M1.(a) $Cr(OH)_3 + 3H_2O + 3H^+ \rightarrow [Cr(H_2O)_6]^{3+}$

Can start with $Cr(H_2O)_3(OH)_3$ for each equation

Ignore any unnecessary preliminary preparation of $Cr(OH)_3$

1

Green / grey−green solid

Mark colours independently from equations

Allow green ppt.

1

Forms green / purple / ruby / violet <u>solution</u>

ignore shades of colours

1

$Cr(OH)_3 + 2H_2O + OH^- \rightarrow [Cr(H_2O)_2(OH)_4]^-$

Allow with 5 or 6 OH^- provided complex has co−ordination number of 6

Penalise complex ions with incorrect charges overall or if shown on ligand.

1

Forms green <u>solution</u>

Note that for each equation final complex must be 6 co−ordinate

1

(b) $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 4H_2O$

Allow two correct equations via intermediate hydroxide in both cases even if first equation uses OH^- instead of NH_3

1

Blue (solution)

Mark colours independently from equations

1

Dark / deep / royal blue <u>solution</u>

1

$[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$

1

pink / red (solution)

1

Brown / straw / yellow <u>solution</u>

ignore darkens in air / with time

1

[11]

M2.B

[1]

M3.(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

[12]

M4.(a) $[Fe(H_2O)_6]^{2+} + 2NH_3 \rightarrow Fe(H_2O)_4(OH)_2 + 2NH_4^+$

Allow equation with OH^- provided equation showing formation of OH^- from NH_3 given

1

Green precipitate

1

$[Fe(H_2O)_6]^{2+} + CO_3^{2-} \rightarrow FeCO_3 + 6H_2O$

1

Green precipitate

effervescence incorrect so loses M4

1

(b) (i) Colourless / (pale) green changes to pink / purple (solution)

Do not allow pale pink to purple

1

Just after the end−point MnO_4^- is in excess / present

1

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

1

Moles $KMnO_4 = 18.7 \times 0.0205 / 1000 = (3.8335 \times 10^{-4})$

Process mark

1

Moles $Fe^{2+} = 5 \times 3.8335 \times 10^{-4} = 1.91675 \times 10^{-3}$

Mark for M2 × 5

1

Moles Fe^{2+} in 250 $cm^3 = 10 \times 1.91675 \times 10^{-3} = 0.0191675$ moles in 50 cm^3

Process mark for moles of iron in titration (M3) × 10

1

Original conc $Fe^{2+} = 0.0191675 \times 1000 / 50 = 0.383$ $\underline{\text{mol dm}^{-3}}$

Answer for moles of iron (M4) × 1000 / 50

Answer must be to at least 2 sig. figs. (0.38)

1

[11]

M5.B

[1]

M6.D

[1]

M7.(a) An electron pair on the ligand

1

Is donated from the ligand to the central metal ion

1

(b) Blue precipitate

1

Dissolves to give a dark blue solution

1

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

1

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

1

(c) $[Cu(NH_3)_4(H_2O)_2]^{2+} + 2H_2NCH_2CH_2NH_2 \longrightarrow [Cu(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+} + 4NH_3$

1

(d) Cu–N bonds formed have similar enthalpy / energy to Cu–N bonds broken

1

And the same number of bonds broken and made

1

(e) 3 particles form 5 particles / disorder increases because more particles are formed / entropy change is positive

1

Therefore, the free-energy change is negative

M2 can only be awarded if M1 is correct

1

[11]

M1.(a) Iron(II): green (solution) gives a green precipitate

Apply list principle throughout if extra colours and / or extra observations given. Ignore state symbols in equations.

Not blue-green ppt.

1

$\underline{[Fe(H_2O)_6]^{2+}} + CO_3^{2-} \rightarrow FeCO_3 + 6H_2O$

Must start from $[Fe(H_2O)_6]^{2+}$

Allow equations with Na_2CO_3

1

Iron(III): yellow / purple / brown / lilac / violet (solution) gives a brown / rusty precipitate

1

Effervescence / gas / bubbles

Allow CO_2 evolved but not just CO_2

1

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

1

(b) Copper(II): blue (solution) gives a green / yellow solution ***OR*** blue solution (turns) to green / yellow / olive green

Apply list principle throughout if extra colours and / or extra observations given. Ignore state symbols in equations.

