Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

12 May 2023

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

Candidate session number

2 hours 15 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].**

2223 – 6108

27 pages

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

1. This question is about acid–base properties.

(a) (i) Deduce the ionic equation, including state symbols, for the reaction of hydrogen chloride gas with water. [2]

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(ii) Calculate the pH of 0.50 mol dm^{-3} hydrochloric acid. [1]

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(iii) Explain why a solution of ethanoic acid has a higher pH than hydrochloric acid of the same concentration. [1]

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(iv) A pH probe can be used to distinguish between the acids in part (a)(iii). Identify another simple instrumental method that could be used in a school laboratory to distinguish between the two acids. [1]

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(v) Outline how the instrumental method identified in part (a)(iv) distinguishes between the acids in part (a)(iii). [1]

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(This question continues on the following page)

(Question 1 continued)

(b) Outline **one** chemical test, other than an indicator, that can distinguish between the two acids in part (a)(iii), and the expected result. [1]

Chemical test: . . . . . .

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Expected result: . . . . . .

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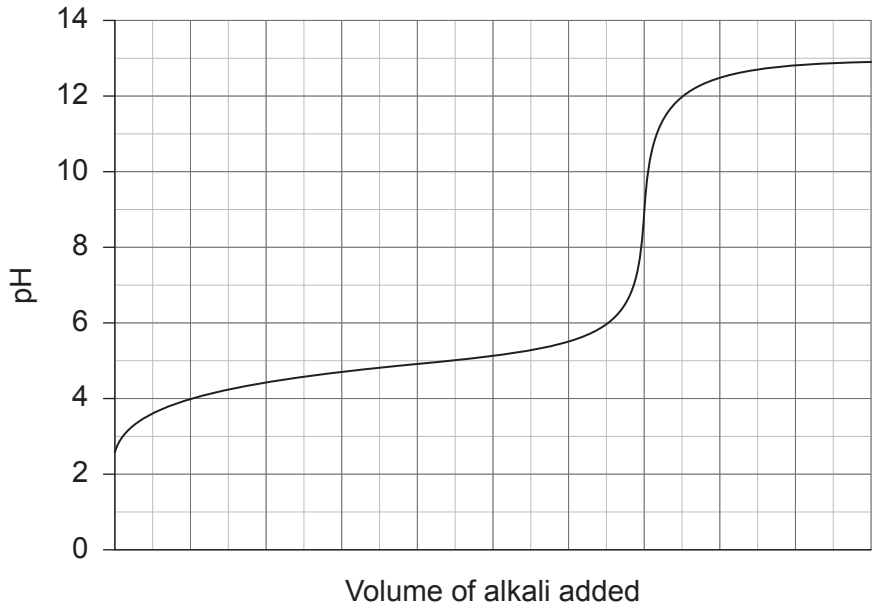
(Question 1 continued)

(c) A neutralization curve for a weak acid, HA, and a strong base is given.



(i) Estimate the pK_a of HA. [1]

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(ii) Explain, using an equation, why adding a strong base to the weak acid, HA, leads to very little change in pH in the buffer zone of the graph. [2]

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(Question 1 continued)

In a separate experiment, 80 cm^3 of 0.1 mol dm^{-3} ammonia, $NH_3(aq)$, was added to 40 cm^3 of 0.1 mol dm^{-3} hydrochloric acid, $HCl(aq)$.

(iii) Determine the final pH of the solution. Use section 21 of the data booklet. [4]

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Answers written on this page
will not be marked.

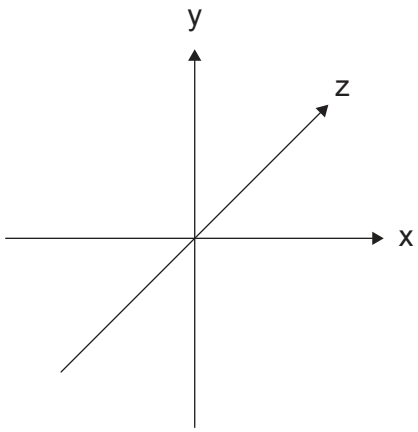
2. The periodic table is a useful tool in explaining trends of chemical behaviour.

