Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

12 May 2023

Zone A afternoon | **Zone B** morning | **Zone C** 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.
- Answers must be written within the answer 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]**.

25 pages

2223–6114

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Answers written on this page
will not be marked.

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Analytical and spectroscopic techniques enable chemists to identify and determine structures of compounds.

(a) An unknown organic compound, **X**, comprising of only carbon, hydrogen and oxygen was found to contain 48.6 % of carbon and 43.2 % of oxygen.

(i) Determine the empirical formula. [3]

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The mass spectrum of **X** is shown.

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(ii) Identify fragments responsible for the peaks at *m/z* 74 and 45 using section 28 of the data booklet. [2]

m/z 74: . . . . . .

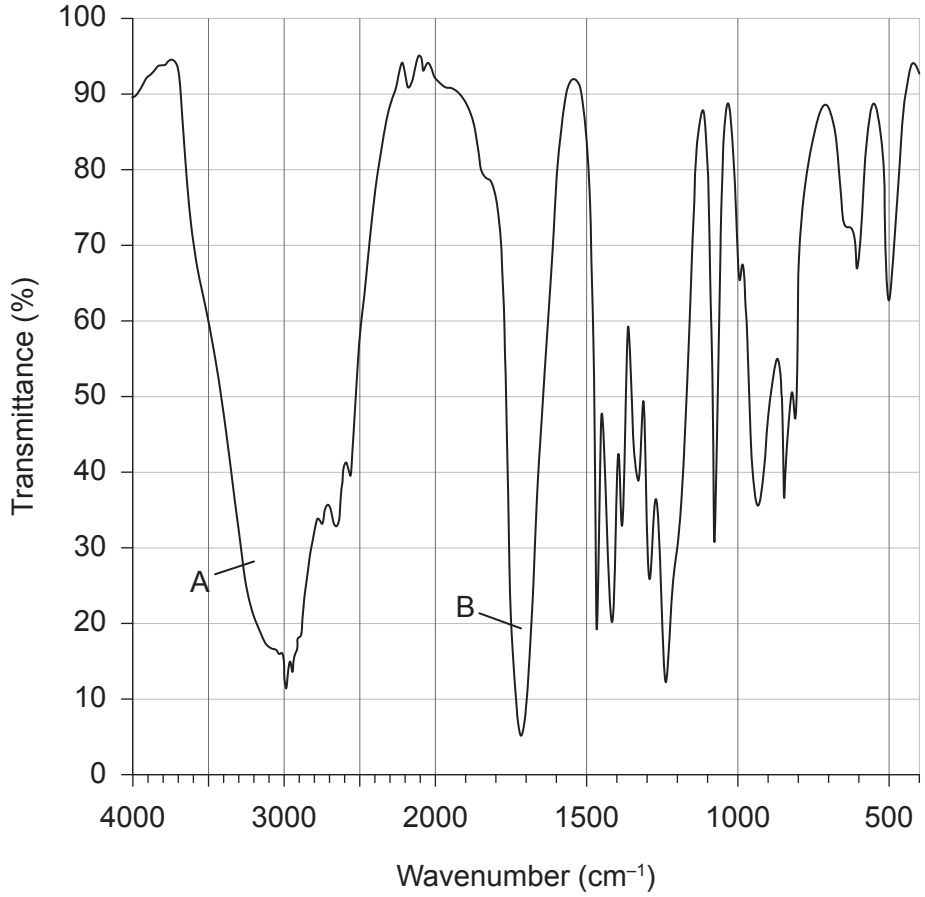
m/z 45: . . . . . .

(This question continues on the following page)

(Question 1 continued)

The infrared spectrum of **X** is shown.

Infrared spectrum of X



(iii) Identify the bonds making the major contribution to peaks A and B using section 26 of the data booklet. [2]

A: . . . . . .

B: . . . . . .

(This question continues on the following page)

(Question 1 continued)

(iv) Deduce the structural formula of **X**. [1]

(b) 0.363 g of organic liquid **Y** was vaporized completely at 95.0 °C and 100.0 kPa. The gas volume was measured to be 81.0 cm^3. Determine the molar mass of **Y**. [3]

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2. Nitrogen (IV) oxide, NO_2, is a brown gas found in photochemical smog and has a pollutant causing acid deposition.

