Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

19 May 2025

Zone A morning | **Zone B** morning | **Zone C** morning

Candidate session number

2 hours 30 minutes

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.

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Iron(II) sulfide can be produced by heating powdered iron and sulfur together.

(a) Describe the difference between an element and a compound. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Outline why solid iron(II) sulfide is a polar covalent compound. Use sections 9 and 17 of the data booklet. [1]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) Contrast **one** physical property of iron and iron(II) sulfide. [1]

. . . . . .

. . . . . .

. . . . . .

(d) Calculate the wavelength, in m, for the limit of convergence observed in the line spectrum of iron. Use sections 1, 2 and 9 of the data booklet. [3]

. . . . . .

. . . . . .

. . . . . .

2. Cobalt ions form coloured compounds.

(a) Deduce the electron configuration of the Co^{2+} ion. [1]

. . . . . .

(b) An equilibrium is established when hydrated cobalt ions are mixed with concentrated hydrochloric acid.

$$[Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons [CoCl_4]^{2-}(aq) + 6H_2O(l)$$

Pink Blue

(i) Predict the effect on the value of *K* and the equilibrium position when solid sodium chloride, NaCl(s), is added to the mixture at constant temperature. [1]

. . . . . .

. . . . . .

. . . . . .

2. Cobalt ions form coloured compounds.

(a) Deduce the electron configuration of the Co^{2+} ion. [1]

. . . . . .

(b) An equilibrium is established when hydrated cobalt ions are mixed with concentrated hydrochloric acid.

$$[Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons [CoCl_4]^{2-}(aq) + 6H_2O(l)$$

Pink Blue

(i) Predict the effect on the value of *K* and the equilibrium position when solid sodium chloride, NaCl(s), is added to the mixture at constant temperature. [1]

. . . . . .

. . . . . .

. . . . . .

Pink Blue

(i) Predict the effect on the value of K and the equilibrium position when solid sodium chloride, NaCl(s), is added to the mixture at constant temperature. [1]

. . . . . .

. . . . . .

. . . . . .

(ii) Heating an equilibrium mixture that is initially pink changes the colour to purplish-blue. Deduce, giving a reason, whether the formation of $[CoCl_4]^{2-}(aq)$ is an exothermic or endothermic process. [1]

. . . . . .

. . . . . .

. . . . . .

3. An equilibrium is established between gaseous carbon monoxide and steam.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

Under certain conditions of temperature and pressure, 2.7 mol of CO(g) and 2.9 mol of $H_2O(g)$ were placed in a 1 dm^3 container and allowed to reach equilibrium.

(a) State the equilibrium constant expression, *K*, for this equilibrium. [1]

. . . . . .

. . . . . .

