Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Wednesday 8 November 2017 (afternoon)

Candidate session number

2 hours 15 minutes

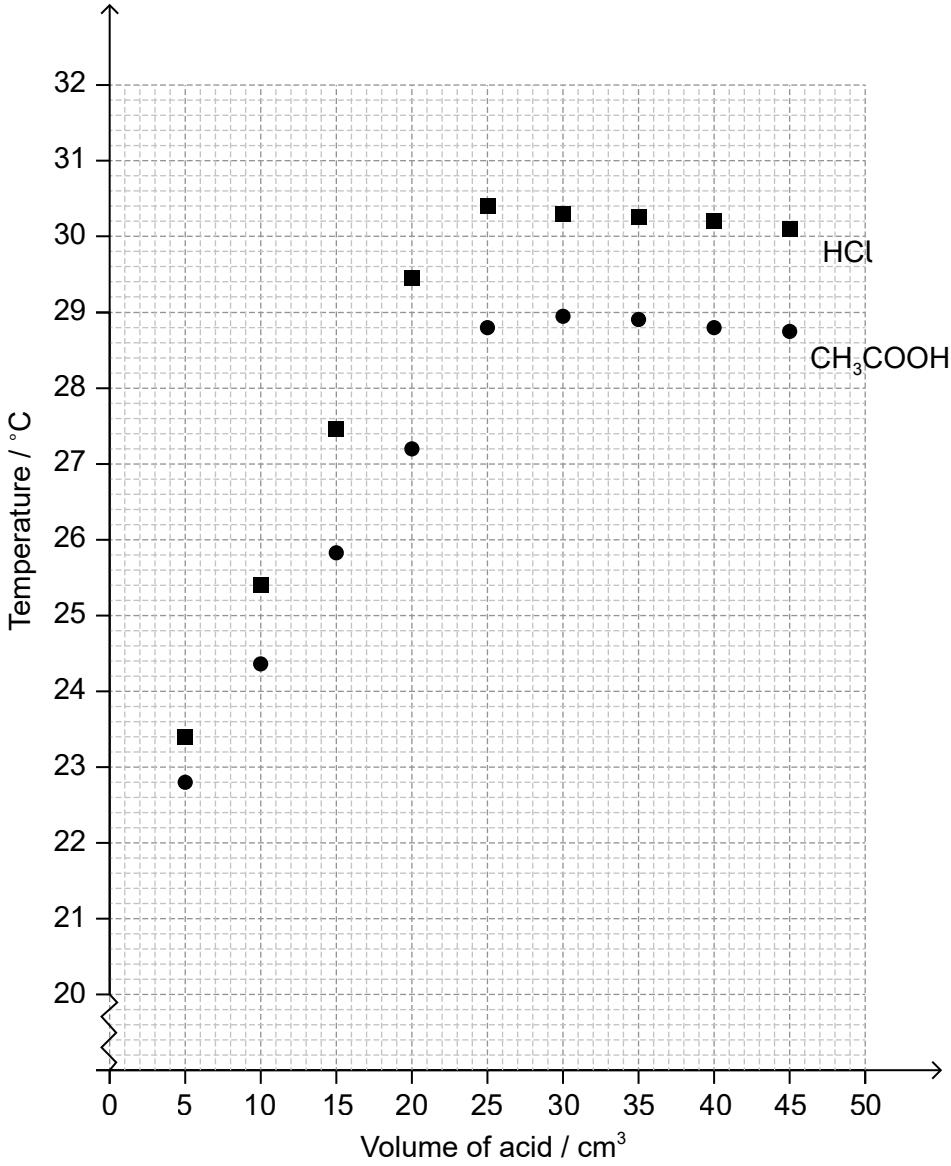
Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- 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]**.

8817 – 6102

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

1. A student titrated two acids, hydrochloric acid, HCl (aq) and ethanoic acid, CH_3COOH (aq), against 50.0 cm^3 of 0.995 mol dm^{-3} sodium hydroxide, NaOH (aq), to determine their concentration. The temperature of the reaction mixture was measured after each acid addition and plotted against the volume of each acid.



