華中國際學校
Hwa Chong INTERNATIONAL SCHOOL
A MEMBER OF THE HWA CHONG FAMILY OF SCHOOLS

PRELIMINARY EXAMINATION
International Baccalaureate 2

Chemistry
Higher level
Paper 2

Tuesday 3 September 2019

2 hour 15 minutes

Candidate name	
Candidate session number	Class

Instructions to candidates

- Write your candidate name and 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]**.

For Examiner's Use	
Q1	/15
Q2	/ 15
Q3	/ 9
Q4	/ 10
Q5	/ 15
Q6	/ 9
Q7	/ 17
Total	/ 90

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

1. 9.74 tonnes of magnesium is needed to react with 1.60×10^2 tonnes of impure titanium (IV) oxide, TiO_2, ore. All the titanium is completely extracted from the sample of impure ore. The following are reactions involved in the extraction process:

Step 1: $TiO_2 + C + 2Cl_2 \rightarrow TiCl_4 + CO_2$

Step 2: $TiCl_4 + 2Mg \rightarrow Ti + 2MgCl_2$

(1 tonne = 10^6 g)

(a) Write an overall equation for extraction of titanium from TiO_2. [1]

……..…

(b) Calculate the amount, in moles, of TiO_2 present in the sample of impure ore. [1]

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(c) Calculate the mass, in tonnes, of TiO_2 in the sample of impure ore. [2]

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(d) Calculate the percentage by mass of TiO_2 in the sample. [1]

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(This question continues on the following page)

(Question 1 continued)

(e) (i) Titanium (IV) oxide, TiO_2, is a solid, however titanium (IV) chloride, $TiCl_4$, is a liquid at room temperature.

Suggest a reason for this difference between the two compounds, in terms of structure and bonding. [2]

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(ii) Titanium (IV) chloride is relatively stable in aqueous solutions. However, it dissolves in concentrated hydrochloric acid to form an acidic solution of the hexachlorotitanate (IV) complex ion.

Draw the structure of the complex ion, suggest its molecular geometry and bond angle. [2]

Geometry: ……

Bond angle: ……

(This question continues on the following page)

(Question 1 continued)

(f) Titanium exists in three important oxidation states, +2, +3 and +4. However, zinc exhibits only +2 oxidation state.

(i) Write the full electron configurations of Ti^{2+} and Zn^{2+} ions. [2]

Ti^{2+}: ……

Zn^{2+}: ……

(ii) Suggest why titanium has variable oxidation states. [1]

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(g) Magnesium is a s–block element.

(i) Define what is meant by ‘s’. [1]

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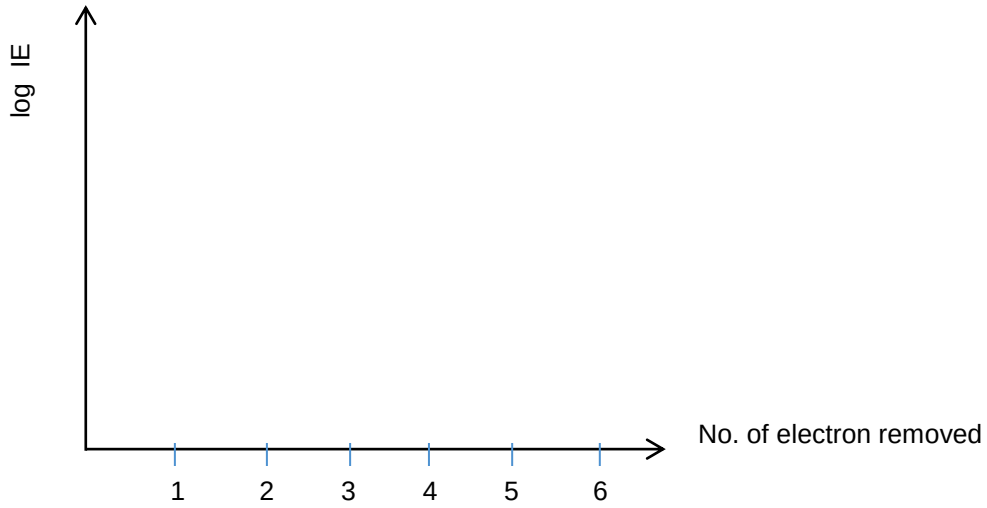
(This question continues on the following page)

