

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

Friday 13 November 2015 (afternoon)

Candidate session number

2 hours 15 minutes

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**Instructions to candidates**

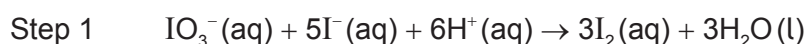
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.



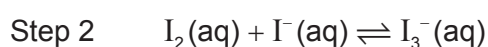
## Section A

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

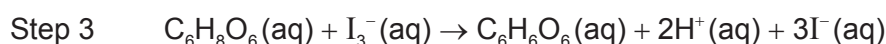
1. A student used the technique of titration to determine the concentration of ascorbic acid ( $C_6H_8O_6$ ) in a sample of orange juice. Excess potassium iodide,  $KI(aq)$ , was added to acidified orange juice. The resulting solution was titrated with potassium iodate,  $KIO_3(aq)$ , in the presence of starch as an indicator. The end-point of the titration was shown by a blue-black colour.



Iodine is only slightly soluble in water; but in the presence of excess iodide ions,  $I^-(aq)$ , it forms the soluble tri-iodide ion,  $I_3^-(aq)$ .



Ascorbic acid reacts with tri-iodide ions as follows.



- (a) (i) Deduce the changes in oxidation number of iodine in step 1. [2]

$IO_3^-$  to  $I_2$ :

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$I^-$  to  $I_2$ :

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- (ii) Identify the oxidizing and reducing agents in step 1. [1]

Oxidizing agent:

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Reducing agent:

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**(Question 1 continued)**

- (b) Calculate the mass, in g, of potassium iodate,  $\text{KIO}_3(\text{s})$ , which was required to prepare  $0.250 \text{ dm}^3$  of a  $2.00 \times 10^{-3} \text{ mol dm}^{-3}$  solution. [2]

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- (c) The concentration of  $\text{KIO}_3$  used in the titration was  $2.00 \times 10^{-3} \text{ mol dm}^{-3}$ . The titration produced the following results.

	<b>Titration 1</b>	<b>Titration 2</b>	<b>Titration 3</b>
Final volume of $\text{KIO}_3 (\pm 0.05 \text{ cm}^3)$	7.10	14.40	21.60
Initial volume of $\text{KIO}_3 (\pm 0.05 \text{ cm}^3)$	0.00	7.10	14.40
Volume added of $\text{KIO}_3 (\pm 0.10 \text{ cm}^3)$	7.10	7.30	7.20
Mean volume added of $\text{KIO}_3 (\pm 0.10 \text{ cm}^3)$	7.20		

- (i) Calculate the percentage uncertainty associated with the mean volume of  $\text{KIO}_3(\text{aq})$ . [1]

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- (ii) The colour of orange juice interfered with the blue-black colour at the equivalence point. State the name of this type of error and suggest how this can be minimized. [2]

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**(Question 1 continued)**

- (iii) Determine the amount, in mol, of  $\text{KIO}_3(\text{aq})$ , in the mean volume. [1]

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- (d) Determine the amount, in mol, of ascorbic acid,  $\text{C}_6\text{H}_8\text{O}_6(\text{aq})$ , in the sample of acidified orange juice. [2]

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- (e) Calculate the mass, in g, of ascorbic acid,  $\text{C}_6\text{H}_8\text{O}_6(\text{aq})$ , present in the sample of acidified orange juice. [1]