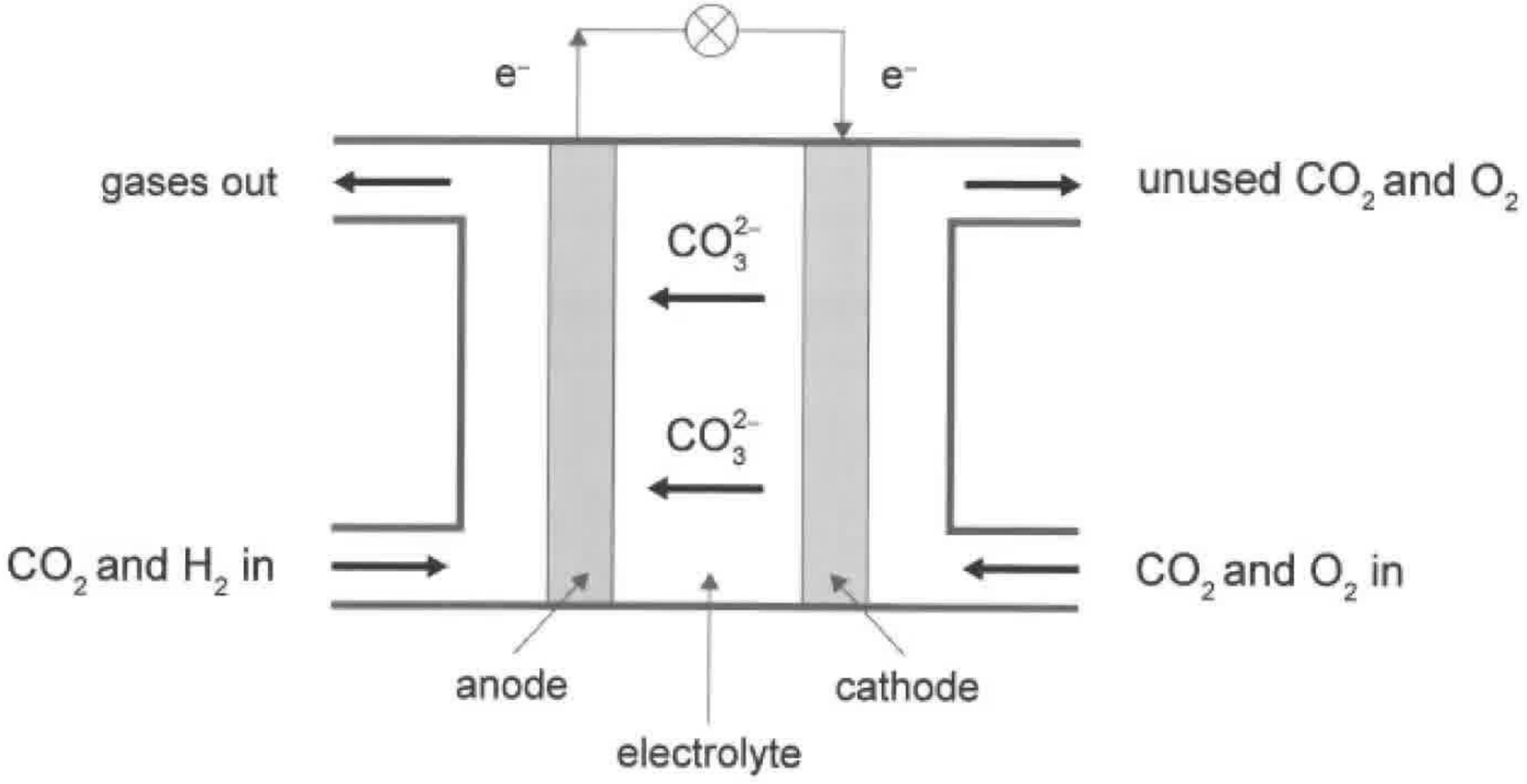
. . . . . .

(b) At equilibrium, there was 1.5 mol of $CO_2(g)$ present. Calculate the amount, in mol, of the other gases and hence find the value of the equilibrium constant, *K*. [2]

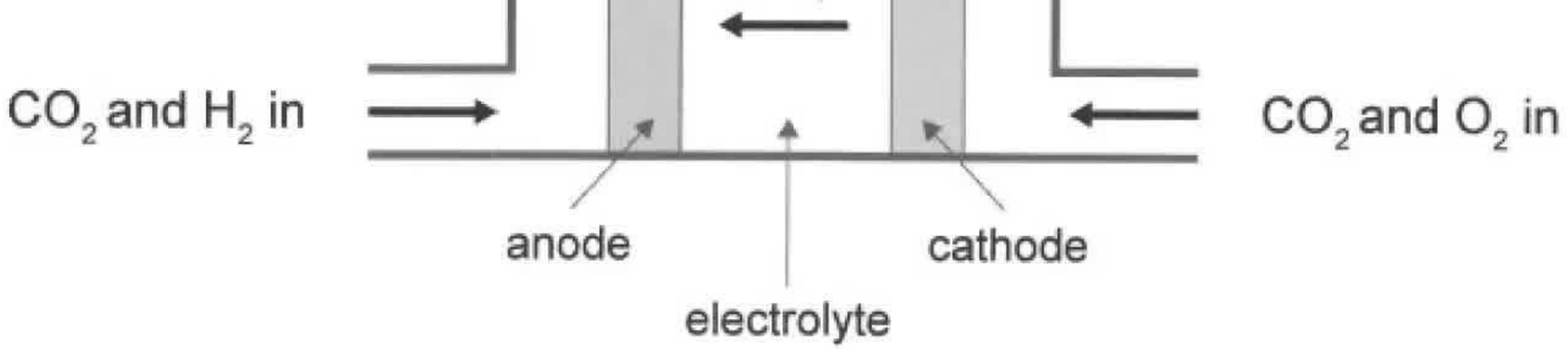
. . . . . .

