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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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WMP/Jun16/E5

**CHEM5**

**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]

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

[1 mark]

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

[1 mark]

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**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]

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

[1 mark]

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**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]

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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]

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

[1 mark]

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

[1 mark]

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

[2 marks]

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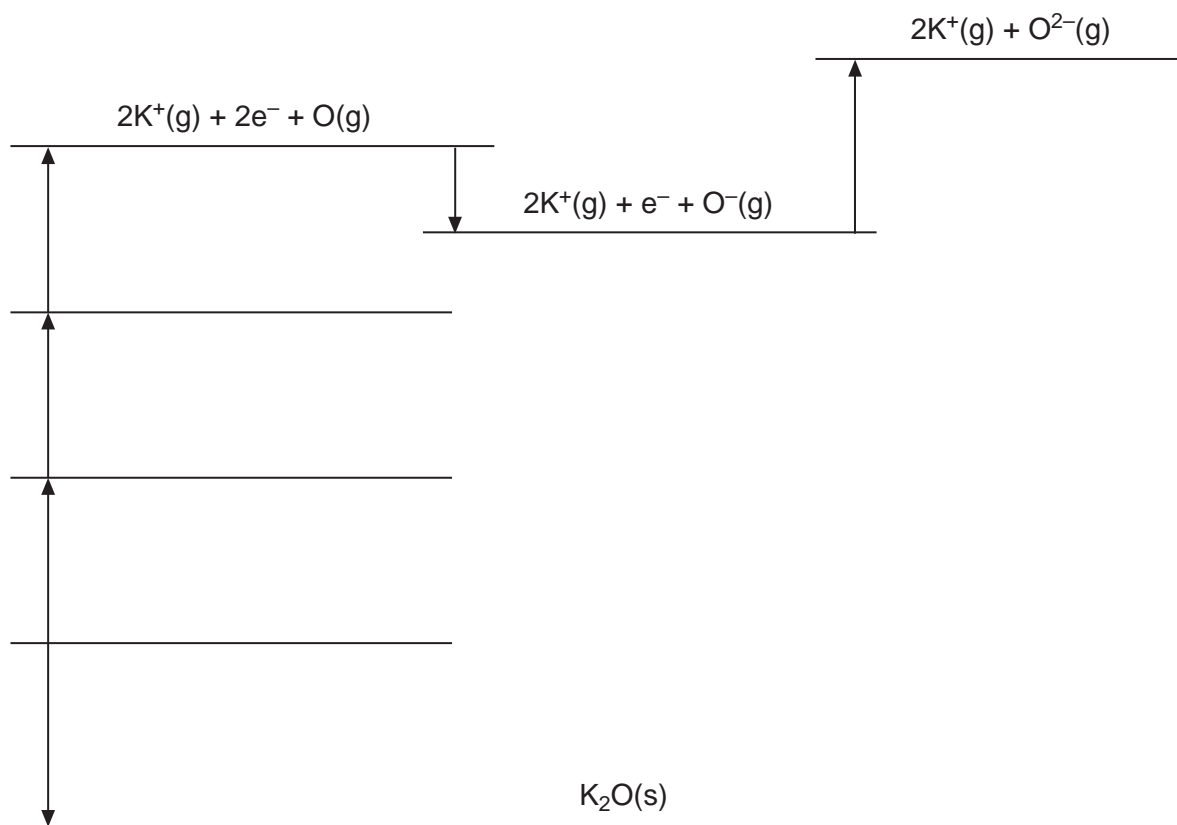


2 (a) **Figure 1** is a Born–Haber cycle for potassium oxide,  $K_2O$ . **Figure 1** is not to scale and not fully labelled.

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**



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

Table 1

Enthalpy change	$\Delta H^\ominus / \text{kJ mol}^{-1}$
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,  $\text{K}_2\text{O}$

[3 marks]

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

[2 marks]

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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]

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

Enthalpy of lattice dissociation of $\text{MgCl}_2$	= +2493 $\text{kJ mol}^{-1}$
Enthalpy of hydration of magnesium ions	= -1920 $\text{kJ mol}^{-1}$
Enthalpy of hydration of chloride ions	= -364 $\text{kJ mol}^{-1}$

[2 marks]

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**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  $\text{MgCl}_2$  changes as the temperature is increased.

Explain your answer.

[3 marks]

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

**Table 2**

Electrode half-reaction	$E^\ominus / \text{V}$
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Zn}(\text{s})$	-0.76
$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Co}(\text{s})$	-0.28
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2\text{O}(\text{l})$	+1.23
$\text{Au}^+(\text{aq}) + \text{e}^- \rightarrow \text{Au}(\text{s})$	+1.68
$\text{Co}^{3+}(\text{aq}) + \text{e}^- \rightarrow \text{Co}^{2+}(\text{aq})$	+1.82

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

[1 mark]

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

[2 marks]

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

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 \_\_\_\_\_

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Half-equation \_\_\_\_\_





**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]**

\_\_\_\_\_

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



- 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]

