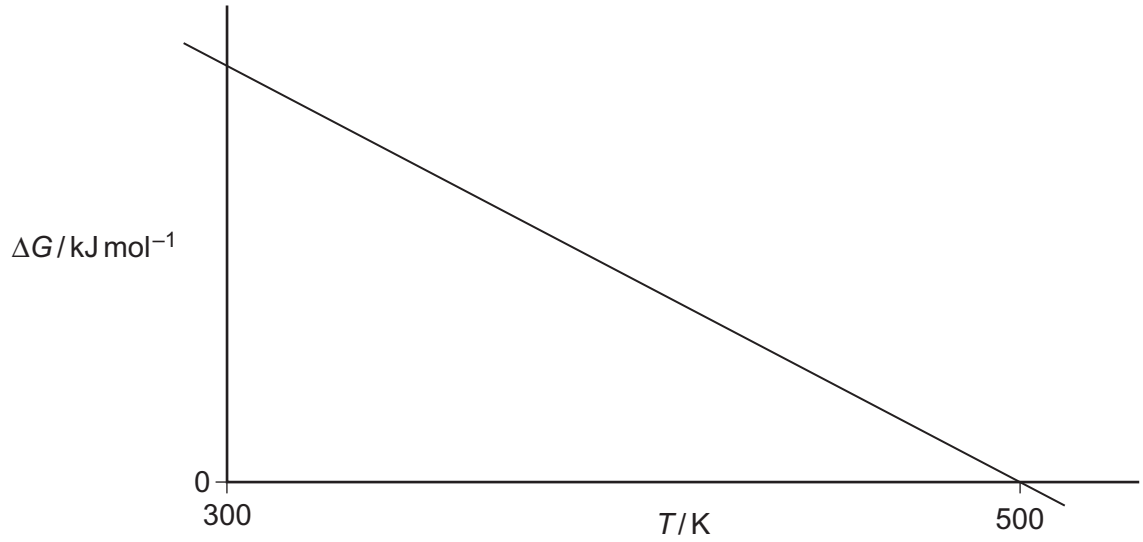
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Question 3 continues on the next page

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3 (b) **Figure 2** shows how the free-energy change for a particular gas-phase reaction varies with temperature.

Figure 2



3 (b) (i) Explain, with the aid of a thermodynamic equation, why this line obeys the mathematical equation for a straight line, $y = mx + c$.

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(2 marks)

3 (b) (ii) Explain why the magnitude of ΔG decreases as T increases in this reaction.

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(1 mark)

3 (b) (iii) State what you can deduce about the feasibility of this reaction at temperatures lower than 500 K.

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(1 mark)

Do not write outside the box

3 (c) The following reaction becomes feasible at temperatures above 5440 K.

$$H_2O(g) \longrightarrow H_2(g) + \tfrac{1}{2}O_2(g)$$

The entropies of the species involved are shown in the following table.

	$H_2O(g)$	$H_2(g)$	$O_2(g)$
S / J K^{-1} mol^{-1}	189	131	205

3 (c) (i) Calculate the entropy change ΔS for this reaction.

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(1 mark)

3 (c) (ii) Calculate a value, with units, for the enthalpy change for this reaction at 5440 K.

(If you have been unable to answer part **(c) (i)**, you may assume that the value of the entropy change is +98 J K^{-1} mol^{-1}. This is **not** the correct value.)

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(3 marks)

15

Do not write outside the box

4 Magnesium oxide, silicon dioxide and phosphorus(V) oxide are white solids but each oxide has a different type of structure and bonding.

4 (a) State the type of bonding in magnesium oxide.
Outline a simple experiment to demonstrate that magnesium oxide has this type of bonding.

Type of bonding .....

Experiment .....

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(3 marks)

4 (b) By reference to the structure of, and the bonding in, silicon dioxide, suggest why it is insoluble in water.

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(3 marks)

Do not write outside the box

4 (c) State how the melting point of phosphorus(V) oxide compares with that of silicon dioxide. Explain your answer in terms of the structure of, and the bonding in, phosphorus(V) oxide.

Melting point in comparison to silicon dioxide .....

Explanation .....

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(3 marks)

4 (d) Magnesium oxide is classified as a basic oxide.

Write an equation for a reaction that shows magnesium oxide acting as a base with another reagent.

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(2 marks)

4 (e) Phosphorus(V) oxide is classified as an acidic oxide.

Write an equation for its reaction with sodium hydroxide.

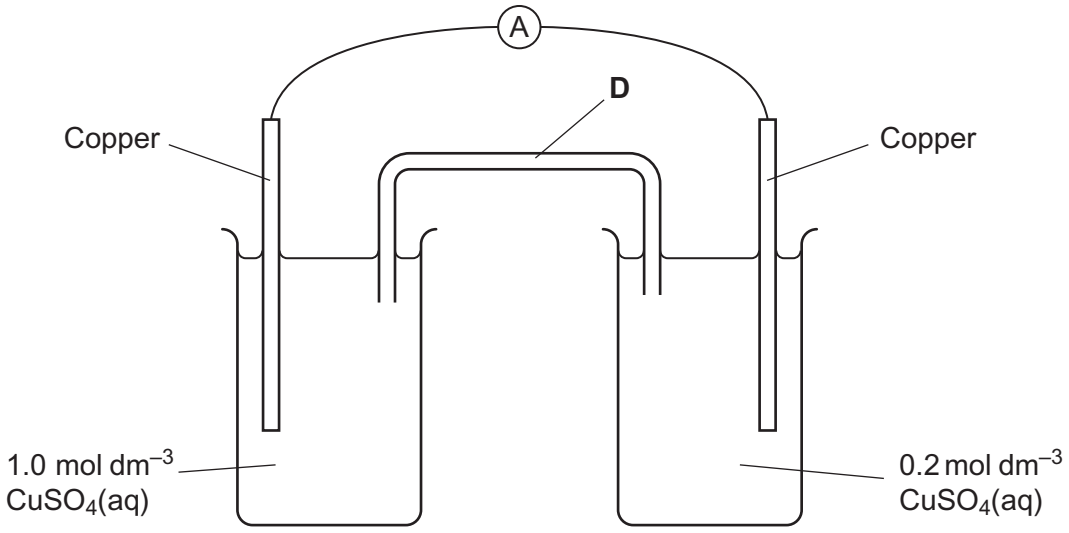
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(1 mark)

12

Do not write outside the box

5 An electrochemical cell is shown in the diagram. In this cell, the amount of copper in the electrodes is much greater than the amount of copper ions in the copper sulfate solutions.



5 (a) Explain how the salt bridge **D** provides an electrical connection between the two electrodes.

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(1 mark)

5 (b) Suggest why potassium chloride would **not** be a suitable salt for the salt bridge in this cell.

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(1 mark)

5 (c) In the external circuit of this cell, the electrons flow through the ammeter from right to left.

Suggest why the electrons move in this direction.

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(2 marks)

Do not write outside the box

5 (d) Explain why the current in the external circuit of this cell falls to zero after the cell has operated for some time.

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(1 mark)

5 (e) The simplified electrode reactions in a rechargeable lithium cell are

Electrode **A** $Li^+ + MnO_2 + e^- \longrightarrow LiMnO_2$ $E = -0.15\,V$

Electrode **B** $Li^+ + e^- \longrightarrow Li$

Electrode **B** is the negative electrode.

5 (e) (i) The e.m.f. of this cell is 2.90 V.

Use this information to calculate a value for the electrode potential of electrode **B**.

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(1 mark)

5 (e) (ii) Write an equation for the overall reaction that occurs when this lithium cell is being **recharged**.

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(2 marks)

5 (e) (iii) Suggest why the recharging of a lithium cell may lead to release of carbon dioxide into the atmosphere.

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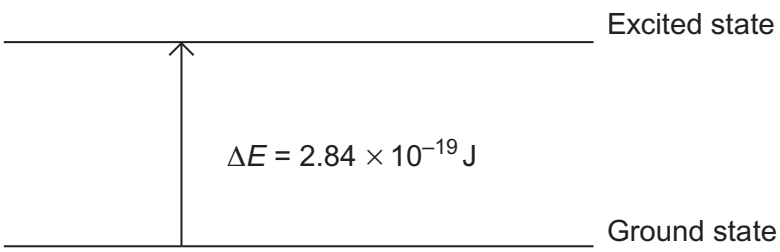
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(1 mark)

9

Do not write outside the box

6 This diagram represents the energy change that occurs when a d electron in a transition metal ion is excited by visible light.



6 (a) Give the equation that relates the energy change ΔE to the Planck constant h and the frequency of the visible light v.

Use this equation and the information in the diagram to calculate a value for the frequency of the visible light, and state the units.
The Planck constant $h = 6.63 \times 10^{-34}$ J s.

Equation .....

Calculation .....

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(2 marks)

6 (b) Explain why this electron transition causes a solution containing the transition metal ion to be coloured.

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(2 marks)

Do not write outside the box

6 (c) The energy change shown in the diagram represents the energy of red light and leads to a solution that appears blue.
Blue light has a higher frequency than red light.

Suggest whether the energy change ΔE will be bigger, smaller or the same for a transition metal ion that forms a red solution. Explain your answer.

Energy change .....

Explanation .....

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(2 marks)

6 (d) State **three** different features of transition metal complexes that cause a change in the value of ΔE, the energy change between the ground state and the excited state of the d electrons.

Feature 1 .....

Feature 2 .....

Feature 3 .....

(3 marks)

9

Turn over for the next question

Do not write outside the box

Section B

Answer **all** questions in the spaces provided.

7 An excess of a given reagent is added to each of the following pairs of aqueous metal ions.

For each metal ion, state the initial colour of the solution and the final observation that you would make.

In each case, write an overall equation for the formation of the final product from the initial aqueous metal ion.

7 (a) An excess of aqueous sodium carbonate is added to separate aqueous solutions containing $[Fe(H_2O)_6]^{2+}$ and $[Fe(H_2O)_6]^{3+}$

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(5 marks)

7 (b) An excess of concentrated hydrochloric acid is added to separate aqueous solutions containing $[Cu(H_2O)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$

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(4 marks)

Do not write outside the box

7 (c) An excess of dilute aqueous sodium hydroxide is added to separate aqueous solutions containing $[Fe(H_2O)_6]^{2+}$ and $[Cr(H_2O)_6]^{3+}$

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(4 marks)

7 (d) An excess of dilute aqueous ammonia is added to separate aqueous solutions containing $[Al(H_2O)_6]^{3+}$ and $[Ag(H_2O)_2]^{+}$

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(4 marks)

17

Turn over for the next question

Do not write outside the box

8 This question explores some reactions and some uses of cobalt compounds.

8 (a) Ethanal is oxidised to ethanoic acid by oxygen. The equation for this reaction is

$$2CH_3CHO + O_2 \longrightarrow 2CH_3COOH$$

This redox reaction is slow at room temperature but speeds up in the presence of cobalt compounds.

Explain why a cobalt compound is able to act as a catalyst for this process.

Illustrate your explanation with **two** equations to suggest how, in the presence of water and hydrogen ions, Co^{3+} and then Co^{2+} ions could be involved in catalysing this reaction.

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(4 marks)

Do not write outside the box

8 (b) In aqueous solution, the $[Co(H_2O)_6]^{2+}$ ion reacts with an excess of ethane-1,2-diamine to form the complex ion **Y**.

8 (b) (i) Write an equation for this reaction.

Explain, in terms of the chelate effect, why the complex ion **Y** is formed in preference to the $[Co(H_2O)_6]^{2+}$ complex ion.

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(3 marks)

8 (b) (ii) Draw a diagram that shows the shape of the complex ion **Y** and shows the type of bond between the ethane-1,2-diamine molecules and the cobalt.

(3 marks)

Question 8 continues on the next page

Do not write outside the box

8 (c) Compound **Z** is a complex that contains only cobalt, nitrogen, hydrogen and chlorine.

A solid sample of **Z** was prepared by reaction of 50 cm^3 of 0.203 mol dm^{-3} aqueous cobalt(II) chloride with ammonia and an oxidising agent followed by hydrochloric acid.

When this sample of **Z** was reacted with an excess of silver nitrate, 4.22 g of silver chloride were obtained.

Use this information to calculate the mole ratio of chloride ions to cobalt ions in **Z**.

Give the formula of the complex cobalt compound **Z** that you would expect to be formed in the preparation described above.

Suggest **one** reason why the mole ratio of chloride ions to cobalt ions that you have calculated is different from the expected value.

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(5 marks)

15

END OF QUESTIONS

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Version 1.0



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>	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
	Forms <u>ions</u> in the gaseous state	1	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 **one** of: • Ions are point charges • Ions are perfect spheres • Only electrostatic attraction / bonds (between ions) • No covalent interaction / character • Only ionic bonding / no polarisation of ions	1 max	If atoms / molecules mentioned, CE = 0
1(c)	(Ionic) radius / distance between ions / size	1	Allow in any order. Do not allow charge / mass or mass / charge.
	(Ionic) charge / charge density	1	Do not allow 'atomic radius'.

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1(d)	$\Delta H_L = \Delta H_a$(chlorine) + ΔH_a(Ag) + I.E(Ag) +EA(Cl) - $\Delta H_f^{\ominus}$ = 121 + 289 + 732 -364 + 127 = (+) 905 (kJ mol^{-1})	1 1 1	Or cycle If $AgCl_2$, CE=0/3 Allow 1 for -905 Allow 1 for (+)844.5 (use of 121/2) Ignore units even if incorrect.
1(e)	**M1** Greater **M2** (Born-Haber cycle method allows for additional) covalent interaction ***OR*** **M1** Equal **M2** AgCl is perfectly ionic / no covalent character	1 1	Do not penalise $AgCl_2$ Allow AgCl has covalent character. Only score M2 if M1 is correct.

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

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

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Question	Marking Guidance	Mark	Comments
3(a)(i)	(At 0 K) particles are stationary / not moving / not vibrating No disorder / perfect order / maximum order	1 1	Allow have zero energy. Ignore atoms / ions. Mark independently.
3(a)(ii)	As *T* increases, particles start to move / vibrate Disorder / randomness increases / order decreases	1 1	Ignore atoms / ions. Allow have more energy. If change in state, CE = 0
3(a)(iii)	Mark on temperature axis vertically below second 'step'	1	Must be marked as a line, an 'x' , T_b or 'boiling point' on the temperature axis.
3(a)(iv)	L_2 corresponds to boiling / evaporating / condensing / l → g / g → l And L_1 corresponds to melting / freezing / s → l / l → s Bigger change in disorder for L_2 / boiling compared with L_1 / melting	1 1	There must be a clear link between L_1, L_2 and the change in state. 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.

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3(b)(i)	$\Delta G = \Delta H - T\Delta S$ $\Delta H = c$ and $(-)\Delta S = m$ / ΔH and ΔS are constants (approx)	1 1	 Allow ΔH 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 / ΔS is positive / $T\Delta S$ gets bigger	1	Allow $-T\Delta S$ gets more negative.
3(b)(iii)	Not feasible / unfeasible / not spontaneous	1	
3(c)(i)	+ 44.5 J K^{-1} mol^{-1}	1	Allow answer without units but if units given they must be correct (including mol^{-1})
3(c)(ii)	At 5440 $\Delta H = T\Delta S$ = 5440 × 44.5 = 242 080 (***OR*** using given value = 5440 × 98 = 533 120) ΔH = 242 kJ mol^{-1} (***OR*** using given value ΔH = 533 kJ mol^{-1})	1 1 1	 Mark is for answer to (c)(i) × 5440 Mark is for correct answer to M2 with correct units (J mol^{-1} or kJ mol^{-1}) linked to answer. If answer consequentially correct based on (c)(i) except for incorrect sign (eg -242), max 1/3 provided units are correct.

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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
	Molecular with covalent bonding	1	M2 can be awarded if molecular mentioned in M3
	Weak / easily broken / not much energy to break intermolecular forces ***OR*** weak vdW / dipole-dipole forces of attraction between molecules	1	Intermolecular / IMF means same as between molecules.

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4(d)	Reagent (water or acid) Equation eg $MgO + 2HCl \rightarrow MgCl_2 + H_2O$	1 1	Can be awarded in the equation. $MgO + H_2O \rightarrow Mg(OH)_2$ Equations can be ionic but must show all of the reagent eg $H^+ + Cl^-$ Simplified ionic equation without full reagent can score M2 only. Allow $6MgO + P_4O_{10} \rightarrow 2Mg_3(PO_4)_2$
4(e)	$P_4O_{10} + 12NaOH \rightarrow 4Na_3PO_4 + 6H_2O$	1	Allow P_2O_5 and acid salts. Must be NaOH not just hydroxide ions.

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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)	Chloride ions react with copper ions / Cu^{2+} ***OR*** $[CuCl_4]^{2-}$ formed	1	If incorrect chemistry, mark = 0
5(c)	The Cu^{2+} ions / $CuSO_4$ in the left-hand electrode more concentrated So the reaction of Cu^{2+} with $2e^-$ will occur (in preference at) left-hand electrode / $Cu \rightarrow Cu^{2+}$ + electrons at right-hand electrode	1 1	Allow converse. Allow left-hand electrode positive / right-hand electrode negative. Also reduction at left-hand electrode / oxidation at right-hand electrode. Also left-hand electrode has oxidising agent / right-hand electrode has reducing agent. Allow *E* left-hand side > *E* right-hand side
5(d)	(Eventually) the copper ions / $CuSO_4$ in each electrode will be at the same concentration	1	
5(e)(i)	-3.05 (V)	1	Must have minus sign. -3.05 only.

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5(e)(ii)	$LiMnO_2 \rightarrow Li + MnO_2$ correct equation Correct direction	1 1	Allow 1 for reverse equation. Allow multiples. If Li+ not cancelled but otherwise correct, max = 1 If electrons not cancelled, CE = 0 $LiMnO_2 \rightarrow Li + MnO_2$ scores 2 $Li^+ + LiMnO_2 \rightarrow Li^+ + Li + MnO_2$ scores 1 $Li + MnO_2 \rightarrow LiMnO_2$ scores 1

5(e)(iii)	Electricity for recharging the cell may come from power stations <u>burning</u> (fossil) fuel	1	Allow any reference to <u>burning</u> (of carbon-containing) fuels. Note combustion = burning.

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

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6(d)	Any **three** from: • (Identity of the) metal • Charge (on the metal) / oxidation state / charge on complex • (Identity of the) ligands • Co-ordination number / number of ligands • Shape	3 max	

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Question	Marking Guidance	Mark	Comments
7(a)	Iron(II): green (solution) gives a green precipitate	1	Apply list principle throughout if extra colours and/or extra observations given. Ignore state symbols in equations. Not blue-green ppt.
	$\underline{[Fe(H_2O)_6]^{2+}} + CO_3^{2-} \rightarrow FeCO_3 + 6H_2O$	1	Must start from $[Fe(H_2O)_6]^{2+}$ Allow equations with Na_2CO_3
	Iron(III):: yellow / purple / brown / lilac / violet (solution) gives a brown / rusty precipitate	1	
	Effervescence / gas / bubbles	1	Allow CO_2 evolved but not just CO_2
	$\underline{2[Fe(H_2O)_6]^{3+}} + 3CO_3^{2-} \rightarrow 2[Fe(H_2O)_3(OH)_3] + 3CO_2 + 3H_2O$	1	
7(b)	Copper(II): blue (solution) gives a green / yellow solution ***OR*** blue solution (turns) to green / yellow / olive green	1	Apply list principle throughout if extra colours and/or extra observations given. Ignore state symbols in equations.
	$\underline{[Cu(H_2O)_6]^{2+}} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$	1	Allow equations with HCl
	Cobalt(II): pink (solution) gives a blue solution ***OR*** pink solution turns blue	1	
	$\underline{[Co(H_2O)_6]^{2+}} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$	1	

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7(c)	Iron(II): green (solution) gives a green precipitate	1	Apply list principle throughout if extra colours and/or extra observations given. Ignore state symbols in equations.
	$\underline{[Fe(H_2O)_6]^{2+}} + 2OH^- \rightarrow Fe(H_2O)_4(OH)_2 + 2H_2O$	1	Allow equations with NaOH
	Chromium(III): green / ruby / purple / violet / red-violet (solution) gives a green solution ***OR*** green / ruby / purple / violet / red-violet solution turns green	1	Ignore green ppt.
	$\underline{[Cr(H_2O)_6]^{3+}} + 6OH^- \rightarrow [Cr(OH)_6]^{3-} + 6H_2O$	1	Allow also with 4 or 5 OH balanced with 2 or 1 waters. Also allow two correct equations showing $Cr(H_2O)_3(OH)_3$ as intermediate.

7(d)	Al: colourless (solution) gives a white ppt	1	Apply list principle throughout if extra colours and/or extra observations given. Ignore state symbols in equations.
	$\underline{[Al(H_2O)_6]^{3+}} + 3NH_3 \rightarrow Al(H_2O)_3(OH)_3 + 3NH_4^+$	1	Allow $+ 3OH^- \rightarrow 3H_2O$ if $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$ also
	Ag: colourless (solution) remains a colourless solution / no visible change	1	Ignore brown ppt.
	$\underline{[Ag(H_2O)_2]^+} + 2NH_3 \rightarrow [Ag(NH_3)_2]^+ + 2H_2O$	1	Allow 2 / 3 equations involving Ag_2O or $Ag(OH)_2$

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Question	Marking Guidance	Mark	Comments
8(a)	Cobalt has variable oxidation states	1	Allow exists as Co(II) and Co(III)
	(It can act as an intermediate that) lowers the activation energy	1	Allow (alternative route with) lower E_a
	$CH_3CHO + 2Co^{3+} + H_2O \rightarrow CH_3COOH + 2Co^{2+} + 2H^+$	1	Allow multiples; allow molecular formulae Allow equations with H_3O^+
	$\frac{1}{2}O_2 + 2Co^{2+} + 2H^+ \rightarrow 2Co^{3+} + H_2O$	1	
8(b)(i)	$[Co(H_2O)_6]^{2+} + 3H_2NCH_2CH_2NH_2 \rightarrow [Co(H_2NCH_2CH_2NH_2)_3]^{2+} + 6H_2O$	1	Do not allow en in equation, allow $C_2H_8N_2$
	The number of particles increases / changes from 4 to 7	1	Can score M2 and M3 even if equation incorrect or missing provided number of particles increases.
	So the entropy change is positive / disorder increases / entropy increases	1	
8(b)(ii)	Minimum for **M1** is 3 bidentate ligands bonded to Co Ligands need not have any atoms shown but diagram must show 6 bonds from ligands to Co, 2 from each ligand	1	Ignore all charges for M1 and M3 but penalise charges on any ligand in M2
	Minimum for **M2** is one ligand identified as H_2N-----NH_2	1	Allow linkage as -C-C- or just a line.
	Minimum for **M3** is one bidentate ligand showing two arrows from separate nitrogens to cobalt	1	

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8(c)	Moles of cobalt = (50 × 0.203)/1000 = <u>0.01015</u> mol	1	Allow 0.0101 to 0.0102
	Moles of AgCl = 4.22/143.4 = 0.0294	1	Allow 0.029 If not AgCl (eg $AgCl_2$ or $AgNO_3$), lose this mark and can only score **M1**, **M4** and **M5**
	Ratio = Cl^- to Co = 2.9 : 1	1	Do not allow 3 : 1 if this is the only answer but if 2.9:1 seen somewhere in answer credit this as **M3**
	$[Co(NH_3)_6]Cl_3$ (square brackets not essential)	1	
	Difference due to incomplete oxidation in the preparation	1	Allow incomplete reaction. Allow formation $[Co(NH_3)_5Cl]Cl_2$ etc. Some chloride ions act as ligands / replace NH_3 in complex. Do not allow 'impure sample' or reference to practical deficiencies.

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Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
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5	
6	
7	
8	
TOTAL	

General Certificate of Education
Advanced Level Examination
January 2013

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Tuesday 22 January 2013 1.30 pm to 3.15 pm

For this paper you must have:
- the Periodic Table/Data Sheet, provided as an insert (enclosed)
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator, where appropriate.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use scientific terminology accurately.

Advice
- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.

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Section A

Answer **all** questions in the spaces provided.

1 This question is about bond dissociation enthalpies and their use in the calculation of enthalpy changes.

1 (a) Define *bond dissociation enthalpy* as applied to chlorine.

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(2 marks)

1 (b) Explain why the enthalpy of atomisation of chlorine is exactly half the bond dissociation enthalpy of chlorine.

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(1 mark)

1 (c) The bond dissociation enthalpy for chlorine is +242 kJ mol^{-1} and that for fluorine is +158 kJ mol^{-1}.
The standard enthalpy of formation of ClF(g) is –56 kJ mol^{-1}.

1 (c) (i) Write an equation, including state symbols, for the reaction that has an enthalpy change equal to the standard enthalpy of formation of gaseous ClF

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(1 mark)

Do not write outside the box

1 (c) (ii) Calculate a value for the bond enthalpy of the Cl—F bond.

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(2 marks)

1 (c) (iii) Calculate the enthalpy of formation of gaseous chlorine trifluoride, $ClF_3(g)$.
Use the bond enthalpy value that you obtained in part **(c) (ii)**.

(If you have been unable to obtain an answer to part **(c) (ii)**, you may assume that the Cl—F bond enthalpy is +223 kJ mol^{-1}. This is **not** the correct value.)

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(3 marks)

1 (c) (iv) Explain why the enthalpy of formation of $ClF_3(g)$ that you calculated in part **(c) (iii)** is likely to be different from a data book value.

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(1 mark)

1 (d) Suggest why a value for the Na—Cl bond enthalpy is **not** found in any data book.

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(1 mark)

11

Turn over ▶

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2 This table contains some values of lattice dissociation enthalpies.

Compound	$MgCl_2$	$CaCl_2$	MgO
Lattice dissociation enthalpy / kJ mol^{-1}	2493	2237	3889

2 (a) Write an equation, including state symbols, for the reaction that has an enthalpy change equal to the lattice dissociation enthalpy of magnesium chloride.

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(1 mark)

2 (b) Explain why the lattice dissociation enthalpy of magnesium chloride is greater than that of calcium chloride.

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(2 marks)

(Extra space) .....

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2 (c) Explain why the lattice dissociation enthalpy of magnesium oxide is greater than that of magnesium chloride.

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(2 marks)

(Extra space) .....

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Do not write outside the box

2 (d) When magnesium chloride dissolves in water, the enthalpy of solution is –155 kJ mol^{-1}. The enthalpy of hydration of chloride ions is –364 kJ mol^{-1}.

Calculate the enthalpy of hydration of magnesium ions.

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(3 marks)

(Extra space) .....

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2 (e) Energy is released when a magnesium ion is hydrated because magnesium ions attract water molecules.

Explain why magnesium ions attract water molecules.
You may use a labelled diagram to illustrate your answer.

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(2 marks)

2 (f) Suggest why a value for the enthalpy of solution of magnesium oxide is **not** found in any data books.

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(1 mark)

11

Turn over ▶

There are no questions printed on this page

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

Do not write outside the box

3 The feasibility of a physical or a chemical change depends on the balance between the thermodynamic quantities of enthalpy change (ΔH), entropy change (ΔS) and temperature (T).

3 (a) Suggest how these quantities can be used to predict whether a change is feasible.

