Diploma Programme
Programme du diplôme
Programa del Diploma

# Chemistry
# Higher level
# Paper 2

3 November 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.
- 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]**.

8825 – 6221

29 pages

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

**1.** Nitrogen monoxide, NO (g), is produced in internal combustion and jet engines.

(a) Outline a reason why NO is a pollutant. [1]

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(b) Calculate the amount, in moles, of NO in $1.0 \times 10^{-3}\,m^3$ of engine exhaust gas which contains 0.10 % NO by volume at 200 °C and $1.0 \times 10^5$ Pa.

Use sections 1 and 2 of the data booklet. [3]

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(c) Outline why NO deviates more than nitrogen, $N_2$, from the ideal gas model. [2]

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

**(Question 1 continued)**

(d) In an exhaust pipe catalytic converter, NO reacts with carbon monoxide, CO, to form $N_2$.

(i) State the initial and final oxidation states of nitrogen. [1]

Initial: . . . . . Final: . . . . . .

(ii) Deduce the second product and the balanced equation for the reaction. [1]

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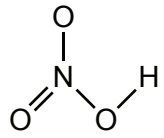
**2.** Nitric acid, $HNO_3$, is a strong acid.

(a) (i) Annotate the structure of nitric acid to indicate the coordination bond. [1]




(ii) Write an equation for the reaction of excess nitric acid with sodium carbonate. [1]

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(b) (i) Draw the Lewis formula of the nitrate ion. [1]

(ii) Write the formula of nickel(II) nitrate. [1]

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

**(Question 2 continued)**

(iii) State the reason why the nitrate ion contains three identical N—O bonds. [1]

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(iv) Predict the bond length of the N—O bonds in the nitrate ion. Use section 11 of the data booklet. [1]

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(c) Predict, with an explanation, what would be observed when manganese and copper metals were added to separate samples of green nickel(II) nitrate solution. Use section 19 of the data booklet. [2]

| **Metal added** | Mn | Cu |
|---|---|---|
| **Observations** | | |

Explanation: . . . . . .

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**(This question continues on page 7)**

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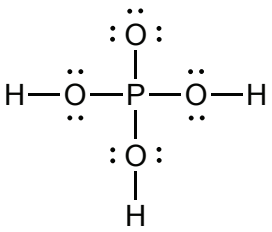
will not be marked.

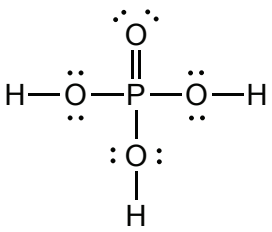
**(Question 2 continued)**

(d) Phosphoric acid has the formula $H_3PO_4$.

(i) Outline, in terms of formal charge, why Lewis formula 2 is preferred. [2]



Lewis formula 1



Lewis formula 2

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(ii) Write the formula of the conjugate base of phosphoric acid. [1]

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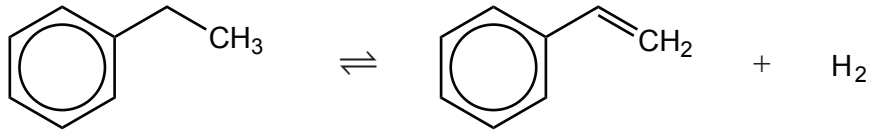
**3.** Phenylethene (styrene) is produced from ethylbenzene in a gas-phase equilibrium.




