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CHEMISTRY
HIGHER LEVEL
PAPER 2

Tuesday 11 November 2008 (afternoon)

2 hours 15 minutes

Candidate session number

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INSTRUCTIONS TO CANDIDATES

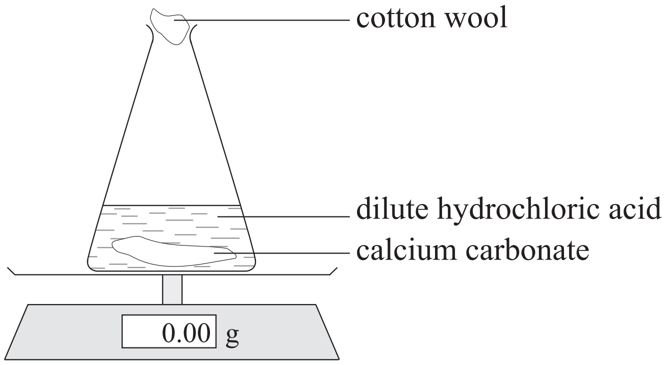
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all of Section A in the spaces provided.
- Section B: answer two questions from Section B. Write your answers on answer sheets. Write your session number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.
- At the end of the examination, indicate the numbers of the questions answered in the candidate box on your cover sheet and indicate the number of sheets used in the appropriate box on your cover sheet.

SECTION A

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

1. (a) The diagram shows the apparatus used to study the rate of reaction between calcium carbonate and hydrochloric acid.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$



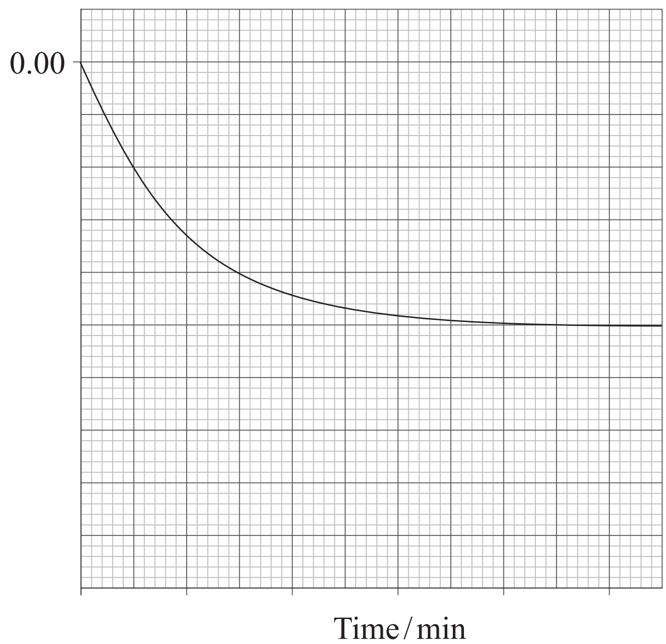
The quantities of reactants added to the flask in one experiment carried out at room temperature were:

mass of single piece of $CaCO_3(s)$ = 5.00 g

volume of 1.00 mol dm^{-3} HCl(aq) = 50.0 cm^3

The balance was set to zero at the start of the experiment.

The graph shows how the mass of the flask and contents changed during Experiment 1.



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(Question 1 continued)

(i) Explain why the mass decreased. *[1]*

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(ii) Calculate the amount, in moles, of each reactant at the start of Experiment 1. *[2]*

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(iii) Use your answers to (a) (ii), and the equation for the reaction, to deduce which reactant was added in excess. *[1]*

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(iv) The experiment was repeated with **small** pieces of calcium carbonate. Draw **two** lines (labelled 2 and 3) on the graph to show how the mass of the flask and contents changes in the following experiments at the same temperature.

Experiment	**Mass of small pieces of $CaCO_3$(s) / g**	**Volume of 1.00 mol dm^{-3} HCl (aq) / cm^3**
2	2.50	50.0
3	5.00	25.0

[4]

(This question continues on the following page)

(Question 1 continued)

(b) For the reaction between compounds **A** and **B** the initial rate was measured in a series of reactions carried out at the same temperature.

