Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Wednesday 18 May 2022 (afternoon)

2 hours 15 minutes

Candidate session number

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]**.

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20 pages

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

1. Lithium reacts with water to form an alkaline solution.

(a) Determine the coefficients that balance the equation for the reaction of lithium with water. [1]

. . . $Li(s)$ + . . . $H_2O(l)$ → . . . $LiOH(aq)$ + . . . $H_2(g)$

(b) A 0.200 g piece of lithium was placed in 500.0 cm^3 of water.

(i) Calculate the molar concentration of the resulting solution of lithium hydroxide. [2]

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(ii) Calculate the volume of hydrogen gas produced, in cm^3, if the temperature was 22.5 °C and the pressure was 103 kPa. Use sections 1 and 2 of the data booklet. [2]

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(iii) Suggest a reason why the volume of hydrogen gas collected was smaller than predicted. [1]

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(Question 1 continued)

(c) The reaction of lithium with water is a redox reaction. Identify the oxidizing agent in the reaction giving a reason. [1]

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(d) Describe two observations that indicate the reaction of lithium with water is exothermic. [2]

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2. Electrons are arranged in energy levels around the nucleus of an atom.

(a) Explain why the first ionization energy of calcium is greater than that of potassium. [2]

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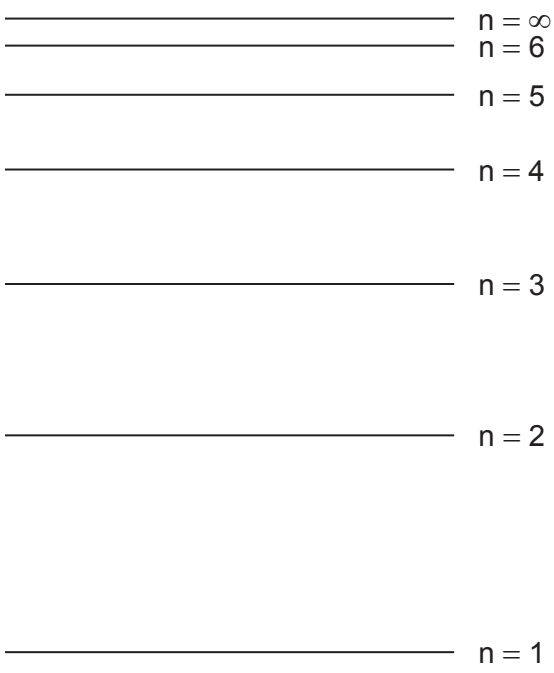
(b) The diagram represents possible electron energy levels in a hydrogen atom.



(i) All models have limitations. Suggest **two** limitations to this model of the electron energy levels. [2]

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(Question 2 continued)

(ii) Draw an arrow, labelled **X**, to represent the electron transition for the ionization of a hydrogen atom in the ground state. [1]

(iii) Draw an arrow, labelled **Z**, to represent the lowest energy electron transition in the visible spectrum. [1]

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Answers written on this page
will not be marked.

3. Standard electrode potential values, $E^{\ominus}$, can be used to predict spontaneity.

(a) (i) Iron(II) is oxidized by bromine.

$$2Fe^{2+}(aq) + Br_2(l) \rightleftharpoons 2Fe^{3+}(aq) + 2Br^{-}(aq)$$

Calculate the $E^{\ominus}_{cell}$, in V, for the reaction using section 24 of the data booklet. [1]

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(ii) Determine, giving a reason, if iodine will also oxidize iron(II). [1]

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(b) (i) Molten zinc chloride undergoes electrolysis in an electrolytic cell at 450 °C.

Deduce the half-equations for the reaction at each electrode. [2]

Cathode (negative electrode):

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Anode (positive electrode):

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(ii) Deduce the overall cell reaction including state symbols. Use section 7 of the data booklet. [2]

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4. Hydrogen and iodine react to form hydrogen iodide.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

(a) The following experimental data was obtained.