Ethylbenzene, $C_8H_{10}(g)$ $\rightleftharpoons$ Styrene, $C_8H_8(g)$ + Hydrogen, $H_2(g)$

(a) (i) Calculate the mass, in g, of styrene produced from 1.0 kg of ethylbenzene if the yield of the reaction is 90 %. [2]

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(ii) Calculate the atom economy of the reaction. [1]

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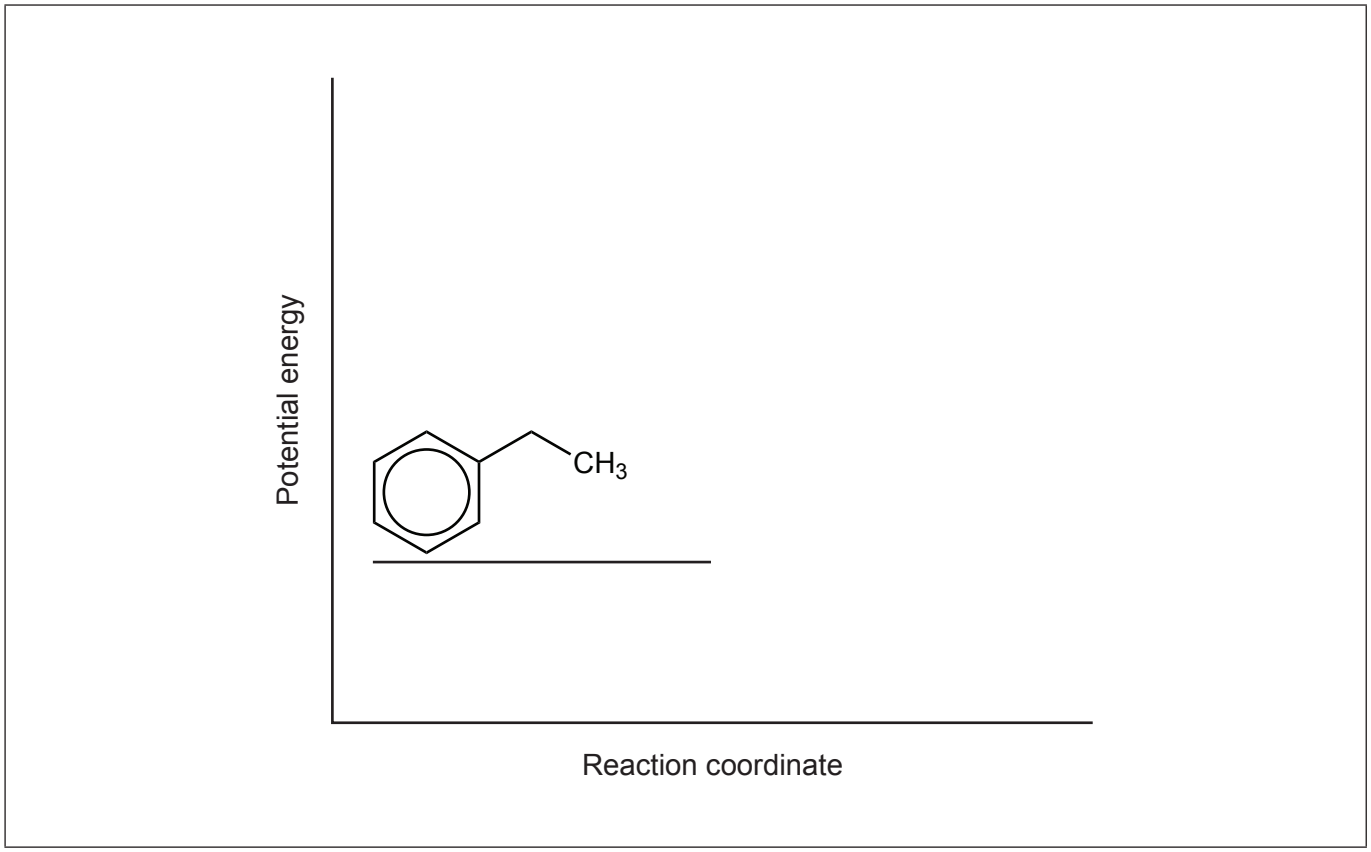
**(This question continues on the following page)**

**(Question 3 continued)**

(b) The forward reaction is endothermic, uses iron(III) oxide as a catalyst, and takes place at 900 K.