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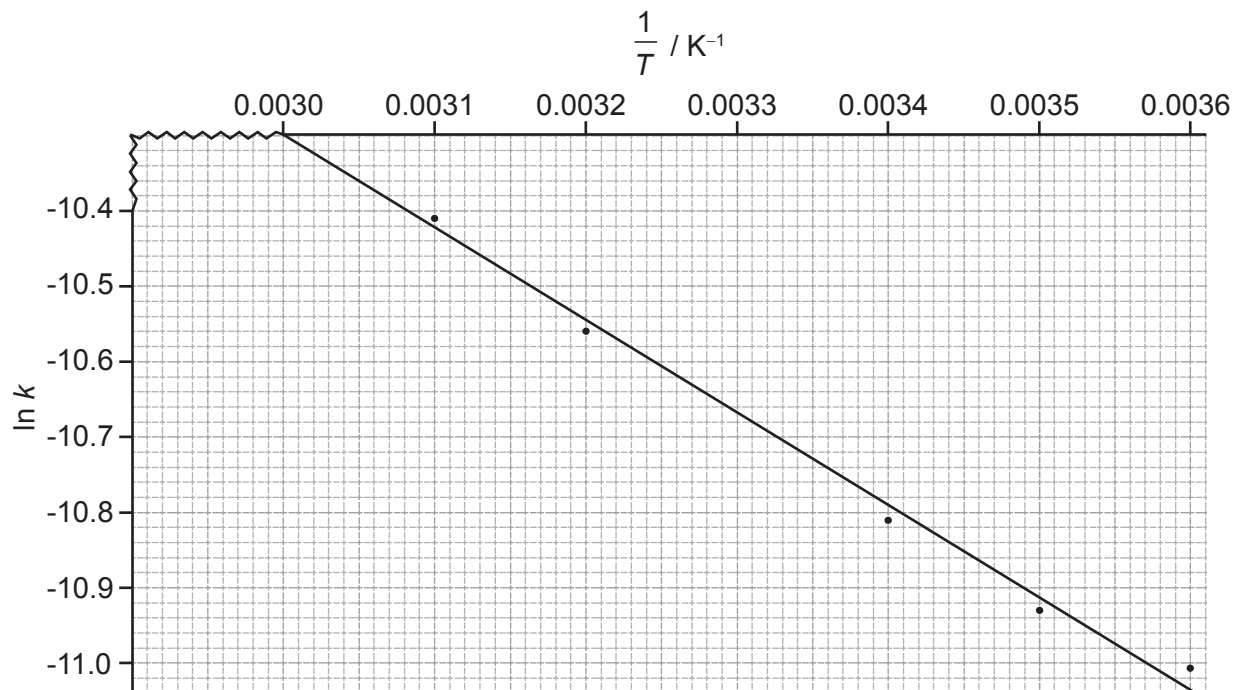


## (Question 1 continued)

- (f) The student found by further experimentation that oxidation of ascorbic acid follows first-order kinetics. The graph of  $\ln k$  against  $\frac{1}{T}$  is shown below.

Determine the activation energy to **three** significant figures, including units.

[3]



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2. (a) State the **full** electron configurations of copper, Cu, and copper(II) ion,  $\text{Cu}^{2+}$ . [2]

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- (b)  $\text{Cu}^{2+}(\text{aq})$  reacts with ammonia to form the complex ion  $[\text{Cu}(\text{NH}_3)_4]^{2+}$ . Explain this reaction in terms of acid-base theory, and outline the bonding in the complex formed between  $\text{Cu}^{2+}$  and  $\text{NH}_3$ . [3]

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- (c) Explain why complexes of  $\text{Zn}^{2+}(\text{aq})$  are colourless whereas complexes of  $\text{Cu}^{2+}(\text{aq})$  are coloured. [4]

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3. Propane,  $C_3H_8(g)$ , undergoes complete combustion to form carbon dioxide,  $CO_2(g)$ , and water,  $H_2O(g)$ .

(a) State an equation for the complete combustion of propane,  $C_3H_8(g)$ . [1]

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(b) Calculate the standard enthalpy change for the reaction in part (a) using bond enthalpy values given in table 10 of the data booklet. [3]

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4. (a) The monomers hexanedioic acid and 1,6-diaminohexane react together to form a synthetic polymer.

Deduce the structural formula of each monomer.

[2]

- (b) State the type of polymerization reaction that occurs between these two monomers and identify the structural feature needed in the monomers.

[2]

Type:

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Structural feature:

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- (c) Draw the structure of the linkage formed in this polymer, and identify the other product of this polymerization reaction.

