

**Chemistry**
Higher level
Paper 2

Friday 13 November 2015 (afternoon)

Candidate session number

2 hours 15 minutes

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Instructions to candidates

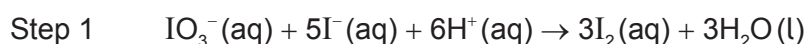
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry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



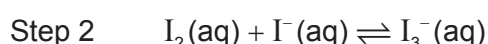
Section A

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

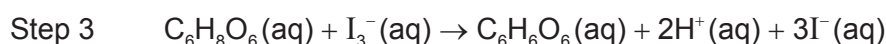
1. A student used the technique of titration to determine the concentration of ascorbic acid ($C_6H_8O_6$) in a sample of orange juice. Excess potassium iodide, $KI(aq)$, was added to acidified orange juice. The resulting solution was titrated with potassium iodate, $KIO_3(aq)$, in the presence of starch 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 dm^3 of a $2.00 \times 10^{-3} \text{ mol dm}^{-3}$ solution. [2]

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- (c) The concentration of KIO_3 used in the titration was $2.00 \times 10^{-3} \text{ mol dm}^{-3}$. The titration produced the following results.

| | Titration 1 | Titration 2 | Titration 3 |
|---|--------------------|--------------------|--------------------|
| 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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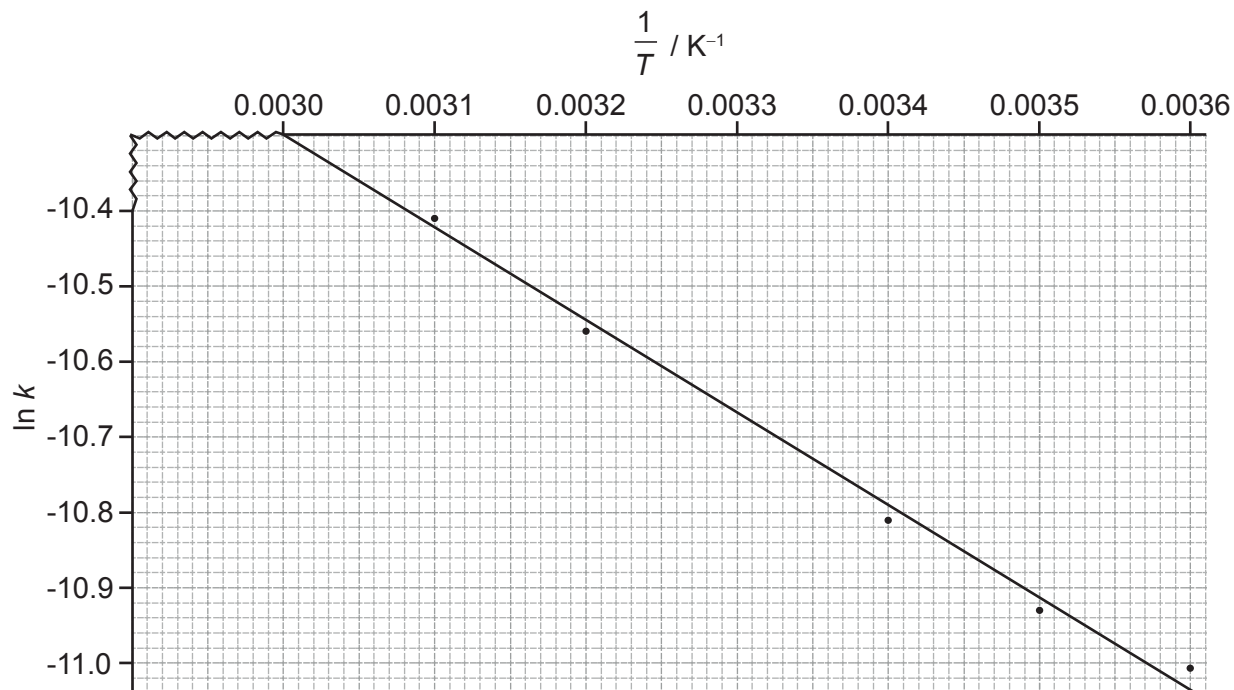


(Question 1 continued)

- (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, 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 Cu^{2+} and 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⁺, has a smaller radius than the sodium atom. [1]

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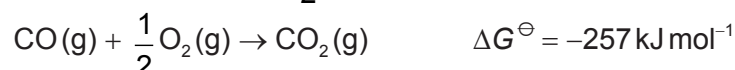
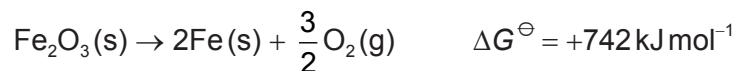


Section B

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 ΔG^\ominus .