Sketch the energy profile for the reaction, both with and without the catalyst, labelling $\Delta H$ and the activation energies. [3]

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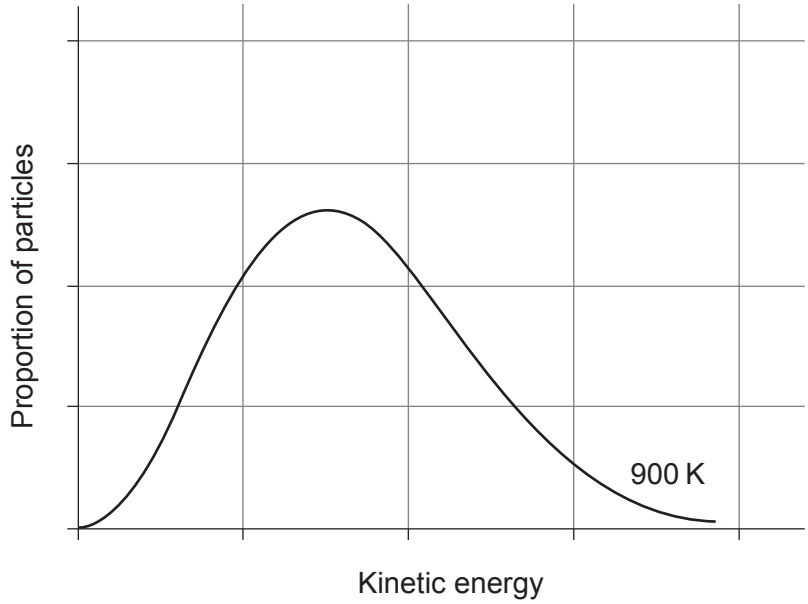
**(Question 3 continued)**

(c) (i) Sketch the Maxwell–Boltzmann distribution curve for 298 K on the same axes as the 900 K curve. [1]




(ii) Annotate the graph to show the activation energy, $E_a$. [1]

(iii) Explain why reducing the temperature decreases the rate of reaction, referring to the graph in your explanation. [2]

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

**(Question 3 continued)**

(iv) Suggest, with a reason, the effect of increasing the pressure on the position of equilibrium. [1]

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(v) Outline the effect of decreasing temperature on the position of equilibrium. [1]

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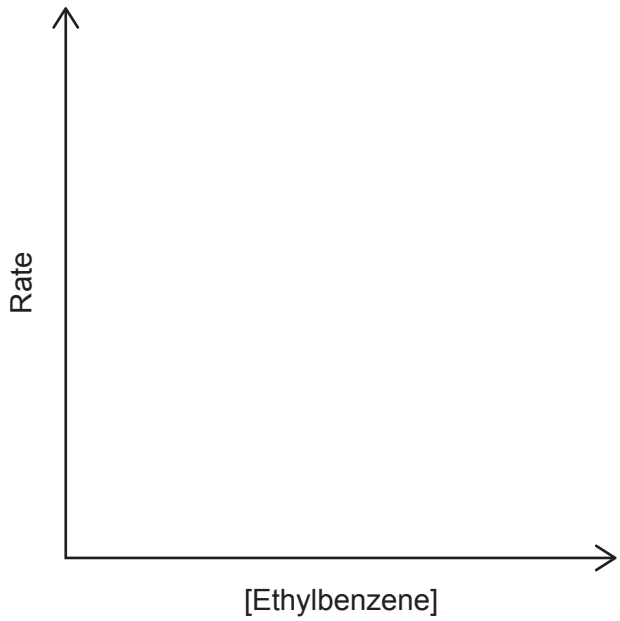
**(This question continues on the following page)**

**(Question 3 continued)**

(d) The forward reaction is first order with respect to ethylbenzene.

$$C_8H_{10}(g) \rightleftharpoons C_8H_8(g) + H_2(g)$$

(i) Sketch the graph of rate vs concentration of ethylbenzene. [1]




(ii) Deduce the rate equation for the reaction and the units of the rate constant *k*. [2]

Rate equation: . . . . . .

