Diploma Programme
Programme du diplôme
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

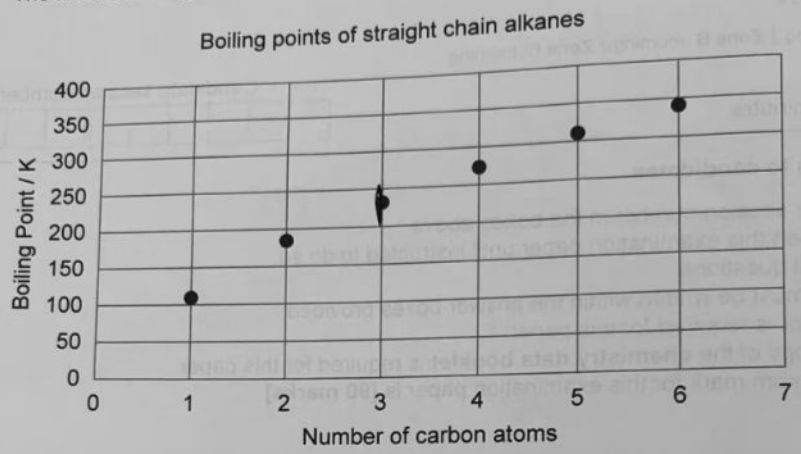
Instructions to candidates

- 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]**.

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]

Increase in molar mass
larger London force higher attraction between molecules

(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]

boiling point of propane is between 200 and 250K
When sample is heated from 200 to 250K propane change from liquid state to gaseous state

(This question continues on the following page)

(Question 1 continued)

C_3H_8.

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

$pV = nRT$ $n = \frac{6.45}{12.01 \times 3 + 8 \times 1.01} = 0.146\ mol$

$100\ kPa \times V = 0.146 \times 8.314 \times (298 + 15)$

$V = 3.50\ dm^3$

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

high pressure the distances between molecules are small.
the size of ~~atom~~ molecule cannot be ignored
can't be regard as ideal gas.
$pV = nRT$ works for ideal gas model.

(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]

free radical substitution

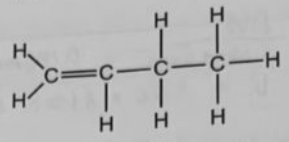
(c) Chloroethane can be converted to ethanol. Identify the reagent and conditions necessary for this reaction to occur. [2]

Reagent: NaOH (aq)

Conditions: heat.

2. Alkenes are useful in industry.

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



A B

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

A: sp^2

B: sp^3

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

σ bonds: head-on overlap of atomic orbital

π bonds: sideways overlap of parallel p orbitals

(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]

$CH_3CHBrCH_2CH_3$

the intermediate $CH_3\overset{\oplus}{C}HCH_2CH_3$ is more stable than $CH_3CH_2\overset{\oplus}{C}H_2$

because electron releasing effect of alkyl group

$CH_3\overset{\oplus}{C}HCH_2CH_3$ is secondary carbocation $CH_3CH_2CH_2\overset{\oplus}{C}H_2$ is primary carbocation.

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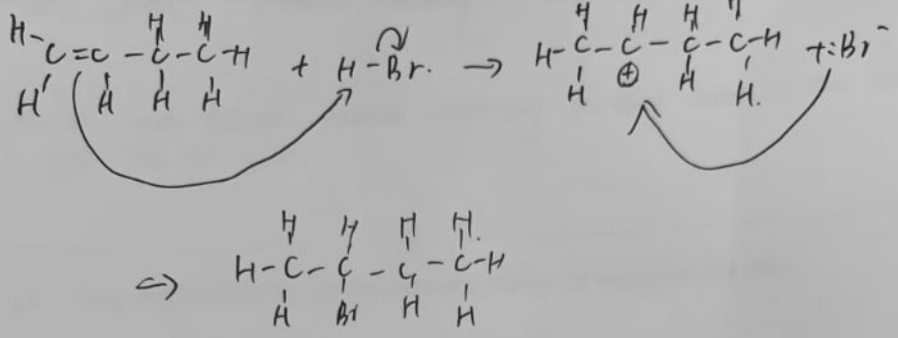
(Question 2 continued)

(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]

.....polarimeter.....

