

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

Thursday 14 May 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]**.

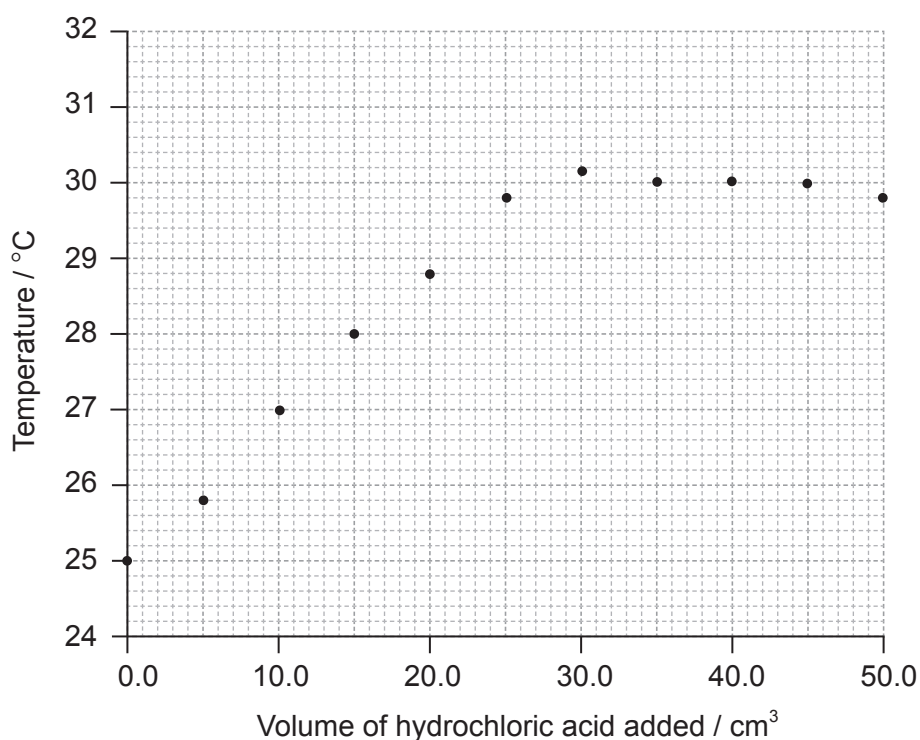


**Section A**

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

1. A student carried out an experiment to determine the concentration of a hydrochloric acid solution and the enthalpy change of the reaction between aqueous sodium hydroxide and this acid by thermometric titration.

She added  $5.0\text{ cm}^3$  portions of hydrochloric acid to  $25.0\text{ cm}^3$  of  $1.00\text{ mol dm}^{-3}$  sodium hydroxide solution in a glass beaker until the total volume of acid added was  $50.0\text{ cm}^3$ , measuring the temperature of the mixture each time. Her results are plotted in the graph below.



The initial temperature of both solutions was the same.

- (a) (i) By drawing appropriate lines, determine the volume of hydrochloric acid required to completely neutralize the  $25.0\text{ cm}^3$  of sodium hydroxide solution. [2]

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**(Question 1 continued)**

- (ii) Determine the concentration of the hydrochloric acid, including units. [2]

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- (b) (i) Determine the change in temperature,  $\Delta T$ . [1]

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- (ii) Calculate the enthalpy change, in  $\text{kJ mol}^{-1}$ , for the reaction of hydrochloric acid and sodium hydroxide solution. [3]

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- (iii) The accepted theoretical value from the literature of this enthalpy change is  $-58 \text{ kJ mol}^{-1}$ . Calculate the percentage error correct to **two** significant figures. [1]

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(Question 1 continued)

- (iv) Suggest the major source of error in the experimental procedure **and** an improvement that could be made to reduce it.

[2]

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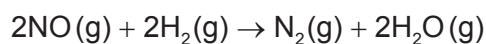
2. (a) Define the term *rate of reaction*. [1]

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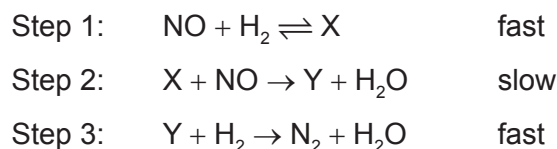
- (b) Explain why increasing the particle size of a solid reactant decreases the rate of reaction. [2]

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- (c) Nitrogen(II) oxide reacts with hydrogen according to the equation below.



