Diploma Programme
Programme du diplôme
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Programa del Diploma

Chemistry
Higher level
Paper 2

5 November 2024

Zone A morning | **Zone B** morning | **Zone C** 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]**.

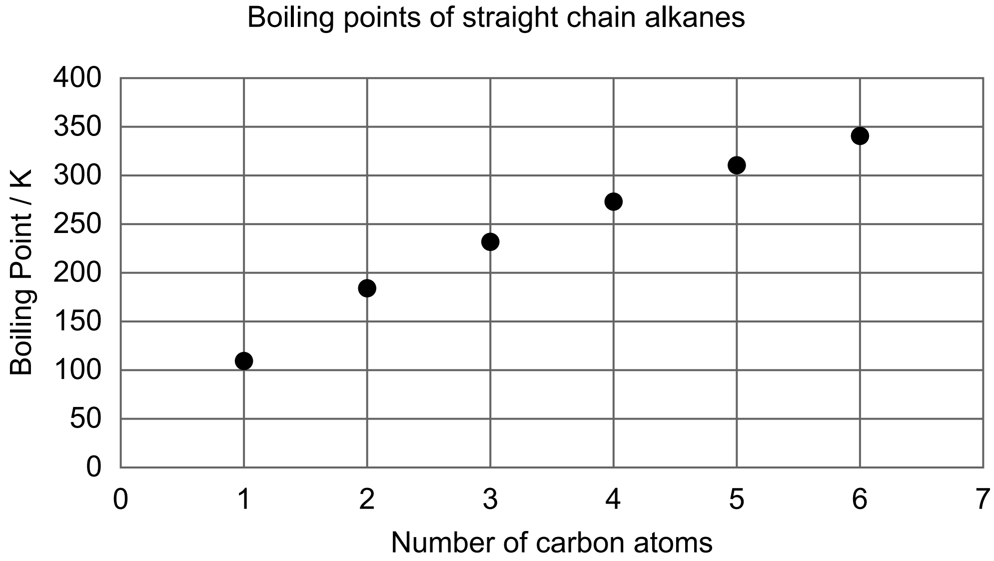
25 pages

8824 – 9541

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

1. Alkanes are commonly occurring organic compounds.

(a) The first four straight chain alkanes are gases at room temperature.



(i) Explain why the boiling point increases from methane to propane. [2]

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(ii) Explain why the volume occupied by a sample of propane increases sharply when the sample is heated up from 200 to 250 K at constant pressure. [2]

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(Question 1 continued)

(iii) Calculate the volume, in dm^3, occupied by 6.45 g of propane gas at 100 kPa and 15 °C. [2]

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(iv) Outline why the volume occupied by propane (g) at very high pressure is higher than the value calculated using $PV = nRT$. [2]

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(b) Ethane can be converted to chloroethane by reacting with chlorine gas, $Cl_2(g)$, in the presence of UV light.

State the type of reaction and the name of the mechanism by which it occurs. [1]

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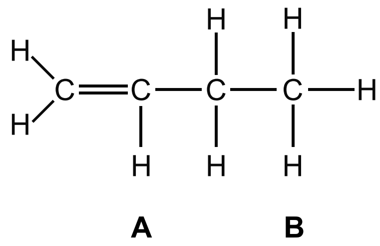
(c) Chloroethane can be converted to ethanol. Identify the reagent and conditions necessary for this reaction to occur. [2]

Reagent: . . . .

Conditions: . . . .

2. Alkenes are useful in industry.

(a) But-1-ene contains sigma (σ) and pi (π) bonds.



(i) Identify the hybridization of the carbon atoms labelled **A** and **B**. [1]

A: . . . .

B: . . . .

(ii) Describe how sigma (σ) and pi (π) bonds are formed. [2]

σ bonds: . . . .

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π bonds: . . . .

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(b) But-1-ene reacts with HBr to produce two structural isomers of bromobutane.