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(2 marks)

3 (b) Explain why the evaporation of water is spontaneous even though this change is endothermic.
In your answer, refer to the change in the arrangement of water molecules and the entropy change.

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(4 marks)

Question 3 continues on the next page

Do not write outside the box

3 (c) This table contains some thermodynamic data for hydrogen, oxygen and water.

	$S^{\ominus}$ / J K^{-1} mol^{-1}	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$H_2(g)$	131	0
$O_2(g)$	205	0
$H_2O(g)$	189	–242
$H_2O(l)$	70	

3 (c) (i) Calculate the temperature above which the reaction between hydrogen and oxygen to form gaseous water is **not** feasible.

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(4 marks)

3 (c) (ii) State what would happen to a sample of gaseous water that was heated to a temperature higher than that of your answer to part **(c) (i)**.
Give a reason for your answer.

What would happen to gaseous water .....

.....

Reason .....

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(2 marks)

Do not write outside the box

3 (d) When hydrogen is used as a fuel, more heat energy can be obtained if the gaseous water formed is condensed into liquid water.

Use entropy data from the table in part **(c)** to calculate the enthalpy change when one mole of gaseous water is condensed at 373 K.
Assume that the free-energy change for this condensation is zero.

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(3 marks)

15

Turn over for the next question

Do not write outside the box

4 Some melting points of Period 3 oxides are given in this table.

	Na_2O	SiO_2	SO_2	SO_3
Melting point / K	1548	1883	200	290

4 (a) Explain, in terms of structure and bonding, why sodium oxide has a high melting point.

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(2 marks)

4 (b) Explain, in terms of structure and bonding, why sulfur trioxide has a higher melting point than sulfur dioxide.

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(2 marks)

4 (c) Some Period 3 oxides have basic properties.

State the type of bonding in these basic oxides.
Explain why this type of bonding causes these oxides to have basic properties.

Type of bonding .....

Explanation .....

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(3 marks)

Do not write outside the box

4 (d) Sulfur dioxide reacts with water to form a weakly acidic solution.

4 (d) (i) Ions are formed when sulfur dioxide reacts with water.
Write an equation for this reaction.

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(1 mark)

4 (d) (ii) With reference to your equation from part **(d) (i)**, suggest why sulfur dioxide forms a weakly acidic solution.

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(1 mark)

4 (e) Suggest why silicon dioxide is described as an acidic oxide even though it is insoluble in water.

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(1 mark)

10

Turn over for the next question

Do not write outside the box

5 This question is about test-tube reactions of some ions in aqueous solution.

For each reaction in parts **(a)** to **(d)**, state the colour of the original solution.
State what you would observe after the named reagent has been added to the solution.
In each case, write an equation for the reaction that occurs.

5 (a) An excess of dilute sulfuric acid is added to a solution containing CrO_4^{2-} ions.

Colour of original solution .....

Observation after an excess of reagent has been added .....

.....

Equation

.....

(3 marks)

5 (b) Sodium hydroxide solution is added to a solution containing $[Fe(H_2O)_6]^{3+}$ ions.

Colour of original solution .....

Observation after reagent has been added .....

.....

Equation

.....

(3 marks)

5 (c) An excess of ammonia solution is added to a solution containing $[Cu(H_2O)_6]^{2+}$ ions.

Colour of original solution .....

Observation after an excess of reagent has been added .....

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Equation

.....

(3 marks)

Do not write outside the box

5 (d) Sodium carbonate solution is added to a solution containing $[Al(H_2O)_6]^{3+}$ ions.

Colour of original solution .....

Observations after reagent has been added .....

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Equation

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(4 marks)

13

Turn over for the next question

Do not write outside the box

6 Transition metal compounds have a range of applications as catalysts.

6 (a) State the general property of transition metals that allows the vanadium in vanadium(V) oxide to act as a catalyst in the Contact Process.

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(1 mark)

6 (b) Write **two** equations to show how vanadium(V) oxide acts as a catalyst in the Contact Process.

Equation 1

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Equation 2

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(2 marks)

6 (c) In the Contact Process, vanadium(V) oxide acts as a heterogeneous catalyst.

6 (c) (i) Give the meaning of the term *heterogeneous*.

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(1 mark)

6 (c) (ii) Give **one** reason why impurities in the reactants can cause problems in processes that use heterogeneous catalysts.

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(1 mark)

Do not write outside the box

6 (d) The oxidation of $C_2O_4^{2-}$ ions by MnO_4^- ions in acidic solution is an example of a reaction that is autocatalysed.

6 (d) (i) Give the meaning of the term *autocatalysed*.

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(1 mark)

6 (d) (ii) Identify the autocatalyst in this reaction.

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(1 mark)

6 (d) (iii) Write **two** equations to show how the autocatalyst is involved in this oxidation of $C_2O_4^{2-}$ ions.

Equation 1

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Equation 2

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(2 marks)

9

Turn over for the next question

Do not write outside the box

Section B

Answer **all** questions in the spaces provided.

7 This table shows some standard electrode potential data.

Electrode half-equation	$E^{\ominus}$ / V
$Au^{+}(aq) + e^{-} \longrightarrow Au(s)$	+1.68
$\frac{1}{2}O_2(g) + 2H^{+}(aq) + 2e^{-} \longrightarrow H_2O(l)$	+1.23
$Ag^{+}(aq) + e^{-} \longrightarrow Ag(s)$	+0.80
$Fe^{3+}(aq) + e^{-} \longrightarrow Fe^{2+}(aq)$	+0.77
$Cu^{2+}(aq) + 2e^{-} \longrightarrow Cu(s)$	+0.34
$Fe^{2+}(aq) + 2e^{-} \longrightarrow Fe(s)$	–0.44

7 (a) Draw a labelled diagram of the apparatus that could be connected to a standard hydrogen electrode in order to measure the standard electrode potential of the Fe^{3+}/Fe^{2+} electrode.

In your diagram, show how this electrode is connected to the standard hydrogen electrode and to a voltmeter. Do **not** draw the standard hydrogen electrode.

State the conditions under which this cell should be operated in order to measure the standard electrode potential.

Conditions .....

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(5 marks)

Do not write outside the box

7 (b) Use data from the table to deduce the equation for the overall cell reaction of a cell that has an e.m.f. of 0.78 V.
Give the conventional cell representation for this cell.
Identify the positive electrode.

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(4 marks)

7 (c) Use data from the table to explain why Au^+ ions are **not** normally found in aqueous solution.
Write an equation to show how Au^+ ions would react with water.

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(3 marks)

7 (d) Use data from the table to predict and explain the redox reactions that occur when iron powder is added to an excess of aqueous silver nitrate.

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(3 marks)

Turn over for the next question

15

Do not write outside the box

8 (a) Explain the meaning of the terms *ligand* and *bidentate* as applied to transition metal complexes.

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(2 marks)

8 (b) Aqueous cobalt(II) ions react separately with an excess of chloride ions and with an excess of ammonia.

For each reaction, draw a diagram to illustrate the structure of, the shape of and the charge on the complex ion formed.

In each case, name the shape and indicate, on the diagram, a value for the ligand–metal–ligand bond angle.

(6 marks)

Do not write outside the box

8 (c) The complex ion formed in aqueous solution between cobalt(II) ions and chloride ions is a different colour from the $[Co(H_2O)_6]^{2+}$ ion.

Explain why these complex ions have different colours.

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(3 marks)

8 (d) In aqueous ammonia, cobalt(II) ions are oxidised to cobalt(III) ions by hydrogen peroxide. The H_2O_2 is reduced to hydroxide ions.

Calculate the minimum volume of 5.00 mol dm^{-3} H_2O_2 solution required to oxidise the Co^{2+} ions in 9.87 g of $CoSO_4.7H_2O$

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(5 marks)

END OF QUESTIONS

16

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Version 1.4



General Certificate of Education (A-level)
January 2013

Chemistry CHEM5

(Specification 2420)

Unit 5: Energetics, Redox and Inorganic Chemistry

Final

Mark Scheme

Mark schemes are prepared by the Principal Examiner 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 examiners 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 examiner understands and applies it in the same correct way. As preparation for standardisation each examiner 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, examiners encounter unusual answers which have not been raised they are required to refer these to the Principal Examiner.

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.

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Question	Marking Guidance	Mark	Comments
1(a)	(Enthalpy change to) break the bond in 1 mol of chlorine (molecules)	1	Allow (enthalpy change to) convert 1 mol of chlorine molecules into atoms Do not allow energy or heat instead of enthalpy, allow heat energy
	To form (2 mol of) gaseous chlorine atoms / free radicals	1	Can score 2 marks for 'Enthalpy change for the reaction': $Cl_2(g) \rightarrow 2Cl(g)$ Equation alone gains M2 only Can only score M2 if 1 mol of chorine molecules used in M1 (otherwise it would be confused with atomisation enthalpy) Any mention of ions, CE = 0
1(b)	(For atomisation) only 1 mol of chlorine atoms, not 2 mol (as in bond enthalpy) is formed / equation showing ½ mol Chlorine giving 1 mol of atoms	1	Allow breaking of one bond gives two atoms Allow the idea that atomisation involves formation of 1 mol of atoms not 2 mol Allow the idea that atomisation of chlorine involves half the amount of molecules of chlorine as does dissociation Any mention of ions, CE = 0
1(c)(i)	$\frac{1}{2}F_2(g) + \frac{1}{2}Cl_2(g) \rightarrow ClF(g)$	1	

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1(c)(ii)	$\Delta H = ½E(F–F) + ½ E(Cl–Cl) – E(Cl–F)$ $E(Cl–F) = ½E(F–F) + ½E(Cl–Cl) - \Delta H$ $= 79 + 121 – (–56)$ $= 256\,(kJ\ mol^{-1})$	1 1	Allow correct cycle -256 scores zero Ignore units even if wrong
1(c)(iii)	$½Cl_2 + 3/2F_2 \rightarrow ClF_3$ $\Delta H = ½ E(Cl–Cl) + 3/2 E(F–F) - 3E(Cl–F)$ $= 121 + 237 – 768$ / (or 3 x value from (c)(ii)) $= –410\,(kJ\ mol^{-1})$	1 1 1	If equation is doubled CE=0 unless correcr answer gained by /2 at end This would score M1 This also scores M1 (note = 358 – 768) If given value of 223 used ans = –311 Allow 1/3 for +410 and +311
1(c)(iv)	(Bond enthalpy of) Cl–F bond in ClF is different from that in ClF_3	1	Allow Cl–F bond (enthalpy) is different in different compounds (QoL)
1(d)	NaCl is ionic / not covalent	1	

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Question	Marking Guidance	Mark	Comments
2(a)	$MgCl_2(s) \rightarrow Mg^{2+}(g) + 2Cl^-(g)$	1	
2(b)	The magnesium <u>ion</u> is smaller / has a smaller radius / greater charge density (than the calcium ion) Attraction between ions / to the chloride ion stronger	1 1	If not ionic or if molecules / IMF / metallic / covalent / bond pair / electronegativity mentioned, CE = 0 Allow ionic bonds stronger Do not allow any reference to polarisation or covalent character Mark independently
2(c)	The oxide ion has a greater charge / charge density than the chloride ion So it attracts the magnesium ion more strongly	1 1	If not ionic or if molecules / IMF / metallic / covalent / bond pair mentioned, CE = 0 Allow oxide ion smaller than chloride ion Allow ionic bonds stronger Mark independently
2(d)	$\Delta H_{solution} = \Delta H_L + \Sigma\Delta H_{hyd}$ Mg^{2+} ions + $\Sigma\Delta H_{hyd}$ Cl^- ions $-155 = 2493 + \Delta H_{hyd}$ Mg^{2+} ions $- 2\times364$ ΔH_{hyd} Mg^{2+} ions $= -155 - 2493 + 728$ $= -1920$ (kJ mol^{-1})	1 1 1	Allow correct cycle Ignore units Allow max 1 for +1920 Answer of + or -1610, CE = 0 Answer of -2284, CE = 0

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2(e)	Water is polar / O on water has a delta negative charge Mg^{2+} ion / +ve ion / + charge attracts (negative) O on a water molecule	1 1	Allow <u>O</u> (not water) has lone pairs (can score on diagram) Allow Mg^{2+} attracts lone pair(s) M2 must be stated in words (QoL) Ignore mention of co-ordinate bonds CE = 0 if O^{2-} or water ionic or H bonding
2(f)	Magnesium oxide reacts with water / forms $Mg(OH)_2$	1	Allow MgO does not dissolve in water / sparingly soluble / insoluble

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Question	Marking Guidance	Mark	Comments
3(a)	$\Delta G = \Delta H - T\Delta S$	1	Or expression $\Delta H - T\Delta S$ must be evaluated
	If ΔG / expression <=0 reaction is feasible	1	Or any explanation that this expression <=0 Do not allow just $\Delta G = 0$
3(b)	The molecules become more disordered / random when water changes from a liquid to a gas / evaporates	1	For M1 must refer to change in state AND increase in disorder
	Therefore the entropy change is positive / Entropy increases	1	Only score M2 if M1 awarded
	$T\Delta S > \Delta H$	1	Allow M3 for *T* is large / high (provided M2 is scored)
	$\Delta G < 0$	1	Mark M3, M4 independently
3(c)(i)	Condition is $T = \Delta H/\Delta S$	1	
	ΔS = 189 –205/2 – 131 = –44.5;	1	
	ΔH = –242 therefore T = (–242 × 1000)/–44.5)	1	
	= 5438 K (allow 5400 – 5500 K)	1	Units essential (so 5438 alone scores 3 out of 4) 2719 K allow score of 2 5.4 (K) scores 2 for M1 and M2 only 1646 (K) scores 1 for M1 only
3(c)(ii)	It would decompose into <u>hydrogen and oxygen</u> / its elements	1	Can score this mark if mentioned in M2
	Because ΔG for this reaction would be <= 0	1	Allow the reverse reaction / decomposition is feasible Only score M2 if M1 awarded

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3(d)	$\Delta H = T\Delta S$	1	Allow correct substituted values instead of symbols
	ΔS = 70-189 = -119 $J K^{-1} mol^{-1}$	1	
	ΔH = (-119 × 373)/1000 = -44.4 kJ (mol^{-1}) (allow -44 to -45)	1	Allow -44000 to -45000 J (mol^{-1}) Answer must have correct units of kJ or J

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Question	Marking Guidance	Mark	Comments
4(a)	Na_2O is an ionic lattice / giant ionic / ionic crystal With strong forces of attraction between ions	1 1	CE= 0 if molecules, atoms, metallic mentioned Mention of electronegativity max 1 out of 2 Allow strong ionic bonds/lots of energy to separate ions
4(b)	SO_3 is a larger molecule than SO_2 So van der Waals' forces between molecules are stronger	1 1	Allow greater M_r / surface area Any mention of ions, CE= 0
4(c)	Ionic Contains O^{2-} ions / oxide ions These / O^{2-} ions (accept protons to) form OH^- / hydroxide / water (must score M2 to gain M3)	1 1 1	Do not allow ionic with covalent character Equations of the form $O^{2-} + H^+ \rightarrow OH^-$ / $O^{2-} + 2H^+ \rightarrow H_2O$ / $O^{2-} + H_2O \rightarrow 2OH^-$ score M2 and M3
4(d)(i)	$SO_2 + H_2O \rightarrow H^+ + HSO_3^-$	1	Allow $2H^+ + SO_3^{2-}$ but no ions, no mark Only score (d)(ii) if (d)(i) correct
4(d)(ii)	Reaction is an equilibrium / reversible reaction displaced mainly to the left / partially ionised / dissociated	1	Allow reaction does not go to completion
4(e)	SiO_2 reacts with bases / NaOH / CaO / $CaCO_3$	1	Ignore incorrect formulae for silicate

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Question	Marking Guidance	Mark	Comments
5(a)	Yellow (solution)	1	
	Orange <u>solution</u>	1	
	$2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$	1	Allow equation with H_2SO_4
5(b)	Yellow / purple (solution)	1	Allow orange / brown (solution)
	Brown precipitate / solid	1	
	$[Fe(H_2O)_6]^{3+} + 3OH^- \rightarrow Fe(H_2O)_3(OH)_3 + 3H_2O$	1	
5(c)	Blue (solution)	1	Allow pale blue
	Dark / deep blue <u>solution</u>	1	Ignore any reference to blue ppt
	$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 4H_2O$	1	Can be in two equations
5(d)	Colourless (solution)	1	
	White precipitate / solid	1	Do not allow grey
	Bubbles / effervescence / gas evolved / given off	1	Do not allow just CO_2
	$2[Al(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2Al(H_2O)_3(OH)_3 + 3CO_2 + 3H_2O$	1	

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Question	Marking Guidance	Mark	Comments
6(a)	Variable / many oxidation states	1	
6(b)	$V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ $V_2O_4 + ½O_2 \rightarrow V_2O_5$	1 1	Equations can be in either order Allow multiples
6(c)(i)	In a different phase / state <u>from reactants</u>	1	
6(c)(ii)	Impurities poison / deactivate the catalyst / block the active sites	1	Allow (adsorbs onto catalyst AND reduces surface area)
6(d)(i)	The catalyst is a reaction product	1	
6(d)(ii)	Mn^{2+}/ Mn^{3+} ion(s)	1	
6(d)(iii)	$4Mn^{2+} + MnO_4^- + 8H^+ \rightarrow 5Mn^{3+} + 4H_2O$ $2Mn^{3+} + C_2O_4^{2-} \rightarrow 2Mn^{2+} + 2CO_2$	1 1	Equations can be in either order

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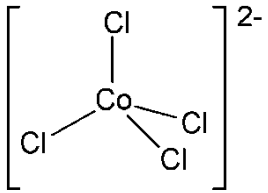
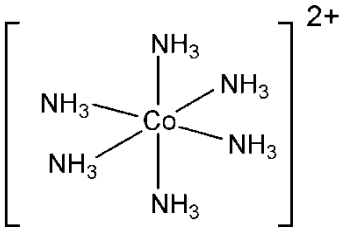
Question	Marking Guidance	Mark	Comments
7(a)	Diagram of an Fe^{3+}/Fe^{2+} electrode that includes the following parts labelled:		
	Solution containing Fe^{2+} and Fe^{3+} ions	1	
	Platinum electrode connected to one terminal of a voltmeter	1	Must be in the solution of iron ions (one type will suffice)
	Salt bridge	1	Do not allow incorrect material for salt bridge and salt bridge must be in the solution (ie it must be shown crossing a meniscus)
	298 K and 100 kPa / 1 bar	1	
	<u>all solutions</u> unit / 1 mol dm^{-3} concentration	1	Allow zero current / high resistanve voltmeter as alternative to M4 or M5 Ignore hydrogen electrode even if incorrect
7(b)	$Cu^{2+} + Fe \rightarrow Cu + Fe^{2+}$	1	Ignore state symbols
	$Fe\|Fe^{2+}\|\|Cu^{2+}\|Cu$ correct order	1	Allow $Cu\|Cu^{2+}\|\|Fe^{2+}\|Fe$
	Phase boundaries and salt bridge correct, no Pt	1	Allow single/double dashed line for salt bridge Penalise phase boundary at either electrode end Can only score M3 if M2 correct
	Copper electrode	1	Allow any reference to copper

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7(c)	$E^{\ominus}$ $Au^{+}(/Au) > E^{\ominus}$ $O_2(/H_2O)$	1	Allow *E* cell/e.m.f. = 0.45 V Allow 1.68 > 1.23
	So Au^{+} ions will oxidise water / water reduces Au^{+}	1	QoL
	$2Au^{+} + H_2O \rightarrow 2Au + 1/2O_2 + 2H^{+}$	1	Allow multiples

7(d)	$E^{\ominus}$ $Ag^{+}(/Ag) > E^{\ominus}$ $Fe^{2+}(/Fe)$	1	Allow *E* cell/e.m.f. = 1.24 Allow 0.80 > -0.44
	And $E^{\ominus}$ $Ag^{+}(/Ag) > E^{\ominus}$ $Fe^{3+}(/Fe^{2+})$	1	Allow *E* cell/e.m.f. = 0.03 Allow 0.80 > 0.77
	So silver ions will oxidise iron (to iron(II) ions) and then oxidise Fe(II) ions (further to Fe(III) ions producing silver metal)	1	Allow Ag^{+} ions will oxidise iron to iron(III)

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Question	Marking Guidance	Mark	Comments
8(a)	A ligand is an electron pair / lone pair donor	1	Allow uses lone / electron pair to form a co-ordinate bond
	A bidentate ligand donates two electron pairs (to a transition metal ion) from different atoms / two atoms (on the same molecule / ion)	1	QoL
8(b)	$CoCl_4^{2-}$ diagram 	1	Four chlorines attached to Co with net 2- charge correct
	Tetrahedral shape	1	Charge can be placed anywhere, eg on separate formula Penalise excess charges
	109° 28'	1	Allow 109° to 109.5^o
	$[Co(NH_3)_6]^{2+}$ diagram 	1	Six ammonia / NH_3 molecules attached to Co with 2+ charge correct
	Octahedral shape	1	
	90°	1	Allow 180° if shown clearly on diagram
			CE= 0 if wrong complex but mark on if only charge is incorrect
8(c)	In different complexes the d orbitals / d electrons (of the cobalt) will have different energies / d orbital splitting will be different	1	
	Light / energy is absorbed causing an electron to be excited	1	
	Different frequency / wavelength / colour of light will be absorbed / transmitted / reflected	1	

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8(d)	1 mol of H_2O_2 oxidises 2 mol of Co^{2+}	1	Or $H_2O_2 + 2Co^{2+} \rightarrow 2OH^- + 2Co^{3+}$
	M_r $CoSO_4.7H_2O$ = 281	1	If M_r wrong, max 3 for M1, M4, M5
	Moles Co^{2+} = 9.87/281 = 0.03512	1	
	Moles H_2O_2 = 0.03512/2 = 0.01756	1	M4 is method mark for (M3)/2 (also scores M1)
	Volume H_2O_2 = (moles × 1000)/concentration = 0.01756 × 1000)/5.00		
	= 3.51 cm^3 / (3.51 x 10^{-3} dm^3)	1	Units essential for answer
			M5 is method mark for (M4) x 1000/5 Allow 3.4 to 3.6 cm^3
			If no 2:1 ratio or ratio incorrect Max 3 for M2, M3 & M5
			Note : Answer of 7 cm^3 scores 3 for M2, M3, M5 (and any other wrong ratio max 3)
			Answer of 16.8 cm^3 scores 3 for M1, M4, M5 (and any other wrong M_r max 3)
			Answer of 33.5 cm^3 scores 1 for M5 only (so wrong M_r AND wrong ratio max 1)

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Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
TOTAL	

General Certificate of Education
Advanced Level Examination
June 2012

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Tuesday 19 June 2012 1.30 pm to 3.15 pm

For this paper you must have:
- the Periodic Table/Data Sheet provided as an insert (enclosed)
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator, where appropriate.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use accurate scientific terminology.

Advice
- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.

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Section A

Answer **all** questions in the spaces provided.

1 White phosphorus (P_4) is a hazardous form of the element. It is stored under water.

1 (a) Suggest why white phosphorus is stored under water.

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(1 mark)

1 (b) Phosphorus(V) oxide is known as phosphorus pentoxide.
Suggest why it is usually represented by P_4O_{10} rather than by P_2O_5

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(1 mark)

1 (c) Explain why phosphorus(V) oxide has a higher melting point than sulfur(VI) oxide.

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(2 marks)

1 (d) Write an equation for the reaction of P_4O_{10} with water to form phosphoric(V) acid.
Give the approximate pH of the final solution.

Equation .....

pH .....

(2 marks)

Do not write outside the box

1 (e) A waste-water tank was contaminated by P_4O_{10}. The resulting phosphoric(V) acid solution was neutralised using an excess of magnesium oxide. The mixture produced was then disposed of in a lake.

1 (e) (i) Write an equation for the reaction between phosphoric(V) acid and magnesium oxide.

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(1 mark)

1 (e) (ii) Explain why an excess of magnesium oxide can be used for this neutralisation.

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(1 mark)

1 (e) (iii) Explain why the use of an excess of sodium hydroxide to neutralise the phosphoric(V) acid solution might lead to environmental problems in the lake.

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(1 mark)

9

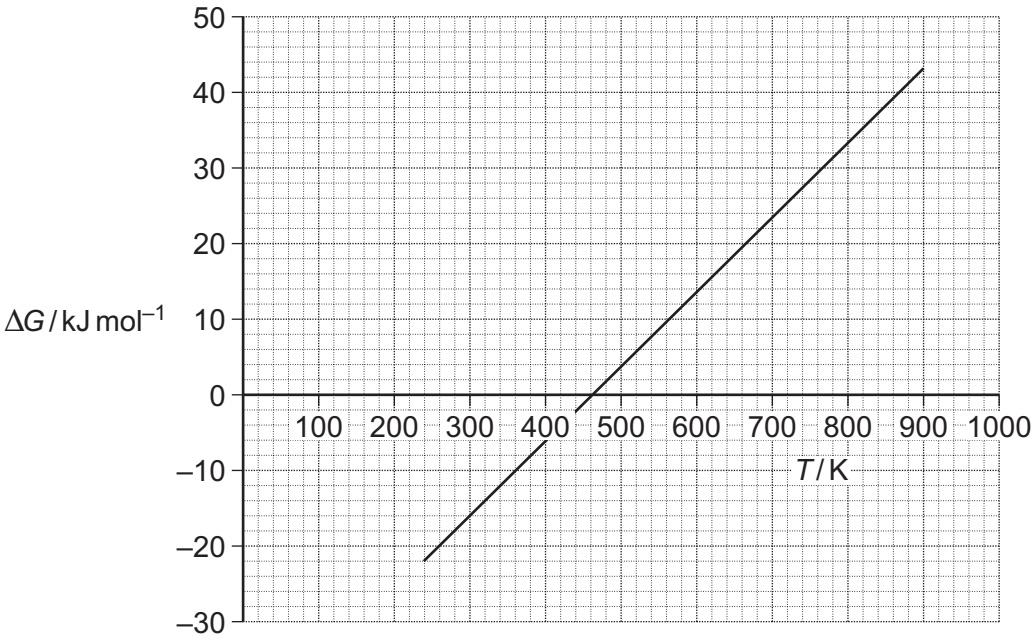
Turn over for the next question

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2 The following equation shows the formation of ammonia.

$$\tfrac{1}{2}N_2(g) + \tfrac{3}{2}H_2(g) \longrightarrow NH_3(g)$$

The graph shows how the free-energy change for this reaction varies with temperature above 240 K.



2 (a) Write an equation to show the relationship between ΔG, ΔH and ΔS.

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(1 mark)

2 (b) Use the graph to calculate a value for the slope (gradient) of the line. Give the units of this slope and the symbol for the thermodynamic quantity that this slope represents.

Value of the slope .....

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Units .....

Symbol .....

(3 marks)

Do not write outside the box

2 (c) Explain the significance, for this reaction, of temperatures below the temperature value where the line crosses the temperature axis.

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(2 marks)

2 (d) The line is not drawn below a temperature of 240 K because its slope (gradient) changes at this point.

Suggest what happens to the ammonia at 240 K that causes the slope of the line to change.