. . . . . .

Units of *k*: . . . . . .

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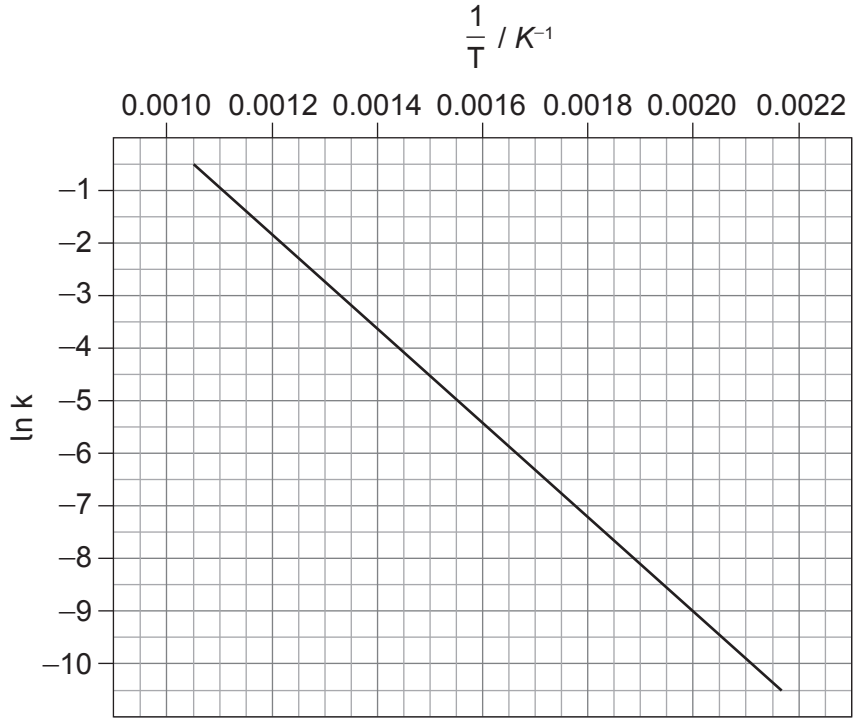
**(This question continues on the following page)**

**(Question 3 continued)**

(iii) Determine the activation energy of the reaction, $E_a$, in kJ mol$^{-1}$, from the Arrhenius plot. Use sections 1 and 2 of the data booklet. [2]

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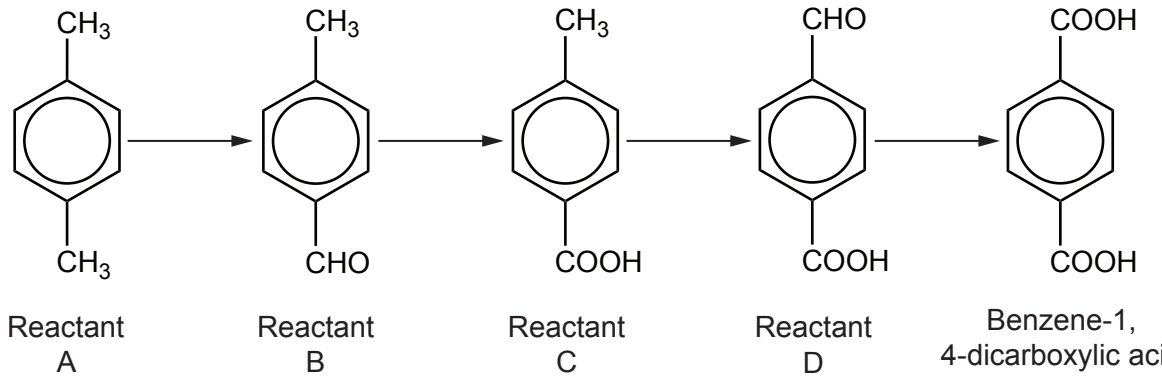
**(Question 3 continued)**

(e) A compound used to make polymers, benzene-1,4-dicarboxylic acid, can be produced by a series of reactions.