(Question 3 continued)

(c) A mixture of $CO_2(g)$ and $H_2(g)$ can be used in a molten carbonate fuel cell, which is similar to a hydrogen fuel cell.



Deduce the half-equations for the reactions occurring at each electrode. [2]



Deduce the half-equations for the reactions occurring at each electrode. [2]

Anode: CO_3^{2-} + _____ → CO_2 + _____

Cathode: CO_2 + _____ → CO_3^{2-} + _____

(d) Suggest why the molten carbonate fuel cell is considered to be environmentally friendly. [1]

. . . . . .

. . . . . .

4. 3.162 g of calcium carbonate, $CaCO_3(s)$, is reacted with 20.0 cm^3 of 4.00 mol dm^{-3} hydrochloric acid, HCl(aq).

(a) (i) Write an equation for the reaction, including all state symbols. [2]

. . . . . .

. . . . . .

(ii) Deduce which reactant is limiting. Use sections 1, 4 and 7 of the data booklet. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

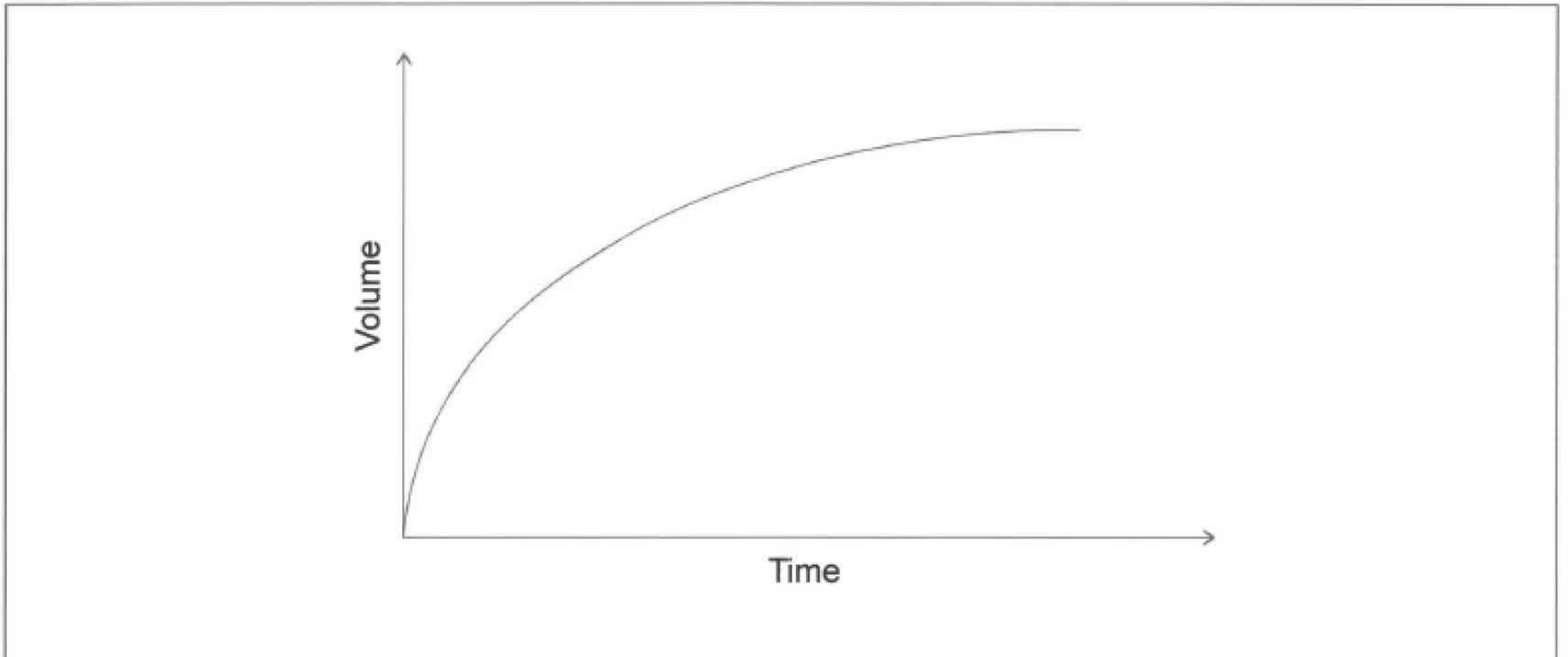
(ii) Deduce which reactant is limiting. Use sections 1, 4 and 7 of the data booklet. [2]

(iii) Calculate the volume, in dm^3 at STP, of the gas produced. Use section 2 of the data booklet. [1]

(Question 4 continued)

(b) The rate of this reaction can be experimentally determined by measuring the volume of gas produced as time progresses.

