Anglo-Chinese School
(Independent)

YEAR 5 Promotional Examination 2022
INTERNATIONAL BACCALAUREATE DIPLOMA PROGRAMME
CHEMISTRY HIGHER LEVEL

PAPER 2

Monday **12th September 2022** **2 hours 15 minutes**

INSTRUCTIONS TO CANDIDATES

- Do not open this examination paper until instructed to do so.
- Write your **candidate session number in the box above**.
- A calculator is required for this paper.
- A copy of the Chemistry Data Booklet is required for this paper.
- Write your answers in the boxes provided.
- If you use additional sheets of paper for your answer, attach them to the booklet. Indicate the question number clearly on these sheets.
- All drawings must be in ink.

For examiner's use	
Qn 1	/10
Qn 2	/6
Qn 3	/11
Qn 4	/5
Qn 5	/13
Qn 6	/8
Qn 7	/17
Qn 8	/11
Qn 9	/9
Wrong s.f. /units	
Total	/90

This question paper consists of 26 printed pages including this cover page.

Answer **all** questions. Write your answers in the boxes provided.

1. Chile saltpetre is a mineral found in Chile and Peru, which mainly consists of sodium nitrate, $NaNO_3$. The mineral is purified to concentrate the $NaNO_3$ which is used as a fertilizer and in some fireworks.

To determine the purity of a sample of $NaNO_3$, a (1.64 ± 0.02) g impure sample was heated in NaOH (aq) with Devarda's alloy which contains aluminium. This reduces the $NaNO_3$ to ammonia which is boiled off and then dissolved in acid as shown in the following equation.

$$3NaNO_3\,(aq) + 8Al\,(s) + 5NaOH\,(aq) + 18H_2O\,(l) \rightarrow 3NH_3\,(g) + 8NaAl(OH)_4\,(aq)$$

The NH_3 gas produced is dissolved in (25.00 ± 0.06) cm^3 of 1.00 mol dm^{-3} H_2SO_4.

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

The resulting solution was titrated with 2.00 mol dm^{-3} NaOH to determine the amount of unreacted H_2SO_4. (16.20 ± 0.10) cm^3 of NaOH were required for complete neutralization.

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$$

(a) (i) Calculate the amount of H_2SO_4 present in 25.0 cm^3 of 1.00 mol dm^{-3} H_2SO_4. [1]

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(ii) Calculate the amount of NaOH present in 16.2 cm^3 of 2.00 mol dm^{-3} NaOH. [1]

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(This question continues on the following page)

(Question 1 continued)

(b) (i) Use your answers in (a)(i) and (a)(ii) to determine the amount of $NaNO_3$ that is present in the sample. [2]

(If you do not have answers for (a)(i) and (a)(ii), use $n(H_2SO_4) = 0.0500$ mol and $n(NaOH) = 0.0250$ mol, but these are not the correct answers).

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(ii) Calculate the percentage uncertainty for the amount $NaNO_3$ determined in (b)(i). [2]

(If you do not have an answer for (b)(i), use $n(NaNO_3) = 0.0100$ mol but this is not the correct answer).

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(This question continues on the following page)

(Question 1 continued)

(iii) Use your answer in (b)(i) to determine the percentage composition of $NaNO_3$ present in the impure sample. [2]

(If you do not have an answer for (b)(i), use $n(NaNO_3) = 0.0100$ mol but this is not the correct answer).

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(iv) Calculate the absolute uncertainty of the percentage composition of $NaNO_3$. [2]

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2. (a) Fluorine reacts with other elements in Group 17 to form interhalogen compounds. The formulae of two such compounds are as shown in the table.

Draw the Lewis structures of ClF_5 and BrF_3. State the bond angle and molecular geometry for each molecule. [4]

	ClF_5	BrF_3
Lewis structure		
Bond angle of F-X-F		
Molecular Geometry		

(This question continues on the following page)

(Question 2 continued)

(b) The boiling point of the molecules are given in the table. [2]

compound	ClF_5	BrF_3
boiling point / ^oC	-13.1	125.7

Suggest why the boiling points of the molecules are significantly different.