(Question 1 continued)

(ii) Sketch on the axes below, the first six ionisation energies (IE), in logarithmic scale, of the element, magnesium. [1]



(iii) Explain **one** salient feature of the graph. [1]

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2. Chlorofluorocarbons, CFCs, have been used previously for a wide range of applications including cleaning solvents and refrigerant. However, they break down easily in the stratosphere that lead to ozone (O_3) depletion.

(a) The following equations illustrate the process of ozone depletion.

$CCl_2F_2 \xrightarrow{h\nu} \bullet CClF_2 + Cl\bullet$ — (1)

$Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$ — (2)

$ClO\bullet + O\bullet \rightarrow Cl\bullet + O_2$ — (3)

(i) Identify the type of processes shown in the three equations by completing the table below: [2]

Process	Equation(s)
initiation	
propagation	
termination	

(ii) Cl in equation (1) is the reactive species in this process. State the name of such species and explain its reactivity. [1]

……..

(b) The hydroflurocarbon, F_3CCFH_2, is a suitable replacement for CFCs. It is prepared industrially by reacting hydrogen fluoride with $Cl_2C{=}CClH$. HCl is the by–product.

(i) State the IUPAC name of F_3CCFH_2. [1]

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(ii) Construct a balanced overall equation for this reaction. [1]

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(This question continues on the following page)

(Question 2 continued)

(iii) Explain how HF can act as a *nucleophile* in this reaction. [1]

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(iv) Draw an isomer of F_3CCFH_2 that can be produced from this reaction. [1]

(c) The breakdown of ozone, O_3 is shown in this equation:

$$O_3\,(g) \longrightarrow O\bullet\,(g) + O_2\,(g) \qquad \Delta H = +107.5\ kJ\ mol^{-1}$$

(i) Use relevant data from section 11 of the data booklet to determine the bond energy between oxygen atoms in ozone. [1]

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(ii) Compare the value in (i) and that in the O_2 molecule. Deduce the relative bond strengths in O_2 and O_3. [2]

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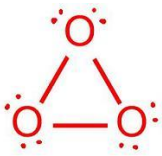
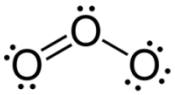
(Question 2 continued)

(d) Ozone O_3, can be represented in a cyclic or bent structure as shown below.



Cyclic structure



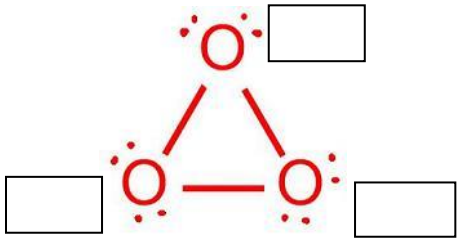
Bent structure

(i) Determine the hybridization of the oxygen atoms in the two structures. [1]

Cyclic structure: ……

Bent structure: ……..……

(ii) Calculate and indicate within the boxes, the formal charges of all the oxygen atoms on both structures. [2]



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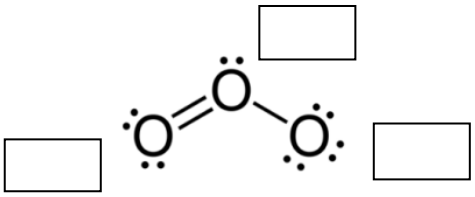

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(e) Hence, based on your answers from (c) and (d), suggest which of the two is the most probable structure of ozone. [2]

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3. The following equation shows the molar coefficients of the dynamic equilibrium between haemoglobin and oxygen in the blood stream.