[2]

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5. (a) (i) Define the term electronegativity. [1]

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- (ii) Suggest why the noble gases are generally not assigned electronegativity values. [1]

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- (b) Explain why the melting points of the group 1 metals (Li → Cs) decrease down the group whereas the melting points of the group 7 elements (F → I) increase down the group. [3]

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- (c) Outline **one** reason why the sodium ion, Na<sup>+</sup>, has a smaller radius than the sodium atom. [1]

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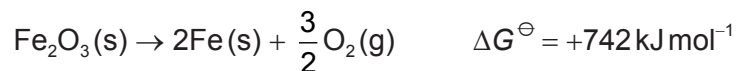


## Section B

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

6. Iron(III) oxide is the main source of iron but the decomposition of  $\text{Fe}_2\text{O}_3(\text{s})$  into its elements is extremely difficult due to a large positive value of  $\Delta G^\ominus$ .

- (a) Consider the following reactions:



Suggest, with a reason, whether it is possible to produce iron by reacting  $\text{Fe}_2\text{O}_3$  with CO. [2]

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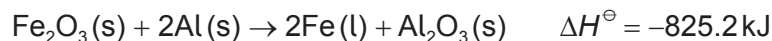
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- (b) The thermite reaction is one of the most exothermic reactions.



Species	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$	$\Delta G_f^\ominus / \text{kJ mol}^{-1}$
Al(s)	+28.3	0
$\text{Al}_2\text{O}_3(\text{s})$	+50.9	-1582
Fe(l)	+34.8	+10.0
$\text{Fe}_2\text{O}_3(\text{s})$	+87.5	-742

- (i) Calculate the standard free energy change,  $\Delta G^\ominus$ , in  $\text{kJ mol}^{-1}$ , by using values of the standard free energy change of formation,  $\Delta G_f^\ominus$ , from the table above. [2]

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**(Question 6 continued)**

- (ii) Calculate the standard entropy change,  $\Delta S^\ominus$ , in  $\text{JK}^{-1}\text{mol}^{-1}$ , by using values of standard entropy,  $S^\ominus$ , from the table. [1]

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- (iii) Calculate the standard free energy change,  $\Delta G^\ominus$ , for the reaction using  $\Delta H^\ominus$  and  $\Delta S^\ominus$  values at  $25^\circ\text{C}$ . [2]

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- (c) (i) Deduce the type of hybridization shown by the nitrogen atoms in  $\text{NF}_4^+$ ,  $\text{N}_2\text{H}_2$  and  $\text{N}_2\text{H}_4$ . [3]

	$\text{NF}_4^+$	$\text{N}_2\text{H}_2$	$\text{N}_2\text{H}_4$
Hybridization	.....	.....	.....

- (ii) Describe how sigma ( $\sigma$ ) and pi ( $\pi$ ) bonds form. [2]

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**(Question 6 continued)**

- (iii) Draw the Lewis (electron dot) structures of SF<sub>4</sub> and SF<sub>6</sub>. Use the valence shell electron pair repulsion (VSEPR) theory to predict the name of the shape of each molecule. [4]

- (d) (i) List the following compounds in order of **increasing** boiling point:  
CH<sub>3</sub>CHO, CH<sub>3</sub>CH<sub>2</sub>CH<sub>3</sub>, CH<sub>3</sub>COOH, CH<sub>3</sub>CH<sub>2</sub>OH. [2]

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- (ii) Explain the order of boiling points in the compounds listed in part (d) (i), in terms of intermolecular forces. [4]

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**(Question 6 continued)**

- (e) In the operation of a mass spectrometer, the first stage is vaporization and the last is detection. State the names of the other three stages and outline what happens in each one.

[3]

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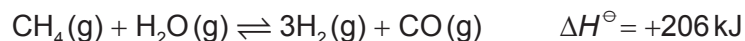
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7. (a) The following reaction is used in industry to obtain hydrogen from natural gas by partial oxidation with steam.



