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**Chemistry**  
**Higher level**  
**Paper 2**

Thursday 5 November 2020 (afternoon)

Candidate session number

2 hours 15 minutes

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**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]**.



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

Answers written on this page  
will not be marked.



24EP02

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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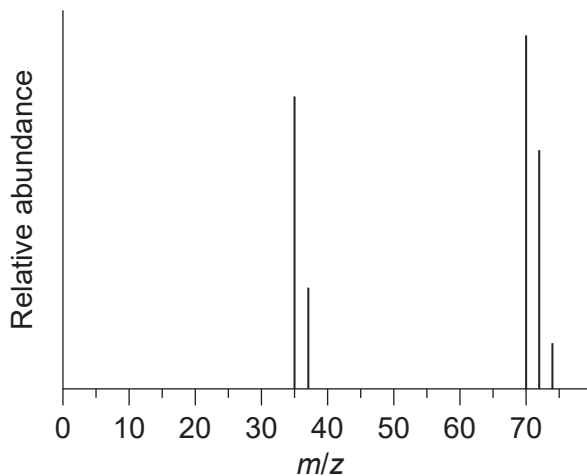


24EP03

Turn over

(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]

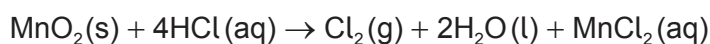
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(v) Explain the presence and relative abundance of the peak at  $m/z = 74$ .

[2]

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(b) 2.67 g of manganese(IV) oxide was added to 200.0 cm<sup>3</sup> of 2.00 mol dm<sup>-3</sup> HCl.



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

[1]

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(This question continues on the following page)



24EP04

**(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<sup>3</sup>, 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<sub>2</sub> and MnCl<sub>2</sub>. [2]

MnO<sub>2</sub>:  
.....  
  
MnCl<sub>2</sub>:  
.....

(vi) Deduce, referring to oxidation states, whether MnO<sub>2</sub> is an oxidizing or reducing agent. [1]

.....  
.....

**(This question continues on the following page)**



24EP05

**Turn over**

**(Question 1 continued)**

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



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

.....  
.....

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

.....

(iii) Calculate the concentration of  $\text{H}^+(\text{aq})$  in a  $\text{HClO}(\text{aq})$  solution with a  $\text{pH} = 3.61$ . [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 <sup>1</sup>H 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)  $\text{CCl}_2\text{F}_2$  is a common chlorofluorocarbon, CFC.

(i) Calculate the percentage by mass of chlorine in  $\text{CCl}_2\text{F}_2$ . [2]

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

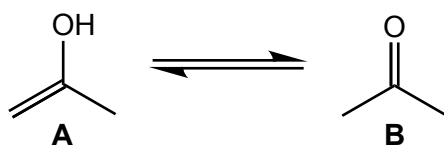
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(iii) CFCs produce chlorine radicals. Write two successive propagation steps to show how chlorine radicals catalyse the depletion of ozone. [2]

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



(a) 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 ( $\sigma$ ) and pi ( $\pi$ ) bonds around the central carbon atom in molecule **B**. [1]

$\sigma$ -bonds:

.....

$\pi$ -bonds:

