Past-paper walk-through

Homogeneous and heterogeneous catalysts ▪ 26.2

eXercise

Questions in this set

- 9701/41 N25 Q3 ▪ 11 marks
- 9701/42 N25 Q2 ▪ 9 marks
- 9701/44 N25 Q4 ▪ 12 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 3

9701/41 N25 ▪ Q3 ▪ 11 marks

3 **(a)** Solid manganese(IV) oxide, MnO_2, catalyses the decomposition of hydrogen peroxide.

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

State the type of catalysis for this reaction. Explain your answer.

Question 3

(b) Hydrogen peroxide reacts with iodide ions in acidic conditions as shown.

$$H_2O_2 + 2I^- + 2H^+ \rightarrow 2H_2O + I_2$$

The initial rate of this reaction is investigated with different concentrations of H_2O_2, I^- and H^+. The results obtained are shown in Table 3.1.

Table 3.1

experiment	$[H_2O_2]$ / mol dm^{-3}	$[I^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.0450	0.0300	0.0125	2.42×10^{-3}
2	0.0225	0.0600	0.0125	2.42×10^{-3}
3	0.0225	0.120	0.0125	4.84×10^{-3}
4	0.0450	0.120	0.0500	9.68×10^{-3}

Question 3

(i) Use the information in Table 3.1 to deduce the rate equation for this reaction.

Explain your reasoning.

Question 3

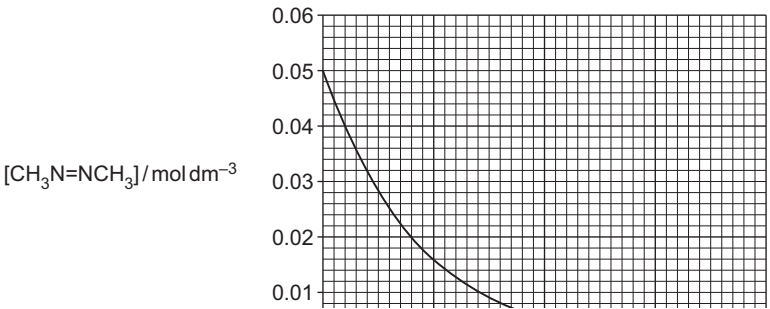
(ii) Use your rate equation from **(b)(i)** and the data from Experiment 1 to calculate the rate constant, k, for this reaction. Include the units of k.

Question 3

(c) The rate of the thermal decomposition of azomethane, $CH_3N{=}NCH_3$, is investigated.

$$CH_3N{=}NCH_3 \rightarrow N_2 + C_2H_6$$

Fig. 3.1 shows the results obtained. The reaction is first order with respect to $CH_3N{=}NCH_3$.



Question 3

Question 3

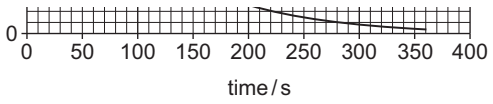


Fig. 3.1

(i) Use Fig. 3.1 to calculate **two** half-lives, $t_{\frac{1}{2}}$, to show that the reaction is first order.

Question 3

(ii) Use your answer to **(c)(i)** to calculate the rate constant, *k*, for the decomposition of azomethane.

Question 3

(d) Describe the effect of increasing temperature on the rate constant and on the rate of a reaction.

Question 3

[Total: 11]

Solution 3

(a)

Mark scheme

- heterogeneous AND MnO2 is in a different state / phase to the reactants / H2O2
- 1

Solution 3

(b)(i) Mark scheme

- M1: (expt 2 and 3) [I–] × 2
- initial rate × 2
- so 1st order wrt [I–]
- M2: (expt 1 and 2) [I–] × 2, [H2O2] × 0.5 initial rate × 1
- so 1st order wrt [H2O2]
- OR (expt 1 and 4) [I–] × 4
- initial rate × 4 AND [H+] × 4 so zero order wrt [H+]
- OR (expt 1 and 3) [I–] × 4, [H2O2] × 0.5

