22096114

International Baccalaureate®
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CHEMISTRY
HIGHER LEVEL
PAPER 2

Monday 18 May 2009 (afternoon)

2 hours 15 minutes

Candidate session number

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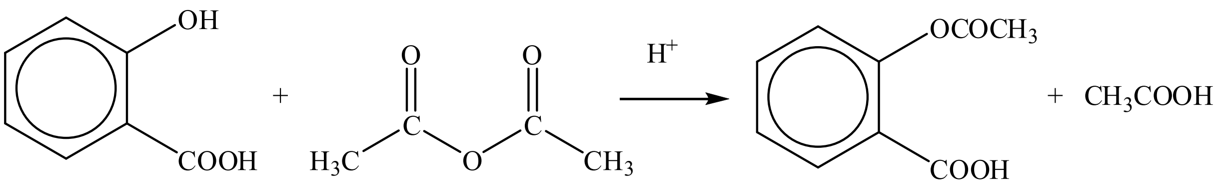
INSTRUCTIONS TO CANDIDATES

- 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. Aspirin, one of the most widely used drugs in the world, can be prepared according to the equation given below.



salicylic acid ethanoic anhydride ***aspirin*** ethanoic acid

(a) State the names of the **three** organic functional groups in aspirin. *[3]*

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(b) A student reacted some salicylic acid with excess ethanoic anhydride. Impure solid aspirin was obtained by filtering the reaction mixture. Pure aspirin was obtained by recrystallization. The following table shows the data recorded by the student.

Mass of salicylic acid used	3.15 ± 0.02 g
Mass of pure aspirin obtained	2.50 ± 0.02 g

(i) Determine the amount, in mol, of salicylic acid, $C_6H_4(OH)COOH$, used. *[2]*

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(Question 1 continued)

(ii) Calculate the theoretical yield, in g, of aspirin, $C_6H_4(OCOCH_3)COOH$. *[2]*

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(iii) Determine the percentage yield of pure aspirin. *[1]*

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(iv) State the number of significant figures associated with the mass of pure aspirin obtained, and calculate the percentage uncertainty associated with this mass. *[2]*

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(v) Another student repeated the experiment and obtained an experimental yield of 150 %. The teacher checked the calculations and found no errors. Comment on the result. *[1]*

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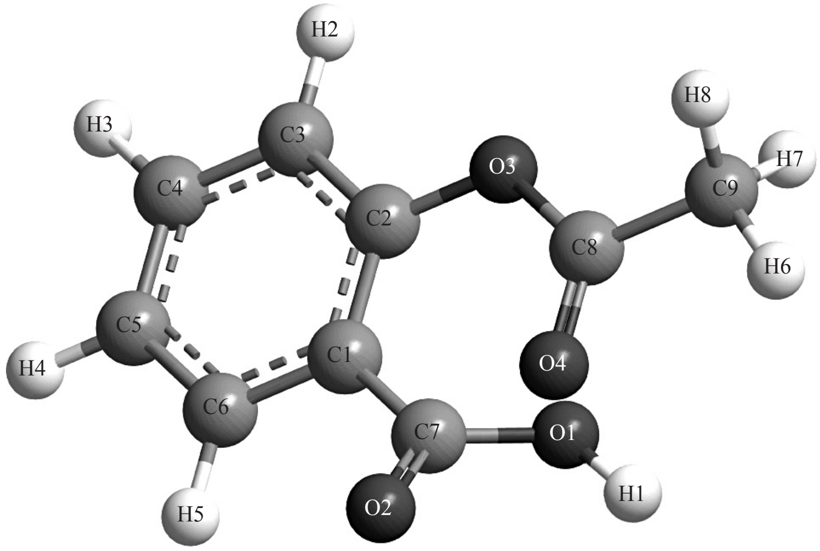
(Question 1 continued)

(vi) The following is a three-dimensional computer-generated representation of aspirin.