A suggested mechanism for this reaction is:



- (i) Identify the rate-determining step. [1]

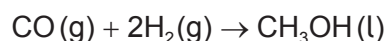
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- (ii) A student hypothesized that the order of reaction with respect to  $\text{H}_2$  is 2. Evaluate this hypothesis. [2]

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3. Carbon monoxide reacts with hydrogen to produce methanol.



Substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$\Delta G_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J mol}^{-1} \text{K}^{-1}$
CO (g)	- 110.5	- 137.2	+ 197.6
CH <sub>3</sub> OH (l)	- 239.0	- 166.0	+ 126.8

- (a) Calculate the standard enthalpy change,  $\Delta H^\ominus$ , in  $\text{kJ mol}^{-1}$ , for the reaction. [1]

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- (b) Calculate the standard free energy change,  $\Delta G^\ominus$ , in  $\text{kJ mol}^{-1}$ , for the reaction ( $\Delta G_f^\ominus(\text{H}_2) = 0 \text{ kJ mol}^{-1}$ ). [1]

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- (c) Using the values obtained in parts (a) and (b), calculate the standard entropy change,  $\Delta S^\ominus$ , in  $\text{J mol}^{-1} \text{K}^{-1}$ , for the reaction at 298 K. [1]

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- (d) Determine the absolute entropy,  $S^\ominus$ , in  $\text{J mol}^{-1} \text{K}^{-1}$ , for  $\text{H}_2(\text{g})$  at 298 K. [2]

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4. A buffer solution with a pH of 3.87 contains  $7.41 \text{ g dm}^{-3}$  of propanoic acid,  $\text{CH}_3\text{CH}_2\text{COOH}$ , together with an unknown quantity of sodium propanoate,  $\text{CH}_3\text{CH}_2\text{COONa}$ .

(a) Define the term *buffer solution*.

[2]

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(b) Explain, using appropriate equations, how this solution acts as a buffer solution.

[2]

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(c) Calculate the concentration, in  $\text{mol dm}^{-3}$ , of sodium propanoate in this buffer solution. The  $\text{p}K_{\text{a}}$  of propanoic acid is 4.87 at 298 K.

[4]

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5. (a) State **two** features of a homologous series. [2]

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- (b) Ethane, a member of the homologous series of alkanes, can react with bromine. Explain the free-radical mechanism of this reaction, including any necessary reaction conditions. [4]

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6. Electrolysis is an important industrial process used to obtain very reactive elements from their common ores.

- (a) Molten magnesium chloride can be electrolysed using inert graphite electrodes at 800 °C.

Deduce the half-equations, including state symbols, for the reactions occurring at each electrode. (The melting points of  $\text{MgCl}_2$  and  $\text{Mg}$  are 714 °C and 649 °C respectively.)

[3]

Positive electrode (anode):

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Negative electrode (cathode):

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- (b) Aluminium can also be obtained by electrolysis. Suggest **one** reason why aluminium is often used instead of iron by engineers.

[1]

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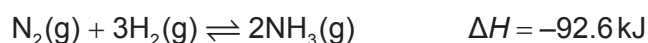
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**Section B**

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

7. When nitrogen gas and hydrogen gas are allowed to react in a closed container the following equilibrium is established.



- (a) (i) Outline **two** characteristics of a reversible reaction in a state of dynamic equilibrium.

[2]

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- (ii) Predict, with a reason, how each of the following changes affects the position of equilibrium.

[2]

The volume of the container is increased.

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Ammonia is removed from the equilibrium mixture.

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- (iii) Define the term *activation energy*,  $E_a$ .

[1]

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**(Question 7 continued)**

- (b) Ammonia is manufactured by the Haber process in which iron is used as a catalyst. Explain the effect of a catalyst on the rate of reaction. [2]

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- (c) Typical conditions used in the Haber process are 500 °C and 200 atm, resulting in approximately 15% yield of ammonia.

- (i) Explain why a temperature lower than 500 °C is **not** used. [2]

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- (ii) Outline why a pressure higher than 200 atm is **not** often used. [1]

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



**(Question 7 continued)**

- (d) (i) Deduce the equilibrium constant expression,  $K_c$ , for the reaction on page 10. [1]

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- (ii) When 1.00 mol of nitrogen and 3.00 mol of hydrogen were allowed to reach equilibrium in a 1.00 dm<sup>3</sup> container at a temperature of 500 °C and a pressure of 1000 atm, the equilibrium mixture contained 1.46 mol of ammonia.

