InkChemistry

ANSWER BOOK

Catalysis: heterogeneous, homogeneous and autocatalytic

Transition metals · Unit C14

AQA 3.2.5.6 · OCR A 5.3.1

17 questions · 55 marks

NAVY EDITION

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SECTION A · Short, 1 to 2 marks

A1 CHH-Q1

B1 a heterogeneous catalyst is in a different phase from the reactants. **B1** a homogeneous catalyst is in the same phase as the reactants. [2]

A2 CHH-Q14

B1 sulfur compounds are strongly adsorbed onto the iron catalyst and poison it by blocking the active sites. **B1** a poisoned catalyst gives a lower rate and must be replaced more often, which raises costs. [2]

A3 CHH-Q20

B1 nitrogen has more than one oxidation state, +4 in NO_2 and +2 in NO. **B1** so it can be reduced in one step and oxidised back in the next, and is regenerated like a transition metal catalyst. [2]

SECTION B · Standard, 3 to 5 marks

B1 CHH-Q5

B1 $SO_2 + V_2O_5 \rightarrow SO_3 + V_2O_4$; allow multiples. **B1** $V_2O_4 + \frac{1}{2}O_2 \rightarrow V_2O_5$; allow $2V_2O_4 + O_2 \rightarrow 2V_2O_5$. **B1** vanadium(V) oxide oxidises sulfur dioxide and is reduced to vanadium(IV) oxide, +5 to +4. **B1** oxygen then oxidises vanadium(IV) oxide back to vanadium(V) oxide, +4 to +5, so the catalyst is regenerated. **B1** the route depends on vanadium's variable oxidation state; 'it lowers the activation energy' alone is not enough. [5]

B2 CHH-Q12

M1 step 1, $S_2O_8^{2-}$ oxidising Fe^{2+}: $E°cell = +2.01 - (+0.77)$. **A1** $E°cell$ for step 1 = +1.24 V. **M1** step 2, Fe^{3+} oxidising I^-: $E°cell = +0.77 - (+0.54)$. **A1** $E°cell$ for step 2 = +0.23 V, to two significant figures; both positive, so both steps are feasible. [4]

B3 CHH-Q15

B1 vanadium(V) oxide is a heterogeneous catalyst, a solid with gaseous reactants; Fe^{2+} is homogeneous, in the same solution as the reactants. **B1** the vanadium reactions happen on the solid surface, whereas the iron reactions happen between ions in solution. **B1** both work by changing oxidation state and back: vanadium between +5 and +4, iron between +2 and +3. **B1** both provide an alternative route with a lower activation energy and are regenerated at the end. [4]

B4 CHH-Q2

B1 adsorption: reactant molecules form weak bonds to active sites on the catalyst surface, which weakens bonds within them. **B1** reaction: the adsorbed molecules, held close together in a favourable orientation, react on the surface. **B1** desorption: the product molecules break away from the surface, freeing the active sites. [3]

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B5 CHH-Q3 **B1** if adsorption is too weak, as with silver, the reactant molecules leave before they react. **B1** if adsorption is too strong, as with tungsten, the products do not desorb and the active sites stay blocked. **B1** intermediate adsorption, as with nickel or platinum, weakens the reactants' bonds but still lets the products leave. [3]

B6 CHH-Q6 **B1** only the surface atoms of the metal act as active sites. **B1** the honeycomb gives a very large surface area, so a thin layer on it exposes most of the metal atoms. **B1** less of the expensive metal is needed for the same catalytic activity, which reduces the cost. [3]

B7 CHH-Q7 **B1** lead is adsorbed very strongly onto the platinum and rhodium surface. **B1** it does not desorb, so it blocks the active sites (poisons the catalyst). **B1** fewer active sites are available, so the converter no longer removes CO and NO effectively. [3]

B8 CHH-Q9 **B1** a catalyst couple must have E° between +0.54 V and +2.01 V, so that both of its steps are feasible. **B1** Mn^{3+}/Mn^{2+} at +1.51 V lies in the range: $S_2O_8^{2-}$ oxidises Mn^{2+} and Mn^{3+} oxidises I^-, so it could catalyse the reaction. **B1** V^{3+}/V^{2+} at −0.26 V lies outside it: V^{3+} cannot oxidise I^- ($E°_{cell}$ −0.80 V), so it cannot complete the cycle. [3]

B9 CHH-Q10 **B1** at first the concentration falls only slowly, so the curve is nearly flat. **B1** the curve then becomes steep, the rate reaching a maximum part way through. **B1** finally the curve levels off towards zero as the manganate(VII) is used up, giving an inverted S shape. [3]

B10 CHH-Q11 **B1** Mn^{2+}, a product of the reaction, catalyses it, so the reaction is autocatalytic. **B1** at the start there is little Mn^{2+}, so the reaction is slow because both reactants are negative ions. **B1** as Mn^{2+} builds up, more of the reaction goes by the catalysed route through Mn^{3+}, so the rate increases. [3]

B11 CHH-Q16 **B1** the slow, nearly flat start disappears and the reaction is fast from the beginning. **B1** the catalyst, Mn^{2+}, is present from the start instead of having to build up. **B1** the curve becomes steepest at the start and less steep throughout, like an ordinary reaction. [3]

B12 CHH-Q17 **M1** moles of Pt = 1.50 ÷ 195.1 = 7.69×10^{-3} mol. **M1** number of atoms = $7.69 \times 10^{-3} \times 6.022 \times 10^{23}$. **A1** 4.63×10^{21} atoms, to three significant figures. [3]

B13 CHH-Q18 **B1** $NO_2 + SO_2 \rightarrow NO + SO_3$, in which nitrogen dioxide oxidises sulfur dioxide and is reduced. **B1** $NO + \frac{1}{2}O_2 \rightarrow NO_2$, in which oxygen oxidises nitrogen monoxide back to nitrogen dioxide. **B1** the nitrogen dioxide is regenerated and is in the same (gas) phase as the reactants, so it is a homogeneous catalyst. [3]

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SECTION C · Long, 6 marks or more

C1 CHH-Q8

Indicative content [6]

B1 both reactants are negative ions, which repel each other, so the activation energy of the direct reaction is high and it is slow. **B1** step 1: $S_2O_8^{2-} + 2Fe^{2+} \rightarrow 2SO_4^{2-} + 2Fe^{3+}$, in which the iron(II) is oxidised to iron(III). **B1** step 2: $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$, in which the iron(III) is reduced back to iron(II) and the catalyst is regenerated. **B1** each step is between oppositely charged ions, which attract, so each has a lower activation energy than the direct reaction. **B1** the uncatalysed profile has one high hump; the catalysed profile has two lower humps with a trough between them for the intermediate, Fe^{3+}. **B1** the reactants and the products are at the same energy levels on both profiles, because the catalyst does not change ΔH.

Levels

Level 3 (5–6 marks) the repulsion between the two negative ions is given as the reason for the slow direct reaction, both steps of the catalysis are written with correct equations and the oxidation state changes, the lower activation energy of each step is explained through the attraction of opposite charges, and the two profiles are compared with the intermediate and the unchanged ΔH.

Level 2 (3–4 marks) the repulsion of the ions and both equations are given; the regeneration of Fe^{2+}, why each step is faster, or the comparison of the two profiles is thin.

Level 1 (1–2 marks) the ions are said to repel or Fe^{2+} to be a catalyst; the catalysed profile is often drawn with a different ΔH, and one equation at most is given.

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