OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE

CHEMISTRY

Trends and Patterns

THURSDAY 25 JANUARY 2007

2815/01

Afternoon

Time: 1 hour

Additional materials: Scientific calculator
Data Sheet for Chemistry (Inserted)

Candidate Name

Centre Number

Candidate Number

INSTRUCTIONS TO CANDIDATES

- Write your name, Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Use blue or black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Do **not** write in the bar code.
- Do **not** write outside the box bordering each page.
- WRITE YOUR ANSWER TO EACH QUESTION IN THE SPACE PROVIDED. ANSWERS WRITTEN ELSEWHERE WILL NOT BE MARKED.

INFORMATION FOR CANDIDATES

- The number of marks for each question is given in brackets [ ] at the end of each question or part question.
- You will be awarded marks for the quality of written communication where this is indicated in the question.
- You may use a scientific calculator.
- A copy of the *Data Sheet for Chemistry* is provided as an insert with this question paper.
- You are advised to show all the steps in any calculations.

FOR EXAMINER'S USE		
Qu.	Max.	Mark
1	7	
2	6	
3	20	
4	12	
TOTAL	45	

This document consists of **12** printed pages and a *Data Sheet for Chemistry*.

2 Mercury thermometers are not used in some laboratories because of the danger of mercury vapour. This vapour is very easily absorbed through the lungs into the blood.

In the blood, mercury reacts with hydrogen peroxide to form mercury(II) oxide.

$$Hg + H_2O_2 \longrightarrow HgO + H_2O$$

The mercury(II) oxide formed accumulates within organs in the body.

(a) Use oxidation numbers to show that the reaction between mercury and hydrogen peroxide is an example of both oxidation and reduction.

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..... [2]

(b) Mercury forms two ions, Hg_2^{2+} and Hg^{2+}. The table shows the electronic configuration of mercury in these ions.

ion	electronic configuration
Hg_2^{2+}	$[Xe]4f^{14}5d^{10}6s^1$
Hg^{2+}	$[Xe]4f^{14}5d^{10}$

Use the electronic configurations to explain why mercury is **not** a transition element.

.....

..... [1]

(c) Hydrogen peroxide has the following displayed formula.

H—O—O—H

(i) Draw a *'dot-and-cross'* diagram for a molecule of H_2O_2 showing only the outer shell electrons.

[1]

(ii) Use the *'dot-and-cross'* diagram to predict the H—O—O bond angle in hydrogen peroxide. Explain your answer.

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..... [2]

[Total: 6]

3 A 167 mg sample of iron reacts with a stream of dry chlorine to form 487 mg of solid **X**. The molar mass of solid **X** was determined to be 324.6 g mol^{-1}.

(a) Calculate the molecular formula of **X**.

molecular formula of **X** is ..... [3]

(b) Two properties of solid **X** are shown below.

- It melts when heated gently.
- It reacts with water to form a solution that is highly acidic.

What do these properties suggest about the structure and bonding in solid **X**?

Explain your answer.

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..... [2]

(c) A sample of iron is heated with a stream of dry hydrogen chloride. A different chloride of iron is formed that contains the Fe^{2+} ion. This chloride dissolves in water to form a pale green solution that contains the hexaaquairon(II) complex ion.

(i) Complete the electronic configuration of Fe^{2+}.

$1s^2 2s^2 2p^6$ ..... [1]

(ii) Draw the shape of the hexaaquairon(II) complex ion. Include the bond angles on your diagram.

[2]

(iii) Aqueous sodium hydroxide is added to a solution containing $Fe^{2+}(aq)$.

State what you would observe.

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Write an ionic equation, with state symbols, for the reaction.

..... [2]

(d) Aqueous hexaaquairon(III) ions react with aqueous thiocyanate ions in a ligand substitution reaction to give a complex ion with the formula $[Fe(H_2O)_5(SCN)]^{2+}$.

(i) Write an equation for this ligand substitution reaction.

..... [1]

(ii) You are provided with

- 0.100 mol dm^{-3} aqueous iron(III) chloride,
- 0.0500 mol dm^{-3} aqueous potassium thiocyanate.

Describe how you would use colorimetry to confirm the formula of the complex ion $[Fe(H_2O)_5(SCN)]^{2+}$.

..... [5]

(e) The percentage purity of a sample of manganese(IV) oxide, MnO_2, can be determined by its reaction with acidified iron(II) ions.

