

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

Model Answer

Forename(s)

Candidate signature

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**.



JUN16CHEM501

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]

Covalent

1 (a) (ii) Identify element X.

[1 mark]

Phosphorus

The low m.p. and acidity is the give away here.

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]

Ionic

1 (b) (ii) Identify element Y.

[1 mark]

Sodium

Can't be Mg as pH is too low - Mg is 9-10.

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

[1 mark]



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

[1 mark]



⇒ Aluminium for period 3.

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]

Ionic

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

[1 mark]

Al₂O₃

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

[1 mark]

It can act as both an acid and a base.

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

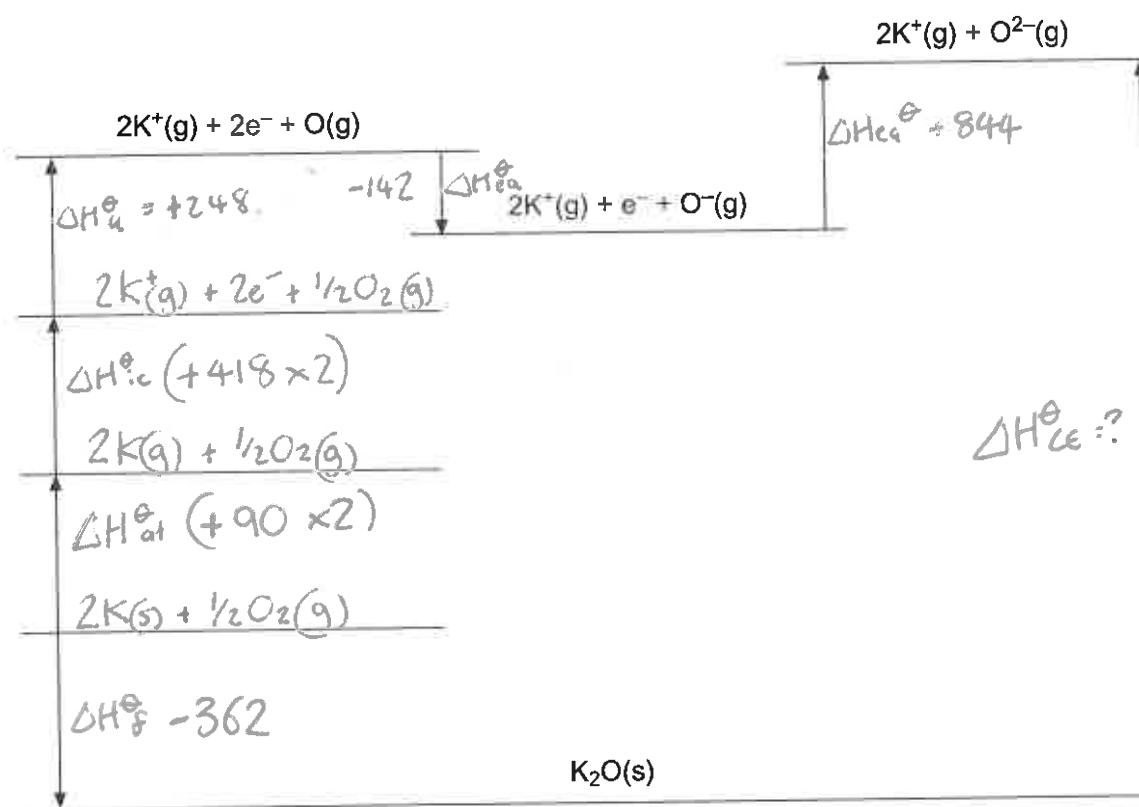
[2 marks]



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, K_2O

Remember that 'ups = downs' - so change sign of ΔH^\ominus_f for ease of calculation! [3 marks]

$$362 + (2 \times 90) + (2 \times 418) + 248 + 844 = 2470$$

$$2470 - 142 = +2328 \text{ kJ mol}^{-1}$$

MUST be a +ve answer as arrow pointing upwards!!

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

[2 marks]

As a K^+ ion is larger than that of Na^+ the attraction between the oppositely charged ions is weaker and therefore easier to break.