(a) Using the graph, estimate the initial temperature of the solutions. [1]

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(Question 1 continued)

(b) Determine the maximum temperature reached in each experiment by analysing the graph. [2]

HCl:

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CH_3COOH:

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(c) Calculate the concentration of ethanoic acid, CH_3COOH, in $mol\,dm^{-3}$. [2]

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(d) (i) Determine the heat change, q, in kJ, for the neutralization reaction between ethanoic acid and sodium hydroxide.
Assume the specific heat capacities of the solutions and their densities are those of water. [2]

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(ii) Calculate the enthalpy change, ΔH, in $kJ\,mol^{-1}$, for the reaction between ethanoic acid and sodium hydroxide. [2]

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(Question 1 continued)

(e) Suggest why the enthalpy change of neutralization of CH_3COOH is less negative than that of HCl. [2]

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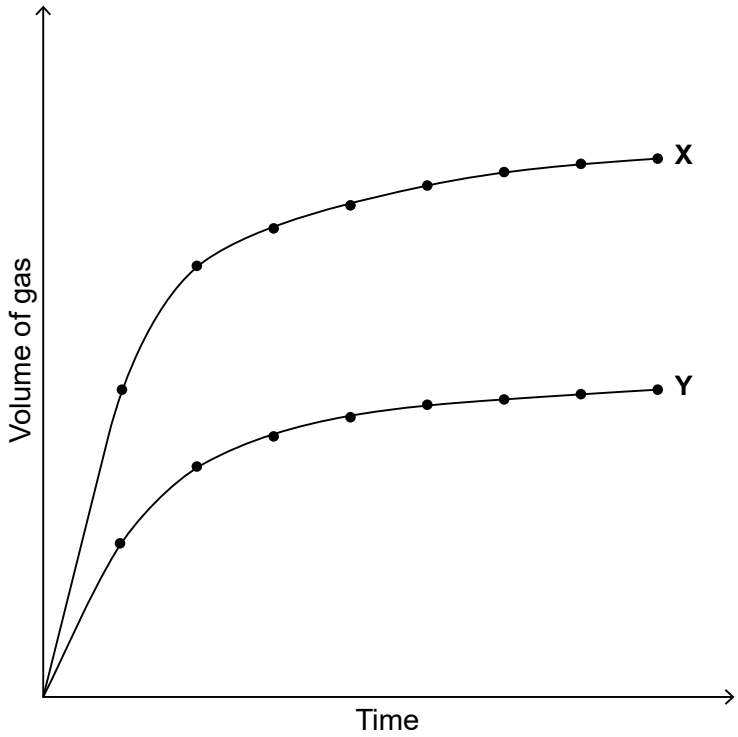
(f) Curves **X** and **Y** were obtained when a metal carbonate reacted with the same volume of ethanoic acid under two different conditions.



(i) Explain the shape of curve **X** in terms of the collision theory. [2]

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(Question 1 continued)

(ii) Suggest **one** possible reason for the differences between curves **X** and **Y**. [1]

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2. Analytical chemistry uses instruments to separate, identify, and quantify matter.

(a) Describe the emission spectrum of hydrogen. [2]

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(b) Outline how this spectrum is related to the energy levels in the hydrogen atom. [1]

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(c) A sample of magnesium has the following isotopic composition.

Isotope	^{24}Mg	^{25}Mg	^{26}Mg
Relative abundance / %	78.6	10.1	11.3

Calculate the relative atomic mass of magnesium based on this data, giving your answer to **two** decimal places. [2]

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(This question continues on the following page)

(Question 2 continued)

(d) Menthol is an organic compound containing carbon, hydrogen and oxygen.

(i) Complete combustion of 0.1595 g of menthol produces 0.4490 g of carbon dioxide and 0.1840 g of water. Determine the empirical formula of the compound showing your working. [3]

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(ii) 0.150 g sample of menthol, when vaporized, had a volume of 0.0337 dm^3 at 150°C and 100.2 kPa. Calculate its molar mass showing your working. [2]

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(iii) Determine the molecular formula of menthol using your answers from parts (d)(i) and (ii). [1]

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(This question continues on the following page)

(Question 2 continued)

(e) Nitric oxide reacts with chlorine.

$$2NO(g) + Cl_2(g) \rightarrow 2NOCl(g)$$

The following experimental data were obtained at 101.3 kPa and 263 K.