Solution 3

- initial rate $\times$ 2 so 1st order wrt [H2O2]
- M3: (expt 1 and 4) [I–] x 4 , [H+] $\times$ 4 initial rate $\times$ 4
- so zero order wrt [H+]
- OR (expt 3 and 4) [H2O2] $\times$ 2 initial rate $\times$ 2AND [H+] x 4 so zero order wrt [H+]
- OR (expt 3 and 4) [H2O2] $\times$ 2, [H+] $\times$ 4 initial rate $\times$ 2
- so 1st order wrt [H2O2]
- M4: rate = k [H2O2] [I–] OR rate = k [H2O2] [I–] [H+]0
- 4

Solution 3

(b)(ii)

Mark scheme

- M1: k = 2.42 × 10–3 ÷ (0.045 × 0.030) = 1.79 min 2sf
- M2: units = dm3 mol-1 s-1
- 2

Solution 3

(c)(i)

Mark scheme

- M1: calculation of one t1/2 $= 60\,\text{s} \pm 5\,\text{s}$
- M2: two t1/2 calculated that are constant
- 2

Solution 3

(c)(ii)

Mark scheme

- $k = \ln 2 \div 60 = 0.0116$ OR $k = 0.693 \div 60 = 0.0116$ min 2sf
- 1

Solution 3

(d)

Mark scheme

- increases k and increases the rate of reaction
- 1

Question 2

9701/42 N25 ▪ Q2 ▪ 9 marks

2 Ethanal, CH_3CHO, reacts with nitrogen dioxide, NO_2. The products of the first step of this reaction are a $CH_3\dot{C}{=}O$ radical and a molecule of nitrous acid, HNO_2.

$$CH_3CHO + NO_2 \rightarrow CH_3\dot{C}{=}O + HNO_2$$

(a) (i) Use **two** words to complete the sentence.

Question 2

covalent bond between a hydrogen atom and a carbon atom in CH_3CHO.

[1]

(ii) The hydrogen atom mentioned in **(a)(i)** forms a covalent bond with one of the oxygen atoms of an NO_2 molecule. An NO_2 molecule has a single, unpaired electron on the nitrogen atom. All electrons are paired in an HNO_2 molecule.

Draw dot-and-cross diagrams of NO_2 and HNO_2 in the boxes. Show outer shell electrons only.

Question 2

NO_2	HNO_2

[1]

(iii) Use VSEPR theory to predict the bond angle at the nitrogen atom in an HNO_2 molecule.

Question 2

(b) The rate equation for the reaction between CH_3CHO and NO_2 is shown.

$$\text{rate} = k[CH_3CHO][NO_2]$$

Under certain conditions, when the concentrations of both CH_3CHO and NO_2 are $0.200\,\text{mol dm}^{-3}$, the rate of the reaction is $1.53 \times 10^{-4}\,\text{mol dm}^{-3}\,\text{s}^{-1}$.

Calculate the value of the rate constant, k, under these conditions. Give the units of k.

Question 2

(c) The reaction mixture described in **(b)** is monitored over a period of time.

Predict whether the graph of $[NO_2]$ against time shows a constant half-life.

Explain your answer.

Question 2

Question 2

Question 2

[1]

(d) NO_2 also reacts with ozone, O_3.

The rate equation is shown.

$$\text{rate} = k_1[NO_2]$$

Under certain conditions, the value of k_1 is $0.0848\,s^{-1}$.

The reaction has a constant half-life under these conditions.

Calculate the half-life in seconds.

Question 2

(e) NO_2 is present in the exhaust gases of cars. It can react with carbon monoxide, CO, on the surface of a heterogeneous catalyst in the car's catalytic converter.

Describe the mode of action of this heterogeneous catalyst.

Question 2

[Total: 9]

Solution 2

(a)(i)

Mark scheme

- homolytic fission
- 1

(a)(ii)

Mark scheme

- 1

Solution 2

(a)(iii)

Mark scheme

- 115–120o
- 1

Solution 2

(b)

Mark scheme

- M1: $3.825 \times 10–3$ / 0.003825 / 0.00383 / 0.0038 / $3.8 \times 10–3$
- M2: units = mol–1 dm3 s–1
- 2

Solution 2

(c)

Mark scheme

- not constant half-life because overall second order
- 1
- 9701/42
- October/November 2025

Solution 2

(d)

Mark scheme

- 8.17 / 8.2
- 1

Solution 2

(e) Mark scheme

- ▪
- reactants are adsorbed onto the catalyst surface
- ▪
- bonds within reactant molecules are weakened
- ▪
- products are desorbed from catalyst surface
- Any two [1], all three [2]
- 2

Question 4

9701/44 N25 ▪ Q4 ▪ 12 marks

4 **(a)** Nitrogen monoxide, NO, reacts with hydrogen, as shown in reaction 3.

reaction 3 $2NO + 2H_2 \rightarrow N_2 + 2H_2O$

(i) The rate equation for reaction 3 is shown.

$$\text{rate} = k[H_2][NO]^2$$

Complete Table 4.1.