A third student measured selected bond lengths in aspirin, using this computer program and reported the following data.

Bond	**Bond length / $\times 10^{-10}$ m**
C1–C2	1.4
C2–C3	1.4
C3–C4	1.4
C4–C5	1.4
C5–C6	1.4
C6–C1	1.4
C2–O3	1.4

The following hypothesis was suggested by the student: "*Since all the measured carbon-carbon bond lengths are equal, all the carbon-oxygen bond lengths must also be equal in aspirin. Therefore, the C8–O4 bond length must be 1.4×10^{-10} m*". Comment on whether or not this is a valid hypothesis. *[2]*

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(Question 1 continued)

(vii) The other product of the reaction is ethanoic acid, CH_3COOH. Define an acid according to the Brønsted-Lowry theory and state the conjugate base of CH_3COOH. *[2]*

Brønsted-Lowry definition of an acid:

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Conjugate base of CH_3COOH:

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2. Some of the most important processes in chemistry involve acid-base reactions.

(a) (i) Calculate the K_a value of benzoic acid, C_6H_5COOH, using Table 15 in the Data Booklet. *[1]*

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(ii) Based on its K_a value, state and explain whether benzoic acid is a strong or weak acid. *[2]*

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(iii) Determine the hydrogen ion concentration and the pH of a 0.010 $mol\,dm^{-3}$ benzoic acid solution. State **one** assumption made in your calculation. *[4]*

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(b) Describe the acid-base character of the oxides of each of the period 3 elements, Na to Cl. *[3]*

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(c) State **one** example of an acidic gas, produced by an industrial process or the internal combustion engine, which can cause large-scale pollution to lakes and forests. *[1]*

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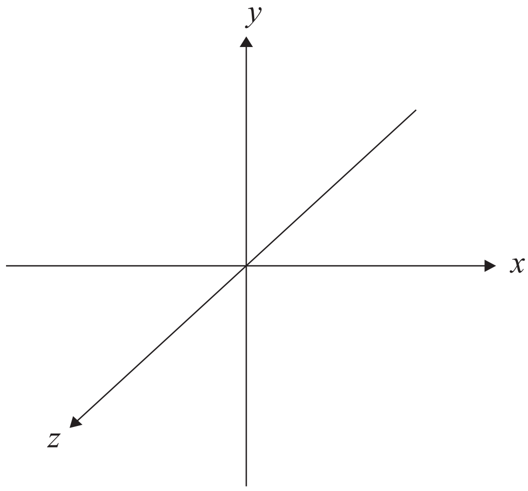
3. (a) (i) Draw the shape of the p_z orbital using the coordinates shown. *[1]*



(ii) State the electron configuration of Fe^{3+}. *[1]*

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(iii) Define the term *ligand.* *[1]*

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(iv) Explain why the complex $[Fe(H_2O)_6]^{3+}$ is coloured. *[3]*

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(v) The element selenium ($Z = 34$) has electrons in the 4s, 3d and 4p orbitals. Draw an orbital box diagram (arrow-in-box notation) to represent these electrons. *[1]*

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4. Consider the following reaction.

$$2CH_3OH(g) + H_2(g) \rightarrow C_2H_6(g) + 2H_2O(g)$$

(a) The standard enthalpy change of formation for $CH_3OH(g)$ at 298 K is –201 kJ mol^{-1} and for $H_2O(g)$ is –242 kJ mol^{-1}. Using information from Table 11 of the Data Booklet, determine the enthalpy change for this reaction. *[2]*

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(b) The standard entropy for $CH_3OH(g)$ at 298 K is 238 J K^{-1} mol^{-1}, for $H_2(g)$ is 131 J K^{-1} mol^{-1} and for $H_2O(g)$ is 189 J K^{-1} mol^{-1}. Using information from Table 11 of the Data Booklet, determine the entropy change for this reaction. *[2]*

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(c) Calculate the standard change in free energy, at 298 K, for the reaction and deduce whether the reaction is spontaneous or non-spontaneous. *[3]*

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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. Nitrogen and silicon belong to different groups in the periodic table.