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(1 mark)

7

Turn over for the next question

Do not write outside the box

3 Some thermodynamic data for fluorine and chlorine are shown in the table.
In the table, X represents the halogen F or Cl

	Fluorine	**Chlorine**
Electronegativity	4.0	3.0
Electron affinity / kJ mol^{-1}	–348	–364
Enthalpy of atomisation / kJ mol^{-1}	+79	+121
Enthalpy of hydration of $X^-(g)$ / kJ mol^{-1}	–506	–364

3 (a) Explain the meaning of the term *electron affinity*.

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(2 marks)

3 (b) Explain why the electronegativity of fluorine is greater than the electronegativity of chlorine.

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(2 marks)

(Extra space) .....

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3 (c) Explain why the hydration enthalpy of the fluoride ion is more negative than the hydration enthalpy of the chloride ion.

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(2 marks)

Do not write outside the box

3 (d) The enthalpy of solution for silver fluoride in water is $-20\ kJ\ mol^{-1}$.

The hydration enthalpy for silver ions is $-464\ kJ\ mol^{-1}$.

3 (d) (i) Use these data and data from the table to calculate a value for the lattice enthalpy of dissociation of silver fluoride.

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(3 marks)

3 (d) (ii) Suggest why the entropy change for dissolving silver fluoride in water has a positive value.

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(1 mark)

3 (d) (iii) Explain why the dissolving of silver fluoride in water is always a spontaneous process.

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(2 marks)

12

Turn over ▶

Do not write outside the box

4 The oxides nitrogen monoxide (NO) and nitrogen dioxide (NO_2) both contribute to atmospheric pollution.

The table gives some data for these oxides and for oxygen.

	$S^{\ominus}$ / J K^{-1} mol^{-1}	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$O_2(g)$	211	0
NO(g)	205	+90
$NO_2(g)$	240	+34

Nitrogen monoxide is formed in internal combustion engines. When nitrogen monoxide comes into contact with air, it reacts with oxygen to form nitrogen dioxide.

$$NO(g) + \tfrac{1}{2}O_2(g) \longrightarrow NO_2(g)$$

4 (a) Calculate the enthalpy change for this reaction.

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(2 marks)

4 (b) Calculate the entropy change for this reaction.

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(2 marks)

Do not write outside the box

4 (c) Calculate the temperature below which this reaction is spontaneous.

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(2 marks)

4 (d) Suggest **one** reason why nitrogen dioxide is **not** formed by this reaction in an internal combustion engine.

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(1 mark)

4 (e) Write an equation to show how nitrogen monoxide is formed in an internal combustion engine.

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(1 mark)

4 (f) Use your equation from part **(e)** to explain why the free-energy change for the reaction to form nitrogen monoxide stays approximately constant at different temperatures.

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(2 marks)

10

Do not write outside the box

5 The table shows some electrode half-equations and the associated standard electrode potentials.

Equation number	Electrode half-equation	$E^{\ominus}$/V
1	$Cd(OH)_2(s) + 2e^- \rightarrow Cd(s) + 2OH^-(aq)$	–0.88
2	$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	–0.76
3	$NiO(OH)(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq)$	+0.52
4	$MnO_2(s) + H_2O(l) + e^- \rightarrow MnO(OH)(s) + OH^-(aq)$	+0.74
5	$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$	+1.23

5 (a) In terms of electrons, state the meaning of the term *oxidising agent*.

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(1 mark)

5 (b) Deduce the identity of the weakest oxidising agent in the table.
Explain how $E^{\ominus}$ values can be used to make this deduction.

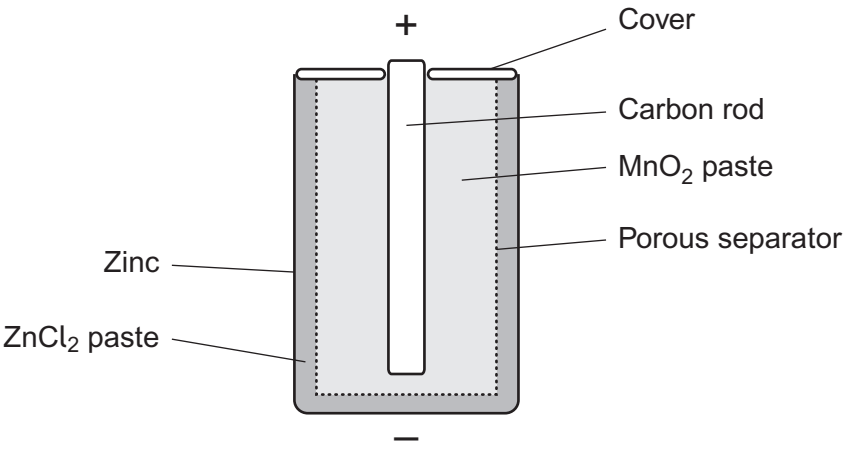
Weakest oxidising agent .....

Explanation .....

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(2 marks)

5 (c) The diagram shows a non-rechargeable cell that can be used to power electronic devices. The relevant half-equations for this cell are equations **2** and **4** in the table above.



Do not write outside the box

5 (c) (i) Calculate the e.m.f. of this cell.

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(1 mark)

5 (c) (ii) Write an equation for the overall reaction that occurs when the cell discharges.

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(1 mark)

5 (c) (iii) Deduce **one** essential property of the non-reactive porous separator labelled in the diagram.

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(1 mark)

5 (c) (iv) Suggest the function of the carbon rod in the cell.

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(1 mark)

5 (c) (v) The zinc electrode acts as a container for the cell and is protected from external damage. Suggest why a cell often leaks after being used for a long time.

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(1 mark)

Question 5 continues on the next page

Do not write outside the box

5 (d) A rechargeable nickel–cadmium cell is an alternative to the cell shown in part **(c)**. The relevant half-equations for this cell are equations **1** and **3** in the table on page 10.

5 (d) (i) Deduce the oxidation state of the nickel in this cell after recharging is complete. Write an equation for the overall reaction that occurs when the cell is **recharged**.

Oxidation state .....

Equation .....

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(3 marks)

5 (d) (ii) State **one** environmental advantage of this rechargeable cell compared with the non-rechargeable cell described in part **(c)**.

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(1 mark)

5 (e) An ethanol–oxygen fuel cell may be an alternative to a hydrogen–oxygen fuel cell. When the cell operates, all of the carbon atoms in the ethanol molecules are converted into carbon dioxide.

5 (e) (i) Deduce the equation for the overall reaction that occurs in the ethanol–oxygen fuel cell.

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(1 mark)

5 (e) (ii) Deduce a half-equation for the reaction at the ethanol electrode. In this half-equation, ethanol reacts with water to form carbon dioxide and hydrogen ions.

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(1 mark)

5 (e) (iii) The e.m.f. of an ethanol–oxygen fuel cell is 1.00 V. Use data from the table on page 10 to calculate a value for the electrode potential of the ethanol electrode.

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(1 mark)

Do not write outside the box

5 (e) (iv) Suggest why ethanol can be considered to be a carbon-neutral fuel.

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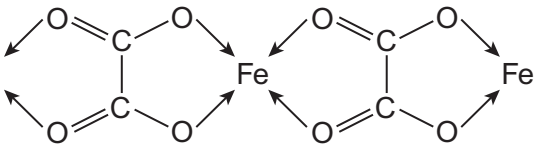
(2 marks)

17

Turn over for the next question

Do not write outside the box

6 Solid iron(II) ethanedioate dihydrate ($FeC_2O_4.2H_2O$) has a polymeric structure. Two repeating units in the polymer chain are shown.



Each iron ion is also bonded to two water molecules. These are **not** shown in the diagram.

6 (a) Name the type of bond that is represented by the arrows.

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(1 mark)

6 (b) In terms of electrons explain how the water molecules, **not** shown in the diagram, form bonds to the iron.

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(2 marks)

6 (c) Predict the value of the bond angle between the two bonds to iron that are formed by these two water molecules.

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(1 mark)

Do not write outside the box

6 (d) Iron(II) ethanedioate dihydrate can be analysed by titration using potassium manganate(VII) in acidic solution. In this reaction, manganate(VII) ions oxidise iron(II) ions and ethanedioate ions.

A 1.381 g sample of impure $FeC_2O_4.2H_2O$ was dissolved in an excess of dilute sulfuric acid and made up to 250 cm^3 of solution.
25.0 cm^3 of this solution decolourised 22.35 cm^3 of a 0.0193 mol dm^{-3} solution of potassium manganate(VII).

6 (d) (i) Use the half-equations given below to calculate the reacting ratio of moles of manganate(VII) ions to moles of iron(II) ethanedioate.

$$MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$$
$$Fe^{2+} \longrightarrow Fe^{3+} + e^-$$
$$C_2O_4^{2-} \longrightarrow 2CO_2 + 2e^-$$

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(1 mark)

6 (d) (ii) Calculate the percentage by mass of $FeC_2O_4.2H_2O$ in the original sample.

(If you have been unable to answer part **(d) (i)** you may assume that three moles of manganate(VII) ions react with seven moles of iron(II) ethanedioate. This is **not** the correct ratio.)

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(5 marks)

10

Do not write outside the box

Section B

Answer **all** questions in the spaces provided.

7 You may find the following electrode potential data helpful when answering this question.

Electrode half-equation	$E^{\ominus}$/V
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l)$	+1.23
$Cr^{3+}(aq) + e^- \longrightarrow Cr^{2+}(aq)$	–0.44
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	–0.76
$Cr^{2+}(aq) + 2e^- \longrightarrow Cr(s)$	–0.91

7 (a) Describe the colour changes that you would observe when an excess of zinc is added to an acidified solution of potassium dichromate(VI) in the absence of air.

For each colour change, identify the coloured ions responsible and write an equation for each reaction that occurs with zinc.
In the equations, you should represent the ions in their simplest form, for example Cr^{3+}

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(5 marks)

(Extra space) .....

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Do not write outside the box

7 (b) Describe what you would observe when dilute aqueous sodium hydroxide is added, dropwise until in excess, to a dilute aqueous solution containing chromium(III) ions.

Write **two** equations to illustrate your observations.
In these equations you should give the full formula of each of the complexes, for example $[Cr(H_2O)_6]^{3+}$

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(4 marks)

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7 (c) When an aqueous solution containing $[Cr(H_2O)_6]^{3+}$ ions is warmed in the presence of Cl^- ions, $[Cr(H_2O)_5Cl]^{2+}$ ions are formed and the colour of the solution changes.

Name this type of reaction.

Suggest, in terms of electrons, why the colours of the complex ions are different.

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(3 marks)

(Extra space) .....

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Question 7 continues on the next page

Turn over ▶

Do not write outside the box

7 (d) The chromium(II) ion $[Cr(H_2O)_6]^{2+}$ has different properties from the $[Cr(H_2O)_6]^{3+}$ ion.

Use data from the table on page 16 to explain why, in an open container, $[Cr(H_2O)_6]^{2+}$(aq) ions change into $[Cr(H_2O)_6]^{3+}$(aq) ions.

Suggest the identity of the products formed in each case when sodium carbonate solution is added to separate solutions containing $[Cr(H_2O)_6]^{2+}$(aq) ions and $[Cr(H_2O)_6]^{3+}$(aq) ions.

Explain why the $[Cr(H_2O)_6]^{3+}$(aq) ions behave differently from the $[Cr(H_2O)_6]^{2+}$(aq) ions.

In your answer to this part of the question, equations are **not** required.

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(7 marks)

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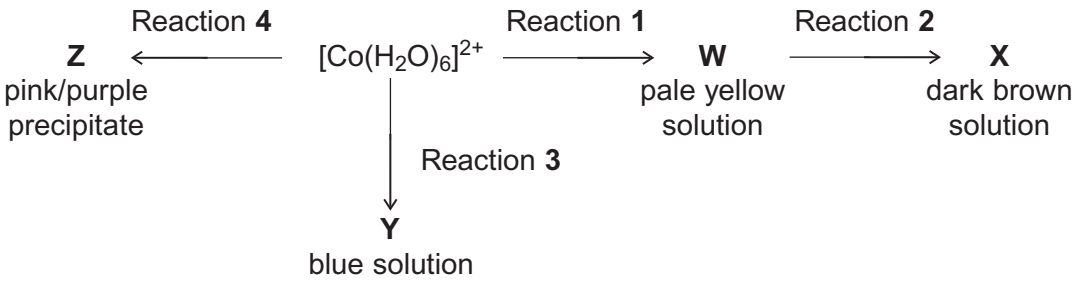
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19

Do not write outside the box

8 This question is about cobalt chemistry.

8 (a) Consider the following reaction scheme that starts from $[Co(H_2O)_6]^{2+}$ ions.
W, **X** and **Y** are ions and **Z** is a compound.



For each of the reactions **1** to **4**, identify a suitable reagent.

Identify **W**, **X**, **Y** and **Z** and write an equation for each of reactions **1** to **4**.

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(12 marks)

(Extra space) .....

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Question 8 continues on the next page

Turn over ▶

Do not write outside the box

8 (b) A flue-gas desulfurisation process involves the oxidation, by oxygen, of aqueous sulfate(IV) ions (SO_3^{2-}) into aqueous sulfate(VI) ions (SO_4^{2-}). This reaction is catalysed by Co^{2+} ions in an acidic aqueous solution.

Write an equation for the overall reaction of sulfate(IV) ions with oxygen to form sulfate(VI) ions.

Suggest why this overall reaction is faster in the presence of Co^{2+} ions.

Suggest a mechanism for the catalysed reaction by writing **two** equations involving Co^{2+} and Co^{3+} ions. You will need to use H^+ ions and H_2O to balance these two equations.

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(4 marks)

16

END OF QUESTIONS

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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

Mark schemes are prepared by the Principal Examiner 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 examiners participate in and is the scheme which was used by them in this examination. The standardisation process ensures that the mark scheme covers the candidates' responses to questions and that every examiner understands and applies it in the same correct way. As preparation for standardisation each examiner analyses a number of candidates' scripts: alternative answers not already covered by the mark scheme are discussed and legislated for. If, after the standardisation process, examiners encounter unusual answers which have not been raised they are required to refer these to the Principal Examiner.

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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 Van der Waals / vdW forces between molecules are stronger/require more energy to break	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

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1(e)(i)	$3MgO + 2H_3PO_4 \rightarrow Mg_3(PO_4)_2 + 3H_2O$ OR $MgO + 2H_3PO_4 \rightarrow Mg(H_2PO_4)_2 + H_2O$ OR $MgO + H_3PO_4 \rightarrow MgHPO_4 + H_2O$	1	Allow $MgO + 2H^+ \rightarrow Mg^{2+} + H_2O$ 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

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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 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 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)	ΔG becomes <u>negative</u>	1	Mark independently unless ΔG +ve then CE = 0
	So reaction becomes spontaneous/feasible	1	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

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Question	Marking Guidance	Mark	Comments
3(a)	Enthalpy change/heat energy change when one mole of gaseous atoms Form (one mole of) gaseous negative ions (with a single charge)	1 1	Allow explanation with an equation that includes state symbols 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 to the nucleus/protons	1 1	Fluorine molecules/ions/charge density CE=0 for both marks
3(c)	Fluoride (ions) smaller (than chloride) / have larger charge density So (negative charge) attracts (δ+ hydrogen on) water more strongly	1 1	Any reference to electronegativity CE=0 Allow H on water, do not allow O on water Allow F^- hydrogen bonds to water, chloride ion does not Mark independently

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3(d)(i)	ΔH(solution) = LE + Σ(hydration enthalpies) / correct cycle *LE* = -20 -(-464 + -506) = (+) 950 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	

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Question	Marking Guidance	Mark	Comments
4(a)	$\Delta H = \Sigma(\Delta H_f$ products) - $\Sigma(\Delta H_f$ reactants) /= +34 - +90 = -56 kJ mol^{-1}	1 1	Allow correct cycle Ignore no units, penalise incorrect units
4(b)	$\Delta S = \Sigma(S$ products) - $\Sigma(S$ 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/-.070 to -.071
4(c)	$T = \Delta H/\Delta S$ / T = (Ans to part(a) ×1000)/ans to part(b) /= -56/(-70.5 ÷ 1000) = 794 K (789 to 800 K)	1 1	Mark consequentially on answers to parts (a) and (b) Must have correct units 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) So entropy/disorder stays (approximately) constant / entropy/disorder change is very small / $\Delta S=0$ / $T\Delta S=0$	1 1	Can only score these marks if the equation in (e) has equal number of moles on each side Numbers, if stated must match equation

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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 *E* / smallest *E*	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)	$2MnO_2 + 2H_2O + Zn \rightarrow 2MnO(OH) + 2OH^- + Zn^{2+}$	1	Ignore state symbols e^- must be cancelled (take care that Zn^{2+} is on RHS)
5(c)(iii)	Allows ions 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 reacts Do not allow just zinc corrodes

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5(d)(i)	3 / +3 / III $2Ni(OH)_2 + Cd(OH)_2 \rightarrow 2NiO(OH) + Cd + 2H_2O$	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)	$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$	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 (atmospheric) $\underline{CO_2}$ taken up in <u>photosynthesis</u>	1 1	Can be answered with the aid of equations

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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 ^{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 = $22.35 \times 0.0193/1000 = \underline{4.31 \times 10^{-4}}$ Method marks for each of the next steps (no arithmetic error allowed for M2): **M2** moles of FeC_2O_4= ratio from (d)(i) used correctly $\times 4.31 \times 10^{-4}$ **M3** moles of FeC_2O_4 in 250 cm^3 = M2 ans $\times$ 10 **M4** Mass of $FeC_2O_4.2H_2O$ = M3 ans $\times$ 179.8 **M5** % of $FeC_2O_4.2H_2O$ = (M4 ans/1.381) $\times$ 100 (OR for M4 max moles of $FeC_2O_4.2H_2O$ = 1.381/179.8 (= 7.68×10^{-3}) for M5 % of $FeC_2O_4.2H_2O$ = (M3 ans/above M4ans) $\times$ 100) eg using correct ratio 5/3: Moles of $FeC_2O_4 = 5/3 \times 4.31 \times 10^{-4} = 7.19 \times 10^{-4}$ Moles of FeC_2O_4 in 250 $cm^3 = 7.19 \times 10^{-4} \times 10 = 7.19 \times 10^{-3}$ Mass of $FeC_2O_4.2H_2O = 7.19 \times 10^{-3} \times 179.8 = 1.29$ g % of $FeC_2O_4.2H_2O$ = $1.29 \times 100/1.381 = 93.4$ (allow 92.4 to 94.4) Note correct answer (92.4 to 94.4) scores 5 marks	1 1 1 1 1	Allow $\underline{4.3 \times 10^{-4}}$ (2 sig figs) Allow other ratios as follows: eg from given ratio of 7/3 **M2** = $7/3 \times 4.31 \times 10^{-4} = 1.006 \times 10^{-3}$ **M3** = $1.006 \times 10^{-3} \times 10 = 1.006 \times 10^{-2}$ **M4** = $1.006 \times 10^{-2} \times 179.8 = 1.81$ g **M5** = $1.81 \times 100/1.381 = 131$ % (130 to 132) Allow consequentially on candidates ratio eg **M2** = $5/2 \times 4.31 \times 10^{-4} = 1.078 \times 10^{-3}$ **M3** = $1.0078 \times 10^{-3} \times 10 = 1.078 \times 10^{-2}$ **M4** = $1.078 \times 10^{-2} \times 179.8 = 1.94$ g **M5** = $1.94 \times 100/1.381 = 140$ % (139 to 141) 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)

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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 d electrons are different (for each complex)	1	
	So a different 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		

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 water	1	Ignore charge/size ratio and mass/charge

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

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Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
TOTAL	

General Certificate of Education
Advanced Level Examination
January 2012

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Wednesday 1 February 2012 9.00 am to 10.45 am

For this paper you must have:
- the Periodic Table/Data Sheet, provided as an insert (enclosed)
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use accurate scientific terminology.

Advice
- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.

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Do not write outside the box

Section A

Answer **all** questions in the spaces provided.

1 This question is about magnesium oxide. Use data from the table below, where appropriate, to answer the following questions.

	$\Delta H^{\ominus}$ / kJ mol^{-1}
First electron affinity of oxygen (formation of $O^-(g)$ from O(g))	–142
Second electron affinity of oxygen (formation of $O^{2-}(g)$ from $O^-(g)$)	+844
Atomisation enthalpy of oxygen	+248

1 (a) Define the term *enthalpy of lattice dissociation.*

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(3 marks)

1 (b) In terms of the forces acting on particles, suggest **one** reason why the first electron affinity of oxygen is an exothermic process.

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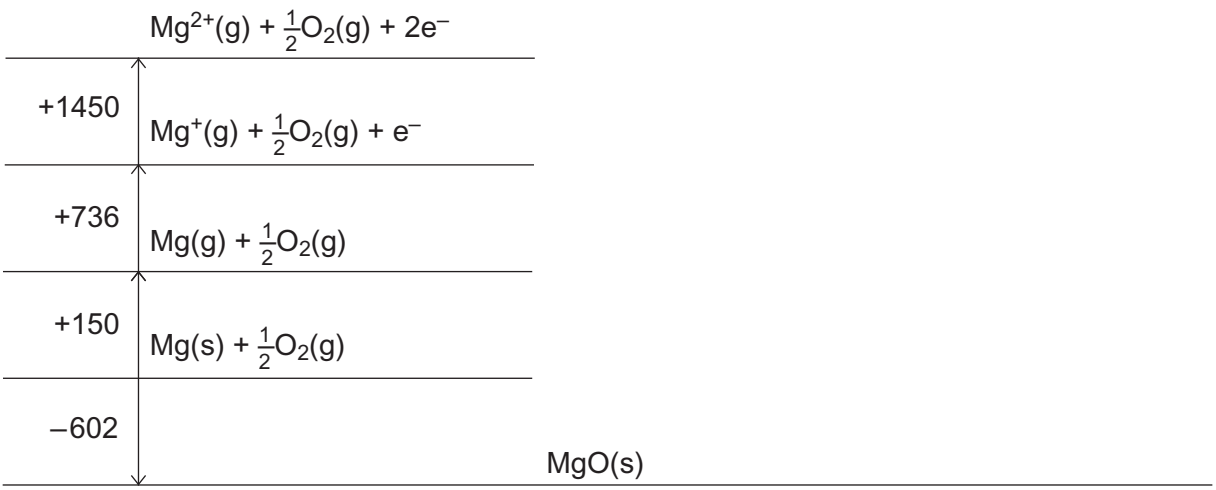
(1 mark)

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Do not write outside the box

1 (c) Complete the Born–Haber cycle for magnesium oxide by drawing the missing energy levels, symbols and arrows.
The standard enthalpy change values are given in kJ mol^{-1}.



(4 marks)

1 (d) Use your Born–Haber cycle from part **(c)** to calculate a value for the enthalpy of lattice dissociation for magnesium oxide.

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(2 marks)

Question 1 continues on the next page

Turn over ▶

Do not write outside the box

1 (e) The standard free-energy change for the formation of magnesium oxide from magnesium and oxygen, $\Delta G_f^{\ominus} = -570$ kJ mol^{-1}.
Suggest **one** reason why a sample of magnesium appears to be stable in air at room temperature, despite this negative value for $\Delta G_f^{\ominus}$.

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(1 mark)

(Extra space) .....

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1 (f) Use the value of $\Delta G_f^{\ominus}$ given in part **(e)** and the value of $\Delta H_f^{\ominus}$ from part **(c)** to calculate a value for the entropy change $\Delta S^{\ominus}$ when one mole of magnesium oxide is formed from magnesium and oxygen at 298 K. Give the units of $\Delta S^{\ominus}$.

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(3 marks)

(Extra space) .....

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1 (g) In terms of the reactants and products and their physical states, account for the sign of the entropy change that you calculated in part **(f)**.

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(2 marks)

16

Do not write outside the box

2 Consider the following process that represents the melting of ice.

$H_2O(s) \longrightarrow H_2O(l)$ $\Delta H^{\ominus} = +6.03\,kJ\,mol^{-1}$, $\Delta S^{\ominus} = +22.1\,J\,K^{-1}\,mol^{-1}$

2 (a) State the meaning of the symbol $^{\ominus}$ in $\Delta H^{\ominus}$.

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(1 mark)

2 (b) Use your knowledge of bonding to explain why $\Delta H^{\ominus}$ is positive for this process.

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(2 marks)

2 (c) Calculate the temperature at which $\Delta G^{\ominus} = 0$ for this process. Show your working.

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(3 marks)

2 (d) The freezing of water is an exothermic process. Give **one** reason why the temperature of a sample of water can stay at a constant value of 0 °C when it freezes.

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(1 mark)

2 (e) Pure ice can look pale blue when illuminated by white light. Suggest an explanation for this observation.

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(2 marks)

9

Turn over ▶

Do not write outside the box

3 The data in the table below show the melting points of oxides of some Period 3 elements.

	Na_2O	P_4O_{10}	SO_2
T_m / K	1548	573	200

3 (a) In terms of structure and bonding, explain why

3 (a) (i) sodium oxide has a high melting point

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(2 marks)

(Extra space) .....

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3 (a) (ii) sulfur dioxide has a low melting point.

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(2 marks)

(Extra space) .....

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3 (b) Explain why the melting point of P_4O_{10} is higher than the melting point of SO_2

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(2 marks)

(Extra space) .....

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Do not write outside the box

3 (c) Write equations for the reactions of Na_2O and P_4O_{10} with water. In each case give the approximate pH of the resulting solution.

Equation for Na_2O .....

pH .....

Equation for P_4O_{10} .....

pH .....

(4 marks)

3 (d) Write an equation for the acid–base reaction that occurs when Na_2O reacts with P_4O_{10} in the absence of water.

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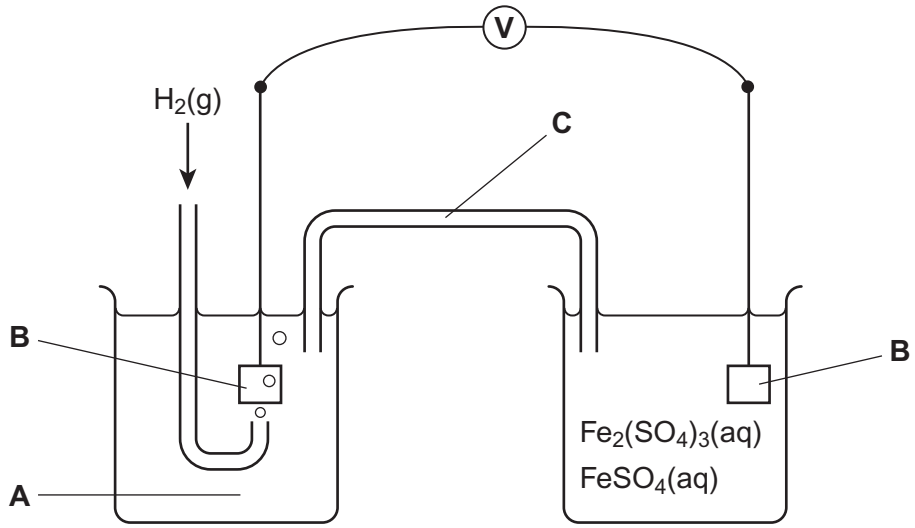
(1 mark)

11

Turn over for the next question

Do not write outside the box

4 The diagram below shows a cell that can be used to measure the standard electrode potential for the half-reaction $Fe^{3+}(aq) + e^- \longrightarrow Fe^{2+}(aq)$. In this cell, the electrode on the right-hand side is positive.