Experiment	Initial [NO] / $mol\,dm^{-3}$	Initial [Cl_2] / $mol\,dm^{-3}$	Initial rate / $mol\,dm^{-3}\,min^{-1}$
1	1.30×10^{-1}	1.30×10^{-1}	3.95×10^{-1}
2	1.30×10^{-1}	2.60×10^{-1}	7.90×10^{-1}
3	2.60×10^{-1}	2.60×10^{-1}	3.16

(i) Deduce the order of reaction with respect to Cl_2 and NO. [2]

Cl_2:

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NO:

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

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(iii) Calculate the value of the rate constant at 263 K. [1]

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3. Trends in physical and chemical properties are useful to chemists.

(a) Explain the general increasing trend in the first ionization energies of the period 3 elements, Na to Ar. [2]

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(b) Explain why the melting points of the group 1 metals (Li $\rightarrow$ Cs) decrease down the group whereas the melting points of the group 17 elements (F $\rightarrow$ I) increase down the group. [3]

Group 1:

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Group 17:

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(Question 3 continued)

(c) State an equation for the reaction of phosphorus(V) oxide, $P_4O_{10}(s)$, with water. [1]

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(d) Cobalt forms the transition metal complex $[Co(NH_3)_4(H_2O)Cl]Br$.

(i) State the shape of the complex ion. [1]

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(ii) Deduce the charge on the complex ion and the oxidation state of cobalt. [2]

Charge on complex ion:

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Oxidation state of cobalt:

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(e) Describe, in terms of acid-base theories, the type of reaction that takes place between the cobalt ion and water to form the complex ion. [2]

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4. Lewis (electron dot) structures are useful models.

(a) Draw the Lewis (electron dot) structures of PF_3 and PF_5 and use the VSEPR theory to deduce the molecular geometry of each species including bond angles. [6]

	PF_3	PF_5
Lewis (electron dot) structure		
Molecular geometry	. . . . .	. . . . .
Bond angles	. . . . .	. . . . .

(b) Predict whether the molecules PF_3 and PF_5 are polar or non-polar. [1]

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(c) State the type of hybridization shown by the phosphorus atom in PF_3. [1]

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5. Ethane-1,2-diol, $HOCH_2CH_2OH$, reacts with thionyl chloride, $SOCl_2$, according to the reaction below.

$$HOCH_2CH_2OH(l) + 2SOCl_2(l) \rightarrow ClCH_2CH_2Cl(l) + 2SO_2(g) + 2HCl(g)$$

(a) Calculate the standard enthalpy change for this reaction using the following data. [2]

	$HOCH_2CH_2OH(l)$	$SOCl_2(l)$	$ClCH_2CH_2Cl(l)$	$SO_2(g)$	$HCl(g)$
$\Delta H_f^\ominus$ / kJ mol^{-1}	–454.7	–245.7	–165.2	–296.9	–92.3

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(b) Calculate the standard entropy change for this reaction using the following data. [1]

	$HOCH_2CH_2OH(l)$	$SOCl_2(l)$	$ClCH_2CH_2Cl(l)$	$SO_2(g)$	$HCl(g)$
$S^\ominus$ / J K^{-1} mol^{-1}	166.9	278.6	208.5	248.1	186.8

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(c) The standard free energy change, $\Delta G^\ominus$, for the above reaction is –103 kJ mol^{-1} at 298 K. Suggest why $\Delta G^\ominus$ has a large negative value considering the sign of $\Delta H^\ominus$ in part (a). [2]

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6. Many reactions are in a state of equilibrium.

(a) The following reaction was allowed to reach equilibrium at 761 K.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H^{\ominus} < 0$$

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

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(ii) The following equilibrium concentrations in mol dm^{-3} were obtained at 761 K.

