16.1 Rate Expression & Reaction Mechanism

Question Paper

Course	DP IB Chemistry
Section	16. Chemical Kinetics (HL only)
Topic	16.1 Rate Expression & Reaction Mechanism
Difficulty	Medium

Time allowed: 50

Score: /40

Percentage: /100

Question 1a

a)
For the reaction below, consider the following experimental data.

$$X(aq) + Y(aq) \rightarrow Z(aq)$$

Experiment	Initial [X] / mol dm^{-3}	Initial [Y] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.030	0.040	4.0×10^{-4}
2	0.045	0.040	6.0×10^{-4}
3	0.060	0.120	2.4×10^{-3}

Deduce the order of reaction with respect to X.

[2 marks]

Question 1b

b)
Deduce the order of the reaction with respect to Y.

[2 marks]

Question 1c

c)
Write the rate expression for the reaction between X and Y.

[1 mark]

Question 1d

d)

Determine the rate constant, *k*, correct to three significant figures and state its units, using data from Experiment 2.

Experiment	Initial [X] / mol dm^{-3}	Initial [Y] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.030	0.040	4.0×10^{-4}
2	0.045	0.040	6.0×10^{-4}
3	0.060	0.120	2.4×10^{-3}

[3 marks]

Question 2a

a)

Explain why the reaction represented below is a redox reaction.

$$2ClO_2\,(aq) + 2NaOH\,(aq) \rightarrow NaClO_3\,(aq) + NaClO_2\,(aq) + H_2O\,(l)$$

[2 marks]

Question 2b

b)

For the reaction below, consider the following experimental data.

$$2ClO_2(aq) + 2OH^-(aq) \rightarrow ClO_3^-(aq) + ClO_2^-(aq) + H_2O(l)$$

Experiment	Initial $[ClO_2]$ / mol dm^{-3}	Initial $[OH^-]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.85	1.70	9.30×10^{-5}
2	1.70	1.70	3.72×10^{-4}
3	1.70	0.85	1.86×10^{-4}

Deduce the rate expression.

[3 marks]

Question 2c

c)

Determine the rate constant, *k*, and state its units, using data from Experiment 3.

[3 marks]

Question 2d

d)

Calculate the rate when $[ClO_2(aq)] = 3.10 \times 10^{-2}$ mol dm^{-3} and $[OH^-(aq)] = 1.50 \times 10^{-2}$ mol dm^{-3}.

[2 marks]

Question 3a

a)
Sketch a graph to show how the rate constant, *k*, varies with temperature.

[1 mark]

Question 3b

b)
The following mechanism is proposed for the reaction where ethanal dimerises in dilute alkaline solution to form 3–hydroxybutanal:

Step 1: $CH_3CHO + :OH^- \rightarrow :CH_2CHO + H_2O$
Step 2: $CH_3CHO + :CH_2CHO \rightarrow CH_3CH(O:^-)CH_2CHO$
Step 3: $CH_3CH(O:^-)CH_2CHO + H_2O \rightarrow CH_3CH(OH)CH_2CHO + :OH^-$

Classify OH^-, CH_2CHO and $CH_3CH(O:^-)CH_2CHO$ as reactant, product, catalyst or intermediate, based on the proposed mechanism.

[3 marks]

Question 3c

c)
Using the following information about the proposed mechanism, deduce the rate expression.

Step 1: $CH_3CHO + :OH^- \rightarrow :CH_2CHO + H_2O$ slow step
Step 2: $CH_3CHO + :CH_2CHO \rightarrow CH_3CH(O:^-)CH_2CHO$ fast step
Step 3: $CH_3CH(O:^-)CH_2CHO + H_2O \rightarrow CH_3CH(OH)CH_2CHO + :OH^-$ fast step

[1 mark]

Question 3d

d)
Calculate the initial rate of reaction for experiment 2, if measured under the same conditions.

Experiment	Initial $[CH_3CHO]$ / mol dm^{-3}	Initial $[OH^-]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.25	0.20	4.2×10^{-2}
2	0.25	0.30	

[1 mark]

Question 3e

e)
State the effect, if any, increasing the concentration of a reactant would have on the value of the rate constant, *k*.

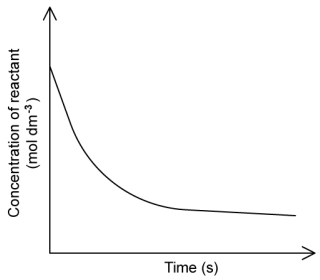
[1 mark]

Question 4a

a)
Nitrogen dioxide and carbon monoxide react according to the following equation.

$$NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g)$$

Using the following graph, what is the order with respect to NO_2?