(i) Sketch another curve for the reaction taking place with the acid at a higher temperature and all other conditions unchanged. [1]



(ii) Outline why the reaction rate would be lower if ethanoic acid, CH_3COOH, were used instead of hydrochloric acid. [1]

. . . . . .

. . . . . .

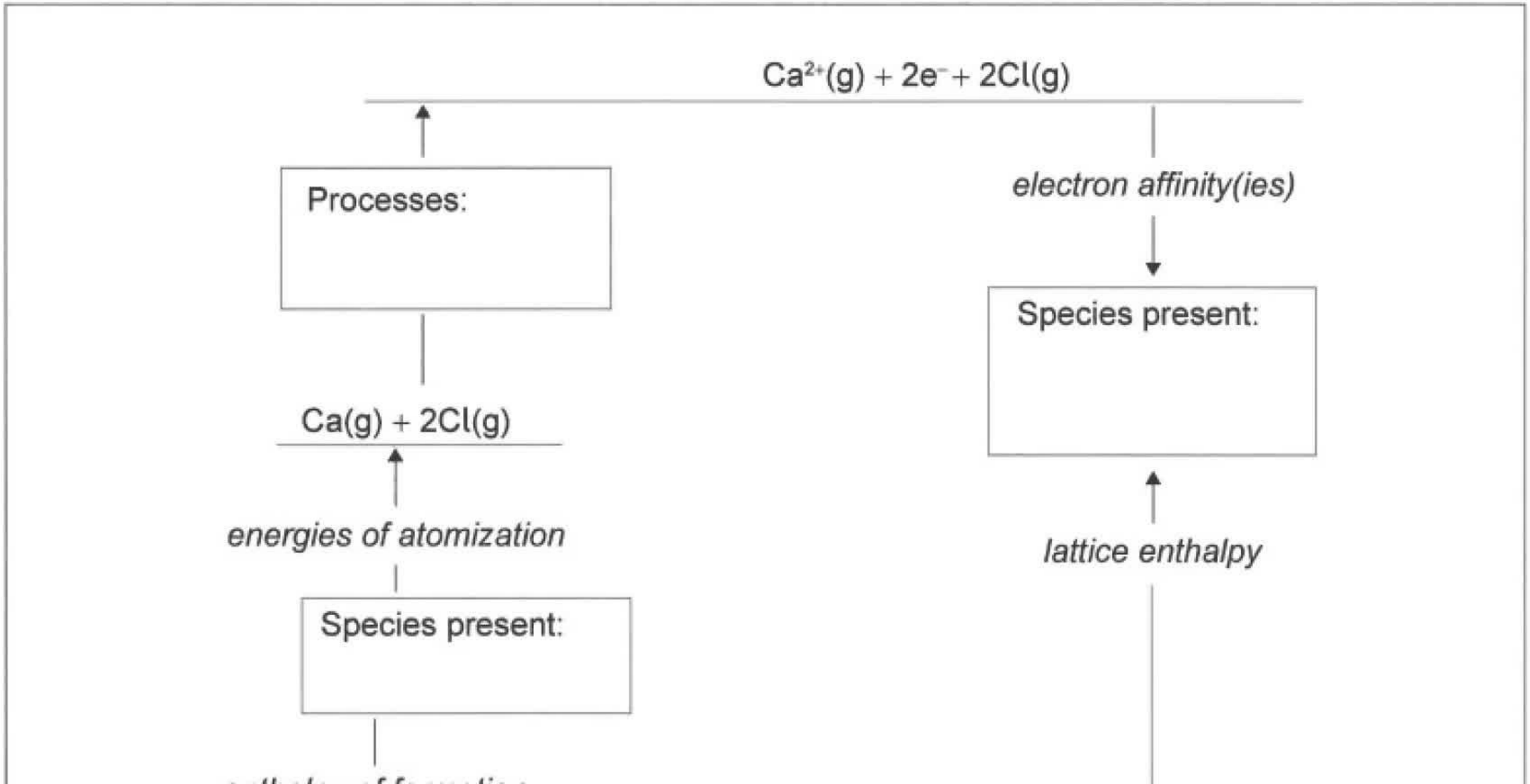
. . . . . .