Experiment	**Initial [A] / $mol\,dm^{-3}$**	**Initial [B] / $mol\,dm^{-3}$**	**Initial rate / $mol\,dm^{-3}\,min^{-1}$**
1	4.2×10^{-2}	7.8×10^{-2}	8.8×10^{-4}
2	4.2×10^{-2}	3.9×10^{-2}	2.2×10^{-4}
3	8.4×10^{-2}	3.9×10^{-2}	2.2×10^{-4}

(i) Deduce the order of reaction with respect to **A** and to **B**, giving a reason in each case. *[2]*

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(ii) Deduce the rate expression for the reaction. *[1]*

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(iii) Use the data for Experiment 1 to determine the value, including units, of the rate constant for the reaction. *[2]*

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2. (a) Define the term *isotopes*. *[2]*

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(b) A sample of krypton contains these isotopes.

Isotope	**Percentage abundance**
^{82}Kr	15.80
^{84}Kr	65.40
^{86}Kr	18.80

(i) Calculate the relative atomic mass of krypton in this sample. Give your answer to **two** decimal places. *[2]*

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(ii) Deduce the number of each sub-atomic particle in an atom of ^{84}Kr. *[2]*

Protons . . . .

Neutrons . . . .

Electrons . . . .

(c) Krypton and xenon are in the same group of the periodic table.

(i) Complete the following to show the electron configuration of krypton. *[1]*

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

(ii) State the number of electrons in d orbitals in an atom of xenon in its ground state. *[1]*

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3. (a) The equation for the reaction that occurs when ammonia gas dissolves in water is shown below.

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

(i) Define the term *Brønsted-Lowry acid*. *[1]*

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(ii) Identify a conjugate pair present in the above equation. *[1]*

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(iii) Identify **one** species in the equation above that acts as a Lewis base and name the type of bond it forms in the reaction. *[2]*

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(b) The ionization constant expression for methylamine is shown below.

$$K_b = \frac{[CH_3NH_3^+][OH^-]}{[CH_3NH_2]} = 4.37 \times 10^{-4} \text{ mol dm}^{-3}$$

(i) Write an equation for the reaction between methylamine and water. *[1]*

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(ii) Calculate the pOH of a $0.0500 \text{ mol dm}^{-3}$ aqueous solution of methylamine. State any assumptions made in your calculation. *[4]*

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(Question 3 continued)

(iii) Calculate the pH of a buffer solution made by mixing together 0.025 mol of CH_3NH_2 and 0.010 mol of HCl in 1.0 dm^3 of solution. *[5]*

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4. Much of the hydrogen used to manufacture ammonia is made using the following reaction between methane and steam.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H^{\ominus} = +210\ \text{kJ}$$

(a) In an experiment using a nickel catalyst, 1.0 mol of methane and 2.0 mol of steam were added to a container of volume 20 dm^3 and heated to a constant temperature. When equilibrium was reached the mixture contained 0.50 mol of carbon monoxide.

(i) Calculate the amount, in moles, of each of the other substances present. *[2]*

Methane . . . .

Steam . . . .

Hydrogen . . . .

(ii) Deduce the equilibrium constant expression, K_c, for this reaction. *[1]*

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(iii) Calculate a value for K_c for this reaction and deduce its units. *[2]*

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SECTION B

*Answer **two** questions. Write your answers on the answer sheets provided. Write your session number on each answer sheet, and attach them to this examination paper and your cover sheet using the tag provided.*

5. (a) (i) Define the term *average bond enthalpy*. *[2]*

(ii) Explain why the H–H bond cannot be used as an example to illustrate average bond enthalpy. *[1]*

(b) The equation for the reaction between carbon dioxide and hydrogen is shown below.

$$CO_2(g) + 4H_2(g) \rightarrow CH_4(g) + 2H_2O(g)$$

(i) Use information from Table 10 in the Data Booklet to calculate the enthalpy change for this reaction. *[3]*

(ii) The following table shows the standard entropy values of the substances in the reaction above.

Substance	$CO_2(g)$	$H_2(g)$	$CH_4(g)$	$H_2O(g)$
$\boldsymbol{S^{\ominus}}$ **/ J K^{-1} mol^{-1}**	214	131	186	189

Calculate the standard entropy change for this reaction. *[3]*

(iii) Explain how the sign of $\Delta S^{\ominus}$ can be predicted from the equation for the reaction. *[2]*

(iv) Use your answers to parts (b) (i) and (b) (ii) to calculate the standard free energy change for the reaction, and so determine whether the above reaction is spontaneous at 298 K. (If you have not obtained answers to parts (b) (i) and (b) (ii), assume the following: $\Delta H^{\ominus} = -120$ kJ mol^{-1} and $\Delta S^{\ominus} = -80$ J K^{-1} mol^{-1}, although these are not the correct values.) *[3]*