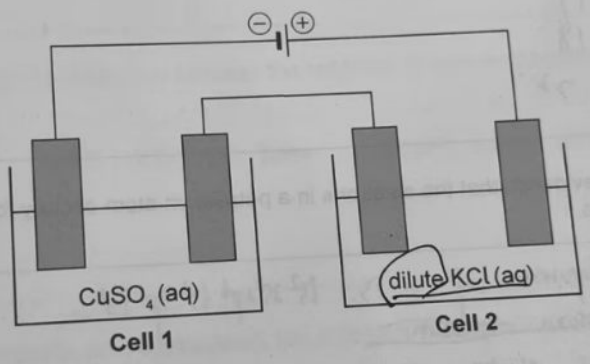
3. Potassium, K, and potassium chloride, KCl, both form lattice structures in the solid state.

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

K(s): ...good.....metallic..bonding.....have..mobile..electron..carry.charge.

KCl(s): ...~~not~~..cannot..conduct..electricity..in..solid..state....the..ions..are ...not..free..to..move.

(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): ~~$2H^+ \rightarrow 4H_2O$~~ $\rightarrow 4e^- + O_2 + 4H^+$

Cathode (negative electrode): $2H_2O + 2e^- \rightarrow 2OH^- + H_2$

(This question continues on the following page)

(Question 3 continued)

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

oxidation loss

O2

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

Cu : H2

1:1

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

Protons: 19

Electrons: 18

Neutrons: 22

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

electron configuration of K is $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$

~~hydrogen emission spectrum~~

the successive electron Ionization energy devide into four main group. there are gap between each group means there are different main energy levels

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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]

$\Delta H = \Sigma \Delta H_f$ (product) $- \Sigma \Delta H_f$ (reactant)

$= 2 \times (-481.8) - [(-285.8) \times 2]$

$= -392\ kJ\,mol^{-1}$

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

potassium with water is more vigorous, more violent.

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

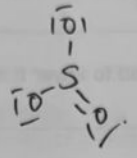
Basic $K_2O + H_2O \rightarrow 2KOH$

4. Sulfur trioxide is an important compound in industry.

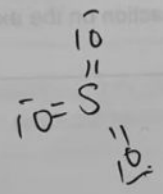
(a) Sulfur trioxide has more than one possible Lewis (electron dot) structure.

(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]

formal charge ... more ... close ... to ... zero ...

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

S-O single bond is 161 pm ... smaller than 161 ...

O=O 121 ... between 121 ~ 189 ... => ... 121 ~ 161 ...

S=S 189 ...

S=O is 140 pm.

(This question continues on the following page)

(Question 4 continued)