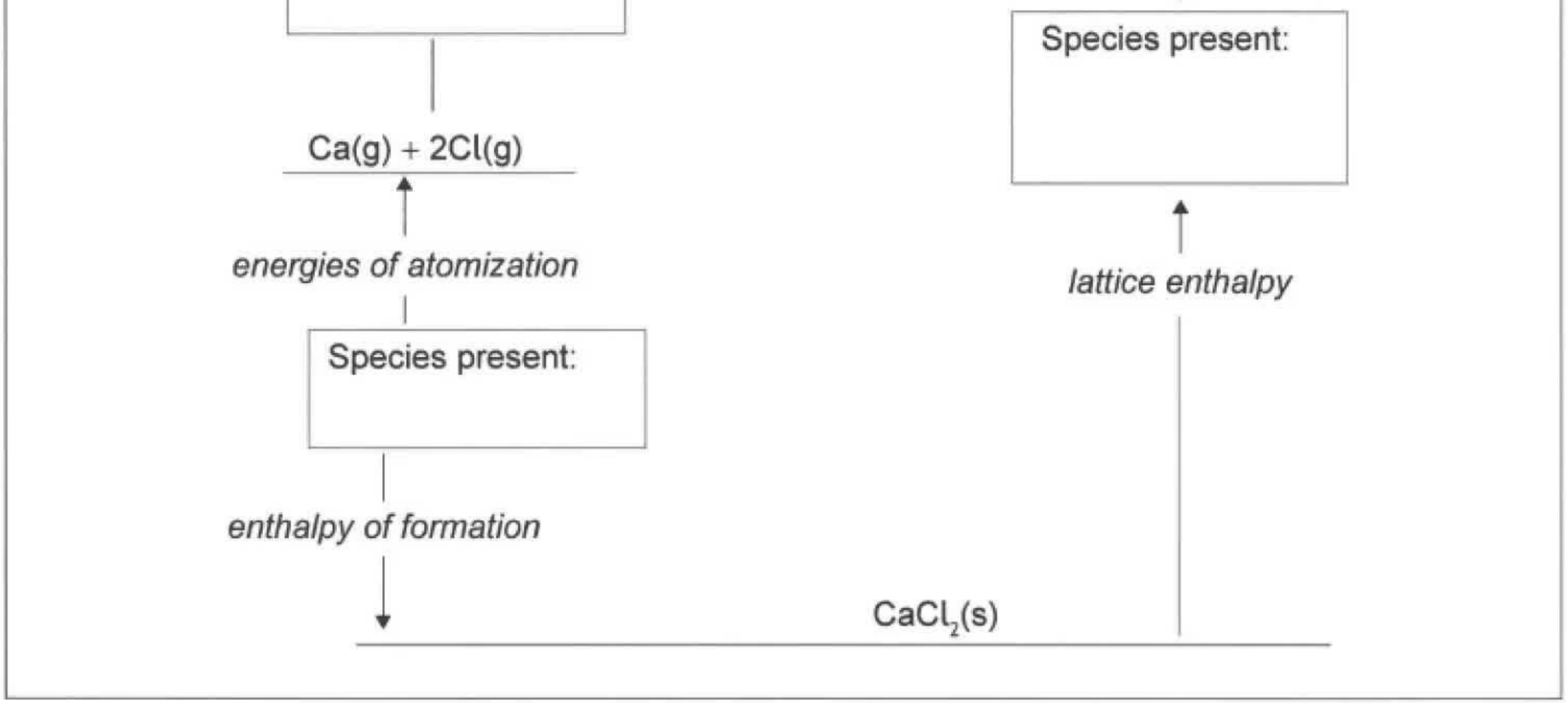
. . . . . .

(This question continues on the following page)

(c) Calcium carbonate and calcium chloride are ionic compounds.