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3. (a) (i) Explain why copper is considered a transition metal while zinc is not. [2]

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(This question continues on the following page)

(Question 3 continued)

(ii) Explain why complexes of Zn^{2+} (aq) are colourless whereas complexes of Cu^{2+} (aq) are coloured. [4]

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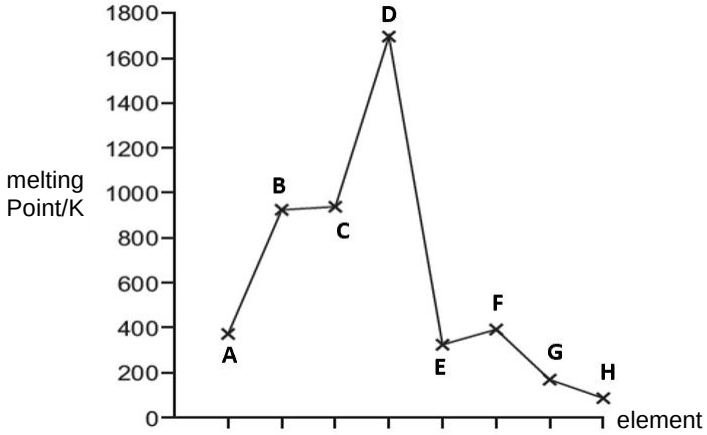
A plot of the melting points of the period 3 elements **A** – **H** is shown below.



(b) (i) Element **C** forms an amphoteric oxide. Construct two chemical equations to show the amphoteric nature of the oxide of **C**. [2]

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(This question continues on the following page)

(Question 3 continued)

(ii) Explain the significant difference in the melting point between elements **D** and **E**. [3]

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4. A novel idea to extract oxygen gas can be carried out by using a moon rock and heating it to very high temperatures, by concentrating the Sun's rays onto the rock sample. Most moon rocks are composed of metal oxides and silicon dioxides. At these temperatures, all the bonds in the sample are broken and the sample atomises. Some of the atoms may be ionised into positively charged ions. The ions may then be separated using magnetic or electric fields. Positively charged ions can be deflected in an electric field and the relationship is given by:

$$\text{Angle of deflection} \propto \frac{charge}{mass}$$

For a monoatomic, gaseous element at one atmosphere and at a temperature T (in K), the fraction, α, of the atoms that are ionised may be approximated by the equation:

$$\alpha = \sqrt{\frac{Ce^{-E_i/RT}}{T^{-\frac{5}{2}} + Ce^{-E_i/RT}}}$$

where E_i is the first ionization energy of the element in J mol^{-1}
R is the molar gas constant = 8.314 J K^{-1} mol^{-1}
T is temperature in kelvins
and C is a constant with a numerical value of 6.58×10^{-7}

(a) Rock sample 1 is composed of the elements O, Na, Mg, Al and Si. By using their relative atomic mass, calculate the $\frac{charge}{mass}$ ratio for the following ions and state which ion will deflect the most in an electric field. [2]

Positive Ions	Charge/mass ratio
O^+	
Na^+	
Mg^{2+}	

Ion which deflects the most: .....

(This question continues on the following page)

(Question 4 continued)

(b) Rock sample 2 contains the elements Ti, Al, Mg, Si and O. Given the first ionization energy of oxygen is 1314 kJ mol^{-1}, use the equation given to calculate the percentage of the oxygen atoms that would be ionized at this temperature of 10000 K. [3]

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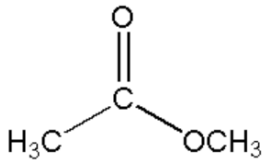
5. (a) Simple esters such as methyl ethanoate and ethyl ethanoate are flammable liquids. The structure of methyl ethanoate, $C_3H_6O_2$, is shown below.