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]

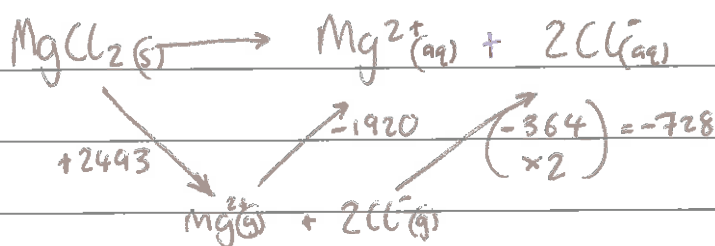


3 (b) Use these data to calculate the standard enthalpy of solution of magnesium chloride.

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]

Hess cycle helps
you understand what
is happening here.



$$2493 + (-1920 + -728) = \underline{\underline{-155 \text{ kJ mol}^{-1}}}$$

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]

Solubility decreases as temperature increases.

Because the enthalpy of solution is exothermic (-155) then as temperature increases equilibrium will move in the endothermic direction.



Turn over for the next question

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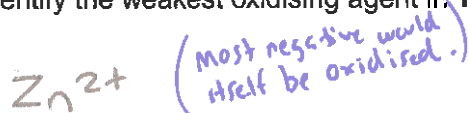
4 Table 2 shows some standard electrode potential data.

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]

298K and all concentrations at 1mol dm^{-3} .

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 $Zn | Zn^{2+} || Co^{2+} | Co$

Half-equation $Zn \rightarrow Zn^{2+} + 2e^-$



- 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 Co^{3+}

It says react with water - (H₂O) - for this to happen water would need to be the most negative half equation.



Oxidation product O_2

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

[2 marks]

for Au to be oxidised its E_{cell} would need to be more negative ... equation but it is

not! $E_{\text{cell}} = +1.23 - (+1.68) = -0.45\text{V}$

NOT FEASIBLE.

If in doubt calculating an E_{cell} value is always worth marks for these questions

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



- 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 $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$

Half-equation at negative electrode $\text{H}_2 + 2\text{OH}^- \rightarrow 2\text{H}_2\text{O} + 2\text{e}^-$

Overall equation $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

- 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]

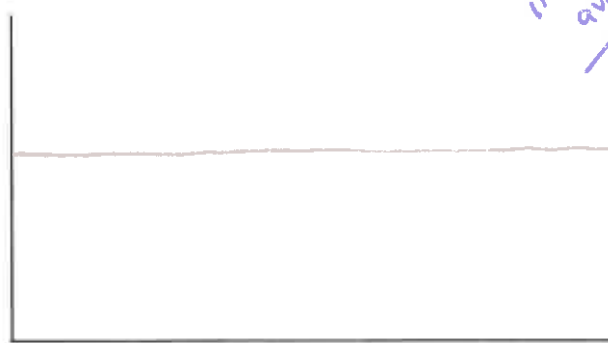
Effect on e.m.f. Increase

Explanation $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$ will move to the right!

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

[1 mark]

e.m.f.



time

*Constant e.m.f.
if fuel is
available.*



- 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]

Unchanged.

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

[1 mark]

No pollutants released - only water.

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

[1 mark]

The generation of hydrogen gas involves the burning of fossil fuels / methane, so CO_2 is released in this process.

9

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

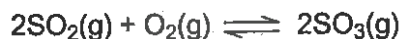
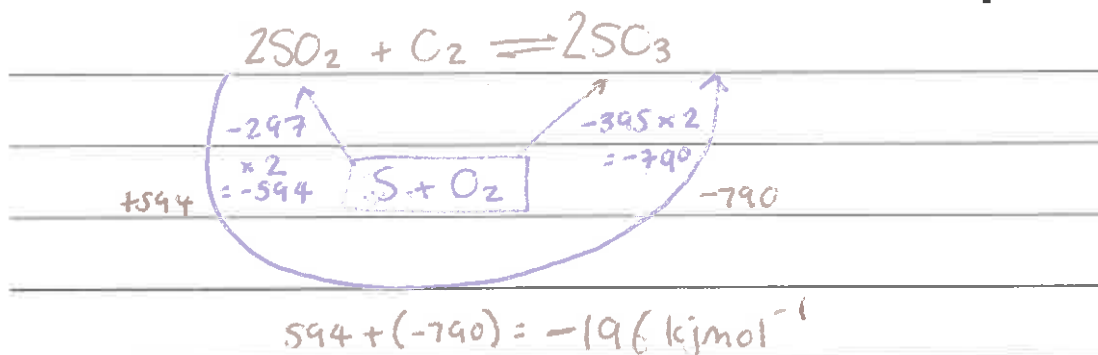


Table 3 shows some thermodynamic data.