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

$SO_3 + H_2O \Rightarrow H_2SO_4$

H_2SO_4 will cause acid rain ~~check~~

erosion on metal bridge

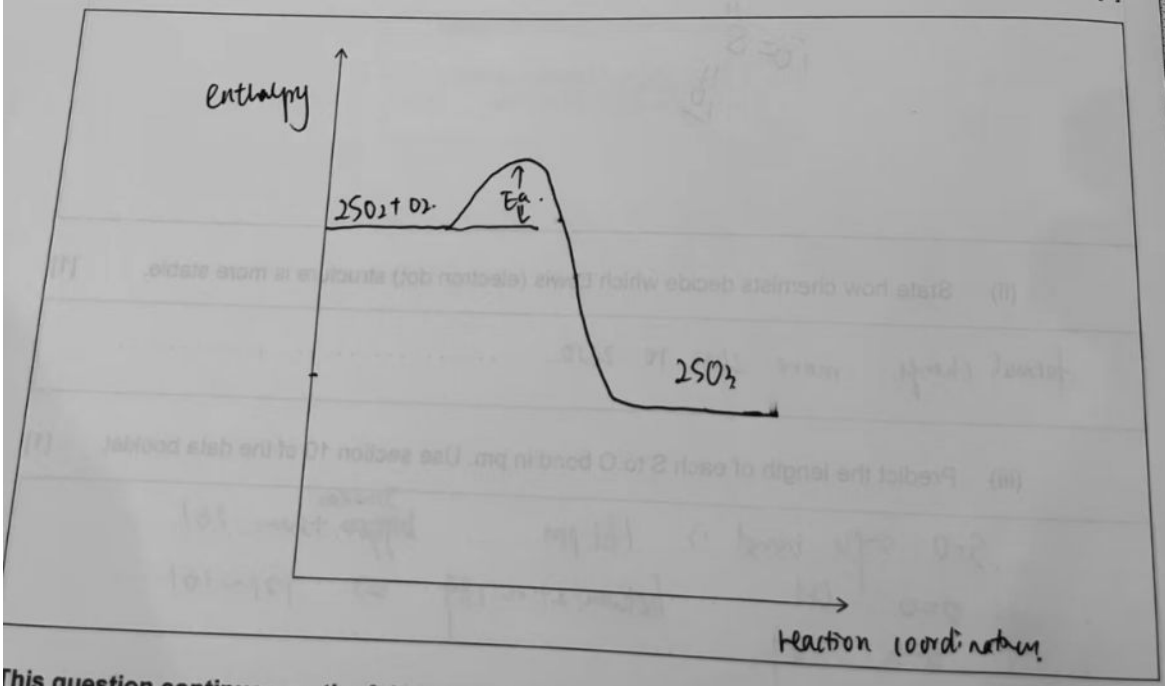
(c) State the name of a post-combustion method used to lower the quantity of $SO_3(g)$ released to the atmosphere. [1]

desulfurisation

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

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

(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]

more collision frequency
higher more particle have higher energy than Ea

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

Catalyst ~~decrease~~ provide alternative a pathway to reaction
lower ~~Ea~~ activation energy
more particle have higher engy than Ea

(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: +5
V_2O_4: +4

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

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

$$K_c = \frac{[SO_3]}{[SO_2][O_2]^{\frac{1}{2}}}$$

(This question continues on the following page)

(Question 4 continued)

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

$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3$

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

$\Delta S = \Sigma S^{\ominus}_{product} - \Sigma S^{\ominus}_{reactant}$

$= 256.8 - 248.2 - \frac{1}{2} \times 205.2$

$= -94\ J \cdot K^{-1} \cdot mol^{-1}$

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

product have 1 mol of gas reactant have 1.5 mol gaseous molecule ~~gas mol~~.
decrease in number of gaseous molecule decrease in disorder.

(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 $-100\,JK^{-1}mol^{-1}$, although this is not the correct answer. [1]

$\Delta G = \Delta H - T\Delta S = -98500 - 773 \times (-94)$

$= -25.8\ kJ\ mol^{-1}$

(This question continues on the following page)

(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]