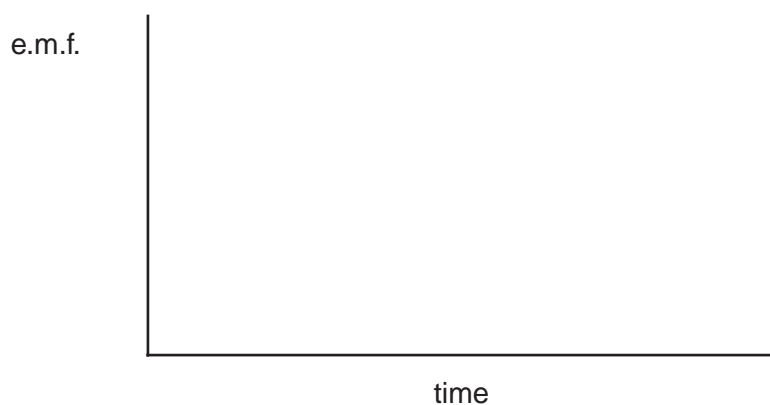
Effect on e.m.f. \_\_\_\_\_

Explanation \_\_\_\_\_

\_\_\_\_\_

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

[1 mark]



**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]

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

[1 mark]

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

[1 mark]

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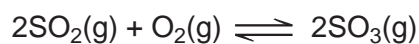
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- 6 In the Contact Process sulfur dioxide reacts with oxygen to form sulfur trioxide as shown in the equation.



**Table 3** shows some thermodynamic data.

**Table 3**

	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{SO}_2(\text{g})$	-297	248
$\text{O}_2(\text{g})$	0	205
$\text{SO}_3(\text{g})$	-395	256

- 6 (a) Use data from **Table 3** to calculate the standard enthalpy change for this reaction. **[2 marks]**

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- 6 (b) Use data from **Table 3** to calculate the standard entropy change for this reaction. **[2 marks]**

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- 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  $\Delta H$  in part **(a)** assume a value of  $-250 \text{ kJ mol}^{-1}$   
If you were unable to calculate  $\Delta S$  in part **(b)** assume a value of  $-250 \text{ J K}^{-1} \text{ mol}^{-1}$   
These are not the correct values.)

**[3 marks]**

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

**[1 mark]**

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**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]**

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

**[2 marks]**

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

**[1 mark]**

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

**[1 mark]**

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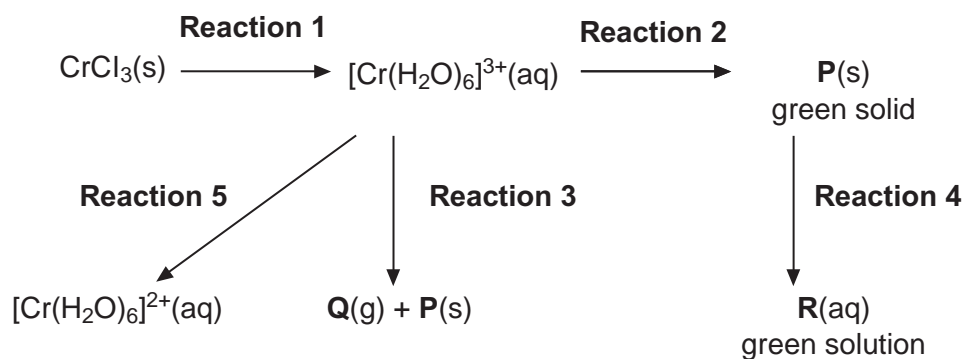
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7 The following scheme shows some reactions of chromium compounds.



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

[1 mark]

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

[3 marks]

Identity of **P** \_\_\_\_\_

Reagent \_\_\_\_\_

Equation \_\_\_\_\_

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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  $[\text{Cr}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ .

[2 marks]

Reagents \_\_\_\_\_

Colour \_\_\_\_\_

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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  $\text{Co}^{2+}$  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  $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$  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]**

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- 9** A student weighed out a 2.29 g sample of impure  $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3] \cdot 3\text{H}_2\text{O}$  and dissolved it in water.  
This solution was added to a  $250 \text{ cm}^3$  volumetric flask and made up to  $250 \text{ cm}^3$  with distilled water.  
A  $25.0 \text{ cm}^3$  portion was pipetted into a conical flask and an excess of acid was added. The mixture was heated to  $60 \text{ }^\circ\text{C}$  and titrated with  $0.0200 \text{ mol dm}^{-3}$   $\text{KMnO}_4$  solution.  $26.40 \text{ cm}^3$  of  $\text{KMnO}_4$  solution were needed for a complete reaction.  
In this titration only the  $\text{C}_2\text{O}_4^{2-}$  ions react with the  $\text{KMnO}_4$  solution.

- 9 (a)** The reaction between  $\text{C}_2\text{O}_4^{2-}$  ions and  $\text{MnO}_4^-$  ions is autocatalysed.  
Explain what is meant by the term autocatalysed and identify the catalyst in the reaction.  
**[2 marks]**

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- 9 (b)** Select from the list the most suitable substance used to acidify the solution in the conical flask.  
Put a tick ( $\checkmark$ ) in the correct box.  
**[1 mark]**

$\text{H}_2\text{C}_2\text{O}_4$

$\text{H}_2\text{SO}_4$

$\text{HCl}$

$\text{HNO}_3$



- 9 (c)** The reaction between  $\text{C}_2\text{O}_4^{2-}$  ions and  $\text{MnO}_4^-$  ions is very slow at first. Explain why the reaction is initially slow.

**[3 marks]**

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- 9 (d)** Write an equation for the reaction between  $\text{C}_2\text{O}_4^{2-}$  ions and  $\text{MnO}_4^-$  ions in acidic solution.  
Calculate the percentage purity of the original sample of  $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3] \cdot 3\text{H}_2\text{O}$   
Give your answer to 3 significant figures.

**[7 marks]**

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**9 (e)** A solution of  $\text{KMnO}_4$  has an unknown concentration.

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

**[3 marks]**

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16

**END OF QUESTIONS**



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