(i) Explain which of the two structural isomers is the major product. [2]

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(Question 2 continued)

(ii) Explain the mechanism for the formation of the major product using curly arrows to represent the movement of electron pairs. [3]

(iii) One of the structural isomers can exist as a pair of enantiomers. State the name of an instrument which can distinguish between the enantiomers. [1]

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Answers written on this page
will not be marked.

3. Potassium, K, and potassium chloride, KCl, both form lattice structures in the solid state.

(a) Predict, with a reason, the electrical conductivity of K(s) and KCl(s). [2]

K(s): . . . .

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KCl(s): . . . .

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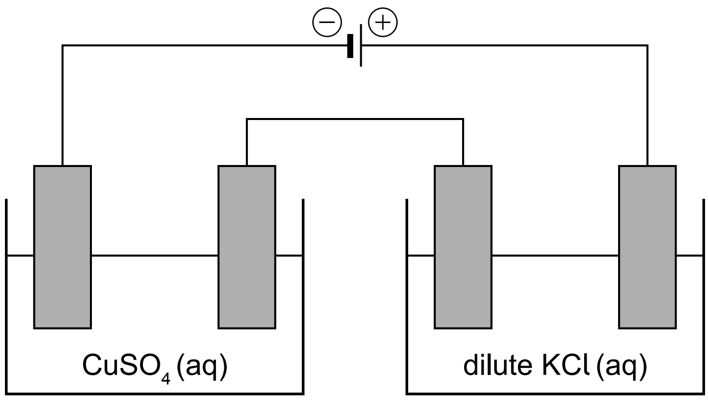
(b) Two electrolytic cells are connected in series. All electrodes are inert.



(i) State the half equation for the reaction occurring at each electrode in Cell 2. Use section 24 of the data booklet. [2]

Anode (positive electrode): . . . .

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Cathode (negative electrode): . . . .

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(This question continues on the following page)

(Question 3 continued)

(ii) Identify the product at the anode in Cell 1. [1]

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(iii) Determine the mole ratio of non-ionic products formed at the cathode (negative electrode) in Cell 1 and Cell 2. [1]

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(c) State the number of each type of subatomic particle in the potassium ion, ${}^{41}_{19}K^{+}$. [1]

Protons: . . . .

Electrons: . . . .

Neutrons: . . . .

(d) Outline the evidence that the electrons in a potassium atom occupy four main energy levels. [2]

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(Question 3 continued)

(e) Potassium reacts with water to produce potassium hydroxide.

$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$

(i) Calculate the enthalpy of reaction, in $kJ\,mol^{-1}$, when 1 mol of potassium reacts with water. Use section 12 of the data booklet. ΔH_f of KOH (aq) is $-481.8\,kJ\,mol^{-1}$. [3]

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(ii) Describe the difference between the reactions of sodium and potassium with water. [1]

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(iii) Demonstrate, with an equation, the acid-base nature of $K_2O(s)$. [1]

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4. Sulfur trioxide is an important compound in industry.

(a) Sulfur trioxide has more than one possible Lewis (electron dot) structure.

(i) Sketch **two** Lewis (electron dot) structures for SO_3, one of which obeys the octet rule and one of which does not. [2]

Obeys octet rule:

Does not obey octet rule:

(ii) State how chemists decide which Lewis (electron dot) structure is more stable. [1]

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(iii) Predict the length of each S to O bond in pm. Use section 10 of the data booklet. [1]

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(Question 4 continued)

(b) Suggest why atmospheric $SO_3(g)$ is an environmental concern. [1]

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(c) State the name of a post-combustion method used to lower the quantity of $SO_3(g)$ released to the atmosphere. [1]