(a) Nitrogen (IV) oxide exists in equilibrium with dinitrogen tetroxide, $N_2O_4(g)$, which is colourless.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

(i) At 100 °C K_c for this reaction is 0.0665. Outline what this indicates about the extent of this reaction. [1]

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(ii) Calculate the Gibbs free energy change, $\Delta G^{\ominus}$, for this equilibrium at 100 °C. Use sections 1 and 2 of the data booklet. [1]

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(iii) Calculate the value of K_c at 100 °C for the equilibrium: [1]

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

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(This question continues on the following page)

(Question 2 continued)

(iv) Calculate the standard enthalpy change, in kJ mol^{-1}, for the reaction: [1]

$$N_2O_4(g) \rightarrow 2NO_2(g)$$

	$\Delta H^{\ominus}_f$ (kJ mol^{-1})
NO_2	33.18
N_2O_4	9.16

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(v) Calculate the standard entropy change, in J mol^{-1}, for the reaction: [1]

$$N_2O_4(g) \rightarrow 2NO_2(g)$$

	$S^{\ominus}$ (J mol^{-1})
NO_2	240.06
N_2O_4	304.29

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(This question continues on the following page)

(Question 2 continued)

(b) Deduce the Lewis structure of N_2O_4. [1]

(c) The NO bond lengths in N_2O_4 are all 1.19×10^{-10} m.

(i) Suggest what the bond lengths indicate about the structure of N_2O_4. [1]

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(ii) Predict the ONN bond angle in N_2O_4. [1]

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(d) Acid deposition is formed when nitrogen oxides dissolve in water. Write an equation for nitrogen (IV) oxide reacting with water to produce two acids. [1]

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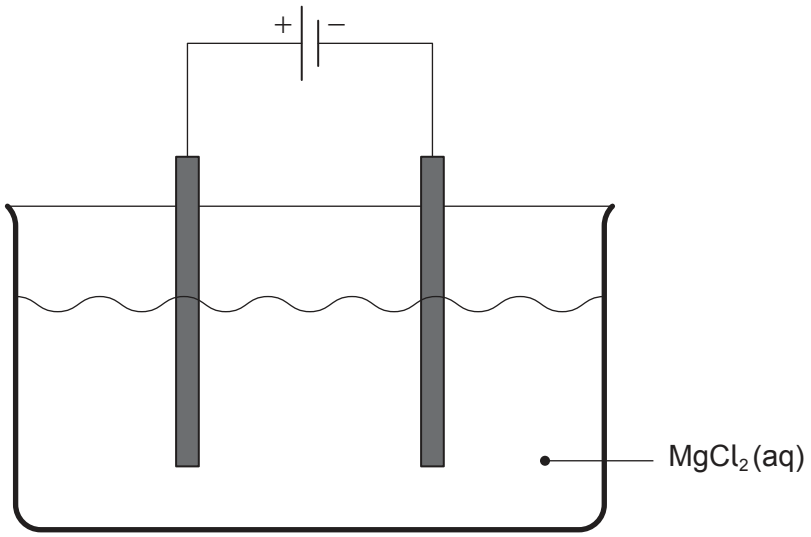
3. Electrolysis and Winkler titrations are both applications of redox reactions.

(a) An electrolytic cell was set up using inert electrodes and a dilute aqueous solution of magnesium chloride, $MgCl_2(aq)$.

(i) Annotate the diagram to show the movement of particles that conduct electricity in this cell. [2]



(ii) Deduce the half-equation for the reaction at each electrode. Use section 24 of the data booklet. [2]

Positive electrode: . . . . . .

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Negative electrode: . . . . . .

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(iii) Graphite rods are sometimes used as inert electrodes. Describe the structure of graphite and explain why graphite conducts electricity. [2]

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(Question 3 continued)

(b) Winkler titrations can be used to determine the biochemical oxygen demand, BOD, of a water sample. One set of equations for the reactions occurring is:

$$2Mn^{2+}(aq) + O_2(aq) + 4OH^- \rightarrow 2MnO(OH)_2(s)$$

$$MnO(OH)_2(s) + 2I^-(aq) + 4H^+ \rightarrow Mn^{2+}(aq) + I_2(aq) + 3H_2O$$

$$I^-(aq) + I_2(aq) \rightarrow I_3^-(aq)$$

$$2S_2O_3^{2-}(aq) + I_3^-(aq) \rightarrow S_4O_6^{2-}(aq) + 3I^-(aq)$$

150 cm^3 of a water sample was tested using a Winkler titration. 36.0 cm^3 of 0.00500 mol dm^{-3} sodium thiosulfate solution, $Na_2S_2O_3(aq)$, was required to reach the end point.