4 (a) Identify solution **A** and give its concentration. State the other essential conditions for the operation of the standard electrode that forms the left-hand side of the cell.

Solution **A** .....

Conditions .....

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(3 marks)

4 (b) Identify the material from which electrodes **B** are made. Give **two** reasons why this material is suitable for its purpose.

Material .....

Reason 1 .....

.....

Reason 2 .....

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(3 marks)

Do not write outside the box

4 (c) Identify a solution that could be used in **C** to complete the circuit. Give **two** reasons why this solution is suitable for its purpose.

Solution .....

Reason 1 .....

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Reason 2 .....

.....

(3 marks)

4 (d) Write the conventional representation for this cell.

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(1 mark)

4 (e) The voltmeter **V** shown in the diagram of the cell was replaced by an ammeter.

4 (e) (i) Write an equation for the overall cell reaction that would occur.

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(1 mark)

4 (e) (ii) Explain why the ammeter reading would fall to zero after a time.

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(1 mark)

12

Do not write outside the box

5 Some electrode potentials are shown in the table below. These values are **not** listed in numerical order.

Electrode half-equation	$E^{\ominus}$/ V
$Cl_2(aq) + 2e^- \longrightarrow 2Cl^-(aq)$	+1.36
$2HOCl(aq) + 2H^+(aq) + 2e^- \longrightarrow Cl_2(aq) + 2H_2O(l)$	+1.64
$H_2O_2(aq) + 2H^+(aq) + 2e^- \longrightarrow 2H_2O(l)$	+1.77
$O_2(g) + 2H^+(aq) + 2e^- \longrightarrow H_2O_2(aq)$	+0.68
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l)$	+1.23

5 (a) Identify the most powerful reducing agent from all the species in the table.

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(1 mark)

5 (b) Use data from the table to explain why chlorine should undergo a redox reaction with water. Write an equation for this reaction.

Explanation .....

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Equation .....

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(2 marks)

5 (c) Suggest **one** reason why the redox reaction between chlorine and water does **not** normally occur in the absence of light.

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(1 mark)

5 (d) Use the appropriate half-equation from the table to explain in terms of oxidation states what happens to hydrogen peroxide when it is reduced.

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(2 marks)

Do not write outside the box

5 (e) Use data from the table to explain why one molecule of hydrogen peroxide can oxidise another molecule of hydrogen peroxide. Write an equation for the redox reaction that occurs.

Explanation .....

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Equation .....

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(2 marks)

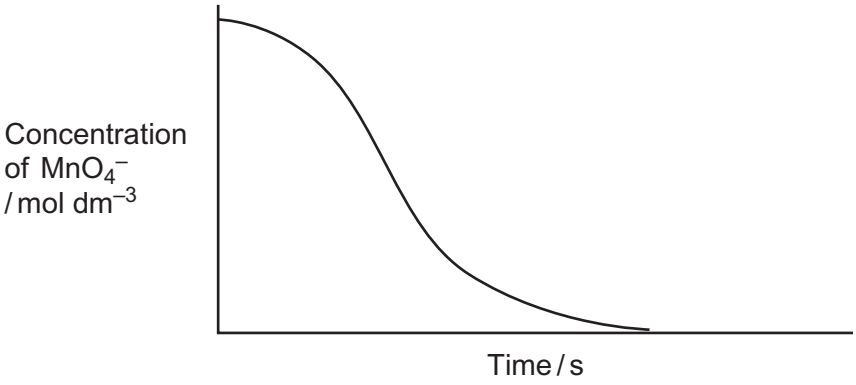
8

Turn over for the next question

Do not write outside the box

6 An acidified solution of potassium manganate(VII) was reacted with a sample of sodium ethanedioate at a constant temperature of 60 °C. The concentration of the manganate(VII) ions in the reaction mixture was determined at different times using a spectrometer to measure the light absorbed.

The following results were obtained.



6 (a) Write an equation for the reaction between manganate(VII) ions and ethanedioate ions in acidic solution.

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(2 marks)

(Extra space) .....

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6 (b) By considering the properties of the reactants and products, state why it is possible to use a spectrometer to measure the concentration of the manganate(VII) ions in this reaction mixture.

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(2 marks)

Do not write outside the box

6 (c) This reaction is autocatalysed. Give the meaning of the term *autocatalyst*.
Explain how the above curve indicates clearly that the reaction is autocatalysed.

Meaning of *autocatalyst* .....

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Explanation .....

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(3 marks)

6 (d) Identify the autocatalyst in this reaction.

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(1 mark)

6 (e) Write **two** equations to show how the autocatalyst is involved in this reaction.

Equation 1 .....

Equation 2 .....

(2 marks)

10

Turn over for the next question

Do not write outside the box

Section B

Answer **all** questions in the spaces provided.

7 Due to their electron arrangements, transition metals have characteristic properties including catalytic action and the formation of complexes with different shapes.

7 (a) Give **two other** characteristic properties of transition metals. For each property, illustrate your answer with a transition metal of your choice.

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(4 marks)

7 (b) Other than octahedral, there are several different shapes shown by transition metal complexes. Name **three** of these shapes and for each one give the formula of a complex with that shape.

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(6 marks)

Do not write outside the box

7 (c) It is possible for Group 2 metal ions to form complexes. For example, the $[Ca(H_2O)_6]^{2+}$ ion in hard water reacts with $EDTA^{4-}$ ions to form a complex ion in a similar manner to hydrated transition metal ions. This reaction can be used in a titration to measure the concentration of calcium ions in hard water.

7 (c) (i) Write an equation for the equilibrium that is established when hydrated calcium ions react with $EDTA^{4-}$ ions.

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(1 mark)

7 (c) (ii) Explain why the equilibrium in part **(c) (i)** is displaced almost completely to the right to form the EDTA complex.

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(3 marks)

7 (c) (iii) In a titration, 6.25 cm^3 of a 0.0532 mol dm^{-3} solution of EDTA reacted completely with the calcium ions in a 150 cm^3 sample of a saturated solution of calcium hydroxide. Calculate the mass of calcium hydroxide that was dissolved in 1.00 dm^3 of the calcium hydroxide solution.

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(3 marks)

(Extra space) .....

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17

Turn over ▶

Do not write outside the box

8 In its reactions with transition metal ions, ammonia can act as a Brønsted–Lowry base and as a Lewis base.

8 (a) Define the term *Lewis base*.

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(1 mark)

8 (b) Write an equation for a reaction between aqueous copper(II) ions ($[Cu(H_2O)_6]^{2+}$) and ammonia in which ammonia acts as a Brønsted–Lowry base. State what you would observe.

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(2 marks)

(Extra space) .....

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8 (c) Write an equation for a different reaction between aqueous copper(II) ions ($[Cu(H_2O)_6]^{2+}$) and ammonia in which ammonia acts as a Lewis base but **not** as a Brønsted–Lowry base. State what you would observe.

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(2 marks)

(Extra space) .....

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Do not write outside the box

8 (d) An excess of dilute ammonia solution is added to an aqueous solution containing iron(II) ions in a test tube that is then left to stand for some time.
State and explain what you would observe.

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(4 marks)

(*Extra space*) .....

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8 (e) Diaminoethane ($H_2NCH_2CH_2NH_2$), like ammonia, can react as a base and as a ligand.

8 (e) (i) Write an equation for the reaction that occurs between an aqueous solution of aluminium chloride and an excess of aqueous diaminoethane.
Describe the appearance of the aluminium-containing reaction product.

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(3 marks)

(Extra space) .....

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Question 8 continues on the next page

Do not write outside the box

8 (e) (ii) Write an equation for the reaction that occurs between an aqueous solution of cobalt(II) sulfate and an excess of aqueous diaminoethane.
Draw a diagram to show the shape of and bonding in the complex product.
Write an equation for the reaction that would occur if the complex product of this reaction were allowed to stand in contact with oxygen gas.

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(5 marks)

17

END OF QUESTIONS

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Version 1.2



General Certificate of Education (A-level)
January 2012

Chemistry CHEM5

(Specification 2420)

Unit 5: Energetics, Redox and Inorganic Chemistry

Final

Mark Scheme

Mark schemes are prepared by the Principal Examiner 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 examiners participate in and is the scheme which was used by them in this examination. The standardisation process ensures that the mark scheme covers the candidates' responses to questions and that every examiner understands and applies it in the same correct way. As preparation for standardisation each examiner analyses a number of candidates' scripts: alternative answers not already covered by the mark scheme are discussed and legislated for. If, after the standardisation process, examiners encounter unusual answers which have not been raised they are required to refer these to the Principal Examiner.

It must be stressed that a mark scheme is a working document, in many cases further developed and expanded on the basis of candidates' 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.

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Question	Marking Guidance	Mark	Comments
1(a)	Enthalpy change when 1 mol of an (ionic) compound/lattice (under standard conditions) Is dissociated/broken/separated into its (component) ions The ions being in the gaseous state (at infinite separation)	1 1 1	Allow heat energy change Mark independently. Ignore any conditions.
1(b)	There is an attractive force between the nucleus of an O atom and an external electron.	1	Allow any statement that implies attraction between the nucleus and an electron
1(c)	$Mg^{2+}(g) + O(g) + 2e^-$ $Mg^{2+}(g) + O^-(g) + e^-$ $Mg^{2+}(g) + O^{2-}(g)$ First new level for Mg^{2+} and O above last on L Next level for Mg^{2+} and O^- below that Next level for Mg^{2+} and O^{2-} above that and also above that for Mg^{2+} and O	1 1 1 1	Ignore lack of state symbols Penalise incorrect state symbols If levels are not correct allow if steps are in correct order with arrows in the correct direction and correct ΔH values Allow +124 Allow M4 with incorrect number of electrons
1(d)	LE MgO = 602 + 150 + 736 + 1450 + 248 - 142 + 844 = +3888 kJ mol^{-1}	1 1	Note use of 124 instead of 248 CE=0 Allow 1 for -3888 Allow no units Penalise wrong units

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1(e)	Forms a protective layer/barrier of MgO / MgO prevents oxygen attacking Mg	1	Allow activation energy is (very) high Allow reaction (very) slow
1(f)	$\Delta G = \Delta H - T\Delta S$ ΔS = (-602 - (-570)) × 1000/ 298 = -107 J K^{-1} mol^{-1} / -0.107 kJ K^{-1} mol^{-1}	1 1 1	$\Delta S = \frac{(\Delta H - \Delta G)}{T}$ If units not correct or missing, lose mark Allow -107 to -108 +107 with correct units scores max 1/3
1(g)	1 mol of solid and 0.5 mol of gas reactants form 1 mol solid products System becomes more ordered	1 1	Decrease in number of moles (of gas/species) Allow gas converted into solid Numbers of moles/species, if given, must be correct Allow consequential provided ΔS is -ve in 1(f) If ΔS is +ve in 1(f) can only score M1

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Question	Marking Guidance	Mark	Comments
2(a)	Standard pressure (100 kPa) (and a stated temperature)	1	Allow standard conditions. Do not allow standard states Allow any temperature Allow 1 bar but not 1atm Apply list principle if extra wrong conditions given Penalise reference to concentrations
2(b)	Hydrogen bonds between water molecules Energy must be supplied in order to break (or loosen) them	1 1	 Allow M2 if intermolecular forces mentioned Otherwise cannot score M2 CE = 0/2 if covalent or ionic bonds broken
2(c)	$T = \Delta H/\Delta S$ $= (6.03 \times 1000)/22.1$ = 273 K	1 1 1	 Allow 272 to 273; units K must be given Allow 0°C if units given 0.273 (with or without units) scores 1/3 only Must score M2 in order to score M3 Negative temperature can score M1 only
2(d)	The heat given out escapes	1	

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2(e)	(Red end of white) light (in visible spectrum) absorbed by ice Blue light / observed light is reflected / transmitted / left	1 1	Allow complementary colour to blue absorbed Penalise emission of blue light

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Question	Marking Guidance	Mark	Comments
3(a)(i)	Ionic lattice / solid / giant ionic Strong (electrostatic) forces/attraction between ions	1 1	CE = 0/2 if molecules / IMFs / atoms / metallic Allow strong ionic bonds for M2 only Allow lot of energy to break ionic bonds
3(a)(ii)	Molecular/molecules Weak dipole-dipole and/or van der Waals forces between molecules	1 1	 QoL Type of force must be mentioned
3(b)	P_4O_{10} bigger molecule/has larger surface area than SO_2 van der Waals forces between molecules stronger	1 1	Allow M_r of P_4O_{10} greater than for SO_2 If P_4O_{10} macromolecule/ionic, CE = 0/2 Allow stronger IMF
3(c)	$Na_2O + H_2O \rightarrow 2Na^+ + 2OH^-$ 14 $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$ 0	1 1 1 1	Allow 2NaOH Allow 12-14 Allow ions Allow -1 to +2
3(d)	$6Na_2O + P_4O_{10} \rightarrow 4Na_3PO_4$	1	Allow ionic Allow correct formula of product with atoms in any order

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Question	Marking Guidance	Mark	Comments
4(a)	HCl 1.0 mol dm^{-3}	1	Allow H_2SO_4 0.5 mol dm^{-3} Allow HNO_3 1.0 mol dm^{-3} Allow name or formula Concentration can be given after "conditions"
	(Hydrogen at) 100kPa / 1 bar	1	
	298 K	1	
4(b)	Pt / Platinum	1	Mark on if no answer for M1 If wrong answer for M1, only mark on if electrode is Au, Ag, Pb or Ti
	Inert / unreactive / does not create a potential difference	1	
	Conducts electricity / allows electron flow / conducts / conductor	1	
4(c)	KCl	1	Allow NaCl, KNO_3, Na_2SO_4 etc NOT NH_4Cl
	Does not react with either electrode / solution in electrode	1	Allow unreactive / inert
	Ions can move	1	Allow conducts electricity / electrical connection / carries charge Do not allow just connects / completes the circuit Do not allow conducts / carries electrons Mark these independently

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4(d)	$Pt\|H_2\|H^+\|\|Fe^{3+},Fe^{2+}\|Pt$	1	Ignore state symbols Order must be correct | must be correct but allow | instead of , separating Fe^{3+} from Fe^{2+} Allow , instead of | separating H_2 and H^+
4(e)(i)	$2Fe^{3+} + H_2 \rightarrow 2Fe^{2+} + 2H^+$	1	Allow multiples
4(e)(ii)	The $\underline{Fe}^{3+}$ ions would be used up / reaction completed	1	Answer must relate to reactants in 4(e)(i) equation if given Allow reactant / reactants used up Do not allow concentration of Fe^{3+} decreases Allow concentration of Fe^{3+} falls to zero

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Question	Marking Guidance	Mark	Comments
5(a)	H_2O_2	1	Ignore state symbols
5(b)	$E^{\ominus}$ Cl_2/Cl^- > $E^{\ominus}$ O_2/H_2O $Cl_2 + H_2O \rightarrow 2Cl^- + 1/2O_2 + 2H^+$	1 1	Allow potential for chlorine/Cl_2 greater than for oxygen/O_2 Allow 1.36 > 1.23 / E cell = 0.13 Allow multiples Allow + HCl
5(c)	Activation energy is high / light/UV provides the activation energy / light breaks chlorine molecule / Cl–Cl bond	1	If light used to break Cl–Cl bond award 1 mark and ignore product e.g. $Cl^{—}$
5(d)	O (-1) (in H_2O_2) Changes to O(-2) (in water)	1 1	Must give oxidation state of O in H_2O_2= -1 Must give oxidation state of O in water = -2 CE = 0/2 if refers to oxidation state of H changing
5(e)	$E^{\ominus}$ H_2O_2/H_2O > $E^{\ominus}$ O_2/H_2O_2 $2H_2O_2 \rightarrow O_2 + 2H_2O$	1 1	Allow stated in words Allow 1.77 > 0.68 / E cell = 1.09 Allow multiples H^+ and e^- must be cancelled

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Question	Marking Guidance	Mark	Comments
6(a)	$2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$	1 1	For all species correct / moles and species correct but charge incorrect For balanced equation including all charges (also scores first mark)
6(b)	Manganate(VII) ions are coloured (purple) All other reactants and products are **not** coloured (or too faintly coloured to detect)	1 1	 Allow (all) other species are colourless Allow Mn^{2+} are colourless / becomes colourless / pale pink
6(c)	The catalyst for the reaction is a reaction product Reaction starts off slowly / gradient shallow Then gets faster/rate increases / gradient increases	1 1 1	 Allow concentration of MnO_4^- decreases faster / falls rapidly
6(d)	Mn^{2+} ions	1	Allow Mn^{3+} ions
6(e)	$MnO_4^- + 8H^+ + 4Mn^{2+} \rightarrow 5Mn^{3+} + 4H_2O$ $2Mn^{3+} + C_2O_4^{2-} \rightarrow 2Mn^{2+} + 2CO_2$	1 1	Allow multiples

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Question	Marking Guidance	Mark	Comments
7(a)	Variable oxidation state	1	
	eg Fe(II) and Fe (III)	1	Any correctly identified pair Allow two formulae showing complexes with different oxidation states even if oxidation state not given
	(Characteristic) colour (of complexes)	1	
	eg Cu^{2+}(aq) / $[Cu(H_2O)_6]^{2+}$ is blue	1	Any correct ion with colour scores M3 and M4 Must show (aq) or ligands OR identified coloured compound (e.g. $CoCO_3$)
7(b)	Tetrahedral	1	
	$[CuCl_4]^{2-}$ / $[CoCl_4]^{2-}$	1	Any correct complex (Note charges must be correct)
	Square planar	1	
	$(NH_3)_2PtCl_2$	1	Any correct complex
	Linear	1	Do not allow linear planar
	$[Ag(NH_3)_2]^+$	1	$[AgCl_2]^-$ etc
7(c)(i)	$[Ca(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [CaEDTA]^{2-} + 6H_2O$	1	If equation does not show increase in number of moles of particles CE = 0/3 for 7(c)(ii) If no equation, mark on

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7(c)(ii)	2 mol of reactants form 7 mol of products	1	Allow more moles/species of products Allow consequential to 7(c)(i)
	Therefore disorder increases	1	
	Entropy increases / +ve entropy change / free-energy change is negative	1	

7(c)(iii)	Moles EDTA = 6.25 x 0.0532 / 1000 = (3.325×10^{-4})	1	
	Moles of Ca^{2+} in 1 dm^3 = 3.325×10^{-4} x 1000 / 150 = (2.217×10^{-3})	1	Mark is for M1 x 1000 / 150 **OR** M1 x 74.1 If ratio of Ca^{2+} : EDTA is wrong or 1000 / 150 is wrong, CE and can score M1 only This applies to the alternative
	Mass of $Ca(OH)_2$ = 2.217×10^{-3} x 74.1 = 0.164 g	1	M1 x 74.1 x 1000 / 150 Answer expressed to 3 sig figs or better Must give unit to score mark Allow 0.164 to 0.165

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Question	Marking Guidance	Mark	Comments
8(a)	Electron pair donor	1	Allow lone pair donor
8(b)	$[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow Cu(H_2O)_4(OH)_2 + 2NH_4^+$ (Blue solution) gives a (pale) blue precipitate/solid	1 1	 M2 only awarded if M1 shows Bronsted-Lowry reaction
8(c)	$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 4H_2O$ (Blue solution) gives a dark/deep blue solution	1 1	Allow formation in two equations via hydroxide If 8(b) and 8(c) are the wrong way around allow one mark only for each correct equation with a correct observation (max 2/4) M2 only awarded if M1 shows Lewis base reaction
8(d)	(Start with) green (solution) Green precipitate of $Fe(H_2O)_4(OH)_2$ / $Fe(OH)_2$ / iron(II) hydroxide Slowly changes to brown solid (Iron(II) hydroxide) oxidised by air (to iron(III) hydroxide)	1 1 1 1	 Do not allow observation if compound incorrect or not given Allow red-brown ppt Allow turns brown or if precipitate implied Can only score M3 if M2 scored Allow $Fe(OH)_2$ oxidised to $Fe(OH)_3$ by air / O_2 Ignore equations even if incorrect

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8(e)(i)	$2[Al(H_2O)_6]^{3+} + 3H_2NCH_2CH_2NH_2 \rightarrow 2Al(H_2O)_3(OH)_3 + 3[H_3NCH_2CH_2NH_3]^{2+}$	1 1	For correct Al species For correct balanced equation Allow equation with formation of $3[H_2NCH_2CH_2NH_3]^{+}$ from 1 mol $[Al(H_2O)_6]^{3+}$
	White precipitate	1	
8(e)(ii)	$[Co(H_2O)_6]^{2+} + 3H_2NCH_2CH_2NH_2 \rightarrow [Co(H_2NCH_2CH_2NH_2)_3]^{2+} + 6H_2O$	1	
	Complex with 3 en showing 6 correct bonds from N to Co	1	Ignore charge Accept N – N for ligand Ignore incorrect H If C shown, must be 2 per ligand
	Co-ordinate bonds (arrows) shown from N to Co	1	Can only score M3 if M2 correct
	$4[Co(H_2NCH_2CH_2NH_2)_3]^{2+} + O_2 + 2H_2O \rightarrow$	1	For Co(III) species
	$4[Co(H_2NCH_2CH_2NH_2)_3]^{3+} + 4OH^-$	1	For balanced equation (others are possible) Allow $+ O_2 + 4H^+ \rightarrow 2H_2O$ If en used can score M4 and M5 only If Cu not Co, can only score M2 and M3 Allow $N_2C_2H_8$ in equations

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Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
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General Certificate of Education
Advanced Level Examination
June 2011

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Friday 24 June 2011 9.00 am to 10.45 am

For this paper you must have:
- the Periodic Table/Data Sheet provided as an insert (enclosed)
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use accurate scientific terminology.

Advice
- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.



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Section A

Answer **all** questions in the spaces provided.

1 Thermodynamics can be used to investigate the changes that occur when substances such as calcium fluoride dissolve in water.

1 (a) Give the meaning of each of the following terms.

1 (a) (i) enthalpy of lattice formation for calcium fluoride

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(2 marks)

1 (a) (ii) enthalpy of hydration for fluoride ions

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(1 mark)

1 (b) Explain the interactions between water molecules and fluoride ions when the fluoride ions become hydrated.

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(2 marks)

Do not write outside the box

1 (c) Consider the following data.

	$\Delta H^{\ominus}$/ kJ mol^{-1}
Enthalpy of lattice formation for CaF_2	–2611
Enthalpy of hydration for Ca^{2+} ions	–1650
Enthalpy of hydration for F^- ions	–506

Use these data to calculate a value for the enthalpy of solution for CaF_2

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(2 marks)

7

Turn over for the next question

There are no questions printed on this page

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ANSWER IN THE SPACES PROVIDED

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2 When potassium nitrate (KNO_3) dissolves in water the value of the enthalpy change ΔH = +34.9 kJ mol^{-1} and the value of the entropy change ΔS = +117 J K^{-1} mol^{-1}.

2 (a) Write an equation, including state symbols, for the process that occurs when potassium nitrate dissolves in water.

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(1 mark)

2 (b) Suggest why the entropy change for this process is positive.

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(1 mark)

2 (c) Calculate the temperature at which the free-energy change, ΔG, for this process is zero.

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(3 marks)

2 (d) (i) Deduce what happens to the value of ΔG when potassium nitrate dissolves in water at a temperature lower than your answer to part **2 (c)**.

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(1 mark)

2 (d) (ii) What does this new value of ΔG suggest about the dissolving of potassium nitrate at this lower temperature?

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(1 mark)

7

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3 Ammonia can be manufactured by the Haber Process.

The equation for the reaction that occurs is shown below.

$$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$$

3 (a) The table below contains some bond enthalpy data.

	N≡N	H—H	N—H
Mean bond enthalpy / kJ mol^{-1}	944	436	388

3 (a) (i) Use data from the table to calculate a value for the enthalpy of formation for one mole of ammonia.

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(3 marks)

3 (a) (ii) A more accurate value for the enthalpy of formation of ammonia is –46 kJ mol^{-1}. Suggest why your answer to part **3 (a) (i)** is different from this value.

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(1 mark)

Do not write outside the box

3 (b) The table below contains some entropy data.

	$H_2(g)$	$N_2(g)$	$NH_3(g)$
$S^{\ominus}$ / J K^{-1} mol^{-1}	131	192	193

Use these data to calculate a value for the entropy change, with units, for the formation of one mole of ammonia from its elements.

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(3 marks)

3 (c) The synthesis of ammonia is usually carried out at about 800 K.

3 (c) (i) Use the ΔH value of -46 kJ mol^{-1} and your answer from part **3 (b)** to calculate a value for ΔG, with units, for the synthesis at this temperature.
(If you have been unable to obtain an answer to part **3 (b)**, you may assume that the entropy change is –112 J K^{-1} mol $^{-1}$. This is not the correct answer.)

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(3 marks)

3 (c) (ii) Use the value of ΔG that you have obtained to comment on the feasibility of the reaction at 800 K.

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(1 mark)

11

Turn over ▶

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4 This question is about the chemistry of the Period 3 elements and the trends in their properties.

4 (a) (i) Describe what you would observe when magnesium burns in oxygen. Write an equation for the reaction that occurs. State the type of bonding in the oxide formed.

Observations .....

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Equation .....

Type of bonding .....

(4 marks)

4 (a) (ii) Describe what you would observe when sulfur burns in oxygen. Write an equation for the reaction that occurs. State the type of bonding in the oxide formed.

Observations .....

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.....

Equation .....

Type of bonding .....

(4 marks)

4 (b) State the type of bonding in sodium oxide. Explain why sodium oxide reacts to form an alkaline solution when added to water.

Type of bonding.....

Explanation.....

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(3 marks)

Do not write outside the box

4 (c) Outline an experiment that could be used to show that aluminium oxide contains ions.

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(2 marks)

(Extra space) .....

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4 (d) Suggest **one** reason why a thin layer of aluminium oxide protects aluminium from corrosion in moist air.

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(1 mark)

4 (e) Write an ionic equation in each case to show how aluminium oxide reacts with the following

4 (e) (i) hydrochloric acid

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(1 mark)

4 (e) (ii) aqueous sodium hydroxide.

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(1 mark)

16

Turn over for the next question

Do not write outside the box

5 Redox reactions occur in the discharge of all electrochemical cells. Some of these cells are of commercial value.
The table below shows some redox half-equations and standard electrode potentials.

Half-equation	$E^{\ominus}$ / V
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	–0.76
$Ag_2O(s) + 2H^+(aq) + 2e^- \longrightarrow 2Ag(s) + H_2O(l)$	+0.34
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l)$	+1.23
$F_2(g) + 2e^- \longrightarrow 2F^-(aq)$	+2.87

5 (a) In terms of electrons, state what happens to a reducing agent in a redox reaction.

.....

(1 mark)

5 (b) Use the table above to identify the strongest reducing agent from the species in the table.

Explain how you deduced your answer.

Strongest reducing agent .....

Explanation .....

.....

(2 marks)

5 (c) Use data from the table to explain why fluorine reacts with water.
Write an equation for the reaction that occurs.

Explanation .....

.....

.....

Equation .....

.....

