Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Monday 14 November 2016 (morning)

Candidate session number

2 hours 15 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[95 marks]**.

8816 – 6102

Answer **all** questions. Write your answers in the boxes provided.

1. Ethane-1,2-diol, $HOCH_2CH_2OH$, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

(a) Ethane-1,2-diol can be formed according to the following reaction.

$$2CO(g) + 3H_2(g) \rightleftharpoons HOCH_2CH_2OH(g)$$

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

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(ii) State how increasing the pressure of the reaction mixture at constant temperature will affect the position of equilibrium and the value of K_c. [2]

Position of equilibrium:

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K_c:

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(iii) Calculate the enthalpy change, $\Delta H^{\ominus}$, in kJ, for this reaction using section 11 of the data booklet. The bond enthalpy of the carbon–oxygen bond in CO(g) is $1077\,kJ\,mol^{-1}$. [3]

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(Question 1 continued)

(b) (i) Calculate $\Delta H^{\ominus}$, in kJ, for this similar reaction below using $\Delta H_f^{\ominus}$ data from section 12 of the data booklet. $\Delta H_f^{\ominus}$ of $HOCH_2CH_2OH(l)$ is $-454.8\,kJ\,mol^{-1}$. [1]

$$2CO(g) + 3H_2(g) \rightleftharpoons HOCH_2CH_2OH(l)$$

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(ii) Deduce why the answers to (a)(iii) and (b)(i) differ. [1]

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(iii) $\Delta S^{\ominus}$ for the reaction in (b)(i) is $-620.1\,J\,K^{-1}$. Comment on the decrease in entropy. [1]

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(iv) Calculate the value of $\Delta G^{\ominus}$, in kJ, for this reaction at 298 K using your answer to (b)(i). (If you did not obtain an answer to (b)(i), use –244.0 kJ, but this is not the correct value.) [2]

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(This question continues on the following page)

(Question 1 continued)

(v) Comment on the statement that the reaction becomes less spontaneous as temperature is increased. [1]

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(c) Determine the average oxidation state of carbon in ethene and in ethane-1,2-diol. [2]

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Ethane-1,2-diol:

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(d) Explain why the boiling point of ethane-1,2-diol is significantly greater than that of ethene. [2]

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(e) Ethane-1,2-diol can be oxidized first to ethanedioic acid, $(COOH)_2$, and then to carbon dioxide and water. Suggest the reagents needed to oxidize ethane-1,2-diol. [1]

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(This question continues on the following page)

(Question 1 continued)

(f) Predict the ^{1}H NMR data for ethanedioic acid and ethane-1,2-diol by completing the table. [2]

	Number of signals	Splitting pattern
Ethanedioic acid:	. . . .	. . . .
Ethane-1,2-diol:	. . . .	Not required

2. The concentration of a solution of a weak acid, such as ethanedioic acid, can be determined by titration with a standard solution of sodium hydroxide, NaOH (aq).

(a) Distinguish between a weak acid and a strong acid. [1]

Weak acid:

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Strong acid:

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(b) Suggest why it is more convenient to express acidity using the pH scale instead of using the concentration of hydrogen ions. [1]

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(c) 5.00 g of an impure sample of hydrated ethanedioic acid, $(COOH)_2 \cdot 2H_2O$, was dissolved in water to make 1.00 dm^3 of solution. 25.0 cm^3 samples of this solution were titrated against a 0.100 mol dm^{-3} solution of sodium hydroxide using a suitable indicator.

$$(COOH)_2(aq) + 2NaOH(aq) \rightarrow (COONa)_2(aq) + 2H_2O(l)$$

The mean value of the titre was 14.0 cm^3.

(i) Suggest a suitable indicator for this titration. Use section 22 of the data booklet. [1]

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(This question continues on the following page)

(Question 2 continued)

(ii) Calculate the amount, in mol, of NaOH in $14.0\,cm^3$ of $0.100\,mol\,dm^{-3}$ solution. [1]

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(iii) Calculate the amount, in mol, of ethanedioic acid in each $25.0\,cm^3$ sample. [1]

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(iv) Determine the percentage purity of the hydrated ethanedioic acid sample. [3]

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(d) Draw the Lewis (electron dot) structure of the ethanedioate ion, $^{-}OOCCOO^{-}$. [1]

(This question continues on the following page)

(Question 2 continued)

(e) Outline why all the C–O bond lengths in the ethanedioate ion are the same length and suggest a value for them. Use section 10 of the data booklet. [2]

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(f) Explain how ethanedioate ions act as ligands. [2]

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3. Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.

$$Na_2S_2O_3\,(aq) + 2HCl\,(aq) \rightarrow S\,(s) + SO_2\,(g) + 2NaCl\,(aq) + X$$

(a) Identify the formula and state symbol of X. [1]

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(b) Suggest why the experiment should be carried out in a fume hood or in a well-ventilated laboratory. [1]

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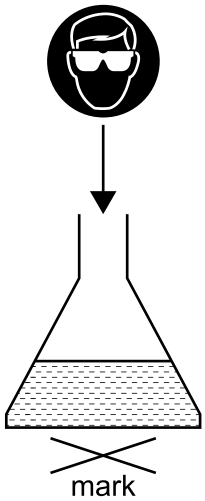
(Question 3 continued)

(c) The precipitate of sulfur makes the mixture cloudy, so a mark underneath the reaction mixture becomes invisible with time.