- (i) Describe the effect, if any, of each of the following changes on the equilibrium amount of hydrogen, giving a reason in each case. [4]

Increasing the pressure, at constant temperature:

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Increasing the temperature, at constant pressure:

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- (ii) Discuss the effects of adding a solid catalyst to the mixture of methane and steam, at constant pressure and temperature. [3]

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- (iii) Deduce the equilibrium constant expression,  $K_c$ , for the reaction. [1]

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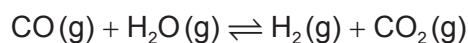


**(Question 7 continued)**

- (iv) Identify which of the changes in part (a) (i) will affect the value of  $K_c$  and whether the value will increase or decrease. [1]

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- (b) The equilibrium constant,  $K_c$ , for the reaction



was found to be 10.0 at 420°C.

1.00 mol of CO(g) and 1.00 mol of H<sub>2</sub>O(g) are mixed in a 1.00 dm<sup>3</sup> container at 420°C. Calculate the equilibrium concentration of each component in the mixture, showing your working. [3]

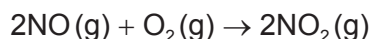
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**(Question 7 continued)**

- (c) The oxidation of nitrogen monoxide takes place as follows:



The following experimental data was obtained at 101.3 kPa and 298 K.

Experiment	Initial [NO] / mol dm <sup>-3</sup>	Initial [O <sub>2</sub> ] / mol dm <sup>-3</sup>	Initial rate / mol dm <sup>-3</sup> s <sup>-1</sup>
1	$2.30 \times 10^{-2}$	$1.15 \times 10^{-2}$	$1.05 \times 10^{-3}$
2	$2.30 \times 10^{-2}$	$2.30 \times 10^{-2}$	$2.09 \times 10^{-3}$
3	$4.60 \times 10^{-2}$	$4.60 \times 10^{-2}$	$1.68 \times 10^{-2}$

- (i) Deduce the orders of reaction with respect to O
- <sub>2</sub>
- and NO. [2]

Order with respect to O<sub>2</sub>:

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Order with respect to NO:

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

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- (iii) Calculate the value of the rate constant,
- k*
- , and include its units. [2]

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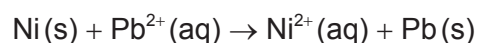
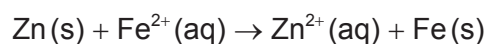
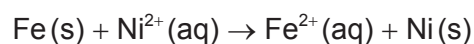


**(Question 7 continued)**

- (iv) Suggest a mechanism that is consistent with the rate expression, indicating the rate-determining step. [3]

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- (d) Consider the following spontaneous reactions.



- (i) Deduce the order of **increasing** reactivity of the metals based on the reactions above. [2]

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- (ii) Identify the strongest oxidizing agent in the reactions above. [1]

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**(Question 7 continued)**

- (e) Deduce the half-equations for the formation of the major product at the positive electrode (anode) when the following aqueous solutions are electrolysed.

[2]

Dilute sodium chloride:

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Concentrated sodium chloride:

