Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Wednesday 9 November 2022 (morning)

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]**.

8822 – 6102

27 pages

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

1. Ammonium nitrate, NH_4NO_3, is used as a high nitrogen fertilizer.

(a) Calculate the percentage by mass of nitrogen in ammonium nitrate. Use section 6 of the data booklet. [1]

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(b) State, with a reason, whether the ammonium ion is a Brønsted-Lowry acid or base. [1]

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(c) A 0.20 mol dm^{-3} solution of ammonium nitrate is prepared.

(i) Calculate the pH of an ammonium nitrate solution with $[H_3O^+] = 1.07 \times 10^{-5}$ mol dm^{-3}. Use section 1 of the data booklet. [1]

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(ii) Ammonium nitrate is neutralized with sodium hydroxide. Write the equation for the reaction. [1]

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(Question 1 continued)

(iii) A 20.00 cm^3 sample of the 0.20 mol dm^{-3} solution of ammonium nitrate is titrated with a 0.20 mol dm^{-3} solution of sodium hydroxide. Determine the pH at the equivalence point, to **two** decimal places using section 1 and 21 of the data booklet. [4]

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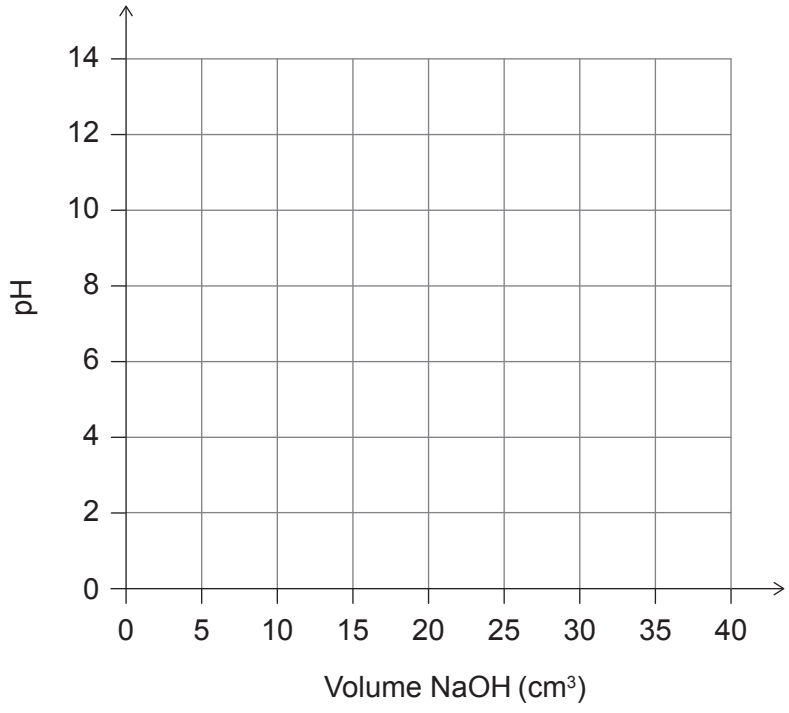
(iv) Sketch the pH curve that would result from the titration of a 0.20 mol dm^{-3} solution of ammonium nitrate with sodium hydroxide. [2]



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(Question 1 continued)

(v) State, with a reason, if bromothymol blue is an appropriate indicator for this titration. Use section 22 of the data booklet. [1]

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(d) Cold packs contain ammonium nitrate and water separated by a membrane.

(i) The mass of the contents of the cold pack is 25.32 g and its initial temperature is 25.2 °C. Once the contents are mixed, the temperature drops to 0.8 °C.

Calculate the energy, in J, absorbed by the dissolution of ammonium nitrate in water within the cold pack. Assume the specific heat capacity of the solution is $4.18\,J\,g^{-1}\,K^{-1}$. Use section 1 of the data booklet. [1]

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(ii) Determine the mass of ammonium nitrate in the cold pack using your answer obtained in (d)(i) and sections 6 and 19 of the data booklet.

If you did not obtain an answer in (d)(i), use 3.11×10^3 J, although this is not the correct answer. [2]

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(Question 1 continued)

(iii) The absolute uncertainty in mass of the contents of the cold pack is ±0.01 g and in each temperature reading is ±0.2 °C. Using your answer in (d)(ii), calculate the absolute uncertainty in the mass of ammonium nitrate in the cold pack.