(3 marks)

Do not write outside the box

5 (d) An electrochemical cell can be constructed using a zinc electrode and an electrode in which silver is in contact with silver oxide. This cell can be used to power electronic devices.

5 (d) (i) Give the conventional representation for this cell.

.....

(2 marks)

5 (d) (ii) Calculate the e.m.f. of the cell.

.....

(1 mark)

5 (d) (iii) Suggest **one** reason why the cell cannot be electrically recharged.

.....

.....

(1 mark)

5 (e) The electrode half-equations in a lead–acid cell are shown in the table below.

Half-equation	$E^{\ominus}$ / V
$PbO_2(s) + 3H^+(aq) + HSO_4^-(aq) + 2e^- \longrightarrow PbSO_4(s) + 2H_2O(l)$	+1.69
$PbSO_4(s) + H^+(aq) + 2e^- \longrightarrow Pb(s) + HSO_4^-(aq)$	to be calculated

5 (e) (i) The $PbO_2/PbSO_4$ electrode is the positive terminal of the cell and the e.m.f. of the cell is 2.15 V.

Use this information to calculate the missing electrode potential for the half-equation shown in the table.

.....

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(1 mark)

5 (e) (ii) A lead–acid cell can be recharged.
Write an equation for the overall reaction that occurs when the cell is being recharged.

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(2 marks)

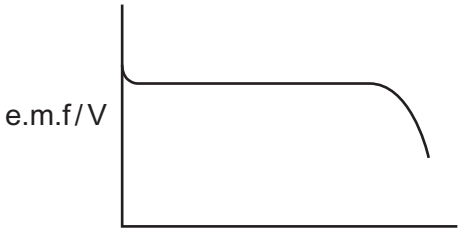
Question 5 continues on the next page

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Do not write outside the box

5 (f) The diagrams below show how the e.m.f. of each of two cells changes with time when each cell is used to provide an electric current.

Lead–acid cell



Cell X



5 (f) (i) Give **one** reason why the e.m.f. of the **lead–acid cell** changes after several hours.

.....

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(1 mark)

5 (f) (ii) Identify the type of cell that behaves like **cell X**.

.....

(1 mark)

5 (f) (iii) Explain why the voltage remains constant in **cell X**.

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(2 marks)

(Extra space) .....

.....

17

Do not write outside the box

6 Transition metals and their complexes have characteristic properties.

6 (a) Give the electron configuration of the Zn^{2+} ion.
Use your answer to explain why the Zn^{2+} ion is **not** classified as a transition metal ion.

Electron configuration .....

Explanation .....

.....

(2 marks)

6 (b) In terms of bonding, explain the meaning of the term *complex*.

.....

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.....

.....

(2 marks)

6 (c) Identify **one** species from the following list that does **not** act as a ligand. Explain your answer.

H_2 O^{2-} O_2 CO

Not a ligand .....

Explanation .....

(2 marks)

6 (d) The element palladium is in the d block of the Periodic Table. Consider the following palladium compound which contains the sulfate ion.

$[Pd(NH_3)_4]SO_4$

6 (d) (i) Give the oxidation state of palladium in this compound.

.....

(1 mark)

6 (d) (ii) Give the names of two possible shapes for the complex palladium ion in this compound.

Shape 1 .....

Shape 2 .....

(2 marks)

9

Do not write outside the box

Section B

Answer **all** questions in the spaces provided.

7 This question is about copper chemistry.

7 (a) Aqueous copper(II) ions $[Cu(H_2O)_6]^{2+}(aq)$ are blue.

7 (a) (i) With reference to electrons, explain why aqueous copper(II) ions are blue.

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(3 marks)

(Extra space) .....

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7 (a) (ii) By reference to aqueous copper(II) ions, state the meaning of each of the **three** terms in the equation $\Delta E = h\nu$.

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(3 marks)

(Extra space) .....

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Do not write outside the box

7 (a) (iii) Write an equation for the reaction, in aqueous solution, between $[Cu(H_2O)_6]^{2+}$ and an excess of chloride ions.
State the shape of the complex produced and explain why the shape differs from that of the $[Cu(H_2O)_6]^{2+}$ ion.

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(3 marks)

(Extra space) .....

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7 (b) Draw the structure of the ethanedioate ion ($C_2O_4^{2-}$).
Explain how this ion is able to act as a ligand.

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(2 marks)

Question 7 continues on the next page

Turn over ▶

Do not write outside the box

7 (c) When a dilute aqueous solution containing ethanedioate ions is added to a solution containing aqueous copper(II) ions, a substitution reaction occurs. In this reaction four water molecules are replaced and a new complex is formed.

7 (c) (i) Write an ionic equation for the reaction. Give the co-ordination number of the complex formed and name its shape.

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(4 marks)

7 (c) (ii) In the complex formed, the two water molecules are opposite each other.
Draw a diagram to show how the ethanedioate ions are bonded to a copper ion and give a value for one of the O—Cu—O bond angles. You are **not** required to show the water molecules.

(2 marks)

17

Do not write outside the box

8 Iron is an important element in living systems. It is involved in redox and in acid–base reactions.

8 (a) Explain how and why iron ions catalyse the reaction between iodide ions and $S_2O_8^{2-}$ ions. Write equations for the reactions that occur.

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(5 marks)

(Extra space) .....

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Question 8 continues on the next page

Turn over ▶

Do not write outside the box

8 (b) Iron(II) compounds are used as moss killers because iron(II) ions are oxidised in air to form iron(III) ions that lower the pH of soil.

8 (b) (i) Explain, with the aid of an equation, why iron(III) ions are more acidic than iron(II) ions in aqueous solution.

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(3 marks)

8 (b) (ii) In a titration, 0.321 g of a moss killer reacted with 23.60 cm^3 of acidified 0.0218 mol dm^{-3} $K_2Cr_2O_7$ solution.

Calculate the percentage by mass of iron in the moss killer. Assume that all of the iron in the moss killer is in the form of iron(II).

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(5 marks)

Do not write outside the box

8 (c) Some sodium carbonate solution was added to a solution containing iron(III) ions. Describe what you would observe and write an equation for the reaction that occurs.

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(3 marks)

16

END OF QUESTIONS

There are no questions printed on this page

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Version 1



General Certificate of Education
June 2011

Chemistry CHEM5

Energetics, Redox and Inorganic Chemistry

Final

Mark Scheme

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Question	Marking Guidance	Mark	Comments
1(a)(i)	(Enthalpy change for formation of) 1 mol (of CaF_2) from its ions	1	allow heat energy change do not allow energy or wrong formula for CaF_2 penalise 1 mol of ions CE=0 if atoms or elements or molecules mentioned ignore conditions
	ions in the gaseous state	1	ions can be mentioned in M1 to score in M2 allow fluorine ions $Ca^{2+}(g) + 2F^-(g) \rightarrow CaF_2$ scores M1 and M2
1(a)(ii)	(enthalpy change when) 1 mol of gaseous (fluoride) ions (is converted) into aqueous ions / an aqueous solution	1	allow $F^-(g) \rightarrow F^-(aq)$ (ignore + aq) do not penalise energy instead of enthalpy allow fluorine ions do not allow F^- ions surrounded by water
1(b)	water is polar / H on water is $\delta+$ / is electron deficient / is unshielded	1	penalise H^+ on water 1 mark
	(F^- ions) attract water / $\delta+$ on H / hydrogen	1	allow H on water forms H-bonds with F^- allow fluorine ions penalise co-ordinate bonds for M2 penalise attraction to O for M2

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1(c)	ΔH = –(–2611) –1650 +2×–506	1	ignore cycles M1 is for numbers and signs correct in expression
	= –51 (kJ mol^{-1})	1	correct answer scores 2 ignore units even if incorrect

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Question	Marking Guidance	Mark	Comments
2(a)	$KNO_3(s) \rightarrow K^+(aq) + NO_3^-(aq)$	1	do not allow equations with H_2O allow aq and the word 'water' in equation
2(b)	increase in disorder because solid → solution / increase in number of particles / 1 mol (solid) gives 2 mol (ions/particles) / particles are more mobile	1	allow random or chaos instead of disorder penalise if molecules/atoms stated instead of ions allow any reference to increase in number of particles even if number of particles wrong
2(c)	$\Delta G = \Delta H - T\Delta S$ / $T = \Delta H/\Delta S$ $T = \Delta H/\Delta S = (34.9 \times 1000)/117$ = 298 K	1 1 1	 also scores M1 correct answer scores 3, units essential 0.298 scores M1 only
2(d)(i)	positive / increases / $\Delta G > 0$	1	Allow more positive
2(d)(ii)	if ans to (d) (i) positive, dissolving is no longer spontaneous / no longer feasible / potassium nitrate does not dissolve / less soluble if ans to (d) (i) negative, dissolving is spontaneous / feasible / potassium nitrate dissolves / more soluble	1	If no mention of change to ΔG in (d)(i), Mark = 0 for (d)(ii)

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Question	Marking Guidance	Mark	Comments
3(a)(i)	ΔH = Σ bonds broken – Σbonds formed = 944/2 + 3/2 $\times$ 436 –3 $\times$ 388 = –38 (kJ mol^{-1})	1 1 1	ignore units even if incorrect correct answer scores 3 –76 scores 2/3 +38 scores 1/3
3(a)(ii)	mean / average bond enthalpies are from a range of compounds or mean / average bond enthalpies differ from those in a single compound / ammonia	1	
3(b)	ΔS = Σ S products – Σ S reactants = 193 – (192/2 + 131 $\times$ 3/2) = –99.5 J K^{-1} mol^{-1}	1 1 1	units essential for M3 correct answer with units scores 3 –199 J K^{-1} mol^{-1} & –99.5 score 2/3 – 199 and + 99.5 J K^{-1} mol^{-1} score 1/3

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3(c)(i)	$\Delta G = \Delta H - T\Delta S = -46 + 800 \times 99.5/1000$ = 33.6 or 33600 kJ mol^{-1} with J mol^{-1}	1 1 1	mark is for putting in numbers with 1000 if factor of 1000 used incorrectly CE = 0 allow 33 to 34 (or 33000 to 34000) correct units for answer essential if answer to part (b) is wrong or if -112 used, mark consequentially e.g. • –199 gives 113 to 114 kJ mol^{-1} (scores 3/3) • –112 gives 43 to 44 kJ mol^{-1} (scores 3/3)
3(c)(ii)	If answer to (c) (i) is positive: not feasible / not spontaneous If answer to (c) (i) is negative: feasible / spontaneous	1	if no answer to (c) (i) award zero marks

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Question	Marking Guidance	Mark	Comments
4(a)(i)	white flame / white light	1	Mark flame independent of other observations
	solid / powder / smoke / ash / <u>white fumes</u>	1	penalise precipitate penalise wrong colour if more than one observation for M2 apply list principle. (If an observation is incorrect, the incorrect observation negates a correct one)
	$2Mg + O_2 \rightarrow 2MgO$	1	ignore state symbols allow multiples
	ionic	1	do not allow reference to covalent character
4(a)(ii)	blue flame	1	do not allow any other colour Mark flame independent of other observations
	fumes or misty or pungent/choking/smelly gas	1	do not allow incorrect smell (e.g. bad eggs) apply list principle as in (a) (i) do not allow just 'gas' or 'colourless gas'
	$S + O_2 \rightarrow SO_2$	1	ignore state symbols allow multiples and S_8
	covalent	1	penalise giant covalent

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4(b)	ionic O^{2-} / oxide ion reacts with water / accepts a proton forming OH^- ions/ NaOH / sodium hydroxide (can show in equation from Na_2O even if incorrect)	1 1 1	If covalent, can only score M3 M2 requires reference to O^{2-} / oxide ion allow $O^{2-} + H_2O \rightarrow 2OH^-$ or $O^{2-} + H^+ \rightarrow OH^-$ to score M2 & M3 also allow equations with spectator Na^+ ions on both sides.
4(c)	(heat until) molten conducts electricity / can be electrolysed / electrolyse and identify Al / O_2 at an electrode	1 1	or dissolve in <u>molten</u> cryolite do not allow solution in water M2 can only be gained if M1 scored
4(d)	insoluble (in water)	1	allow oxide impermeable to air / water or oxide is unreactive / inert
4(e)(i)	$Al_2O_3 + 6H^+ \rightarrow 2Al^{3+} + 3H_2O$	1	allow $O^{2-} + 2H^+ \rightarrow H_2O$ and formation of aquated Al^{3+} species allow spectator Cl^- ions penalise HCl (not ionic!)
4(e)(ii)	$Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2Al(OH)_4^-$ or $Al_2O_3 + 6OH^- + 3H_2O \rightarrow 2Al(OH)_6^{3-}$	1	allow formation of $Al(H_2O)_2(OH)_4^-$ allow Na^+ spectator ions penalise NaOH (not ionic!)

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Question	Marking Guidance	Mark	Comments
5(a)	loses electrons / donates electrons	1	penalise donates electron pair
5(b)	Zn	1	
	(most) negative E^{o} / lowest E^{o} / least positive	1	can only score M2 if M1 correct do not allow e.m.f instead of E^{o}
5(c)	$\underline{E^{o}\ F_2}$ ($/F^-$) > $\underline{E^{o}\ O_2}$ ($/H_2O$)	1	or e.m.f is positive or e.m.f = 1.64 V
	Fluorine reacts to form oxygen (can score from equation in M3 even if equation unbalanced provided no contradiction) or fluorine oxidises water or fluorine is a more powerful oxidising agent than oxygen	1	
	$2F_2 + 2H_2O \rightarrow 4F^- + 4H^+ + O_2$	1	allow 4HF in equation balanced equation scores M2 and M3

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5(d)(i)	order correct Zn Zn^{2+} Ag_2O Ag or reverse of this order all phase boundaries correct e.g. $Zn\|Zn^{2+}\|\|Ag_2O\|Ag$ or $Ag\|Ag_2O\|\|Zn^{2+}\|Zn$ scores 2	1 1	ignore ss , H^+ and H_2O, no. of moles allow $Zn\|Zn^{2+}\|\|Ag_2O$,Ag or $Zn\|Zn^{2+}\|\|Ag_2O\|H^+\|Ag$ for M1 & M2 M2 cannot be gained unless M1 scored allow H^+ either side of Ag_2O with comma or | for M2 penalise • wrong phase boundary (allow dashed lines for salt bridge) • Pt • use of + (from half equation) • water/H^+ outside Ag in Ag electrode
5(d)(ii)	1.1 (V)	1	Allow no units, penalise wrong units allow correct answer even if no answer to (d)(i) or answer to (d)(i) incorrect allow –1.1 if silver electrode on Left in (d)(i) even if the species are in the wrong order.
5(d)(iii)	<u>Reaction(s)</u> not reversible or H_2O electrolyses	1	do not allow hard to reverse mention of primary cell is not enough to show that reaction(s) are irreversible
5(e)(i)	–0.46 (V)	1	Allow no units, penalise wrong units

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5(e)(ii)	$2PbSO_4 + 2H_2O \rightarrow Pb + PbO_2 + 2HSO_4^- + 2H^+$ lead species correct on correct sides of equation equation balanced and includes H_2O, HSO_4^- and H^+ (or H_2SO_4)	 1 1	 allow ions / species must be fully cancelled out or combined allow 1/2 for balanced reverse equation
5(f)(i)	reagents / PbO_2 / H_2SO_4 /acid / ions used up (or concentration decreases)	1	
5(f)(ii)	fuel cell	1	Ignore any other words
5(f)(iii)	reagents / fuel supplied continuously concentrations (of reagents) remain constant	1 1	

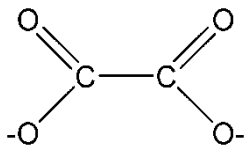
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Question	Marking Guidance	Mark	Comments
6(a)	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$	1	allow [He] $2s^2$. or [Ne] $3s^2$.or [Ar]$3d^{10}$
	d sub-shell / shell / orbitals / sub-level full (or not partially full)	1	can only score M2 if d^{10} in M1 correct allow 'full d orbital' if d^{10} in M1 do not allow d block
6(b)	atom or ion or transition metal bonded to / surrounded by one or more ligands	1	Allow Lewis base instead of ligand
	by co–ordinate / dative (covalent) bonds / donation of an electron pair	1	can only score M2 if M1 correct
6(c)	H_2 / hydrogen	1	do not allow H
	no lone / spare / non-bonded pair of electrons	1	only score M2 if M1 correct or give 'H' in M1
6(d)(i)	+2 or 2+ or Pd^{2+} or II or +II or II+ or two or two plus	1	
6(d)(ii)	tetrahedral	1	these shapes can be in any order
	square planar	1	allow phonetic spelling e.g. tetrahydral

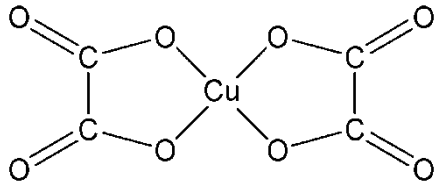
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Question	Marking Guidance	Mark	Comments
7(a)(i)	absorbs (certain frequencies of) (white) light / photons	1	not absorbs white / u.v. light
	<u>d</u> electrons excited / promoted	1	or <u>d</u> electrons move between levels / orbitals d electrons can be implied elsewhere in answer
	the colour observed is the light not absorbed / light reflected / light transmitted	1	allow blue light transmitted penalise emission of light in M3
7(a)(ii)	ΔE is the energy gained by the (excited) electrons (of Cu^{2+})	1	allow: • energy difference between orbitals / sub-shells • energy of photon / light absorbed • change in energy of the electrons • energy lost by excited electrons • energy of photon / light emitted
	h (Planck's) constant	1	
	ν frequency of light (absorbed by $Cu^{2+}(aq)$)	1	do not allow wavelength If energy lost / photon lost / light emitted in M1 do not penalised light emitted

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7(a)(iii)	$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$	1	note that $[CuCl_4^-]^{2-}$ is incorrect penalise charges shown separately on the ligand and overall penalise HCl
	tetrahedral	1	
	Cl^- / Cl / chlorine too big (to fit more than 4 round Cu)	1	allow water smaller than Cl^- explanation that change in shape is due to change in co-ordination number
7(b)	 	1	allow: • ion drawn with any bond angles • ion in square brackets with overall / 2- charge shown outside the brackets • ion with delocalised O=C—O bonds in carboxylate group(s)
	lone pair(s) on O^- / O	1	allow position of lone pair(s) shown on O in the diagram even if the diagram is incorrect.
7(c)(i)	$[Cu(H_2O)_6]^{2+} + 2C_2O_4^{2-} \rightarrow [Cu(C_2O_4)_2(H_2O)_2]^{2-} + 4H_2O$		
	product correct	1	
	equation balanced	1	
	6	1	note can only score M3 and M4 if M1 awarded or if complex in equation has 2 waters and 2 ethanedioates
	octahedral	1	If this condition is satisfied the complex can have the wrong charge(s) to allow access to M3 and M4 but not M1

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7(c)(ii)	 90°	1 1	ignore charges diagram must show both ethanedioates with correct bonding ignore water allow 180° mark bond angle independently but penalise if angle incorrectly labelled / indicated on diagram

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Question	Marking Guidance	Mark	Comments
8(a)	$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$	1	
	$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$	1	
	two negative ions repel / lead to reaction that is slow / lead to reaction that has high E_a	1	
	iron able to act because changes its oxidation state	1	allow iron has variable oxidation state
	With iron ions have alternative route / route with lower activation energy	1	
8(b)(i)	$[Fe(H_2O)_6]^{3+} \rightarrow [Fe(H_2O)_5OH]^{2+} + H^+$	1	can have H_2O on LHS and H_3O^+ on R do not penalise further hydrolysis equations allow high charge density
	Fe^{3+} ion has higher charge (to size ratio) (than Fe^{2+})	1	
	increases polarisation of co-ordinated water / attracts O releasing an H^+ ion / weakens O—H bond	1	

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8(b)(ii)	$Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$	1	or 6 mol Fe(II) react with 1 mol dichromate If factor of 6 not used max =3 for M2, M4 and M5 e.g. 1:1 gives ans= 8.93 to 8.98% (scores 3)
	moles dichromate = $23.6 \times 0.218/1000 = 5.14 \times 10^{-4}$	1	
	moles iron = $5.14 \times 10^{-4} \times 6 = 0.00309$	1	M3 also scores M1
	mass iron = $0.00309 \times 55.8 = 0.172$	1	Mark is for moles of iron $\times$ 55.8 conseq Allow use of 56 for iron
	% by mass of iron = $0.172 \times 100/0.321 = 53.7\%$	1	Answer must be to at least 3 sig figures allow 53.6 to 53.9 Mark is for mass of iron $\times$ 100/0.321 conseq

8(c)	brown precipitate / solid	1	Allow red-brown / orange solid Not red or yellow solid
	bubbles (of gas) / effervescence/ fizz	1	Allow gas evolved / given off Do not allow just gas or CO_2 or CO_2 gas
	$2[Fe(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2Fe(H_2O)_3(OH)_3 + 3CO_2 + 3H_2O$	1	Allow $2[Fe(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2Fe(OH)_3 + 3CO_2 + 9H_2O$ Use of Na_2CO_3 e.g. …+ $3Na_2CO_3 \rightarrow$ .. + .. + .. + $6Na^+$

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Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
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Question	Mark
1	
2	
3	
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5	
6	
7	
TOTAL	

General Certificate of Education
Advanced Level Examination
January 2011

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Monday 31 January 2011 9.00 am to 10.45 am

For this paper you must have:
- the Periodic Table/Data Sheet, provided as an insert (enclosed)
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use accurate scientific terminology.

Advice
- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.

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Do not write outside the box

Section A

Answer **all** questions in the spaces provided.

1 Comparisons of lattice enthalpies from Born–Haber cycles with lattice enthalpies from calculations based on a perfect ionic model are used to provide information about bonding in crystals.

1 (a) Define the terms *enthalpy of atomisation* and *lattice dissociation enthalpy.*

Enthalpy of atomisation .....

.....

.....

Lattice dissociation enthalpy .....

.....

.....

(4 marks)

1 (b) Use the following data to calculate a value for the lattice dissociation enthalpy of sodium chloride.

	$\Delta H^{\ominus}$/ kJ mol^{-1}
$Na(s) \longrightarrow Na(g)$	+109
$Na(g) \longrightarrow Na^+(g) + e^-$	+494
$Cl_2(g) \longrightarrow 2Cl(g)$	+242
$Cl(g) + e^- \longrightarrow Cl^-(g)$	–364
$Na(s) + \frac{1}{2}Cl_2(g) \longrightarrow NaCl(s)$	–411

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(3 marks)

Do not write outside the box

1 (c) Consider the following lattice dissociation enthalpy ($\Delta H_L^{\ominus}$) data.

	NaBr	AgBr
$\Delta H_L^{\ominus}$(experimental) / kJ mol^{-1}	+733	+890
$\Delta H_L^{\ominus}$(theoretical) / kJ mol^{-1}	+732	+758

The values of $\Delta H_L^{\ominus}$ (experimental) have been determined from Born–Haber cycles.

The values of $\Delta H_L^{\ominus}$ (theoretical) have been determined by calculation using a perfect ionic model.

1 (c) (i) Explain the meaning of the term *perfect ionic model.*

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(2 marks)

1 (c) (ii) State what you can deduce about the bonding in NaBr from the data in the table.

.....

.....

(1 mark)

1 (c) (iii) State what you can deduce about the bonding in AgBr from the data in the table.

.....

.....

(1 mark)

11

Turn over ▶

Do not write outside the box

2 The balance between enthalpy change and entropy change determines the feasibility of a reaction. The table below contains enthalpy of formation and entropy data for some elements and compounds.

	$N_2(g)$	$O_2(g)$	NO(g)	C(graphite)	C(diamond)
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	0	0	+90.4	0	+1.9
$S^{\ominus}$ / J K^{-1} mol^{-1}	192.2	205.3	211.1	5.7	2.4

2 (a) Explain why the entropy value for the element nitrogen is much greater than the entropy value for the element carbon (graphite).

.....

.....

.....

(2 marks)

2 (b) Suggest the condition under which the element carbon (diamond) would have an entropy value of zero.

.....

(1 mark)

2 (c) Write the equation that shows the relationship between ΔG, ΔH and ΔS for a reaction.

.....

(1 mark)

2 (d) State the requirement for a reaction to be feasible.

.....

(1 mark)

Do not write outside the box

2 (e) Consider the following reaction that can lead to the release of the pollutant NO into the atmosphere.

$$\tfrac{1}{2}N_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow NO(g)$$

Use data from the table on page 4 to calculate the minimum temperature above which this reaction is feasible.

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(5 marks)

2 (f) At temperatures below the value calculated in part **2 (e)**, decomposition of NO into its elements should be spontaneous. However, in car exhausts this decomposition reaction does **not** take place in the absence of a catalyst.
Suggest why this spontaneous decomposition does **not** take place.

.....

.....

(1 mark)

2 (g) A student had an idea to earn money by carrying out the following reaction.

$$C(\text{graphite}) \longrightarrow C(\text{diamond})$$

Use data from the table on page 4 to calculate values for $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$ for this reaction. Use these values to explain why this reaction is **not** feasible under standard pressure at any temperature.

$\Delta H^{\ominus}$.....

$\Delta S^{\ominus}$.....

Explanation.....

.....

(3 marks)

14

Do not write outside the box

3 There is a link between the properties of the oxides of the Period 3 elements and their structure and bonding. The table below shows the melting points of the oxides of some Period 3 elements.

	Na_2O	SiO_2	P_4O_{10}
T_m / K	1548	1883	573

3 (a) In terms of crystal structure and bonding, explain in each case why the melting points of sodium oxide and silicon dioxide are high.

Na_2O .....

.....

.....

SiO_2 .....

.....

.....

(4 marks)

3 (b) Predict whether the melting point of lithium oxide is higher than, the same as, or lower than the melting point of sodium oxide and explain your prediction.

Prediction.....

Explanation.....

.....

.....

(3 marks)

3 (c) Phosphorus(V) oxide has a lower melting point than sodium oxide.

3 (c) (i) State the structure of and bonding in phosphorus(V) oxide.

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(2 marks)

Do not write outside the box

3 (c) (ii) Explain why the melting point of phosphorus(V) oxide is low.

.....

.....

(1 mark)

3 (d) Separate samples of phosphorus(V) oxide and sodium oxide were reacted with water. In each case, predict the pH of the solution formed and write an equation for the reaction.

pH with P_4O_{10} .....

Equation .....

pH with Na_2O.....

Equation .....

(4 marks)

3 (e) Write an equation for the reaction between Na_2O and P_4O_{10}
State the general type of reaction illustrated by this example.

Equation .....

Reaction type .....

(2 marks)

16

Turn over for the next question

There are no questions printed on this page

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ANSWER IN THE SPACES PROVIDED

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4 Three characteristic properties of transition metals are complex formation, coloured ions and catalytic activity.

4 (a) State the feature of transition metals that gives rise to these characteristic properties.

.....

(1 mark)

4 (b) State a fourth characteristic property of transition metals.

.....

(1 mark)

4 (c) For each of the following shapes of complex, identify an appropriate example by drawing its structure.