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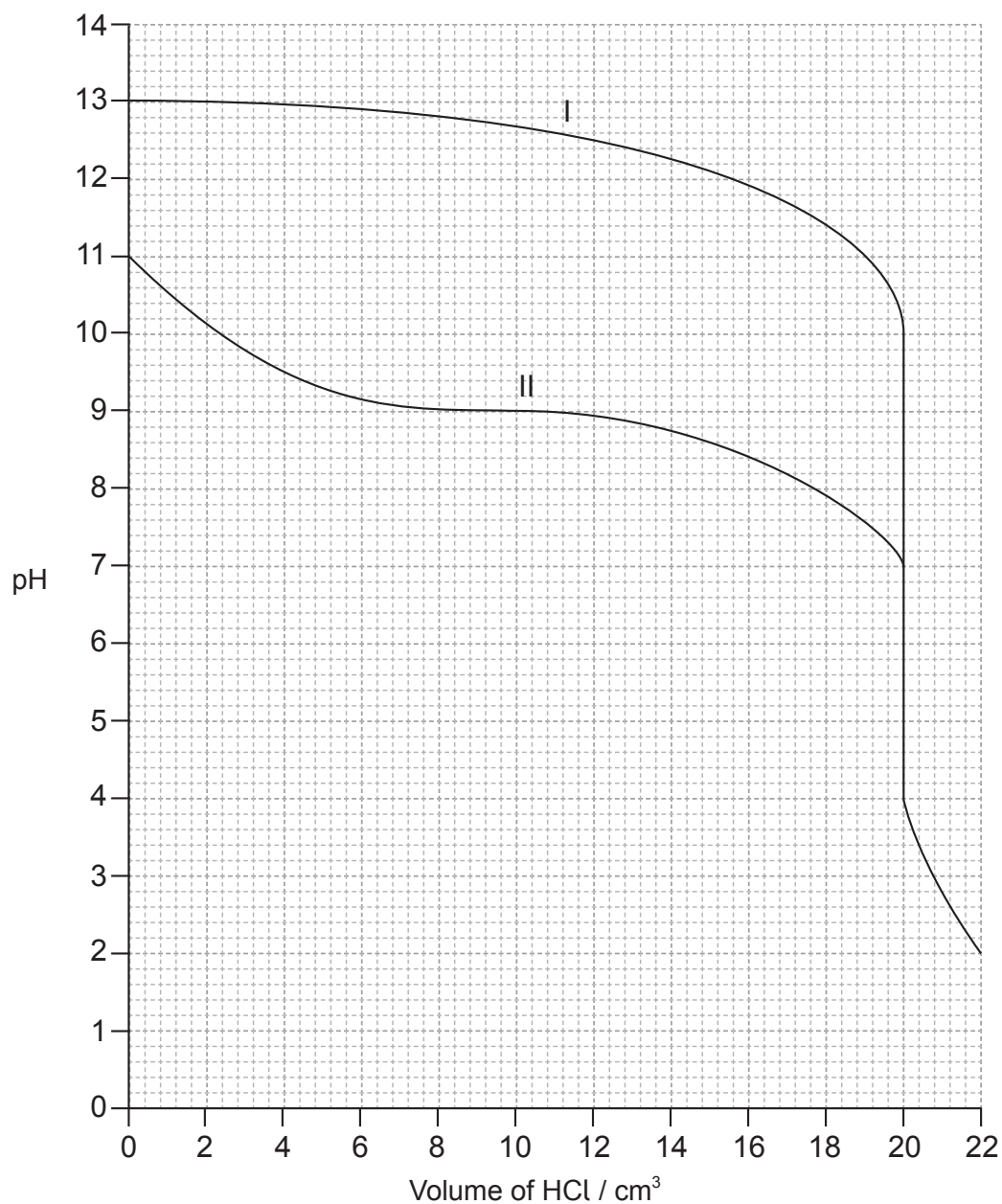
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28EP19

Turn over

8. (a)  $20.0 \text{ cm}^3$  aqueous solutions of two bases, each with a concentration of  $0.100 \text{ mol dm}^{-3}$  were separately titrated with  $0.100 \text{ mol dm}^{-3}$  hydrochloric acid,  $\text{HCl}(\text{aq})$ , and the following graph was obtained.



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**(Question 8 continued)**

- (i) Deduce the pH at the equivalence points for base I and base II. [2]

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- (ii) Suggest why the titration curve for base I is different from base II. [1]

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- (iii) State the formulas of **two** possible bases which could be used as base I. [1]

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- (iv) Calculate, using data from the graph, the dissociation constant,  $K_b$ , of base II, showing your working. [3]

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- (v) Suggest an indicator that can be used for both titrations. [1]

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28EP21

Turn over

**(Question 8 continued)**

- (b) (i) State what is meant by the term buffer solution. [2]

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- (ii) Calculate the pH of a solution prepared by mixing 40.0 cm<sup>3</sup> of 0.200 mol dm<sup>-3</sup> NH<sub>3</sub>(aq) and 40.0 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> HCl(aq), showing your working. (pK<sub>b</sub> NH<sub>3</sub> = 4.75 at 298 K) [3]

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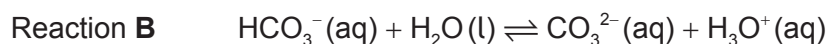
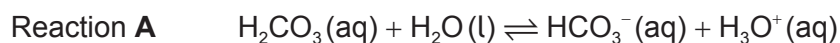
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- (c) The equations of two acid-base reactions are given below.