If you did not obtain an answer in (d)(ii), use 6.55 g, although this is not the correct answer. [3]

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(iv) The cold pack contains 9.50 g of ammonium nitrate. Calculate the percentage error in the experimentally determined mass of ammonium nitrate obtained in (d)(ii).

If you did not obtain an answer in (d)(ii), use 6.55 g, although this is not the correct answer. [1]

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(v) Calculate the standard entropy change, $\Delta S^{\ominus}$, for the dissolution of ammonium nitrate. [1]

$$S^{\ominus}NH_4NO_3(s) = 151.1\,J\,mol^{-1}\,K^{-1}$$

$$S^{\ominus}NH_4NO_3(aq) = 259.8\,J\,mol^{-1}\,K^{-1}$$

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(This question continues on the following page)

(Question 1 continued)

(vi) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, in kJ mol^{-1}, for the dissolution of ammonium nitrate at 298 K. Use sections 1 and 19 of the data booklet as well as your answer for question part (d)(v).

If you did not obtain an answer in (d)(v), use 102.3 J mol^{-1} K^{-1}, although this is not the correct answer. [1]

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(vii) Calculate the value of the equilibrium constant for the dissolution of ammonium nitrate at 298 K using the answer to question part (d)(vi) and section 1 of the data booklet.

$$NH_4NO_3(s) \rightleftharpoons NH_4NO_3(aq)$$

If you did not obtain an answer in (d)(vi), use −7.84 kJ/mol, although this is not the correct answer. [2]

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(viii) Deduce, with a reason, the position of the equilibrium. [1]

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(Question 1 continued)

(e) Predict, using the given values, the reaction that would take place at the anode and cathode for the electrolysis of an aqueous solution of ammonium nitrate using graphite electrodes. [2]

	$E^{\ominus}$ / V
$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l)$	+ 1.23
$NO_3^-(aq) + 4H^+(aq) + 3e^- \rightarrow NO(g) + 2H_2O(l)$	+ 0.96
$H^+(aq) + e^- \rightarrow \frac{1}{2}H_2(g)$	0.00

Anode: . . . . . .

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Cathode: . . . . . .

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(f) Solid ammonium nitrate can decompose to gaseous dinitrogen monoxide and liquid water.

(i) Write the chemical equation for this decomposition. [1]

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(ii) Calculate the volume of dinitrogen monoxide produced at STP when a 5.00 g sample of ammonium nitrate decomposes. Use section 2 of the data booklet. [2]

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(Question 1 continued)

(iii) Calculate the standard enthalpy change, $\Delta H^{\ominus}$, of the reaction. Use section 12 of the data booklet. [2]

$\Delta H_f^{\ominus}$ ammonium nitrate $= -366\,\text{kJ mol}^{-1}$

$\Delta H_f^{\ominus}$ dinitrogen monoxide $= 82\,\text{kJ mol}^{-1}$

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(iv) Predict, with a reason, the signs for the entropy change, $\Delta S^{\ominus}$, and Gibbs free energy change, $\Delta G^{\ominus}$, of the reaction. [2]

Entropy change: . . . . . .

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Gibbs free energy change: . . . . . .

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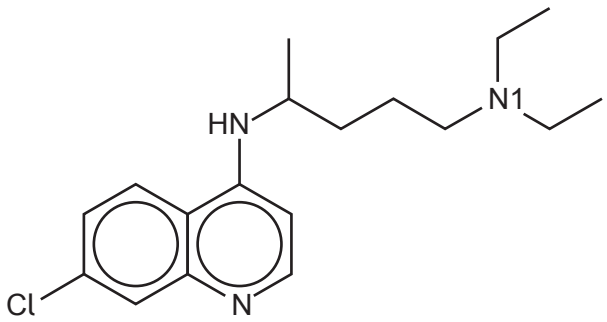
(v) Deduce the Lewis (electron dot) structure, including formal charges, and shape for dinitrogen monoxide showing nitrogen as the central atom. [3]

Lewis structure:

Shape: . . . . . .

