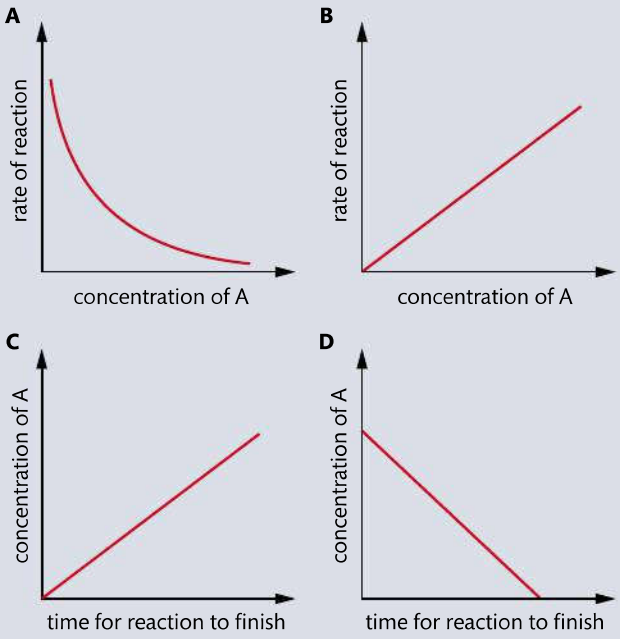
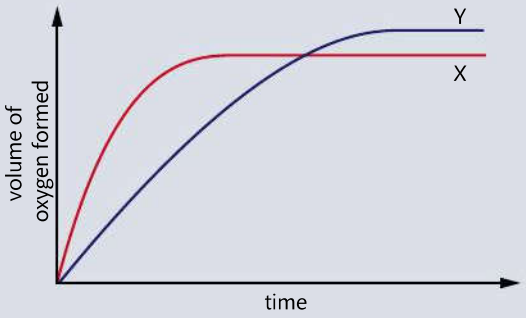
Practice questions

1 Which graph represents a reaction that is first order with respect to reactant A?



2 Curve X on the graph below shows the volume of oxygen formed during the catalytic decomposition of a 1.0 mol dm^{-3} solution of hydrogen peroxide:

$$2H_2O_2(aq) \rightarrow O_2(g) + 2H_2O(l)$$



Which change would produce the curve Y?

A adding water
B adding some 0.1 mol dm^{-3} hydrogen peroxide solution
C using a different catalyst
D lowering the temperature

3 Bromine and nitrogen(II) oxide react according to the following equation.

$$Br_2(g) + 2NO(g) \rightarrow 2NOBr(g)$$

Which rate equation is consistent with the experimental data?

$[Br_2]$ / mol dm^{-3}	[NO] / mol dm^{-3}	Rate / mol dm^{-3} s^{-1}
0.10	0.10	1.0×10^{-6}
0.20	0.10	4.0×10^{-6}
0.20	0.40	4.0×10^{-6}

A rate = $k\,[Br_2]^2\,[NO]$
B rate = $k\,[Br_2]\,[NO]^2$
C rate = $k\,[Br_2]^2$
D rate = $k\,[NO]^2$

4 Which step is the rate-determining step of a reaction?

A the step with the lowest activation energy
B the final step
C the step with the highest activation energy
D the first step

5 Consider the following reaction.

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

A proposed reaction mechanism is:

$$NO(g) + NO(g) \rightleftharpoons N_2O_2(g) \quad \text{fast}$$
$$N_2O_2(g) + H_2(g) \rightarrow N_2O(g) + H_2O(g) \quad \text{slow}$$
$$N_2O(g) + H_2(g) \rightarrow N_2(g) + H_2O(g) \quad \text{fast}$$

What is the rate expression?

A rate = $k\,[H_2]\,[NO]^2$
B rate = $k\,[N_2O_2]\,[H_2]$
C rate = $k\,[NO]^2\,[H_2]^2$
D rate = $k\,[NO]^2\,[N_2O_2]^2\,[H_2]$

6 Which changes increase the rate of the reaction below?

$$C_4H_{10}(g) + Cl_2(g) \rightarrow C_4H_9Cl(l) + HCl(g)$$

I increase of pressure
II increase of temperature
III removal of HCl(g)

A I and II only **B** I and III only **C** II and III only **D** I, II, and III

7 What happens when the temperature of a reaction increases?

A the activation energy increases
B the rate constant increases
C the enthalpy change increases
D the order of the reaction increases

8 Which experimental procedure could be used to determine the rate of reaction for the reaction between a solution of cobalt chloride, $CoCl_2(aq)$, and concentrated hydrochloric acid, HCl(aq)?

$$Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons CoCl_4^{2-}(aq) + 6H_2O(l)$$

A measure the change in pH in a given time
B measure the change in mass in a given time
C use a colorimeter to measure the change in colour in a given time
D measure the change in volume of the solution in a given time

9 Powdered manganese(IV) oxide, $MnO_2(s)$, increases the rate of the decomposition reaction of hydrogen peroxide, $H_2O_2(aq)$. Which statements about MnO_2 are correct?

