A-Level Chemistry

Reactions of Metal Aqua Ions

Mark Scheme

Time available: 78 minutes
Marks available: 70 marks

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) **M1** **B** = $Al(H_2O)_3(OH)_3$

Ignore [ ]

1

M2 bubbles/effervescence

***M2** Do not allow gas evolved*

1

M3 $2\ [Al(H_2O)_6]^{3+} + 3CO_3^{2-} \rightarrow 2\ Al(H_2O)_3(OH)_3 + 3H_2O + 3CO_2$

***M3** Ignore absence of square brackets around Al complex*

***M3** Allow correct balanced equations with Na_2CO_3*

1

(b) **M1** **C** = $[Al(OH)_4]^-$ OR $[Al(H_2O)_2(OH)_4]^-$ OR $[Al(OH)_6]^{3-}$

1

M2 Excess NaOH

***M2** Allow excess OH^-*

1

M3 $[Al(H_2O)_6]^{3+} + 4\ OH^- \rightarrow [Al(OH)_4]^- + 6\ H_2O$

OR

$[Al(H_2O)_6]^{3+} + 4\ OH^- \rightarrow [Al(H_2O)_2(OH)_4]^- + 4\ H_2O$

OR

$[Al(H_2O)_6]^{3+} + 6\ OH^- \rightarrow [Al(OH)_6]^{3-} + 6\ H_2O$

***M3** Allow equations to form $Al(H_2O)(OH)_5^{2-}$*

***M3** Allow correct balanced equations with NaOH*

1

(c) $[Al(EDTA)]^-$

Do not penalise absence of square brackets

1

(d) **M1** $[Al(H_2O)_6]^{3+} + H_2O \rightleftharpoons [Al(H_2O)_5(OH)]^{2+} + H_3O^+$ OR
$[Al(H_2O)_6]^{3+} \rightleftharpoons [Al(H_2O)_5(OH)]^{2+} + H^+$

Accept other equations

1

M2 $\underline{Al^{3+}}$ has a small size <u>and</u> high charge OR has a high charge density

1

M3 Weakens the OH bond (in water) releasing H^+ ions

***M2** Allow the aluminium ion has a small size <u>and</u> high charge OR has a high charge density*

1

[10]

3. (a) $[Fe(OH)_3(H_2O)_3]$

1

Brown

***M2:** Allow red-brown*

1

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

***M3:** Allow correct equations with Na_2CO_3*

***M3:** Ignore State symbols*

1

(b) $[FeCl_4]^-$

1

$[Fe(H_2O)_6]^{3+} + 4\ Cl^- \rightarrow [FeCl_4]^- + 6\ H_2O$

M2: *Allow correct equations with HCl*

1

(c) (XS) Zn (in acid or CHl or H_2SO_4)

Allow Kl/potassium iodide

1

(d) $[Fe(OH)_2(H_2O)_4]$

1

green

1

(e)

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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 Answer is illustrated using diagrams of at least 2 specific examples of pairs of cobalt or platinum complex isomers.
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. Answer is illustrated using diagrams of at least 1 specific example of a pair of cobalt or platinum complex isomers.
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. Answer is illustrated using at least 1 appropriate diagram or formula.
0 marks	Insufficient correct chemistry to gain a mark.

Indicative Chemistry content

Stage 1: shapes of complexes

1a octahedral or 6 co-ordinate diagram

1b tetrahedral or square planar or 4 co-ordinate diagram

Stage 2: cis/ trans isomerism (or E-Z or geometric)

2a cis/trans isomerism in either square planar and/or octahedral complexes

2b Diagrams showing cis and trans isomerism in a square planar complex

2c Diagrams showing cis and trans isomerism in both isomers of octahdedral complexes eg draw cis and trans $M(H_2O)_4(OH)_2$ or $[M(NH_3)_4(H_2O)_2]^{2+}$

Stage 3: optical isomerism

3a optical isomerism / non superimposable mirror images in octahedral complexes

3b occurs with a specific bidentate ligands eg.$C_2O_4^{2-}$ or $NH_2CH_2CH_2NH_2$

3c draw both optical isomers of eg $[M(NH_2CH_2CH_2NH_2)_3]^{2+}$

6

[14]

4.

(a) $AlCl_3 + 6H_2O \rightarrow [Al(H_2O)_6]^{3+} + 3Cl^-$

Allow

$AlCl_3 + 6H_2O \rightarrow Al(H_2O)_5(OH)_2^+ + H^+ + 3Cl^-$

Or equation to form $Al(H_2O)_4(OH)_2^+$

1

(b) $[Al(H_2O)_6]^{3+} + H_2O \rightarrow [Al(H_2O)_5(OH)]^{2+} + H_3O^+$

allow equations to form $[Al(H_2O)_4(OH)_2]^+$

1

(c) white ppt/solid

M1 and M2 in either order

1

effervescence/bubbles/fizzing

1

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

accept multiples

only allow spectator ions in a balanced equation

1

(d) White ppt/solid

1

$[Al(H_2O)_6]^{3+} + 3OH^- \rightarrow [Al(H_2O)_3(OH)_3] + 3H_2O$

only allow spectator ions in a balanced equation

1

Colourless solution forms / ppt or solid dissolves

1

$[Al(H_2O)_3(OH)_3] + OH^- \rightarrow [Al(H_2O)2(OH)4]- + H_2O$

OR

$[Al(H_2O)_3(OH)_3] + OH^- \rightarrow [Al(OH)_4]^- + 3H_2O$

only allow 6 or 4 co-ordination

Allow $[Al(OH)_6]^{3-}$ in a balanced equation

1

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5. (a) **Reaction 1**

General principles in marking this question

Square brackets are not essential

Penalise charges on individual ligands rather than on the whole complex

Reagent and species can be extracted from the equation

Ignore conditions such as dilute, concentrated, excess

Reagent must be a compound NOT just an ion

Equations must start from $[Cu(H_2O)_6]^{2+}$ except in part (b)

Mark reagent, species and equation independently

ammonia (NH_3) (solution) / NaOH

1

$[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow [Cu(H_2O)_4(OH)_2] + 2NH_4^+$ /

$[Cu(H_2O)_6]^{2+} + 2OH^- \rightarrow [Cu(H_2O)_4(OH)_2] + 2H_2O$

Do not allow OH^- for reagent

Product 1, balanced equation 1

Allow either equation for ammonia

2

(b) **Reaction 2**

Ammonia (conc / xs)

1

$[Cu(H_2O)_4(OH)_2] + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 2H_2O + 2OH^-$

Product 1, balanced equation 1

Note that the equation must start from the hydroxide $[Cu(H_2O)_4(OH)_2]$

2

(c) **Reaction 3**

Na_2CO_3 / any identified soluble carbonate / $NaHCO_3$

Do not allow $NaCO_3$ or any insoluble carbonate but mark on

1

$[Cu(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow CuCO_3 + 6H_2O$

OR $[Cu(H_2O)_6]^{2+} + Na_2CO_3 \rightarrow CuCO_3 + 6H_2O + 2Na^+$

OR $2[Cu(H_2O)_6]^{2+} + 2CO_3^{2-} \rightarrow Cu(OH)_2.CuCO_3 + 11H_2O + CO_2$

OR with $NaHCO_3$

$[Cu(H_2O)_6]^{2+} + HCO_3^- \rightarrow CuCO_3 + 6H_2O + H^+$

Product 1, balanced equation 1

2

(d) **Reaction 4**

HCl (conc / xs) / NaCl

Allow any identified soluble chloride

1

$[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$

Product 1, balanced equation 1

2

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