(a) (i) Annotate and label the ground state orbital diagram of boron, using arrows to represent electrons. [1]

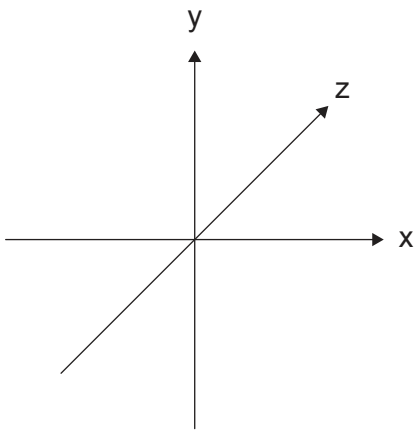
[He] ☐ ☐ ☐ ☐

Orbital label: _____ _____

(ii) Sketch the shapes of the occupied orbitals identified in part (a)(i). [2]



Orbital type: . . . . . .



Orbital type: . . . . . .

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(Question 2 continued)

(b) Explain the decrease in first ionization energy from Li to Cs, group 1. [2]

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(c) (i) State the electron domain geometry of the ammonia molecule. [1]

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(ii) Deduce the Lewis (electron dot) structure of ammonia and sketch its 3D molecular shape. [2]

Lewis structure:

3D molecular shape:

(This question continues on the following page)

(Question 2 continued)

(iii) Explain, with reference to the forces between molecules, why ammonia has a higher boiling point than phosphine (PH_3). [3]

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(Question 2 continued)

(d) (i) Ammonia is manufactured by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H_r^{\ominus} = -92.0\,kJ\,mol^{-1}$$

Outline what is meant by dynamic equilibrium. [1]

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(ii) Deduce the K_c expression for the reaction in part (d)(i). [1]

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(iii) Determine the entropy change, $\Delta S^{\ominus}$ for the forward reaction to **four** significant figures, using the data given. [2]

Substance	Entropy ($S^{\ominus}$) J K^{-1} mol^{-1}
H_2	130.7
N_2	191.6
NH_3	192.8

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(This question continues on the following page)

(Question 2 continued)

(iv) Calculate the temperature, in K, below which this reaction becomes spontaneous. Use section 1 of the data booklet. (If you were unable to obtain an answer for part (d)(iii) use $-210.0\,J\,K^{-1}\,mol^{-1}$, but this is not the correct value.) [2]

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(v) The value of K_c for this reaction is 6.84×10^{-5} at 500 °C. Suggest, with a reason, how lowering the temperature affects the value of K_c. [1]

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(vi) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for this reaction. Use sections 1 and 2 of the data booklet. [2]

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will not be marked.

(Question 2 continued)

(e) (i) The Haber process requires a catalyst. State how a catalyst functions. [1]

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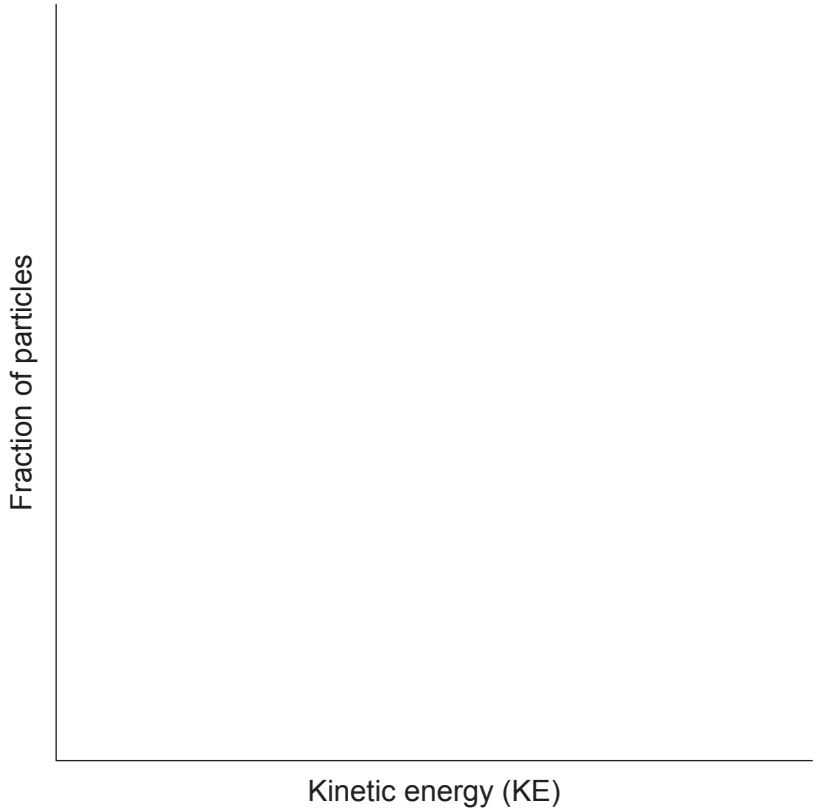
(ii) Sketch a Maxwell–Boltzmann distribution curve showing the activation energies with and without a catalyst. [2]