$$Hb(aq) + 4O_2(aq) \rightleftharpoons Hb(O_2)_4(aq)$$

(a) Define the term *dynamic equilibrium*. [1]

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(b) Deduce the equilibrium expression for the reaction and state its units. [2]

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(c) At standard conditions, the equilibrium concentration of Hb and $Hb(O_2)_4$ are equal when concentration of O_2 is 7.6×10^{-6} mol dm^{-3}. Calculate the equilibrium constant, K_c, of the reaction. [2]

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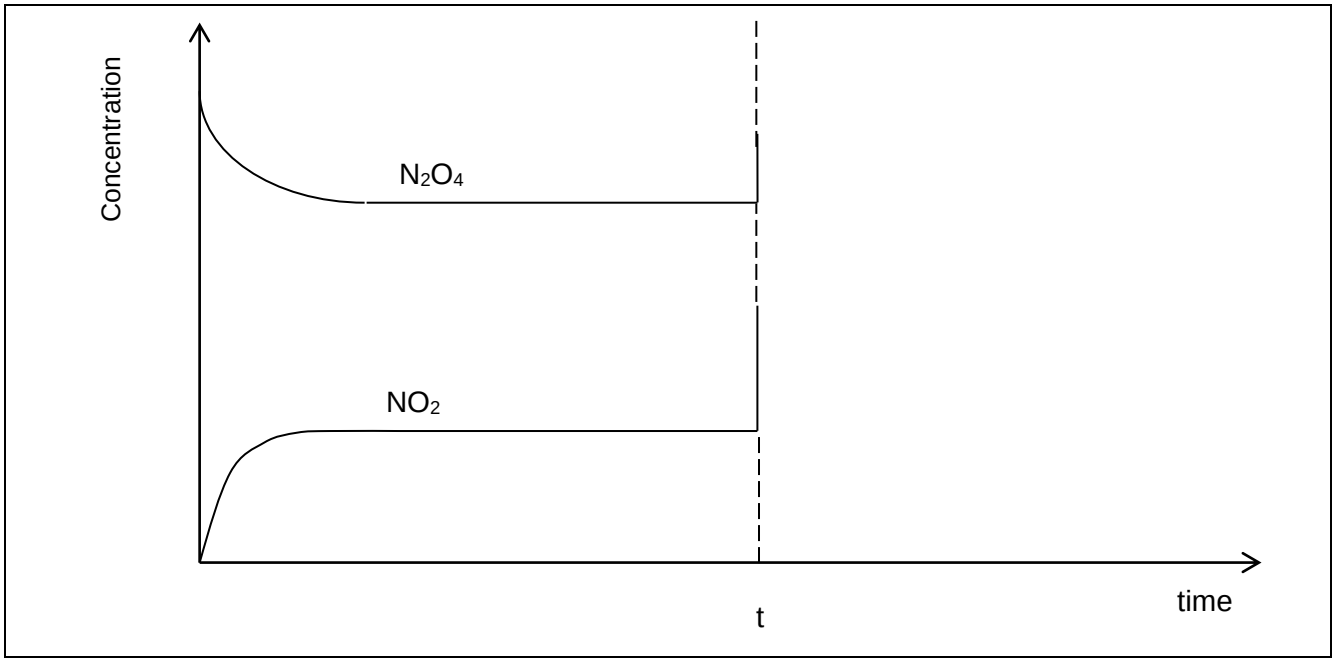
(This question continues on the following page)

(Question 3 continued)

(d) The graph below shows the changes occurring to an equilibrium system in a closed vessel, containing N_2O_4 and NO_2, reacting according to the equation:

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



The volume of the reaction vessel is decreased at time, t min.
Sketch clearly (in the correct proportion) on the graph above, the change in concentration of the reactant and product after t minutes. Explain your answer. [3]

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(e) Suggest how would the K_c be affected if the concentration of NO_2 introduced were to decrease by 0.2 times at the same temperature. [1]

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4. For the reaction between bromate ions, BrO_3^-, and bromide ions, Br^-, in an acidic environment, the reaction proceeds as shown.