Reactant A | Reactant B | Reactant C | Reactant D | Benzene-1, 4-dicarboxylic acid

(i) Deduce the relationship between reactant A and ethylbenzene. [1]

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(ii) State the structural formula, functional group name and homologous series of the CHO functional group. [2]

| Structural formula drawing | Functional group name | Homologous series name |
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| | . . . . . | . . . . . |
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(iii) Suggest the conditions required and the role of the reagent $KMnO_4$ used to convert intermediate B into intermediate C. [2]

Conditions: . . . . . .

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Role of $KMnO_4$: . . . . . .

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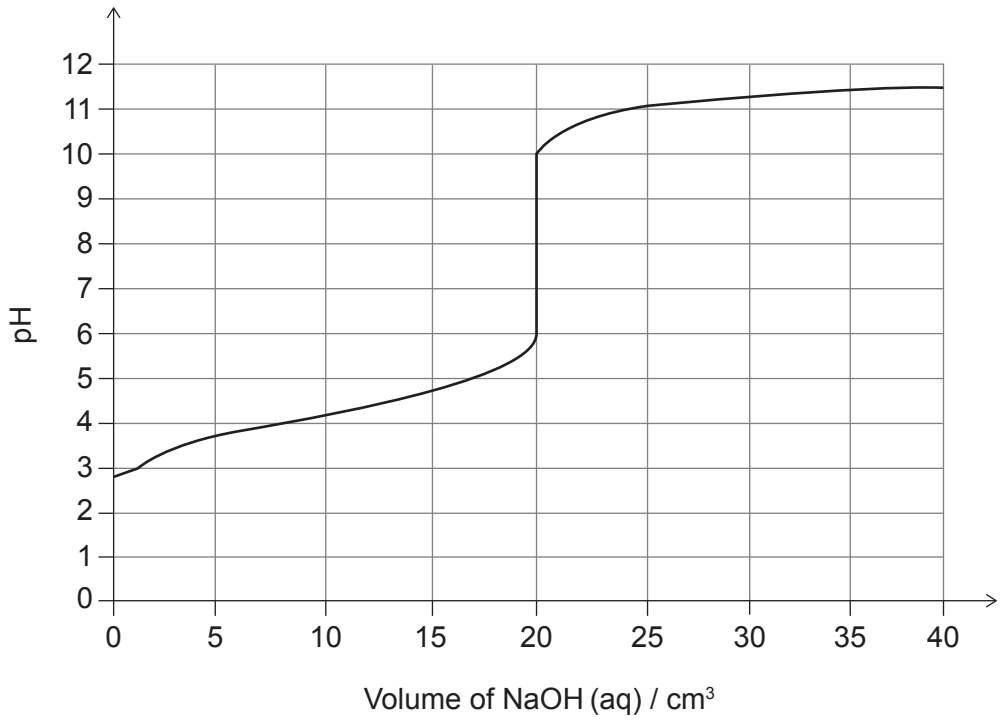
**(This question continues on the following page)**

**(Question 3 continued)**

(f) Benzoic acid is a weak acid. The graph shows how the pH changes during the titration of a 10.0 $cm^3$ aqueous solution of benzoic acid with aqueous sodium hydroxide.




(i) Deduce the equilibrium constant expression, $K$, for the ionization of benzoic acid ($C_6H_5COOH$). [1]

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(ii) Annotate the graph to find the p$K_a$ of benzoic acid. [1]

(iii) Suggest a suitable indicator for the titration. Use section 18 of the data booklet. [1]

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

**(Question 3 continued)**

(iv) Explain, with reference to acid–base equilibria, why the sodium benzoate solution formed has a pH $> 7$. [1]

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(v) Calculate the concentration of the benzoic acid solution, in mol $dm^{-3}$, given that the sodium hydroxide concentration was 0.010 mol $dm^{-3}$. [1]

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(g) (i) Describe how a buffer solution could be made from aqueous benzoic acid and aqueous sodium hydroxide. [1]

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(ii) Predict how adding a small quantity of water would affect the pH of the buffer. [1]

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**(This question continues on page 19)**

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will not be marked.