(a) (i) Distinguish in terms of electronic structure, between the terms *group* and *period*. *[2]*

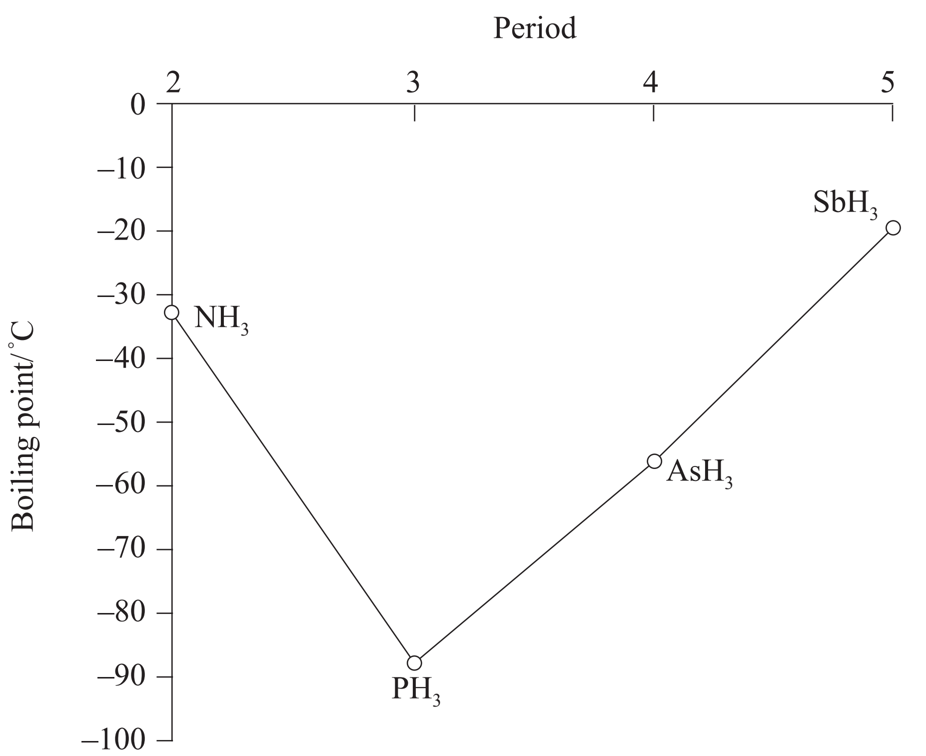
(ii) State the maximum number of orbitals in the $n = 2$ energy level. *[1]*

(b) Draw the Lewis structures, state the shapes and predict the bond angles for the following species.

(i) SiF_6^{2-} *[3]*

(ii) NO_2^+ *[3]*

(c) The graph below shows the boiling points of the hydrides of group 5. Discuss the variation in the boiling points. *[4]*



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(Question 5 continued)

(d) Explain, using diagrams, why NO_2 is a polar molecule but CO_2 is a non-polar molecule. *[3]*

(e) Describe the structure and bonding in silicon dioxide. *[2]*

(f) Consider the molecule $HCONH_2$.

(i) State the name of the compound and draw its structural formula, showing all the bonds present. *[2]*

(ii) Explain the term *hybridization*. *[1]*

(iii) Describe how σ and π bonds form. *[2]*

(iv) State the type of hybridization of the carbon and nitrogen atoms in $HCONH_2$. *[2]*

6. (a) Consider the following equilibrium.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H^{\ominus} = -198 \text{ kJ mol}^{-1}$$

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

(ii) State and explain the effect of increasing the pressure on the yield of sulfur trioxide. *[2]*

(iii) State and explain the effect of increasing the temperature on the yield of sulfur trioxide. *[2]*

(iv) State the effects of a catalyst on the forward and reverse reactions, on the position of equilibrium and on the value of K_c. *[3]*

(b) When a mixture of 0.100 mol NO, 0.051 mol H_2 and 0.100 mol H_2O were placed in a 1.0 dm^3 flask at 300 K, the following equilibrium was established.