(i) Determine the concentration, in mol dm^{-3}, of oxygen dissolved in the water sample. [3]

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(ii) Outline how the BOD of the water sample could be determined. [2]

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(iii) Suggest what a low BOD value indicates about a water sample. [1]

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4. The periodic table provides information about electron configuration, and physical and chemical properties of elements.

(a) Bismuth has atomic number 83. Deduce **two** pieces of information about the electron configuration of bismuth from its position on the periodic table. [2]

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(b) Outline why aluminium is malleable. [1]

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(c) An 11.98 g block of pure aluminium was heated. Calculate the heat energy absorbed, in J, to increase its temperature from 18.0 °C to 40.0 °C. The specific heat capacity of aluminium is 0.902 J g^{-1} K^{-1}. [1]

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(Question 4 continued)

(d) Argon has three naturally occurring isotopes, ^{36}Ar, ^{38}Ar and ^{40}Ar.

(i) Identify the technique used to determine the relative proportions of the isotopes of argon. [1]

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The isotopic composition of a sample of argon is 0.34 % of ^{36}Ar, 0.06 % of ^{38}Ar and 99.6 % of ^{40}Ar.

(ii) Calculate the relative atomic mass of this sample, giving your answer to two decimal places. [2]

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5. Methanoic acid is a monoprotic weak acid.

(a) The concentration of methanoic acid was found by titration with a 0.200 mol dm^{-3} standard solution of sodium hydroxide, NaOH(aq), using an indicator to determine the end point.

(i) Calculate the pH of the sodium hydroxide solution. [2]

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(ii) Write an equation for the reaction of methanoic acid with sodium hydroxide. [1]

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(iii) 22.5 cm^3 of NaOH(aq) neutralized 25.0 cm^3 of methanoic acid. Determine the concentration of the methanoic acid. [1]

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(This question continues on the following page)

(Question 5 continued)

(iv) Calculate the pH of the original solution of methanoic acid. Use your answer to (a)(iii) and section 21 of the data booklet. If you did not get an answer to (a)(iii) use 0.300 mol dm^{-3}, but this is not the correct answer. [2]

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(v) Identify, giving a reason, a suitable indicator for this titration. Use section 22 of the data booklet. [2]

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(b) Write an ionic equation to show why a solution of sodium methanoate does not have a pH of 7. [1]

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6. Bromine, $Br_2(l)$, and methanoic acid, $HCOOH(aq)$, react in the presence of sulfuric acid.

$$Br_2(l) + HCOOH(aq) \rightarrow 2HBr(aq) + CO_2(g)$$

(a) Suggest an experimental method that could be used to determine the rate of reaction. [2]

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(b) The sulfuric acid is a catalyst in this reaction. Explain how a catalyst increases the reaction rate. [2]

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(c) Methanoic acid can react with ethanol to produce an ester.

(i) Draw the full structural formula of the organic product and state its name. [2]

Structural formula:

Name: . . . . . .

(This question continues on the following page)

(Question 6 continued)

(ii) Predict the number of signals, and their splitting patterns, in the ^{1}H NMR spectrum of this organic product. [2]

Number of signals: . . . . . .

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Splitting patterns: . . . . . .

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(iii) State **one** reason why tetramethylsilane, TMS, is often chosen as an internal reference standard for the calibration of ^{1}H NMR spectroscopy. [2]

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(d) (i) Write the equation for the complete combustion of ethanol. [1]

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(ii) Determine the enthalpy change for the combustion of ethanol, in kJ mol^{-1}, using section 11 of the data booklet. [3]

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7. Hydrogen bromide, HBr, reacts with but-1-ene.

(a) Identify the type of reaction. [1]

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(b) Two products are possible.