**(Question 3 continued)**

(h) (i) State the type of polymer formed by reacting benzene-1,4-dicarboxylic acid with ethanediol, $HOCH_2CH_2OH$. [1]

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(ii) Draw the structure of the polymer, showing one repeating unit. [2]

**4.** Bromoethane, $C_2H_5Br$, is produced by reacting ethene, $C_2H_4$, with hydrogen bromide, HBr.

$$C_2H_4(g) + HBr(g) \rightarrow C_2H_5Br(l)$$

(a) (i) State the type of reaction and the role of HBr. [1]

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(ii) Outline why ethene is susceptible to attack by molecules such as HBr. [1]

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(b) (i) Determine the standard enthalpy change of the reaction, in $kJ\,mol^{-1}$. Use section 12 of the data booklet. [2]

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(ii) State **two** reasons why the result using bond enthalpies is less accurate than one calculated from enthalpies of formation. [2]

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

**(Question 4 continued)**

(iii) Outline why the entropy change of the reaction is negative. [1]

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(iv) Predict, showing your working, if the reaction is spontaneous at 298 K.
Use section 13 of the data booklet and your answer for part (b)(i). If you did not get an answer in part (b)(i), use $-58\,kJ\,mol^{-1}$. [2]

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

**(Question 4 continued)**

(c) Bromoethane can react with aqueous hydroxide ions to produce ethanol.

$$H_3CCH_2Br(l) + OH^-(aq) \rightarrow H_3CCH_2OH(aq) + Br^-(aq)$$

(i) State the type of reaction. [1]

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

(iii) Outline why the reaction takes place by this mechanism. [1]

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(iv) State the order of reaction. [1]

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**(Question 4 continued)**

(v) Predict, with a reason, a halogenoethane that would react more quickly than bromoethane. [1]

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(vi) Bromoethane shows a signal in the 3.5–4.4 ppm region of its $^{1}$H NMR spectrum. Deduce the splitting pattern of this signal. Use section 21 of the data booklet. [1]

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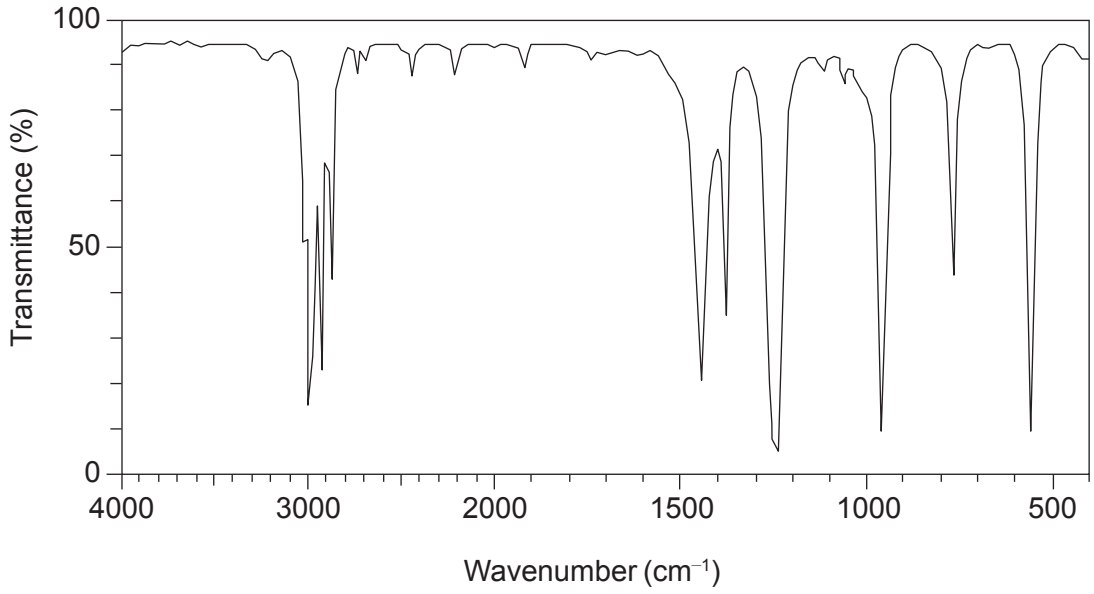
(vii) Deduce whether this infrared spectrum is produced by bromoethane or ethanol. Give evidence from section 20 of the data booklet. [1]