(iii) Suggest how the progress of the reaction could be monitored. [1]

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3. Alkanes form a homologous series.

(a) (i) Outline the meaning of homologous series. [1]

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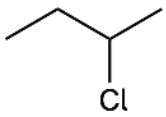
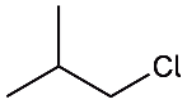
(ii) State the preferred IUPAC name for the following compounds. [2]

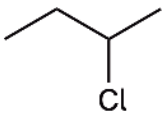


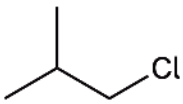
IUPAC name: . . . . . .



IUPAC name: . . . . . .

(iii) Identify **one** chiral carbon atom present in one of the following structures with an asterisk (*). [1]



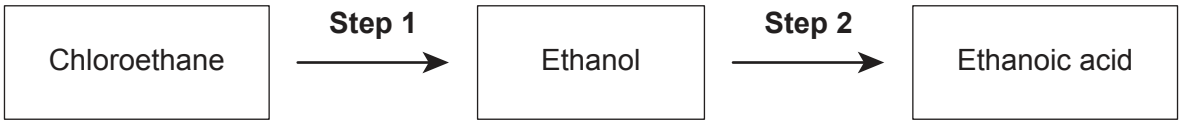


(This question continues on the following page)

(Question 3 continued)

(iv) But-2-ene can be polymerized. Draw a section of the resulting polymer showing **two** repeating units. [1]

(b) Chloroethane can be converted into ethanoic acid in a two-step process.



Identify reagents for each step. [2]

Step 1: . . . . . .

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Step 2: . . . . . .

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(Question 3 continued)

(c) (i) Identify the type of reaction that takes place in step 1 of part (b). [1]

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(ii) Sketch the mechanism of the reaction for step 1 in part (b), using curly arrows to show the movement of electron pairs. [4]

(iii) Identify the products formed from the reaction of ethanol and ethanoic acid in the presence of an acid catalyst. [1]

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4. Redox reactions can be used to produce electricity.

(a) State the oxidation state of sulfur in copper(II) sulfate. [1]

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(b) A voltaic cell was constructed using a copper(II) sulfate/copper half-cell and a zinc sulfate/zinc half-cell.

(i) Outline why electrons flow from zinc to copper when these half cells are connected with a wire. Use section 25 of the data booklet. [1]

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(ii) Formulate equations for the reactions taking place at each electrode. [2]

Anode (negative electrode): . . . . . .

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Cathode (positive electrode): . . . . . .

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(c) (i) Calculate the standard cell potential for the voltaic cell in part (b). Use section 24 of the data booklet. [1]

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(ii) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for this reaction. Use section 1 of the data booklet. (If you did not answer part (c)(i) use 1.05 V, but this is not the correct value.) [2]

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5. Double salts are substances with two cations and one anion. A hydrated sulfate containing two cations has this percentage composition.

Element	Percentage (%)
Nitrogen (N)	7.09
Hydrogen (H)	5.11
Sulfur (S)	16.22
Cobalt (Co)	14.91
Oxygen (O)	—

(a) (i) Draw **one** Lewis (electron dot) structure of the sulfate ion. [1]

(ii) Calculate the percentage of oxygen present in the double salt. [1]

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(Question 5 continued)

(iii) Determine the empirical formula of the double salt. Use section 6 of the data booklet. [3]

(iv) The molar mass of the empirical formula is the same as the molar mass of the formula unit. Deduce the formula unit of the hydrated double salt. [1]

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(Question 5 continued)

(b) 1.20 g of the double salt was dissolved in water and an excess of aqueous barium chloride was added, precipitating all the sulfate ions as barium sulfate.