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]



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

$$\Delta S^\ominus = \text{Products} - \text{Reactants}$$

$$\Delta S^\ominus = (256 \times 2) - (205 + (2 \times 248))$$

$$\Delta S^\ominus = 512 - 701$$

$$\Delta S^\ominus = -189 \text{ J K}^{-1} \text{ mol}^{-1}$$

MUST GIVE UNITS!!

- 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]

Less disorder.

a negative ΔS means it is now more ordered.



- 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 $-250 \text{ J K}^{-1} \text{ mol}^{-1}$
These are not the correct values.)

[3 marks]

$$\Delta G = \Delta H - T\Delta S$$

$$\Delta G = -196 - (323 \times -0.189)$$

$$\Delta G = -134.915 \text{ kJ mol}^{-1}$$

$$\Delta H = -196 \text{ kJ mol}^{-1}$$

$$\Delta S = -0.189 \text{ kJ K}^{-1} \text{ mol}^{-1}$$

$$T = 323 \text{ K}$$

Remember to ensure
that both S and
H are in either kJ
or J!

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

[1 mark]

Reaction is feasible as ΔG is negative.

- 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]

Catalyst is in a different state to reactants.

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

[2 marks]



A very popular
question - learn
this!!

Turn over ►



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

[1 mark]

It gives a larger surface area.

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

[1 mark]

So the catalyst is not poisoned (blocking active sites).



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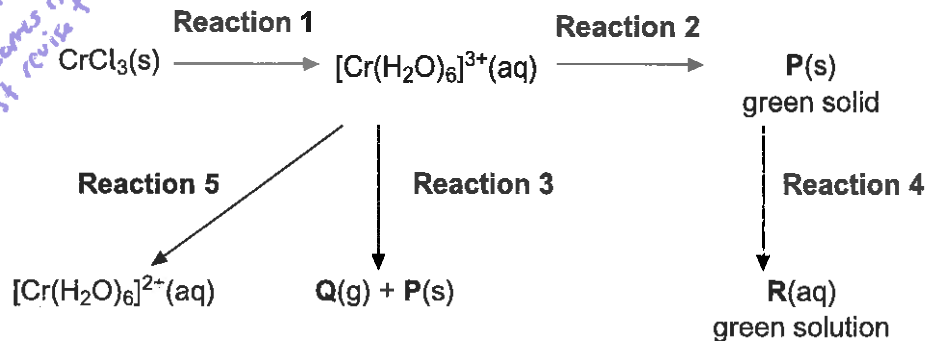
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7 The following scheme shows some reactions of chromium compounds.

This where your transition metal complex colour practice comes in handy!! Must revise this.



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 $\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3$

Reagent NaOH (or NH_3)

Equation $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \longrightarrow \text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3 + 3\text{H}_2\text{O}$

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

[3 marks]

Identity of Q CO_2

Reagent Na_2CO_3

Equation $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{CO}_3^{2-} \longrightarrow 2\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3 + 3\text{CO}_2 + 3\text{H}_2\text{O}$

AS Q is a (g) then has to be carbonate reagent.



- 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 $[\text{Cr}(\text{OH})_6]^{3-}$

Reagent NaOH

Equation $\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3 + 3\text{OH}^- \rightarrow [\text{Cr}(\text{OH})_6]^{3-} + 3\text{H}_2\text{O}$

- 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 Zn/HCl

Colour Blue

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]



• it has variable oxidation states

• forms coloured complexes and ions.

• Can act as a catalyst.



- 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.