Calculate the value of  $K_c$  at 500 °C. [2]

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- (e) (i) Define the term *base* according to the Lewis theory. [1]

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- (ii) Define the term *weak base* according to the Brønsted–Lowry theory. [1]

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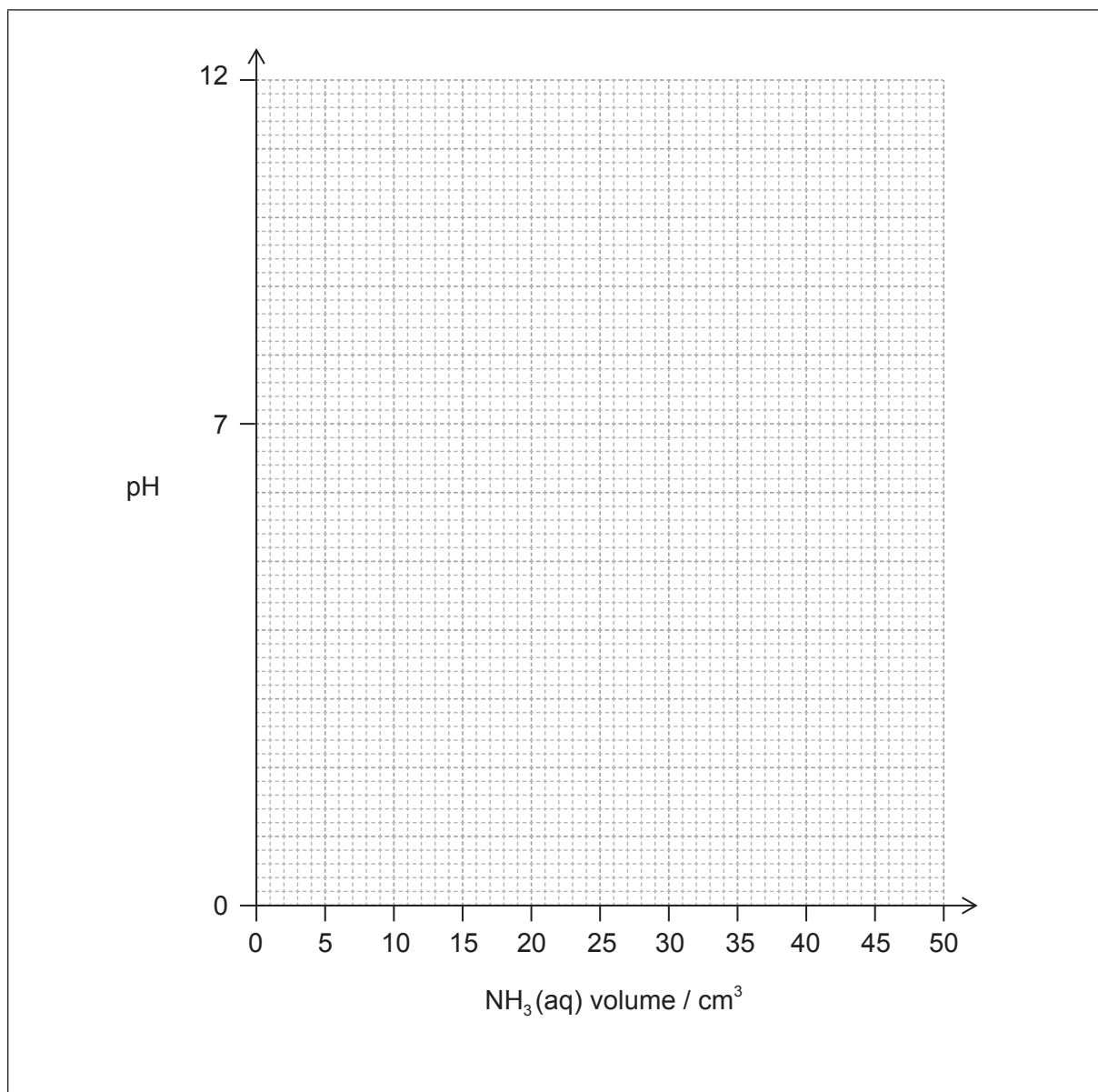




## (Question 7 continued)

- (g) (i) Sketch the pH titration curve obtained when  $50.0 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3} \text{ NH}_3(\text{aq})$  is added to  $25.0 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3} \text{ HCl}(\text{aq})$ .