4 (c) (i) a linear complex

(1 mark)

4 (c) (ii) a square planar complex

(1 mark)

4 (c) (iii) a tetrahedral complex

(1 mark)

Question 4 continues on the next page

Do not write outside the box

4 (d) The chemical industry makes use of the catalytic activity of transition metal compounds. For example, vanadium(V) oxide is used as a heterogeneous catalyst in the Contact Process.

4 (d) (i) Write an equation for the overall reaction in the Contact Process.

.....

(1 mark)

4 (d) (ii) Explain the meaning of the term *heterogeneous* as applied to a catalyst.

.....

(1 mark)

4 (d) (iii) Write two equations to illustrate how vanadium(V) oxide acts as a catalyst in the Contact Process.

Equation 1 .....

Equation 2 .....

(2 marks)

4 (d) (iv) Suggest what is done to a heterogeneous catalyst such as vanadium(V) oxide to maximise its efficiency and how this is achieved.

.....

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(2 marks)

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4 (e) The porphyrin ring is a multidentate ligand that is found in living systems complexed with iron(II) ions in haemoglobin and with cobalt(II) ions in vitamin B_{12}

4 (e) (i) Give the meaning of the term *multidentate.*

.....

.....

(1 mark)

4 (e) (ii) A porphyrin ring can be represented by the symbol PR. It reacts with aqueous iron(II) ions as shown in the equation below.
The enthalpy change for this reaction is approximately zero.

$$PR(aq) + [Fe(H_2O)_6]^{2+}(aq) \longrightarrow [FePR(H_2O)_2]^{2+}(aq) + 4H_2O(l)$$

Explain why the free-energy change for this reaction is negative.

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.....

.....

(2 marks)

4 (e) (iii) In vitamin B_{12} the cobalt(II) ion is co-ordinated to a porphyrin ring, a cyanide (CN^-) ion and an additional unidentate ligand. The cyanide ion is very toxic.

Predict the co-ordination number of the cobalt ion in vitamin B_{12}
Suggest why vitamin B_{12} is **not** toxic.

Co-ordination number .....

Reason why vitamin B_{12} is **not** toxic

.....

.....

(2 marks)

16

Turn over ▶

Do not write outside the box

5 (a) Lithium ion cells are used to power cameras and mobile phones.
A simplified representation of a cell is shown below.

$$Li \mid Li^+ \parallel Li^+ , CoO_2 \mid LiCoO_2 \mid Pt$$

The reagents in the cell are absorbed onto powdered graphite that acts as a support medium. The support medium allows the ions to react in the absence of a solvent such as water.

The half-equation for the reaction at the positive electrode can be represented as follows.

$$Li^+ + CoO_2 + e^- \longrightarrow Li^+[CoO_2]^-$$

5 (a) (i) Identify the element that undergoes a change in oxidation state at the positive electrode and deduce these oxidation states of the element.

Element .....

Oxidation state 1 .....

Oxidation state 2 .....

(3 marks)

5 (a) (ii) Write a half-equation for the reaction at the negative electrode during operation of the lithium ion cell.

.....

(1 mark)

5 (a) (iii) Suggest two properties of platinum that make it suitable for use as an external electrical contact in the cell.

Property 1 .....

Property 2 .....

(2 marks)

5 (a) (iv) Suggest **one** reason why water is **not** used as a solvent in this cell.

.....

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(1 mark)

Do not write outside the box

5 (b) The half-equations for two electrodes used to make an electrochemical cell are shown below.

$$ClO_3^-(aq) + 6H^+(aq) + 6e^- \longrightarrow Cl^-(aq) + 3H_2O(l) \quad E^\ominus = +1.45\ V$$

$$SO_4^{2-}(aq) + 2H^+(aq) + 2e^- \longrightarrow SO_3^{2-}(aq) + H_2O(l) \quad E^\ominus = +0.17\ V$$

5 (b) (i) Write the conventional representation for the cell using platinum contacts.

.....

(2 marks)

5 (b) (ii) Write an overall equation for the cell reaction and identify the oxidising and reducing agents.

Overall equation .....

.....

.....

Oxidising agent .....

Reducing agent .....

(3 marks)

12

Turn over for the next question

Do not write outside the box

Section B

Answer **all** questions in the spaces provided.

6 Aqueous metal ions can be identified by test-tube reactions.

For each of the following, describe what you would observe.

Write an equation or equations for any reactions that occur.

6 (a) The addition of aqueous sodium carbonate to a solution containing $[Fe(H_2O)_6]^{3+}(aq)$ ions.

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(4 marks)

6 (b) The addition of aqueous sodium hydroxide, dropwise until in excess, to a solution containing $[Al(H_2O)_6]^{3+}(aq)$ ions.

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(4 marks)

Do not write outside the box

6 (c) The addition of dilute aqueous ammonia, dropwise until in excess, to a solution containing $[Cu(H_2O)_6]^{2+}(aq)$ ions.

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(4 marks)

6 (d) The addition of concentrated hydrochloric acid, dropwise until in excess, to a solution containing $[Cu(H_2O)_6]^{2+}(aq)$ ions.

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(2 marks)

14

Turn over for the next question

Do not write outside the box

7 Hydrogen peroxide is used as an oxidising agent in the preparation of transition metal complexes.

7 (a) Consider the following reaction scheme. All the complexes are in aqueous solution.

$$[Co(H_2O)_6]^{2+} \xrightarrow{\text{Reaction 1}} \text{cobalt(II) complex} \xrightarrow[H_2O_2]{\text{Reaction 2}} [Co(NH_3)_6]^{3+}$$

7 (a) (i) Identify a reagent for Reaction **1** and describe the colour change that occurs.

.....

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.....

(3 marks)

7 (a) (ii) State the colour of the final solution formed in Reaction **2**.

.....

(1 mark)

Do not write outside the box

7 (b) Consider the following reaction scheme. All the complexes are in aqueous solution.

$$[Cr(H_2O)_6]^{3+} \xrightarrow[\text{Excess NaOH(aq)}]{\text{Reaction 3}} \text{chromium(III) complex} \xrightarrow[H_2O_2]{\text{Reaction 4}} CrO_4^{2-}$$

7 (b) (i) For Reaction **3**, state the colour of the initial and of the final solution and write an equation for the reaction.

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(4 marks)

7 (b) (ii) Write a half-equation for the reduction of hydrogen peroxide to hydroxide ions.

Deduce an overall equation for Reaction **4** and state the colour of the final solution.

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(4 marks)

Question 7 continues on the next page

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7 (c) The concentration of a hydrogen peroxide solution can be determined by titration with acidified potassium manganate(VII) solution. In this reaction the hydrogen peroxide is oxidised to oxygen gas.

A 5.00 cm^3 sample of the hydrogen peroxide solution was added to a volumetric flask and made up to 250 cm^3 of aqueous solution. A 25.0 cm^3 sample of this diluted solution was acidified and reacted completely with 24.35 cm^3 of 0.0187 mol dm^{-3} potassium manganate(VII) solution.

Write an equation for the reaction between acidified potassium manganate(VII) solution and hydrogen peroxide.
Use this equation and the results given to calculate a value for the concentration, in mol dm^{-3}, of the original hydrogen peroxide solution.
(If you have been unable to write an equation for this reaction you may assume that 3 mol of $KMnO_4$ react with 7 mol of H_2O_2. This is **not** the correct reacting ratio.)

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(5 marks)

(Extra space) .....

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17

END OF QUESTIONS

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Version 1



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Chemistry CHEM5

(Specification 2420)

Unit 5: Energetics, Redox and Inorganic Chemistry

Final

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Question	Marking Guidance	Mark	Comments
1(a)	Enthalpy change for the formation of 1 mol of gaseous atoms From the element (in its standard state) Enthalpy change to separate 1 mol of an ionic lattice/solid/compound Into (its component) gaseous ions	1 1 1 1	allow heat energy change for enthalpy change ignore reference to conditions enthalpy change not required but penalise energy mark all points independently
1(b)	$\Delta H_L = {}^{-}\Delta H_f + \Delta H_a$ + I.E. + 1/2E(Cl-Cl) + EA = +411 + 109 + 494 + 121 – 364 = +771 (kJ mol $^{-1}$)	1 1 1	Or correct Born-Haber cycle drawn out –771 scores 2/3 +892 scores 1/3 –51 scores 1/3 –892 scores zero +51 scores zero ignore units
1(c)(i)	Ions are perfect spheres (or point charges) Only electrostatic attraction/no covalent interaction	1 1	mention of molecules/intermolecular forces/covalent bonds CE = 0 allow ionic bonding only If mention of atoms CE = 0 for M2
1(c)(ii)	Ionic	1	Allow no covalent character/bonding

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1(c)(iii)	Ionic with additional covalent bonding	1	Or has covalent character/partially covalent Allow mention of polarisation of ions or description of polarisation

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Question	Marking Guidance	Mark	Comments
2(a)	Because it is a gas compared with solid carbon Nitrogen is more disordered/random/chaotic/free to move	1 1	Mark independently
2(b)	0 K / –273 C / absolute zero	1	
2(c)	$\Delta G = \Delta H - T\Delta S$	1	Allow $\Delta H = \Delta G - T\Delta S$ $T\Delta S = \Delta H - \Delta G$ $\Delta S = (\Delta H - \Delta G)/T$ Ignore θ in ΔG^{θ}
2(d)	ΔG is less than or equal to zero ($\Delta G \leq 0$)	1	Allow ΔG is less than zero ($\Delta G < 0$) Allow ΔG is equal to zero ($\Delta G = 0$) Allow ΔG is negative
2(e)	When $\Delta G = 0$ $T = \Delta H / \Delta S$ $\Delta H = +90.4$ $\Delta S = \sum S(\text{products}) - \sum S(\text{reactants})$ $\Delta S = 211.1 - 205.3/2 - 192.2/2 = 12.35$ $T = (90.4 \times 1000)/12.35 = 7320$ K /7319.8 K	1 1 1 1 1	Allow $\Delta H = +90$ Allow 7230 to 7350 K (Note 7.32 K scores 4 marks) Units of temperature essential to score the mark

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2(g)	ΔH = 1.9 (kJ mol^{-1}) ΔS = 2.4 – 5.7 = –3.3 (J K^{-1} mol^{-1}) ΔG is always positive	1 1 1	 for M1 and M2 allow no units, penalise wrong units This mark can only be scored if ΔH is +ve and ΔS is –ve

2(f)	Activation energy is high	1	Allow chemical explanation of activation energy Allow needs route with lower activation energy Allow catalyst lowers activation energy

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Question	Marking Guidance	Mark	Comments
3(a)	Na_2O ionic	1	mention of molecules/intermolecular forces/delocalised electrons, CE = 0
	Strong forces between ions/strong ionic bonding	1	Allow lots of energy to break bonds provided M1 scored
	SiO_2 macromolecular	1	Allow giant molecular/giant covalent. If ions mentioned, CE = 0
	Strong covalent bonds (between atoms)	1	Allow lots of energy to break covalent bonds If breaking intermolecular forces are mentioned, CE = 0 for M4
3(b)	Higher	1	
	Li^+ (or Li ion) smaller than Na^+	1	Must imply Li^+ ion Allow Li^+ has higher charge/size ratio **not** charge/mass
	Attracts O^{2-} ion more strongly	1	Allow stronger ionic bonding Allow additional attraction due to polarisation in Li_2O M3 can only be scored if M2 gained
3(c)(i)	Molecular	1	Do not allow simple covalent BUT simple covalent molecule scores M1 and M2
	Covalent bonds (between P and O)	1	Ignore reference to van der Waals' or dipole-dipole

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3(c)(ii)	Weak van der Waals' forces and/or dipole-dipole forces <u>between molecules</u>	1	Allow weak <u>inter-molecular</u> forces – can score "between" molecules in (c)(i) CE = 0 if ionic or macromolecular mentioned in (c)(i) Must state van der Waals' forces are weak ***OR*** low energy needed to break van der Waals' forces

3(d)	Allow –1 to +2	1	
	$P_4O_{10} + 6H_2O \rightarrow 12H^+ + 4PO_4^{3-}$ (or $4H_3PO_4$)	1	Allow balanced equations to form HPO_4^{2-} or $H_2PO_4^-$ ignore state symbols
	Allow 12 to 14	1	
	$Na_2O + H_2O \rightarrow 2Na^+ + 2OH^-$	1	Allow $2Na^+ + O^{2-}$ on LHS, 2NaOH on RHS, ignore s.s. Mark independently

3(e)	$6Na_2O + P_4O_{10} \rightarrow 4Na_3PO_4$	1	
	Acid-base	1	Allow neutralisation, mark independently of M1 Do not allow Acid + Base $\rightarrow$ Salt + Water

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Question	Marking Guidance	Mark	Comments
4(a)	Incomplete (or partially filled) d orbitals/sub-shells	1	Do not allow d shell
4(b)	Variable oxidation states	1	
4(c)(i)	$[H_3N–Ag–NH_3]^+$	1	Allow $[Cl–Ag–Cl]^–$ or similar Cu(I) ion Allow compounds in (i), (ii) and (iii) (eg Cl-Be-Cl) Allow no charge shown, penalise wrong charge(s)
4(c)(ii)	Cis platin drawn out as square planar	1	Allow $NiX_4^{2–}$ etc
4(c)(iii)	$[CuCl_4]^{2–}$ drawn out as tetrahedral ion	1	Or $[CoCl_4]^{2–}$ drawn out
4(d)(i)	$SO_2 + 1/2O_2 \rightarrow SO_3$	1	Allow multiples Allow $SO_2 + 1/2O_2 + H_2O \rightarrow H_2SO_4$ ignore state symbols
4(d)(ii)	In a different phase/state (from the reactants)	1	
4(d)(iii)	$V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ $V_2O_4 + 1/2O_2 \rightarrow V_2O_5$	1 1	can be in either order allow multiples
4(d)(iv)	Surface area is increased By use of powder or granules or finely divided	1 1	 Allow suspending/spreading out onto a mesh or support

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4(e)(i)	Forms two or more co-ordinate bonds	1	Allow more than one co-ordinate bond or donates more than 1 electron pair. Do not allow "has more than one electron pair" Allow uses more than one atom to bond (to TM)
4(e)(ii)	Number of product particles > Number of reactant particles	1	Allow molecules/entities instead of particles Penalise incorrect numbers (should be 2→5)
	Disorder increases or entropy increases (or entropy change is positive)	1	Allow ΔG must be negative because ΔH = 0 and ΔS is +ve
4(e)(iii)	6	1	
	Cyanide strongly bound to Co (by co-ordinate/covalent bond)	1	

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Question	Marking Guidance	Mark	Comments
5(a)(i)	Co/Cobalt (+) 4 (+) 3	1 1 1	If Co or Cobalt not given CE = 0 ignore case in symbol for Co Allow 4 and 3 in either order
5(a)(ii)	$Li \rightarrow Li^+ + e^-$	1	Ignore state symbols Allow e without -ve sign Do not allow equilibrium sign
5(a)(iii)	Platinum is a conductor (Platinum is) unreactive/inert	1 1	Ignore mention of surface area or catalyst Allow 2 marks if two properties given on one answer line Apply list principle to contradictions/wrong answers Do not allow platinum resists corrosion
5(a)(iv)	Li reacts with water/forms lithium hydroxide	1	Allow water breaks down (or is electrolysed) on re-charge

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5(b)(i)	Pt | SO_3^{2-} (aq), SO_4^{2-} (aq) || ClO_3^- (aq), Cl^-(aq) | Pt	2	State symbols and ',' not necessary Allow | in place of ',' NOT ',' in place of | Ignore H^+ and H_2O Deduct one mark for each mistake (e.g. Pt missed twice counts as two mistakes) Allow reverse order for whole cell Pt | Cl^-, ClO_3^- || SO_4^{2-}, SO_3^{2-} | Pt

5(b)(ii)	$ClO_3^- + 3SO_3^{2-} \rightarrow Cl^- + 3SO_4^{2-}$ Oxidising agent ClO_3^- Reducing agent SO_3^{2-}	1 1 1	

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Question	Marking Guidance	Mark	Comments
6(a)	Brown ppt/solid	1	
	Gas evolved/effervescence	1	Must be stated, Allow CO_2 evolved. Do not allow CO_2 alone
	$2[Fe(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2Fe(H_2O)_3(OH)_3 + 3CO_2 + 3H_2O$	2	Correct iron product (1) allow $Fe(OH)_3$ and in equation Balanced equation (1)
6(b)	White ppt/solid	1	
	Colourless Solution	1	Only award M2 if M1 given or initial ppt mentioned
	$[Al(H_2O)_6]^{3+} + 3OH^- \rightarrow Al(H_2O)_3(OH)_3 + 3H_2O$	1	Allow $[Al(H_2O)_6]^{3+} + 3OH^- \rightarrow Al(OH)_3 + 6H_2O$
	$Al(H_2O)_3(OH)_3 + 3OH^- \rightarrow [Al(OH)_6]^{3-} + 3H_2O$	1	Allow formation of $[Al(H_2O)_{6-x}(OH)_x]^{(x-3)-}$ where x=4,5,6 Allow product without water ligands Allow formation of correct product from $[Al(H_2O)_6]^{3+}$
6(c)	Blue ppt/solid	1	
	(Dissolves to give a) deep blue solution	1	Only award M2 if M1 given or initial ppt mentioned
	$[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow Cu(H_2O)_4(OH)_2 + 2NH_4^+$	1	Allow $[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow Cu(OH)_2 + 2NH_4^+ + 4H_2O$ Allow two equations: $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$ then $[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow Cu(OH)_2 + 4H_2O$ etc
	$Cu(H_2O)_4(OH)_2 + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 2OH^- + 2H_2O$	1	Allow $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 4H_2O$
6(d)	Green/yellow solution	1	
	$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$	1	

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Question	Marking Guidance	Mark	Comments
7(a)(i)	Ammonia	1	If reagent is missing or incorrect cannot score M3
	Starts as a pink (solution)	1	
	Changes to a yellow/straw (solution)	1	Allow pale brown Do not allow reference to a precipitate
7(a)(ii)	(dark) brown	1	Do not allow pale/straw/yellow-brown (i.e. these and other shades except for dark brown)
7(b)(i)	Ruby / red-blue / purple / violet / green	1	Do not allow red or blue If ppt mentioned contradiction/CE =0
	Green	1	If ppt mentioned contradiction/CE =0
	$[Cr(H_2O)_6]^{3+} + 6OH^- \rightarrow [Cr(OH)_6]^{3-} + 6H_2O$	1	
	Formula of product	1	Can score this mark in (b) (ii)
7(b)(ii)	$H_2O_2 + 2e^- \rightarrow 2OH^-$	1	
	$2[Cr(OH)_6]^{3-} + 3H_2O_2 \rightarrow 2CrO_4^{2-} + 8H_2O + 2OH^-$	2	Allow 1 mark out of 2 for a balanced half-equation such as $Cr(III) \rightarrow Cr(VI) + 3e^-$ or $Cr^{3+} + 4H_2O \rightarrow CrO_4^{2-} + 8H^+ + 3e^-$ etc also for $2Cr(III) + 3H_2O_2 \rightarrow 2CrO_4^{2-}$ (unbalanced)
	Yellow	1	Do not allow orange

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7(c)	$2MnO_4^- + 6H^+ + 5H_2O_2 \rightarrow 2Mn^{2+} + 8H_2O + 5O_2$	1	if no equation and uses given ratio can score M2, M3, M4 & M5
	Moles MnO_4^- = (24.35/1000) x 0.0187 = $\underline{4.55 \times 10^{-4}}$	1	Note value must be quoted to at least 3 sig. figs. M2 is for 4.55×10^{-4}
	Moles H_2O_2 = (4.55×10^{-4}) $\underline{\times 5/2}$ = 1.138×10^{-3}	1	M3 is for x 5/2 (or7/3) Mark consequential on molar ratio from candidate's equation
	Moles H_2O_2 in 5 cm^3 original = (1.138×10^{-3}) $\underline{\times 10}$ = 0.01138	1	M4 is for x 10
	Original $[H_2O_2]$ = 0.01138 $\underline{\times (1000/5)}$ = 2.28 mol dm^{-3} (allow 2.25-2.30)	1	M5 is for consequentially correct answer from (answer to mark 4) x (1000/5) Note an answer of between 2.25 and 2.30 is worth 4 marks) If candidate uses given ratio 3/7 max 4 marks: **M1**: Moles of MnO_4^- = $\underline{4.55 \times 10^{-4}}$ **M2**: Moles H_2O_2 = (4.55×10^{-4}) $\underline{\times 7/3}$ = 1.0617×10^{-3} **M3**: Moles H_2O_2 in 5 cm^3 original = (1.0617×10^{-3}) x 10 = 0.01062 **M4**: Original $[H_2O_2]$ = 0.01062 x (1000/5) = 2.12 mol dm^{-3} (allow 2.10 to 2.15)

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Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
TOTAL	

General Certificate of Education
Advanced Level Examination
June 2010

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Monday 28 June 2010 9.00 am to 10.45 am

For this paper you must have:
- the Periodic Table/Data Sheet provided as an insert (enclosed)
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use accurate scientific terminology.

Advice
- You are advised to spend about 1 hour 15 minutes on **Section A** and about 30 minutes on **Section B**.

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Do not write outside the box

Section A

Answer **all** questions in the spaces provided.

1 Calcium fluoride occurs naturally as the mineral fluorite, a very hard crystalline solid that is almost insoluble in water and is used as a gemstone.

Tables 1 and **2** contain thermodynamic data.

Table 1

Process	$\Delta H^{\ominus}$ / kJ mol^{-1}
$Ca(s) \rightarrow Ca(g)$	+193
$Ca(g) \rightarrow Ca^{+}(g) + e^{-}$	+590
$Ca^{+}(g) \rightarrow Ca^{2+}(g) + e^{-}$	+1150
$F_2(g) \rightarrow 2F(g)$	+158
$F(g) + e^{-} \rightarrow F^{-}(g)$	–348

Table 2

Name of enthalpy change	$\Delta H^{\ominus}$ / kJ mol^{-1}
Enthalpy of lattice dissociation for calcium fluoride	+2602
Enthalpy of lattice dissociation for calcium chloride	+2237
Enthalpy of hydration for F^{-} ions	–506
Enthalpy of hydration for Cl^{-} ions	–364
Enthalpy of hydration for Ca^{2+} ions	–1650

1 (a) Write an equation, including state symbols, for the process that occurs when the calcium fluoride lattice dissociates and for which the enthalpy change is equal to the lattice enthalpy.

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(1 mark)

Do not write outside the box

1 (b) (i) Define the term *standard enthalpy of formation*.

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(3 marks)

(Extra space) .....

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1 (b) (ii) Write an equation, including state symbols, for the process that has an enthalpy change equal to the standard enthalpy of formation of calcium fluoride.

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(1 mark)

1 (b) (iii) Use data from the **Tables 1** and **2** to calculate the standard enthalpy of formation for calcium fluoride.

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(3 marks)

(Extra space) .....

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Question 1 continues on the next page

Do not write outside the box

1 (c) Explain why the enthalpy of lattice dissociation for calcium fluoride is greater than that for calcium chloride.

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(2 marks)

1 (d) Calcium chloride dissolves in water. After a certain amount has dissolved, a saturated solution is formed and the following equilibrium is established.

$$CaCl_2(s) \rightleftharpoons Ca^{2+}(aq) + 2Cl^-(aq)$$

1 (d) (i) Using data from **Table 2**, calculate the enthalpy change for this reaction.

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(2 marks)

1 (d) (ii) Predict whether raising the temperature will increase, decrease or have no effect on the amount of solid calcium chloride that can dissolve in a fixed mass of water.
Explain your prediction.
(If you have been unable to obtain an answer to part **(d) (i)**, you may assume that the enthalpy change = –60 kJ mol^{-1}. This is **not** the correct answer.)

Effect on amount of solid that can dissolve .....

Explanation .....

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(3 marks)

Do not write outside the box

1 (e) Calcium fluoride crystals absorb ultra-violet light. Some of the energy gained is given out as visible light. The name of this process, fluorescence, comes from the name of the mineral, fluorite.

Use your knowledge of the equation $\Delta E = h\nu$ to suggest what happens to the electrons in fluorite when ultra-violet light is absorbed and when visible light is given out.

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(2 marks)

(Extra space) .....

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17

Turn over for the next question

Do not write outside the box

2 Sodium, aluminium and silicon are solid elements with a silver colour. These elements react with oxygen to form oxides with high melting points. Aluminium is a reactive metal, but it resists corrosion in water because it has a surface coating of aluminium oxide.

2 (a) In terms of its structure and bonding, explain why silicon dioxide has a high melting point.

.....

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(3 marks)

(Extra space) .....

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2 (b) State the type of bonding in aluminium oxide.

.....

(1 mark)

2 (c) Write an equation for the reaction of aluminium with oxygen.

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(1 mark)

2 (d) Suggest **one** property of the aluminium oxide coating that causes aluminium to resist corrosion in water.

.....

(1 mark)

2 (e) Sodium metal is **not** resistant to corrosion in water, despite having a surface coating of sodium oxide. Write an equation to show how sodium oxide reacts with water.

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(1 mark)

Do not write outside the box

2 (f) Aluminium oxide is amphoteric. It reacts with acids and alkalis.

2 (f) (i) Write an equation for the reaction between aluminium oxide and hydrochloric acid.

.....

(1 mark)

2 (f) (ii) Write an equation for the reaction between aluminium oxide and an excess of aqueous sodium hydroxide.

.....

(1 mark)

2 (g) Silicon dioxide does **not** react with hydrochloric acid but it does react with sodium hydroxide. State **one** property of silicon dioxide that can be deduced from this information and write an equation for its reaction with sodium hydroxide.

Property .....

Equation .....

(2 marks)

11

Turn over for the next question

Do not write outside the box

3 Transition metal ions can act as homogeneous catalysts in redox reactions. For example, iron(II) ions catalyse the reaction between peroxodisulfate ($S_2O_8^{2-}$) ions and iodide ions.

3 (a) State the meaning of the term *homogeneous*.

.....

(1 mark)

3 (b) Suggest why ions from s block elements do **not** usually act as catalysts.

.....

.....

(1 mark)

3 (c) Write an equation for the overall reaction that occurs, in aqueous solution, between $S_2O_8^{2-}$ ions and I^- ions.

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(1 mark)

3 (d) Give **one** reason why, in the absence of a catalyst, the activation energy for the reaction between $S_2O_8^{2-}$ ions and I^- ions is high.

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(1 mark)

3 (e) Write two equations to show how Fe^{2+} ions can catalyse the reaction between $S_2O_8^{2-}$ ions and I^- ions. Suggest **one** reason why the activation energy for each of these reactions is low.

Equation 1 .....

Equation 2 .....

Reason .....

.....

(3 marks)

Do not write outside the box

3 (f) Explain why Fe^{3+} ions are as effective as Fe^{2+} ions in catalysing this reaction.

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(1 mark)

8

Turn over for the next question

Do not write outside the box

4 Transition elements form complex ions with a range of colours and shapes.

4 (a) By considering its electron arrangement, state how an element can be classified as a transition element.

.....

.....

(1 mark)

4 (b) Explain the meaning of the term *complex ion*.

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(2 marks)

4 (c) In terms of electrons, explain why an aqueous solution of cobalt(II) sulfate has a red colour.