10.0 cm^3 of 2.00 $mol\,dm^{-3}$ hydrochloric acid was added to a 50.0 cm^3 solution of sodium thiosulfate at temperature, T_1. Students measured the time taken for the mark to be no longer visible to the naked eye. The experiment was repeated at different concentrations of sodium thiosulfate.

Experiment	**$[Na_2S_2O_3(aq)]$ / $mol\,dm^{-3}$**	**Time, t, for mark to disappear / s ± 1 s**	**$\frac{1}{t}$* / $10^{-3}\,s^{-1}$**
1	0.150	23	43.5
2	0.120	27	37.0
3	0.090	36	27.8
4	0.060	60	16.7
5	0.030	111	9.0

* The reciprocal of the time in seconds can be used as a measure of the rate of reaction.

[Source: Adapted from http://www.flinnsci.com/]

Show that the hydrochloric acid added to the flask in experiment 1 is in excess. [2]

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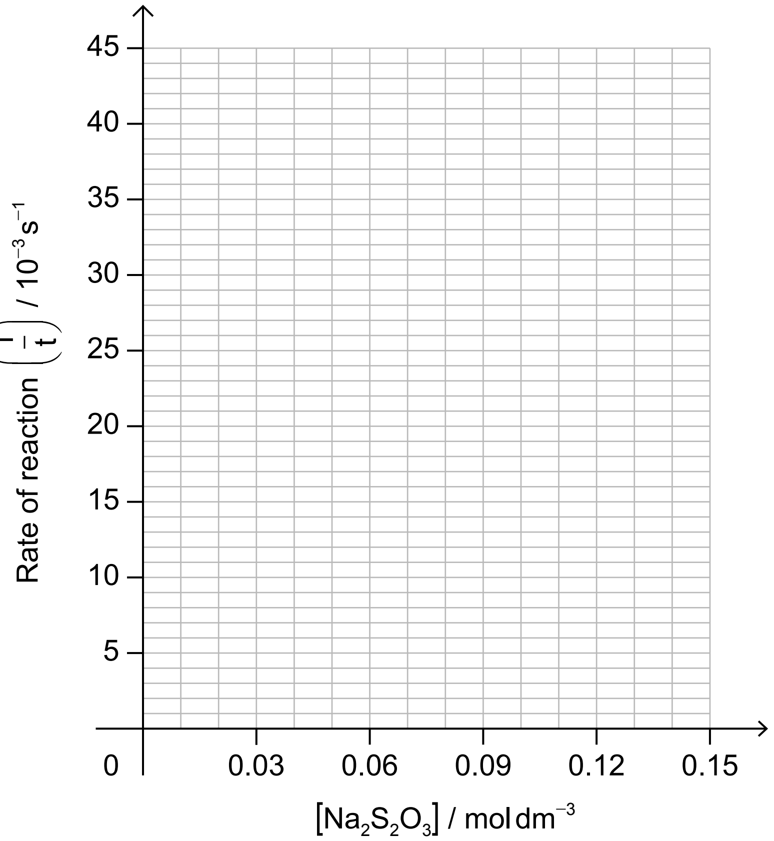
(Question 3 continued)

(d) Draw the best fit line of $\frac{1}{t}$ against concentration of sodium thiosulfate on the axes provided. [2]



(e) (i) Using the graph, explain the order of reaction with respect to sodium thiosulfate. [2]

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(Question 3 continued)

(ii) In a different experiment, this reaction was found to be first order with respect to hydrochloric acid. Deduce the overall rate expression for the reaction. [1]

(f) A student decided to carry out another experiment using 0.075 $mol\,dm^{-3}$ solution of sodium thiosulfate under the same conditions. Determine the time taken for the mark to be no longer visible. [2]

(g) An additional experiment was carried out at a higher temperature, T_2.

(i) On the same axes, sketch Maxwell–Boltzmann energy distribution curves at the two temperatures T_1 and T_2, where $T_2 > T_1$. [2]

(This question continues on the following page)

(Question 3 continued)

(ii) Explain why a higher temperature causes the rate of reaction to increase. [2]

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(h) Suggest one reason why the values of rates of reactions obtained at higher temperatures may be less accurate. [1]

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4. Magnesium is a group 2 metal which exists as a number of isotopes and forms many compounds.