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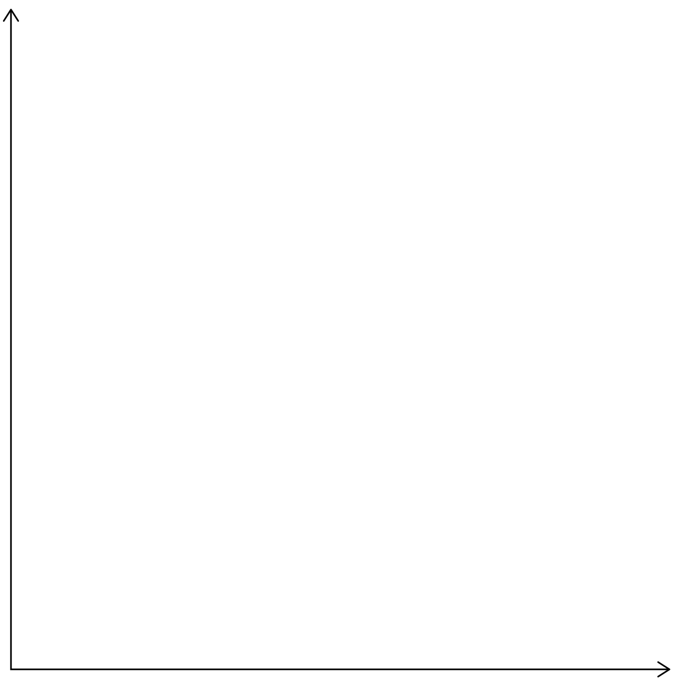
(d) $SO_3(g)$ is made using the contact process.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H^{\ominus} < 0$$

(i) Sketch a potential energy profile for this reaction on the axes provided. Label E_a and include labels on the axes. [3]



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(Question 4 continued)

(ii) Explain why increasing the temperature increases the rate of reaction. [2]

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(iii) Vanadium pentoxide, V_2O_5, is used as a catalyst. Explain how a catalyst increases the rate of a reaction. [2]

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(iv) During the reaction, V_2O_5 changes to V_2O_4. Identify the oxidation states of vanadium in each compound. [1]

V_2O_5: . . . .

V_2O_4: . . . .

(v) State the equilibrium constant expression, K_c, for the production of 1 mol of SO_3. [1]

$$SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$$

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(Question 4 continued)

(vi) Calculate the entropy change, $\Delta S^{\ominus}$, in $J\,K^{-1}\,mol^{-1}$, for the production of 1 mol of $SO_3(g)$. Use the absolute entropy values given in the table. [1]

	$S^{\ominus}$ / $J\,K^{-1}\,mol^{-1}$
$SO_2(g)$	248.2
$O_2(g)$	205.2
$SO_3(g)$	256.8

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(vii) Outline, with reference to the equation, why the sign for the entropy change obtained in part (vi) is expected. [1]

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(viii) Calculate the value of Gibbs free energy, $\Delta G^{\ominus}$, of the reaction, in $kJ\,mol^{-1}$, at 773 K. Use section 1 of the data booklet and $\Delta H^{\ominus} = -98.5\,kJ\,mol^{-1}$. If you did not obtain an answer for (d)(vi), use $-100\,J\,K^{-1}\,mol^{-1}$, although this is not the correct answer. [1]

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(Question 4 continued)

(ix) Calculate the value of the equilibrium constant for the formation of SO_3(g) at 773 K. Use sections 1 and 2 of the data booklet. If you did not obtain an answer to (d)(viii), use –25.0 kJ mol^{-1}, although this is not the correct answer. [2]

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(x) A flask contains 0.120 mol dm^{-3} SO_2(g), 0.050 mol dm^{-3} O_2(g) and 0.150 mol dm^{-3} SO_3(g) at 773 K. Deduce whether the system is at equilibrium and in which direction the reaction will proceed spontaneously if not at equilibrium. [2]