(i) Define the standard enthalpy change of formation of methyl ethanoate. [1]

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(ii) Calculate the standard enthalpy change of formation of methyl ethanoate. [2]

species	$\Delta H^{\ominus}_c$ / kJ mol^{-1}
carbon	−393.5
hydrogen	−285.8
methyl ethanoate	−1592.1

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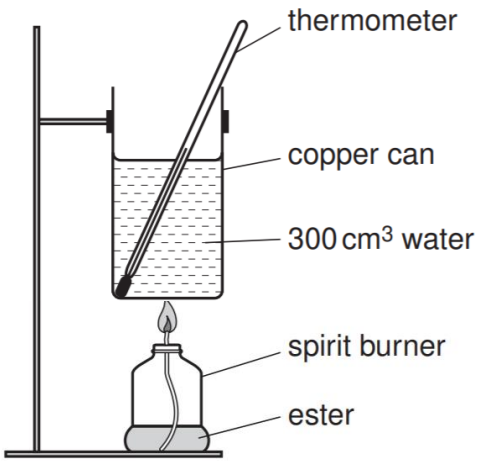
(Question 5 continued)

(b) A student used the experimental set-up shown to carry out experiments to determine the standard enthalpy change of combustion for methyl ethanoate.



The mass of the copper can is 250 g and the volume of water is 300 cm^3.

(i) The ester was combusted in a spirit burner underneath a copper can so that the flame from the burner heated the water in the can. It was found that 0.980 g of ester was required to raise the temperature of the water in the can by 9.0 °C. [2]

Calculate the total thermal energy in kJ gained by the water and the copper can in this initial experiment.

The specific heat capacities of water and copper are 4.18 and 0.384 J g^{-1} K^{-1}, respectively. Assume that the water and copper are in thermal equilibrium with each other.

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(Question 5 continued)

(ii) Given that the heat transfer to the entire experimental set-up is 65 % efficient and using your answer in (b)(i), calculate the standard enthalpy change of combustion for methyl ethanoate. [2]

(If you do not have answer for (b)(i), use 10.0 kJ, but this is not the correct answer.)

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(iii) With reference to standard enthalpy change of combustion given in (a)(ii), calculate the percentage error in the experimentally determined value of $\Delta H_c^{\ominus}$ for methyl ethanoate in (b)(ii). [1]

(If you do not have answer for (b)(ii), use the magnitude of 1250 kJ mol^{-1}, but this is not the correct answer.)

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(iv) Suggest **one** source of systematic error in the experiment that would lead to the deviation from the literature value. [1]

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(This question continues on the following page)

(Question 5 continued)

(v) Suggest **one** improvement to the experimental set-up that could increase the accuracy of the raw data recorded in these experiments. [1]

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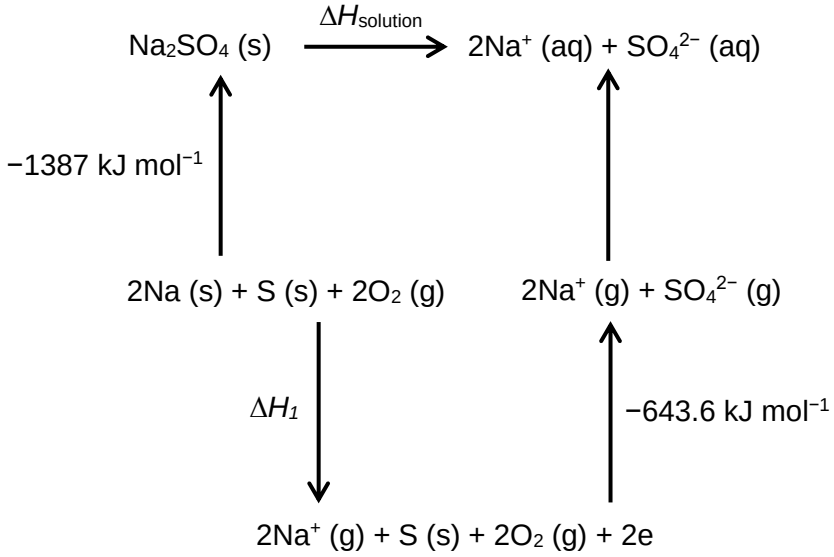
(c) The energy cycle of sodium sulfate is shown.