2. Chloroquine is a medication used to prevent and treat malaria.



(a) Draw a circle around the secondary amino group in chloroquine. [1]

(b) State the number of sp^2 hybridized carbons in chloroquine. [1]

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(c) Determine the index of hydrogen deficiency, IHD, of chloroquine. [1]

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(d) Compare, giving a reason, the length of the carbon-nitrogen bond in the ring to the length of the carbon-N1 bond. [1]

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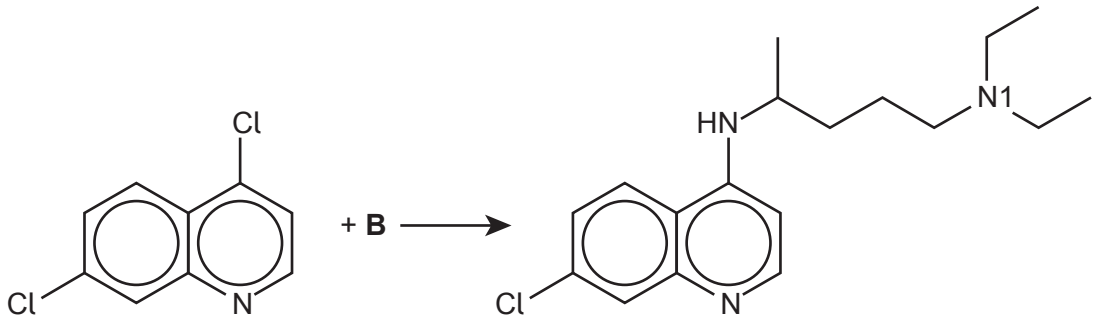
(Question 2 continued)

(e) Chloroquine can be synthesized by reacting 4,7-dichloroquinoline with another reactant, **B**.



4,7-dichloroquinoline **chloroquine**

(i) Deduce the structure of **B**. [2]

(ii) This reaction can be done with a copper catalyst. State the ground-state electron configuration for copper. [1]

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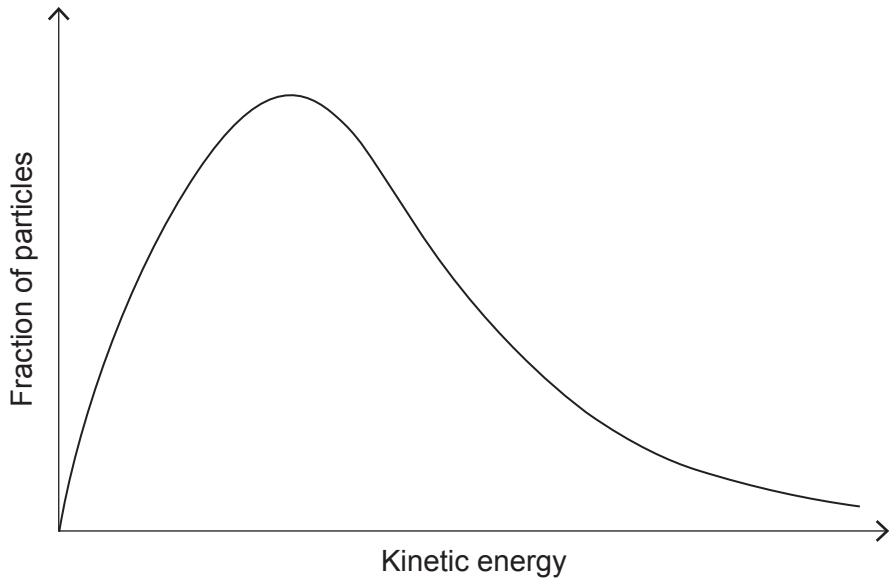
(Question 2 continued)

(iii) Annotate the Maxwell–Boltzmann distribution curve showing the activation energies, E_a, for the catalysed and uncatalysed reactions. [1]



(iv) Explain, referring to the Maxwell–Boltzmann distribution curve, the effect of a catalyst on a chemical reaction. [1]

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3. Consider the following reaction:

$$Cu^{2+}(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + Cu(s)$$

(a) State the ground-state electron configuration for Fe^{2+}. [1]

