Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Thursday 14 May 2015 (afternoon)

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.
- Section A: answer all questions.
- Section B: answer two 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 **[90 marks]**.

2215–6108

24 pages

Section A

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

1. Ethanedioic acid is a diprotic acid. A student determined the value of x in the formula of hydrated ethanedioic acid, HOOC–COOH•xH_2O, by titrating a known mass of the acid with a 0.100 mol dm^{-3} solution of NaOH (aq).

0.795 g of ethanedioic acid was dissolved in distilled water and made up to a total volume of 250 cm^3 in a volumetric flask.

25 cm^3 of this ethanedioic acid solution was pipetted into a flask and titrated against aqueous sodium hydroxide using phenolphthalein as an indicator.

The titration was then repeated twice to obtain the results below.

Volume of 0.100 mol dm^{-3} NaOH / cm^3	**Titration 1**	**Titration 2**	**Titration 3**
Final burette reading (± 0.05)	13.00	25.70	38.20
Initial burette reading (± 0.05)	0.00	13.00	25.70
Volume added			

(a) Calculate the average volume of NaOH added, in cm^3, in titrations 2 and 3, and then calculate the amount, in mol, of NaOH added. [2]

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(This question continues on the following page)

(Question 1 continued)

(b) (i) The equation for the reaction taking place in the titration is:

$$HOOC–COOH(aq) + 2NaOH(aq) \rightarrow NaOOC–COONa(aq) + 2H_2O(l)$$

Determine the amount, in mol, of ethanedioic acid that reacts with the average volume of NaOH (aq). [1]

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(ii) Determine the amount, in mol, of ethanedioic acid present in 250 cm^3 of the original solution. [1]

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(iii) Determine the molar mass of hydrated ethanedioic acid. [1]

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(iv) Determine the value of x in the formula $HOOC–COOH•xH_2O$. [2]

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(c) Identify the strongest intermolecular force in solid ethanedioic acid. [1]

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(This question continues on the following page)

(Question 1 continued)

(d) Deduce the Lewis (electron dot) structure of ethanedioic acid, HOOC–COOH. [1]

(e) Predict and explain the difference in carbon-oxygen bond lengths in ethanedioic acid and its conjugate base, $^{-}$OOC–COO^{-}. [3]

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2. This question is about the compounds of some period 3 elements.

(a) State the equations for the reactions of sodium oxide with water and phosphorus(V) oxide with water. [2]

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(b) (i) Explain why the melting point of phosphorus(V) oxide is lower than that of sodium oxide in terms of their bonding and structure. [2]

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(ii) Predict whether phosphorus(V) oxide and sodium oxide conduct electricity in their solid and molten states. Complete the boxes with "yes" or "no". [2]

	Phosphorus(V) oxide	**Sodium oxide**
Solid state	. . . . .	. . . . .
Molten state	. . . . .	. . . . .

(This question continues on the following page)

(Question 2 continued)

(c) Predict and explain the pH of the following aqueous solutions, using equations to support your answer. [4]

Ammonium chloride, $NH_4Cl(aq)$:

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Sodium methanoate, $HCOONa(aq)$:

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3. The rate of reaction is an important factor in industrial processes such as the Contact process to make sulfur trioxide, $SO_3(g)$.

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

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(b) Describe the collision theory. [3]

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(c) The Contact process involves this homogeneous equilibrium:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -198\,kJ$$

(i) State and explain how increasing the pressure of the reaction mixture affects the yield of SO_3. [2]

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(This question continues on the following page)

(Question 3 continued)

(ii) 2.00 mol of $SO_2(g)$ are mixed with 3.00 mol of $O_2(g)$ in a 1.00 dm^3 container until equilibrium is reached. At equilibrium there are 0.80 mol of $SO_3(g)$.

Determine the equilibrium constant (K_c) assuming all gases are at the same temperature and pressure. [4]

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(iii) State the effect of increasing temperature on the value of K_c for this reaction. [1]

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(d) Outline the economic importance of using a catalyst in the Contact process. [2]

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4. Copper is a metal that has been used by humans for thousands of years.