- (i) Explain whether HCO<sub>3</sub><sup>-</sup>(aq) behaves as an acid or a base in each of the reactions **A** and **B**. [2]

Reaction **A**:

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Reaction **B**:

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**(Question 8 continued)**

- (ii) Deduce **two** conjugate acid-base pairs from reactions **A** and **B**. [2]

	Acid	Base
<b>Conjugate acid-base pair 1</b>	.....	.....
<b>Conjugate acid-base pair 2</b>	.....	.....

- (d) Nitric acid,  $\text{HNO}_3$ , and nitrous acid,  $\text{HNO}_2$ , are described as strong and weak acids respectively.

- (i) Distinguish between *strong* and *weak* acids. [1]

<p>.....</p> <p>.....</p> <p>.....</p>
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- (ii) A 1.00 g sample of solid magnesium carbonate,  $\text{MgCO}_3$ , is added to separate solutions of  $\text{HNO}_3$  and  $\text{HNO}_2$  of the same concentration and temperature. State **one** similarity and **one** difference in the observations made in these reactions. [2]

<p>Similarity:</p> <p>.....</p> <p>.....</p> <p>Difference:</p> <p>.....</p> <p>.....</p>
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**(Question 8 continued)**

- (iii) A solution of  $\text{HNO}_3$  has a pH of 1, while a solution of  $\text{HNO}_2$  has a pH of 5.  
Determine the ratio of the hydrogen ion concentration in  $\text{HNO}_3:\text{HNO}_2$ . [1]

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- (e) (i) State the acid-base character of the oxides of the period 3 elements Na to Ar. [2]

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- (ii) State balanced equations to illustrate the acid-base character of sodium oxide and sulfur trioxide. [2]

Sodium oxide:  
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Sulfur trioxide:  
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9. (a) A 0.842g sample of a liquid halogenoalkane, RBr(l), was heated under reflux with  $1.35 \times 10^{-2}$  mol of aqueous sodium hydroxide, NaOH(aq). After cooling the mixture, the excess NaOH was titrated with hydrochloric acid, HCl(aq), and required  $7.36 \times 10^{-3}$  mol of the acid.

- (i) State the equation for the substitution reaction of the halogenoalkane with sodium hydroxide. [1]

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- (ii) Calculate the amount, in mol, of sodium hydroxide that reacted with the halogenoalkane. [1]

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- (iii) Calculate the molar mass of the halogenoalkane. [1]

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- (iv) Given that each molecule of the halogenoalkane contains one bromine atom, determine its molecular formula. [1]

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**(Question 9 continued)**

- (v) Deduce the structural formulas of **four** structural isomers of the halogenoalkane based on the molecular formula **and** label each isomer as primary, secondary or tertiary. [4]  
(If you have not been able to determine the molecular formula in part (a) (iv), use  $C_5H_{11}Br$  to deduce the four structural isomers.)

- (b) The reaction between a primary halogenoalkane drawn in part (a) (v) and potassium cyanide follows a  $S_N2$  mechanism.

- (i) State the importance of this reaction in organic synthesis. [1]

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



**(Question 9 continued)**

- (ii) Explain the mechanism of the reaction using curly arrows to represent the movement of electron pairs. [4]

- (iii) The organic product obtained in part (b) (ii) can be reduced to form an amine. State an equation for this reaction and a suitable catalyst. [2]

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- (c) The reaction between the primary halogenoalkane, obtained in part (a) (v), and hot, concentrated alcoholic NaOH is an example of an elimination reaction.

- (i) Explain the mechanism of the elimination reaction using curly arrows to represent the movement of electron pairs. [4]

(This question continues on the following page)



**(Question 9 continued)**

- (ii) Under certain conditions, the major product obtained in the elimination reaction can undergo polymerization. Identify the type of polymerization and draw a section of the polymer consisting of **two** repeating units. [2]

Type of polymerization:

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Section of polymer:

- (d) Ethane can react with chlorine. Explain the free-radical mechanism of this reaction, including any necessary reaction conditions. [4]

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