(This question continues on the following page)

(Question 5 continued)

(c) The standard enthalpy changes for the following reactions can be found in Table 13 of the Data Booklet.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

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

$$C_8H_{18}(l) + 12\tfrac{1}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$$

Use this information to determine the standard enthalpy change for the formation of octane from its elements.

$$8C(s) + 9H_2(g) \rightarrow C_8H_{18}(l)$$ *[4]*

(d) A Born-Haber cycle can be used to calculate the lattice enthalpy of potassium fluoride, KF, from five known enthalpy changes. The equation for one of these enthalpy changes, the standard enthalpy change of formation, is shown below.

$$K(s) + \tfrac{1}{2}F_2(g) \rightarrow KF(s)$$

For each of the other **four** enthalpy changes, state the name of the enthalpy change and write an equation, including state symbols. *[4]*

(e) Lattice enthalpy values obtained from Born-Haber cycles are shown in Table 14 of the Data Booklet.

(i) Explain why sodium fluoride, NaF, has a greater lattice enthalpy value than potassium fluoride, KF. *[1]*

(ii) Explain why calcium fluoride, CaF_2, has a greater lattice enthalpy than potassium fluoride, KF. *[2]*

6. (a) The reaction between chlorine and bromide ions is a redox reaction.

$$Cl_2(g) + 2Br^-(aq) \rightarrow Br_2(aq) + 2Cl^-(aq)$$

Define the term *oxidation* in terms of electron transfer and identify the species that is oxidized in this reaction. *[2]*

(b) The oxidation number of oxygen is –2 in most compounds containing oxygen. Identify the oxidation numbers of all the other elements in both reactants and products in the following equation.

$$TiO_2(s) + 2Cl_2(g) + C(s) \rightarrow TiCl_4(l) + CO_2(g)$$ *[3]*

(c) By referring to oxidation numbers, deduce what happens, if anything, in terms of oxidation and reduction, to the named element in each of these reactions.

(i) Chromium in
$2K_2CrO_4(aq) + 2HCl(aq) \rightarrow K_2Cr_2O_7(aq) + 2KCl(aq) + H_2O(l)$ *[2]*

(ii) Chlorine in
$Cl_2(g) + H_2O(l) \rightarrow HCl(aq) + HClO(aq)$ *[2]*

(d) The table shows some reactions involving the metals **W**, **X**, **Y** and **Z**.

Reaction	**Reactants**	**Products**
1	$W + Z(NO_3)_2$	$Z + W(NO_3)_2$
2	$X + YCl_2$	no reaction
3	$Y + ZSO_4$	no reaction
4	Z + XO	X + ZO

(i) Use the information to arrange the four metals in a reactivity series, starting with the most reactive. Explain with reference to each of the metals how you decided which metal was the least reactive. *[4]*

(ii) Metal **V** forms compounds in which it has an oxidation number of +3. It is more reactive than any of the metals in the table. Predict the equation for the reaction between metal **V** and the oxide of metal **X**. *[1]*

(This question continues on the following page)

(Question 6 continued)

(e) Some standard electrode potentials are shown in Table 15 of the Data Booklet.

(i) From this table, identify a species that will reduce bromine to bromide ions but not iodine to iodide ions under standard conditions. Deduce the redox equation for the spontaneous reaction that occurs. *[2]*

(ii) Calculate the cell potential of a cell set up by connecting half-cells of aluminium and silver together under standard conditions. *[1]*

(iii) The cell potential of the cell represented below, under standard conditions is +0.48 V.

$$Zn(s) \mid Zn^{2+}(aq) \parallel Co^{2+}(aq) \mid Co(s)$$

Deduce the standard electrode potential for the following half-reaction.

$$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$$ *[1]*

(f) Water acts as a ligand when it reacts with ions of both zinc and cobalt, forming the complexes $[Zn(H_2O)_4]^{2+}$ and $[Co(H_2O)_6]^{2+}$.

(i) Explain how water acts as a ligand in the formation of these complexes and predict the shape of $[Co(H_2O)_6]^{2+}$. *[3]*

(ii) Explain why solutions containing $[Co(H_2O)_6]^{2+}$ are coloured but solutions containing $[Zn(H_2O)_4]^{2+}$ are not. *[4]*

7. (a) Several **straight-chain** organic compounds have the molecular formula $C_4H_8O_2$. Compound **A** is acidic but compounds **B**, **C** and **D** are neutral liquids with characteristic smells. None of the compounds contain C=C bonds.