- Stage 1 – A sample of known mass of the impure MnO_2 is added to a conical flask.
- Stage 2 – The sample is reacted with a known excess amount of Fe^{2+} acidified with dilute sulphuric acid.
- Stage 3 – The contents of the flask are heated gently.
- Stage 4 – The cooled contents of the flask are titrated with aqueous potassium manganate(VII) in acidic conditions to find the amount of unreacted Fe^{2+}.

(i) The reduction half-equation for manganese(IV) oxide in the presence of dilute acid is shown below.

$$MnO_2(s) + 4H^+(aq) + 2e^- \longrightarrow Mn^{2+}(aq) + 2H_2O(l)$$

Construct the balanced equation for the redox reaction between $Fe^{2+}(aq)$, $MnO_2(s)$ and $H^+(aq)$.

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..... [1]

(ii) In Stage 1 and Stage 2 a student uses a 0.504 g sample of impure MnO_2 and 100 cm^3 of 0.200 mol dm^{-3} Fe^{2+}.

In Stage 4 the student determines that the amount of unreacted Fe^{2+} is 0.0123 mol.

1 mol of MnO_2 reacts with 2 mol of Fe^{2+}.

Calculate the percentage purity of the impure sample of MnO_2.

percentage purity = ... % [3]

[Total: 20]

4 In this question, one mark is available for the quality of spelling, punctuation and grammar.

The lattice enthalpy of magnesium chloride, $MgCl_2$, can be determined using a Born-Haber cycle and the following enthalpy changes.

name of process	enthalpy change / kJ mol^{-1}
enthalpy change of formation of $MgCl_2$(s)	–641
enthalpy change of atomisation of magnesium	+148
first ionisation energy of magnesium	+738
second ionisation energy of magnesium	+1451
enthalpy change of atomisation of chlorine	+123
electron affinity of chlorine	–349

- Define, using an equation with $MgCl_2$ as an example, what is meant by the term *lattice enthalpy*.
- Construct a Born-Haber cycle for $MgCl_2$, including state symbols, and calculate the lattice enthalpy of $MgCl_2$.
- Explain why the lattice enthalpy of NaBr is much less exothermic than that of $MgCl_2$.

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Answer **all** the questions.

1 Nitrogen monoxide reacts with hydrogen at 500 °C as in the equation below.

$$2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

A series of experiments was carried out to investigate the kinetics of this reaction. The results are shown in the table below.

experiment	[NO] / mol dm^{-3}	[H_2] / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.10	0.20	2.6
2	0.10	0.50	6.5
3	0.30	0.50	58.5

(a) In this question, one mark is available for the quality of spelling, punctuation and grammar.

(i) For each reactant, deduce the order of reaction. Show your reasoning.

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..... [4]

Quality of Written Communication [1]

(ii) Deduce the rate equation for this reaction.

..... [1]

(iii) Calculate the rate constant, k, for this reaction. State the units for k.

k = ... units ..... [3]

(b) Nitrogen monoxide, NO, is involved in formation of ozone at low levels and the breakdown of ozone at high levels.

(i) In the lower atmosphere, NO is produced by combustion in car engines. Ozone is then formed following the series of reactions shown below.

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

$$NO_2(g) \longrightarrow NO(g) + O(g)$$

$$O_2(g) + O(g) \longrightarrow O_3(g)$$

- Write the overall equation for this reaction sequence.
- Identify the catalyst and justify your answer.

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..... [3]

(ii) In the upper atmosphere, NO removes O_3 by the following reaction mechanism.

$$NO(g) + O_3(g) \longrightarrow NO_2(g) + O_2(g) \qquad \text{slow}$$

$$O(g) + NO_2(g) \longrightarrow NO(g) + O_2(g) \qquad \text{fast}$$

Suggest the rate equation for this process. Explain your reasoning.

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..... [2]

[Total: 14]

2 When heated, phosphorus pentachloride, PCl_5, dissociates.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

A chemist placed a mixture of the three gases into a container. The initial concentration of each gas was the same: 0.30 mol dm^{-3}. The container was left until equilibrium had been reached.

Under these conditions, $K_c = 0.245$ mol dm^{-3}.

(a) Write an expression for K_c for this equilibrium.

[1]

(b) Use the value of K_c for this equilibrium to deduce whether the concentration of each gas increases, decreases or stays the same as the mixture approaches equilibrium.

(i) Show your answer by placing a tick in the appropriate cells in the table below.

	initial concentration / mol dm^{-3}	greater than 0.30 mol dm^{-3}	less than 0.30 mol dm^{-3}	equal to 0.30 mol dm^{-3}
PCl_5	0.30			
PCl_3	0.30			
Cl_2	0.30			

[1]

(ii) Explain your deduction.