[Source: SDBS. National Institute of Advanced Industrial Science and Technology.]

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**5.** A sample of bromine has the following composition by mass:

$^{79}Br$: 50.75 %

$^{81}Br$: 49.25 %

(a) Contrast the atomic structures of the isotopes. [1]

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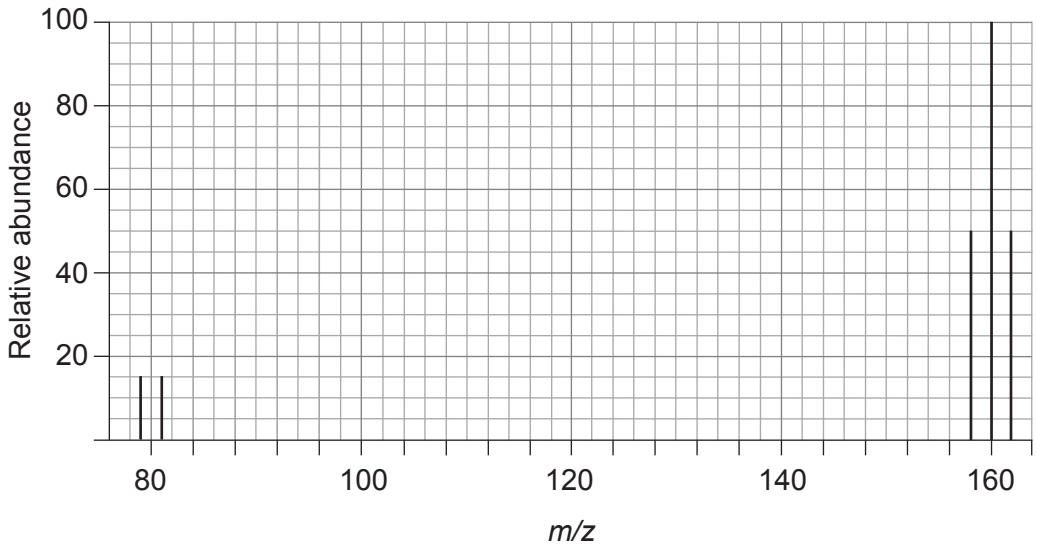
(b) The sample produces the following mass spectrum.




(i) Explain the relative heights of the three peaks around *m/z* 160. [2]

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

**(Question 5 continued)**

(ii) Calculate the relative atomic mass of bromine from the sample, giving your answer to two decimal places. [2]

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(c) (i) Deduce, showing your working, the type of bonding and percentage covalent character in calcium bromide, $CaBr_2$. Use sections 9 and 17 of the data booklet. [2]

