A-Level Chemistry

Transition Metal Catalysts

Mark Scheme

Time available: 70 minutes
Marks available: 64 marks

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Mark schemes

1. (a)

This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.	
Level 3 **5-6 marks**	All stages are covered and the description of each stage is generally correct and virtually complete. Answer is communicated coherently and shows a logical progression from stage 1 to stage 2 and stage 3.
Level 2 **3-4 marks**	All stages are covered but the description of each stage may be incomplete or may contain inaccuracies **OR** two stages are covered and the explanations are generally correct and virtually complete. Answer is mainly coherent and shows progression from stage 1 to stage 2 and/or stage 3.
Level 1 **1-2 marks**	Two stages are covered but the description of each stage may be incomplete or may contain inaccuracies, **OR** only one stage is covered but the explanation is generally correct and virtually complete. Answer includes isolated statements and these are presented in a logical order.
Level 0	**0 marks** Insufficient correct chemistry to gain a mark.

Stage 1
1a Heterogeneous means in a different phase/state from reactants
1b Catalyst speeds up reaction and is left unchanged **OR** lowers the activation energy for the reaction

Stage 2
2a Hydrogen and nitrogen/reactants adsorb onto the surface/ active sites of the iron
2b Bonds weaken/reaction takes place
2c Products desorb/leave from the surface (of the iron)

Stage 3
3a Large surface area (of iron) by using powder or small pellets or support medium/mesh
3b Catalyst poisoned / sulfur poisons or binds to the catalyst
3c Active sites blocked

Ignore references to temperature and pressure

6

(b) Two negative ions repel

1

So activation energy is high

1

$2\ Fe^{2+} + S_2O_8^{2-} \rightarrow 2\ SO_4^{2-} + 2\ Fe^{3+}$

1

$2\ Fe^{3+} + 2\ I^- \rightarrow 2\ Fe^{2+} + I_2$

Ignore any state symbols given

Allow multiples for both equations

Allow equations in either order

1

(c) (Zn ions) have only one oxidation state
Or
Zn^{2+} is the only ion

Allow doesn't have variable oxidation state

Allow cannot be oxidised to Zn^{3+}

Ignore has a full d shell

1

(d) M1 Amount of Fe = 0.998 ÷ 55.8 = 0.0179 mol

1

M2 Amount of HCl = 0.0300 mol

1

M3 HCl is the limiting reagent

1

M4 Amount of H_2 produced = 0.0150 mol

M4 = M2÷2

1

M5 T = 303 K P = 100 000 Pa

1

M6 $V \left(= \frac{0.0150 \times 8.31 \times 303}{100\ 000}\right) = 3.78 \times 10^{-4}\ (m^3)$

M6 $V \left(= \frac{M4 \times 8.31 \times 303}{100\ 000}\right) (m^3)$

1

(e) $FeCO_3$ or iron(II) carbonate

1

Green

Allow white

1

(f) $Fe(H_2O)_3(OH)_3$

Ignore square brackets if added

1

brown

1

$2\ [Fe(H_2O)_6]^{3+} + 3\ CO_3^{2-} \rightarrow 2\ Fe(H_2O)_3(OH)_3 + 3\ H_2O + 3\ CO_2$

Accept multiples

1

(g) M1 Fe^{3+} is smaller (than Fe^{2+}) **OR** Fe^{3+} has a greater charge **OR** Fe^{3+} has a greater charge density **OR** Fe^{3+} has a greater charge to size ratio

Penalise $Fe(H_2O)_6^{3+}$ ions once in M1 or M2

1

M2 Fe^{3+} ions are more polarising **OR** Fe^{3+} ions polarise water molecules more

1

M3 So more O-H bonds (in the water ligands) break **OR** more H^+ ions released **OR** weaken O-H bonds in ligands more (in the Fe^{3+} solution)

Do not allow Fe^{3+} releases $3H^+$ ions

1

[25]

2. (a) A reaction that produces its own catalyst/ one of the products is the catalyst

1

Mn^{2+}

Allow Mn^{3+}

1

(b) H_2SO_4

1

(c) There is no/very little catalyst at the start OR the reaction only speeds up when the catalyst is produced

1

Two negative ions (MnO_4^- and $C_2O_4^{2-}$) repel

Reference to molecules loses M2

1

The activation energy for the reaction is high / heat is required to overcome the activation energy

1

(d) M1 $5\ C_2O_4^{2-}(aq) + 2\ MnO_4^{-}(aq) + 16\ H^+(aq) \longrightarrow 10\ CO_2(g) + 2\ Mn^{2+}(aq) + 8\ H_2O(l)$

Ignore state symbols

1

M2 $n(MnO_4^-) = \frac{26.40 \times 0.02}{1000}$ OR $n(MnO_4^-) = 5.28 \times 10^{-4}$

1

M3 $n(C_2O_4^{2-}) = \frac{5}{2} \times 5.28 \times 10^{-4} = 1.32 \times 10^{-3}$

M3 is for M2 × 5/2

If wrong ratio used then can only score M2, M4, M5 and M6

1

M4 $n(C_2O_4^{2-}$ in flask originally$) = 1.32 \times 10^{-3} \times 10 = 1.32 \times 10^{-2}$