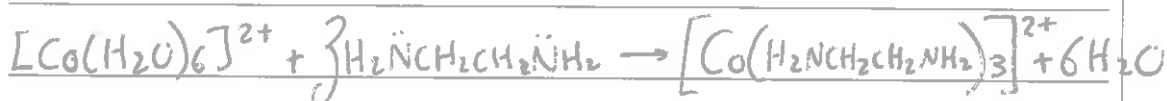
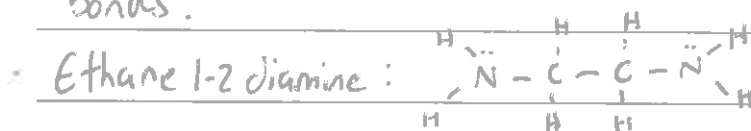
Explain what is meant by the term bidentate ligand. ✓

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

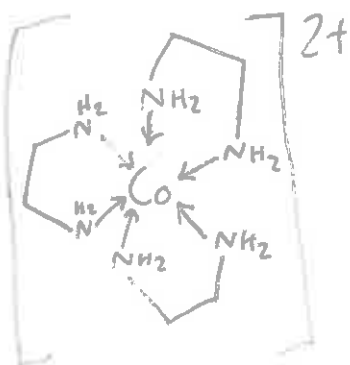
Draw a diagram to show the structure of the complex ion formed.

[7 marks]

A bidentate ligand has two atoms that can each donate a pair of electrons to form two coordinate bonds.



This goes from four moles of reactants to 7 moles of products which gives a large entropy change and therefore would have a negative ΔG .



Another very common question - sometimes a variation of this is with EDTA - same principles apply.



- 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 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 $60 \text{ }^\circ\text{C}$ and titrated with $0.0200 \text{ mol dm}^{-3}$ KMnO_4 solution. 26.40 cm^3 of KMnO_4 solution were needed for a complete reaction.
In this titration only the $\text{C}_2\text{O}_4^{2-}$ ions react with the KMnO_4 solution.

- 9 (a) The reaction between $\text{C}_2\text{O}_4^{2-}$ ions and MnO_4^- ions is autocatalysed.
Explain what is meant by the term autocatalysed and identify the catalyst in the reaction. [2 marks]

A reaction where the catalyst is one of the products. In this case it is Mn^{2+} .

- 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]

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

H_2SO_4

HCl

HNO_3



- 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.

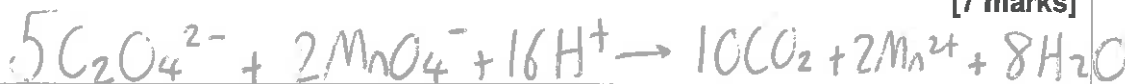
[3 marks]

At the start there is no catalyst. Also two negative ions ($C_2O_4^{2-}$ and MnO_4^-) are trying to react together but there is a lot of repulsion so the activation energy for this is very high.

These questions sometimes have a bit of dry one, be prepared for this.

- 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 $K_3[Fe(C_2O_4)_3] \cdot 3H_2O$. Give your answer to 3 significant figures.

[7 marks]



$$c = \frac{\text{mol}}{\text{Vol}}$$

$$KMnO_4 = 0.02 \text{ mol dm}^{-3} \times \frac{26.40}{1000} = 5.28 \times 10^{-4} \text{ moles}$$

$$\text{moles} = \frac{\text{mass}}{\text{Mr}}$$

$$5.28 \times 10^{-4} \times 2.5 = 1.32 \times 10^{-3} \text{ moles of } C_2O_4^{2-} \text{ in } 25 \text{ cm}^3$$

$$1.32 \times 10^{-3} \times 10 = 1.32 \times 10^{-2} \text{ moles in } 250 \text{ cm}^3$$

tricky bit here!
easy to miss!

$K_3[Fe(C_2O_4)_3] \cdot 3H_2O$ has three $C_2O_4^{2-}$ inside, therefore moles of sample is three times less! So: $\frac{1.32 \times 10^{-2}}{3} = 4.4 \times 10^{-3}$ moles

$$4.4 \times 10^{-3} \times 491.1 = 2.16 \text{ g}$$

$$\frac{2.16}{2.29} \times 100 = 94.3\%$$

Turn over ►



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]

first make up some solutions of known concentrations, and use colorimeter to measure absorbance of these. plot a graph of absorption vs concentration and then compare the sample absorption to your plotted calibration curve.

16

END OF QUESTIONS



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