- (a) Consider the following reactions:



Suggest, with a reason, whether it is possible to produce iron by reacting Fe_2O_3 with CO. [2]

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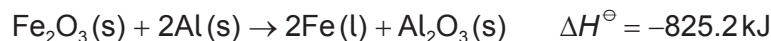
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- (b) The thermite reaction is one of the most exothermic reactions.



| 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, ΔG^\ominus , in kJ mol^{-1} , by using values of the standard free energy change of formation, ΔG_f^\ominus , from the table above. [2]

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(Question 6 continued)

- (ii) Calculate the standard entropy change, ΔS^\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, ΔG^\ominus , for the reaction using ΔH^\ominus and ΔS^\ominus values at 25°C . [2]

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- (c) (i) Deduce the type of hybridization shown by the nitrogen atoms in NF_4^+ , N_2H_2 and N_2H_4 . [3]

| | NF_4^+ | N_2H_2 | N_2H_4 |
|---------------|-----------------|------------------------|------------------------|
| Hybridization | | | |

- (ii) Describe how sigma (σ) and pi (π) bonds form. [2]

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(Question 6 continued)

- (iii) Draw the Lewis (electron dot) structures of SF₄ and SF₆. 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:
CH₃CHO, CH₃CH₂CH₃, CH₃COOH, CH₃CH₂OH. [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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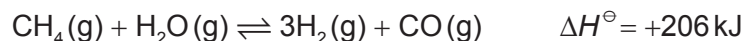
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7. (a) The following reaction is used in industry to obtain hydrogen from natural gas by partial oxidation with steam.



- (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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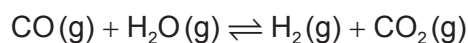


(Question 7 continued)

- (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 H₂O(g) are mixed in a 1.00 dm³ container at 420°C. Calculate the equilibrium concentration of each component in the mixture, showing your working. [3]

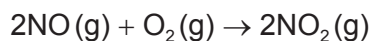
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(Question 7 continued)

- (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 ⁻³ | Initial [O ₂] / mol dm ⁻³ | Initial rate / mol dm ⁻³ s ⁻¹ |
|------------|--|---|--|
| 1 | 2.30×10^{-2} | 1.15×10^{-2} | 1.05×10^{-3} |
| 2 | 2.30×10^{-2} | 2.30×10^{-2} | 2.09×10^{-3} |
| 3 | 4.60×10^{-2} | 4.60×10^{-2} | 1.68×10^{-2} |

- (i) Deduce the orders of reaction with respect to O
- ₂
- and NO.

[2]

Order with respect to O₂:

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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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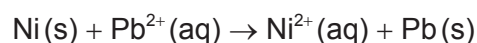
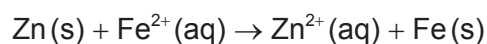
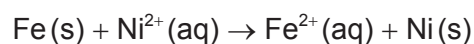


(Question 7 continued)