(i) Annotate the Born–Haber cycle for calcium chloride, $CaCl_2$, by filling the names of processes and formulas of species, including state symbols, in the boxes. [3]





(ii) Outline why the lattice enthalpy of calcium chloride is lower than the lattice enthalpy of magnesium chloride. [1]

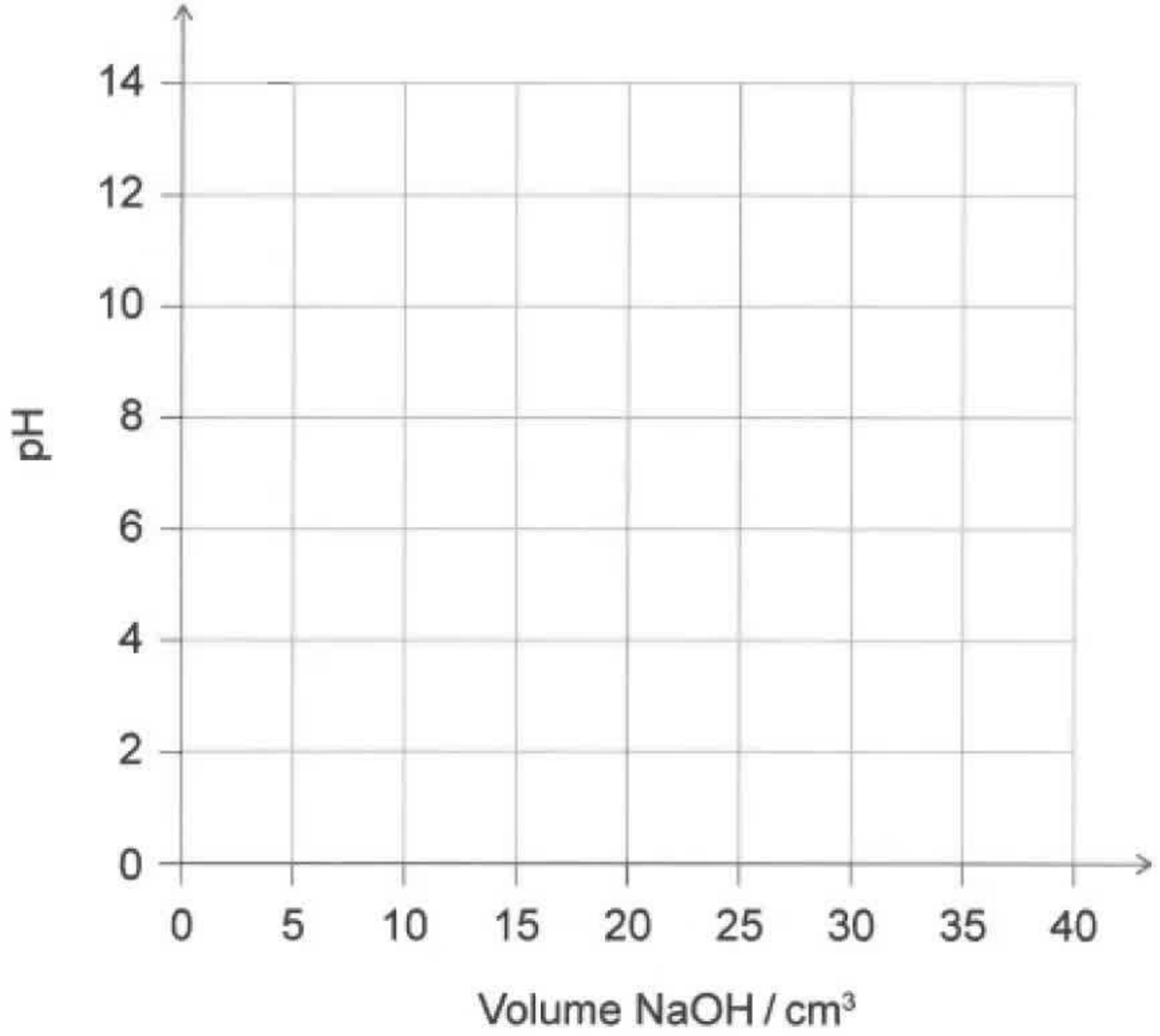
. . . . . .

. . . . . .

. . . . . .

5. 40.0 cm^3 of 1.0 mol dm^{-3} sodium hydroxide, NaOH(aq), was gradually added to 15.0 cm^3 of 1.0 mol dm^{-3} ethanoic acid, $CH_3COOH(aq)$.

(a) Sketch a pH curve for this titration. [3]



Volume NaOH / cm^3

(b) NaOH(aq) and CH_3COOH(aq) can be mixed to make a buffer solution.