(i) Given that the $\Delta H_{atomisation}$ of sodium is +107 kJ mol^{-1}, calculate a value for ΔH_1 using section 8 of the data booklet. [1]

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(This question continues on the following page)

(Question 5 continued)

(ii) Determine the enthalpy change of solution of Na_2SO_4, in kJ mol^{-1}, using your answer to (c)(i) and section 20 of data booklet. [2]

(If you do not have answer for (c)(i), use the magnitude of 1000 kJ mol^{-1}, but this is not the correct answer.)

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6. The elements of Group 14 can form monoxides and dioxides. The stabilities of the monoxides, with respect to disproportionation into the element and the dioxide, vary. The equations for some of the disproportionation reactions are given below together with some thermodynamic data for the reactions.

disproportionation equation	$\Delta H^{\ominus}$ / kJ mol^{-1}	$\Delta S^{\ominus}$ / J K^{-1} mol^{-1}	$\Delta G^{\ominus}$ / kJ mol^{-1}
$2CO(g) \rightarrow C(s) + CO_2(g)$	−172.5	−175.9	−120.1
$2SiO(g) \rightarrow Si(s) + SiO_2(s)$	−711.5	−362.9	−603.4
$2GeO(s) \rightarrow Ge(s) + GeO_2(s)$	−126.8		
$2PbO(s) \rightarrow P(s) + PbO_2(s)$	+157.2	−4.000	+158.4

(a) Explain why the magnitude of the entropy change for the disproportionation of

(i) SiO is much bigger than that for CO, [2]

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(Question 6 continued)

(ii) PbO is close to zero. [1]

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(b) The standard molar entropies for germanium and its oxides are provided.

Species	$S^{\ominus}$ / J K^{-1} mol^{-1}
germanium, Ge(s)	31.1
germanium monoxide, GeO(s)	50.0
germanium dioxide, GeO_2(s)	55.3

(i) Calculate the standard entropy change, $\Delta S^{\ominus}$, for the disproportionation of germanium monoxide. [1]

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(Question 6 continued)

(ii) Using your answer to (b)(i), calculate the standard free energy change, $\Delta G^{\ominus}$, for the disproportionation of germanium oxide and determine its spontaneity at 25 ^{o}C. [2]

(If you do not have answer for (b)(i), use −30 J K^{-1} mol^{-1}, but this is not the correct answer.)

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(iii) Predict the effect of increasing the temperature on the spontaneity of the disproportionation of germanium monoxide. [2]

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7. (a) In a Cannizzaro Reaction between an aldehyde, RCHO and a strong base such as sodium hydroxide, its respective carboxylate salt $RCOO^-$ and alcohol, RCH_2OH, are formed.

$$2RCHO + OH^- \rightarrow RCOO^- + RCH_2OH$$

The kinetic study of the reaction could be followed by measuring the rate of disappearance of hydroxide ions by varying initial concentrations of the aldehyde, RCHO and hydroxide ions, OH^- at a constant temperature, T_1.

Experiment number	[RCHO] / mol dm^{-3}	[OH^-] / mol dm^{-3}	Initial rate of disappearance of OH^- / mol dm^{-3} s^{-1}
1	0.050	0.100	3.3×10^{-6}
2	0.100	0.050	6.3×10^{-6}
3	0.100	0.100	1.3×10^{-5}
4	0.200	0.150	

(i) Deduce with reasoning, the order of reaction with respect to RCHO and OH^-. Hence, deduce the overall order of the reaction. [3]

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(Question 7 continued)

(ii) State the rate expression. [1]

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(iii) Calculate the value of *k* and state its units clearly. [2]

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(iv) Calculate the rate of disappearance of OH^- for experiment 4. [1]

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(v) Given that the reaction proceeds in a two-step mechanism, forming $[RCHO(OH)]^-$ as an intermediate, propose a possible mechanism. [3]