[1 mark]

Question 4b

b)
The rate expression for the reaction of nitrogen dioxide and carbon monoxide at $T < 227\ ^{O}C$ is:

$$\text{Rate} = k[NO_2]^2$$

Sketch a labelled graph of concentration against time for carbon monoxide.

[2 marks]

Question 4c

c)
A student proposed the following single step mechanism for the reaction of nitrogen dioxide and carbon monoxide.

$$NO_2 + CO \rightarrow NO + CO_2 \quad \text{slow}$$

$$\text{Rate} = k[NO_2]^2$$

Justify whether the student's proposed mechanism is correct.

[2 marks]

Question 4d

d)
Another student proposed the following mechanism for the reaction of nitrogen dioxide and carbon monoxide.

$$\text{Step 1:} \quad NO_2 + NO_2 \rightarrow NO + NO_3$$
$$\text{Step 2:} \quad NO_3 + 2CO \rightarrow NO + 2CO_2$$

$$\text{Rate} = k[NO_2]^2$$

Explain which of the student's proposed mechanism steps is the rate determining step.

[1 mark]

Question 5a

a)

Nitrogen(II) oxide is oxidised according to the following equation.

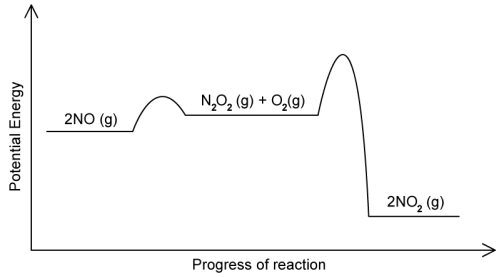
$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

The following mechanism is proposed for the two-step oxidation of nitrogen(II) oxide.

Step 1: $NO(g) + NO(g) \rightarrow N_2O_2(g)$

Step 2: $N_2O_2(g) + O_2(g) \rightarrow 2NO_2(g)$

The potential energy profile for this two-step reaction is shown.



Explain which step is the rate determining step.

[1 mark]

Question 5b

b)

Energy profile diagrams give evidence for or against a proposed mechanism or proposed rate expression.

i)

Explain why the rate expression for the oxidation of nitrogen(II) oxide is **not** rate = $k[N_2O_2][O_2]$.

ii)

Deduce the rate expression for the oxidation of nitrogen(II) oxide.

[3 marks]

Question 5c

c)
Explain why the following reaction between iodide ions and peroxodisulfate ions has a high activation energy.

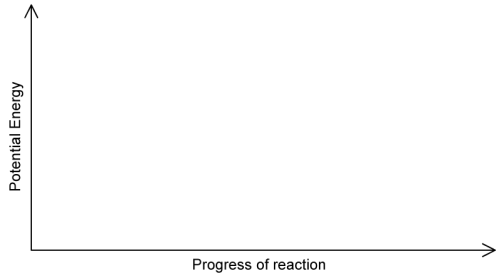
$$S_2O_8^{2-}(aq) + 2I^-(aq) \rightarrow 2SO_4^{2-}(aq) + I_2(aq)$$

[2 marks]

Question 5d

d)
Sketch the potential energy diagram for the reaction of iodide ions with peroxodisulfate ions catalysed by iron(II) ions according to the following mechanism.

$$2Fe^{2+}(aq) + S_2O_8^{2-}(aq) \rightarrow 2Fe^{3+}(aq) + 2SO_4^{2-}(aq) \quad \text{slow}$$
$$2Fe^{3+}(aq) + 2I^-(aq) \rightarrow 2Fe^{2+}(aq) + I_2(aq) \quad \text{fast}$$



[2 marks]

Question 5e

e)
Deduce the rate expression for the reaction of iodide ions with peroxodisulfate ions catalysed by iron(II) ions according to the following mechanism.

$$2Fe^{2+}(aq) + S_2O_8^{2-}(aq) \rightarrow 2Fe^{3+}(aq) + 2SO_4^{2-}(aq) \quad \text{slow}$$
$$2Fe^{3+}(aq) + 2I^-(aq) \rightarrow 2Fe^{2+}(aq) + I_2(aq) \quad \text{fast}$$

[1 mark]