(i) Explain the mechanism for the formation of the major product, using curly arrows to indicate the movement of electron pairs. [4]

(ii) Explain why the mechanism results in one product being formed in greater quantities than the other. [2]

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(Question 7 continued)

(c) Draw the structure of a section of a polymer formed from **three** monomers of but-1-ene. [1]

(d) Deduce the hybridization of the first **two** carbon atoms in but-1-ene. [1]

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(e) Describe the bonding between the first two carbon atoms in but-1-ene in terms of orbitals on these atoms. [3]

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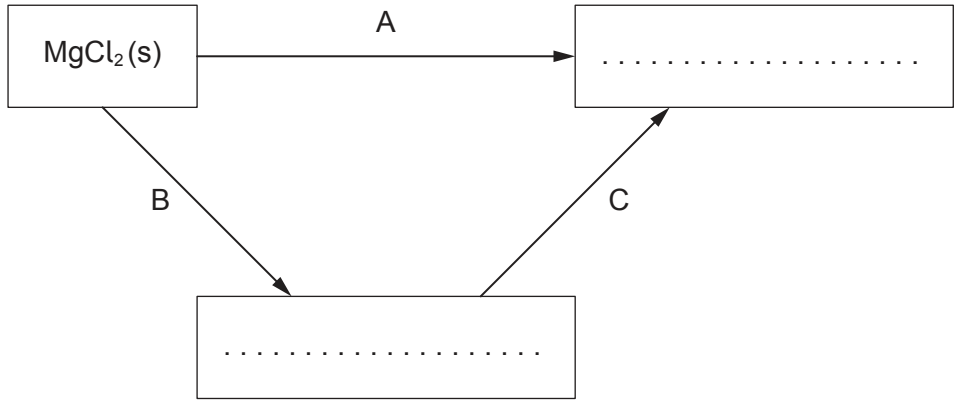
(Question 7 continued)

(f) One isomer of C_4H_9Br can exist as stereoisomers. Draw the three-dimensional structures of the **two** stereoisomers using wedge-dash notation, clearly showing the relationship between them. [2]

8. Solid ionic compounds form crystal lattices.

(a) Enthalpy of solution, enthalpy of hydration and lattice enthalpy are related in an energy cycle.

(i) Annotate the energy cycle for the enthalpy of solution of solid magnesium chloride, $MgCl_2(s)$, by naming the processes A, B and C and completing the boxes. Include state symbols. [2]



A: . . . . . .

B: . . . . . .

C: . . . . . .

(ii) Calculate the enthalpy of solution for magnesium chloride, $MgCl_2$. Use sections 18 and 20 of the data booklet. [1]

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(This question continues on the following page)

(Question 8 continued)

(b) Explain why the lattice enthalpy of barium chloride, $BaCl_2$, is lower than that of magnesium chloride. [2]

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(Question 8 continued)

(c) Cobalt also forms chlorides with the formula $CoCl_2$.

(i) State the full electron configuration of the cobalt(II) ion, Co^{2+}. [1]

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(ii) Hydrated cobalt(II) ions, $Co(H_2O)_6^{2+}$, are pink. Describe the interaction between the cobalt ion and a water molecule in terms of the type of bond and how this bond is formed. [2]

Type of bond: . . . . . .

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How the bond forms: . . . . . .

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$CoCl_4^{2-}$ ions are blue.

(iii) Explain why the different ligands cause different coloured complexes. [2]

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9. The initial rate of reaction was determined for the reaction between bromide ions, $Br^-(aq)$, and bromate ions, $BrO_3^-(aq)$, in acidic solution.

$$5Br^-(aq) + BrO_3^-(aq) + 6H^+(aq) \rightarrow 3Br_2(aq) + 3H_2O(l)$$

Four trials were carried out and the results are given in the following table.

Experiment	$[BrO_3^-]$ (mol dm^{-3})	$[Br^-]$ (mol dm^{-3})	$[H^+]$ (mol dm^{-3})	Initial rate (mol dm^{-3} s^{-1})
1	0.050	0.250	0.300	2.13×10^{-6}
2	0.050	0.250	0.600	8.60×10^{-6}
3	0.100	0.250	0.600	17.2×10^{-6}
4	0.050	0.500	0.300	4.26×10^{-6}

(a) Deduce the overall rate equation. [2]

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(b) The rate of a reaction at 50 °C is three times the rate at 25 °C. Calculate the activation energy, in kJ mol^{-1}, for this reaction using sections 1 and 2 of the data booklet. [2]

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References:

1.(a)(iii) SDBS, National Institute of Advanced Industrial Science and Technology.

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