$\Delta G = -RT\ln K$

$-25800 = -8.314 \times 773 \ln K$

$\ln K = -4.02$

$K = 0.0179$

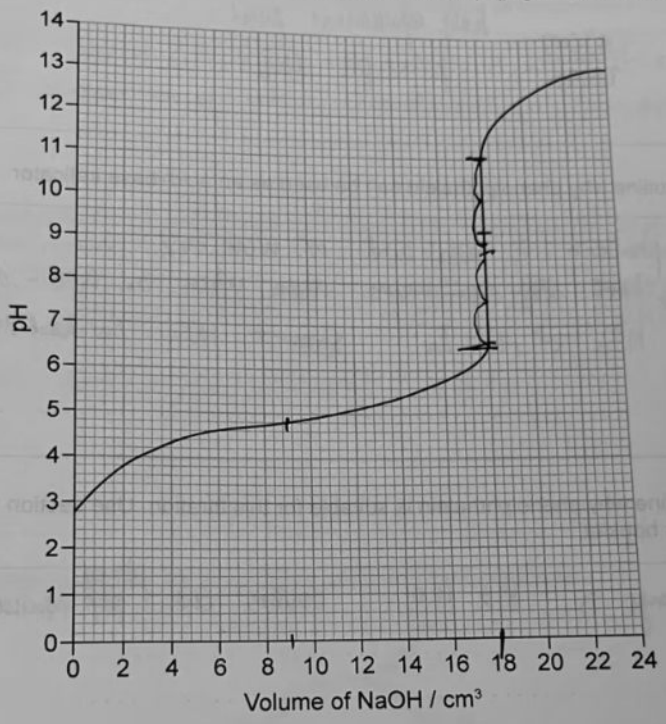
(x) A flask contains $0.120\,mol\,dm^{-3}$ $SO_2(g)$, $0.050\,mol\,dm^{-3}$ $O_2(g)$ and $0.150\,mol\,dm^{-3}$ $SO_3(g)$ at 773 K. Deduce whether the system is at equilibrium and in which direction the reaction will proceed spontaneously if not at equilibrium. [2]

$Q = \dfrac{[SO_3]}{[SO_2][O_2]^2} = \dfrac{0.15}{0.12 \times \sqrt{0.05}} = 5.59 > K$

$Q > K$ ~~eq~~ shift to left

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]

Equivalence point V(NaOH) = 18 cm^3

~~18 x 10~~ ~~18 cm^3 x~~

$\frac{20.00 \times 0.150}{18} = 0.167$ mol dm^{-3}

(This question continues on the following page)

(Question 5 continued)

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

half equivalent point

$K_a = \frac{[A^-][H^+]}{[HA]}$ $pK_a = pH = 4.8$

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

phenolphalein is weak acid or weak base

have equilibrium when in acidic or basic environment

$HIn \rightleftarrows H^+ + In^-$ ~~Show~~ HIn : In^- have different color

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

pH range is 8.3 - 10.0 covers the pH of equivalent point 8.8

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

Method: react with $CaCO_3$

Observation: more violent is strong acid less violent is weak acid

(This question continues on the following page)

(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]

$K_w = [OH^-][H^+]$

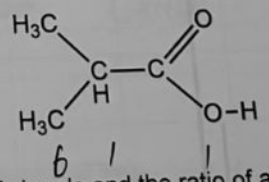
↑ dissociation of water is endothermic Temperature increase

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

60°C $K_w = 9.55 \times 10^{-14}$ $[H^+] = [OH^-] = \sqrt{K_w} = 3.09 \times 10^{-7}$

$pH = pOH = -\log_{10}(3.09 \times 10^{-7}) = 6.51$

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



6 1 1

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

Number of signals: 3

Ratio of areas: 6 : 1 : 1

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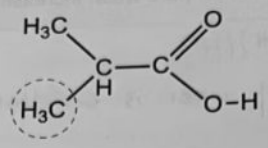
(Question 5 continued)

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

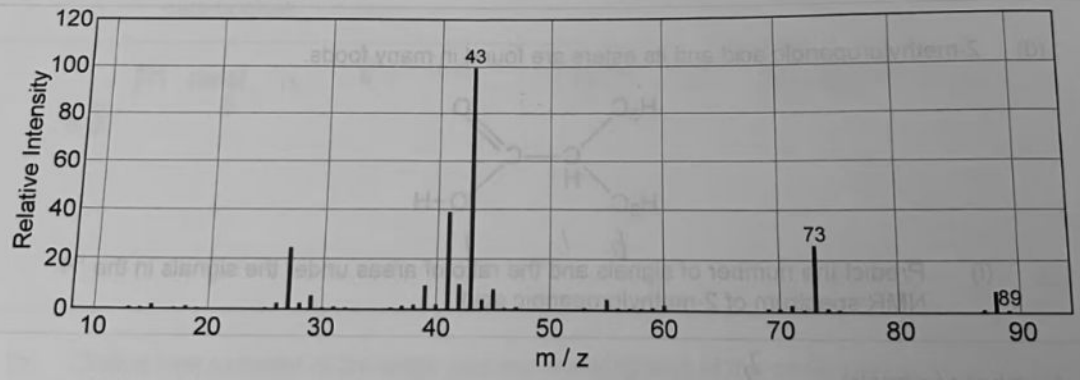


doublet

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

chemically stable. All H in same chemical environment

(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]