(i) Formulate an ionic equation, including state symbols, for the reaction of barium ions with sulfate ions. [1]

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(ii) Calculate the mass of barium sulfate precipitate. Use your answer to part (a)(iii) and section 6 of the data booklet. (If you did not obtain an answer for part (a)(iii), use 400.0 g mol^{-1} as M_r for the double salt, but this is not the correct value.) [2]

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6. The element sulfur has many industrial uses.

(a) (i) Determine the standard enthalpy of reaction ($\Delta H_r^{\ominus}$), in kJ mol^{-1}, for the oxidation of SO_2 to SO_3. [1]

Substance	Enthalpy of formation, $\Delta H_f^{\ominus}$ (kJ mol^{-1})
SO_2	–296.8
SO_3	–395.8

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(ii) Formulate equations showing how SO_2 and SO_3 lead to acid deposition. [1]

SO_2: . . . . . .

SO_3: . . . . . .

(iii) Explain the polarity of the S—O bond. Use section 8 of the data booklet. [2]

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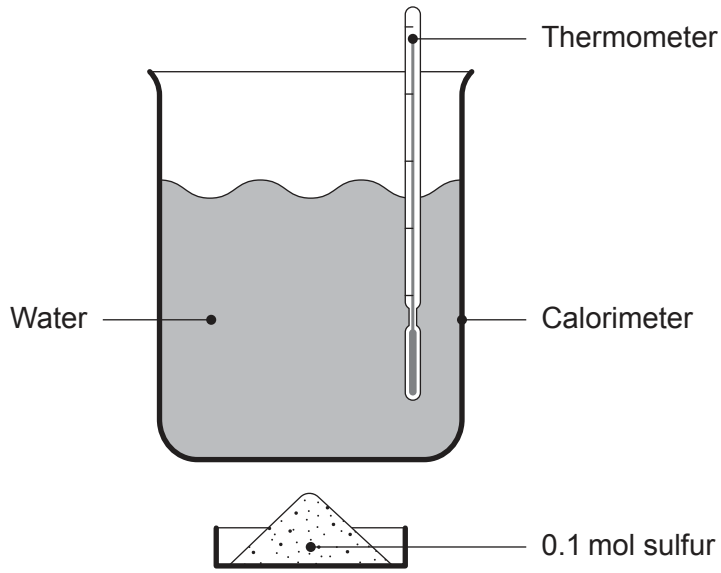
(Question 6 continued)

(b) The combustion of 0.1 moles of sulfur (S) was demonstrated in a school laboratory using the following apparatus in a fume cupboard.



(i) Calculate the enthalpy of combustion of sulfur, ΔH_c, in kJ mol^{-1} from this data. Use sections 1 and 2 of the data booklet. [2]

Mass of water (g) ±0.01	50.00
Initial temperature of water (°C) ±0.5	20.0
Final temperature of water (°C) ±0.5	35.0

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(Question 6 continued)

(ii) Suggest the major source of systematic error in this experiment and an improvement to reduce this error. [2]

Source of systematic error: . . . . . .

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Improvement: . . . . . .

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(iii) Calculate the percentage uncertainty in the temperature change to **two** significant figures. [1]

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(iv) Suggest **one** way of reducing the percentage uncertainty in this experiment. [1]

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(v) Calculate the overall percentage error of this experiment. Use part (b)(i) and section 13 of the data booklet. (If you did not obtain an answer for part (b)(i) use $-50.0\,kJ\,mol^{-1}$, but this is not the correct value.) [1]

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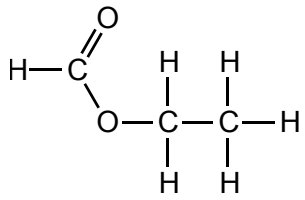
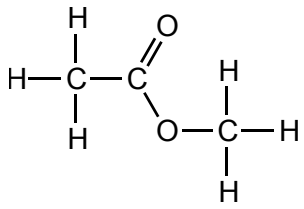
7. The structural formulae of two esters of formula $C_3H_6O_2$ are shown.