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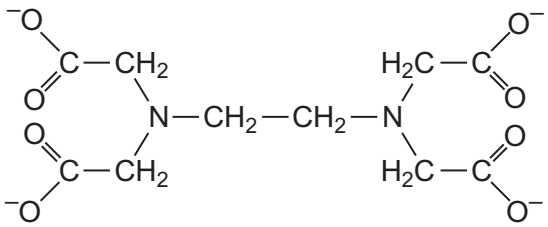
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(3 marks)

4 (d) The ligand $EDTA^{4-}$ is shown below.



4 (d) (i) Draw circles around the atoms of **two** different elements that link to a transition metal ion by a co-ordinate bond when $EDTA^{4-}$ behaves as a ligand.

(2 marks)

4 (d) (ii) Write an equation for the reaction between $EDTA^{4-}$ and a $[Co(H_2O)_6]^{2+}$ ion. Use the abbreviation $EDTA^{4-}$ in your equation.

.....

(1 mark)

Do not write outside the box

4 (d) (iii) Explain why the complex ion, formed as a product of the reaction in part **(d) (ii)**, is more stable than the $[Co(H_2O)_6]^{2+}$ ion.

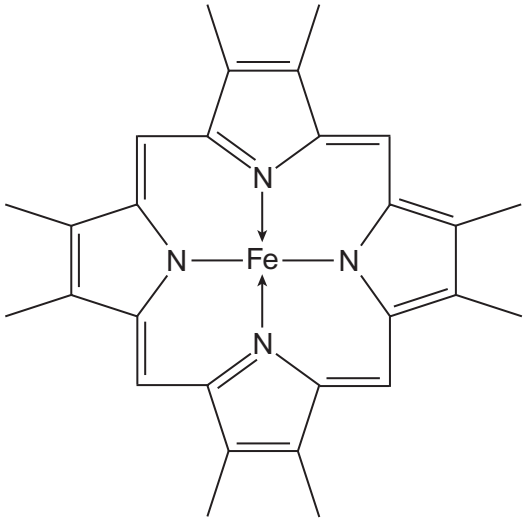
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(2 marks)

4 (e) The diagram below shows part of the structure of haemoglobin.



Haemoglobin contains an iron(II) ion bonded to five nitrogen atoms and one other ligand. The fifth nitrogen atom and the additional ligand are not shown in this diagram.

4 (e) (i) In this diagram, bonds between nitrogen and iron are shown as N→Fe and as N—Fe. State the meaning of each of these symbols.

Meaning of → .....

Meaning of — .....

(2 marks)

4 (e) (ii) State the function of haemoglobin in the blood.

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(1 mark)

4 (e) (iii) With reference to haemoglobin, explain why carbon monoxide is toxic.

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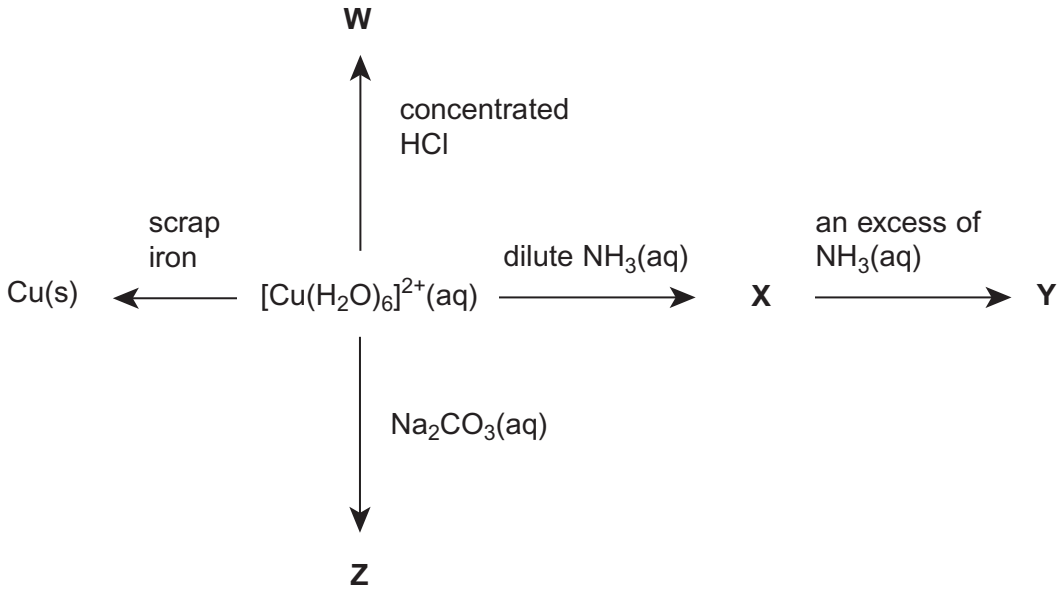
(2 marks)

16

Turn over ▶

Do not write outside the box

5 The scheme below shows some reactions of copper(II) ions in aqueous solution. **W**, **X**, **Y** and **Z** are all copper-containing species.



5 (a) Identify ion **W**. Describe its appearance and write an equation for its formation from $[Cu(H_2O)_6]^{2+}(aq)$ ions.

Ion **W** .....

Appearance .....

Equation .....

(3 marks)

5 (b) Identify compound **X**. Describe its appearance and write an equation for its formation from $[Cu(H_2O)_6]^{2+}(aq)$ ions.

Compound **X**.....

Appearance .....

Equation .....

(3 marks)

Do not write outside the box

5 (c) Identify ion **Y**. Describe its appearance and write an equation for its formation from **X**.

Ion **Y** .....

Appearance .....

Equation .....

(3 marks)

5 (d) Identify compound **Z**. Describe its appearance and write an equation for its formation from $[Cu(H_2O)_6]^{2+}(aq)$ ions.

Compound **Z** .....

Appearance .....

Equation .....

(3 marks)

5 (e) Copper metal can be extracted from a dilute aqueous solution containing copper(II) ions using scrap iron.

5 (e) (i) Write an equation for this reaction and give the colours of the initial and final aqueous solutions.

Equation .....

Initial colour .....

Final colour .....

(3 marks)

5 (e) (ii) This method of copper extraction uses scrap iron. Give **two** other reasons why this method of copper extraction is more environmentally friendly than reduction of copper oxide by carbon.

Reason 1 .....

Reason 2 .....

(2 marks)

17

Turn over ▶

Do not write outside the box

Section B

Answer **all** questions in the spaces provided.

6 Methanol can be regarded as a carbon-neutral fuel because it can be synthesised from carbon dioxide as shown in the equation below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Standard enthalpy of formation and standard entropy data for the starting materials and products are shown in the following table.

	$CO_2(g)$	$H_2(g)$	$CH_3OH(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	–394	0	–201	–242
$S^{\ominus}$ / J K^{-1} mol^{-1}	214	131	238	189

6 (a) Calculate the standard enthalpy change for this reaction.

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(3 marks)

6 (b) Calculate the standard entropy change for this reaction.

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(3 marks)

Do not write outside the box

6 (c) Use your answers to parts **(a)** and **(b)** to explain why this reaction is **not** feasible at high temperatures.

Calculate the temperature at which the reaction becomes feasible.

Suggest why the industrial process is carried out at a higher temperature than you have calculated.

(If you have been unable to calculate values for ΔH and ΔS you may assume that they are $-61\ kJ\ mol^{-1}$ and $-205\ J\ K^{-1}\ mol^{-1}$ respectively. These are **not** the correct values.)

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(6 marks)

(Extra space) .....

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Question 6 continues on the next page

Do not write outside the box

6 (d) Write an equation for the complete combustion of methanol. Use your equation to explain why the combustion reaction in the gas phase is feasible at all temperatures.

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(4 marks)

(Extra space) .....

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6 (e) Give **one** reason why methanol, synthesised from carbon dioxide and hydrogen, may **not** be a carbon-neutral fuel.

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(1 mark)

17

Do not write outside the box

Turn over for the next question

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ANSWER IN THE SPACES PROVIDED

Do not write outside the box

7 The electrons transferred in redox reactions can be used by electrochemical cells to provide energy.

Some electrode half-equations and their standard electrode potentials are shown in the table below.

Half-equation	$E^{\ominus}$/V
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$2H^+(aq) + 2e^- \rightarrow H_2(g)$	0.00
$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$	–0.44
$Li^+(aq) + e^- \rightarrow Li(s)$	–3.04

7 (a) Describe a standard hydrogen electrode.

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(4 marks)

Do not write outside the box

7 (b) A conventional representation of a lithium cell is given below.
This cell has an e.m.f. of +2.91 V

$$Li(s) \mid Li^+(aq) \parallel Li^+(aq) \mid MnO_2(s)\ ,\ LiMnO_2(s) \mid Pt(s)$$

Write a half-equation for the reaction that occurs at the positive electrode of this cell.

Calculate the standard electrode potential of this positive electrode.

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(2 marks)

7 (c) Suggest what reactions occur, if any, when hydrogen gas is bubbled into a solution containing a mixture of iron(II) and iron(III) ions. Explain your answer.

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(2 marks)

Question 7 continues on the next page

Do not write outside the box

7 (d) A solution of iron(II) sulfate was prepared by dissolving 10.00 g of $FeSO_4.7H_2O$ (M_r = 277.9) in water and making up to 250 cm^3 of solution. The solution was left to stand, exposed to air, and some of the iron(II) ions became oxidised to iron(III) ions. A 25.0 cm^3 sample of the partially oxidised solution required 23.70 cm^3 of 0.0100 mol dm^{-3} potassium dichromate(VI) solution for complete reaction in the presence of an excess of dilute sulfuric acid.

Calculate the percentage of iron(II) ions that had been oxidised by the air.

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(6 marks)

(Extra space) .....

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14

END OF QUESTIONS

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Version 1.2

General Certificate of Education
June 2010

Chemistry CHEM5

Energetics, Redox and Inorganic Chemistry

Mark Scheme

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Mark schemes are prepared by the Principal Examiner and considered, together with the relevant questions, by a panel of subject teachers. This mark scheme includes any amendments made at the standardisation meeting attended by all examiners and is the scheme which was used by them in this examination. The standardisation meeting ensures that the mark scheme covers the candidates' responses to questions and that every examiner understands and applies it in the same correct way. As preparation for the standardisation meeting each examiner analyses a number of candidates' scripts: alternative answers not already covered by the mark scheme are discussed at the meeting and legislated for. If, after this meeting, examiners encounter unusual answers which have not been discussed at the meeting they are required to refer these to the Principal Examiner.

It must be stressed that a mark scheme is a working document, in many cases further developed and expanded on the basis of candidates' 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.

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Q	Part	Sub Part	Marking Guidance	Mark	Comments
1	(a)		$CaF_2(s) \rightarrow Ca^{2+}(g) + 2F^-(g)$	1	
1	(b)	(i)	Enthalpy change for formation of 1 mol of substance	1	Allow <u>heat energy change</u>, NOT energy
			From its elements	1	
			Reactants and products/all substances in their standard states	1	Or normal states at 298 K, 1 bar (100 kPa)
1	(b)	(ii)	$Ca(s) + F_2(g) \rightarrow CaF_2(s)$	1	
1	(b)	(iii)	$\Delta H_f(CaF_2) = \Delta H_a(Ca) + 1st\ IE(Ca) + 2^{nd}\ IE(Ca) + BE(F_2) + 2xEA(F) - \Delta H_L(CaF_2)$	1	Or labelled diagram
			$= 193 + 590 + 1150 + 158 + (2 \times -348) - 2602$	1	
			$= -1207\ kJ\ mol^{-1}$	1	Correct answer scores 3 -842 scores 2 (transfer error) -859 scores 1 only (using one E.A.) Units not required, wrong units lose 1 mark
1	(c)		Electrostatic attraction stronger/ionic bonding stronger/attraction between ions stronger/more energy to separate ions	1	Molecular attraction /atoms/intermolecular forces CE=0
			Because fluoride (ion) smaller than chloride	1	Do not allow F or fluorine
1	(d)	(i)	$\Delta H = \Delta H_L + \Sigma\Delta H_{hyd} = 2237 - 1650 + (2 \times -364)$	1	Can be on cycle/diagram
			$= -141\ kJ\ mol^{-1}$	1	Correct answer scores 2 Units not required, wrong units lose 1 mark

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1	(d)	(ii)	Decreases Reaction exothermic/ΔH -ve (Equilibrium)shifts to left/backwards (as temperature rises)/ equilibrium opposes the change	1 1 1	If ans to (d)(i) positive allow increases If (d)(i) +ve allow endothermic/Δ*H* +ve If (d) (i) +ve allow shifts to right/forwards / equilibrium opposes the change If no answer to (d) (i) assume –ve Δ*H* used If effect deduced incorrectly from any Δ*H* CE=0 for these 3 marks

1	(e)		u.v. absorbed: electrons/they move to higher energy (levels)/ electrons excited visible light given out: electrons/they fall back down/move to lower energy (levels)	1 1	Must refer to absorbing u.v. NOT visible light or this must be implied.

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Q	Part	Sub Part	Marking Guidance	Mark	Comments
2	(a)		Macromolecular	1	Or giant molecule Or giant covalent (also gains M2) Do not allow giant atomic Ionic/metallic CE=0 for all 3 marks
			Covalent bonding (between atoms)	1	Do NOT allow if between molecules
			Many/strong bonds to be broken (or lots of energy required)	1	Lose both bonding marks if contradiction e.g. mention of intermolecular forces Note: 'covalent bonds between molecules' loses M2 but **not** M3
2	(b)		Al_2O_3 ionic	1	Allow ionic + covalent/ ionic with covalent character
2	(c)		$2Al + 3/2O_2 \rightarrow Al_2O_3$	1	Allow multiples Ignore state symbols
2	(d)		Insoluble/impermeable/non-porous	1	Or does not react/inert Do not allow thick layer Must imply property of Al_2O_3 not Al
2	(e)		$Na_2O + H_2O \rightarrow 2NaOH$	1	Or $Na_2O + H_2O \rightarrow 2Na^+ + 2OH^-$
2	(f)	(i)	$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$	1	Ionic equations with Al_2O_3 possible e.g. $Al_2O_3 + 6H^+ \rightarrow 2Al^{3+} + 3H_2O$ Do not allow formation of Al_2Cl_6

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2	(f)	(ii)	$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$	1	Other equations with Al_2O_3 are possible e.g. $Al_2O_3 + 2OH^- + 3H_2O \rightarrow 2[Al(OH)_4]^-$ $Al_2O_3 + 2OH^- + 7H_2O \rightarrow 2[Al(H_2O)_2(OH)_4]^-$
2	(g)		SiO_2 acidic/Lewis acid/electron pair acceptor $SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O$	1 1	Allow SiO_2 **not** amphoteric Do NOT allow BL acid Other equations with SiO_2 are possible e.g. $SiO_2 + 2OH^- \rightarrow SiO_3^{2-} + H_2O$ $SiO_2 + 2OH^- + 2H_2O \rightarrow Si(OH)_6^{2-}$

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Q	Part	Sub Part	Marking Guidance	Mark	Comments
3	(a)		Same phase/state	1	
3	(b)		Because only exist in one oxidation state	1	Allow do not have variable oxidation states
3	(c)		$2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$	1	Ignore state symbols Allow multiples
3	(d)		Both (ions)have a negative charge	1	Or both have the same charge Or (ions) repel each other Do not allow both molecules have the same charge (contradiction)
3	(e)		$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$ $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ Positive and negative (ions)/oppositely charged (ions)	1 1 1	 Equations can be in any order Mark independently
3	(f)		Equations 1 and 2 can occur in any order	1	Allow idea of Fe^{3+} converted to Fe^{2+} then Fe^{2+} converted back to Fe^{3+}

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Q	Part	Sub Part	Marking Guidance	Mark	Comments
4	(a)		Partially filled/incomplete d sub-shell/orbital/shell	1	Ignore reference to f orbitals Do **not** allow d block Do **not** allow half-filled d orbitals
4	(b)		Has ligand(s) linked by co-ordinate bonds	1 1	Allow molecules/ions with lone pairs Allow dative/donation of lone pair
4	(c)		(Blue) light is absorbed (from incident white light) Due to electrons moving to higher levels / electrons excited Red light (that) remains (is transmitted) / light that remains (transmitted light) is the colour observed	1 1 1	 Allow d $\rightarrow$ d transitions Allow red light reflected
4	(d)	(i)	Circle round any O^- Circle round either N	1 1	List principle
4	(d)	(ii)	$EDTA^{4-} + [Co(H_2O)_6]^{2+} \rightarrow [CoEDTA]^{2-} + 6H_2O$	1	Allow missing square brackets Ignore state symbols
4	(d)	(iii)	Increase in entropy/ΔS positive Because 2 mol (of particles/molecules/species/entities) form 7 mol	1 1	Or increase in disorder Allow 'increase in number' as stated in words or as shown by any numbers deduced correctly from an incorrect equation Do not allow increase in ions/atoms

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4	(e)	(i)	Co-ordinate/dative/dative covalent bond Covalent bond	1 1	Allow pair of electrons donated by nitrogen/ligand Do not allow pair of electrons donated from Iron/Fe Shared electron pair
4	(e)	(ii)	Transport of oxygen/O_2	1	Allow any statement that implies oxygen carried (around the body) Do not allow transport of carbon dioxide (CO_2). This also contradicts the mark (list principle)
4	(e)	(iii)	Because it bonds to the iron/haemoglobin Displaces <u>oxygen</u>	1 1	Allow blocks site /CO has greater affinity for haemoglobin /carboxyhaemoglobin more stable than oxyhaemoglobin Or prevents transport of <u>oxygen</u> QoL

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Q	Part	Sub Part	Marking Guidance	Mark	Comments
5	(a)		W is $CuCl_4^{2-}$	1	
			Yellow-green/yellow/green	1	Not necessary to indicate solution Do not allow precipitate/solid
			$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow CuCl_4^{2-} + 6H_2O$	1	Allow $+ 4HCl \rightarrow 4H^+$
5	(b)		X is $Cu(H_2O)_4(OH)_2$	1	Allow $Cu(OH)_2$/copper hydroxide
			Blue precipitate/solid	1	Ignore shades
			$[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow Cu(H_2O)_4(OH)_2 + 2NH_4^+$	1	Allow any balanced equation/equations leading to this hydroxide or $Cu(OH)_2$ But must use ammonia
5	(c)		Y is $[Cu(NH_3)_4(H_2O)_2]^{2+}$	1	
			Deep/dark/royal blue solution	1	QoL
			$Cu(H_2O)_4(OH)_2 + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 2H_2O + 2OH^-$	1	Accept equation for formation from $Cu(OH)_2$
5	(d)		Z is $CuCO_3$	1	Allow copper carbonate
			Green solid/precipitate	1	Allow blue-green precipitate
			$[Cu(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow CuCO_3 + 6H_2O$	1	
5	(e)	(i)	$Cu^{2+}(aq) + Fe(s) \rightarrow Cu(s) + Fe^{2+}(aq)$	1	Allow hydrated ions State symbols not essential but penalise if wrong
			Blue	1	Do not allow description of solids
			Green	1	Allow yellow/(red-)brown/orange

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5	(e)	(ii)	Any two correct points about copper extraction from two of these three categories: Any relevant mention of lower energy consumption Any relevant mention of benefits of less mining (of copper ore) Less release of CO_2 (or CO) into the atmosphere	Max 2	 Do not allow reference to electricity alone or to temperature alone. Allow avoids depletion of (copper ore) resources Not just greenhouse gases. Must mention CO_2 or CO

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Q	Part	Sub Part	Marking Guidance	Mark	Comments
6	(a)		$\Delta H = \Sigma\Delta H_f$(products) – $\Sigma\Delta H_f$(reactants)	1	
			= –201 – 242 –(–394)	1	
			= –49 kJ mol^{-1}	1	+49 kJ mol^{-1} = 1 mark units not required, wrong units lose 1 mark
6	(b)		$\Delta S = \Sigma S$(products) – ΣS(reactants)	1	
			=238 + 189 –(214 + 3x131)	1	
			= –180 J K^{-1} mol^{-1}	1	+180 = 1 mark units not required, wrong units lose 1 mark
6	(c)		$\Delta G = \Delta H - T\Delta S$	1	If use G not ΔG penalise M1 but not M2 and M3
			(ΔS is negative so) at high temp $-T\Delta S$ (is positive and) greater than ΔH / large	1	Do not award M2 or M3 if positive ΔS value used
			So $\Delta G > 0$	1	Independent mark unless positive ΔS value used
			(Limiting condition $\Delta G = 0$ so) $T = \Delta H/\Delta S$	1	
			= 272 K	1	Allow 297-298 if used given values. Do not award M5 if T –ve or if M4 should give T -ve
			Reaction is too slow at this temperature/to speed up the reaction	1	

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6	(d)		$CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O$	1	Allow multiples. Ignore state symbols. Do not allow equation for wrong compound but mark on provided number of moles increases or stays the same. If no equation or equation that gives a decrease in the number of moles, CE = 0
			2.5 mol give 3 mol (gases)	1	Allow statement 'increase in number of moles/molecules' If numerical values given, they must match the equation in M1 Ignore the effect of incorrect state symbols on the number of moles of particles unless used correctly
			Therefore ΔS is positive/entropy increases	1	If correct deduction from wrong equation is ΔS =0 or ΔS very small must say ΔH –ve
			(combustion exothermic so ΔH –ve so $\Delta H - T\Delta S$) and hence ΔG always negative (less than zero)	1	Allow G instead of ΔG Can score 3 out of 4 marks if equation wrong but leads to increase or no change in number of moles M4 dependent on M3 Note, if equation wrong AND there is an incorrect deduction about the change in number of moles, CE = 0

6	(e)		CO_2 /CO/CH_4 may be produced during H_2 manufacture/building the plant/transport/operating the plant	1	

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Q	Part	Sub Part	Marking Guidance	Mark	Comments
7	(a)		Hydrogen /H_2 <u>gas/bubbles</u>	1	
			1.0 mol dm^{-3} HCl / H^+	1	
			At 298K and 100kPa	1	Allow 1 bar instead of 100 kPa Do not allow 1 atm
			Pt (electrode)	1	
7	(b)		$Li^+ + MnO_2 + e^- \rightarrow LiMnO_2$	1	Ignore state symbols
			–0.13(V)	1	
7	(c)		Fe^{3+} ions reduced to Fe^{2+}	1	Can score from equation/scheme
			Because $E(Fe^{3+}/Fe^{2+}) > E(H^+/H_2)$ /E(hydrogen)	1	Allow emf/E_{cell} +ve/0.77V Allow Fe^{3+} better oxidising agent than H^+ Allow H_2 better reducing agent than Fe^{2+} Only award this explanation mark if previous mark given

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7	(d)		Moles $Cr_2O_7^{2-}$ $=\underline{23.7 \times 0.01/1000}$ = 2.37×10^{-4}	1	
			1 mol $Cr_2O_7^{2-}$ reacts with 6 mol Fe^{2+} so moles Fe^{2+} in 25 cm^3 = $6 \times 2.37 \times 10^{-4} = 1.422 \times 10^{-3}$	1	M1 x 6
			Moles Fe^{2+} in 250 cm^3 = 1.422×10^{-2}	1	M2 x 10 or M4/10
			Original moles Fe^{2+} = $\underline{10.00/277.9}$ = 0.0360	1	Independent mark
			Moles Fe^{2+} oxidised = 0.0360 – 0.0142 = 0.0218	1	M4 – M3
			% oxidised = $(0.0218 \times 100)/0.0360$ = 60.5%	1	(M5 x 100)/M4 Allow 60 to 61 Note Max 3 if mol ratio for M2 wrong eg 1:5 gives 67.1% 1:1 gives 93.4% Note also, 39.5% (39-40) scores M1, M2, M3 and M4 (4 marks)

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Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
9	
TOTAL	

General Certificate of Education
Advanced Level Examination
January 2010

Chemistry CHEM5

Unit 5 Energetics, Redox and Inorganic Chemistry

Monday 1 February 2010 9.00 am to 10.45 am

For this paper you must have:
- the Periodic Table/Data Sheet, provided as an insert (enclosed)
- a calculator.

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. **Answers written in margins or on blank pages will not be marked.**
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- The Periodic Table/Data Sheet is provided as an insert.
- Your answers to the questions in **Section B** should be written in continuous prose, where appropriate.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use accurate scientific terminology.

Advice
- You are advised to spend about 70 minutes on **Section A** and about 35 minutes on **Section B**.

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Areas outside the box will not be scanned for marking

SECTION A

Answer **all** questions in the spaces provided.

1 This question is about the use of transition metals as catalysts.

1 (a) State how a catalyst speeds up a chemical reaction.

.....

.....

(2 marks)

1 (b) State the characteristic property of transition metals that enables them to act as catalysts in redox reactions.

.....

(1 mark)

1 (c) In the Contact Process for the conversion of sulfur dioxide into sulfur trioxide, vanadium(V) oxide acts as a heterogeneous catalyst.

1 (c) (i) Write **two** equations to show how the catalyst is involved in this reaction.

Equation 1 .....

Equation 2 .....

(2 marks)

1 (c) (ii) Suggest **one** reason why poisoning reduces the effectiveness of a heterogeneous catalyst.

.....

(1 mark)

1 (c) (iii) Suggest how poisoning of a catalyst, used in an industrial process, can be minimised.

.....

(1 mark)

7

Areas outside the box will not be scanned for marking

2 Nickel–cadmium cells are used to power electrical equipment such as drills and shavers. The electrode reactions are shown below.

$$NiO(OH) + H_2O + e^- \longrightarrow Ni(OH)_2 + OH^- \qquad E^{\ominus} = +0.52\ V$$

$$Cd(OH)_2 + 2e^- \longrightarrow Cd + 2OH^- \qquad E^{\ominus} = -0.88\ V$$

2 (a) Calculate the e.m.f. of a nickel–cadmium cell.

.....

(1 mark)

2 (b) Deduce an overall equation for the reaction that occurs in the cell when it is used.

.....

.....

.....

(2 marks)

2 (c) Identify the oxidising agent in the overall cell reaction and give the oxidation state of the metal in this oxidising agent.

Oxidising agent .....

Oxidation state .....

(2 marks)

5

Turn over for the next question

Areas outside the box will not be scanned for marking

3 Hydrogen–oxygen fuel cells can operate in acidic or in alkaline conditions but commercial cells use porous platinum electrodes in contact with concentrated aqueous potassium hydroxide. The table below shows some standard electrode potentials measured in acidic and in alkaline conditions.

Half-equation	$E^{\ominus}$/**V**
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l)$	+1.23
$O_2(g) + 2H_2O(l) + 4e^- \longrightarrow 4OH^-(aq)$	+0.40
$2H^+(aq) + 2e^- \longrightarrow H_2(g)$	0.00
$2H_2O(l) + 2e^- \longrightarrow 2OH^-(aq) + H_2(g)$	–0.83

3 (a) State why the electrode potential for the standard hydrogen electrode is equal to 0.00 V.

.....

(1 mark)

3 (b) Use data from the table to calculate the e.m.f. of a hydrogen–oxygen fuel cell operating in alkaline conditions.

.....

(1 mark)

3 (c) Write the conventional representation for an alkaline hydrogen–oxygen fuel cell.

.....

(2 marks)

3 (d) Use the appropriate half-equations to construct an overall equation for the reaction that occurs when an alkaline hydrogen–oxygen fuel cell operates. Show your working.