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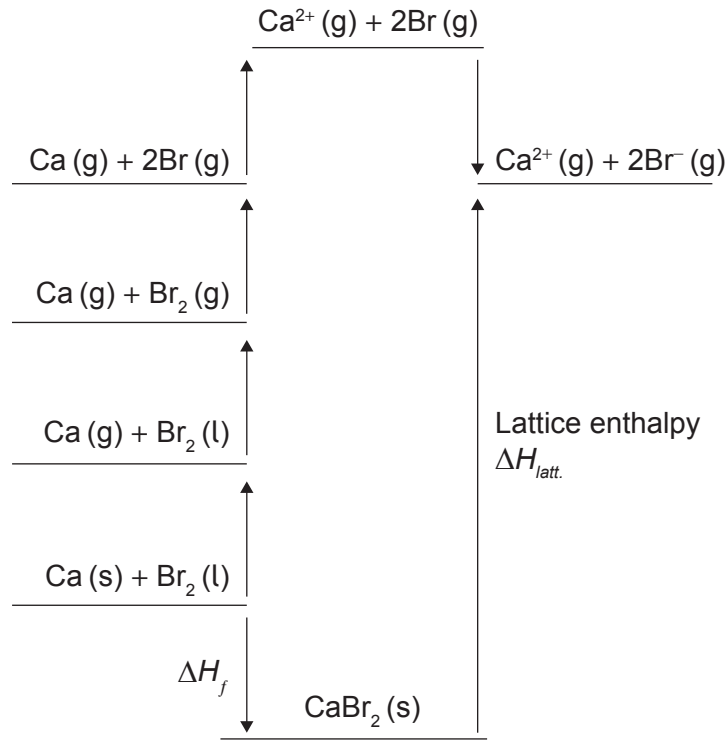
**(This question continues on the following page)**

**(Question 5 continued)**

(ii) Determine the lattice enthalpy of calcium bromide, assuming the bonding is purely ionic. Use sections 9 and 12 of the data booklet and the following data:

Enthalpy of formation of calcium bromide = $-648\,kJ\,mol^{-1}$
Second ionization energy of calcium = $+1145\,kJ\,mol^{-1}$
Enthalpy of atomization of calcium = $+178\,kJ\,mol^{-1}$
Enthalpy of vaporization of $Br_2(l)$ = $+31\,kJ\,mol^{-1}$ [3]

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**(Question 5 continued)**

(iii) Explain, with reference to electron structure, why the ionic radii of period 4 ions $Ca^{2+}$, $Co^{2+}$ and $Br^{-}$ are different. Use section 10 of the data booklet. [3]

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(iv) Predict, with a reason, which has stronger ionic bonding, cobalt(II) bromide, $CoBr_2$, or calcium bromide. [1]

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

**(Question 5 continued)**

(d) Calcium bromide is white, but cobalt(II) bromide is green.

(i) State the condensed electron configuration of cobalt. [1]

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(ii) State the reason, in terms of electron configuration, why cobalt(II) bromide is coloured. [1]

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(iii) Cobalt(II) bromide absorbs light of frequencies around $4.5 \times 10^{14}$ Hz.

Describe why this is consistent with the observed colour of the compound, including a calculation in your answer.

Use sections 1, 2 and 15 of the data booklet. [2]

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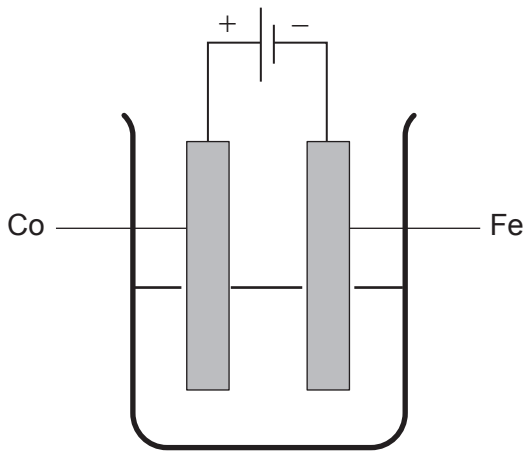
**(This question continues on the following page)**

**(Question 5 continued)**

(e) An iron object is electroplated with cobalt, using an aqueous cobalt(II) bromide electrolyte.




(i) Deduce half-equations for the reactions at each electrode. [2]

Anode: . . . . . .

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Cathode: . . . . . .

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(ii) Deduce an equation for the reaction of chlorine gas with aqueous bromide solution. [1]

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**References:**

**4. (c)(vii)** SDBS. National Institute of Advanced Industrial Science and Technology.

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