Ethyl methanoate



Methyl ethanoate



(a) (i) Deduce the number of signals you would expect to find in the ^1H NMR spectrum of each compound. [1]

Name	Number of signals
Ethyl methanoate	. . . . .
Methyl ethanoate	. . . . .

(ii) Outline why infrared spectroscopy is not used to differentiate between the two esters. [1]

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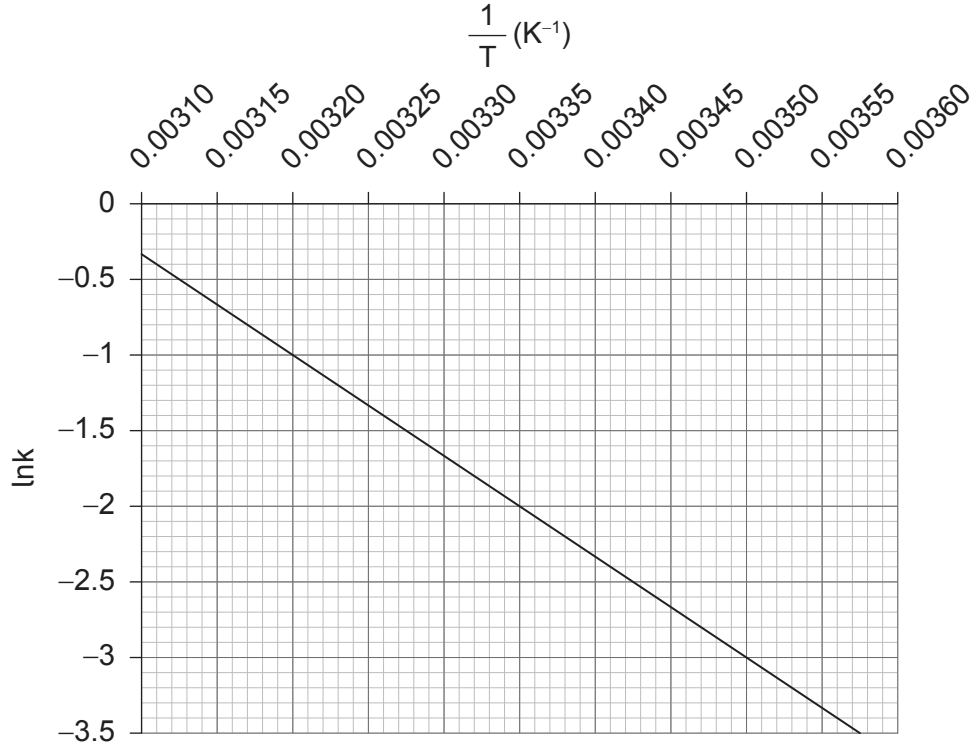
8. A series of experiments were carried out at different temperatures and the rate of reaction, in mol dm^{-3} s^{-1}, was determined for each. The rate constant for the reaction of propanone (CH_3COCH_3) with iodine (I_2) was calculated and the processed data is represented in the following graph.



Determine the activation energy for this reaction, stating the units. Use sections 1 and 2 of the data booklet. [3]

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9. (a) Explain why a colorimeter set at a wavelength of 500 nm is not suitable to investigate reactions of Zn^{2+} compounds. Use section 3 of the data booklet. [2]

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(b) Nitrogen (II) oxide radicals (NO•) catalyse the decomposition of ozone (O_3).

(i) Formulate equations showing how NO• acts as a catalyst in this reaction. [2]

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Chlorine also forms free radicals; the bond enthalpy for Cl_2 is 4.02×10^{-19} J.

(ii) Calculate the minimum frequency of light needed to break this bond. Use sections 1 and 2 of the data booklet. [1]

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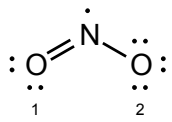
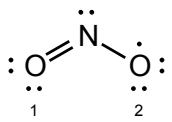
(Question 9 continued)

(iii) Calculate the formal charge on each atom in the **two** Lewis structures of the NO_2• (g) radical. [1]

	Structure A 	**Structure B** 
Oxygen 1	. . . . .	. . . . .
Nitrogen	. . . . .	. . . . .
Oxygen 2	. . . . .	. . . . .

(iv) Lewis structure A is more stable. Suggest, giving **one** reason, whether the formal charge model supports this. [1]

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References: