Reaction Kinetics

Question Paper 1

Level	International A Level
Subject	Chemistry
Exam Board	CIE
Topic	Reaction Kinetics
Sub-Topic	
Paper Type	Theory
Booklet	Question Paper 1

Time Allowed: **60 minutes**

Score: **/50**

Percentage: **/100**

Grade Boundaries:

A*	A	B	C	D	E	U
>85%	777.5%	70%	62.5%	57.5%	45%	<45%

1 **(a)** The oxidation of nitrogen(II) oxide is shown in the equation.

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

The initial rate of this reaction was measured, starting with different concentrations of the two reactants. The following results were obtained.

experiment number	[NO] / mol dm^{-3}	[O_2] / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.032	0.012	4.08×10^{-3}
2	0.032	0.024	8.15×10^{-3}
3	0.064	0.024	3.28×10^{-2}
4	0.096	0.036	

(i) Use the data in the table to determine the order with respect to each reactant. Show your reasoning.

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(ii) Calculate the initial rate in experiment 4. Give your answer to **two** significant figures.

initial rate = ... mol dm^{-3} s^{-1}

(iii) Write the rate equation for this reaction.

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(iv) Use the results of experiment 1 to calculate the rate constant, *k*, for this reaction. Include the units of *k*.

rate constant, *k* = ... units .....

[6]

(b) On the following axes

- draw two Boltzmann distribution curves, at two different temperatures, T_1 and T_2 ($T_2 > T_1$),
- label the curves and the axes.

(ii) State and explain, using your diagram, the effect of increasing temperature on the rate of reaction.

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[5]

(c) The compound nitrosyl fluoride, NOF, can be formed by the following reaction.

$$2NO(g) + F_2(g) \rightleftharpoons 2NOF(g)$$

The rate is first order with respect to NO and F_2.
The reaction mechanism has **two** steps.

Suggest equations for the two steps of this mechanism, stating which is the rate determining slower step.

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..... [2]

[Total: 13]

2 **(a)** Bromate(V) ions, BrO_3^-, react with bromide ions in the presence of acid to produce bromine. Write an **ionic** equation for this reaction.

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..... [2]

(b) The initial rate of this reaction was measured, starting with different concentrations of the three reactants.

The following results were obtained.

experiment number	$[BrO_3^-]$ / mol dm^{-3}	$[Br^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.040	0.020	0.50	2.64×10^{-4}
2	0.040	0.020	1.00	1.06×10^{-3}
3	0.040	0.080	0.50	1.06×10^{-3}
4	0.080	0.020	0.50	5.21×10^{-4}

(i) Use the data in the table to determine the order with respect to each reactant. Show your reasoning.

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(ii) Write the rate equation for this reaction.

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(iii) Use the results of experiment 1 to calculate the rate constant, *k*, for this reaction. Include the units of *k*.

rate constant, *k* = ... units .....
[6]

[Total: 8]

3 Alcohols such as methanol, CH_3OH, are considered to be possible replacements for fossil fuels because they can be used in car engines.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, $\Delta H_c^\ominus$, for methanol at 298 K.

equation .....

definition .....

.....

..... [3]

Methanol may be synthesised from carbon monoxide and hydrogen. Relevant $\Delta H_c^\ominus$ values for this reaction are given in the table below.

compound	$\Delta H_c^\ominus$ / kJ mol^{-1}
CO(g)	–283
H_2(g)	–286
CH_3OH(g)	–726

(b) Use these values to calculate $\Delta H_{reaction}^\ominus$ for the synthesis of methanol, using the following equation. Include a sign in your answer.

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$$

$\Delta H_{reaction}^\ominus$ = ...kJ mol^{-1}

[3]

(c) The operating conditions for this reaction are as follows.

pressure	200 atmospheres (2×10^7 Pa)
temperature	600 K
catalyst	oxides of Cr, Cu, and Zn

In the spaces below, explain how **each** of these conditions affects the **rate of formation** of methanol.

pressure

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temperature

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catalyst

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[6]

[Total: 12]

4 Nitrogen monoxide, NO, is formed in a reversible reaction when air is heated to the temperature of a car engine.

(a) Suggest a 'dot-and-cross' electronic structure for nitrogen monoxide.

(ii) The enthalpy change of formation of nitrogen monoxide is +90 kJ mol^{-1}. What is the enthalpy change for the following reaction?

$$2NO(g) \rightarrow N_2(g) + O_2(g) \qquad \Delta H_r = \text{.....} \text{ kJ mol}^{-1}$$

(iii) Explain why nitrogen monoxide is formed in the car engine.

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(iv) Using bond enthalpy values from the *Data Booklet* and your answer in **(ii)** above, calculate a value for the bond energy of nitrogen monoxide.

bond energy = ... kJ mol^{-1}
[5]

(b) At 800 K, nitrogen monoxide reacts with hydrogen according to the following equation.

equation **I** $2H_2(g) + 2NO(g) \rightarrow 2H_2O(g) + N_2(g)$

The following table shows how the initial rate of this reaction depends on the partial pressures of the reagents.

experiment	p(H_2) / atm	p(NO) / atm	initial rate / atm s^{-1}
1	0.64	1.60	1.50×10^{-7}
2	0.64	0.80	3.75×10^{-8}
3	0.32	1.60	7.50×10^{-8}

(i) Find the order of the reaction with respect to each reactant, explaining how you arrive at your answer.

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(ii) Write down the rate equation and the units of the rate constant.

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The following mechanism has been put forward for this reaction.

step 1 $NO + NO \rightarrow N_2O + O$

step 2 $H_2 + O \rightarrow H_2O$

step 3 $H_2 + N_2O \rightarrow N_2 + H_2O$

(iii) Show how the overall stoichiometric equation **I** can be derived from the three equations for the individual steps given above.

(iv) Suggest which of the three reactions in the mechanism is the rate determining step. Explain your answer.

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[8]

(c) The following information on half-reactions relates to the reaction between HNO_3 and an excess of $FeSO_4$.

$Fe^{3+} + e^- \rightarrow Fe^{2+}$ $\quad E^\ominus = +0.77\,V$

$3H^+ + NO_3^- + 2e^- \rightarrow HNO_2 + H_2O$ $\quad E^\ominus = +0.94\,V$

$HNO_2 + H^+ + e^- \rightarrow NO + H_2O$ $\quad E^\ominus = +0.99\,V$

(i) Suggest the formula of the nitrogen-containing final product of this reaction.

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(ii) Write an equation for the formation of this nitrogen-containing product.

(iii) Nitrogen monoxide forms a dark brown complex with an excess of $FeSO_4(aq)$. What kind of bonding is involved in the complex formation?

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(iv) Suggest a formula for this complex.

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[4]

[Total: 17]