1

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

Allow equations with HCl

1

Cobalt(II): pink (solution) gives a blue solution ***OR*** pink solution turns blue

1

$\underline{[Co(H_2O)_6]^{2+}} + 4Cl^- \rightarrow [CoCl_4]^{2-} + 6H_2O$

1

(c) Iron(II): green (solution) gives a green precipitate

Apply list principle throughout if extra colours and / or extra observations given. Ignore state symbols in equations.

1

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

Allow equations with NaOH

1

Chromium(III): green / ruby / purple / violet / red-violet (solution) gives a green solution ***OR*** green / ruby / purple / violet / red-violet solution turns green

Ignore green ppt.

1

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

Allow also with 4 or 5 OH balanced with 2 or 1 waters.

Also allow two correct equations showing $Cr(H_2O)_3(OH)_3$ as intermediate.

1

(d) Al: colourless (solution) gives a white ppt

Apply list principle throughout if extra colours and / or extra observations given. Ignore state symbols in equations.

1

$\underline{[Al(H_2O)_6]^{3+}} + 3NH_3 \rightarrow Al(H_2O)_3(OH)_3 + 3NH_4^+$

Allow + $3OH^- \rightarrow 3H_2O$ if

$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$ also

1

Ag: colourless (solution) remains a colourless solution / no visible change

Ignore brown ppt.

1

$\underline{[Ag(H_2O)_2]^+} + 2NH_3 \rightarrow [Ag(NH_3)_2]^+ + 2H_2O$

Allow 2 / 3 equations involving Ag_2O or $Ag(OH)_2$

1

[17]

M2.(a) Yellow (solution)

1

Orange <u>solution</u>

1

$2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$

Allow equation with H_2SO_4

1

(b) Yellow / purple (solution)

Allow orange / brown (solution)

1

Brown precipitate / solid

1

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

1

(c) Blue (solution)

Allow pale blue

1

Dark / deep blue <u>solution</u>

Ignore any reference to blue ppt

1

$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 4H_2O$

Can be in two equations

1

(d) Colourless (solution)

1

White precipitate / solid

Do not allow grey

1

Bubbles / effervescence / gas evolved / given off

Do not allow just CO_2

1

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

1

[13]

M3.(a) Idea that <u>over time / after storage</u> meter does not give accurate readings

Do not accept 'to get an accurate reading' without further qualification.

Allow 'temperature variations affect reading'.

1

(b) $$\frac{[[Fe(H_2O)_5OH]^{2+}(aq)]\,[H^+(aq)]}{[[Fe(H_2O)_6]^{3+}(aq)]}$$

Allow without (aq) symbols.

Need at least one set of square brackets around complex ions

1

(c) $pH = -\log [H^+]$

1

$[H^+] = 0.0240$

Do not penalise precision of $[H^+]$

Correct answer scores M1 and M2.

1

$K_a = (0.0240)^2 / 0.1 = 5.75 \times 10^{-3}$ or 5.76×10^{-3}

Correct answer without working loses M1 and M2.
Allow 7.58×10^{-3}

1

Answer, even if incorrect, given to 3 sig figs

1

(d) Oxygen (in the air) / O_2

Ignore 'air' or 'the atmosphere' or 'chemicals in soil'.
List principle.

1

(e) 4.0 – 6.9

Do not penalise precision.

[7]

M4.(a) Electron <u>pair</u> donor

Allow lone <u>pair</u> donor

1

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

1

(Blue solution) gives a (pale) <u>blue precipitate/solid</u>

M2 only awarded if M1 shows Bronsted–Lowry reaction

1

(c) $[Cu(H_2O)_6]^{2+} + 4NH_3 \longrightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 4H_2O$

Allow formation in two equations via hydroxide

1

(Blue solution) gives a dark/deep blue solution

If (b) and (c) are the wrong way around allow one mark only for each correct equation with a correct observation (max 2/4)

M2 only awarded if M1 shows Lewis base reaction

1

(d) (Start with) green (solution)

1

Green precipitate of $Fe(H_2O)_4(OH)_2$ / $Fe(OH)_2$ / iron(II) hydroxide

Do not allow observation if compound incorrect or not given

1

Slowly changes to brown solid

Allow red-brown ppt

Allow turns brown or if precipitate implied

Can only score M3 if M2 scored

1

(Iron(II) hydroxide) oxidised by air (to iron(III) hydroxide)