(a) State the full electron configuration of ^{65}Cu. [1]

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(b) State one difference in the physical properties of the isotopes ^{63}Cu and ^{65}Cu and explain why their chemical properties are the same. [2]

Physical:

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Chemical:

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(c) Describe the bonding in solid copper. [2]

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Section B

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

5. Ethanol has many industrial uses.

(a) State an equation for the formation of ethanol from ethene and the necessary reaction conditions. [3]

Equation:

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Conditions:

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

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(ii) Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in $kJ\,mol^{-1}$, using the values in table 10 of the data booklet, assuming all reactants and products are gaseous. [4]

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(Question 5 continued)

(c) Students can also measure the enthalpy of combustion of ethanol in the laboratory using calorimetry. Suggest the major source of systematic error in these procedures. [1]

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(d) State the equation for the acid-catalysed reaction of ethanol with propanoic acid and state the name of the organic product. [2]

Equation:

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Name of the organic product:

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(e) (i) A polyester can be formed when ethane-1,2-diol reacts with benzene-1,4-dicarboxylic acid.

Deduce the structure of the repeating unit and state the other product formed. [2]

Repeating unit:

Other product:

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(This question continues on the following page)

(Question 5 continued)

(ii) State the type of polymerization that occurs. [1]

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(f) (i) The standard enthalpy change of combustion, $\Delta H_c^{\ominus}$, of propanoic acid is $-1527\,kJ\,mol^{-1}$. Determine the standard enthalpy change of formation of propanoic acid, in $kJ\,mol^{-1}$, using this information and data from table 12 of the data booklet. [4]

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(ii) Deduce, giving a reason, the sign of the standard entropy change of the system for the formation of propanoic acid from its elements. [2]

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(g) Identify **three** allotropes of carbon and describe their structures. [4]

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6. Bromomethane was used as a pesticide until it was found to be ozone-depleting.

(a) State the equation for the reaction between methane and bromine to form bromomethane. [1]

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(b) (i) Explain, using equations, the complete free-radical mechanism for the reaction of methane with bromine, including necessary reaction conditions. [4]

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(ii) Bromomethane reacts with aqueous sodium hydroxide. State the organic product of this reaction. [1]

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(c) Explain why the rate of the reaction between iodomethane, CH_3I, and NaOH (aq) is faster than the rate of the reaction between CH_3Br and NaOH (aq). [2]

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(This question continues on the following page)

(Question 6 continued)

(d) (i) Bromine can be produced by the electrolysis of **molten** sodium bromide. Deduce the half-equation for the reaction at each electrode. [2]

Positive electrode (anode):

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Negative electrode (cathode):

. . . . . .

(ii) Predict the products formed at the electrodes during the electrolysis of concentrated **aqueous** sodium bromide. [2]

Positive electrode (anode):

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Negative electrode (cathode):

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(This question continues on the following page)

(Question 6 continued)

(e) Bromine reacts with aqueous sodium iodide.

$$Br_2(aq) + 2NaI(aq) \rightarrow I_2(aq) + 2NaBr(aq)$$

Identify the oxidizing agent in this reaction. [1]

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(f) (i) Define the term *standard electrode potential,* $E^{\ominus}$. [1]

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(ii) Draw a labelled diagram for the voltaic cell in which the following reaction occurs.

$$Mg(s) + Cu^{2+}(aq) \rightarrow Mg^{2+}(aq) + Cu(s)$$

Include in your answer the direction of electron flow and the polarity of the electrodes. [4]

(This question continues on the following page)

(Question 6 continued)

(iii) A student measures a voltage of 2.65 V in the voltaic cell formed between magnesium and copper half-cells using a digital voltmeter.