(i) Deduce the structural formula and name of compound **A**. *[2]*

(ii) State the name of the functional group present in compounds **B**, **C** and **D**. *[1]*

(b) The following is a sequence of reactions starting from butane.

$$\underset{\text{butane}}{C_4H_{10}} \xrightarrow{Br_2} \underset{\mathbf{E}}{C_4H_9Br} \xrightarrow{S_N2} \underset{\substack{\mathbf{F}\\ \text{butan-2-ol}}}{C_4H_{10}O} \longrightarrow \underset{\mathbf{G}}{C_4H_8O}$$

(i) The reaction of butane with bromine involves the species Br•, but the species Br^- is formed in the S_N2 reaction. State the name of each of these species and describe the **two** types of bond fission responsible for their formation. *[3]*

(ii) State the meaning of each of the three symbols in the term S_N2. *[2]*

(iii) Use curly arrows to describe the mechanism of this S_N2 reaction. *[4]*

(iv) Some butan-2-ol (compound **F**) is also formed by an S_N1 reaction. Draw the structure of the intermediate formed in this reaction. *[1]*

(v) Deduce the structure of compound **G** and identify the reagents used in its formation. *[3]*

(vi) An isomer of compound **G** can be directly converted into compound **A**. Draw the structure of this isomer. *[1]*

(c) (i) Predict which of the compounds **E**, **F** or **G** has the highest boiling point and identify the strongest intermolecular force in this compound. *[2]*

(ii) Predict which of the compounds **E**, **F** or **G** has the lowest solubility in water, and explain your choice with reference to intermolecular forces. *[2]*

(d) The compound butan-2-ol exists as optical isomers. Describe the molecular feature responsible for this and draw 3-dimensional structures for each optical isomer, showing the relationship between them. State how separate samples of each isomer could be distinguished using plane polarized light. *[4]*

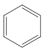
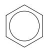
8. This question is concerned with the following compounds.

Benzene	C_6H_6
Benzoic acid	C_6H_5COOH
Cyclohexane	C_6H_{12}
Cyclohexene	C_6H_{10}
Ethyne	C_2H_2
Sodium benzoate	$C_6H_5COO^- Na^+$

The electron configuration of carbon is $1s^22s^22p^2$.

(a) Use the idea of hybridization to discuss the formation of the **two** different types of bond between carbon atoms in a molecule of ethyne. *[4]*

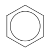
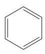
(b) Identify the **two** types of hybridization present in cyclohexene and predict the **two** different bond angles in the molecule. *[4]*

(c) The symbol  is sometimes used to represent benzene. Explain, with reference to the following data, why the symbol  is often considered to be a better way to represent benzene.

$$C_6H_{10}(g) + H_2(g) \rightarrow C_6H_{12}(g) \qquad \Delta H^\ominus = -120 \text{ kJ}$$

$$C_6H_6(g) + 3H_2(g) \rightarrow C_6H_{12}(g) \qquad \Delta H^\ominus = -208 \text{ kJ}$$

[3]

(d) Explain how the carbon-to-carbon bond lengths also support the use of the  symbol in preference to the  symbol. *[2]*

(e) (i) Discuss the bonding in the COO^- part of the benzoate ion in terms of delocalization of electrons. *[1]*

(ii) Compare the carbon-to-oxygen bond lengths in benzoic acid and in the benzoate ion. *[2]*

(f) Explain, with reference to the types of reaction and your answer to part (c), why reaction **I** is more likely to occur than reaction **II**.

I $C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl$

II $C_6H_6 + Cl_2 \rightarrow C_6H_6Cl_2$ *[2]*

(This question continues on the following page)

(Question 8 continued)

For the following questions use information from Tables 16 and 17 in the Data Booklet where relevant.

(g) A 25.0 cm^3 sample of an aqueous solution of benzoic acid needed 17.0 cm^3 of 0.0300 $mol\,dm^{-3}$ aqueous sodium hydroxide for complete neutralization.

(i) Calculate the acid dissociation constant, K_a, for benzoic acid. *[1]*

(ii) Write an equation for the neutralization reaction. *[1]*

(iii) Identify a suitable indicator for the titration and explain your choice. *[2]*

(iv) Calculate the concentration, in $mol\,dm^{-3}$, of the benzoic acid solution. *[3]*