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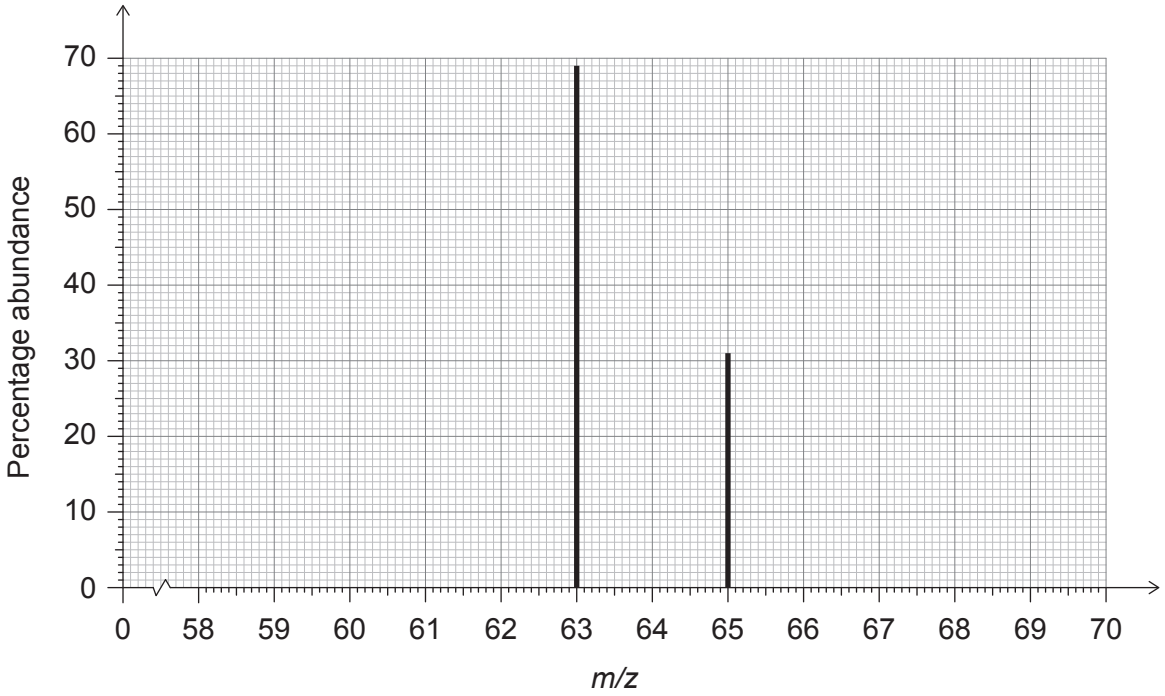
(b) The mass spectrum for copper is shown:



Show how a relative atomic mass of copper of 63.62 can be obtained from this mass spectrum. [1]

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(Question 3 continued)

(c) Predict, with a reason, whether Cu or Cu^{2+} has the greater ionization energy. [1]

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(d) Determine the frequency, in s^{-1}, of a photon that will cause the first ionization of copper. Use sections 1, 2 and 8 of the data booklet. [2]

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(e) Outline the magnetic properties of iron by referring to its electron configuration. [2]

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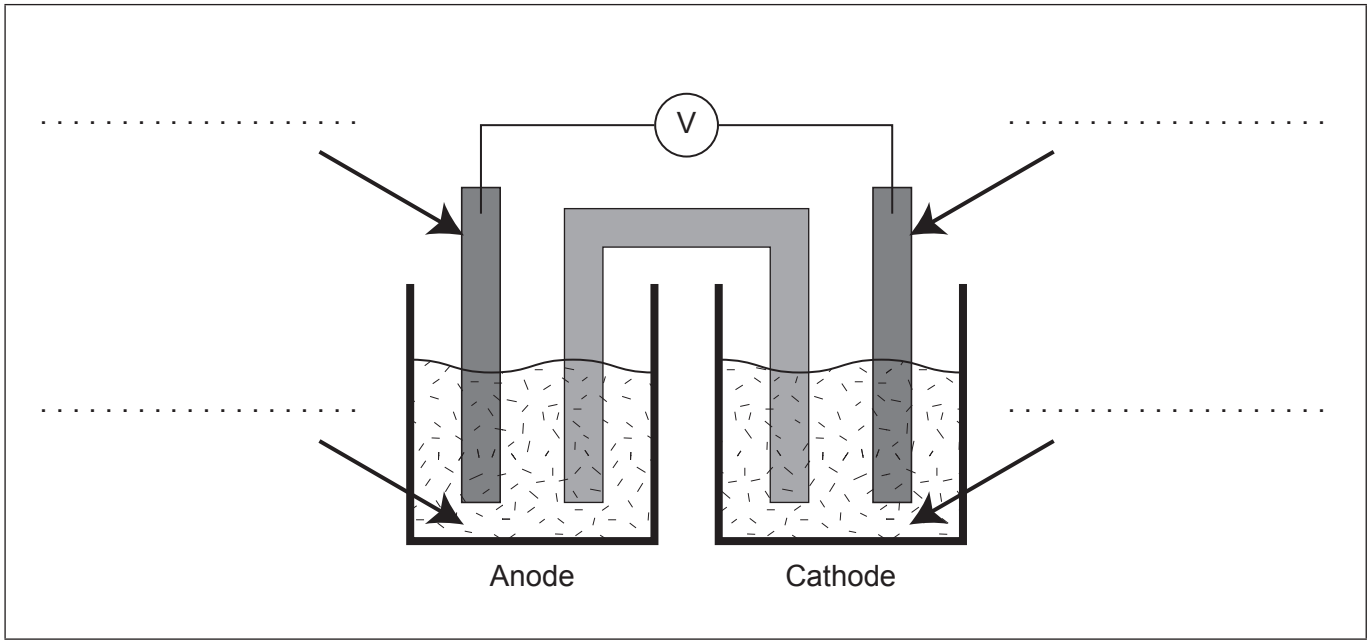
(Question 3 continued)