(a) State the nuclear symbol notation, ${}^{A}_{Z}X$, for magnesium-26. [1]

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(b) Mass spectroscopic analysis of a sample of magnesium gave the following results:

	% abundance
Mg-24	78.60
Mg-25	10.11
Mg-26	11.29

Calculate the relative atomic mass, A_r, of this sample of magnesium to two decimal places. [2]

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(c) Magnesium ions produce no emission or absorption lines in the visible region of the electromagnetic spectrum. Suggest why most magnesium compounds tested in a school laboratory show traces of yellow in the flame. [1]

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(This question continues on the following page)

(Question 4 continued)

(d) (i) Explain the convergence of lines in a hydrogen emission spectrum. [1]

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(ii) State what can be determined from the frequency of the convergence limit. [1]

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(e) Magnesium burns in air to form a white compound, magnesium oxide. Formulate an equation for the reaction of magnesium oxide with water. [1]

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(f) Describe the trend in acid-base properties of the oxides of period 3, sodium to chlorine. [2]

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(g) In addition to magnesium oxide, magnesium forms another compound when burned in air. Suggest the formula of this compound. [1]

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(This question continues on the following page)

(Question 4 continued)

(h) Describe the structure and bonding in solid magnesium oxide. [2]

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(i) Magnesium chloride can be electrolysed.

(i) Deduce the half-equations for the reactions at each electrode when **molten** magnesium chloride is electrolysed, showing the state symbols of the products. The melting points of magnesium and magnesium chloride are 922 K and 987 K respectively. [2]

Anode (positive electrode):

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Cathode (negative electrode):

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(ii) Identify the type of reaction occurring at the cathode (negative electrode). [1]

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(iii) State the products when a very **dilute** aqueous solution of magnesium chloride is electrolysed. [2]

Anode (positive electrode):

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Cathode (negative electrode):

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(This question continues on the following page)

(Question 4 continued)

(j) Standard electrode potentials are measured relative to the standard hydrogen electrode. Describe a standard hydrogen electrode. [2]

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(k) A magnesium half-cell, $Mg(s)/Mg^{2+}(aq)$, can be connected to a copper half-cell, $Cu(s)/Cu^{2+}(aq)$.

(i) Formulate an equation for the spontaneous reaction that occurs when the circuit is completed. [1]

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(ii) Determine the standard cell potential, in V, for the cell. Refer to section 24 of the data booklet. [1]

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(iii) Predict, giving a reason, the change in cell potential when the concentration of copper ions increases. [2]

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5. Propane and propene are members of different homologous series.

(a) Draw the full structural formulas of propane and propene. [1]

Propane:

Propene:

(b) (i) Draw diagrams to show how sigma (σ) and pi (π) bonds are formed between atoms. [2]

Sigma (σ):

Pi (π):

(This question continues on the following page)

(Question 5 continued)

(ii) State the number of sigma (σ) and pi (π) bonds in propane and propene. [2]

	Number of sigma (σ) bonds	Number of pi (π) bonds
Propane	. . . .	. . . .
Propene	. . . .	. . . .

(c) Both propane and propene react with bromine.

(i) State an equation and the condition required for the reaction of 1 mol of propane with 1 mol of bromine. [2]

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(ii) State an equation for the reaction of 1 mol of propene with 1 mol of bromine. [1]

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(iii) State the type of each reaction with bromine. [1]

Propane:

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Propene:

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(Question 5 continued)

(d) Construct the mechanism of the formation of 2-bromopropane from hydrogen bromide and propene using curly arrows to denote the movement of electrons. [3]

6. One structural isomer of C_4H_9Br is a chiral molecule.

(a) Draw the three-dimensional shape of each enantiomer of this isomer showing their spatial relationship to each other. [2]

(b) When one enantiomer undergoes substitution by alkaline hydrolysis approximately 75 % of the product molecules show inversion of configuration. Comment on the mechanisms that occur. [2]

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(c) Suggest why the rate of alkaline hydrolysis of an enantiomer of iodopropane is greater than that of an enantiomer of bromopropane. [1]

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7. This question is about the weak acid methanoic acid, HCOOH.

(a) Calculate the pH of 0.0100 mol dm^{-3} methanoic acid stating any assumption you make. $K_a = 1.6 \times 10^{-4}$. [3]

Calculation:

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Assumption:

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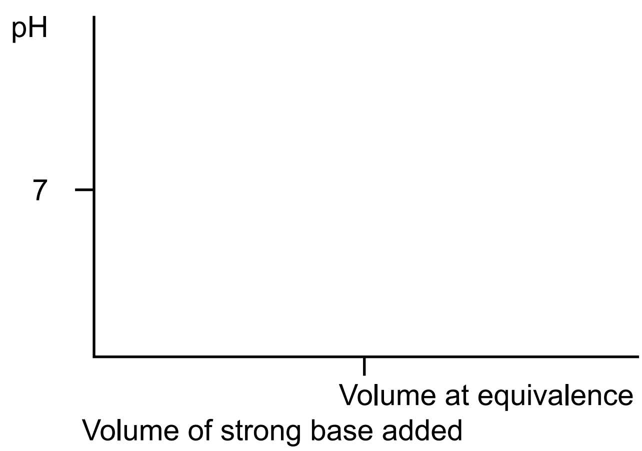
(b) (i) Sketch a graph of pH against volume of a strong base added to a weak acid showing how you would determine pK_a for the weak acid. [2]



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(Question 7 continued)

(ii) Explain, using an equation, why the pH increases very little in the buffer region when a small amount of alkali is added. [2]

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Please **do not** write on this page.

Answers written on this page
will not be marked.