$[H_2(g)]$	$[I_2(g)]$	$[HI(g)]$
8.72×10^{-4}	2.72×10^{-3}	1.04×10^{-2}

Calculate the value of the equilibrium constant at 761 K. [1]

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(iii) Determine the value of $\Delta G^{\ominus}$, in kJ, for the above reaction at 761 K using section 1 of the data booklet. [1]

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(Question 6 continued)

(iv) Outline the effect, if any, of each of the following changes on the position of equilibrium, giving a reason in each case. [2]

	Effect	Reason
Increasing the volume, at constant temperature	. . . . .	. . . . .
Increasing the temperature, at constant pressure	. . . . .	. . . . .

(b) The equations for two acid-base reactions are given below.

$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$$
$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$$

(i) Identify two different amphiprotic species in the above reactions. [1]

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(ii) State what is meant by the term conjugate base. [1]

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(iii) State the conjugate base of the hydroxide ion, OH^-. [1]

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(This question continues on the following page)

(Question 6 continued)

(c) The pH of 0.010 mol dm^{-3} carbonic acid, $H_2CO_3(aq)$, is 4.17 at 25 °C.

$$H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq).$$

(i) Calculate $[H_3O^+]$ in the solution and the dissociation constant, K_a, of the acid at 25 °C. [3]

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(ii) Calculate K_b for HCO_3^- acting as a base. [1]

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(d) A student working in the laboratory classified HNO_3, H_2SO_4, H_3PO_4 and $HClO_4$ as acids based on their pH. He hypothesized that "all acids contain oxygen and hydrogen". Evaluate his hypothesis. [2]

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7. Consider the following half-cell reactions and their standard electrode potentials.

	$E^{\ominus}$ / V
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	−1.18
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.26
$I_2(aq) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54

(a) Deduce a balanced equation for the overall reaction when the standard nickel and iodine half-cells are connected. [1]

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(b) Predict, giving a reason, the direction of movement of electrons when the standard nickel and manganese half-cells are connected. [2]

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(c) Calculate the cell potential, in V, when the standard iodine and manganese half-cells are connected. [1]

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(d) Identify the best reducing agent in the table above. [1]

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(Question 7 continued)

(e) State and explain the products of electrolysis of a concentrated aqueous solution of sodium chloride using inert electrodes. Your answer should include half-equations for the reaction at each electrode. [4]

Positive electrode (anode):

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Negative electrode (cathode):

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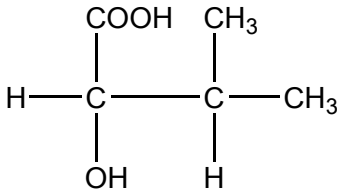
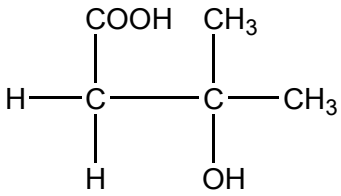
8. The reactivity of organic compounds depends on the nature and positions of their functional groups.

(a) The structural formulas of two organic compounds are shown below.



A



B

(i) Deduce the type of chemical reaction and the reagents used to distinguish between these compounds. [1]

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(This question continues on the following page)

(Question 8 continued)

(ii) State the observation expected for each reaction giving your reasons. [2]

Compound **A**:

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Compound **B**:

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(iii) Deduce the number of signals and the ratio of areas under the signals in the ^{1}H NMR spectra of the two compounds. [4]

Compound	Number of signals	Ratio of areas
A	. . . . .	. . . . .
B	. . . . .	. . . . .

(iv) Deduce, giving a reason, which of the two compounds can show optical activity. [1]

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(This question continues on the following page)

(Question 8 continued)

(v) Draw three-dimensional representations of the two enantiomers. [1]

(b) Explain, with the help of equations, the mechanism of the free-radical substitution reaction of ethane with bromine in presence of sunlight. [4]

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(c) State the reagents used in the nitration of benzene. [1]

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(d) State an equation for the formation of NO_2^+. [1]

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(Question 8 continued)

(e) Explain the mechanism of the reaction between 2-bromo-2-methylpropane, $(CH_3)_3CBr$, and aqueous sodium hydroxide, NaOH(aq), using curly arrows to represent the movement of electron pairs. [4]

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Answers written on this page
will not be marked.