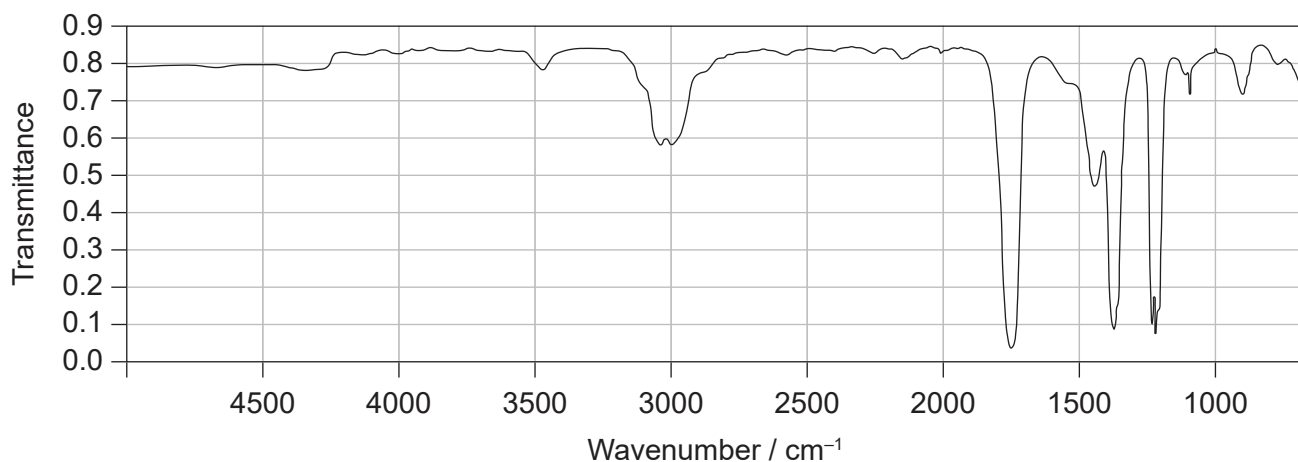
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(Question 2 continued)

(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)



24EP10

**(Question 2 continued)**

- (f) (i) The equilibrium constant,  $K_c$ , for the conversion of **A** to **B** is  $1.0 \times 10^8$  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  $\text{kJ mol}^{-1}$ , 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)**

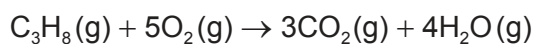


**(Question 2 continued)**

(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.



(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  $\text{JK}^{-1}$ , using section 12 of the data booklet.

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

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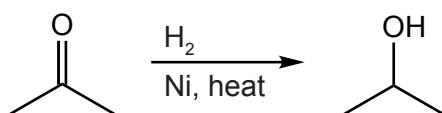
- (e) Calculate the standard Gibbs free energy change,  $\Delta G^\ominus$ , in **kJ**, for the reaction at  $5^\circ\text{C}$ , using your answers to (b) and (d). Use section 1 of the data booklet.

(If you did not obtain an answer to (b) or (d) use values of  $-1952 \text{kJ}$  and  $+113 \text{JK}^{-1}$  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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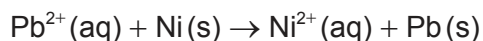
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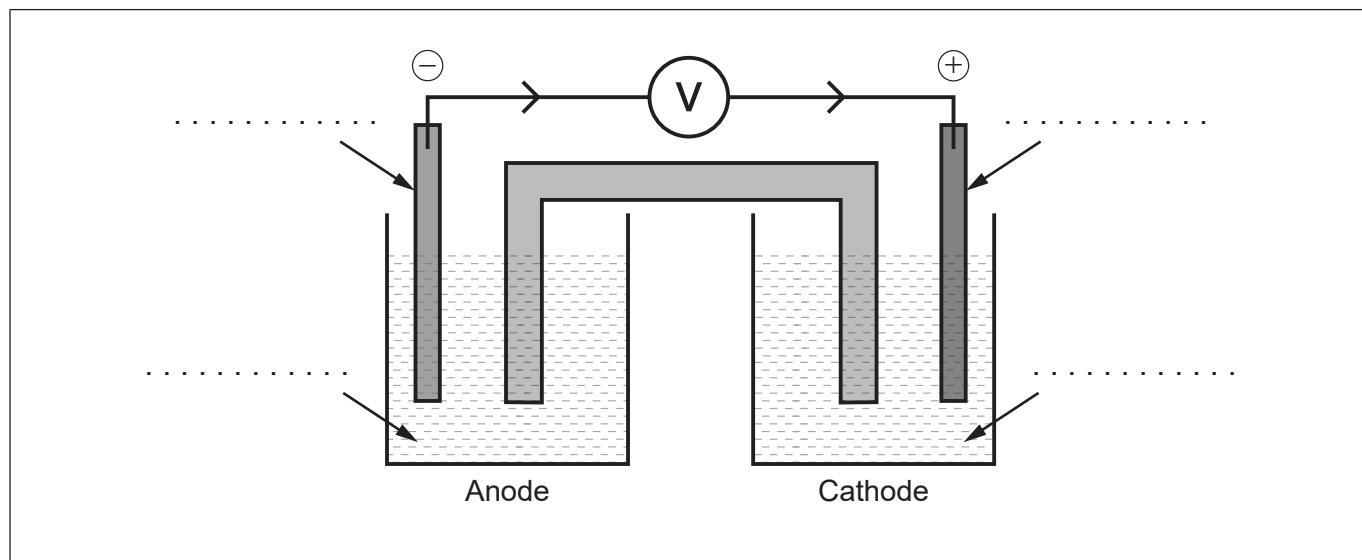
(Question 4 continued)

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



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)



24EP15

Turn over



**(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,  $\text{CH}_3\text{COOH}$ , in vinegar using potassium hydroxide.

(a) Write a balanced equation for the reaction.

[1]

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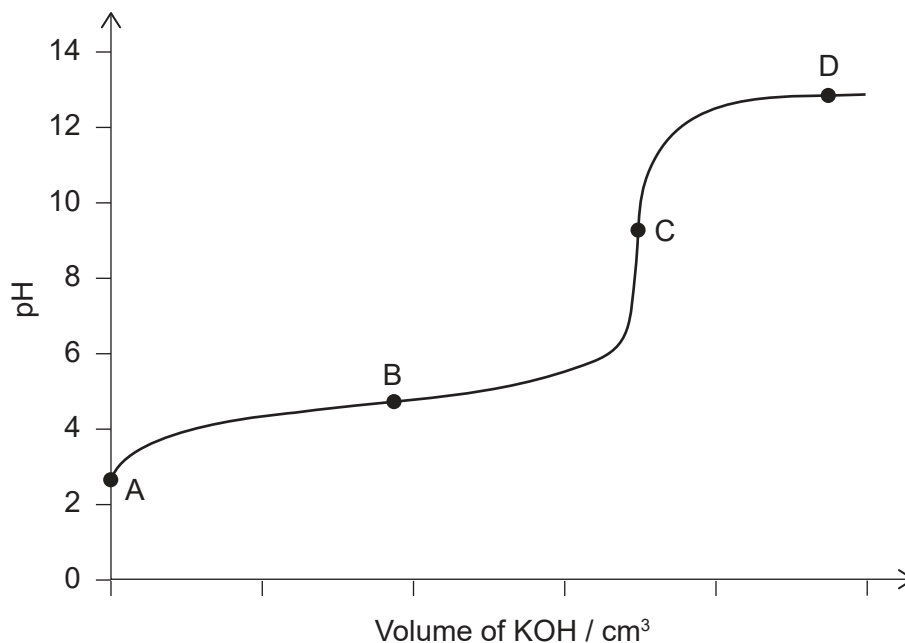
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(Question 5 continued)

(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:  
.....

C:  
.....

(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)



24EP17

Turn over

**(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<sup>3</sup> of vinegar required 20.75 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> 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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**(This question continues on the following page)**



**(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] / $\text{mol dm}^{-3}$	Initial [O <sub>2</sub> ] / $\text{mol dm}^{-3}$	Initial rate / $\text{mol dm}^{-3} \text{ s}^{-1}$
1	0.0100	0.0300	$2.13 \times 10^{-2}$
2	0.0100	0.0600	$4.26 \times 10^{-2}$
3	0.0300	0.0300	$1.92 \times 10^{-1}$

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

[2]

NO:  
.....

O<sub>2</sub>:  
.....

**(This question continues on the following page)**



24EP20

(Question 7 continued)

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

First step:	$2\text{NO}(\text{g}) \rightarrow \text{N}_2\text{O}_2(\text{g})$	slow
Second step:	$\text{N}_2\text{O}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$	fast

[1]

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**References:**

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- 2.(d) COBLENTZ SOCIETY. Collection © 2018 copyright by the U.S. Secretary of Commerce on behalf of the United States of America. All rights reserved.



24EP22

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24EP23



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24EP24