.....

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(2 marks)

Areas outside the box will not be scanned for marking

3 (e) Give **one** reason, other than cost, why the platinum electrodes are made by coating a porous ceramic material with platinum rather than by using platinum rods.

.....

.....

(1 mark)

3 (f) Suggest why the e.m.f. of a hydrogen–oxygen fuel cell, operating in acidic conditions, is exactly the same as that of an alkaline fuel cell.

.....

(1 mark)

3 (g) Other than its lack of pollution, state briefly the main advantage of a fuel cell over a re-chargeable cell such as the nickel–cadmium cell when used to provide power for an electric motor that propels a vehicle.

.....

.....

(1 mark)

3 (h) Hydrogen–oxygen fuel cells are sometimes regarded as a source of energy that is carbon neutral. Give **one** reason why this may **not** be true.

.....

(1 mark)

10

Turn over for the next question

Areas outside the box will not be scanned for marking

4 The table below gives some values of standard enthalpy changes. Use these values to answer the questions.

Name of enthalpy change	$\Delta H^{\ominus}$/kJ mol^{-1}
Enthalpy of atomisation of chlorine	+121
Electron affinity of chlorine	–364
Enthalpy of atomisation of silver	+289
First ionisation enthalpy of silver	+732
Enthalpy of formation of silver chloride	–127

4 (a) Calculate the bond enthalpy of a Cl−Cl bond.

.....

(1 mark)

4 (b) Explain why the bond enthalpy of a Cl−Cl bond is greater than that of a Br−Br bond.

.....

.....

.....

.....

(2 marks)

4 (c) Suggest why the electron affinity of chlorine is an exothermic change.

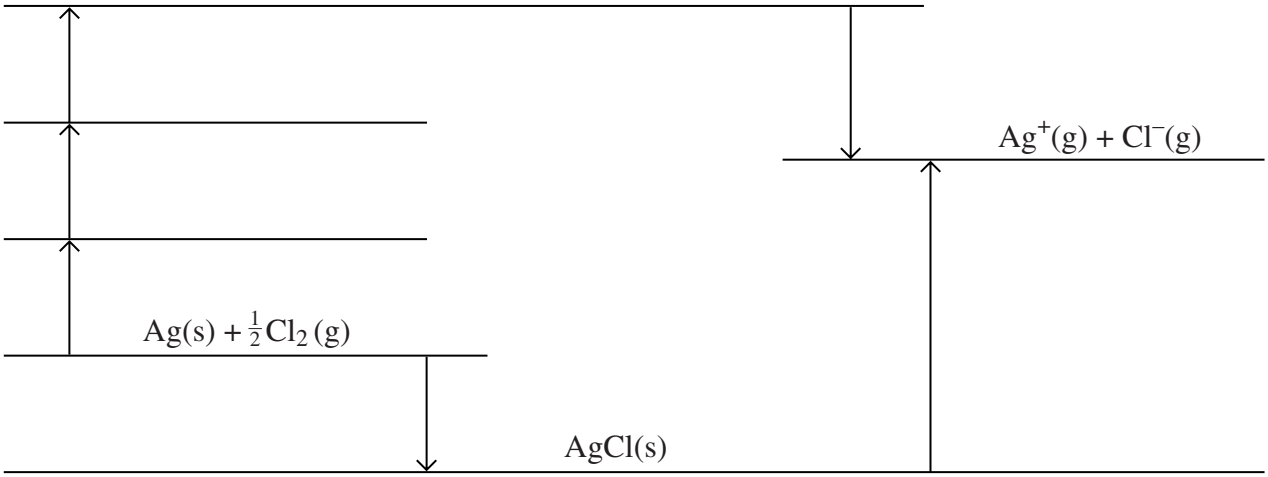
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(1 mark)

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4 (d) The diagram below is an incomplete Born–Haber cycle for the formation of silver chloride. The diagram is not to scale.



4 (d) (i) Complete the diagram by writing the appropriate chemical symbols, with state symbols, on each of the three blank lines. *(3 marks)*

4 (d) (ii) Calculate a value for the enthalpy of lattice dissociation for silver chloride.

.....

.....

.....

.....

(2 marks)

Question 4 continues on the next page

Areas outside the box will not be scanned for marking

4 (e) The enthalpy of lattice dissociation for silver chloride can also be calculated theoretically assuming a perfect ionic model.

4 (e) (i) Explain the meaning of the term *perfect ionic model*.

.....

.....

(1 mark)

4 (e) (ii) State whether you would expect the value of the theoretical enthalpy of lattice dissociation for silver chloride to be greater than, equal to or less than that for silver bromide. Explain your answer.

Theoretical lattice enthalpy for silver chloride .....

Explanation .....

.....

.....

(3 marks)

(Extra space) .....

.....

.....

4 (e) (iii) Suggest why your answer to part (d) (ii) is greater than the theoretical value for the enthalpy of lattice dissociation for silver chloride.

.....

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(2 marks)

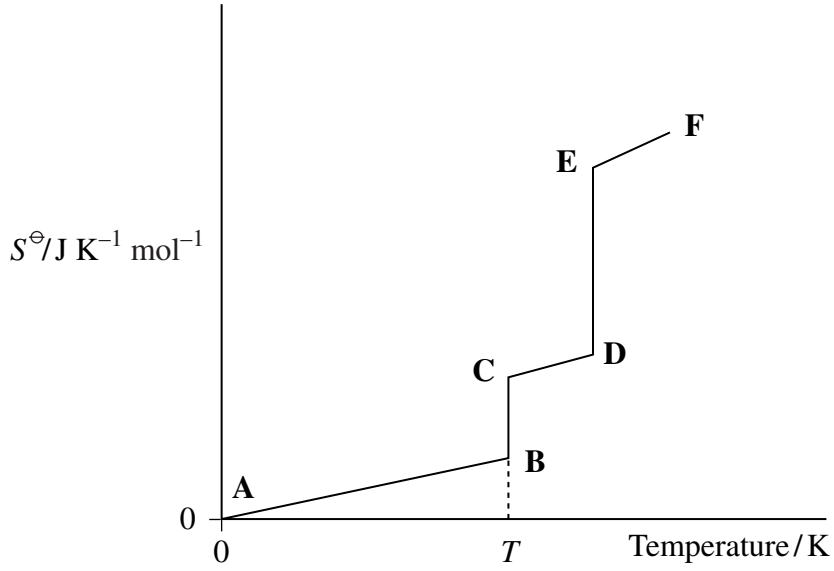
15

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ANSWER IN THE SPACES PROVIDED

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5 The simplified diagram below shows how the entropy of ammonia varies with temperature at a pressure of 100 kPa. In this diagram, ammonia is a solid at point **A** and a gas at point **F**.



5 (a) State why the entropy value for ammonia is equal to zero at 0 K.

.....

(1 mark)

5 (b) Explain, in terms of the movement of particles, why the entropy value increases between points **A** and **B** on the diagram.

.....

.....

(1 mark)

5 (c) Temperature *T* is marked on the diagram. What does the value of this temperature represent?

.....

(1 mark)

5 (d) Explain why there is a large entropy change between points **D** and **E** on the diagram.

.....

.....

(2 marks)

Areas outside the box will not be scanned for marking

5 (e) An equation for the reaction in the Haber Process is shown below, together with some entropy data.

$$\tfrac{1}{2}N_2(g) + \tfrac{3}{2}H_2(g) \rightleftharpoons NH_3(g) \qquad \Delta H^{\ominus} = -46.2\,kJ\,mol^{-1}$$

	$N_2(g)$	$H_2(g)$	$NH_3(g)$
$S^{\ominus}$/ J K^{-1} mol^{-1}	192	131	193

5 (e) (i) Calculate a value for the entropy change, $\Delta S^{\ominus}$, for the formation of one mole of ammonia.

.....

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.....

.....

(2 marks)

5 (e) (ii) Give the equation that relates free-energy change, $\Delta G^{\ominus}$, to enthalpy change, $\Delta H^{\ominus}$, and entropy change, $\Delta S^{\ominus}$.

Use this equation to calculate the temperature at which the value of $\Delta G^{\ominus} = 0$ for the formation of ammonia in the Haber Process.
(If you have been unable to calculate an answer to part (e) (i), you may assume that $\Delta S^{\ominus} = -81.4$ J K mol^{-1} but this is not the correct value.)

Equation .....

Calculation .....

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(4 marks)

(Extra space) .....

5 (e) (iii) What can you deduce about the formation of ammonia if the reaction mixture is heated to a temperature above the value that you have calculated in part (e) (ii)?

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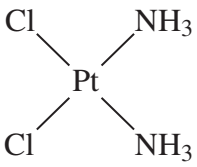
(1 mark)

12

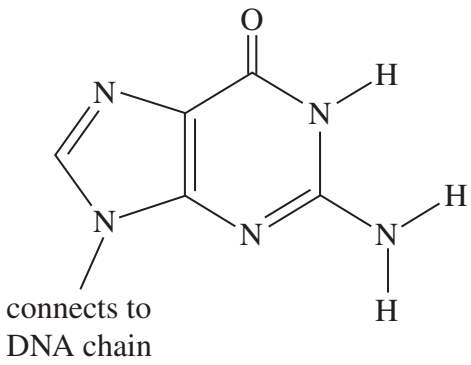
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6 The complex cisplatin acts as an anticancer drug by changing the properties of DNA when it reacts with guanine, a component of DNA.



cisplatin



guanine

When cisplatin is absorbed into the human body, it undergoes a ligand substitution reaction and one chloride ligand is replaced by a water molecule forming a complex ion **Q**.

6 (a) Write an equation for this substitution reaction to form the complex ion **Q**.

.....

(2 marks)

6 (b) The complex ion **Q** can bond to guanine in two different ways.

6 (b) (i) The first way involves a hydrogen atom, from one of the ammonia ligands on **Q**, bonding to an atom in a guanine molecule. State the type of bond formed to guanine and identify an atom in guanine that could form a bond to this hydrogen atom.

Type of bond .....

Atom in guanine .....

(2 marks)

6 (b) (ii) The second way involves a ligand substitution reaction in which an atom in a guanine molecule bonds to platinum by displacing the water molecule from **Q**. State the type of bond formed between guanine and platinum when a water molecule is displaced and identify an atom in guanine that could bond to platinum in this way.

Type of bond .....

Atom in guanine .....

(2 marks)

Areas outside the box will not be scanned for marking

6 (c) State and explain **one** risk associated with the use of cisplatin as an anticancer drug.

Risk .....

Explanation .....

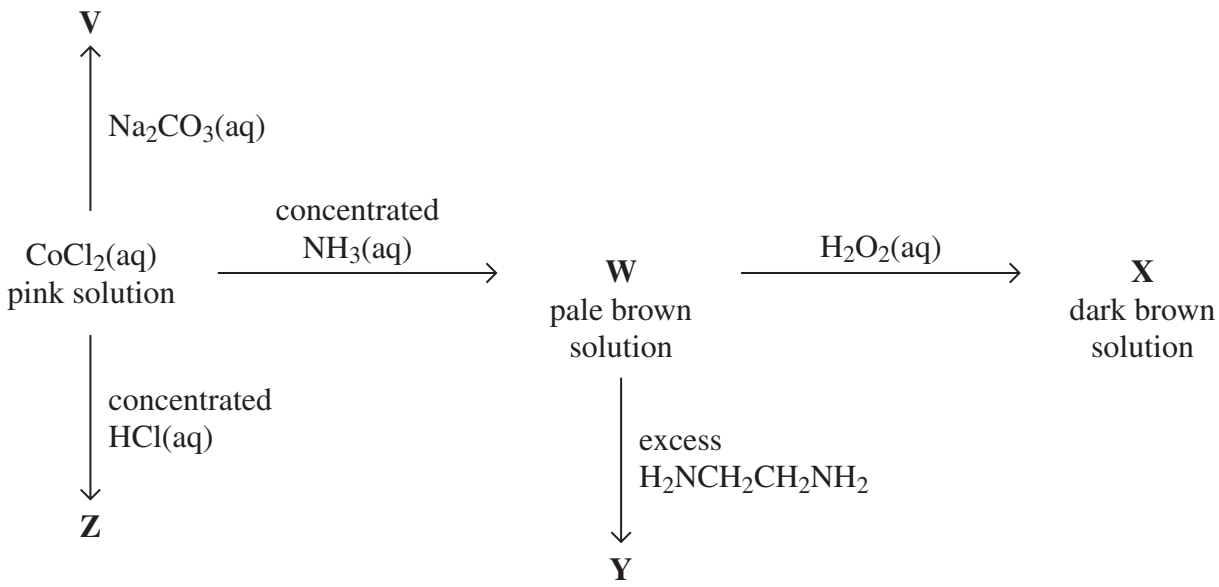
(2 marks)

8

Turn over for the next question

Areas outside the box will not be scanned for marking

7 This question is about some reactions of cobalt compounds.



7 (a) Give the formula of the complex responsible for the pink colour in aqueous $CoCl_2$ and name its shape.

Formula .....

Name of shape .....

(2 marks)

7 (b) Give the formula of the cobalt-containing compound **V** and describe its appearance.

Formula .....

Appearance .....

(2 marks)

7 (c) Write an equation for the reaction that occurs when the pink solution is converted into **W**.

.....

(2 marks)

Areas outside the box will not be scanned for marking

7 (d) Give the formula of the cobalt-containing complex in **X** and state the role of the H_2O_2 in this reaction.

Formula .....

Role of H_2O_2 .....

(2 marks)

7 (e) Give the formula of the cobalt-containing complex in **Y** and explain why this complex is more stable than the cobalt-containing complex in **W**.

Formula .....

Explanation .....

.....

.....

(3 marks)

7 (f) Identify the cobalt-containing complex in solution **Z** and explain why its co-ordination number is different from that in the pink solution of $CoCl_2$

Complex .....

Explanation .....

.....

(2 marks)

13

Turn over for the next question

Areas outside the box will not be scanned for marking

SECTION B

Answer **all** questions in the spaces provided.

8 (a) State and explain the trend in electronegativities across Period 3 from sodium to sulfur.

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(4 marks)

(Extra space) .....

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Areas outside the box will not be scanned for marking

8 (b) Explain why the oxides of the Period 3 elements sodium and phosphorus have different melting points. In your answer you should discuss the structure of and bonding in these oxides, and the link between electronegativity and the type of bonding.

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(6 marks)

(Extra space) .....

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Question 8 continues on the next page

Areas outside the box will not be scanned for marking

8 (c) A chemical company has a waste tank of volume 25 000 dm^3. The tank is full of phosphoric acid (H_3PO_4) solution formed by adding some unwanted phosphorus(V) oxide to water in the tank.

A 25.0 cm^3 sample of this solution required 21.2 cm^3 of 0.500 mol dm^{-3} sodium hydroxide solution for complete reaction.

Calculate the mass, in kg, of phosphorus(V) oxide that must have been added to the water in the waste tank.

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(5 marks)

(Extra space) .....

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15

Areas outside the box will not be scanned for marking

9 (a) State the electron configuration of a Ti(III) ion and that of a Ti(IV) ion. Explain, in terms of electron configurations and electron transitions, why Ti(III) compounds are usually coloured but Ti(IV) compounds are colourless.

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(5 marks)

(Extra space) .....

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Question 9 continues on the next page

Areas outside the box will not be scanned for marking

9 (b) Transition metal ions and their complexes can often be identified from their colours. For each of the following, identify a complex ion responsible for the colour of the aqueous solution. Restrict your answers to complexes formed from the elements Cr, Fe, Co and Cu.

A deep blue solution formed in an excess of concentrated aqueous ammonia.

A green solution formed in an excess of aqueous sodium hydroxide.

A yellow–green solution formed in an excess of concentrated hydrochloric acid.

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(3 marks)

9 (c) An experiment is carried out to investigate the rate of the autocatalysed reaction between aqueous potassium manganate(VII) and ethanedioate ions in an excess of dilute sulfuric acid. When these reagents are mixed together, the colour of the reaction mixture gradually fades. The concentration of the manganate(VII) ions is recorded at different times using a spectrometer. The temperature of the reaction mixture is constant.

9 (c) (i) Give **two** reasons why the use of a spectrometer is the most appropriate method for measuring the concentration of the coloured ions in this experiment.

.....

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(2 marks)

(Extra space) .....

.....

Areas outside the box will not be scanned for marking

9 (c) (ii) Sketch a curve to show how you would expect the concentration of manganate(VII) ions to change with time until the colour has faded because the concentration has reached a very low value. Explain the shape of the curve.

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(5 marks)

(Extra space) .....

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15

END OF QUESTIONS

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Version 1.0: 02/2010



General Certificate of Education

Chemistry 2421

CHEM5 Energetics, Redox and Inorganic Chemistry

Mark Scheme

2010 examination - January series

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Mark schemes are prepared by the Principal Examiner and considered, together with the relevant questions, by a panel of subject teachers. This mark scheme includes any amendments made at the standardisation meeting attended by all examiners and is the scheme which was used by them in this examination. The standardisation meeting ensures that the mark scheme covers the candidates' responses to questions and that every examiner understands and applies it in the same correct way. As preparation for the standardisation meeting each examiner analyses a number of candidates' scripts: alternative answers not already covered by the mark scheme are discussed at the meeting and legislated for. If, after this meeting, examiners encounter unusual answers which have not been discussed at the meeting they are required to refer these to the Principal Examiner.

It must be stressed that a mark scheme is a working document, in many cases further developed and expanded on the basis of candidates' 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.

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Dr Michael Cresswell Director General

Question	Part	Sub Part	Marking Guidance	Mark	Comments
1	(a)		Alternative route Lower activation energy	1 1	Allow mechanism outlined allow forms intermediate species
1	(b)		Variable oxidation state	1	allow changes oxidation states
1	(c)	(i)	$SO_2 + V_2O_5 \rightarrow SO_3 + V_2O_4$ $O_2 + 2V_2O_4 \rightarrow 2V_2O_5$	1 1	allow $2VO_2$ instead of V_2O_4
1	(c)	(ii)	Poison attaches to surface	1	Allow blocks active site/surface Decreases surface area
1	(c)	(iii)	Purify reactants	1	Allow remove impurities

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Question	Part	Sub Part	Marking Guidance	Mark	Comments
2	(a)		1.4 V	1	Allow + or -
2	(b)		$2NiO(OH) + 2H_2O + Cd \rightarrow 2Ni(OH)_2 + Cd(OH)_2$ Balanced	1 1	Mark for species, Deduct a mark for additional species (eg OH^-) but allow balance mark If equation is reversed CE=0
2	(c)		NiO(OH) or Ni(III) or nickel +3	1 1	 Allow conseq on wrong species

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Question	Part	Sub Part	Marking Guidance	Mark	Comments
3	(a)		By definition	1	allow 'set to this value'
3	(b)		1.23 V	1	Allow + or -
3	(c)		$Pt\|H_2(g)\|OH^-(aq),H_2O(l)\|\|O_2(g)\|H_2O(l),OH^-(aq)\|Pt$ Correct but with Pt missing Includes Pt with correct representation	 1 1	H_2O not essential, allow reverse order
3	(d)		Uses $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ And (2x) $2OH^- + H_2 \rightarrow 2H_2O + 2e^-$ $2H_2 + O_2 \rightarrow 2H_2O$	1 1	
3	(e)		Increases the surface area (so reaction faster)	1	
3	(f)		Overall reaction is the same ($2H_2 + O_2 \rightarrow 2H_2O$)	1	Or shows e.m.f. is the same
3	(g)		Hydrogen and oxygen supplied continuously ***OR*** Can be operated without stopping to recharge	1	Or can be refuelled quickly Allow any one mark
3	(h)		Hydrogen may need to be made using an energy source that is not 'carbon neutral'	1	

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Question	Part	Sub Part	Marking Guidance	Mark	Comments
4	(a)		242	1	Units not essential
4	(b)		Bond is shorter or bonding pair closer to nucleus So attraction (between nucleus and) (to) bond pair is stronger	1 1	Allow Cl is a smaller atom Allow fewer electron shells do not allow smaller molecules Allow shared pair (or bonding electrons) held more tightly Mention of Cl^- loses M2
4	(c)		Net attraction between the chlorine nucleus and the extra electron	1	Allow Cl^- ion more stable than Cl
4	(d)	(i)	step 1 $Ag(s) \rightarrow Ag(g)$ only change step 2 $Ag(s) \rightarrow Ag^+(g) + e^-$ only change step 3 $^1/_2Cl_2(g) \rightarrow Cl(g)$ only change	1 1 1	 This step can be first, second or third
4	(d)	(ii)	127 + 289 + 732 + 121 – 364 = 905 kJ mol^{-1}	1 1	 -905 scores 1 mark only
4	(e)	(i)	Ions can be regarded as point charges (or perfect spheres)	1	Allow no polarisation ***OR*** only bonding is ionic ***OR*** no covalent character
4	(e)	(ii)	Greater Chloride <u>ions</u> are smaller than bromide They are attracted more strongly to the silver ions	1 1 1	Electronegativity argument or mention of intermolecular, CE =0 Mark independently but see above Mark independently
4	(e)	(iii)	AgCl has covalent character Forces in the lattice are stronger than pure ionic attractions	1 1	Ignore reference to molecules Allow stronger bonding OR additional/extra bonding

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Question	Part	Sub Part	Marking Guidance	Mark	Comments
5	(a)		No disorder (or maximum order or molecules stationary)	1	Allow by definition Do not allow just 'particles are ordered'
5	(b)		Molecules <u>vibrate</u> more (so more disorder)	1	
5	(c)		Melting point of ammonia	1	
5	(d)		Molecules changing from liquid to gas <u>Big</u> increase in disorder or <u>much more</u> random movement	1 1	Allow becomes a gas Allow gases are <u>very</u> disordered
5	(e)	(i)	= Σentropy products – Σentropy reactants Or = 193 – 0.5×192 – 1.5×131 = –99.5 J K^{-1} mol^{-1}	1 1	
5	(e)	(ii)	$\Delta G = \Delta H - T\Delta S$ When $\Delta G = 0$ $T = \Delta H/\Delta S$ = –46.2×1000/–99.5 = 464 K	1 1 1 1	 Allow conseq on wrong ΔS Allow 568 K if use given ΔS
5	(e)	(iii)	No longer spontaneous or yield decreases	1	Either point scores do not allow 'formation of ammonia decreases' Must say or imply clearly that yield of ammonia decreases or equilibrium shifts to left.

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Question	Part	Sub Part	Marking Guidance	Mark	Comments
6	(a)		$Pt(NH_3)_2Cl_2 + H_2O \rightarrow [Pt(NH_3)_2Cl(H_2O)]^+ + Cl^-$ Correct product Balanced equation	 1 1	
6	(b)	(i)	Hydrogen bond Oxygen (or nitrogen)	1 1	 Only score this mark if type of bond is correct
6	(b)	(ii)	Co-ordinate Nitrogen (or oxygen)	1 1	 Bond type must be correct to score this mark but allow M2 if bond is covalent
6	(c)		Killing them or causing damage (medical side effects) May attach to DNA in normal cells	1 1	Allow any correct side effect (e.g. hair loss) Allow kills healthy (or normal) cells

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Question	Part	Sub Part	Marking Guidance	Mark	Comments
7	(a)		$[Co(H_2O)_6]^{2+}$ octahedral	1 1	 Only allow if species has 6 ligands but allow if M1 not given because charge missing
7	(b)		$CoCO_3$ Purple solid (allow pink)	1 1	Mark independently Allow pink precipitate
7	(c)		$[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$ Formula of product Balanced equation	 1 1	Allow $[Co(NH_3)_5H_2O]^{3+}$
7	(d)		$[Co(NH_3)_6]^{3+}$ Oxidising agent	1 1	Allow $[Co(NH_3)_5H_2O]^{3+}$
7	(e)		$[Co(H_2NCH_2CH_2NH_2)_3]^{2+}$ Entropy change for reaction is positive Because 4 mol reactants form 7 mol products (or increase in number of particles)	1 1 1	Allow use of en $[Coen_3]^{2+}$ Mark independently Or bidentate replaces unidentate
7	(f)		$[CoCl_4]^{2-}$ Cl^- ligand too big to fit more than 4 round Co^{2+}	1 1	 Allow Cl^- is bigger Allow chlorine and Cl but NOT chlorine molecules.

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Question	Part	Sub Part	Marking Guidance	Mark	Comments
8	(a)		Electronegativity increases	1	
			Proton number increases (increase in nuclear charge)	1	
			Same number of electron shells/levels	1	Or same radius or Shielding of outer electrons remains the same
			Attraction of <u>bond pair</u> to nucleus increases	1	Allow 'electrons in bond' instead of 'bond pair'
8	(b)		Big <u>difference</u> in electronegativity leads to ionic bonding, smaller covalent	1	Lose a mark if formula incorrect
			Sodium oxide ionic lattice	1	
			Strong forces of attraction <u>between ions</u>	1	
			P_4O_{10} covalent molecular	1	Must have covalent and molecular (or molecules)
			Weak (intermolecular) forces between molecules	1	Or weak vdW, or weak dipole-dipole between molecules
			melting point Na_2O greater than for P_4O_{10}	1	Or argument relating mpt to strength of forces

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8	(c)		Moles NaOH = $0.0212 \times 0.5 = 0.0106$ Moles of H_3PO_4 = 1/3 moles of NaOH (= 0.00353) Moles of P in 25000 l = $0.00353 \times 10^6 = 3.53 \times 10^3$ Moles of $P_4O_{10} = 3.53 \times 10^3/4$ Mass of $P_4O_{10} = 3.53 \times 10^3/4 \times 284 = 0.251 \times 10^6$ g = 251 kg	1 1 1 1 1	M1 moles of NaOH correct M2 is for 1/3 M3 is for factor of 1,000,000 M4 is for factor of 1/4 (or 1/2 if P_2O_5) (Or if P_2O_5 $3.53 \times 10^3/2 \times 142$) M5 is for multiplying moles by M_r with correct units allow conseq on incorrect M4 (allow 250-252)

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Question	Part	Sub Part	Marking Guidance	Mark	Comments
9	(a)		Ti(IV) [Ar]	1	Or $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$
			Ti(III) [Ar]$3d^1$	1	Or $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^1$
			Ti(III) has a d electron that can be excited to a higher level	1	Allow idea that d electrons can be excited to another level (or move between levels)
			Absorbs one colour of light from white light	1	Allow idea that light is absorbed
			Ti(IV) has no d electron so no electron transition with energy equal to that of visible light	1	Allow Ti(IV) has no d electrons
9	(b)		$[Cu(NH_3)_4(H_2O)_2]^{2+}$	1	
			$[Cr(OH)_6]^{3-}$	1	
			$[CuCl_4]^{2-}$	1	
9	(c)	(i)	Rapid determination of concentration	1	Or easy to get many readings
			Does not use up any of the reagent/does not interfere with the reaction	1	Or possible to measure very low concentrations
9	(c)	(ii)	Curve starts with small gradient (low rate)	1	**5 max**
			Because negative ions collide so E_a high	1	
			Curve gets steeper	1	
			Because autocatalyst (Mn^{2+}) formed	1	
			Curve levels out approaching time axis	1	Can score this mark and next one ONLY with simple curve (that is curve with gradually decreasing gradient)
			Because MnO_4^- ions used up	1	

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