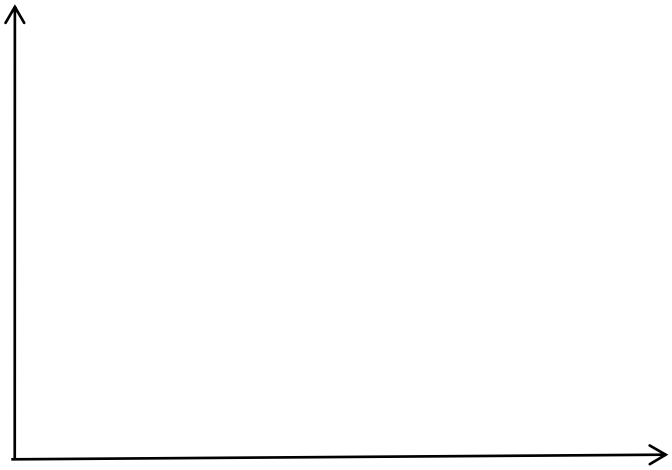
$$5Br^-(aq) + BrO_3^-(aq) + 6H^+(aq) \rightarrow 3Br_2(aq) + 3H_2O(l)$$

The rate equation is experimentally determined as

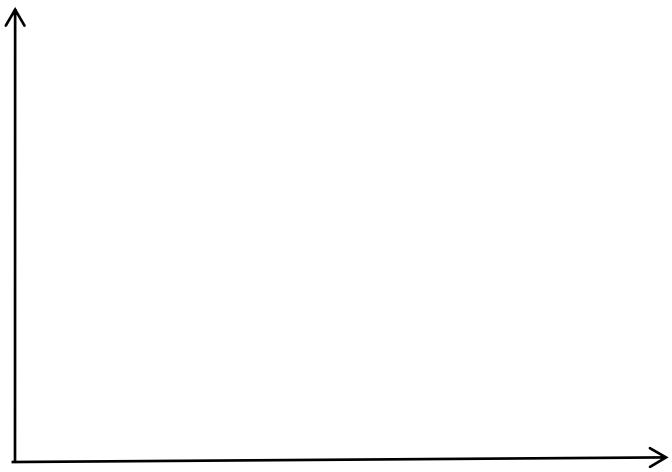
Rate = $k[H^+]^2[BrO_3^-]^1[Br^-]^1$

(a) Based on the rate equation, sketch the following graphs below. [2]

<u>Rate against $[H^+]$,</u> given $[BrO_3^-]$, $[Br^-]$ are constant



<u>$[BrO_3^-]$ against time</u>, given $[H^+]$, $[Br^-]$ are constant



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(Question 4 continued)

(b) A student designed a series of experiments to study the rate equation for the Br^-/BrO_3^- reaction using the variables as given in the following table.

Experiment	$[H^+]$ / mol dm^{-3}	$[BrO_3^-]$/mol dm^{-3}	$[Br^-]$/ mol dm^{-3}	Rate/mol dm^{-3} s^{-1}
1	0.01	0.02	0.01	0.4
2	0.005	0.02	0.01	**x**
3	0.005	0.02	**y**	**2x**
4	0.01	**z**	0.01	1.0

Using relevant values form the table and the rate equation given above, deduce the values for **x, y** and **z**. [3]

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(c) Comment on the significance of the rate constant, *k*, in the rate equation. [1]