State the random uncertainty of this value, in V, and the number of significant figures in the answer. [2]

Random uncertainty:

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Significant figures:

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(iv) Outline how the student can reduce the random error in her results. [1]

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(g) Determine the standard enthalpy change of formation, $\Delta H_f^{\ominus}$, of NaCl (s), in kJ mol^{-1}, using a Born-Haber cycle and tables 7, 10 and 13 of the data booklet. The standard enthalpy change of atomization (standard enthalpy change of sublimation), $\Delta H_{at}^{\ominus}$, of Na (s) is +108 kJ mol^{-1}. [4]

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7. (a) (i) Ethanol is a primary alcohol that can be oxidized by acidified potassium dichromate(VI). Distinguish between the reaction conditions needed to produce ethanal and ethanoic acid. [2]

Ethanal:

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Ethanoic acid:

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(ii) Determine the oxidation number of carbon in ethanol and ethanal. [2]

Ethanol:

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Ethanal:

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(iii) Deduce the half-equation for the oxidation of ethanol to ethanal. [1]

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(iv) Deduce the overall redox equation for the reaction of ethanol to ethanal with acidified potassium dichromate(VI). [2]

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(This question continues on the following page)

(Question 7 continued)

(b) Ethanol can be made by reacting aqueous sodium hydroxide with bromoethane. Explain the mechanism for this reaction, using curly arrows to represent the movement of electron pairs. [4]

(c) (i) Determine the orders of reaction of the reactants and the overall rate expression for the reaction between 2-bromobutane and aqueous sodium hydroxide using the data in the table.

Experiment	[NaOH] / mol dm^{-3}	[C_4H_9Br] / mol dm^{-3}	Rate / mol dm^{-3} s^{-1}
1	1.00	1.00	1.66×10^{-3}
2	0.50	1.00	8.31×10^{-4}
3	0.25	0.25	1.02×10^{-4}
4	1.00	0.50	8.29×10^{-4}

[2]

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(This question continues on the following page)

(Question 7 continued)

(ii) Determine the rate constant, *k*, with its units, using the data from experiment 3. [2]

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(iii) Identify the molecularity of the rate-determining step in this reaction. [1]

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(d) 2-bromobutane exists as optical isomers.

(i) State the essential feature of optical isomers. [1]

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(ii) Outline how a polarimeter can distinguish between these isomers. [2]

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(e) Describe, using an equation, the elimination of HBr from 2-bromobutane, stating the reagent used. [2]

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(This question continues on the following page)

(Question 7 continued)

(f) Describe the formation of σ and π bonds in an alkene. [2]

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(g) The two most abundant isotopes of bromine have the mass numbers 79 and 81. Calculate the relative abundance of ^{79}Br using table 5 of the data booklet, assuming the abundance of the other isotopes is negligible. [2]

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8. Acids can be described as strong or weak.

(a) (i) Outline the difference in dissociation between strong and weak acids of the same concentration. [1]

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(ii) Describe **three** tests that can be carried out in the laboratory, and the expected results, to distinguish between $0.10\,mol\,dm^{-3}$ HCl(aq) and $0.10\,mol\,dm^{-3}$ $CH_3COOH(aq)$. [3]

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(b) Calculate the pH, using table 15 of the data booklet, of a solution of ethanoic acid made by dissolving 1.40 g of the acid in distilled water to make a $500\,cm^3$ solution. [4]