Experiment	Initial concentration of H_2 / mol dm^{-3}	Initial concentration of I_2 / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	2.0×10^{-3}	3.0×10^{-3}	1.2×10^{-6}
2	6.0×10^{-3}	3.0×10^{-3}	3.6×10^{-6}
3	6.0×10^{-3}	6.0×10^{-3}	7.2×10^{-6}

(i) Deduce the order of reaction with respect to hydrogen. [1]

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

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(iii) Calculate the value of the rate constant stating its units. [2]

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(Question 4 continued)

(b) State **two** conditions necessary for a successful collision between reactants. [1]

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

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(d) Consider the reaction of hydrogen with solid iodine.

$$H_2(g) + I_2(s) \rightleftharpoons 2HI(g) \qquad \Delta H^{\ominus} = +53.0\,kJ\,mol^{-1}$$

(i) Calculate the entropy change of reaction, $\Delta S^{\ominus}$, in $J\,K^{-1}\,mol^{-1}$. [1]

	$S^{\ominus}$ / J K^{-1} mol^{-1}
$H_2(g)$	130.6
$I_2(s)$	116.1
$HI(g)$	206.6

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(ii) Predict, giving a reason, how the value of the $\Delta S^{\ominus}_{reaction}$ would be affected if $I_2(g)$ were used as a reactant. [1]

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(This question continues on the following page)

(Question 4 continued)

(iii) Calculate the Gibbs free energy change, $\Delta G^{\ominus}$, in $kJ\,mol^{-1}$, for the reaction at 298 K. Use section 1 of the data booklet. [1]

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(iv) Calculate the equilibrium constant, K_c, for this reaction at 298 K. Use your answer to (d)(iii) and sections 1 and 2 of the data booklet.

(If you did not obtain an answer to (d)(iii) use a value of $2.0\,kJ\,mol^{-1}$, although this is not the correct answer). [2]

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5. Iron(II) disulfide, FeS_2, has been mistaken for gold.

(a) (i) State the full electronic configuration of Fe^{2+}. [1]

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(ii) Explain why there is a large increase from the 8th to the 9th ionization energy of iron. [2]

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(b) Calculate the oxidation state of sulfur in iron(II) disulfide, FeS_2. [1]

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(c) Describe the bonding in iron, Fe(s). [1]

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6. Sulfur trioxide is produced from sulfur dioxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(a) Outline, giving a reason, the effect of a catalyst on a reaction. [2]

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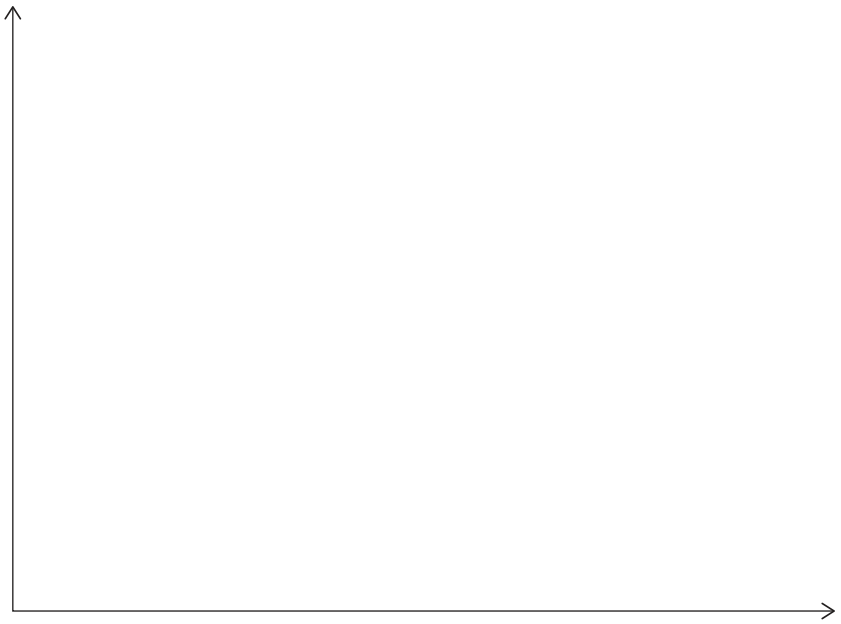
(b) The reaction between sulfur dioxide and oxygen can be carried out at different temperatures.