[3]



- (ii) Identify an indicator from table 16 of the data booklet that could be used for this titration.

[1]

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8. Chromium is a transition metal with many uses.

- (a) (i) Draw an orbital diagram (using the arrow-in-box notation) showing the electrons in the 4s and 3d sub-levels in chromium metal. [1]

- (ii) Outline the nature of the metallic bonding present in chromium. [1]

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- (iii) Explain why chromium metal is malleable. [1]

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- (b) (i) State the name of  $\text{Cr}_2\text{O}_3$ . [1]

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- (ii) Describe the ionic bonding present in  $\text{Cr}_2\text{O}_3$  and how the ions are formed. [2]

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**(Question 8 continued)**

- (iii) Suggest why solid  $\text{Cr}_2\text{O}_3$  does **not** conduct electricity. [1]

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- (c) Chromium forms the complex ion  $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]^+$ .

- (i) Deduce the oxidation number of chromium in this complex. [1]

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- (ii) Describe the nature of the ligand-chromium ion bonds in terms of acid-base theory. [2]

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- (iii) Explain why  $[\text{Cr}(\text{NH}_3)_4\text{Cl}_2]^+$  is coloured. [4]

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**(Question 8 continued)**

- (iv) Draw the structures of **two** possible isomers of this complex ion. [2]

- (d) (i) The dichromate ion,  $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ , and the iodide ion,  $\text{I}^-(\text{aq})$ , react together in the presence of an acid to form  $\text{Cr}^{3+}(\text{aq})$  and  $\text{IO}_3^-(\text{aq})$  ions. Deduce the half-equation for the reaction of  $\text{I}^-$  to  $\text{IO}_3^-$  and the overall equation for this reaction. [2]

Half-equation:

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Overall equation:

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- (ii) Explain in terms of oxidation numbers whether iodine is oxidized or reduced in part (d) (i). [1]

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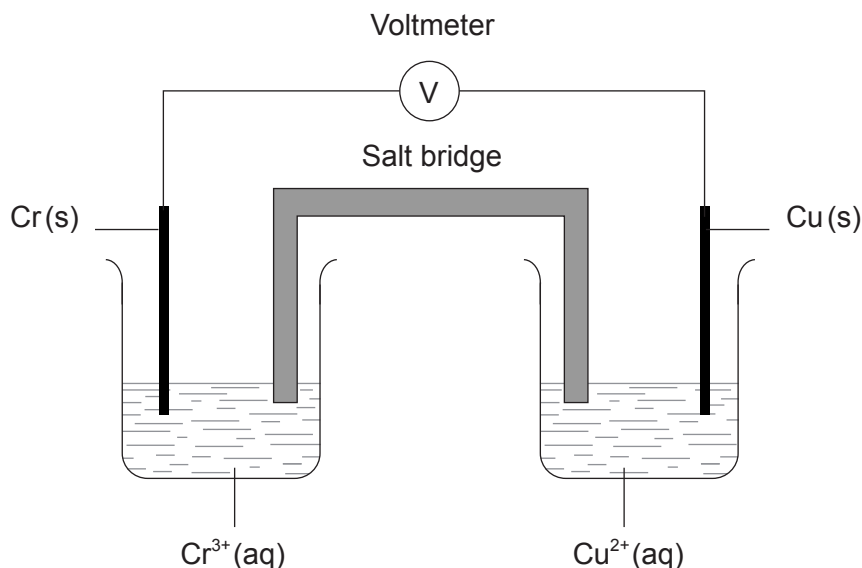
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## (Question 8 continued)

- (e) A voltaic cell is constructed as follows. One half-cell contains a chromium electrode immersed in a solution containing  $\text{Cr}^{3+}(\text{aq})$  ions. The other half-cell contains a copper electrode immersed in a solution containing  $\text{Cu}^{2+}(\text{aq})$  ions. The two electrodes are connected to a voltmeter and the two solutions by a salt bridge.