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

At equilibrium, the concentration of NO was found to be 0.062 $mol\,dm^{-3}$. Determine the equilibrium constant, K_c, of the reaction at this temperature. *[4]*

(c) (i) Outline **two** differences between an electrolytic cell and a voltaic cell. *[2]*

(ii) Explain why solid sodium chloride does not conduct electricity but **molten** sodium chloride does. *[2]*

(iii) Molten sodium chloride undergoes electrolysis in an electrolytic cell. For each electrode deduce the half-equation and state whether oxidation or reduction takes place. Deduce the equation of the overall cell reaction including state symbols. *[5]*

(iv) Electrolysis has made it possible to obtain reactive metals such as aluminium from their ores, which has resulted in significant developments in engineering and technology. State **one** reason why aluminium is preferred to iron in many uses. *[1]*

(v) Electroplating is an important application of electrolysis. State the composition of the electrodes and the electrolyte used in the silver electroplating process. *[3]*

7. (a) (i) Define the term *rate of reaction*. *[1]*

(ii) State an equation for the reaction of magnesium carbonate with dilute hydrochloric acid. *[1]*

(iii) The rate of this reaction in (a) (ii), can be studied by measuring the volume of gas collected over a period of time. Sketch a graph which shows how the volume of gas collected changes with time. *[1]*

(iv) The experiment is repeated using a sample of hydrochloric acid with double the volume, but half the concentration of the original acid. Draw a second line on the graph you sketched in part (a) (iii) to show the results in this experiment. Explain why this line is different from the original line. *[4]*

(b) Nitrogen monoxide reacts at 1280 °C with hydrogen to form nitrogen and water. All reactants and products are in the gaseous phase.

(i) The kinetics of the reaction were studied at this temperature. The table shows the initial rate of reaction for different concentrations of each reactant.

Experiment	**[NO (g)]/ mol dm^{-3} × 10^{-3}**	**[H_2(g)]/ mol dm^{-3} × 10^{-3}**	**Initial rate/ mol dm^{-3} s^{-1} × 10^{-5}**
1	5.00	2.00	1.25
2	10.00	2.00	5.00
3	10.00	4.00	10.00

Deduce the order of the reaction with respect to NO and H_2, and explain your reasoning. *[4]*

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

(iii) Determine the value of the rate constant for the reaction from Experiment 3 and state its units. *[2]*

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(Question 7 continued)

(c) The gas-phase decomposition of dinitrogen monoxide is considered to occur in two steps.

$$\text{Step 1:}\quad N_2O(g) \xrightarrow{k_1} N_2(g) + O(g)$$

$$\text{Step 2:}\quad N_2O(g) + O(g) \xrightarrow{k_2} N_2(g) + O_2(g)$$

The experimental rate expression for this reaction is rate = $k\,[N_2O]$.

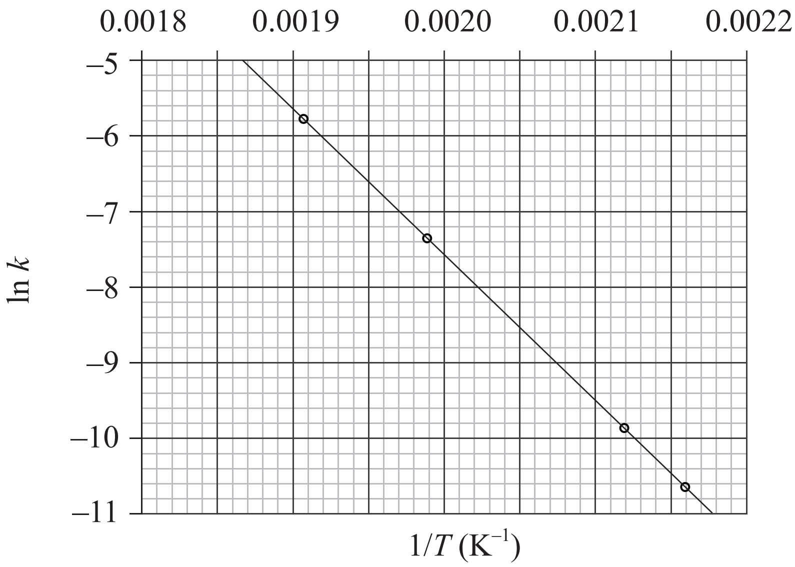
(i) Identify the rate-determining step. *[1]*

