Diploma Programme
Programme du diplôme
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Chemistry
Higher level
Paper 2

Thursday 5 November 2020 (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]**.

21 pages

8820 – 6102

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

Answers written on this page
will not be marked.

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

1. Chlorine undergoes many reactions.

(a) (i) State the full electron configuration of the chlorine atom. [1]

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(ii) State, giving a reason, whether the chlorine atom or the chloride ion has a larger radius. [1]

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(iii) Outline why the chlorine atom has a smaller atomic radius than the sulfur atom. [2]

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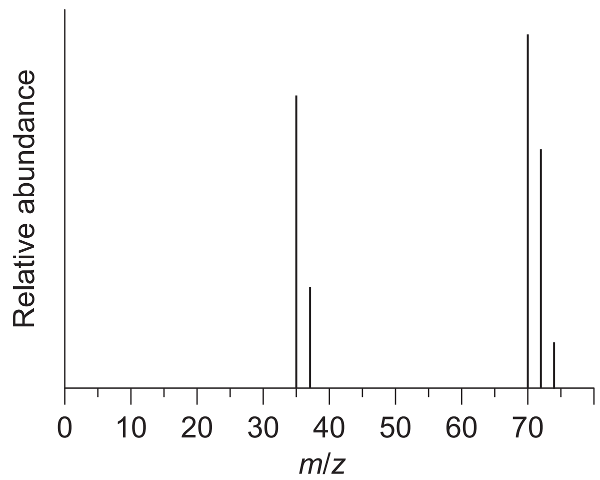
(Question 1 continued)

(iv) The mass spectrum of chlorine is shown.



Outline the reason for the two peaks at $m/z = 35$ and 37. [1]

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(v) Explain the presence and relative abundance of the peak at $m/z = 74$. [2]

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(b) 2.67 g of manganese(IV) oxide was added to 200.0 cm^3 of 2.00 mol dm^{-3} HCl.

$$MnO_2(s) + 4HCl(aq) \rightarrow Cl_2(g) + 2H_2O(l) + MnCl_2(aq)$$

(i) Calculate the amount, in mol, of manganese(IV) oxide added. [1]

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(This question continues on the following page)

(Question 1 continued)

(ii) Determine the limiting reactant, showing your calculations. [2]

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(iii) Determine the excess amount, in mol, of the other reactant. [1]

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(iv) Calculate the volume of chlorine, in dm^3, produced if the reaction is conducted at standard temperature and pressure (STP). Use section 2 of the data booklet. [1]

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(v) State the oxidation state of manganese in MnO_2 and $MnCl_2$. [2]

MnO_2:

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$MnCl_2$:

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(vi) Deduce, referring to oxidation states, whether MnO_2 is an oxidizing or reducing agent. [1]

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(This question continues on the following page)

(Question 1 continued)

(c) Chlorine gas reacts with water to produce hypochlorous acid and hydrochloric acid.

$$Cl_2(g) + H_2O(l) \rightleftharpoons HClO(aq) + HCl(aq)$$

(i) Hypochlorous acid is considered a weak acid. Outline what is meant by the term weak acid. [1]

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(ii) State the formula of the conjugate base of hypochlorous acid. [1]

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(iii) Calculate the concentration of $H^+(aq)$ in a $HClO(aq)$ solution with a pH = 3.61. [1]

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(d) (i) State the type of reaction occurring when ethane reacts with chlorine to produce chloroethane. [1]

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(ii) Predict, giving a reason, whether ethane or chloroethane is more reactive. [1]

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(This question continues on the following page)

(Question 1 continued)

(iii) Explain the mechanism of the reaction between chloroethane and aqueous sodium hydroxide, NaOH (aq), using curly arrows to represent the movement of electron pairs. [3]

(iv) Ethoxyethane (diethyl ether) can be used as a solvent for this conversion. Draw the structural formula of ethoxyethane. [1]

(v) Deduce the number of signals and chemical shifts with splitting patterns in the ^1H NMR spectrum of ethoxyethane. Use section 27 of the data booklet. [3]

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(This question continues on the following page)

(Question 1 continued)

(e) CCl_2F_2 is a common chlorofluorocarbon, CFC.