I The rate is independent of the particle size of MnO_2.
II MnO_2 provides an alternative reaction pathway for the decomposition with a lower activation energy.
III All the MnO_2 is present after the decomposition of the hydrogen peroxide is complete.

A I and II only **B** I and III only **C** II and III only **D** I, II, and III

10 Consider the following reaction.

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

At $T < 227$ °C the rate expression is rate = $k\,[NO_2]^2$. Which of the following mechanisms is consistent with this rate expression?

A $NO_2 + NO_2 \leftrightharpoons N_2O_4$ fast
$N_2O_4 + 2CO \rightarrow 2NO + 2CO_2$ slow

B $NO_2 + CO \rightarrow NO + CO_2$ slow

C $NO_2 \rightarrow NO + O$ slow
$CO + O \rightarrow CO_2$ fast

D $NO_2 + NO_2 \rightarrow NO_3 + NO$ slow
$NO_3 + CO \rightarrow NO_2 + CO_2$ fast

11 (a) Nitrogen monoxide, NO, is involved in the decomposition of ozone according to the following mechanism.

$$O_3 \rightarrow O_2 + O\bullet$$
$$O_3 + NO \rightarrow NO_2 + O_2$$
$$NO_2 + O\bullet \rightarrow NO + O_2$$

Overall: $2O_3 \rightarrow 3O_2$

State and explain whether or not NO is acting as a catalyst. (2)

(b) The following is a proposed mechanism for the reaction of NO(g) with H_2(g).

Step 1: $2NO(g) \rightarrow N_2O_2(g)$

Step 2: $N_2O_2(g) + H_2(g) \rightarrow N_2O(g) + H_2O(g)$

(i) Identify the intermediate in the reaction. (1)

(ii) The observed rate expression is rate = $k\,[NO]^2\,[H_2]$. Assuming that the proposed mechanism is correct, comment on the relative speeds of the two steps. (1)

(c) The following two-step mechanism has been suggested for the reaction of NO_2(g) with CO (g), where $k_2 \gg k_1$.

Step 1: $NO_2(g) + NO_2(g) \rightarrow NO(g) + NO_3(g)$

Step 2: $NO_3(g) + CO(g) \rightarrow NO_2(g) + CO_2(g)$

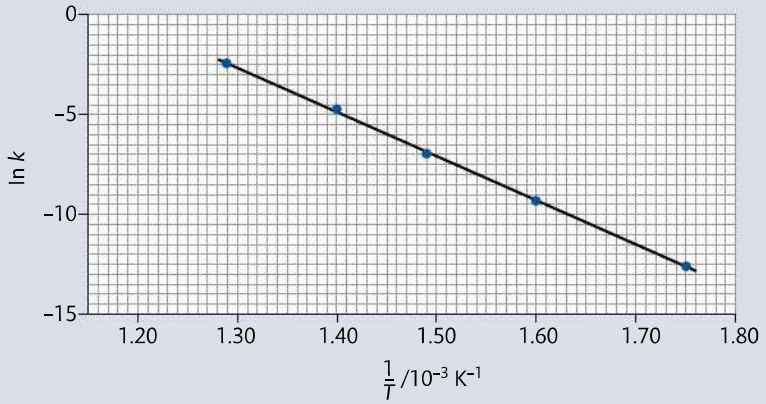
Overall: $NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g)$

The experimental rate expression is rate = $k_1\,[NO_2]^2$. Explain why this mechanism produces a rate expression consistent with the experimentally observed one. (2)

(d) HI(g) decomposes into H_2(g) and I_2(g) according to the reaction below.

$$2HI(g) \rightarrow H_2(g) + I_2(g)$$

The reaction was carried out at different temperatures and a value of the rate constant, k, was obtained for each temperature. A graph of ln k against $\frac{1}{T}$ is shown below.



Calculate the activation energy, E_a, for the reaction using these data and Section 1 of the IB Data booklet, showing your working. (4)

(Total 10 marks)