Allow $Fe(OH)_2$ oxidised to $Fe(OH)_3$ by air / O_2

Ignore equations even if incorrect

1

(e) (i) $2[Al(H_2O)_6]^{3+} + 3H_2NCH_2CH_2NH_2 \longrightarrow 2Al(H_2O)_3(OH)_3 + 3[H_3NCH_2CH_2NH_3]^{2+}$

For correct Al species

1

For correct balanced equation

Allow equation with formation of $3[H_2NCH_2CH_2NH_3]$ + from 1 mol $[Al(H_2O)_6]^{3+}$

1

White precipitate

1

(ii) $[Co(H_2O)_6]^{2+} + 3H_2NCH_2CH_2NH_2 \longrightarrow [Co(H_2NCH_2CH_2NH_2)_3]^{2+} + 6H_2O$

1

Complex with 3 en showing 6 correct bonds from N to Co

Ignore charge

Accept N – N for ligand

Ignore incorrect H

If C shown, must be 2 per ligand

1

Co–ordinate bonds (arrows) shown from N to Co

Can only score M3 if M2 correct

1

$4[Co(H_2NCH_2CH_2NH_2)_3]^{2+} + O_2 + 2H_2O \longrightarrow 4[Co(H_2NCH_2CH_2NH_2)_3]^{3+} 4OH^-$

For Co(III) species

1

For balanced equation (others are possible)

Allow $+ O_2 \quad + \quad 4H^+ \longrightarrow \quad 2H_2O$

If en used can score M4 and M5 only

If Cu not Co, can only score M2 and M3

Allow $N_2C_2H_8$ *in equations*

1

[17]

1 (a) Brown ppt/solid

1

Gas evolved/effervescence

1

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

Must be stated, Allow CO_2 evolved. Do not allow CO_2 alone

Correct iron product (1) allow $Fe(OH)_3$ and in equation

Balanced equation (1)

2

(b) White ppt/solid

1

Colourless Solution

Only award M2 if M1 given or initial ppt mentioned

1

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

Allow $[Al(H_2O)_6]^{3+} + 3OH \rightarrow Al(OH)_3 + 6H_2O$

1

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

Allow formation of $[Al(H_2O)_{6-x}(OH)_x]^{(x-3)}$ where x = 4,5,6

Allow product without water ligands

Allow formation of correct product from $[Al(H_2O)_6]^{3+}$

1

(c) Blue ppt/solid

1

(Dissolves to give a) deep blue solution

Only award M2 if M1 given or initial ppt mentioned

1

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

Allow $[Cu(H_2O)_6]^{2+} + 2NH_3 \rightarrow Cu(OH)_2 + 2NH_4^{+} + 4H_2O$

Allow two equations: $NH_3 + H_2O \rightarrow NH_4^{+} + OH$

then $[Cu(H_2O)_6]^{2+} + 2OH \rightarrow Cu(OH)_2 + 4H_2O$ etc

1

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

Allow $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 4H_2O$

1

(d) Green/yellow solution

1

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

1

[14]

2 (a) oxidation state of N in $Cu(NO_3)_2$: +5;

1

oxidation state of N in NO_2: +4;

1

oxidation product: oxygen;

1

(b) copper-containing species: $[Cu(H_2O)_6]^{2+}$;

1

shape: octahedral;

1

(c) (i) precipitate B: $Cu(H_2O)_4(OH)_2$ or $Cu(OH)_2$ or name;

1

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

OR

$NH_3 + H_2O \rightarrow NH_4^+ + OH$

and

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

1

(ii) NH_3 accepts a proton;

1

(d) (i) identity: $[Cu(NH_3)_4(H_2O)_2]^{2+}$;

1

colour: deep blue;

1

equation:

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

1

(ii) NH_3 is an electron pair donor;

1

(e) identity: $[CuCl_4]^{2-}$;

1

colour: yellow-green;

1

shape: tetrahedral;

1

(f) (i) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$;

1

(ii) role of Cu: a reducing agent;

1

[17]

3 (a) Iron

1

Heterogeneous; catalyst in a different phase from that of the reactants

1

Poison; a sulphur compound (allow sulphur)