- (i) Define the term *standard electrode potential*. [1]

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- (ii) Calculate the cell potential, in V, under standard conditions, for this voltaic cell, using table 14 of the data booklet and  $E^{\ominus}_{\text{Cr}^{3+}/\text{Cr}} = -0.74 \text{ V}$ . [1]

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**(Question 8 continued)**

- (iii) Predict the balanced equation for the spontaneous reaction which will produce a current in this voltaic cell. [1]

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- (iv) Identify the negative and the positive electrodes in this cell. [1]

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- (v) Predict the direction of movement of electrons in the external circuit. [1]

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- (vi) State the directions in which the negative ions (anions) and the positive ions (cations) flow in the salt bridge. [1]

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9. (a) Consider the structure and bonding in  $\text{MgCl}_2$  and  $\text{PCl}_3$ .

(i) State and explain the electrical conductivities of these two chloride compounds in their liquid state. [3]

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(ii) Suggest, giving your reasons, the approximate pH values of the solutions formed by adding each chloride compound separately to distilled water. [4]

$\text{MgCl}_2$ :

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$\text{PCl}_3$ :

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(b) (i) Identify the acid-base character of the oxides of each of the elements from sodium to chlorine in period 3. [2]

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**(Question 9 continued)**

- (ii) State the equations for the separate reactions of sodium oxide and phosphorus(V) oxide with water. [2]

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- (c) Consider the molecules  $\text{PBr}_3$  and  $\text{SF}_4$ .

- (i) Deduce the Lewis (electron dot) structure of both molecules. [2]

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- (ii) Predict the shapes of the two molecules, giving the  $\text{Br-P-Br}$  bond angle in  $\text{PBr}_3$  and the  $\text{F-S-F}$  bond angles in  $\text{SF}_4$ . [4]

$\text{PBr}_3$	$\text{SF}_4$
Shape:	Shape:
.....	.....
.....	.....
Bond angle:	Bond angles:
.....	.....
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## (Question 9 continued)

(iii) Explain why both  $\text{PBr}_3$  and  $\text{SF}_4$  are polar.

[2]

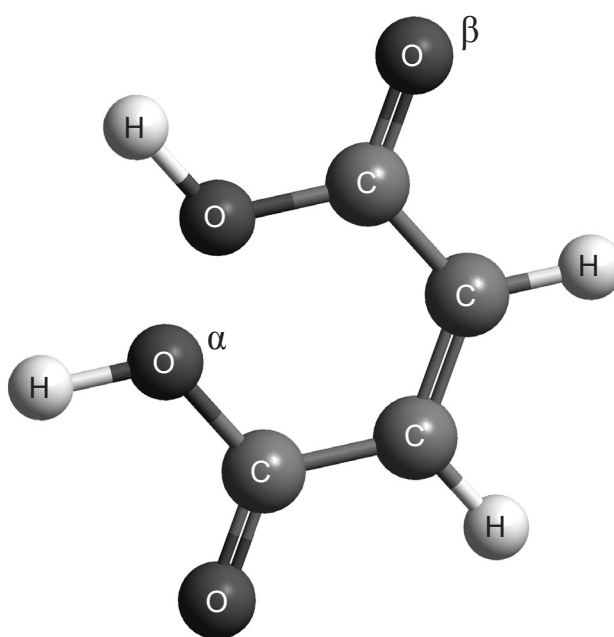
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(d) The structure of *cis*-but-2-ene-1,4-dioic acid is shown below.



(i) Describe the covalent bond between carbon and hydrogen in the molecule above and how it is formed.

[2]

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(This question continues on the following page)



**(Question 9 continued)**

- (ii) Deduce the hybridization of the oxygen atoms labelled  $\alpha$  and  $\beta$ . [1]

$\alpha$ :  
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$\beta$ :  
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- (iii) Describe sigma ( $\sigma$ ) and pi ( $\pi$ ) bonds between atoms. [2]