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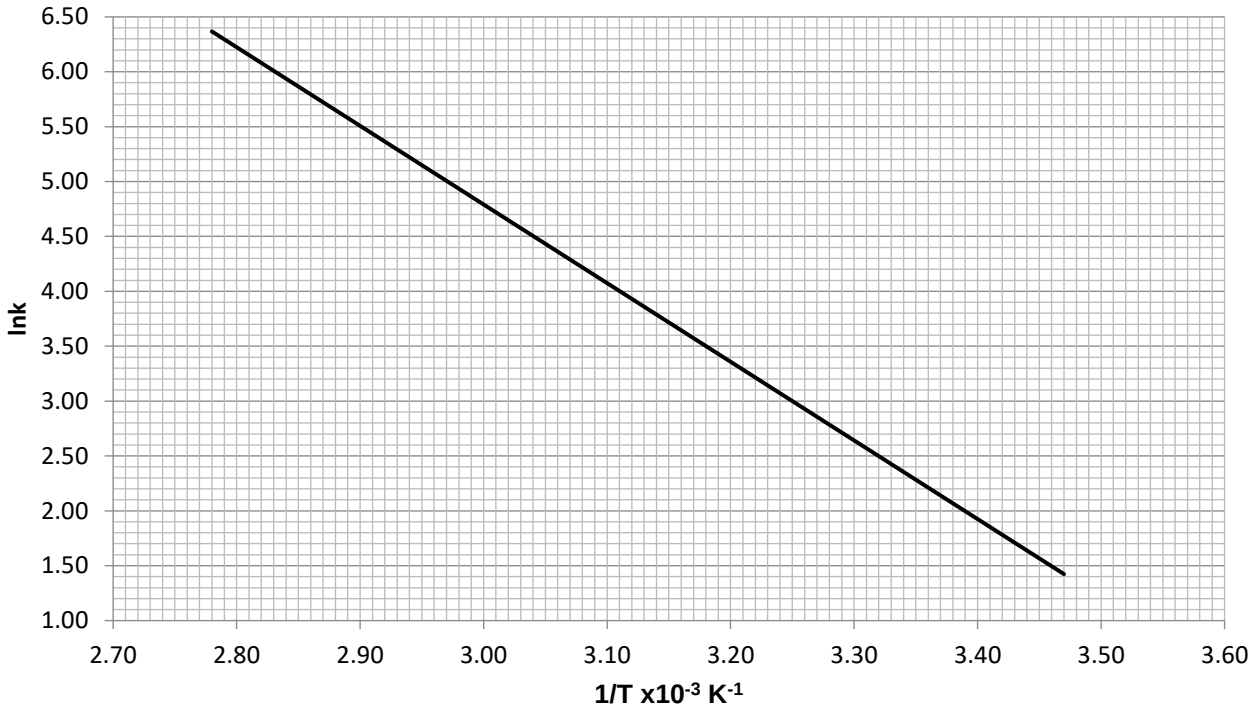
(This question continues on the following page)

(Question 4 continued)

(d) In order to determine the activation energy, E_a, of the reaction, the student conducted a series of experiments by changing the temperature and calculating the rates of the reaction at those temperatures. He obtained the following graph.



(i) Using the data from the graph and the values from section 1 and 2 of the data booklet, calculate the activation energy, E_a, of the reaction. [3]

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(This question continues on the following page)

(Question 4 continued)

(ii) Describe qualitatively the relationship between the rate constant, k, and the temperature, T. [1]

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5. Nitric acid, HNO_3, is a strong acid while nitrous acid, HNO_2, is a weak acid.

(a) Distinguish between the terms *strong* and *weak acid* and construct the equations to show the dissociation of each acid in aqueous solution. [2]

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(b) Describe **one** chemical method that could be used to distinguish between nitric acid and nitrous acid solutions of the same concentration. [2]

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(c) A student conducted two titration experiments to determine the volume of 0.20 mol dm^{-3} sodium hydroxide solution required to completely neutralise separate samples of the acid.

(i) Calculate the volume of sodium hydroxide solution required to completely neutralise 25.0 cm^3 of 0.10 mol dm^{-3} nitric acid. [1]

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(This question continues on the following page)

(Question 5 continued)

(ii) The student made the following hypothesis: "Since nitrous acid is a weak acid, 25.0 cm^3 of 0.10 mol dm^{-3} of nitrous acid requires a smaller volume of sodium hydroxide solution for complete neutralisation."
Comment if this is a valid hypothesis. [1]

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(iii) Using section 22 of the data booklet, identify a suitable indicator that can be used to determine the end–point in both titrations. [1]

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(iv) Using a relevant equation, describe how an indicator, HIn, works. [2]

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(d) The pH of 25.0 cm^3 of 0.10 mol dm^{-3} of nitrous acid, HNO_2, is 2.17 at 298 K.