~~Isotope~~ Isotope with mr of 89 may contain C-13 or O-17

(This question continues on the following page)

(Question 5 continued)

88 / 73 / 15 — 88 / 43 / 45

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

m/z 73: ~~$(CH_3)_3CH$~~ $[(CH_3)_2CHC{=}O]^+$

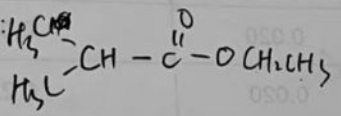
m/z 43: $[H_3C{-}CH{-}CH_2]^+$

(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]

C=O ... 1700 ~ 1750 ... strong peak

(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: ~~$C_6H_{12}O_2$~~ C_3H_6O

~~$CH_3C{=}COOH$~~

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]

change in pressure on constant volume

(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

compare 1 & 2 double [O_2] rate doubles [O_2] is 1st order

compare 2 & 3 double [NO] rate becomes four times [NO] is 2nd

Rate = $k[O_2][NO]^2$

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

$k = \frac{0.0227 \text{ mol dm}^{-3} \text{ s}^{-1}}{(0.04)^2 \times 0.02 \text{ (mol dm}^{-3})^2} = 7.1 \times 10^3 \text{ dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$

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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: ... coordination covalent bond .....

Role of NO_2: ..... Lewis base .....

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]

Mn^{2+}

(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]

$n = \frac{4.8 \times 10^{-3}}{4} = 1.2 \times 10^{-3}$ mole

(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]

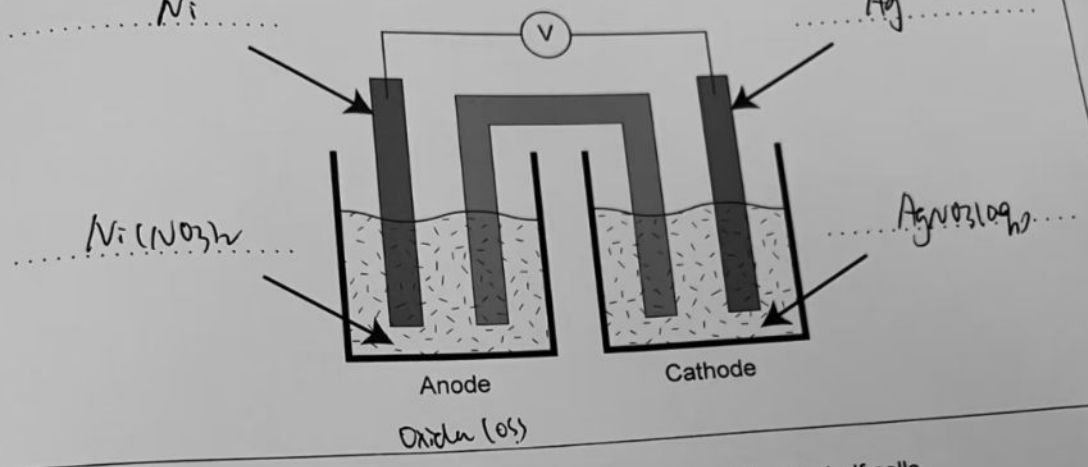
$1.2 \times 10^{-3} \times 16 \times 2 = 0.0384$ g

$\frac{0.0384\,g}{0.2\,dm^3} = 0.192\,g\,dm^{-3}$

10/10

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.

allow ions to flow in or out of half cell
to balance the charges in half-cells