1

Poison strongly adsorbed onto active sites/ blocked

1

Poison not desorbed or reactants not adsorbed or catalyst surface area reduced

1

(b) Pale green solution 1

Green precipitate formed

1

Insoluble in excess ammonia

1

Equation:

e.g. $[Fe(H_2O)_6]^{2+} + 2NH_3 \rightarrow [Fe(H_2O)_4(OH)_2] + 2NH_4^+$ Species

1

Balance

1

NB Allow equations with H_2O and OH if reaction of H_2O with NH_3 also given

Max 4

[9]

M1. (a) (i) An atom, ion or molecule which can donate a lone electron pair

1

(ii) A central metal ion/species surrounded by co-ordinately bonded ligands or ion in which co-ordination number exceeds oxidation state

1

(iii) The number of co-ordinate bonds formed to a central metal ion or number of electron pairs donated or donor atoms

1

(b) (i) *Allow the reverse of each substitution*

$[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$

Complex ions

1

Balanced

1

Allow partial substitution

(ii) $[Co(H_2O)_6]^{2+} + 4Cl^- \rightarrow CoCl_4^{2-} + 6H_2O$

Complex ions

1

Balanced

or H_2O or NH_3 or $C_2O_4^{2-}$ by Cl^-

1

eg. (iii) $[Co(H_2O)_6]^{2+} + 3C_2O_4^{2-} \rightarrow [Co(C_2O_4)_3]^{4-} + 6H_2O$

Complex ions

1

Balanced

1

Allow all substitution except
(i) NH_3 by H_2O
(ii) more than $2Cl^-$ substituted for NH_3 or H_2O

eg. (iv) $[Co(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [Co(EDTA)]^{2-} + 6H_2O$

Complex ions

1

Balanced

or H_2O or NH_3 by $C_2O_4^{2-}$ and NH_3 or Cl^- by $EDTA^{4-}$

1

(c) (i) $[Fe(H_2O)_6]^{2+}$

1

(ii) $Fe(OH)_2$ or $Fe(OH)_2(H_2O)_x$ where x = 0 to 4

1

(iii) Fe^{2+} is oxidised to Fe^{3+} or $Fe(OH)_3$

1

By oxygen in the air

1

[15]

M2. (a) (i) Deductions:

Ionic **(1)**
Ions not free to move in the solid state **(1)**
Ions free to move when molten or in aqueous solution **(1)**
Identity of **P**: Na_2O or sodium oxide **(1)**

N.B. If a formula given this must be correct

Equation: $Na_2O + H_2O \rightarrow 2\ NaOH$ **(1)**

5

(ii) Deductions:

Covalent
Intermolecular forces are weak or van der Waals forces,
or dipole-dipole

N.B. Any answer including a reference to hydrogen bonding is incorrect

Identity of **Q**: SO_2 or sulphur dioxide **(1)**

Equation: $SO_2 + H_2O \rightarrow H_2SO_3$ **(1)**

NB Allow max one for SO_3

4

(b) (i) Amphoteric **(1)**

(ii) Equation with NaOH

$Al(OH)_3 + NaOH \rightarrow NaAl(OH)_4$

OR $Al(OH)_3(H_2O)_3 + OH^- \rightarrow [Al(OH)_4(H_2O)_2]^- + H_2O$
OR $Al(OH)_3 + OH^- \rightarrow [Al(OH)_4]^-$

R identified as $Al(OH)_3$ or $Al(OH)_3(H_2O)_3$ **(1)**
A balanced equation **(1)**

N.B. Allow equation with six co-ordinate Aluminium and up to six OH^- ligands
N.B. Allow equation mark if $M(OH)_3$ given in a balanced equation

Equation with H_2SO_4

$2Al(OH)_3 + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6H_2O$

OR $Al(OH)_3(H_2O)_3 + H^+ \rightarrow [Al(OH)_2(H_2O)_4]^+ + H_2O$

NB Allow equations with six co-ordinate Aluminium and up to six H_2O ligands NB Allow equation mark if $M(OH)_3$ given in a balanced equation

Correct Al species as product **(1)**
A balanced equation **(1)**

(iii) Large lattice energy
or strong covalent bonds
or ΔH_{soln} is very positive
or ΔG is positive
or sum of hydration energies less than covalent bond energies **(1)**

6

[15]