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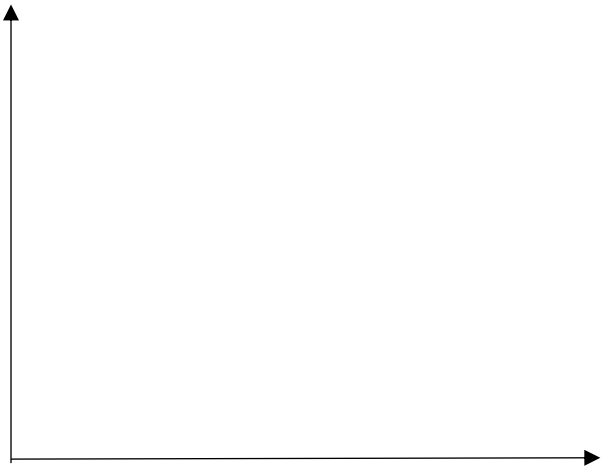
(Question 7 continued)

(b) (i) An additional experiment was carried out at a higher temperature T_2. [2]

On the same axes, sketch the Maxwell-Boltzmann energy distribution curve at the two temperatures T_1 and T_2, where $T_2 > T_1$. Label your graphs and axes clearly. Draw a dotted line to represent the activation energy.



(ii) Explain in terms of collision theory, the effect on rate of reaction when temperature is increased. [2]

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(Question 7 continued)

(c) Describe how the activation energy of a chemical reaction could be determined experimentally. [3]

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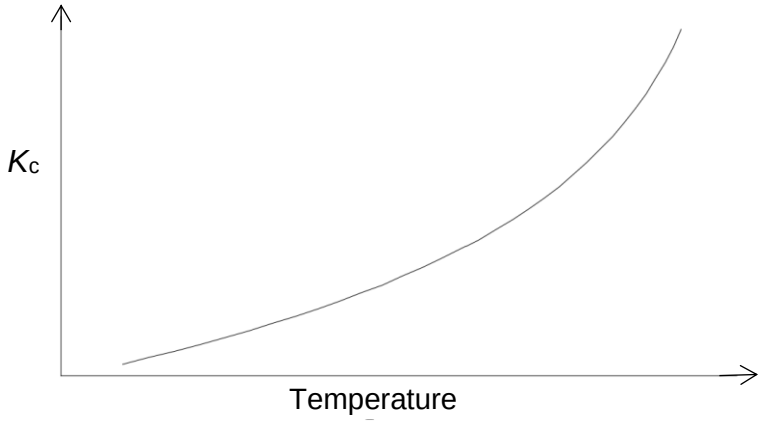
8. Nitrogen monoxide, NO is formed when nitrosyl chloride, NOCl, dissociates according to the following equation.

$$2NOCl\ (g) \rightleftharpoons 2NO\ (g) + Cl_2\ (g)$$

(a) (i) The sketch graph below shows how the value of K_c for this reaction changes with temperature. [2]



State and explain whether the reaction is exothermic or endothermic.

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(ii) State and explain how increasing the pressure of the reaction mixture at constant temperature will affect the position of equilibrium and the equilibrium constant, K_c. [2]

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(Question 8 continued)

(iii) At 230 °C, the equilibrium constant, K_c, is 0.0045. [2]

At a given time, 0.400 mol NOCl, 0.300 mol NO and 0.100 mol Cl_2 were mixed in a 2.00 dm^3 flask.

Calculate the reaction quotient, Q, and deduce, showing your reasoning, if the forward or the reverse reaction is favoured at this time.

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(iv) As a first step in the manufacture of nitric acid it has been suggested that nitrogen monoxide, NO, can be formed from nitrogen and oxygen in a reversible reaction. [2]

The value of K_c for this reaction is 1×10^{-5} at 1500 K.

Explain the significance of this value for an industrial chemist interested in manufacturing nitrogen monoxide by the direct combination of the elements.