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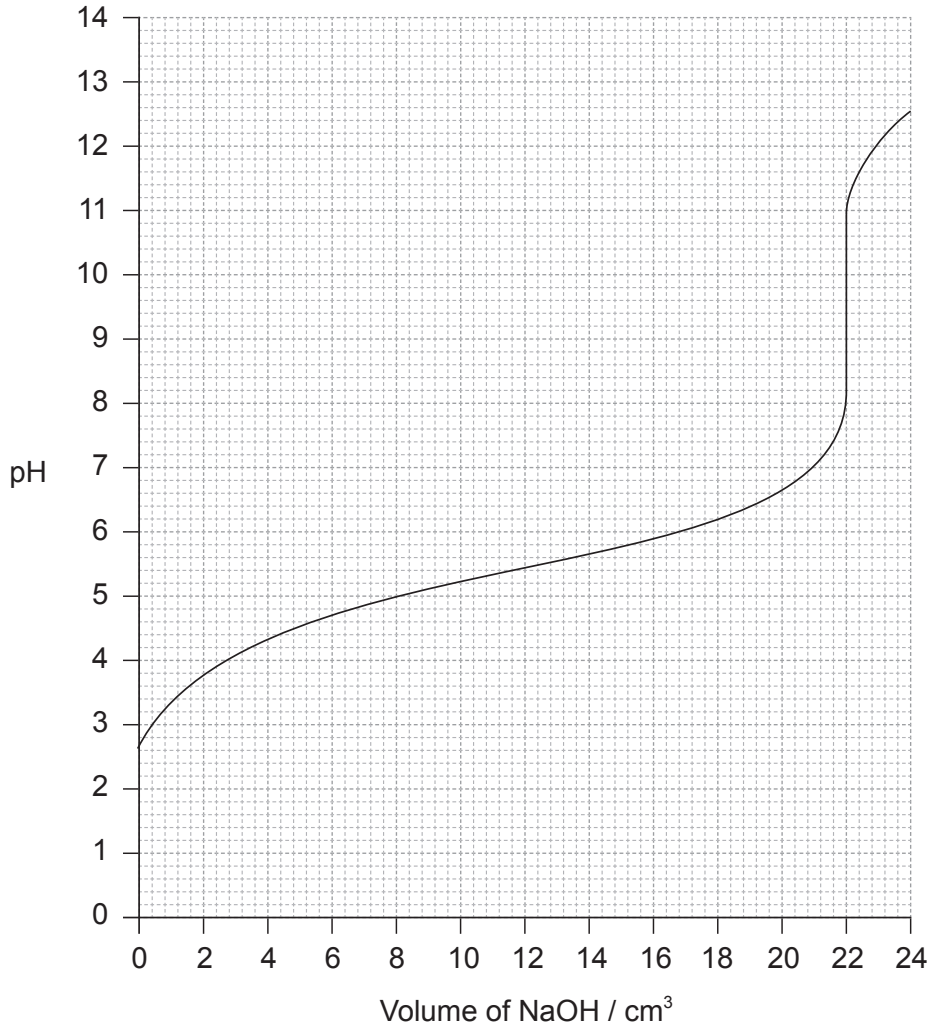
(This question continues on the following page)

(Question 8 continued)

(c) (i) Determine the pH at the equivalence point of the titration and the pK_a of an unknown acid using the acid-base titration curve below. [3]



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(ii) Identify, using table 16 of the data booklet, a suitable indicator to show the end-point of this titration. [1]

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(This question continues on the following page)

(Question 8 continued)

(iii) Describe how an indicator, that is a weak acid, works. Use Le Chatelier's principle in your answer. [2]

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(d) (i) State the formula of the conjugate base of chloroethanoic acid, $CH_2ClCOOH$. [1]

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(ii) Identify, with a reason, whether chloroethanoic acid is weaker or stronger than ethanoic acid using table 15 of the data booklet. [1]

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(This question continues on the following page)

(Question 8 continued)

(iii) Determine the pH of the solution resulting when 100 cm^3 of 0.50 mol dm^{-3} $CH_2ClCOOH$ is mixed with 200 cm^3 of 0.10 mol dm^{-3} NaOH. [4]

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(e) Describe how chlorine's position in the periodic table is related to its electron arrangement. [2]

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(f) SCl_2 and $SClF_5$ are two sulfur chloride type compounds with sulfur having different oxidation states. Predict the name of the shape, the bond angle and polarity of these molecules. [3]

Molecule	Shape	Bond angle	Polarity
SCl_2	. . . . .	. . . . .	. . . . .
$SClF_5$	. . . . .	. . . . .	. . . . .