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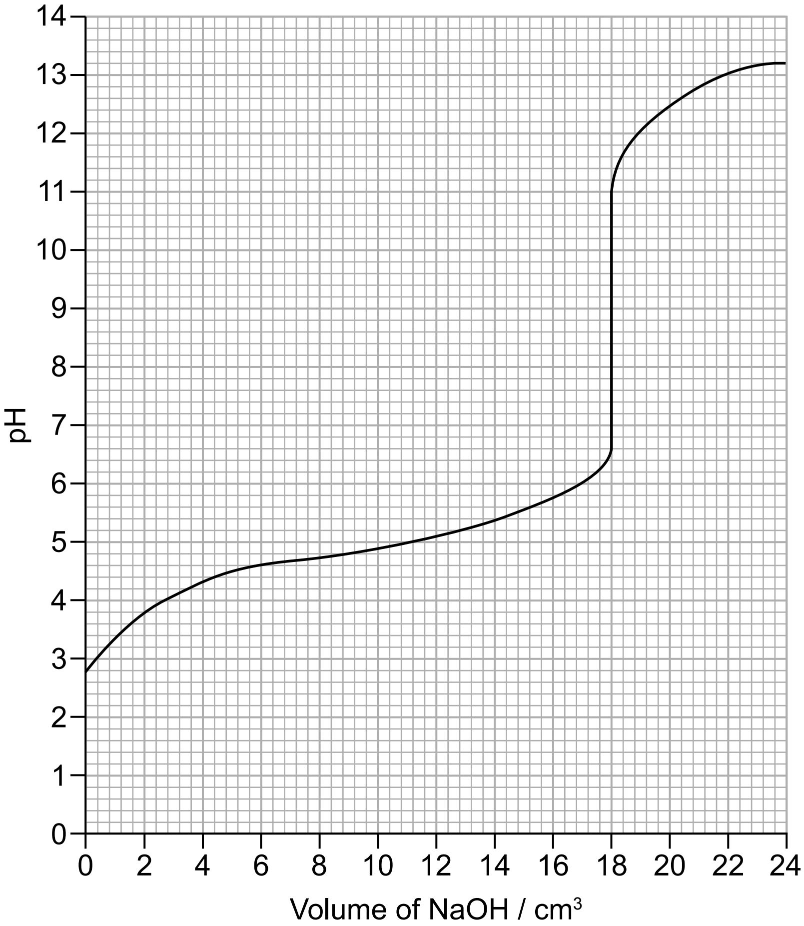
5. Organic acids are weak acids.

(a) A 20.00 cm^3 sample of a weak monoprotic acid with a concentration of 0.150 mol dm^{-3} was titrated with a solution of sodium hydroxide, NaOH (aq), giving the pH curve shown.



(i) Determine the concentration, in mol dm^{-3}, of the NaOH (aq) used in the titration. [2]

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(Question 5 continued)

(ii) Determine the pK_a of the weak acid using the graph. [1]

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(iii) Outline why phenolphthalein can be used as an acid–base indicator. [1]

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(iv) Outline why phenolphthalein is suitable for this titration. Use section 22 of the data booklet. [1]

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(b) Outline how samples of the weak acid and a strong acid of the same concentration can be distinguished from each other. [2]

Method: . . . .

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Observation: . . . .

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(Question 5 continued)

(c) The K_w of pure water is 1.00×10^{-14} at 25 °C.

(i) Suggest why the K_w value for pure water increases as temperature increases. [1]

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(ii) Calculate the pH and pOH of pure water at 60 °C. Use section 23 of the data booklet. [2]

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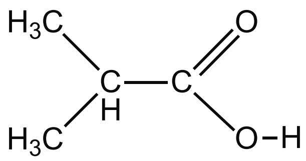
(d) 2-methylpropanoic acid and its esters are found in many foods.



(i) Predict the number of signals and the ratio of areas under the signals in the ¹H NMR spectrum of 2-methylpropanoic acid. [2]

Number of signals: . . . .

Ratio of areas: . . . .