- (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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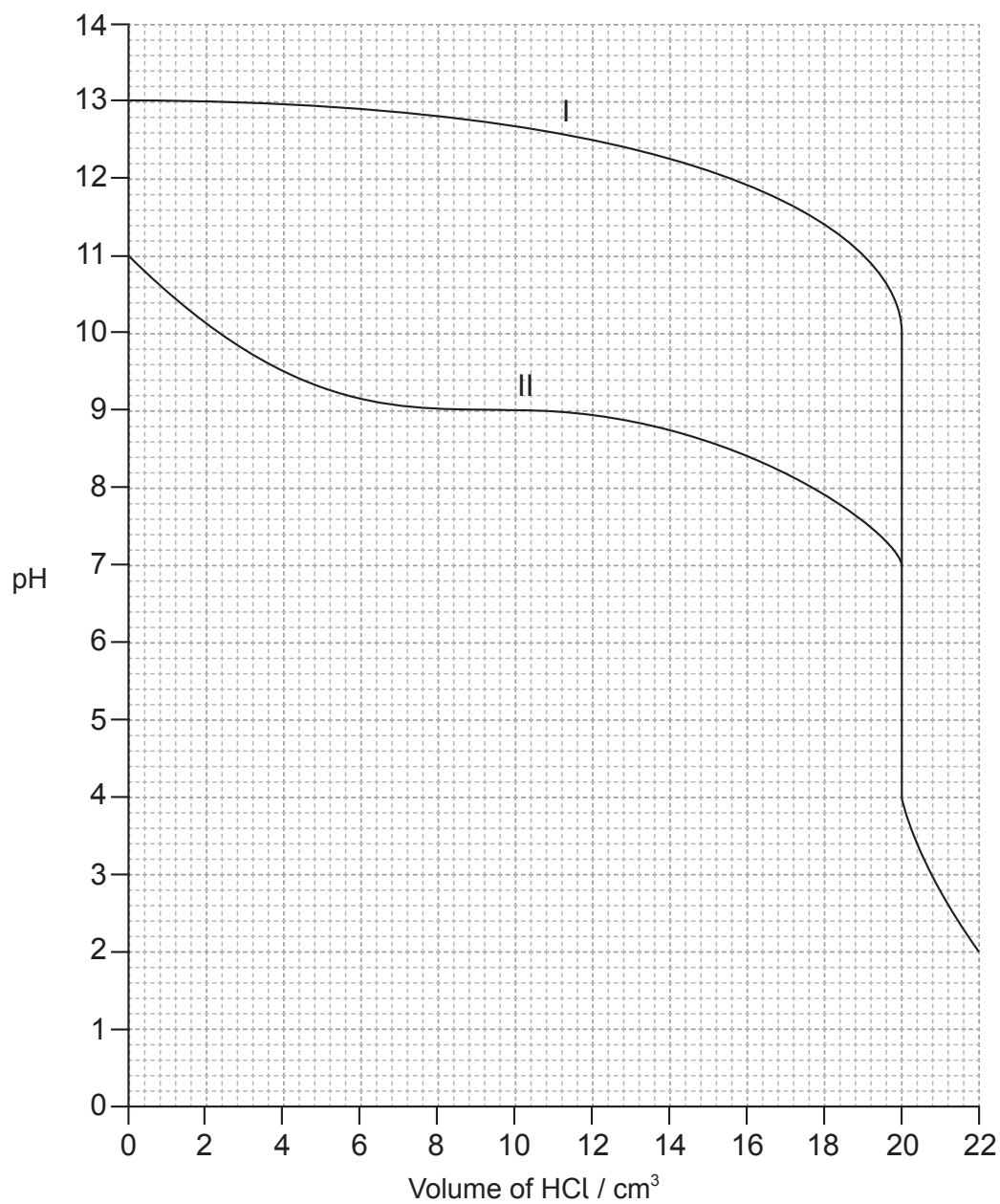
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will not be marked.



28EP19

Turn over

8. (a) 20.0 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 cm³ of 0.200 mol dm⁻³ NH₃(aq) and 40.0 cm³ of 0.100 mol dm⁻³ HCl(aq), showing your working. (pK_b NH₃ = 4.75 at 298 K) [3]

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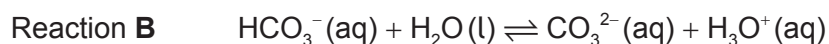
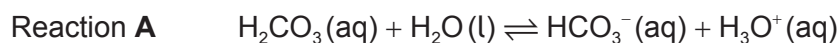
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- (c) The equations of two acid-base reactions are given below.



- (i) Explain whether HCO₃⁻(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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(This question continues on the following page)



(Question 8 continued)

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

| | Acid | Base |
|-----------------------------------|-------|-------|
| Conjugate acid-base pair 1 | | |
| Conjugate acid-base pair 2 | | |

- (d) Nitric acid, HNO_3 , and nitrous acid, HNO_2 , are described as strong and weak acids respectively.

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

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- (ii) A 1.00 g sample of solid magnesium carbonate, MgCO_3 , is added to separate solutions of HNO_3 and HNO_2 of the same concentration and temperature. State **one** similarity and **one** difference in the observations made in these reactions. [2]

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| Similarity: Difference: |
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(Question 8 continued)

- (iii) A solution of HNO_3 has a pH of 1, while a solution of 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 1.35×10^{-2} mol of aqueous sodium hydroxide, $NaOH(aq)$. After cooling the mixture, the excess $NaOH$ was titrated with hydrochloric acid, $HCl(aq)$, and required 7.36×10^{-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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