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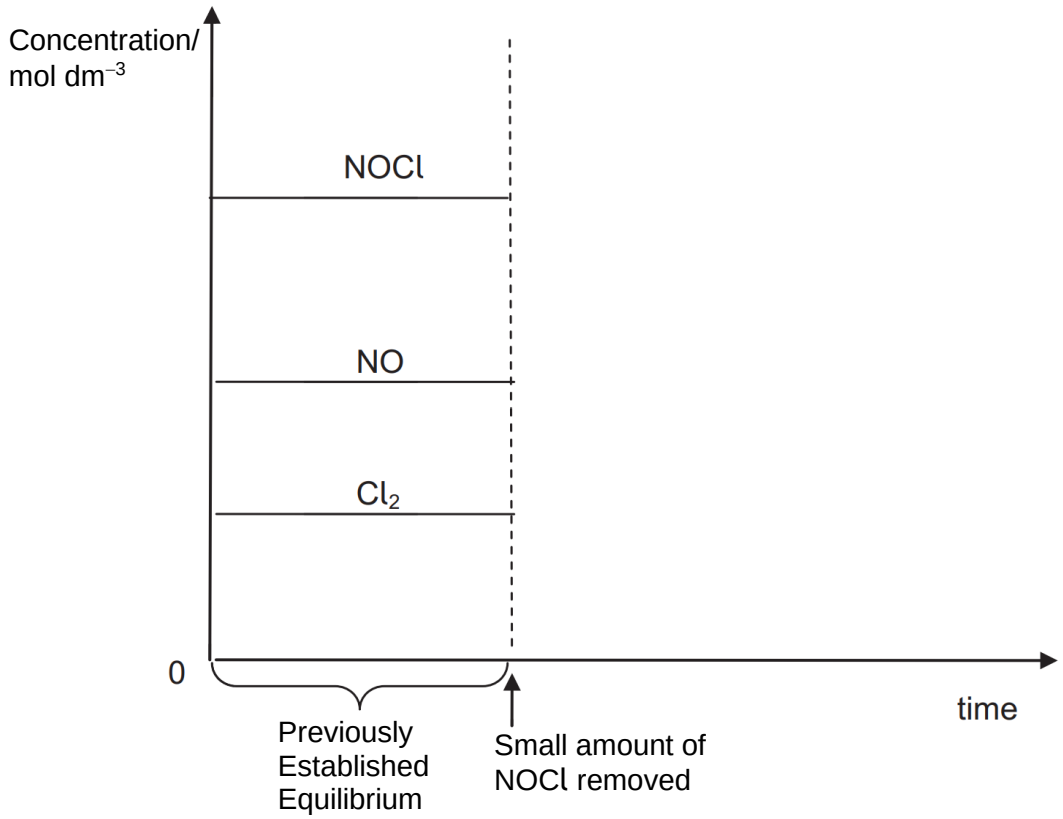
(Question 8 continued)

(b) A small amount of NOCl is suddenly removed from the equilibrium mixture containing NOCl, NO and Cl_2, keeping the temperature constant. The mixture is then allowed to reach equilibrium again. [3]

Complete the sketch below to show how the amount of each of the three gases would change until a new equilibrium is established.



9. The key stage in the manufacture of sulfuric acid is the reaction between sulfur dioxide and oxygen.

$$2SO_2\,(g) + O_2\,(g) \rightleftharpoons 2SO_3\,(g)$$

(a) (i) State the equilibrium constant expression, K_c of this reaction. [1]

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(ii) When a 5.2 mol of SO_2 and 2.6 mol of O_2 were allowed to reach equilibrium in a 2 dm^3 vessel at 500 ^oC, the amount of SO_3 at equilibrium is 4.8 mol. Calculate the value of K_c at 500 ^oC. [2]

(b) (i) At exactly 727 ^oC, the value of the equilibrium constant is 280. Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, for the reaction, in kJ, using sections 1 and 2 of the data booklet. State your answer to three significant figures. [2]

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(This question continues on the following page)

(Question 9 continued)

(ii) Comment on the value of ΔG when the reaction quotient equals the equilibrium constant, $Q = K$. [2]

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(c) The reaction can be sped up with the use of V_2O_5 catalyst. State and explain how the use of the catalyst could affect the yield of SO_3 produced in this reaction. [2]

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