(i) Write an expression for the *acid dissociation constant*, K_a, of nitrous acid, and determine the value of K_a for this acid at 298 K, stating its units. [2]

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(This question continues on the following page)

(Question 5 continued)

(ii) The dissociation of nitrous acid into its ions in aqueous solution is an endothermic process. State and explain the effect of increasing temperature on its pH value. [2]

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(e) Solution **A** contains *n* moles of nitrous acid. The addition of some sodium hydroxide to **A** neutralises half of the nitrous acid present to produce solution **B**.

(i) Using your answer in part (d)(i), determine the pH of solution **B**. [1]

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(ii) Solution **B** can act as a buffer. Construct an equation to show how solution **B** can act as a buffer when a small amount of hydrochloric acid is added. [1]

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6. (a) Besides ozone, chlorine dioxide (ClO_2) is also used in water treatment. In the laboratory, ClO_2 can be prepared by oxidising sodium chlorite ($NaClO_2$) with Cl_2. Cl_2 is reduced to Cl^- in the process.

(i) Determine the oxidation state of chlorine in ClO_2 and in ClO_2^-. [1]

ClO_2 ……

ClO_2^- ……

(ii) Identify the reducing agent in this reaction. [1]

……..

(iii) Given the following electrode potential, [1]

$ClO_2(aq) + e^- \rightleftharpoons ClO_2^-(aq)$ $\quad E^\theta = +0.95$ V

use relevant data from section 24 of the data booklet to calculate the E^θ_{cell} of the reaction.

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(b) Another method of producing ClO_2 is to electrolyse an aqueous solution of sodium chlorite ($NaClO_2$) using inert electrodes.

(i) Deduce the reaction occurring at the cathode and anode by writing a balanced half–equation at each electrode. [2]

anode: ……..

cathode: ……..

(This question continues on the following page)

(Question 6 continued)

(ii) Construct the overall balanced equation for the electrolysis process. [1]

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(iii) Explain the reaction occurring at the anode by stating relevant E^{θ} values from section 24 of the data booklet. [2]

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(iv) Describe the observation(s) at the cathode. [1]

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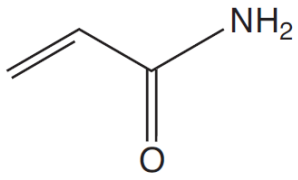
7. (a) Compound **A**, $C_2H_3CONH_2$, is a suspected carcinogen. It is formed in starchy foods when they are heated at high temperatures such as those found in frying and roasting.



compound **A**

State the name the functional groups in compound **A**. [1]

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(b) Through a series of intermediate steps, compound **A** can be reduced to compound **B**, $C_3H_7NH_2$.