(f) The diagram shows an unlabelled voltaic cell for the reaction:

$$Cu^{2+}(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + Cu(s)$$



(i) Label the diagram with the species from the equation and the direction of electron flow. [2]

(ii) Write the half-equation for the reaction occurring at the anode (negative electrode). [1]

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(iii) The diagram includes a salt bridge that is filled with a saturated solution of KNO_3. Outline the function of the salt bridge. [1]

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(Question 3 continued)

(iv) Predict the movement of **all** ionic species through the salt bridge. [2]

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(v) Calculate the standard cell potential, in V, for this cell. Use section 24 of the data booklet. [1]

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(vi) Calculate the standard free energy change, **in kJ**, for the cell. Use your answer in (f)(v) and sections 1 and 2 of the data booklet.

If you did not obtain an answer in (f)(v), use 0.68 V, although this is not the correct answer. [1]

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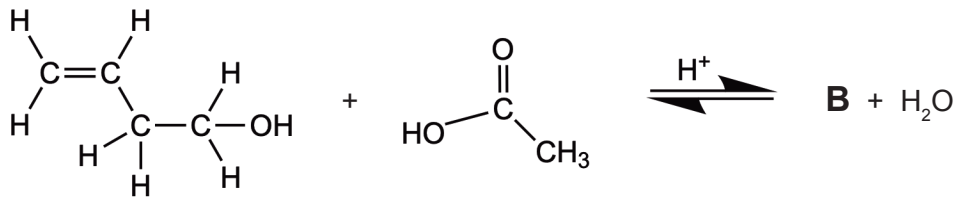
4. An organic compound, **A**, reacts with ethanoic acid to produce **B** using concentrated sulfuric acid as a catalyst.



A ethanoic acid

(a) (i) Deduce the structural and empirical formulas of **B**. [3]

Structural formula:

Empirical formula: . . . . . .

(ii) Explain, with reference to Le Châtelier's principle, the effect of using dilute rather than concentrated sulfuric acid as the catalyst on the yield of the reaction. [2]

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(Question 4 continued)

(iii) Explain, with reference to intermolecular forces, why **B** is more volatile than **A**. [2]

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(b) Compound **A** can also react with bromine. Describe the change observed if **A** is reacted with bromine. [1]

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5. Lignite, a type of coal, contains about 0.40 % sulfur by mass.

(a) Calculate the amount, in mol, of sulfur dioxide produced when 500.0 g of lignite undergoes combustion. [2]

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

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(b) Write an equation that shows how sulfur dioxide can produce acid rain. [1]

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(c) Deduce the Lewis (electron dot) structure for sulfur dioxide. [1]

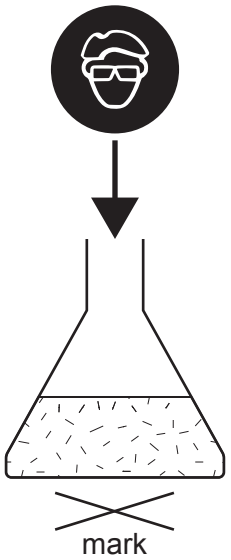
(This question continues on the following page)

(Question 5 continued)

(d) Sodium thiosulfate reacts with hydrochloric acid as shown:

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow S(s) + SO_2(aq) + 2NaCl(aq) + H_2O(l)$$

The precipitate of sulfur makes the mixture cloudy, so a mark underneath the reaction mixture becomes invisible with time.