(i) Describe how these solutions can produce the most effective buffer. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Write equations to show the action of the buffer solution when small amounts of a strong acid or a strong base are added. [2]

Addition of strong acid: . . . . . .

. . . . . .

Addition of strong base: . . . . . .

. . . . . .

6. The rate of reaction between solutions of iron(III) nitrate and sodium thiosulfate can be measured using the time it takes for the colour to change.

(a) The first step in the reaction produces an unstable dark violet complex.

$$[Fe(H_2O)_6]^{3+}(aq) + 2S_2O_3^{2-}(aq) \rightarrow [Fe(S_2O_3)_2(H_2O)_2]^{-}(aq) + 4H_2O(l)$$

(i) Deduce the oxidation state of S in $[Fe(S_2O_3)_2(H_2O)_2]^{-}$. [1]

. . . . . .

. . . . . .

(ii) Explain why the complex is coloured. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Explain why the complex is coloured. [3]

(iii) $CoCl_2(s)$ is used as a catalyst. Explain how the catalyst increases the reaction rate. [2]

(This question continues on the following page)

(iv) The reaction continues until the violet colour disappears. The thiosulfate ion, $S_2O_3^{2-}$, is oxidized to SO_2, and Fe^{3+} is reduced to Fe^{2+}.
Deduce the oxidation half-equation, and the overall redox equation for this second step of the reaction. [2]

Oxidation half-equation: .....

.....

Overall redox equation: .....

.....

(v) Sketch an energy profile for the two-step reaction, labelling reactants, intermediate and products, activation energies, E_a, and overall enthalpy change, ΔH. Assume that the reaction is exothermic. [4]

(v) Sketch an energy profile for the two-step reaction, labelling reactants, intermediate and products, activation energies, E_a, and overall enthalpy change, ΔH. Assume that the reaction is exothermic. [4]

(b) Iron(III) nitrate is a compound that involves both ionic and covalent bonding.

(i) Describe the two types of bonding. [2]

Ionic bonding: . . . . . .

. . . . . .

Covalent bonding: . . . . . .

. . . . . .

(ii) Deduce a Lewis formula of the nitrate ion. [1]

(iii) State the molecular geometry of the nitrate ion. [1]

. . . . . .

(iv) Predict, with a reason, the bond lengths of the nitrate ion. Use section 11 of the data booklet. [2]

(iii) State the molecular geometry of the nitrate ion. [1]

. . . . . .

(iv) Predict, with a reason, the bond lengths of the nitrate ion. Use section 11 of the data booklet. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

7. An unknown organic compound contains only carbon, hydrogen and oxygen.

(a) 4.32 g of the compound was combusted completely in oxygen and produced 9.49 g of CO_2 and 5.18 g of H_2O.
Determine the empirical formula of the compound, using sections 1 and 7 of the data booklet. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) The same organic compound was vaporized completely at a controlled temperature and pressure.

(i) 0.108 g of the vaporized compound was found to have a volume of 55.7 cm^3 at 100 °C and a pressure of 1.00×10^5 Pa.
Calculate the amount, in moles, of the compound. Use sections 1, 2 and 4 of the data booklet. [2]

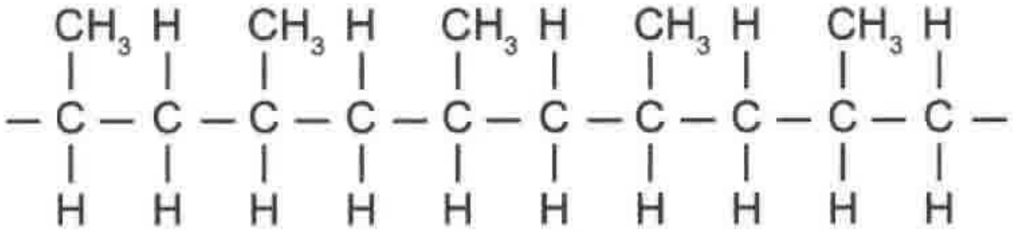
(b) The same organic compound was vaporized completely at a controlled temperature and pressure.

(i) 0.108 g of the vaporized compound was found to have a volume of 55.7 cm^3 at 100 °C and a pressure of 1.00×10^5 Pa.
Calculate the amount, in moles, of the compound. Use sections 1, 2 and 4 of the data booklet. [2]

(ii) Determine the molar mass of the organic compound, using section 1 of the data booklet.
If you did not get an answer to (i), use $n = 0.00220$ mol, although this is not the correct answer. [1]

8. Organic compounds have many industrial applications.

(a) A section of an addition polymer is shown.



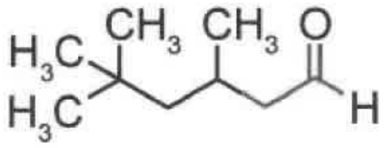
(i) Deduce the structure of the monomer that forms this polymer. [1]

(ii) Describe **one** chemical property that makes this type of polymer a useful material. [1]

. . . . . .

. . . . . .

(b) The following organic compound, ***X***, is used as a flavouring agent.



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

. . . . . .

(ii) Deduce the systematic name of ***X*** using IUPAC nomenclature. [1]

. . . . . .

(This question continues on the following page)

(Question 8 continued)

(iii) Deduce the number of signals and their relative areas (integration traces) in an ^{1}H NMR spectrum of ***X***. [2]

Number of signals: .....

Relative areas: .....

(iv) Draw an isomer of ***X*** which belongs to a different homologous series. [1]

(v) Molecule ***X*** can undergo both oxidation and reduction.
Deduce the formulas of the organic products when ***X*** reacts separately with an oxidizing agent and with a reducing agent.
Use RCHO to represent ***X***. [2]

Product of reaction with oxidizing agent:

Product of reaction with reducing agent:

(This question continues on the following page)

(Question 8 continued)

(c) An alkene such as ethene can be used as starting material for a range of compounds.

(i) Predict the product of the reaction between ethene and bromine. [1]

. . . . . .

. . . . . .

(ii) Describe the mechanism of this reaction, using curly arrows to represent the movement of electron pairs. [3]

(Question 8 continued)

(iii) Outline why unsaturated molecules, such as ethene, readily undergo this type of reaction. [1]

. . . . . .

. . . . . .

. . . . . .

(iv) State the general formula for the homologous series of alkenes. [1]

. . . . . .

(v) Explain, in terms of the intermolecular forces present, the trend in the boiling points of the first four alkenes. [2]

Alkene	Boiling point / K
ethene	169

(iv) State the general formula for the homologous series of alkenes. [1]

. . . . . .

(v) Explain, in terms of the intermolecular forces present, the trend in the boiling points of the first four alkenes. [2]

Alkene	Boiling point / K
ethene	169
propene	225
but-1-ene	267
pent-1-ene	303

. . . . . .

. . . . . .

. . . . . .

(Question 8 continued)

(d) 1-Bromobutane reacts with aqueous sodium hydroxide, NaOH(aq), to form butan-1-ol.

(i) State the name of the mechanism by which this reaction occurs. [1]

. . . . . .

(ii) Draw the transition state produced in this mechanism. [1]

(iii) Deduce the rate equation for this reaction. [1]

(iii) Deduce the rate equation for this reaction. [1]

. . . . . .

. . . . . .

(iv) Predict, giving a reason, the quantitative effect of doubling the concentration of NaOH(aq) on the reaction rate. Assume that all other conditions remain unchanged. [1]

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 8 continued)

(v) Outline how the rate of reaction of 1-bromobutane with sodium hydroxide compares with the rate of reaction of 1-chlorobutane with sodium hydroxide under the same conditions. [1]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(e) The chloroalkene with the formula C_4H_7Cl can exist as several stereoisomers.

(i) Draw the structural formula of *cis*-1-chlorobut-2-ene. [1]

(ii) Outline why the *cis*-isomer is polar. [1]

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 8 continued)

(iii) Deduce the structure of a chloroalkene, C_4H_7Cl, that can exhibit optical isomerism, and identify the chiral carbon atom with an asterisk (*). [2]

(f) Ethene reacts with steam to produce ethanol.

$$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$$

(f) Ethene reacts with steam to produce ethanol.

$$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(g)$$

(i) Calculate the enthalpy, in kJ, of the reaction using section 12 of the data booklet. [3]

(ii) Calculate the enthalpy of the reaction, in kJ. Use section 13 of the data booklet and $\Delta H_f^{\ominus}$ of $CH_3CH_2OH(g) = -235\,kJ\,mol^{-1}$. [2]

(Question 8 continued)

(iii) Outline why the enthalpies calculated in (i) and (ii) are different. [1]

. . . . . .

. . . . . .

. . . . . .