(ii) Identify the intermediate involved in the reaction. *[1]*

(d) The conversion of CH_3NC into CH_3CN is an exothermic reaction which can be represented as follows.

$$CH_3{-}N{\equiv}C \longrightarrow \text{transition state} \longrightarrow CH_3{-}C{\equiv}N$$

This reaction was carried out at different temperatures and a value of the rate constant, *k*, was obtained for each temperature. A graph of ln *k* against 1/*T* is shown below.



(i) Define the term *activation energy*, E_a. *[1]*

(ii) Construct the enthalpy level diagram and label the activation energy, E_a, the enthalpy change, ΔH, and the position of the transition state. *[3]*

(iii) Describe qualitatively the relationship between the rate constant, *k*, and the temperature, *T*. *[1]*

(iv) Calculate the activation energy, E_a, for the reaction, using Table 1 of the Data Booklet. *[4]*

8. In some countries, ethanol is mixed with gasoline (petrol) to produce a fuel for cars called gasohol.

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

(ii) Use the information from Table 10 of the Data Booklet to determine the standard enthalpy change for the complete combustion of ethanol.

$$CH_3CH_2OH(g) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$ *[3]*

(iii) The standard enthalpy change for the complete combustion of octane, C_8H_{18}, is –5471 kJ mol^{-1}. Calculate the amount of energy produced in kJ when 1 g of ethanol and 1 g of octane is burned completely in air. *[2]*

(iv) Ethanol can be oxidized using acidified potassium dichromate, $K_2Cr_2O_7$, to form two different organic products.

$$CH_3CH_2OH \xrightarrow[H^+]{Cr_2O_7^{2-}} \textbf{A} \xrightarrow[H^+]{Cr_2O_7^{2-}} \textbf{B}$$

State the structural formulas of the organic products **A** and **B** and describe the conditions required to obtain a high yield of each of them. *[4]*

(v) Ethene can be converted into ethanol by direct hydration in the presence of a catalyst according to the following equation.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$$

For this reaction, identify the catalyst used and state **one** use of the ethanol formed other than as a fuel. *[2]*

(b) Deduce a two-step synthesis for each of the following conversions. For each step, state the structural formulas of all reactants and products and state the conditions used in the reactions.

(i) Ethanol to ethyl ethanoate. *[2]*

(ii) Propene to propanone. *[2]*

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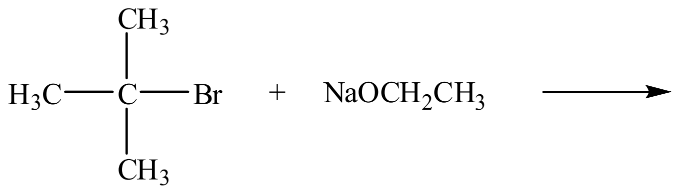
(Question 8 continued)

(c) The reagents used in an elimination reaction are shown below.



Explain the mechanism of this reaction using curly arrows to represent the movement of electron pairs. *[3]*

(d) (i) Describe *geometrical isomerism*. *[1]*

(ii) Draw the geometrical isomers of but-2-ene. *[2]*

(iii) Draw the two enantiomers of butan-2-ol. *[2]*