Suggest **two** variables, other than concentration, that should be controlled when comparing relative rates at different temperatures. [2]

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(e) Discuss **two** different ways to reduce the environmental impact of energy production from coal. [2]

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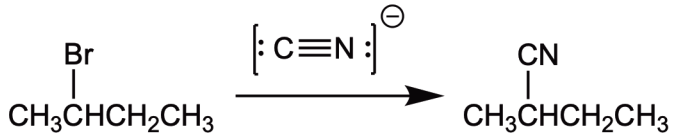
(Question 5 continued)

(f) SF_4Cl_2 can form two isomers, one which is polar and another non-polar. Deduce the 3-dimensional representations of both isomers of SF_4Cl_2. [2]

Non-polar isomer:

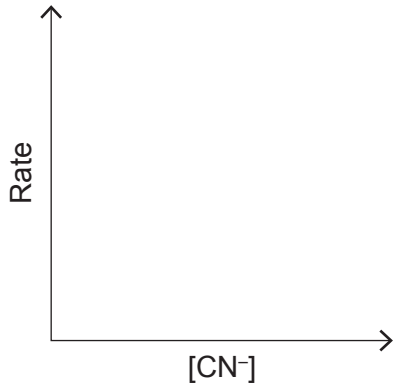
Polar isomer:

6. 2-Bromobutane can react with cyanide, CN^-, in a nucleophilic substitution reaction.

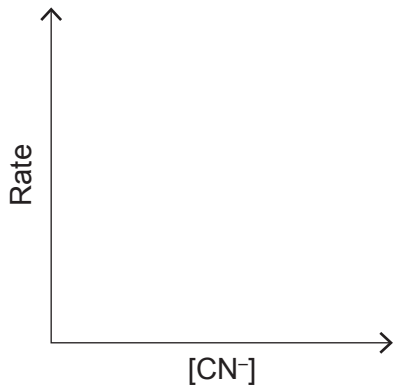


(a) This reaction could proceed through either S_N1 or S_N2 mechanisms depending on the reaction conditions. Sketch a graph of the rate versus nucleophile concentration, $[CN^-]$, for each of the mechanisms. [2]

S_N1 mechanism:



S_N2 mechanism:



(b) Suggest, with a reason, whether the reaction follows an S_N1 or S_N2 mechanism if only one stereoisomer was obtained as a product. [1]

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(This question continues on the following page)

(Question 6 continued)

(c) State an instrument that could be used to determine whether the product was a single enantiomer or a racemic mixture. [1]

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(d) S_N1 and S_N2 reactions are better conducted using different types of solvents. Identify **two** properties of a solvent most suited for the mechanism proposed in (b). [1]

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(e) State, with a reason, how the rate of reaction of cyanide with 2-chlorobutane differs from its rate of reaction with 2-bromobutane under the same conditions. [1]

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(f) 2-Bromobutane reacts with hydroxide via the same mechanism identified in (b). Explain this mechanism using curly arrows to represent the movement of electron pairs. [3]

(This question continues on page 27)

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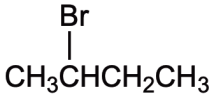
will not be marked.

(Question 6 continued)

(g) (i) Deduce the number of signals and the ratio of areas under the signals in the ^{1}H NMR spectrum of 2-bromobutane. [2]



Number of signals:

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Ratio of areas:

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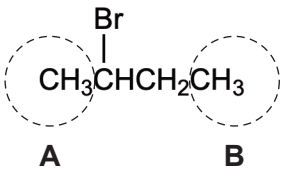
(ii) Identify the splitting pattern of the signal of the hydrogen atoms on the circled carbon atoms in 2-bromobutane. [2]



Splitting pattern of the signal of the hydrogen atoms in circle **A**:

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Splitting pattern of the signal of the hydrogen atoms in circle **B**:

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References:

3.(b) WebElements, n.d. *Copper: isotope data* [online] Available at: https://www.webelements.com/copper/isotopes.html [Accessed 6 October 2021].