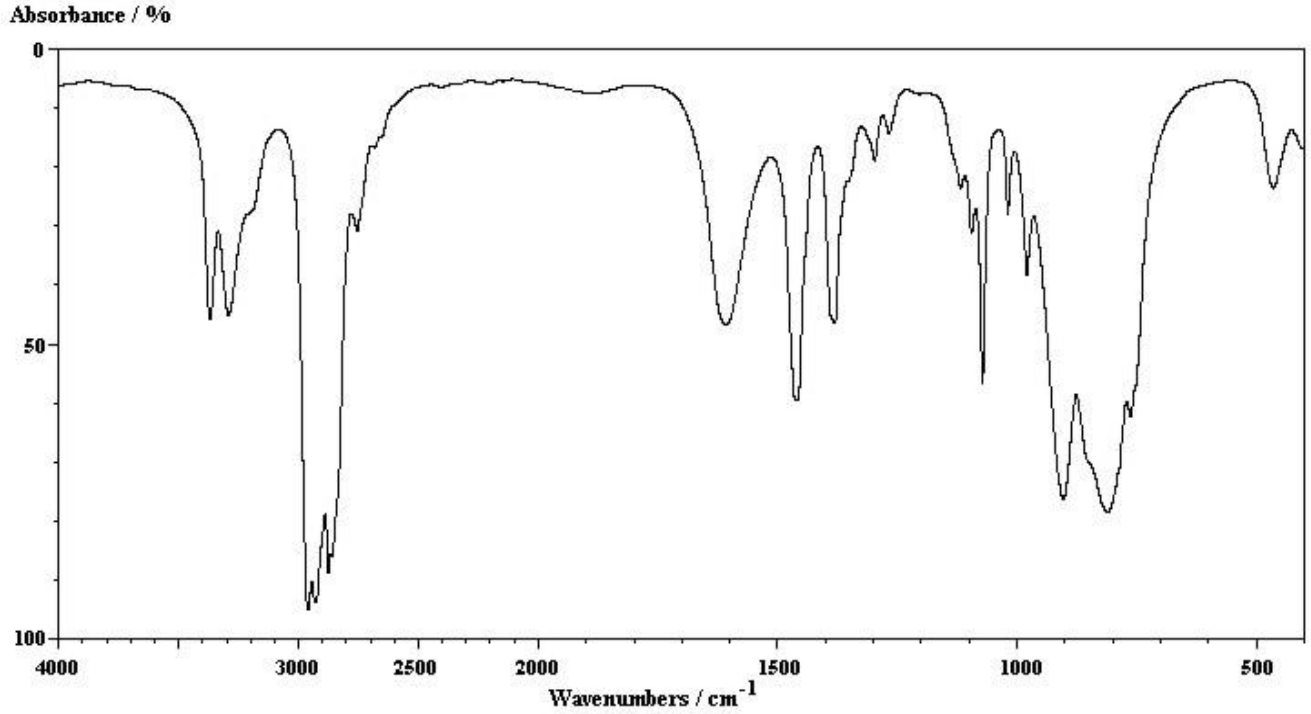
(i) Draw the structure of compound **B**. [1]

(This question continues on the following page)

(Question 7 continued)

(ii) A student attempted the reduction of compound **A** and obtained the IR spectrum of the product **B** as shown below.

Justify with two pieces of evidence that compound **A** is reduced to **B**. [2]



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(c) Compound **A** has a relative molecular mass of 71.
It can be reduced to another compound **C** with a molecular ion peak that occurs at m/z value 73. There are also base peaks found at m/z value 29 and m/z value 16.

(i) Compound **C** does not decolourise bromine water. Comment on this observation. [1]

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(This question continues on the following page)

(Question 7 continued)

(ii) Suggest the formula of the species at m/z value 29 and at m/z value 16. [1]

……..

(iii) Hence, deduce the structural formula of compound **C**. [1]

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(d) Hydrolysis of compound **C** produces propanoic acid. [1]

(i) Other than propan–1–ol, identify a suitable 3–carbon compound that can be converted to propanoic acid.

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(ii) Explain the mechanism of the reaction of 1–chloropropane to form propan–1–ol using curly arrows to represent the movement of electron pairs. [2]

(This question continues on the following page)

(Question 7 continued)

(e) Liquid propan–1–ol readily undergoes combustion. [1]

(i) Construct a balanced equation with state symbols for the combustion of propan–1–ol.

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(ii) Given that the enthalpy change of formation of liquid propan–1–ol is –303 kJ mol^{-1}, use relevant data from section 12 the data booklet to determine the enthalpy change of combustion of propan–1–ol. [2]

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(iii) Use your answer in (ii) to calculate the mass of propan–1–ol needed to boil 100 cm^3 of water in a calorimeter at 25 °C. It is found that this process is only 80% efficient. [3]

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(iv) State one assumption used in the calculation in (iii). [1]

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