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..... [1]

(c) The chemist compressed the equilibrium mixture at constant temperature and allowed it to reach equilibrium under these new conditions.

(i) Explain what happens to the value of K_c.

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..... [1]

(ii) Explain what happened to the composition of the equilibrium mixture.

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..... [2]

(d) The chemist heated the equilibrium mixture and the equilibrium moved to the left.

(i) Explain what happens to the value of K_c.

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..... [1]

(ii) Explain what additional information this observation reveals about the reaction.

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..... [2]

(e) Phosphorus pentachloride reacts with magnesium oxide to form phosphorus(V) oxide, P_4O_{10}, and magnesium chloride.

(i) Write a balanced equation for this reaction.

..... [1]

(ii) Calculate the mass of PCl_5 needed to form 100 g of P_4O_{10} in this reaction.

mass = ... [4]

[Total: 14]

3 In sewage plants, biological activity can be reduced by increasing the pH of the water. This is achieved by adding small amounts of solid calcium hydroxide, $Ca(OH)_2$, to the sewage water.

In all parts of this question, assume that measurements have been made at 25 °C.

(a) The pH of aqueous solutions is determined by K_w.

K_w has a value of 1.0×10^{-14} mol^2 dm^{-6} at 25 °C.

(i) What name is given to K_w?

..... [1]

(ii) Write the expression for K_w.

..... [1]

(b) A chemist checked the concentration of aqueous calcium hydroxide, $Ca(OH)_2$, in the sewage water by titration with 5.00×10^{-3} mol dm^{-3} hydrochloric acid.

$$Ca(OH)_2(aq) + 2HCl(aq) \longrightarrow CaCl_2(aq) + 2H_2O(l)$$

The chemist titrated 25.0 cm^3 of the sewage water with 21.35 cm^3 of HCl to reach the endpoint of the titration.

Calculate the concentration, in mol dm^{-3}, of the calcium hydroxide in the sewage water.

concentration = ... mol dm^{-3} [3]

(c) The chemist analysed a sample of water from another part of the sewage works and he found that the calcium hydroxide concentration was 2.7×10^{-3} mol dm^{-3}.

Assume that when solid calcium hydroxide dissolves in water, its ions completely dissociate.

$$Ca(OH)_2(s) \longrightarrow Ca^{2+}(aq) + 2OH^-(aq)$$

Calculate the pH of this sample.

[3]

(d) After further treatment, the water could be used for drinking. In the drinking water produced, the OH^- concentration was 100 times greater than the H^+ concentration.

What was the pH of this drinking water?

[1]

[Total: 9]

4 'Superphosphate' fertilisers contain calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$. This compound is one of the world's most important fertilisers. When dissolved in water, $Ca(H_2PO_4)_2$ dissociates forming $H_2PO_4^-$ ions which are easily taken up by plants.

(a) Calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$, is produced by treating rock phosphate, containing $Ca_3(PO_4)_2$, with sulphuric acid, H_2SO_4.

Write a balanced equation for this reaction.

..... [1]

(b) Aqueous $H_2PO_4^-$ ions can act as a weak acid.

Write an equation to represent the dissociation of the $H_2PO_4^-$ ion.

..... [1]

(c) The $H_2PO_4^-$ ion can act as either an acid or a base.

(i) State the formula of the conjugate **base** of $H_2PO_4^-$.

..... [1]

(ii) State the formula of the conjugate **acid** of $H_2PO_4^-$.

..... [1]

(iii) A solution of calcium dihydrogenphosphate, $Ca(H_2PO_4)_2$, in water acts as a buffer solution.

Suggest, with the aid of equations, how this buffering action takes place.

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..... [3]

[Total: 7]

(b) Dilute sulphuric acid takes part in the typical acid reactions, reacting with metals, carbonates and bases.

Write balanced equations for the reaction of sulphuric acid with

a metal, ...

a carbonate, ...

a base. ..... [3]

5 **(c)** Concentrated sulphuric acid will readily oxidise halide ions to the halogen.

Equation 5.1 represents the unbalanced equation for the oxidation of iodide ions by sulphuric acid.

$$\square\ H^+ + \square\ SO_4^{2-} + \square\ I^- \rightarrow \square\ I_2 + \square\ H_2S + H_2O \qquad \textbf{equation 5.1}$$

(i) Write the oxidation numbers of sulphur and iodine in the boxes above the equation. [2]

(ii) Balance **equation 5.1**.

[1]