M4 is for M3 × 10

1

M5 $n(K_3[Fe(C_2O_4)_3].3H_2O) = \frac{1.32 \times 10^{-2}}{3} = 4.40 \times 10^{-3}$

(*Mr* $K_3[Fe(C_2O_4)_3].3H_2O = 491.1$)

M5 is for M4 ÷ 3

1

M6 Mass of $K_3[Fe(C_2O_4)_3].3H_2O$ reacted $= 4.40 \times 10^{-3} \times 491.1 = 2.16$ g

M6 is for M5 × 491(.1)

1

M7 % purity $= \frac{2.16}{2.29}$ x100 = <u>94.3 or 94.4</u>%

Answer must be to 3 s.f.

Correct answer scores 6 marks; mark equation separately

Alternative method using ratio by moles:

M5 $n(C_2O_4^{2-}) = 4.66 \times 10^{-3} \times 3 = 0.0140$ *moles in* $250 cm^3$

M6 n(complex) = 2.29/491.1 = 4.66×10^{-3} *moles in* $250 cm^3$

M7 % = 0.0132/0.0140 × 100 = <u>94.3 or 94.4</u>%

1

(e) Make some known concentrations (of the coloured solution and read the absorbance of each one using a colorimeter)

Ignore addition of suitable ligand

1

Plot a graph of absorbance vs concentration

Not just "plot a calibration curve" / reference to Beer-Lambert graph is insufficient

Do not allow transmittance in M2

1

Read/compare unknown concentration from calibration curve/graph (and hence the concentration from the graph)

M3 can only be scored if graph/curve mentioned

1

[16]

3. (a) $2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$

1

Mn^{2+} OR Mn^{3+}

If catalyst incorrect can only score M1 and M3

1

(Possible because) Mn can exist in variable oxidation states

1

E_a lowered because oppositely charged ions attract

These marks can be gained in any order

1

Mn^{3+} (reduced) to Mn^{2+} by $C_2O_4^{2-}$ / equation

M5 may appear before M2

1

Mn^{2+} (oxidised (back)) to Mn^{3+} by MnO_4^- / equation

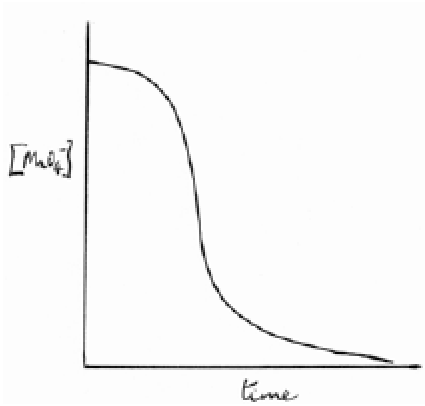
M5 and M6 can be scored in unbalanced equations or in words showing:

$Mn^{3+} + C_2O_4^{2-} \rightarrow Mn^{2+}$

$Mn^{2+} + MnO_4^- \rightarrow Mn^{3+}$

1

(b) **Graph marks**



S-shaped curve must not rise significantly and must not fall rapidly initially.

Starts on concentration axis **and** is levelling out (can level out on time axis or above but parallel to time axis)

Cannot score graph marks (M1 and M2) if no axes and / or no labels

1
1

Explanation marks

<u>Slope</u> / rate increases as catalyst (concentration) forms

1

Slope / rate decreases as (concentration) of MnO_4^- ions / reactant(s) decreases (OR reactants are being used up)

Explanation marks can be awarded independent of graph.

1

[10]

4. (a) Negative ions <u>repel</u> one another

1

(b) Positive ions <u>attract</u> negative ions in catalysed process

Allow activation energy decreases.

Allow alternative route with lower E_a

Ignore references to heterogenous catalysis.

1

(c) $S_2O_8^{2-} + 2e^- \longrightarrow 2SO_4^{2-}$

Allow multiples including fractions.

Ignore state symbols.

1

(d) $S_2O_8^{2-} + 2I^- \longrightarrow 2SO_4^{2-} + I_2$

Allow multiples including fractions.

Ignore state symbols.

Allow the correct equation involving I_3^-

$S_2O_8^{2-} + 3I^- \longrightarrow 2SO_4^{2-} + I_3^-$

1

[4]

5. (a) Variable / many oxidation states

1

(b) $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$

Equations can be in either order

Allow multiples

1

$V_2O_4 + ½O_2 \rightarrow V_2O_5$

1

(c) (i) In a different phase / state <u>from reactants</u>

1

(ii) Impurities poison / deactivate the catalyst / block the active sites

Allow (adsorbs onto catalyst AND reduces surface area)

1

(d) (i) The catalyst is a reaction product

1

(ii) Mn^{2+} / Mn^{3+} ion(s)

1

(iii) $4Mn^{2+} + MnO_4^- + 8H^+ \rightarrow 5Mn^{3+} + 4H_2O$

Equations can be in either order

1

$2Mn^{3+} + C_2O_4^{2-} \rightarrow 2Mn^{2+} + 2CO_2$

1

[9]