(i) On the axes, sketch Maxwell–Boltzmann energy distribution curves for the reacting species at two temperatures T_1 **and** T_2, where $T_2 > T_1$. [3]



(ii) Explain the effect of increasing temperature on the yield of SO_3. [2]

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(Question 6 continued)

(c) (i) Draw the Lewis structure of SO_3. [1]

(ii) Explain the electron domain geometry of SO_3. [2]

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(d) (i) State the product formed from the reaction of SO_3 with water. [1]

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(ii) State the meaning of a strong Brønsted–Lowry acid. [2]

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7. The overall equation for the production of hydrogen cyanide, HCN, is shown below.

$$CH_4(g) + NH_3(g) + \frac{3}{2}O_2(g) \rightarrow HCN(g) + 3H_2O(g)$$

(a) (i) State why NH_3 is a Lewis base. [1]

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(ii) Calculate the pH of a 1.00×10^{-2} mol dm^{-3} aqueous solution of ammonia.

$pK_b = 4.75$ at 298 K. [3]

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(iii) Justify whether a 1.0 dm^3 solution made from 0.10 mol NH_3 and 0.20 mol HCl will form a buffer solution. [1]

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(Question 7 continued)

(b) (i) Sketch the shape of one sigma (σ) and one pi (π) bond. [2]

Sigma (σ):

Pi (π):

(ii) Identify the number of sigma and pi bonds in HCN. [1]

Sigma (σ):

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Pi (π):

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(iii) State the hybridization of the carbon atom in HCN. [1]

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(This question continues on the following page)

(Question 7 continued)

(c) Suggest why hydrogen chloride, HCl, has a lower boiling point than hydrogen cyanide, HCN. [1]

	M_r	Boiling point
HCN	27.03	26.00 °C
HCl	36.51	–85.05 °C

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(d) Explain why transition metal cyanide complexes are coloured. [3]

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8. Carbon forms many compounds.

(a) C_{60} and diamond are allotropes of carbon.

(i) Outline **two** differences between the bonding of carbon atoms in C_{60} and diamond. [2]

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(This question continues on the following page)

(Question 8 continued)

(ii) Explain why C_{60} and diamond sublime at different temperatures and pressures. [2]

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(b) (i) State two features showing that propane and butane are members of the same homologous series. [2]

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(ii) Suggest the fragment causing peak **R** in the mass spectrum of butane. [1]

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(Question 8 continued)

(c) Describe a test and the expected result to indicate the presence of carbon–carbon double bonds. [2]

Test:

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Result:

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(d) (i) Draw the full structural formula of (Z)-but-2-ene. [1]

(ii) Write the equation for the reaction between but-2-ene and hydrogen bromide. [2]

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

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(This question continues on the following page)

(Question 8 continued)

(iv) Suggest **two** differences in the ^{1}H NMR of but-2-ene and the organic product from (d)(ii). [2]

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(v) Predict, giving a reason, the major product of reaction between but-1-ene and steam. [2]

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(e) (i) Explain the mechanism of the reaction between 1-bromopropane, $CH_3CH_2CH_2Br$, and aqueous sodium hydroxide, NaOH(aq), using curly arrows to represent the movement of electron pairs. [4]

(ii) Deduce the splitting pattern in the ^{1}H NMR spectrum for 1-bromopropane. [1]

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(This question continues on the following page)

(Question 8 continued)

(f) Chlorine reacts with methane.

$$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$$

(i) Calculate the enthalpy change of the reaction, ΔH, using section 11 of the data booklet. [3]

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(ii) Draw and label an enthalpy level diagram for this reaction. [2]