Table 4.1

the order of reaction with respect to $[H_2]$	
the order of reaction with respect to [NO]	
the overall order of the reaction	

[1]

Question 4

(ii) Predict how the initial rate for reaction 3 changes when the concentration of NO is halved.

Question 4

(iii) Predict how the initial rate for reaction 3 changes when the concentrations of NO and H_2 are both increased **three** times.

Question 4

(iv) Suggest why reaction 3 is unlikely to proceed by a mechanism involving only a single step.

Question 4

(v) Suggest equations for the **three** steps of the reaction mechanism for reaction 3.

Each step involves a reaction between **two** molecules.

Question 4

Question 4

Question 4

[2]

(vi) Suggest the role of N_2O in this mechanism.

Explain your reasoning.

Question 4

(b) Iodine, I_2, reacts with thiosulfate ions, $S_2O_3^{2-}$, as shown in reaction 4.

reaction 4 $$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^-$$

Reaction 4 is carried out in the presence of a large excess of I_2. Under these conditions, the reaction is first order with respect to $[S_2O_3^{2-}]$ and zero order with respect to $[I_2]$.

The half-life, $t_{\frac{1}{2}}$, for reaction 4 is 720 s under certain conditions.

Calculate the value of the rate constant, *k*, for reaction 4. Include the units of *k*.

Question 4

(c) The reaction between iodide ions, $I^-(aq)$, and peroxydisulfate ions, $S_2O_8^{2-}(aq)$, is catalysed by $Co^{3+}(aq)$. The mechanism is similar to the mechanism of this reaction when $Fe^{3+}(aq)$ is used as the catalyst.

(i) State the type of catalysis that occurs in this reaction.

Explain your reasoning.

Question 4

(ii) Write **two** equations to show how $Co^{3+}(aq)$ catalyses this reaction.

Question 4

[2]

(iii) Suggest why this reaction is slow in the absence of $Co^{3+}(aq)$.

Question 4

[Total: 12]

Solution 4

(a)(i) Mark scheme

- the order of reaction with respect to [H2]
- 1
- the order of reaction with respect to [NO]
- 2
- overall order of the reaction
- 3
- 1

Solution 4

(a)(ii)

Mark scheme

- rate $\times$ $1/4$
- 1

(a)(iii)

Mark scheme

- rate $\times$ $27/1$

Solution 4

(a)(iv)

Mark scheme

- a four-particle collision is unlikely
- 1

Solution 4

(a)(v) Mark scheme

- step 1
- $2NO \rightarrow N2O2$
- step 2
- $N2O2 + H2 \rightarrow N2O + H2O$
- step 3
- $N2O + H2 \rightarrow N2 + H2O$
- 2

Solution 4

(a)(vi)

Mark scheme

- intermediate formed (step 2) then used up later (step 3)
- 1

Solution 4

(b)

Mark scheme

- $k = 0.693 / 720 = 9.625 \times 10–4$ min 2sf
- AND units: s–1
- 1

Solution 4

(c)(i)

Mark scheme

- homogeneous
- AND Co3+ / catalyst / it is in the same phase / same state as the reactants
- 1

Solution 4

(c)(ii)

Mark scheme

- M1: (equation 1)
- $2Co^{3+} + 2I^- \rightarrow 2Co^{2+} + I_2$
- M2: (equation 2)
- $2Co^{2+} + S_2O_8^{2-} \rightarrow 2Co^{3+} + 2SO_4^{2-}$
- 2

Solution 4

(c)(iii)

Mark scheme

- repulsion of two negative / same charge ions slows the reaction / raises EA
- 1
- 9701/44
- October/November 2025