12 Hydrogen and nitrogen(II) oxide react according to the following equation.

$$2H_2(g) + 2NO(g) \rightleftharpoons N_2(g) + 2H_2O(g)$$

At time = t seconds, the rate of the reaction is

rate = $k\,[H_2(g)]\,[NO(g)]^2$

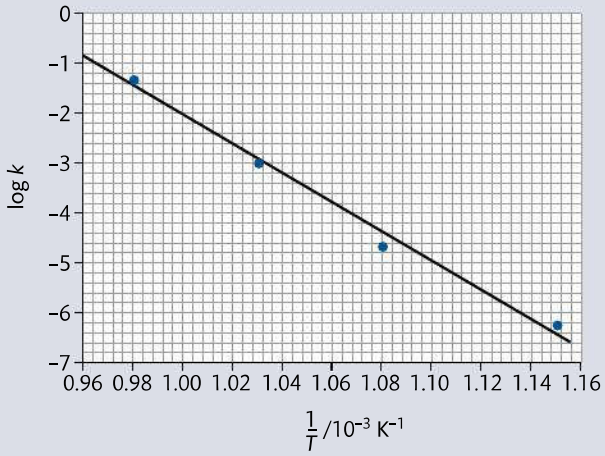
(a) Explain precisely what the square brackets around nitrogen(II) oxide, [NO(g)], represent in this context. (1)

(b) Deduce the units for the rate constant k. (1)

(Total 2 marks)

13 Consider the following graph of ln k against $\frac{1}{T}$ (temperature in Kelvin) for the second-order decomposition of N_2O into N_2 and O:

$$N_2O \rightarrow N_2 + O$$



(a) State how the rate constant, k, varies with temperature, T. (1)

(b) Determine the activation energy, E_a, for this reaction. (3)

(c) The rate expression for this reaction is rate $= k\,[N_2O]^2$ and the rate constant is 0.244 $dm^3\ mol^{-1}\ s^{-1}$ at 750 °C. A sample of N_2O of concentration 0.200 mol dm^{-3} is allowed to decompose. Calculate the rate when 10% of the N_2O has reacted. (2)

(Total 6 marks)

14 Alex and Hannah were asked to investigate the kinetics involved in the iodination of propanone. They were given the following equation by their teacher:

$$CH_3COCH_3(aq) + I_2(aq) \xrightarrow{H^+(aq)} CH_2ICOCH_3(aq) + HI(aq)$$

Alex's hypothesis was that the rate will be affected by changing the concentrations of the propanone and the iodine, as the reaction can happen without a catalyst. Hannah's hypothesis was that as the catalyst is involved in the reaction, the concentrations of the propanone, iodine, and the hydrogen ions will all affect the rate.

They carried out several experiments varying the concentration of one of the reactants or the catalyst whilst keeping other concentrations and conditions the same, and obtained the results below.

Experiment	Composition by volume of mixture / cm^3				Initial rate / mol $dm^{-3}\ s^{-1}$
	1.00 mol dm^{-3} $CH_3COCH_3(aq)$	water	1.00 mol dm^{-3} $H^+(aq)$	5.00×10^{-3} mol dm^{-3} I_2 in KI	
1	10.0	60.0	10.0	20.0	4.96×10^{-6}
2	10.0	50.0	10.0	30.0	5.04×10^{-6}
3	5.0	65.0	10.0	20.0	2.47×10^{-6}
4	10.0	65.0	5.0	20.0	2.51×10^{-6}

(a) Explain why they added water to the mixtures. (1)

(b) (i) Deduce the order of reaction for each substance and the rate expression from the results. (2)

(ii) Comment on whether Alex's or Hannah's hypothesis is correct. (1)

(c) Using the data from Experiment 1, determine the concentration of the substances used and the rate constant for the reaction including its units. (3)

(d) (i) This reaction uses a catalyst. Sketch and annotate the Maxwell–Boltzmann energy distribution curve for a reaction with and without a catalyst on labelled axes. (3)

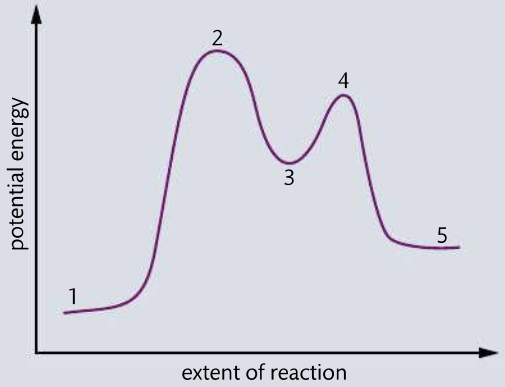
(ii) Describe how a catalyst works. (1)

(Total 11 marks)

15 The diagram below shows a potential energy level profile for a reaction. It occurs by the following mechanism:

$$W + XY \rightarrow WY + X$$

$$WY + Z \rightarrow W + YZ$$



(a) Deduce the equation for the overall reaction. (1)

(b) Label each step 1–5 as reactant, product, transition state, or intermediate. (3)

(c) Identify the species present at each step. (3)

(d) Determine which step is the rate-determining step and deduce the rate expression for the overall reaction. (2)

(e) Consider whether the reaction is catalysed, and if so identify the catalyst. (1)

(f) Add labelled arrows to the diagram to show the activation energy, E_a, and the enthalpy change, ΔH. (2)

(Total 12 marks)

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