$\sigma$  bond:  
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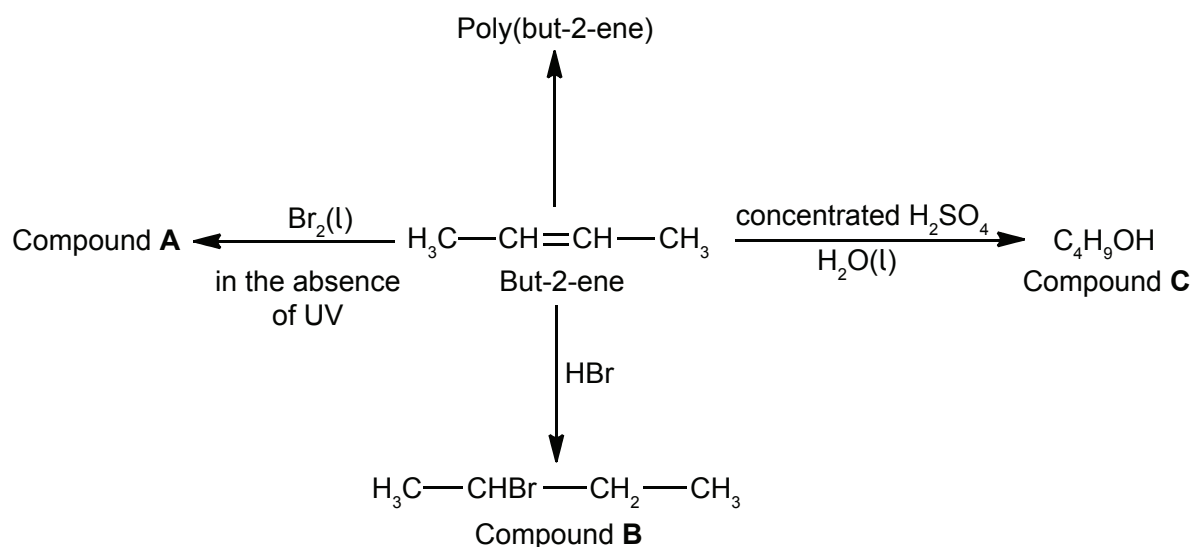
$\pi$  bond:  
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- (iv) Identify the number of sigma ( $\sigma$ ) and pi ( $\pi$ ) bonds present in a molecule of *cis*-but-2-ene-1,4-dioic acid. [1]

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10. Some reactions of but-2-ene are given below.



- (a) (i) Deduce the full structural formula of compound **A**. [1]

- (ii) Apply IUPAC rules to name compound **A**. [1]

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- (iii) Describe the colour change observed when excess but-2-ene reacts with bromine to form compound **A**. [1]

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**(Question 10 continued)**

- (b) (i) Outline **two** reasons why the polymerization of alkenes is of economic importance. [2]

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- (ii) Identify the structure of the repeating unit of poly(but-2-ene). [1]

- (c) (i) Compound **C**,  $C_4H_9OH$ , can also be formed by reacting compound **B**,  $CH_3CHBrCH_2CH_3$ , with aqueous potassium hydroxide. This reaction proceeds by both  $S_N1$  and  $S_N2$  mechanisms. Explain the  $S_N2$  mechanism, using curly arrows to represent the movement of electron pairs. [4]

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## (Question 10 continued)

- (ii) Explain why the hydroxide ion is a better nucleophile than water. [2]

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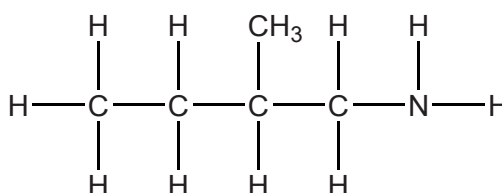
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- (d) (i) Compound **B**,  $\text{CH}_3\text{CHBrCH}_2\text{CH}_3$ , also reacts with potassium cyanide. Apply IUPAC rules to name the organic product formed. [1]

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- (ii) The organic product of the reaction in part (d) (i) can be reduced to:



- State the **two** reagents required. [1]

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- (iii) Deduce the full structural formula of the organic product formed when the compound in part (d) (ii) reacts with ethanoic acid in the presence of an acid catalyst. [1]

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(This question continues on the following page)



**(Question 10 continued)**

(e) Compound **C**,  $C_4H_9OH$ , can be oxidized by acidified potassium dichromate(VI) to form compound **F**.

(i) State the name of the functional group present in compound **F**. [1]

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(ii) Deduce the structural formula of an alcohol which is a structural isomer of compound **C** and **cannot** be oxidized by acidified potassium dichromate(VI). [1]

(f) Explain why but-2-ene is more volatile than compound **C**. [2]

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(g) Deduce the equation for the complete combustion of compound **C**. [1]

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



**(Question 10 continued)**

(h) But-2-ene can exist as two geometrical isomers. Geometrical isomerism is a form of stereoisomerism.

(i) Define the term *stereoisomers*.

[1]

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(ii) State the conditions needed for a compound to show geometrical isomerism.

[2]

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(iii) Draw the structures of the two geometrical isomers of but-2-ene, clearly identifying each as *cis* or *trans*.

[2]