(i) Calculate the percentage by mass of chlorine in CCl_2F_2. [2]

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(ii) Comment on how international cooperation has contributed to the lowering of CFC emissions responsible for ozone depletion. [1]

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(iii) CFCs produce chlorine radicals. Write two successive propagation steps to show how chlorine radicals catalyse the depletion of ozone. [2]

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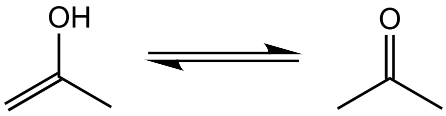
2. Compound **A** is in equilibrium with compound **B**.



A **B**

(a) Predict the electron domain and molecular geometries around the **oxygen** atom of molecule **A** using VSEPR. [2]

Electron domain geometry:

. . . .

Molecular geometry:

. . . .

(b) State the type of hybridization shown by the central carbon atom in molecule **B**. [1]

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(c) State the number of sigma (σ) and pi (π) bonds around the central carbon atom in molecule **B**. [1]

σ-bonds:

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π-bonds:

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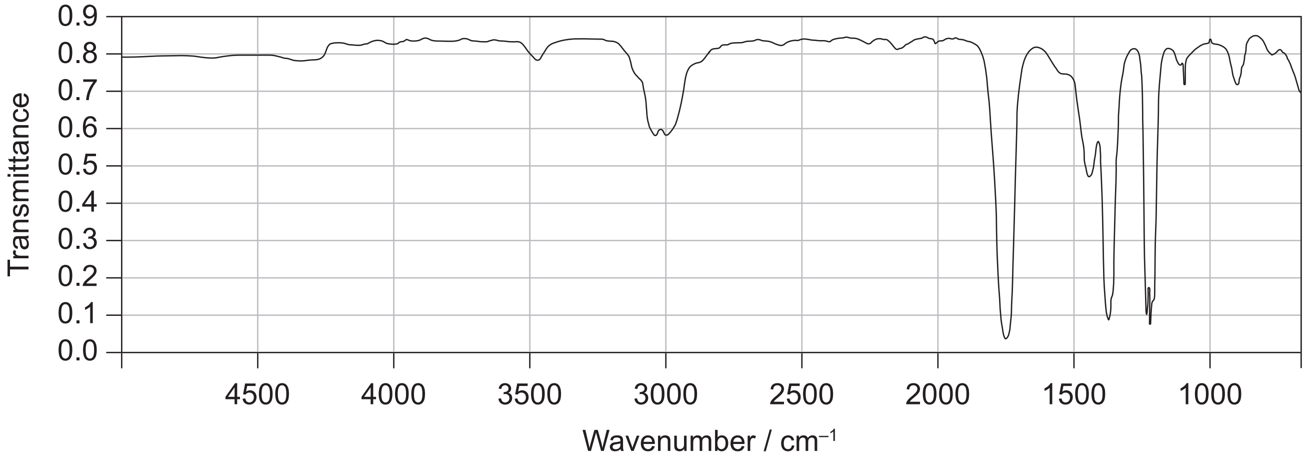
(This question continues on the following page)

(Question 2 continued)

(d) The IR spectrum of one of the compounds is shown:



Deduce, giving a reason, the compound producing this spectrum. [1]

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(e) Compound **A** and **B** are isomers. Draw two other structural isomers with the formula C_3H_6O. [2]

(This question continues on the following page)

(Question 2 continued)

(f) (i) The equilibrium constant, K_c, for the conversion of **A** to **B** is 1.0×10^8 in water at 298 K.

Deduce, giving a reason, which compound, **A** or **B**, is present in greater concentration when equilibrium is reached. [1]

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(ii) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, **in kJ mol^{-1}**, for the reaction (**A** to **B**) at 298 K. Use sections 1 and 2 of the data booklet. [1]

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(g) Propanone can be synthesized in two steps from propene.

(i) Suggest the synthetic route including all the necessary reactants and steps. [3]

(This question continues on the following page)

(Question 2 continued)

(ii) Suggest why propanal is a minor product obtained from the synthetic route in (g)(i). [2]

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3. An equation for the combustion of propane is given below.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

(a) Determine the standard enthalpy change, $\Delta H^{\ominus}$, for this reaction, using section 11 of the data booklet. [3]

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(b) Calculate the standard enthalpy change, $\Delta H^{\ominus}$, for this reaction using section 12 of the data booklet. [2]

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(This question continues on the following page)

(Question 3 continued)

(c) Predict, giving a reason, whether the entropy change, $\Delta S^{\ominus}$, for this reaction is negative or positive. [1]

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(d) Calculate $\Delta S^{\ominus}$ for the reaction in $J\,K^{-1}$, using section 12 of the data booklet.

The standard molar entropy for oxygen gas is $205\,J\,K^{-1}\,mol^{-1}$. [2]

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(e) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, **in kJ**, for the reaction at 5 °C, using your answers to (b) and (d). Use section 1 of the data booklet.

(If you did not obtain an answer to (b) or (d) use values of $-1952\,kJ$ and $+113\,J\,K^{-1}$ respectively, although these are not the correct answers.) [2]

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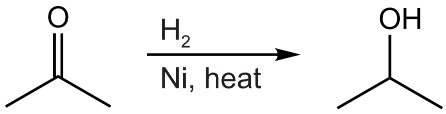
4. Nickel catalyses the conversion of propanone to propan-2-ol.



(a) Outline how a catalyst increases the rate of reaction. [1]

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(b) Explain why an increase in temperature increases the rate of reaction. [2]

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(c) Discuss, referring to intermolecular forces present, the relative volatility of propanone and propan-2-ol. [3]

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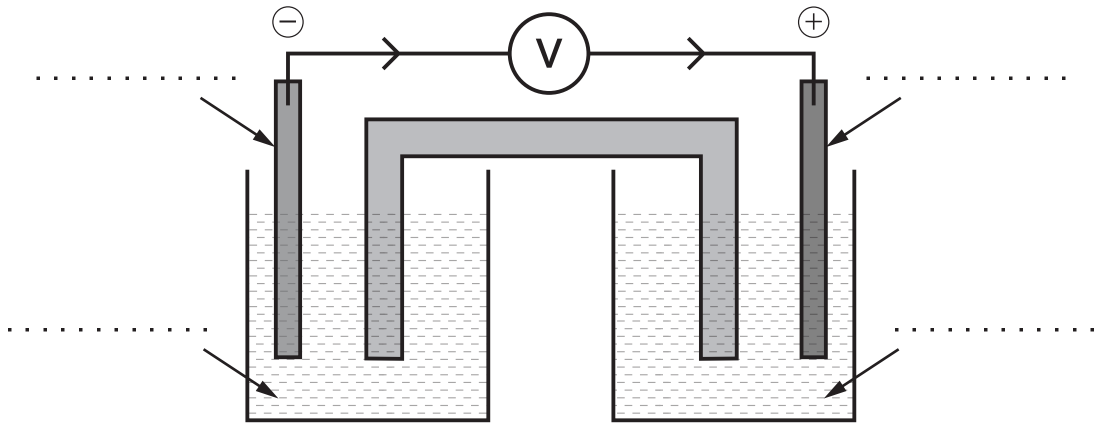
(Question 4 continued)

(d) (i) The diagram shows an unlabelled voltaic cell for the reaction.

$$Pb^{2+}(aq) + Ni(s) \rightarrow Ni^{2+}(aq) + Pb(s)$$

Label the diagram with the species in the equation. [1]



(ii) Calculate the standard cell potential, in V, for the cell at 298 K. Use section 24 of the data booklet. [1]

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(iii) Calculate the standard free energy change, $\Delta G^{\ominus}$, **in kJ**, for the cell using sections 1 and 2 of the data booklet. [1]

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(iv) Suggest a metal that could replace nickel in a new half-cell and reverse the electron flow. Use section 25 of the data booklet. [1]

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(This question continues on the following page)

(Question 4 continued)

(v) Describe the bonding in metals. [2]

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(vi) Nickel alloys are used in aircraft gas turbines. Suggest a physical property altered by the addition of another metal to nickel. [1]

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5. A student performs a titration to determine the concentration of ethanoic acid, CH_3COOH, in vinegar using potassium hydroxide.

(a) Write a balanced equation for the reaction. [1]

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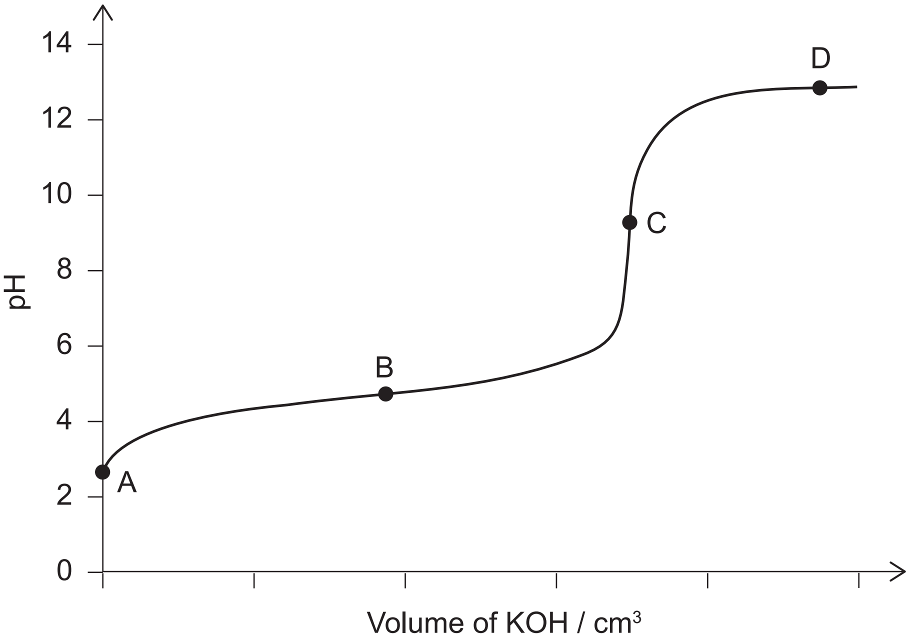
(Question 5 continued)

(b) The pH curve for the reaction is given.



(i) Identify the **major** species, other than water and potassium ions, at these points. [2]

B:

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C:

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

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(iii) Suggest, giving a reason, which point on the curve is considered a buffer region. [1]

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(This question continues on the following page)

(Question 5 continued)

(c) State the K_a expression for ethanoic acid. [1]

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(d) Calculate the K_b of the conjugate base of ethanoic acid using sections 2 and 21 of the data booklet. [1]

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(e) In a titration, 25.00 cm^3 of vinegar required 20.75 cm^3 of 1.00 $mol\,dm^{-3}$ potassium hydroxide to reach the end-point.

Calculate the concentration of ethanoic acid in the vinegar. [2]

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(f) Potassium hydroxide solutions can react with carbon dioxide from the air. The solution was made one day prior to using it in the titration.

(i) State the type of error that would result from the student's approach. [1]

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(This question continues on the following page)

(Question 5 continued)

(ii) Predict, giving a reason, the effect of this error on the calculated concentration of ethanoic acid in 5(e). [2]

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6. The electron configuration of copper makes it a useful metal.

(a) Determine the frequency of a photon that will cause the first ionization of copper. Use sections 1, 2 and 8 of the data booklet. [2]

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(b) Explain why a copper(II) solution is blue, using section 17 of the data booklet. [3]

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(Question 6 continued)

(c) Copper plating can be used to improve the conductivity of an object.

State, giving your reason, at which electrode the object being electroplated should be placed. [1]

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7. Nitrogen monoxide reacts with oxygen gas to form nitrogen dioxide.

(a) The following experimental data was obtained.

Experiment	**Initial [NO] / $mol\,dm^{-3}$**	**Initial [O_2] / $mol\,dm^{-3}$**	**Initial rate / $mol\,dm^{-3}\,s^{-1}$**
1	0.0100	0.0300	2.13×10^{-2}
2	0.0100	0.0600	4.26×10^{-2}
3	0.0300	0.0300	1.92×10^{-1}

Deduce the partial order of reaction with respect to nitrogen monoxide and oxygen. [2]

NO:

. . . .

O_2:

. . . .

(This question continues on the following page)

(Question 7 continued)

(b) Deduce, giving a reason, whether the following mechanism is possible.

First step:	$2NO(g) \rightarrow N_2O_2(g)$	slow
Second step:	$N_2O_2(g) + O_2(g) \rightleftharpoons 2NO_2(g)$	fast

[1]

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References:

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