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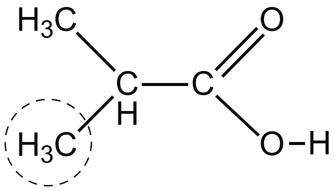
(Question 5 continued)

(ii) Predict the splitting pattern of the signal of the hydrogen atoms on the circled carbon atom in 2-methylpropanoic acid. [1]



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(iii) Outline why tetramethylsilane, TMS, is often used as a reference standard in ^{1}H NMR spectroscopy. [1]

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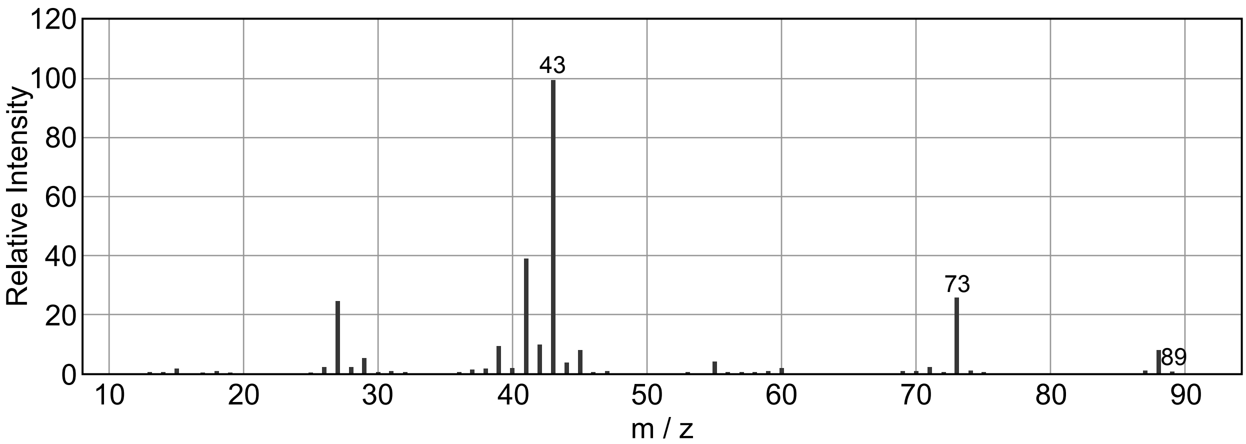
(e) The mass spectrum of 2-methylpropanoic acid is shown.



(i) The molar mass of 2-methylpropanoic acid is 88.12 g mol^{-1}. Suggest why there is a small peak with m/z 89. [1]

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(Question 5 continued)

(ii) Identify the fragments with m/z 73 and 43. Use section 28 of the data booklet [2]

m/z 73: . . . .

m/z 43: . . . .

(f) Predict the wavenumber of one absorbance, other than one due to the C–H bond, in the IR spectrum of 2-methylpropanoic acid. Use section 26 of the data booklet. [1]

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(g) 2-methylpropanoic acid reacts with ethanol in the presence of concentrated H_2SO_4 catalyst. Deduce the structural and empirical formulas of the organic product. [3]

Structural formula:

Empirical formula:

6. NO_2 is a brown gas found in photochemical smog.

(a) NO_2 forms from the reaction of NO and O_2 in the atmosphere.

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

(i) Suggest a method to measure the rate of reaction. [1]

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(ii) Determine the order of reaction for each reactant and the rate expression. [2]

Experiment	[NO] / $mol\,dm^{-3}$	[O_2] / $mol\,dm^{-3}$	initial rate / $mol\,dm^{-3}\,s^{-1}$
1	0.020	0.010	0.028
2	0.020	0.020	0.057
3	0.040	0.020	0.227

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(iii) Determine the value and the units of the rate constant, k, using data from experiment 3. [2]

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(Question 6 continued)

(b) NO_2 can form complexes with metals such as copper and magnesium. Describe the bonding within the complex, and the role of NO_2 in acid-base terms. [2]

Type of bonding: . . . .

Role of NO_2: . . . .

7. The Winkler Method is used to find the concentration of oxygen in water.

200 cm^3 of water was taken from a river and analysed using this method. The reactions taking place are summarized.

Step 1: $2Mn^{2+}(aq) + 4OH^-(aq) + O_2(aq) \rightarrow 2MnO_2(s) + 2H_2O(l)$

Step 2: $MnO_2(s) + 2I^-(aq) + 4H^+(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2H_2O(l)$

Step 3: $2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$

(a) Identify, with a reason, the species which is reduced in step 1. [1]

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(b) 4.8×10^{-3} moles of I^- were formed in step 3. Determine the number of moles of O_2 in the water sample. [1]

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(c) Calculate the concentration of oxygen, in $g\,dm^{-3}$, in the water sample. If you did not obtain an answer in (b), use 2.0×10^{-3} mol although this is not the correct answer. [1]

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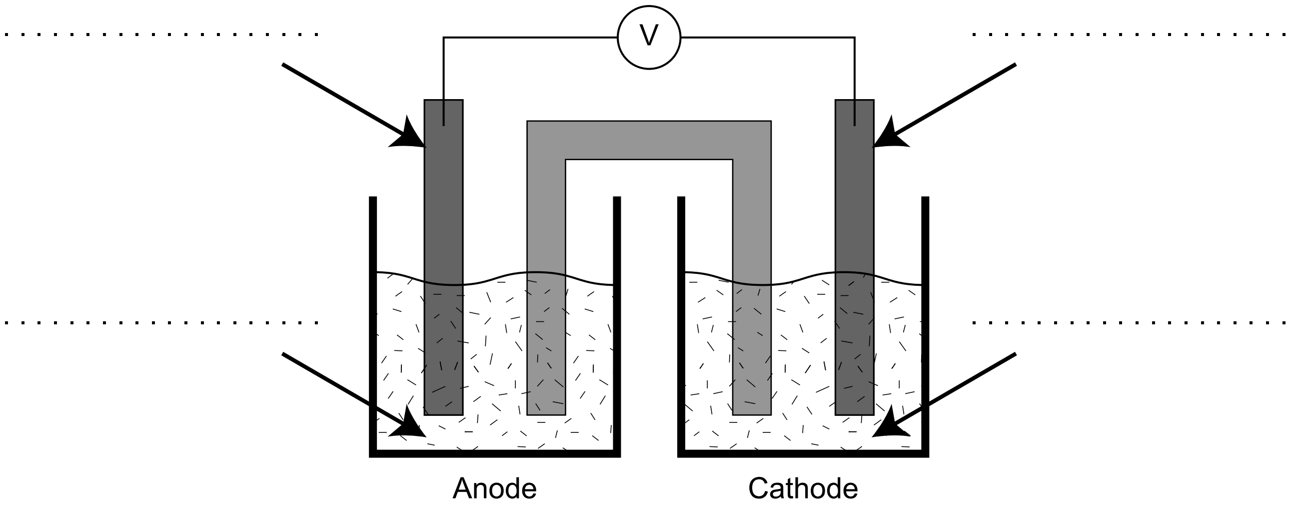
8. A voltaic cell is made using a nickel electrode, Ni (s), a silver electrode, Ag (s), and solutions of nickel nitrate, $Ni(NO_3)_2$ (aq), and silver nitrate, $AgNO_3$ (aq).

(a) Label the diagram with the electrodes and electrolytes, and the direction of electron flow. Use section 24 or 25 of the data booklet. [2]



(b) Outline why a salt bridge must be included to connect the two half cells. [1]

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References:

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6.(a)(ii) Vitz, E., Moore, J.W., Shorb, J., Prat-Resina, X., Wendorff, T. and Hahn, A., n.d. *18.3: The Rate Equation*. [online] Available at: https://chem.libretexts.org/Bookshelves/General_Chemistry/ChemPRIME_(Moore_et_al.)/18%3A_Chemical_Kinetics/18.03%3A_18.2-The_Rate_Equation [Accessed 6 October 2023]. Source adapted.

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